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Effects of Sheep-Dip Disposal on Terrestrial Invertebrates

Technical Report P2-250/1/7/TR

Cyngor Cefn Gwlad Cymru
Countryside Council for Wales

English Nature

Environment Agency

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Professor Mike Depledge Head of Science

EXECUTIVE SUMMARY

This study, into the effects of sheep dip disposal on terrestrial invertebrates, was initiated as a response to a change in disposal policy and has been jointly funded by the Environment Agency, English Nature and the Countryside Council for Wales. The 1998 Groundwater Regulations required the majority of dip to be disposed to farmland. However, little information was available on the effects of disposal on soil invertebrates and the possible consequences for their bird predators. The present study aimed to assess the significance of organophosphate and synthetic pyrethroid dip disposal in upland terrestrial habitats, especially in relation to bird populations, and to provide guidelines for best practice.

A questionnaire was used to make a preliminary survey of dip disposal practice on 42 hill farms on or adjacent to SSSIs. These areas support breeding waders and it is possible that significant decreases in soil invertebrate densities could have adverse effects on the birds. The survey exposed a wide variety of practices and considerable deviation from the recommended procedures in many cases.

The effects of sheep dip disposal were further investigated by sampling paired disposal and control sites on a subset of the surveyed farms. Invertebrate abundance was estimated by taking soil samples, followed by Berlese extraction (or hand sorting for worms), pitfall trapping and suction sampling. Comparisons of total, sedentary and active invertebrate species densities were made between control and disposal sites; active species being more likely to recolonise an area rapidly after disposal. Spiders, bugs and ground beetles were identified to species and multivariate analysis was carried out on the pitfall samples of spiders and ground beetles.

Sampling the farm sites indicated that variables, other than the application of pesticide, influenced the densities and species composition of the invertebrate communities. However, invertebrate densities on disposal sites were significantly lower than on control sites in 7 out of 15 cases and the multivariate analysis indicated significant effects of dip disposal on carabid, but not spider, species composition six months after application. Density reductions were greatest on areas that had been used for dip disposal over many years.

An experimental site was set up on an area of rough pasture on 10 x 10 m plots in a "Latin-square" design. OP and SP were applied at full made-up dip strength and at the recommended 1:3 dilution, allowing comparison of the effects of the two insecticides under more controlled conditions than on the farms. The same sampling methods were used as on the farm sites and densities of all invertebrate groups, except linyphiid spiders and carabids (the latter showed increases) were significantly reduced on the disposal plots on one or more sampling occasion after application. The invertebrates living above the soil surface, taken by suction sample, showed the most severe and consistent reductions. Densities were lower on both OP and SP plots, at both dilutions, than on the controls at both 20 and 40 days after application.

A second Latin square experiment on more productive inby pasture, was used to determine the effects of disposal on during 2002. Again, densities of all invertebrate groups were significantly reduced on the disposal plots on one or more sampling

occasion after application. Additional sampling for Collembola on the treated plots showed significant reductions 20 days after treatment application, indicating possible consequences for larger carnivorous invertebrates for which smaller invertebrates are an essential food source.

A small-scale laboratory study of the effects of dip application to tipulid larvae showed that both OP and SP dips were toxic to larvae introduced 17 days after application with possible persistence to 133 days.

A risk assessment, based on the results, suggests that spring disposal should not be undertaken on areas where there are young wader chicks. Small chicks are restricted in movement and could suffer from food reduction in their immediate area. As there is also the possibility of poisoning by contaminated prey, there should be no disposal during the wader breeding season in areas where there is a high likelihood of the presence of nesting birds. In autumn, disposal on improved ground should be avoided. These areas often have high tipulid densities and are used as a resource by adult waders when they arrive in the uplands in spring. *Tipula paludosa*, which is the predominant species, has an annual cycle and, from September onwards, young larvae will be vulnerable in the soil.

CRYNODEB GWEITHREDOL

Dechreuwyd yr astudiaeth hon ynghylch effaith gwaredu dip defaid ar greaduriaid di-asgwrn cefn mewn ymateb i newid yn y polisi gwaredu ac fe'i hariannwyd ar y cyd gan Asiantaeth yr Amgylchedd, English Nature a Chyngor Cefn Gwlad Cymru. Yn Rheoliadau Dŵr Daear 1998 roedd raid i fwyafrif y dip gael ei waredu i ffermdir. Fodd bynnag, ychydig iawn o wybodaeth oedd ar gael ynghylch effaith y gwaredu ar greaduriaid di-asgwrn cefn yn y pridd a'r canlyniadau posib o ran eu hysglyfaethwyr sef yr adar. Anelir yr astudiaeth bresennol tuag at asesu arwyddocâd dip organoffosffad a pyrethroid synthetig ar gynefinoedd yn yr ucheldir, yn arbennig mewn perthynas â phoblogaeth yr adar, ac er mwyn darparu canllawiau ar gyfer arfer da.

Defnyddiwyd holiadur i wneud yr arolwg rhagarweiniol ynghylch yr arferion wrth waredu dip ar 42 o ffermydd mynydd sydd ar, neu'n gyfagos i SoDdGA. Mae'r ardaloedd hyn yn cynnal rhydwyr sy'n bridio ac mae'n bosib y gallai lleihad yn y creaduriaid di-asgwrn cefn yn y pridd, gael effaith andwyol ar yr adar. Dangosodd yr arolwg amrywiaeth eang o arferion ac mewn sawl achos gwyriad sylweddol oddi wrth y gweithdrefnau a gymeradwyir.

Archwiliwyd effaith gwaredu dip ymhellach drwy samplu safleoedd gwaredu a safleoedd rheoli ar is-set o'r ffermydd a arolygwyd. Amcangyfrifwyd bod digonedd o greaduriaid di-asgwrn cefn drwy gymryd samplau o'r pridd, gan ddilyn hyn â thyniad Berleses (neu ddidoli am bryf genwair â llaw), sampl pydew a samplu drwy sugno. Gwnaed cymariaethau o gyfanswm y rhywogaethau sefydlog, gweithredol yn y safleoedd rheoli a gwaredu; roedd rhywogaethau gweithredol yn llawer mwy tebygol o ail-gytrefu ardal yn fuan ar ôl gwaredu. Dynodwyd pryf copyn, bygiau, a chwilod fel rhywogaethau a gwnaed dadansoddiad aml-amrywedd ar y samplau pydew o bryf copyn a chwilod.

Nododd samplau safleoedd y ffermydd bod newidynnau oni bai am daenu pla laddwyr, yn dylanwadu ar ddwyserdd a chyfansoddiad rhywogaethau cymunedau'r creaduriaid di-asgwrn cefn. Fodd bynnag, roedd dwysedd creaduriaid di-asgwrn cefn ar safleoedd gwaredu yn sylweddol yn îs nag ar safleoedd rheoli yn 7 o'r 15 achos, a nododd y dadansoddiad aml-amrywedd effaith arwyddocaol gwaredu dip ar gyfansoddiad rhywogaethau carabid chwe mis ar ôl ei daenu, ond nid pryf copyn,. Roedd y lleihad dwysedd mwyaf ar ardaloedd a ddefnyddiwyd am sawl blwyddyn ar gyfer gwaredu dip.

Sefydlwyd safle arbrofol ar ardal o borfa fras ar rannau 10x10 fel cynllun 'Sgwâr-Lladin'. Taenwyd dip OP a SP ar ei gryfder llawn ac ar y gwanhad a argymhellir sef 1:3, gan alluogi cymharu effaith y ddau bryfleiddiad dan amodau a reolwyd, yn well nag ar y ffermydd. Defnyddiwyd yr un dulliau samplu ar un neu fwy achlysur ar ôl taeniad ar safleoedd y ffermydd, a lleihaodd holl grwpiau y creaduriaid di-asgwrn cefn yn sylweddol ar y mannau gwaredu, oni bai am bryf copyn linyphiid a carabid (dangosodd yr olaf gynnydd). Y creaduriaid di-asgwrn cefn a oedd yn byw uwchben arwyneb y pridd, a gymerwyd â sampl sugno ddangosodd y lleihad mwyaf difrifol a chyson. Roedd dwysedd yn llai ar y mannau OP a SP, ar y ddau wanhad, nag ar y ddau reolydd, a hynny 20 a 40 niwrnod ar ôl y taeniad.

Defnyddiwyd ail arbrawf sgwâr Lladin ar borfa mwy cynhyrchiol i benderfynu ar effaith y gwaredu yn ystod 2002. Unwaith eto, ar achlysur un sampl neu fwy, lleihawyd dwysedd yr holl grwpiau o greaduriaid di-asgwrn cefn yn arwyddocaol ar y mannau gwaredu. Dangosodd samplu ychwanegol am Collembola ar fannau a daenwyd leihad mewn 20 niwrnod, gan nodi canlyniadau posibl ar gyfer y creaduriaid di-asgwrn cefn mwy, y mae'r creaduriaid di-asgwrn cefn llai yn ffynhonnell bwyd hanfodol iddynt.

Ar raddfa fechan yn y labordy, dangosodd astudiaeth ar effaith taenu dip ar tipulid larfa bod dip OP a SP yn wenwynig i larfa a gyflwynwyd 17 niwrnod ar ôl y taeniad ac roedd parhad posibl i hyd at 133 diwrnod i hyn.

Awgryma asesiad o beryglon, yn seiliedig ar y canlyniad, na ddylid gwaredu dip yn y gwanwyn ar ardaloedd lle mae cywion ifanc rhydwyr. Mae cywion bychain yn rhwystredig mewn symudiad, a gallent ddioddef o ddiffyg bwyd yn eu hardal gyfagos. Gan fod posibilrwydd o wenwyno gan ysglyfaeth a ddifwynwyd, ni ddylid gwaredu yn ystod tymor bridio y rhydwyr mewn ardaloedd sy'n debygol o gynnal adar sy'n nythu. Yn yr hydref dylid osgoi gwaredu ar dir wedi ei wella. Yn aml mae gan yr ardaloedd hyn ddwysedd tipulid uchel ac fe'u defnyddir fel ffynhonnell i rydwyr aeddfed pan gyrhaeddant o'r ucheldir yn y gwanwyn. Mae gan Tipula paludosa sy'n rywogaeth bwysig, gylch blynyddol, ac o fis Medi ymlaen, bydd larfa ifanc yn hawdd i'w niweidio yn y pridd.

CONTENTS

1. INTRODUCTION

The practice of sheep dipping is widespread among sheep farmers. Sheep Scab and other pests such as blowfly, ticks and lice have traditionally been controlled using organophosphate based dips (OPs). Although treatments such as pour-ons and injectables can be effective against some of the pests, synthetic pyrethroids (SPs), (e.g. those with the active ingredient Flumethrin and High-Cis Cypermethrin), are effective against sheep scab and other pests and are becoming more commonly used as an alternative to organophosphates. Both the organophosphate and synthetic pyrethroid dips are potentially hazardous to the environment since they comprise highly active and broad-spectrum insecticides.

Under the 1998 Groundwater Regulations the Environment Agency (The Agency) is required to authorise sheep dip disposal sites in order to ensure no risks to groundwater. Disposal of spent sheep dip must comply with the Ground Water Regulations (1998) in order to minimise the risk to the environment and strict guidelines are in place (Health and Safety Executive, 1998). Details of the guidelines are widely available, in particular from Health and Safety Executive (HSE), Veterinary Medicines Directorate (VMD), Environment Agency and the Scottish Environment Protection Agency (SEPA) and are listed on dip containers. The approved method of dip disposal is to spread spent dip on a suitable area of farmland at the correct dilution for that dip. Therefore there is a possibility of adverse effects on the invertebrate populations in such disposal areas. There are also potential effects for birds that rely on the invertebrates as an important component of their diet, either through a localised reduction in their prey populations at a critical time of year or through secondary poisoning (following consumption of exposed vegetation or invertebrates). The latter effect is not addressed within this research project.

At the time the regulations were introduced, the majority of sheep dip was already disposed to land. However, the authorisation process was considered likely to increase the area of land used for dip disposal since soakaways (the other main route for on farm disposal at that stage) were unlikely to be approved. The Environment Agency is required to consult English Nature (EN) and the Countryside Council for Wales (CCW) where a Natura 2000 site i.e., Special Area of Conservation (SAC) for certain habitats and species or a Special Protection Area for birds (SPA) might be affected by an authorisation for disposal. The present research project was set up in order to evaluate the impacts on terrestrial invertebrates of dip disposal onto land and assess the possible consequences for upland breeding birds. The potential risks of secondary poisoning of birds were not examined within this programme. The information will provide further guidance for the Environment Agency, EN and CCW staff assessing applications for dip disposal near or within Sites of Special Scientific Interest (SSSIs) and Natura 2000 sites.

In response to the invitation to assess the significance of sheep dip disposal to land for terrestrial organisms (and in particular the consequences of any changes in invertebrate prey availability for bird populations), the following programme was set up:

i. A survey of farm practice and compliance with regulatory requirements. This was intended to provide a broad assessment of the nature of the disposal operation to land, including compliance with guidelines, and to allow a preliminary selection of potential areas for further study.

ii. An invertebrate survey of disposal sites and matched control areas of farms where sheep dip disposal to land had been undertaken, to investigate whether historic disposal had measurable impacts.

iii. Multifactorial experimental plot investigations of the effects of organophosphates and synthetic pyrethroid dip disposal on invertebrates of upland grassland to test the impacts of dip disposal under controlled conditions and provide results to compliment those from the historic disposal sites.

1.1 Objectives in 1999

The aim of the first part of the project was (i) to determine, as far as possible, current practice, in order to help assess the scale of any risk and (ii) to carry out a preliminary investigation into the possible effects of disposal to land within ‘historic’ disposal sites.

i. Assess the nature and scale of the operation of disposal to land in England and Wales. The programme set out to achieve this by:

   a. Initial examination of the applications from farmers (in selected areas) to the Environment Agency for "authorisation to dispose"
   b. Selection of locations and site visits to identify disposal practices
   c. Identification of potential risk to birds during site visits to selected localities based on habitat type and potential use of the habitats by birds.

An initial questionnaire was produced to help gather information regarding b and c from the farmers wishing to dispose of the dip on the sites chosen. The questionnaires also helped in choosing suitable sites for further sampling.

ii. Assess the effects of dip disposal on the invertebrate fauna by sampling selected paired disposal and control areas on “historic” sites used previously for disposal.

1.2 Objectives in 2000

The findings from the project in 1999 gave preliminary indications of potential effects within certain of the “historic”disposal sites so it was decided to increase the number of sites investigated as well as carrying out a controlled experiment into the effects of dip on groups of invertebrate taxa. The objectives in the second year of the project were:

i. Selectively re-sample and increase the replication of historic farm disposal and control areas to investigate the possibility of recovery or other changes in the invertebrate populations.

ii. Assess the usage of the disposal areas by birds during the breeding season.

iii. Assess the activity and abundance of key invertebrate taxa within the same areas used for the bird counts.

iv. Carry out a multifactorial replicated plot experiment to investigate the effects of different dilutions of SP and OP dip on invertebrate activity and abundance within trial plots.

1.3 Objectives in 2001

The findings from the multifactorial replicated plot experiment in 2000 showed significant effects of different dilutions of SP and OP dip on all the invertebrate groups studied. It was therefore decided to repeat the experiment on more productive pasture to compliment the initial trial on rough grazing land. The results allowed an assessment of the potential risk to wading birds from reduced invertebrate prey availability. The objectives in the third year of the project were:

i. Repeat the multifactorial replicated plot experiment to investigate the effects of different dilutions of SP and OP dip on invertebrate activity and abundance within trial plots on more productive inby pasture.

ii. Produce an assessment of the potential risk to upland wading birds from reduced invertebrate prey availability based on the findings from the multifactorial replicated plot experiments, findings from the initial farm studies in 1999 and 2000 and information about upland wading species from published material.

2. ASSESSMENT OF CURRENT DIP DISPOSAL PRACTICE

2.1 Introduction

Farming practices differ across Britain as a result of many factors including terrain, rainfall, quality of land and more sociological factors connected with long held traditions. The purpose of this survey was to determine the range of current dip disposal practices, by investigating the nature and scale of the operation of disposal to land in England and Wales, and to use this information in assessing the scale of any environmental risk.

2.2 Methodology

The assessment of the scale and nature of dip disposal was carried out by:

a) Examining the applications from farmers to the Environment Agency for "authorisation to dispose"
b) Choosing locations and visiting sites to identify disposal practices
c) Identifying wildlife at risk during site visits to selected localities based on habitat type and potential use of the habitats by birds.

Information regarding b and c was obtained using a preliminary questionnaire (Appendix 1) to aid the gathering of information. The questionnaire was also used to find suitable sites for invertebrate sampling and further study.

2.2.1 Examination of the applications from farmers to the Environment Agency for "authorisation to dispose"

The regions originally selected from which to choose sites for the questionnaires were northern England and Wales. Hill sheep farming is particularly prevalant in these regions and they also contain many important SSSIs so any detrimental effects of the dip disposal practice could potentially affect large proportions of these environmentally sensitive areas. The applications submitted to the Environment Agency by farmers for authorisation to dispose of dip in summer 1999 were used to identify sites on SSSIs or other areas of designated conservation value. In the uplands of northern England and Wales this approach successfully identified a number of sites within the Teesdale area (County Durham/North Yorkshire), where many farms are comprised almost entirely of SSSI land. Details of more than twenty potential survey sites were obtained from Teesdale, an area of particular interest because of ongoing research and data available about bird species that reside and feed there. Details of suitable farms in Cumbria, Northumberland and Wales were more difficult to obtain since the authorisation process was less advanced in these areas. Many farms in these areas also incorporated land that is not within a SSSI and chose to apply for disposal on the land considered to be of lesser conservation value. Particularly in Cumbria, the farms surveyed included a more diverse range of land quality, partly because of the tendency for larger farm sizes and groups of estate owned tenant farms, allowing for more choice of disposal site, usually using the poorest land possible for this purpose.

2.2.2 Selection of locations and site visits to identify disposal practices

Farmers were selected to receive the preliminary questionnaire, on the basis that their farms were in areas of conservation importance to upland birds. Farm sites, in or adjacent to protected areas, were identified using the disposal applications submitted to the Environment Agency. The sites used were in four regions including Cumbria, NorthYorkshire/Durham /Northumberland and Wales and the additional region of West Yorkshire, chosen because there were insufficient suitable survey sites in the initial search.

2.3 Methods used in the Preliminary Questionnaire

The initial questionnaires were essential to establish what were 'typical' dip disposal locations and allow a choice from these for invertebrate sampling. The preliminary surveys of sheep dip disposal sites were also intended to provide information about the type of farmland chosen for disposal and the disposal methods. This preliminary assessment of potential effects on the terrestrial environment of the study regions would encompass important details to aid the assessment of likely impact on nature conservation interests.

The questionnaire was designed to provide information about: (i) the numbers of farmers using alternatives to sheep dip, (ii) the number of farmers that had switched to alternatives since their original disposal applications (iii) the types of disposal methods (iv) the reasons for any change in practice, (v) the potential wildlife value of the dip disposal locations. A copy of the questionnaire used is in Appendix 1.

The questionnaire was carried out on as many sites as possible, chosen from the applications submitted to the Environment Agency by farmers for authorisation to dispose of dip. In most cases, data from the applications had not been recorded electronically at the time of site selection and a considerable amount of time was required to sort through the original forms. A relatively small number of applications for disposal onto environmentally sensitive land were found, resulting in the initial selection of suitable sites for the questionnaire. This number was cut down again by the reluctance of up to 50% of farmers to take part, due to fears of potential adverse consequences resulting from their involvement in the study. Some of these farmers were persuaded to take part once they were assured of their anonymity. The farmers who did take part were very helpful and often expressed a desire to learn the outcome of any environmental studies. They were eager to know how the dip would affect their land, since they are keen to keep their land in as good condition as possible. All those taking part considered that insufficient investigations have been carried out into the possible detrimental effects of dip disposal to the soil and important soil invertebrates, particularly newer dips such as SPs, and were generally supportive of the need for research into this issue.

Forty-two questionnaires were completed, including 10 in Teesdale, 6 in Cumbria and 6 in Wales, based on information from the applications by farmers to the Environment Agency for authorisation to dispose of dip, and 20 in West Yorkshire, based on knowledge of farms known to have previously used sheep dip.

2.4 Results of the Questionnaire

Responses to the Confidential Questionnaire:

Question 1 – Do you use sheep dip?

The 22 sites for which there were dip disposal applications in 1999 all used dip in that year. Of the additional 20 farms surveyed in West Yorkshire, 10 no longer use sheep dip.

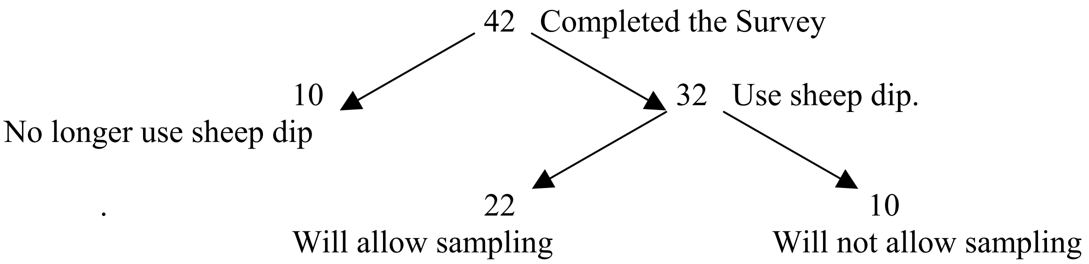


Figure 2.1: **A breakdown of how many farmers were using dip and how many were prepared to allow further sampling:**

Farmers using sheep dip then proceeded to question 2, whilst those that did not were asked a different series of questions from the end of the survey sheet. These are discussed in questions 18-20.

Question 2 – What is the name of the dip? (Active ingredients or product names, from which the active ingredient could be deduced if the farmer was uncertain, were requested)

Of the 32 farmers that used dip, 8 were using SPs, whilst 24 were using OPs.

All respondants gave a reason for their choice of dip. The reason given for the low percentage of SP users was because SPs were believed to be less effective against sheep scab. Two of the OP users had found SPs to be ineffective and considered that they had lost sheep because of it, thereafter reverting to the use of OPs. In addition to answering the question, many of the farmers expressed concern about the health risks of using OPs but have found no effective alternatives. For farmers who do not share common grazing land SPs provide effective treatment for other pests such as flies. Sheep scab is less of a problem for them if there is little or no contact with other flocks. Small numbers of sheep that might have jumped out of enclosed ground or been infected by other sheep jumping in can easily be treated individually by injection. However, the 24 OP users all had common grazing rights and had problems with scab outbreaks in numbers that required the use of dip.

Question 3 – Is there any subsequent treatment, e.g. decontaminant used.

Three of the eight farmers using SP dip were also using a decontaminant, either added to the dip or soil, which imposes an extra cost above that of the actual dip. There is no widely available and effective decontaminant for OP dip for farmers to buy.

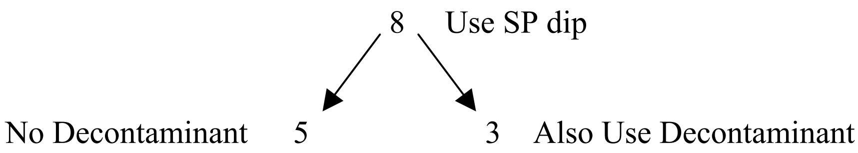


Figure 2.2: A breakdown of the farmers' choice of whether to use decontaminants.

Question 4 – How many sheep are dipped? (Numbers are per annum and are approximate, not taking into account unusual years where conditions require sheep to be dipped twice)

Answers varied between 300 to 6000 but were most commonly between 2000-4000.

Question 5 – Where is the dip disposed of? E.g. own land, neighbours land, mobile dip?

All those questioned disposed of the dip on their own land, although managers of Cumbrian estates commented that in their case they would apply for a single site for all their farms to use.

Question 6 - What is the method of application to the land?

Five out of the 32 dip users used a hosepipe connected to the dip bath or allowed the dip to soak away because of extra cost of hiring someone with a slurry tanker (if they did not have access to one) and the extra time involved with alternative disposal methods. All five claimed they would be better equipped next year and would use the authorised disposal methods, available from Environment Agency, HSE, VMD, Scottish Environment Protection Agency (SEPA) and listed on dip containers, or they would not dip at all. The remaining 27 farmers all disposed of the dip via slurry tanker in an approved manner.

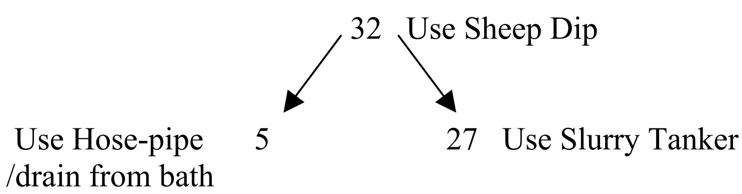


Figure 2.3 Methods of disposal used.

Question 7a – What area is used for disposal, e.g. acreage, part or whole fields and enclosed or open land.

Acreage obviously depended on the amount of dip being disposed of but 28 of the 32 farmers disposed on whole, enclosed fields of between 0.5 and 6 ha in area, spreading dip sparingly over as much of the disposal area as possible. However, some of the disposal sites had not been approved at this stage and were later reduced or completely changed. One of the 28 disposed of the dip using a long hosepipe, so only covered a small area within the disposal site. The remaining 4, who had used hosepipes or allowed the dip to drain away, had applied for disposal areas similar to those of the other 28.

Question 7b – Why was the area chosen and how long has it been used for this purpose?

The areas were chosen mainly because there were no watercourses or open drains that might become polluted. Convenience and accessibility with a slurry tanker were also important issues.

On larger farms the areas had usually been used for disposal before, sometimes for more than 10 years. This is because they had volumes of dip that were too large to let soak away and they had historically been using the current approved method of dip disposal. Smaller farms were usually new to the approved disposal methods, previously having let dip soak away. Disposal areas were therefore generally new in these cases.

Question 8 – What is the volume/ dilution of the dip disposed of?

Dilution ranged between 2:1 and 6:1 volume water to dip, although six farmers out of the 27 spreading with a slurry tanker were mixing it with dry muck rather than diluting with water. Volume disposed of was difficult to assess as the majority of the farmers put an approximately correct but unmeasured amount of dip into a slurry tanker then filled it to the top with water. This led to the variation in dilution rates and volumes dependant on the size of slurry tanker used. Slurry tankers ranged in size from approximately 1500 to 9000 litres capacity. This information was particularly approximate if the slurry tanker had to be hired in for the disposal process and quantities were estimations.

Question 9 – How often and at what time of the year is dip disposed of?

Timing of dipping depends on the other duties of the farmer, outbreaks of scab and the weather, since some conditions are more conducive to scab outbreaks. All the farmers dip between July and October. Those in Teesdale also dip earlier in the year as well, as do some in West Yorkshire and Cumbria depending on the year. Twelve of the 32 farms dipped twice in 1999.

Question 10 – Is the dip mixed with slurry?

None of the farmers claimed to be mixing the dip with slurry, although six were mixing it with dry muck.

Question 11a - What type of vegetation is on the disposal area e.g. improved pasture, rough grazing, hay meadow, other?

20 of the farmers were disposing on rough pasture, five on hay meadow and five on improved pasture. Two in Cumbria dispose on fields of stubble soon after the crop has been removed..

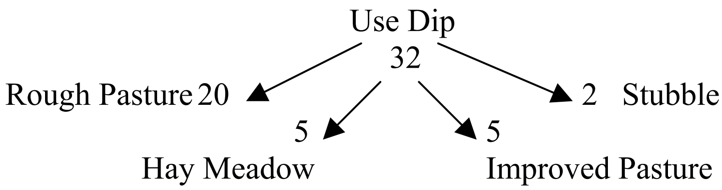


Figure 2.4: Vegetation on the different types of disposal areas

Question 11b – What is the soil type of the area? Can I take a sample?

The soil type in Cumbria was mostly believed to be sandy loam, whereas it tended to have a high peat content in the other areas. Due to concern expressed by some farmers, few samples were taken at the time of this first survey.

Question 12 – Are there clumps of rushes on the disposal area?

20 of the farms had rushes present. These mostly corresponded with those farms where disposal was on rough grazing land. The presence of rushes indicates high water content of the soil, likely to result in dip remaining close to the soil surface and hindering its adsorption. Rushes also feature in habitat selection by some nesting birds since they provide cover and indicate soft ground suitable for feeding. Surface contamination by dip on such areas could have particularly adverse affects.

Question 13 – Is the disposal area likely to have any wildlife value, e.g. do waders nest or feed on the land?

15 of the farmers believed their disposal sites might be of wildlife value, particularly in Teesdale. Five others thought nearby land might be important for wildlife but not specifically their disposal sites.

Question 14 – Do you use other chemical controls on the land i.e. insecticides for leatherjackets?

Two of the Cumbrian farms were using insecticides on their cereal crops early in the season and disposing of dip onto stubble. Six others used spot herbicide control for weeds, which is sprayed directly onto the individual weeds on improved pasture. The remaining 24 farms used no other chemicals on the land (other than muck as fertiliser).

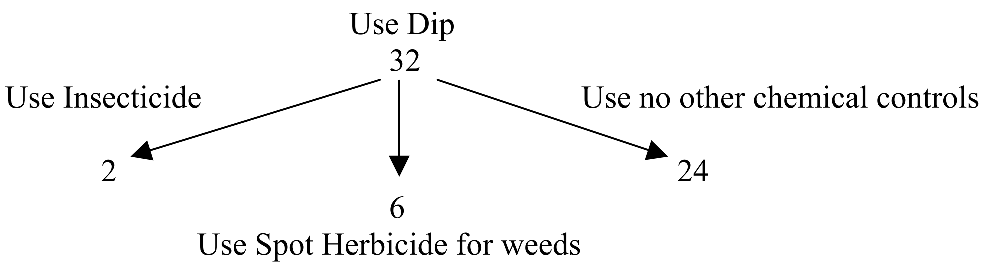


Figure 2.5: Number of farms using other chemical controls.

Question 15 – What guidance have you received about dip disposal and was it practical?

20 of the farmers felt they had received insufficient guidance. Eight believed they had received impractical guidance, since new disposal methods were difficult to comply with and involved extra expense. Four of the 32 farmers that used dip believed they had received adequate and helpful guidance.

Question 16 – Would you be happy for me to come back and survey the vegetation and soil type on the disposal area?

28 of the farmers were happy to help in this way

Question 17 – Could I sample for invertebrates? This would involve taking 24 spadefuls of soil from the disposal area and a suitable uncontaminated control site nearby in October and again next spring.

22 of the farmers were happy to help in this way. The remaining 10 were worried about damage to land, disruption of wildlife and inconvenience. Most were also concerned that they should remain anonymous, which they were again assured of.

Questions 18-20 were for farmers that have ceased to use sheep dip:

18) What alternative to sheep dip do you use to treat the sheep for pests and why?

Eight out of the ten farmers who had ceased dipping had changed to injectables. Two had decided to do nothing at all unless symptoms arose. Reasons for these changes were mostly to do with problems of dip disposal. One farmer had been refused permission to dispose of his dip because the disposal site was too close to a group of houses. Others did not have the correct equipment for disposing of the dip, having previously let it soak away and they considered it too expensive to pay for removal or disposal. This is discussed in greater detail at the end of the questionnaire.

19) Did you use dip regularly before the current legislation came into force?

All the farmers questioned had previously used sheep dip.

20) How did you dispose of the dip?

Two of the farmers had spread the dip with muck out of a muck spreader, whilst the other eight had let it soak away.

2.4.1 Further Use of the Questionnaire

Appropriate farms for more detailed assessment of invertebrate fauna and vegetation characteristics were chosen on the basis of information gathered in the questionnaire, as described in Chapter 3. Sites chosen were within or adjacent to SSSIs or other areas of nature conservation importance, and were in Wales, Teesdale and West Yorkshire. A 'worst case' site was also chosen near Derwent Reservoir where there have been repeated dip disposals from many farms in the vicinity. Two sites from each of the three different regions and the 'worst case' site meant that seven different sampling sites were finally chosen in 1999, some of which were replaced with other farms in the same area in 2000 for continuation of the study (see Chapter 3).

2.5 Discussion of Questionnaire Results

Although the main reasons for farmers' chosen methods of disposal were short term economies, they made it clear during general discussion at the time of the questionnaire that they recognised that long term environmental impact needed to be investigated. Those involved in the questionnaire volunteered additional detail and reasoning behind their responses, some of which is incorporated into this discussion.

This survey has exposed issues with dipping and disposal methods on hill farms where overall profit margins are low. In order to survive in the current farming conditions in Britain farmers need to find solutions to pest problems that are least costly in financial terms. It is also important to minimise damage or stress to land and livestock, and to keep labour costs low.

Hill sheep are required to be hardy and withstand conditions in which lowland sheep could not survive. Their fleeces and meat are of poorer quality than lowland sheep and so they are worth less. Even in good years margins are dependent on maintaining low input regimes. The recent state of the livestock markets, with sheep being sold for a few pence, has focussed farmers' attentions on ways of reducing overheads. An average OP dip costs between £0.30 and £0.40 per sheep per dipping occasion. With the added costs of the permits and licences required to use dip, along with the hiring of slurry tankers and drivers often contracted in for dip disposal, and costs of other handling equipment to deal with the dip, this often amounts to more than the individual sheep is worth. These extra expenses, including the disposal permit, are blamed for the reluctance of some farmers to dip sheep or, if they do use dip, for unauthorised disposal methods.

These variations in dipping and disposal practice are fundamental to the interpretation of the invertebrate studies on the historical farm sites. For example, despite assurances of top-up in dip bath to keep concentrations in line with dip manufacturer and MAFF guidelines, anecdotal evidence suggests that guidelines were not always being followed by farmers, with the dip bath half empty at the completion of dipping. Dip would then be diluted by a much greater amount for disposal than is estimated using practice recommendations based on a full dip bath and results could then underestimate the effects of dip disposal at recommended strengths. Although the Certificate of Competency is required for the purchase of dip, pressure of farm work dictated that the buyer was not necessarily present during the whole of the dipping period. In addition, when questioned formally in the preliminary questionnaire, farmers answered queries about dip concentrations and best practice correctly whilst admitting to encountering logistical difficulties in following the procedures precisely.

The equipment available sometimes restricts those farmers who intend to carry out all the disposal instructions correctly, as they fill their tankers or muck spreaders containing the spent dip with an unknown quantity of water or muck until they are full. These factors make dilution rates of the dip very variable and the varying equipment used also makes the discharge rate of the dilute dip difficult to measure and control. Farmers often spread the dip until it has run out rather than when the designated area for that amount of dip has been covered. This led to problems in subsequent sampling as the exact area of disposal within a designated site may not be obvious (see Chapter 3). Other factors such as storage/degradation time of spent dip before disposal, which depends on the farmer's schedule, weather and accessibility of the disposal sites, are also uncontrollable yet important variables. Further, if disposal is carried out by a third party, because the farmer does not have appropriate equipment, the exact disposal site may not be accurately identified.

This preliminary survey suggests an inconsistent approach to scab and pest control. Scab may cause problems for farmers, particularly on common land where many flocks come into contact with each other and scab is easily spread. Although the extra costs of dipping have meant some farmers will not dip at all, the resultant outbreaks of sheep scab can mean that other farmers using common grazing might have to dip more than twice in the same year. This could lead to large areas of land being repeatedly used for dip disposal between April and November. Repeated disposal occurred in 1999 in Teesdale, where co-ordinated dipping times were used in an attempt to eradicate scab off the fell altogether. However, since not all farmers dispose of the spent dip at the same time (storing it until disposal is convenient) dip can be spread over many sites within the area, over several months. The potential for constant presence of sheep dip and the re-inundation of land over the course of the year may present increased environmental hazards to the soil invertebrates and other animals, especially rare bird species that feed on them. Such variation also presents problems in designing experiments, which may represent assessments of ‘worst case’ scenarios, as well as leading to a multiplicity of scenarios for consideration during risk assessment. The effects of disposing of dip may therefore affect both invertebrates and their dependent predators at many points in their life and breeding cycles. Farmers questioned understood that there could be such environmental issues and were concerned about the impact of disposal timings and methods. Many expressed an eagerness to learn the optimum techniques to avoid affecting the quality and environmental importance of grazing land.

2.5.1 Level of confidence in the Questionnaire

The questionnaire was intended to be indicative of the range of dip disposal practices used and to highlight the terrestrial environments that could potentially be at risk, in order to enable a range of realistic scenarios to be investigated further. It was highly successful in this and was invaluable in determining sites for further study. Due to the small sample size it is representative of a tiny proportion of farms where dip disposal takes place and is not intended to be a definitive survey of practices either within the study areas or more widely. However, the wide variation in disposal methods found in this small sample does indicate the difficulties encountered by farmers trying to follow best practice guidelines.

3. INVERTEBRATE SAMPLING ON FARM SITES 1999-2000

3.1 Introduction

This part of the project was designed to test the hypothesis that, where a site had been used historically for disposal, invertebrate densities and community composition were likely to differ from a comparable 'control' site. As the aim of the study was to assess the consequences of sheep dip application on land of conservation importance, it was necessary to evaluate the effects of disposal in upland farms within, or close to, conservation areas. Site selection, in northern England and Wales, was over a wide geographical area and reflected the requirement that resultant information would be used for guidance by both English Nature and Countryside Council for Wales staff, as well as the Environment Agency. Evaluation of the effects of dip disposal on terrestrial invertebrates was based on a comparison between historic disposal areas and adjacent uncontaminated control areas, under the same management regime.

To evaluate the conservation implications of dip disposal on the upland fauna, areas used for dip disposal were compared with adjacent uncontaminated areas, and four sampling techniques were used:

1. Standardised, measured soil samples were taken to determine the densities of soil inhabiting invertebrates
2. Pitfall traps were used to capture surface-active invertebrates
3. Timed suction sampling was used to compare the densities of surface dwelling invertebrates on disposal and control areas
4. Bird counts were made in disposal fields and adjacent control fields

Mobile invertebrates rapidly re-colonise areas when pesticide toxicity decreases and the size of area receiving the pesticide application, such as that in dip disposal, influences the recovery rate (Jepson 1989). In the present study, paired comparisons were made between the densities of invertebrates on disposal and control sites at each farm. Major taxa were compared and the densities of sedentary and active invertebrate groups were also assessed separately, thus allowing the effects of dip disposal to be determined in the absence of recolonisation. Soil samples for density measurements were taken at 7 sites in autumn 1999 and 8 sites in spring 2000. The autumn samples were taken, when possible, within two weeks of dip disposal to measure the immediate effects of pesticide application. The intention was to sample the same sites in the following spring to measure longer-term effects.

Within a single taxon different species may also show different capacities for colonisation. Rushton et al. (1989) have suggested that, while active ground beetles will probably re-colonise insecticide treated areas rapidly, less active species will not. The less active species are therefore likely to suffer more persistent local population declines if exposed to dip and this will alter the species composition on the disposal area. In the present study, the large numbers of spiders and ground beetles caught in pitfalls allowed such differential effects to be investigated within two taxa of surface-active invertebrates using the CANOCO programme (Ter Braak 1988). This multivariate approach relates the distribution of species to environmental variables, including the effects of dip disposal. Differentiation between sedentary and active groups in the soil samples from paired control and disposal areas allows a broad assessment of the effects of dip disposal on density, in the absence of recolonisation. The multivariate approach, which does not depend on paired samples, allows the more subtle effects of differences between species re-colonising ability to be investigated.

Suction samples and pitfall trap catches reflect the food available for wader chicks and adults such as golden plover and nesting lapwing, which take surface-active arthropods (Baines 1990, Whittingham et al 2001), whereas species extracted from soil samples are important to soil probing waders such as curlew and oystercatchers (Zwarts and Blomert 1996). The invertebrate sampling methods are, therefore, appropriate for examining the effects of dip disposal on the food supply of upland birds while the bird counts provided information on use of dip contaminated land by the foraging birds.

3.2 Methods 1999

3.2.1 Site selection

The results of the questionnaires, together with site visits to ascertain whether there was an appropriate control area near the disposal site, were used to select six farms for invertebrate sampling in 1999. The hypothesis that repeated disposal of OP and SP sheep dip could have cumulative deleterious effects on invertebrate populations led to the selection of Derwent as a “worst case” site. Farmers with grazing land abutting Derwent Reservoir (54º 52’N 1º 53’W) are not allowed to dispose of dip on their own land because of potential contamination of the ground water. The Derwent site constituted the disposal area for all the farmers in the reservoir catchment, receiving repeated applications of both OP and SP dips before and during the 1999 sampling period of this study. The choice of Derwent, therefore, provided a baseline site, which was known to be heavily contaminated and where invertebrate populations were expected to be adversely affected. Sites were also chosen on the basis that they were in or adjacent to SSSIs. Two farms from each of Wales, West Yorkshire and Teesdale were chosen which, with the addition of the “worst case” site at Derwent Reservoir, made seven sites in total. Control sites were chosen from fields adjacent to the disposal field at each farm. The controls had not had dip applied to them but were selected to be, as far as possible, of similar soil type and under the same management regime as the disposal sites. At Derwent, the edges of the ungrazed, disposal field, beyond the turning area of the slurry tankers, were used as the control area because the surrounding fields were grazed and were therefore inappropriate controls.

3.2.2 Site characteristics

At each site, the timing of dip application, altitude and slope were determined, land use described and pH and organic content measured (Table 3.1). Organic content and pH measurements were based on 12 replicate $0.001m^2$ soil cores taken from each disposal and control area. Six cores were used for pH measurement and the other six dried to constant weight before ignition, at 440 ºC for 4h. pH was measured by stirring 2g of each soil sample in 20 ml of 0.1M KCl solution and allowing to stand before testing with a pH meter. Organic content was calculated from the loss of weight on ignition. In each case the mean of the six values was calculated (Table 3.1).

3.2.3 Timing of invertebrate sampling

Due to differing farming practices, soil sampling for invertebrates was carried out over three months, between September and November, depending on when the farmers had disposed of the dip. Where possible, samples were taken approximately two weeks after the dip had been spread. This allowed time for the dip to have an impact on the invertebrates, without significant recovery and recolonisation, and for the dip concentration to drop to a safer level for handling by the observer. Longer-term effects were investigated by resampling, where possible, in spring 2000 before another disposal had been carried out.

3.2.4 Invertebrate sampling (soil invertebrates only)

In order to determine densities of soil invertebrates, 12 soil samples were taken, each approximately 17.5 cm x 17.5 cm x 17.5 cm, from each disposal and each control site at each farm. The number of samples was determined by the requirement for an adequate sample size for statistical analysis, moderated by the restraints of time and labour. Random sampling was stratified to cover the area where disposal was understood to have taken place and an equivalent area was sampled on the control site. At Derwent, the areas of the disposal field, which were not accessible to the disposal tankers, were used as control areas. Mobile invertebrates were collected from each soil sample by heat extraction in Berlese funnels for one week. Invertebrates were sorted and identified to family level (or as precise a level as possible depending on the quality and stage of development of the individuals).

A further 12 soil samples, of approximately 12cm x 12cm x 12cm, were taken from both the control and disposal sites at Yorkshire 2, Teesdale 1 and 2 and Derwent for an investigation of densities of earthworms. These were either sorted by hand on site or on return to the laboratory. Earthworm sampling was not carried out at the sites in Wales 1, 2 and Yorkshire 1 because the samples could not be sorted on site and transportation of the additional samples was not possible.

3.3 Methods 2000

Sampling was carried out in 2000 to investigate whether the differences in densities, found between control and disposal areas in autumn, persisted into the following spring. However, a number of the sites used in 1999 were either not available for sampling in 2000 or had proved unsatisfactory (cf. section 3.4). Extra farm sites were added as substitutes, for further density comparisons, and to increase the sample size of sites within reasonable travelling distance. Pitfall collections, at these more accessible sites, provided spiders and ground beetles used in multivariate analyses. The same site characteristics were measured for the new sites as in 1999 (Table 3.1).

3.3.1 Sampling for soil invertebrates

Soil sampling to determine invertebrate densities was repeated in spring on four of the original farm sites from 1999, Teesdale 1 and 2, Wales 2 and Derwent. Yorkshire 1 and 2 were replaced by Yorkshire 3 and 4, Wales 1 was replaced by Wales 3 and an additional site, Teesdale 1A, was sampled pre and post dip disposal. The methods were those used in 1999.

3.3.2 Sampling for surface-active invertebrates

The sites added in 2000, particularly those that were not sampled for soil invertebrates using Berlese extraction, were intended to increase the sample size for the purposes of multivariate analysis. Pitfall sampling was carried out in spring and early summer 2000, 6 to 8 months after the last dip disposal and could only be expected to detect longer-term effects. Pitfall traps were used on 10 farm sites, 7 in Teesdale (Teesdale 1-6) and 3 in Yorkshire (Yorkshire 3-5). The Welsh sites were situated at too great a distance to sample on a fortnightly basis and three of the Yorkshire sites, where bird counts were carried out (see below) were not available because they were being used for late lambing or hay crops which could not be disturbed. Six pitfalls, 7 cm in diameter with approximately 50ml of ethylene glycol (Clark and Blom, 1992), were sunk level to the ground surface in a line at approximately 2 m intervals in each control and disposal area. These were laid down in mid-May and collected at fortnightly intervals for later identification of the invertebrates. Pitfalls were finally taken up at the end of July.

Suction sampling for surface-active invertebrates was carried out on the pitfall sites, once at each site in June using an Echo “Blower-vacuum” with an extension sampling tube (aperture 0.01 m^2). Sampling was carried out for two 30s intervals at each site (Macleod, A. *et al*, 1994). Timing of suction sampling was determined by the weather, as sampling on wet vegetation is not possible.

3.3.3 Bird counts

The purpose of the bird counts was to determine the usage of the habitat type during the breeding season rather than to estimate the relative abundance in treated and untreated areas. Bird counts were carried out at approximately fortnightly intervals between April and June 2000 on 13 farm sites, 7 in Teesdale and 6 in Yorkshire. This entailed early morning visits to each site, walking through the control and disposal areas, or observing from the field boundary where entrance to fields was not possible, identifying and recording bird numbers and species seen using the areas on each visit. The sequence of visits was rotated to observe the sites at different times of the day.

3.3.4 Statistical analysis of invertebrate groups on the farm sites

Density comparisons (soil samples and suction samples)

Arthropods from soil samples were grouped as:

(i) Beetles, flies, tipulid larvae and earthworms (important taxa for feeding upland birds)

(ii) Sedentary and active, to distinguish between invertebrate groups with poor and high potential for re-colonising disposal areas on the farm sites.

Student’s t-tests, carried out on log-transformed data, were used to compare invertebrate densities on control and disposal areas at each farm. Geometric mean densities are presented in tables.

Density comparisons for surface-active invertebrates, taken by suction sample, were based on paired t-tests. The data set comprised all farms where suction samples were taken, with control and disposal areas at each farm forming the pairs.

3.3.5 Multivariate Analysis (pitfall samples)

Pitfall traps capture invertebrates from an unknown area and give comparative abundance estimates only (Southwood and Henderson 2000). Pitfall samples have therefore not been used to provide density comparisons but to provide large numbers of individuals to allow comparison of community composition at different sites. The total species assemblage of spiders and of ground beetles from pitfall trap catches at the farm sites (Appendix 3) were analysed as two separate groups using CANOCO (Ter Braak 1988). Numbers of individual species were log transformed and sample scores were calculated as weighted mean species scores. Single occurrences of spider species at a site were ignored and rare species were down-weighted for both spiders and beetles. The qualitative environmental variables entered in the analyses included: altitude, slope, pH and organic content of the soil. Dip type and field management were entered as nominal variables: OP, SP and control, pasture, improved grazing and hay meadow. With the exception of Teesdale 1A, where dip was disposed for the first time in spring 2000, all sites received their last application of dip in autumn 1999 and the timing of dip disposal has not been entered as a variable.

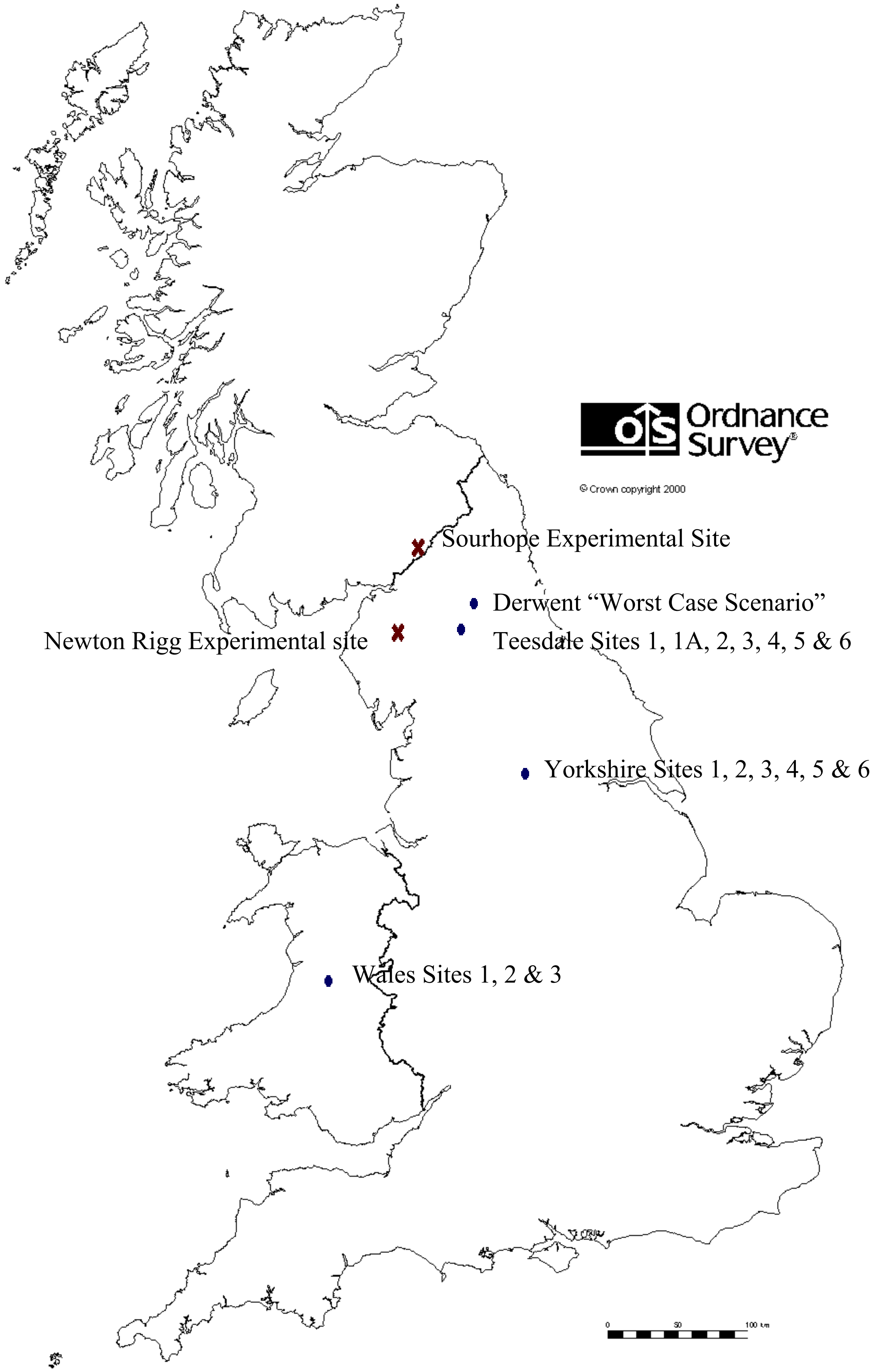
Table 3.1: Site characteristics and dip disposal information for the farm sites in 1999 and 2000

Site	Dip Type	1999 Interval ^	2000 Interval ^	Altitude (m)*	Slope (degrees)	pH	Organic Content %	Landuse
Derwent c.	N/A	N/A	N/A	220	15-20	4.5	7.63	Setaside
Derwent d.	OP/SP	<30 days	6 months	220	15-20	5.2	8.54	Setaside
Teesdale 1 c.	N/A	N/A	N/A	420	20-25	4.9	21.6	Hay Meadow
Teesdale 1 d.	OP	10 days	6 months	420	20-25	4.7	18.8	Hay Meadow
Teesdale 1A c.	N/A	N/A	N/A	410	5-10	4.6	19.4	Hay Meadow
Teesdale 1A d.	OP	N/A	14 days	410	5-10	4.7	20.2	Hay Meadow
Teesdale 2 c.	N/A	N/A	N/A	420	0-5	4.2	18.7	Hay Meadow
Teesdale 2 d.	OP	14 days	6 months	420	0-5	4.4	19.4	Hay Meadow
Teesdale 3 c.	N/A	N/A	N/A	420	0-5	4.8	18.5	Improved Pasture
Teesdale 3 d.	OP	N/A	6 months	420	0-5	4.9	19	Improved Pasture
Teesdale 4 c.	N/A	N/A	N/A	430	0-5	4.6	19.2	Improved Pasture
Teesdale 4 d.	OP	N/A	6 months	430	0-5	4.7	18.7	Improved Pasture
Teesdale 5 c.	N/A	N/A	N/A	450	0-5	4.5	20	Rough Grazing
Teesdale 5 d.	OP	N/A	6 months	450	0-5	4.5	19.8	Rough Grazing
Teesdale 6 c.	N/A	N/A	N/A	460	0-5	4.3	21.1	Rough Grazing
Teesdale 6 d.	OP	N/A	6 months	460	0-5	4.2	21.2	Rough Grazing
Wales 1 c.	N/A	N/A	N/A	450	unknown	3.9	86.5	Rough Grazing
Wales 1 d.	OP	>60 days	N/A	450	unknown	4.2	unknown	Rough Grazing
Wales 2 c.	N/A	N/A	N/A	400	10-15	3.8	38.2	Improved Pasture
Wales 2 d.	SP(dec)	10 days	6 months	400	10-15	3.9	40.1	Improved Pasture
Wales 3 c.	N/A	N/A	N/A	380	5-10	4.3	40.2	Improved Pasture
Wales 3 d.	SP	N/A	6 months	380	5-10	3.9	46.3	Improved Pasture
Yorkshire 1 c.	N/A	N/A	N/A	420	5-10	4.2	17.8	Improved Pasture
Yorkshire 1 d.	SP(dec)	10 days	N/A	420	5-10	4.5	18.1	Improved Pasture
Yorkshire 2 c.	N/A	N/A	N/A	350	10-15	4.3	18.4	Hay Meadow
Yorkshire 2 d.	SP	21 days	N/A	350	10-15	4.6	18.9	Hay Meadow
Yorkshire 3 c.	N/A	N/A	N/A	350	0-5	3.2	21.4	Rough Grazing
Yorkshire 3 d.	SP	N/A	6 months	350	0-5	3.5	23.1	Rough Grazing
Yorkshire 4 c.	N/A	N/A	N/A	300	5-10	4.3	16.5	Hay Meadow
Yorkshire 4 d.	SP	N/A	6 months	300	5-10	3.8	17.1	Hay Meadow
Yorkshire 5 c.	N/A	N/A	N/A	350	5-10	4.4	18.2	Improved Pasture
Yorkshire 5 d.	OP	N/A	6 months	350	5-10	4.3	17.9	Improved Pasture
Yorkshire 6 c.	N/A	N/A	N/A	400	5-10	N/A	unknown	Improved Pasture
Yorkshire 6 d.	OP	N/A	6 months	400	5-10	N/A	unknown	Improved Pasture

c. = control site
d. = disposal site
* = m above sea level
^ = interval since dip application
N/A = site not used for disposal or not resampled at this time.

The control plot of site Teesdale 2 (Teesdale 2c) was changed in 2000 and had an average organic content of 18.7% as shown in the table. The change in control plots was made after the organic content of the soil of the control area in 1999 had been shown to be significantly lower (12%) than that of the disposal area (19.4%), meaning the control was not truly comparable.

Map Of Sheep Dip Disposal Sites Investigated 1999 – 2002



3.4 Results

3.4.1 Farm Case Studies

Sheep shed wool while being dipped and this provides a visible marker of the disposal area, when dip has been recently applied. On farms where application had taken place several months before soil sampling, the investigators had to rely on the farmer giving an accurate location. On some of the farms there was doubt that the exact disposal area had been identified and difficulties were also encountered in choosing appropriate control sites. In other cases, field management changed between years or the farm changed ownership and the sites used in 1999 were not available in 2000. Because of this high degree of variability, each farm is described individually below with a summary table of sampling results and comparison between farms is made in a following section. Figure 3.1 shows the study areas used in 1999 and 2000, on a large scale to preserve anonymity promised to those farmers taking part. Site characteristics, with type of dip disposed and interval between disposal and sampling, are given in Table 3.1. Landuse of control and disposal areas is also given in Table 3.1. In all cases, use of the disposal and control areas were similar, differing only for the month immediately after dip disposal, when grazing animals were excluded from the disposal area (Health and Safety Executive, 1998). Lists of groups invertebrates were sorted into are in Appendix 2. Species lists of beetles, spiders and bugs caught on the farm sites are in Appendix 3.

3.4.1.1 Site "Derwent"

Worst case scenario
Sampled September 1999 and May 2000
Sampling methods: soil sampling with heat extraction 1999 and 2000, earthworm sampling in 1999.

Site Description

The site near Derwent Reservoir was selected to represent a probable worst case scenario site. The farmers in the catchment area of the reservoir are not permitted to dispose of sheep dip onto their land as it might cause pollution of the water. They therefore dispose, using their own equipment, onto one field set aside by Northumbrian Water for sheep dip disposal. This field receives multiple disposals of both SP and OP dips during the April-November dipping season. The exact amount of dip disposed and the proportions of each dip type are not known.

The disposal field was previously used for grazing and is bordered to the North and East with pasture, separated by dry stone walls, and to the South and West by wooded areas. The entire field, measuring approximately 0.5 ha, is used for disposal, leaving up to a 2m boundary around the field edges, with areas of approximately 10 x 20 m, beyond the turning circles and area of distribution of the tankers, at the corners. The vegetation coverage was mainly long grasses interspersed with thistles and other invasive plants. The "control" area for this site was in part of the same field as the disposal site, since there was not another comparable ungrazed field nearby. Corners of the field that were beyond the reach of the heavy farm vehicles (because of large turning circles) were utilised as the control (untreated area), keeping as far away from the walls as possible so as to lessen any possible edge effects.

Site results summary
The total mean densities of soil arthropods were significantly lower on the disposal areas than on the control areas in both autumn 1999 and in spring 2000. Both active and sedentary groups were 50-70% lower on the disposal sites in both years, with no over winter recovery, despite the lack of dip disposal during the winter period (Table 3.2).

Table 3.2: Summary of organisms sampled at Derwent showing geometric mean numbers m^{-2} (with 95% confidence limits) and percentage difference between control and disposal areas.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*	P
Autumn 1999	OP SP	1 month	worms (hand sorting)	237	307	-29.54	NS
			total soil invertebrates (Berlese extraction)	2516 (2444-2587)	1092 (1016-1167)	56.59	< 0.01
			active soil invertebrates (Berlese extraction)	930 (857-1003)	467 (392-542)	49.78	< 0.01
			sedentary soil invertebrates (Berlese extraction)	1455 (1382-1527)	573 (493-653)	60.62	< 0.01
Spring 2000		6 months	total soil invertebrates (Berlese extraction)	1835 (1761-1909)	810 (737-883)	55.87	< 0.01
			active soil invertebrates (Berlese extraction)	938 (857-1019)	267 (188-346)	71.54	< 0.01
			sedentary soil invertebrates (Berlese extraction)	679 (607-750)	335 (258-412)	50.66	< 0.01

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
* control - disposal x 100
control
P = level of significance
NS - not statistically significant
P < 0.05 = Significant
P < 0.01 = Highly Significant

3.4.1.2 Site "Wales 1"

Sampled September 1999
Sampling methods: soil sampling with heat extraction

Site Description
Site Wales 1 consisted of very rough grazing land with coarse grasses and mosses overlying peaty soil with the highest organic content of any of the historic sites (86.5%, Table 3.1). This site was sampled several months after dip disposal in spring 1999 and it was not certain that the actual disposal site had been sampled. The area designated for disposal was extensive and the information from the farmer on the actual area used was not thought to be reliable. Some sampling may therefore have occurred outside the actual disposal area. In view of this uncertainty this site was not re-sampled in 2000.

The exact disposal area had not been used for dip disposal previously although disposal had occurred within the same field.

Site results summary
There were no significant differences between densities in control and disposal sites for any of the invertebrate groups tested.

Table 3.3: Summary of organisms sampled at Wales 1 showing geometric mean numbers m^{-2} (with 95% confidence limits) and percentage difference between control and disposal areas.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*	P
Autumn 1999	OP	> 30 days	total soil invertebrates (Berlese extraction)	1228 (1148-1309)	818 (747-890)	33.39	NS
			active soil invertebrates (Berlese extraction)	706 (627-784)	664 (593-736)	5.95	NS
			sedentary soil invertebrates (Berlese extraction)	480 (393-568)	179 (106-253)	62.71	NS

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
* control - disposal x 100
control
P = level of significance
NS - not statistically significant
P < 0.05 = Significant
P < 0.01 = Highly Significant

3.4.1.3 Site "Wales 2"

Sampled November 1999 and May 2000
Sampling methods: soil sampling with heat extraction

Site Description
Site Wales 2 had a disposal area on pasture covered mainly by short grass. The control is part of the same field, which was over 1 ha in area and appeared homogeneous. SP with decontaminant was applied at the end of October in 1999. This application followed at least 5 years of use of OP with a similar disposal method. Although the exact boundary of the disposal area was known, disposal was done by bucketing out the dip rather than using a slurry tanker. The dip therefore fell on very localised patches of land, within the general disposal area, which sampling may have missed in some cases.

Site results summary
In 1999 site Wales 2 was sampled 10 days after dip disposal. The densities of the active arthropod group on the disposal area were 25 % lower and significantly different from those on the control area. Six months after disposal in spring 2000, however, invertebrate densities had risen on both control and disposal areas and the total mean densities were significantly higher on the disposal area. Neither sedentary nor active

arthropods densities differed significantly (Table 3.4) but non-arthropods were at significantly higher densities in the disposal area in spring 2000 (Table 3.24).

Table 3.4: Summary of organisms sampled at Wales 2 showing geometric mean numbers m^{-2} (with 95% confidence limits) and percentage difference between control and disposal areas.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*	P
Autumn 1999	SP (dec)	10 days	total soil invertebrates (Berlese extraction)	1015 (910-1119)	837 (717-957)	17.54	NS
			active soil invertebrates (Berlese extraction)	661 (584-739)	493 (401-586)	25.42	< 0.05
			sedentary soil invertebrates (Berlese extraction)	299 (227-371)	284 (208-361)	5.02	NS
Spring 2000		6 months	total soil invertebrates (Berlese extraction)	896 (824-967)	1665 (1588-1742)	-85.83	< 0.05
			active soil invertebrates (Berlese extraction)	530 (458-602)	1002 (920-1084)	-89.06	NS
			sedentary soil invertebrates (Berlese extraction)	403 (326-480)	627 (552-702)	-55.58	NS

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
* control - disposal x 100
control
P = level of significance
NS - not statistically significant
P < 0.05 = Significant
P < 0.01 = Highly Significant
dec = decontaminant used

3.4.1.4 Site "Wales 3"

Sampled May 2000
Sampling methods: soil sampling with heat extraction

Site Description
Site Wales 3 was introduced in 2000 to replace Wales 1. The disposal site at Wales 3 was on improved pasture consisting of a large field of 2-3 ha, bounded by fencing. A matching adjacent field was used for the control. SP was disposed in autumn 1999 on an area that had not previously received dip.

Site results summary
There were no statistically significant differences between densities in disposal and control areas for any invertebrate group at Wales 3 in 2000.

Table 3.5: Summary of organisms sampled at Wales 3 showing geometric mean numbers m^{-2} (with 95% confidence limits) and percentage difference between control and disposal areas.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*	P
Spring 2000	SP	6 months	total soil invertebrates (Berlese extraction)	1027 (944-1110)	1018 (944-1092)	0.88	NS
			active soil invertebrates (Berlese extraction)	733 (645-820)	577 (467-656)	21.28	NS
			sedentary soil invertebrates (Berlese extraction)	278 (205-350)	461 (384-538)	-65.83	NS

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
* control - disposal x 100
control
P = level of significance
NS - not statistically significant
P < 0.05 = Significant
P < 0.01 = Highly Significant

3.4.1.5 Site "Yorkshire 1"

Sampled October 1999
Sampling methods: soil sampling with heat extraction

Site Description
Site Yorkshire 1 had a disposal site measuring approximately 0.25 ha, on improved pasture bordered by dry stone walls, quite close to the farm buildings and also to open moorland. The disposal site had not been used before. SP with decontaminant was applied to the disposal area in October 1999 and a matching adjacent field of comparable size was used as the control. This site could not be utilised in 2000 since it was not made available.

Site results summary
In 1999, site Yorkshire 1 was sampled 10 days after dip disposal. Total invertebrate densities were 80% lower on the disposal areas with the significant difference largely contributed by the lower numbers of sedentary invertebrates m^{-2} (Table 3.6).

Table 3.6: Summary of organisms sampled at Yorkshire 1 showing geometric mean numbers m^{-2} (with 95% confidence limits) and percentage difference between control and disposal areas.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*	P
Autumn 1999	SP (dec)		total soil invertebrates (Berlese extraction)	2299 (2041-2556)	403 (261-544)	82.47	< 0.05
			active soil invertebrates (Berlese extraction)	113 (38-189)	69 (0-142)	38.94	NS
			sedentary soil invertebrates (Berlese extraction)	2739 (2631-2846)	218 (132-304)	92.04	< 0.05

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
* control - disposal x 100
control
P = level of significance
NS - not statistically significant
P < 0.05 = Significant
P < 0.01 = Highly Significant
dec = decontaminant used

3.4.1.6 Site "Yorkshire 2"

Sampled November 1999:
Sampling methods: soil sampling with heat extraction, earthworm counts
April - June 2000: bird counts

Site Description
Site Yorkshire 2 had a disposal site on a hay meadow, used for one or two crops of hay per year and grazed in autumn and winter by sheep and cattle. The matching control area was an adjacent hay meadow and both fields measured approximately 0.5 ha. SP was applied to the disposal area in October 1999. Above both fields there is a small road for access to other farms with small wooded areas beyond. Moorland adjoining fields across the road is visible from the disposal site. Due to the use of the fields as hay meadows they could not be utilised for pitfall traps or soil sampling in Spring 2000, but it was possible to count birds from the road, thereby not disturbing the crop.

Site results summary
In 1999 site Yorkshire 2, sampled 3 weeks after dip disposal, showed no significant difference in total number of invertebrates m^{-2} between control and disposal areas (Table 3.7) although there were significantly higher densities of beetles and tipulid larvae in the control areas (Table 3.20).

Bird counts in April, May and June 2000 reflect the habitat available at site Yorkshire 2. lapwings, nesting on the open upland and nearby moorland were observed on the site and tree sparrows and greenfinches were probably nesting in the wooded areas. Swallows nested in barns in the adjacent fields but fed in and around both the control and disposal sites.

Table 3.7: Summary of organisms sampled at Yorkshire 2 showing geometric mean numbers m^{-2} (with 95% confidence limits) and percentage difference between control and disposal areas. Bird counts are grouped as waders and others, given as mean numbers recorded per visit.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*	P
Autumn 1999	SP	21 days	worms (hand sorting)	237	191	19.41	NS
			total soil invertebrates (Berlese extraction)	740 (648-633)	965 (880-1049)	-30.41	NS
			active soil invertebrates (Berlese extraction)	94 (20-167)	126 (50-201)	-34.04	NS
			sedentary soil invertebrates (Berlese extraction)	634 (535-734)	838 (749-927)	-32.18	NS
Spring 2000		6 months	waders (area counts)	1 (0-3)	1 (0-3)		
			other birds (area counts)	3 (1-5)	4 (2-6)		

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
* control - disposal x 100
control
P = level of significance
NS - not statistically significant
P < 0.05 = Significant

3.4.1.7 Site "Yorkshire 3"

Sampled April - June 2000
Sampling methods: soil sampling with heat extraction, pitfall traps, suction sampling, bird counts

Site Description
Site Yorkshire 3 was a replacement for Site Yorkshire 1 in 2000 and the disposal and control areas were matching adjacent expanses of improved pasture which grades into rougher grazing further up the hillside and then into moorland. The control and disposal areas each covered approximately 0.25 ha of the grazing area within a total area of 1 ha. The vegetation cover consisted of patches of long and short grass on uneven ground with large tussocks at irregular intervals. The ground was waterlogged in places and mosses were prevalent. SP was applied to the disposal area in autumn 1999.

Table 3.8: Summary of organisms sampled at Yorkshire 3 showing geometric mean numbers m^{-2} (with 95% confidence limits) and percentage difference between control and disposal areas. Pitfall catches and suction samples are given as total numbers caught at a site and bird counts, grouped as waders and others, as the mean numbers recorded per visit.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*	P
Spring 2000	SP	6 months	total soil invertebrates (Berlese extraction)	1142 (1067-1217)	512 (429-594)	55.17	< 0.01
			active soil invertebrates (Berlese extraction)	632 (553-711)	337 (253-422)	46.68	< 0.05
			sedentary soil invertebrates (Berlese extraction)	555 (481-630)	220 (138-303)	60.36	< 0.01
			surface active invertebrates (suction sampling)+	48	104	-116.67	
			surface active invertebrates (pitfall samples)+	630	522	17.14	
			waders (area counts)	2.72 (0.61-4.83)	2.72 (0.55-4.9)		
			other birds (area counts)	1.44 (0-3.7)	2.02 (0-4.24)		

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
* control - disposal x 100
control
P = level of significance
NS - not statistically significant
P < 0.05 = Significant
P < 0.01 = Highly Significant

+N.B. suction and pitfall samples are not compared for each farm but analysed for the complete data set where these sampling methods were used.

Site results summary

Total densities of soil invertebrates on the disposal area were 55% lower than on the control area, with both active and sedentary arthropods present in significantly lower numbers on the disposal area (Table 3.8).

In April to June 2000 the bird counts revealed three species feeding on the control and disposal areas. These were lapwings, curlews and skylarks, all of which might be expected in open areas so close to moorland where they were nesting.

3.4.1.8 Site "Yorkshire 4"

Sampled May - June 2000
Sampling methods: soil sampling with heat extraction, pitfall traps, suction samples

Site Description
Site Yorkshire 4 was particularly useful for this study since it had been used as the dip disposal site for more than 30 years and replaced Yorkshire 2 in 2000. OP based dips had been used and disposed of on the disposal site until the last few years (the farmer was not sure of the actual year of the changeover) when SPs had been used instead. However, permission was not granted for disposal to continue and an alternative disposal area was used in 2001. The matching disposal and control areas used in 2000 each cover an area of around 0.15 ha and were on improved pasture used mostly for grazing. SP dip was applied to the disposal area in autumn 1999. The site was close to the farmhouse and heavily grazed at lambing time, which made it unsuitable for bird counts. A B-road runs along the top of both the control and adjacent disposal fields.

Site results summary
The total mean densities of invertebrates were almost 80% lower on the disposal area than on the control area and both active and sedentary groups were present in significantly lower numbers on the disposal area (Table 3.9).

Table 3.9: Summary of organisms sampled at Yorkshire 4 showing geometric Mean numbers m^{-2} (with 95% confidence limits) and percentage difference between control and disposal areas. Pitfall catches and suction samples are given as total numbers caught at a site.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*	P
Spring 2000	SP	6 months	total soil invertebrates (Berlese extraction)	1176 (1101-1250)	250 (174-326)	78.74	< 0.01
			active soil invertebrates (Berlese extraction)	749 (673-825)	151 (79-224)	79.84	< 0.01
			sedentary soil invertebrates (Berlese extraction)	462 (389-535)	132 (51-213)	71.43	< 0.01
			surface active invertebrates (suction sampling)+	73	115	-57.53	
			surface active invertebrates (pitfall samples)+	1397	312	77.67	

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
* control - disposal x 100
control
P = level of significance
NS - not statistically significant
P < 0.05 = Significant
P < 0.01 = Highly Significant

+N.B. suction and pitfall samples are not compared for each farm but analysed for the complete data set where these sampling methods were used.

3.4.1.9 Site "Yorkshire 5"

Sampled April - June 2000
Sampling methods: pitfall traps, suction samples, bird counts

Site Description
Site Yorkshire 5 had matching disposal and control areas on improved pasture in two adjacent fields enclosed by dry stone walls and bordering on open moorland on two sides. Each field measures approximately 0.5 ha and the estimated disposal coverage was 0.25 ha during any one disposal occasion. The vegetation cover was short grass and the fields were used for grazing by sheep for most of the year. OP was applied to the disposal area in autumn 1999.

Site results summary
More surface active invertebrates were caught on the disposal area than the control area at this site, which is further analysed using multivariate analysis later in this chapter. Magpies were the most prevalent bird species at site Yorkshire 5 and are considered a severe pest in this area. They are attracted by afterbirth and occasionally kill vulnerable newborn lambs by pecking at the eyes and umbilicus. They also feed on the eggs of the many birds that nest on the nearby moorland. Despite these pests, lapwings were still seen feeding in both the control and disposal areas, although not usually at the same time as the magpies. On one occasion a female Blackbird was also seen feeding in the control field.

Table 3.10: Summary of organisms sampled at Yorkshire 5. Pitfall catches and suction samples are given as total numbers caught at a site and bird counts, grouped as waders and others, as the mean numbers recorded per visit.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*
Spring 2000	OP	6 months	surface active invertebrates (suction sampling)+	88	164	-86.36
			surface active invertebrates (pitfall samples)+	1021	1223	-19.78
			waders (area counts)	2 (0-4)	1 (0-4)	
			other birds (area counts)	2 (0-4)	2 (0-4)	

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
* control - disposal x 100
control

+N.B. suction and pitfall samples are not compared for each farm but analysed for the complete data set where these sampling methods were used.

3.4.1.10 Site "Yorkshire 6"

Sampled April - June 2000
Sampling methods: bird counts

Site Description
Site Yorkshire 6 had comparable control and disposal areas in adjacent fields containing improved pasture that is grazed by sheep for most of the year. The fields are bounded by dry stone walls and footpaths run along the top and bottom of both fields. Pitfall traps were not laid at this site because of disturbance to the sheep at lambing time. OP dip was applied to the disposal area in Autumn 1999.

Table 3.11: Summary of bird counts, grouped as waders and others and given as mean numbers recorded per visit at Yorkshire 6.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean
Spring 2000	OP	6 months	waders (area counts)	2 (0-4)	1 (0-3)
			other birds (area counts)	2 (0-4)	2 (0-5)

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
* control - disposal x 100
control

Site results summary
Swallows were the most abundant species at this site. These were nesting in farm buildings approximately 300m away from the disposal site. Lapwings, curlews and skylarks were also seen, reflecting the proximity of the site to moorland where they nest. The sitings of the kestrel are not uncommon in this area and it was seen feeding on small mammals and, less commonly, small birds in and around the disposal area.

3.4.1.11 Site "Teesdale 1"

Sampled November 1999
Sampling methods: soil sampling with heat extraction, earthworm counts.
April - June 2000
Sampling methods: soil sampling with heat extraction, pitfall traps, suction samples, bird counts

Site Description
In 1999 Site Teesdale 1 had a disposal site and an adjacent matching control area within the same field consisting of improved pasture used for sheep grazing and as hay meadow for one crop per year. Disposal and control areas were both approximately 0.10 ha. This site was not permitted for use for dip disposal in 2000 so the new site Teesdale 1A on the same farm was also sampled in Spring/Summer 2000. Along the

top of the control and disposal areas at Teesdale 1 is a minor road leading to other farms. The site is surrounded by other fields on a valley side with moorland above and a river running along the valley bottom. The dip disposal site had been used for this purpose for up to 5 years prior to 1999, sometimes with more than one dip application per year. In 1999 OP was applied to the disposal area in November.

Site results summary

In November 1999 soil sampling at Site Teesdale 1, 10 days after dip disposal, showed highly significant differences between disposal and control areas. Total numbers of invertebrates were at 60% lower density in the disposal area, with the sedentary arthropods, at significantly lower densities, providing the main difference (Table 3.12). In Spring 2000, although total invertebrates were still at significantly lower densities on the disposal area than the control, neither of the broad categories of active and sedentary invertebrates showed significant differences (Table 3.12).

Table 3.12: Summary of organisms sampled at Teesdale 1 showing geometric mean numbers m^{-2} (with 95% confidence limits) and percentage difference between control and disposal areas. Pitfall catches and suction samples are given as total numbers caught at a site and bird counts, grouped as waders and others, as the mean numbers recorded per visit.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*	P
Autumn 1999	OP	10 days	worms (hand sorting)	417	457	-9.59	NS
			total soil invertebrates (Berlese extraction)	352 (275-428)	140 (67-213)	60.23	< 0.01
			active soil invertebrates (Berlese extraction)	93 (16-171)	61 (0-138)	34.41	NS
			sedentary soil invertebrates (Berlese extraction)	159 (83-235)	57 (0-130)	64.15	< 0.01
Spring 2000		6 months	total soil invertebrates (Berlese extraction)	563 (488-638)	307 (233-382)	45.47	< 0.05
			active soil invertebrates (Berlese extraction)	171 (89-253)	109 (33-186)	36.26	NS
			sedentary soil invertebrates (Berlese extraction)	300 (225-376)	196 (118-275)	34.67	NS
			surface active invertebrates (suction sampling)$^{+}$	9	26	-188.89	
			surface active invertebrates (pitfall samples)$^{+}$	575	1105	-92.17	
			waders (area counts)	3 (1-6)	4 (1-7)		
			other birds (area counts)	0	0		

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
$* \frac{\text{control - disposal}}{\text{control}} \times 100$
P = level of significance
NS - not statistically significant
P < 0.05 = Significant
P < 0.01 = Highly Significant

$^{+}$N.B. suction and pitfall samples are not compared for each farm but analysed for the complete data set where these sampling methods were used.

Lapwings were the only bird species seen at site Teesdale 1 between April and June. They began to settle and look for nesting sites in early April but by the second count there had been a substantial fall of snow. They briefly reformed large feeding flocks, which split up again by the middle of the month. The importance of the site for feeding Lapwings varied at different stages of the breeding season and although no nests were discovered in the disposal site, their empty egg shells were found on a number of occasions in the disposal area.

3.4.1.12 Site "Teesdale 1A"

Sampled April - June 2000
Sampling methods; soil sampling with heat extraction, pitfall traps, suction samples, bird counts
N.B. This was the only site where sampling both pre and post dip disposal was possible.

Site Description
Site Teesdale 1A was the replacement disposal site for Site Teesdale 1 in 2000 and has a possible disposal area of approximately 0.10 ha. A matching control site was used in an adjacent field. The Teesdale 1A disposal area is close to the previous site and shares similar characteristics, also being improved pasture used for one hay crop per year, but had not been used for dip disposal previously. The new site is further from the road and closer to the river and valley bottom, therefore on a much shallower slope (Table 3.1). Soil sampling was carried out before and after the spring disposal of some OP dip that had been stored from dipping the previous year. The dip might have slightly degraded chemically during storage, particularly as disposal was after the last date recommended for use by the manufacturer.

Table 3.13: Summary of organisms sampled post disposal at Teesdale 1A showing geometric mean numbers m^{-2} (with 95% confidence limits) and percentage difference between control and disposal areas. Pitfall catches and suction samples are given as total numbers caught at a site and bird counts, grouped as waders and others, as the mean numbers recorded per visit.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*	P
Spring 2000	OP	14 days	total soil invertebrates (Berlese extraction)	844 (772-916)	927 (852-1002)	-9.83	NS
			active soil invertebrates (Berlese extraction)	492 (415-569)	529 (446-612)	-7.52	NS
			sedentary soil invertebrates (Berlese extraction)	406 (331-480)	451 (379-522)	-11.08	NS
			surface active invertebrates (suction sampling)+	99	37	62.63	
			surface active invertebrates (pitfall samples)+	506	885	-74.90	
			waders (area counts)	3 (0-5)	2 (0-4)		
			other birds (area counts)	1 (0-3)	2 (0-4)		

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
* $\frac{\text{control - disposal}}{\text{control}} \times 100$
P = level of significance
NS - not statistically significant
P < 0.05 = Significant
P < 0.01 = Highly Significant

+N.B. suction and pitfall samples are not compared for each farm but analysed for the complete data set where these sampling methods were used.

Site results summary

This was the only farm site from which a pre-disposal sample was possible. These results (Table 3.22) show that there were significantly greater total invertebrate densities in the disposal site than the control site prior to disposal. However, 14 days after disposal, no statistically significant differences could be detected between control and disposal areas in densities of any of the invertebrate groups tested (Table 3.13), because densities of total invertebrates had increased in the control area but not on the disposal site.

Further analysis to determine the percentage change in invertebrate numbers in control and disposal plots pre and post disposal was carried out for this site. Testing for goodness of fit using a Chi-square analysis revealed that there was a significant increase (14%) in total invertebrates on the control site between pre and post disposal sampling (χ^2 = 7.2, $p<0.05$) but a significant decrease (-22%) in total invertebrates on the disposal site (χ^2 = 33.4, $p<0.05$). Active invertebrates did not show significant change for the control site between pre and post disposal sampling (-2%) but there was a significant decrease (-37%, Table 3.25) on the disposal site (χ^2 = 71.9, $p<0.05$). Sedentary invertebrates increased significantly (59%) at the control site (χ^2 = 34.5, $p<0.05$) and also increased significantly (35%, Table 3.25) at the disposal site (χ^2 = 17.8, $p<0.05$) between pre and post disposal sampling. Beetles did not alter significantly on the control site but there was a significant decrease (-17%) in beetles on the disposal site between pre and post disposal (χ^2 = 4.1, $p<0.05$). Flies significantly increased by 69% on the control area between pre and post disposal sampling ($\chi2$ = 40.6, $p<0.05$) and significantly decreased (-44%) on the disposal area (χ^2 = 95.1, $p<0.05$). Tipulid larvae increased significantly (524%) on the control area (χ^2 = 154.8, $p<0.05$) and also increased significantly (238%) on the disposal area (χ^2 = 108, $p<0.05$). Chi-square analyses are in Appendix 4.

Although the data was not analysed for significance, more bird species were recorded at site Teesdale 1A than Teesdale 1 in both the control and disposal areas, probably because of the proximity to the river and the greater distance from the road. The use of the site by lapwing fluctuated in parallel with the use of site Teesdale 1.

3.4.1.13 Site "Teesdale 2"

Sampled November 1999 and April - June 2000

Sampling methods: soil sampling with heat extraction, pitfall traps in 2000, suction samples in 2000, bird counts in 2000, earthworm sampling in 1999.

Site Description

The disposal and control areas on this site were matching adjacent fields used for grazing by sheep and cattle and as hay meadow. Both fields measured approximately 0.5 ha. They are close to the river in the valley bottom and bordered above by rougher grazing which changes into moorland further up the valley side. The control site used in 1999 was found to have a lower organic content (12.2%) than the disposal area (19.4%), so it was abandoned. This difference in organic content was greater than any of the other sites. The control used in 2000 was more comparable to the disposal area in pH values and organic content (Table 3.1). The possible disposal area encompasses two large fields, each of about 1 ha in size. In autumn 1999 the dip was spread in the first field until the tanker was empty. The actual disposal area used was difficult to gauge and some of the sampling in both years may have taken place outside the area. The large size of the possible disposal area meant that disposing on exactly the same area in successive years could be avoided. In practice, the farmer tried not to make multiple applications on the same area. This increased the problem of identifying the exact disposal location. Neither field had been used for disposal prior to 1999.

Site results summary
The soil sampling results in November 1999 at site Teesdale 2, examined 2 weeks after dip disposal, did not show a significant difference between control and disposal areas in total densities of invertebrates. However, densities of sedentary arthropods were significantly different, with higher densities on the disposal site (Table 3.14). This was probably due to the higher organic content on the disposal site, which might allow the disposal site to support a larger population of sedentary invertebrates. In 2000, using the control with a similar organic content, there were no significant differences between control and disposal areas in total numbers of invertebrates or sedentary invertebrates.

The bird counts revealed the greatest number of species present on any site in 2000, probably because of the proximity of both moorland and the river, providing a diverse range of habitats.

Two lapwing nests with clutches of three and four eggs were found on the disposal area and another containing four eggs on the control area, establishing the importance of this site for breeding waders.

Table 3.14: Summary of organisms sampled at Teesdale 2 showing geometric mean numbers m^{-2} (with 95% confidence limits) and percentage difference between control and disposal areas. Pitfall catches and suction samples are given as total numbers caught at a site and bird counts, grouped as waders and others, as the mean numbers recorded per visit.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*	P
Autumn 1999	OP	14 days	worms (hand sorting)	64	249	-289.06	NS
			total soil invertebrates (Berlese extraction)	158 (82-234)	269 (193-345)	-70.25	NS
			active soil invertebrates (Berlese extraction)	84 (8-161)	132 (55-210)	-57.14	NS
			sedentary soil invertebrates (Berlese extraction)	92 (16-169)	159 (83-235)	-72.83	< 0.05
Spring 2000		6 months	total soil invertebrates (Berlese extraction)	687 (613-761)	781 (701-862)	-13.68	NS
			active soil invertebrates (Berlese extraction)	365 (295-435)	386 (303-470)	-5.75	NS
			sedentary soil invertebrates (Berlese extraction)	295 (211-379)	396 (313-479)	-34.24	NS
			surface active invertebrates (suction sampling)+	34	53	-55.88	
			surface active invertebrates (pitfall samples)+	1118	1778	-59.03	
			waders (area counts)	5 (3-8)	5 (3-8)		
			other birds (area counts)	1 (0-4)	1 (0-3)		

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
$* \frac{\text{control - disposal}}{\text{control}} \times 100$
P = level of significance
NS - not statistically significant
P < 0.05 = Significant
P < 0.01 = Highly Significant

+N.B. suction and pitfall samples are not compared for each farm but analysed for the complete data set where these sampling methods were used.

3.4.1.14 Site "Teesdale 3"

Sampled April - June 2000
Sampling methods: pitfall traps, suction samples, bird counts

Site Description
Site Teesdale 3 had matching adjacent disposal and control sites with a river running along the bottom of the fields and a minor road passing along the top. The disposal site measured approximately 0.10 ha. The land is used for grazing and as hay meadow. To the left of the control field is a barn, which is used to store animal feed. OP dip was applied to the disposal site in autumn 1999.

Site results summary
Many birds were seen close to this site but not on it because of its proximity to the road and human activities. However, chicks of both lapwings and redshanks were seen (or sometimes just heard) here later in the season. Swifts were nesting in the eaves of the open barn and were very active in May and June, skimming the surface of the grassland for insects.

Table 3.15: Summary of organisms sampled at Teesdale 3. Pitfall catches and suction samples are given as total numbers caught at a site and bird counts, grouped as waders and others, as the mean numbers recorded per visit.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*
Spring 2000	OP	6 months	surface active invertebrates (suction sampling)+	138	49	64.49
			surface active invertebrates (pitfall samples)+	1301	2365	-81.78
			waders (area counts)	3 (0-5)	2 (0-4)	
			other birds (area counts)	2 (0-5)	1 (0-4)	

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
$\frac{\text{control - disposal}}{\text{control}} \times 100$ *

+N.B. suction and pitfall samples are not compared for each farm but analysed for the complete data set where these sampling methods were used.

3.4.1.15 Site "Teesdale 4"

Sampled April - June 2000
Sampling methods: pitfall traps, suction samples, bird counts

Site Description
Site Teesdale 4 had a dip disposal site measuring approximately 0.25 ha adjacent to an area renowned for the presence of a black grouse lek. The disposal and control sites are

comparable fields of rough grazing land close to a relatively busy link road across the moorland. Disposal had occurred the previous autumn.

Site results summary
This site is unique in the bird counts because of the presence of black grouse on more than one occasion. It was also utilised by other species seen flying in from nearby moorland to feed.

Table 3.16: Summary of organisms sampled at Teesdale 4. Pitfall catches and suction samples are given as total numbers caught at a site and bird counts, grouped as waders and others, as the mean numbers recorded per visit.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*
Spring 2000	OP	6 months	surface active invertebrates (suction sampling)+	204	133	34.80
			surface active invertebrates (pitfall samples)+	1105	1101	0.36
			waders (area counts)	3 (0-5)	2 (0-4)	
			other birds (area counts)	1 (0-3)	2 (0-4)	

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
* (control - disposal) / control x 100

+N.B. suction and pitfall samples are not compared for each farm but analysed for the complete data set where these sampling methods were used.

3.4.1.16 Site "Teesdale 5"

Sampled 2000
Sampling methods: pitfall traps, suction samples, bird counts

Site Description
Site Teesdale 5 had disposal and control areas that are part of one large field divided by a seldom-used access track. The disposal area had a B-road running down one side of it, often utilised by heavy vehicles from nearby quarries. The land type changes into moorland to the other side of the control area. Dip was spread onto the land by driving along the access track, expelling the diluted dip out of the side of a slurry tanker until it was empty, probably on an area measuring approximately 0.1 ha. This resulted in a long strip of land becoming the potential disposal area. The actual area covered was unclear. Choosing appropriate locations for sampling was therefore quite difficult and

judgement on the area to be covered by the bird counts fairly arbitrary. Disposal had occurred the previous autumn.

Site results summary
Lapwings were the most abundant bird species at site Teesdale 5 and again, as at Teesdale 1, more were present during the second bird count after heavy snowfall. There were also many birds present in the surrounding area on each visit, but usually they kept away from the road.

Table 3.17: Summary of organisms sampled at Teesdale 5. Pitfall catches and suction samples are given as total numbers caught at a site and bird counts, grouped as waders and others, as the mean numbers recorded per visit.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*
Spring 2000	OP	6 months	surface active invertebrates (suction sampling)+	55	56	-1.82
			surface active invertebrates (pitfall samples)+	2410	1448	39.92
			waders (area counts)	3 (1-5)	2 (0-4)	
			other birds (area counts)	1 (0-4)	1 (0-3)	

95% confidence limits are given in parentheses
^ between last dip disposal and sample date
$* \frac{\text{control} - \text{disposal}}{\text{control}} \times 100$

+N.B. suction and pitfall samples are not compared for each farm but analysed for the complete data set where these sampling methods were used.

3.4.1.17 Site "Teesdale 6"

Sampled April - June 2000
Sampling methods: pitfall traps, suction samples, bird counts

Site Description
Site Teesdale 6 had unmarked control and disposal areas at the top of a river-cut valley, which holds rough grazing land merging into moorland further away from the farm. Both areas contained deep drainage ditches to prevent waterlogging of the peaty soil. Dip spreading of was on an area accessible to heavy farm vehicles, namely on a plateau at the hilltop, measuring approximately 0.1 ha. The actual area covered was uncertain and may have been missed by some of the sampling. Disposal had occurred the previous autumn.

Site results summary

Lapwings were again the most abundant species at site Teesdale 6 with two breeding pairs clearly visible on most occasions feeding on either the control or disposal area with no apparent preference. Meadow pipits were also prevalent in and around the sampling areas and pied wagtails seen close by.

Table 3.18: Summary of organisms sampled at Teesdale 6. Pitfall catches and suction samples are given as total numbers caught at a site and bird counts, grouped as waders and others, as the mean numbers recorded per visit.

Sample Period	Dip Type	Interval ^	Organisms sampled and method	Control mean	Disposal mean	%diff.*
Spring 2000	OP	6 months	surface active invertebrates (suction sampling)+	98	130	-32.65
			surface active invertebrates (pitfall samples)+	1190	1307	-9.83
			waders (area counts)	2 (0-5)	3 (0-5)	
			other birds (area counts)	2 (0-4)	2 (0-4)	

95% confidence limits are given in parentheses

^ between last dip disposal and sample date

$$\frac{\text{control - disposal}}{\text{control}} \times 100$$

+N.B. suction and pitfall samples are not compared for each farm but analysed for the complete data set where these sampling methods were used.

3.4.2 Between farm comparison

3.4.2.1 Density responses

Soil samples Autumn 1999

Total Numbers of Invertebrates

Mean densities of total invertebrates were significantly lower on disposal areas than on control areas at three sites, Yorkshire 1, Teesdale 1 and Derwent, in autumn 1999. Disposal and control areas at Teesdale 2, Wales 1 and 2 and Yorkshire 2 showed no significant differences, although at Teesdale 2 invertebrate densities were 70% higher on the disposal area than on the control, possibly influenced by the higher organic content on the disposal area (Table 3.19).

Beetles, Flies and Tipulid Larvae

Comparing three abundant groups (beetles, flies and tipulid larvae, which are important food for birds), beetle densities on disposal areas were about half the level on the controls and differed significantly at Yorkshire 1, Teesdale 1 and Derwent. Flies showed a high degree of between sample variation but were at significantly lower densities on the disposal areas at the first two sites but not at Derwent, while lower densities of tipulid larvae on the disposal area were significant at Teesdale 1 only. There were significantly higher numbers of tipulids on the disposal area than on the control at Teesdale 2 and Yorkshire 2 and beetle densities were also significantly higher on the disposal area of the latter site (Table 3.20).

Active and Sedentary Invertebrates

Grouping the invertebrates as active (mainly predators) and sedentary, there were significantly lower densities of sedentary arthropods on the disposal than on the control areas at Yorkshire 1, Teesdale 1 and Derwent but significantly higher densities on the disposal area at Teesdale 2. The densities of predatory arthropods were significantly lower on the disposal areas than on the controls at Wales 2 and Derwent only. There were no significant differences between the densities of non-arthropod invertebrates on disposal and control areas (Table 3.21)

Table 3.19: Student's t-tests comparing log transformed densities of invertebrates in Berlese extracted soil samples from control and disposal areas in 1999. Earthworms were hand sorted.

Site	Sampling Date	Dip Type	Approx.interval since dip application		Earthworm Numbers For Each Site	Geometric mean /m^2	t-tests for total numbers of invertebrates			
							t	df	P	Sig
Wales 1	02/09/99	OP	several months	Control	Unknown	1228.08				
				Disposal	Unknown	818.29	0.78	18	>0.05	NS
Wales 2	06/11/99	SP	few days	Control	Unknown	1014.53				
		(Dec)		Disposal	Unknown	836.90	1.08	22	>0.05	NS
Yorkshire 1	31/10/1999	SP	10 days	Control	Unknown	2298.78				
		(Dec)		Disposal	Unknown	402.61	2.14	22	<0.05	*
Yorkshire 2	03/11/1999	SP	21 days	Control	41	740.24				
				Disposal	33	964.57	-1.25	22	>0.05	NS
Teesdale 1	12/11/1999	OP	10 days	Control	72	351.67				
				Disposal	62	139.76	3.4	22	<0.01	**
Teesdale 2	17/11/1999	OP	14 days	Control	11	158.04				
				Disposal	43	269.39	-2.01	22	>0.05	NS
Derwent	02/09/1999	OP	within month	Control	41	2515.59				
		SP		Disposal	53	1092.24	4.17	22	<0.01	**

t = t-test value
df = degrees of freedom
P = level of significance
* = P < 0.05 Significant
** = P < 0.01 Highly Significant

Table 3.20: Student's t-tests comparing log-transformed densities of beetles, flies and tipulid larvae from soil samples within control and sheep dip disposal Sites in 1999.

Site	Date	Dip Type		Beetles geometric mean /m^2	Beetles t	Beetles df	Beetles P	Beetles Sig	Flies geometric mean /m^2	Flies t	Flies df	Flies P	Flies Sig	Tipulid Larvae geometric mean /m^2	Tipulid Larvae t	Tipulid Larvae df	Tipulid Larvae P	Tipulid Larvae Sig
Wales 1	02/09/99	OP	Control	387.27					288.98					55.84				
			Disposal	192.33	1.52	18	>0.05	NS	86.53	1.14	18	>0.05	NS	45.71	0.16	18	>0.05	NS
Wales 2	06/11/99	SP	Control	337.96					163.92					101.22				
		(Dec)	Disposal	290.29	1.33	22	>0.05	NS	129.96	0.79	22	>0.05	NS	54.86	1.25	22	>0.05	NS
Yorkshire 1	31/10/1999	SP	Control	138.45					3205.22					48.98				
		(Dec)	Disposal	81.96	2.22	22	<0.05	*	154.12	2.15	22	<0.05	*	48.98	0.14	22	>0.05	NS
Yorkshire 2	03/11/1999	SP	Control	66.29					361.14					32.65				
			Disposal	116.24	-2.15	22	<0.05	*	835.27	-0.78	22	>0.05	NS	46.04	-2.26	22	<0.05	*
Teesdale 1	12/11/1999	OP	Control	83.27					148.57					96.33				
			Disposal	32.65	4.8	22	<0.01	**	46.37	4.48	22	<0.01	**	40.82	3.14	22	<0.01	**
Teesdale 2	17/11/1999	OP	Control	79.35					46.04					60.73				
!			Disposal	155.43	-1.85	22	>0.05	NS	54.53	-0.67	22	>0.05	NS	108.41	-3.1	22	<0.01	**
Derwent	02/09/1999	OP	Control	676.24					597.22					54.86				
			Disposal	295.84	2.58	22	<0.05	*	237.71	1.05	22	>0.05	NS	37.55	1.13	22	>0.05	NS

Beetles: carabids, staphilinids, weevils, other beetles, beetle larvae
Flies: flies and fly larvae
Tipulid larvae: Tipulid larvae

t = t-test value
df = degrees of freedom
P = level of significance
! = significantly higher soil organic content in the disposal area

* = P < 0.05 Significant
** = P < 0.01 Highly Significant

Table 3.21: Student's t-tests comparing log-transformed densities of active predators, more sedentary herbivores/soil dwellers and non-arthropods in soil samples from control and sheep dip disposal sites in 1999.

Site	Date	Dip Type		Active arthropods (mainly predators)					Soil and more sedentary arthropods					Non-arthropods				
				geometric mean /m^2	t	df	P	Sig	geometric mean /m^2	t	df	P	Sig	geometric mean /m^2	t	df	P	Sig
Wales 1	02/09/99	OP	Control	705.53					480.47					35.92				
			Disposal	664.70	-0.4	18	>0.05	NS	179.27	1.82	18	>0.05	NS	41.14	-0.4	18	>0.05	NS
Wales 2	06/11/99	SP	Control	661.47					299.28					88.49				
		(Dec)	Disposal	493.23	2.15	22	<0.05	*	284.42	0.83	22	>0.05	NS	99.59	0.16	22	>0.05	NS
Yorkshire 1	31/10/1999	SP	Control	113.22					2738.75					93.39				
		(Dec)	Disposal	69.09	2.03	22	>0.05	NS	217.83	2.4	22	<0.05	*	137.47	-1.6	22	>0.05	NS
Yorkshire 2	03/11/1999	SP	Control	93.52					634.30					60.41				
			Disposal	125.55	-1.1	22	>0.05	NS	838.02	-1.3	22	>0.05	NS	57.80	0.24	22	>0.05	NS
Teesdale 1	12/11/1999	OP	Control	93.15					159.10					59.10				
			Disposal	61.43	1.48	22	>0.05	NS	57.39	5.34	22	<0.01	**	51.92	0.2	22	>0.05	NS
Teesdale 2	17/11/1999	OP	Control	84.24					92.47					46.04				
			Disposal	132.29	-1.65	22	>0.05	NS	158.67	-2.42	22	<0.05	*	38.20	0.83	22	>0.05	NS
Derwent	02/09/1999	OP	Control	930.02					1454.80					146.94				
			Disposal	466.65	3.49	22	<0.01	**	572.93	4.4	22	<0.01	**	96.33	1.83	22	>0.05	NS

Active Arthropods (mainly predators): carabids, staphilinids, other beetle adults, Diptera adults, ants, other Hymenoptera, spiders, harvestmen, centipedes
Soil and more sedentary arthropods: weevils, beetle larvae, tipulid larvae, all other fly larvae, Hemiptera, Lepidoptera and sawfly caterpillars
Non-arthropods: earthworms, slugs and snails. For complete legend see Table 3.19

Table 3.22: Student's t-tests comparing log-transformed densities of total invertebrates found in soil samples from control and disposal sites sampled in Spring 2000

Site	Sampling Date	Dip Type	Approx.interval since dip application		Geometric mean / m^2	t-tests for total numbers of invertebrates			
						t	df	P	Sig
Derwent	04/05/00	SP/OP	several months	Control Disposal	1835.45 810.22	4.06	22	<0.01	**
Teesdale 1	18/04/2000	OP	several months	Control Disposal	562.79 307.06	2.68	22	<0.05	*
Teesdale 1A (pre-disposal)	16/05/2000	OP	pre-disposal	Control Disposal	737.48 1193.07	-2.15	22	<0.05	*
Teesdale 1A (post disposal)	11/07/2000	OP	14 days	Control Disposal	844.04 926.92	-0.18	22	>0.05	NS
Teesdale 2	18/04/2000	OP	several months	Control Disposal	687.22 781.45	0.2	22	>0.05	NS
Yorkshire 3	18/05/2000	SP	several months	Control Disposal	1142.00 511.71	3.41	22	<0.01	**
Yorkshire 4	02/06/2000	SP	several months	Control Disposal	1175.80 249.62	7	22	<0.01	**
Wales 2	24/05/2000	SP	several months	Control Disposal	895.76 1664.79	-2.33	22	<0.05	*
Wales 3	24/05/2000	SP	several months	Control Disposal	1027.22 1018.28	-0.9	22	>0.05	NS

t = t-test value
df = degrees of freedom
P = level of significance
* = P < 0.05 Significant
** = P < 0.01 Highly Significant

NB. Although for site Teesdale 1A the differences between invertebrate populations on control and disposal areas post disposal were not significant, the percentage decrease between pre and post disposal invertebrate densities is significantly greater on the disposal area at 32% compared with -2% on the control area.
Anomalous results at Wales 2 occured probably due to sampling difficulties (see text)

Table 3.23: Student's t-tests comparing log-transformed densities of beetles, flies and tipulid larvae densities from soil samples within control and sheep dip disposal sites in 2000

Site	Date	Dip Type		Beetles					Flies					Tipulid Larvae				
				geometric mean /m^2	t	df	P	Sig	geometric mean /m^2	t	df	P	Sig	geometric mean /m^2	t	df	P	Sig
Derwent	04/05/00	OP SP	Control Disposal	406.86 262.53	2.2	22	<0.05	*	570.45 170.12	4.49	22	<0.01	**	136.49 99.92	0.25	22	>0.05	NS
Teesdale1	18/04/00	OP	Control Disposal	243.27 85.88	2.7	22	<0.05	*	153.47 104.49	1.17	22	>0.05	NS	83.59 119.18	-0.81	22	>0.05	NS
Teesdale 1A Pre-disposal	15/05/00	OP	Control Disposal	243.59 274.94	-0.68	22	>0.05	NS	231.84 758.86	-2.84	22	<0.01	**	40.82 83.59	-2.41	22	<0.05	*
Teesdale 1A Post-disposal	11/07/00	OP	Control Disposal	239.02 229.55	0.47	22	>0.05	NS	390.86 423.51	0.1	22	>0.05	NS	254.69 282.45	-1.42	22	>0.1	NS
Teesdale 2	18/04/00	OP	Control Disposal	140.41 334.69	-1.92	22	>0.05	NS	296.49 235.76	1.81	22	>0.05	NS	117.22 124.73	-0.5	22	>0.05	NS
Yorkshire 3	18/05/00	SP	Control Disposal	394.45 211.27	3.08	22	<0.01	**	556.41 293.88	2.4	22	<0.05	*	51.92 43.43	1.06	22	>0.05	NS
Yorkshire 4	02/06/00	SP	Control Disposal	353.63 140.41	3.78	22	<0.01	**	432.65 122.12	5.11	22	<0.01	**	177.63 43.43	4.4	22	<0.01	**
Wales 2	24/05/00	SP	Control Disposal	401.96 486.53	-1.79	22	>0.05	NS	248.16 169.47	-1.24	22	>0.05	NS	37.88 35.27	0.59	22	>0.05	NS
Wales 3	24/05/00	SP	Control Disposal	125.39 124.08	0.65	22	>0.05	NS	320.33 367.67	-0.39	22	>0.05	NS	57.47 51.59	0.61	22	>0.05	NS

Beetles: carabids, staphilinids, weevils, other beetles, beetle larvae
Flies: flies and fly larvae
Tipulid larvae: Tipulid larvae

t = t-test value
df = degrees of freedom
P = level of significance

* = P < 0.05 Significant
** = P < 0.01 Highly Significant

Table 3.24: Student's t-tests comparing log-transformed densities of active predators, more sedentary herbivores/soil dwellers and non-arthropods from soil samples in control and sheep dip disposal sites in 2000.

Site	Date	Dip Type		Active arthropods (mainly predators)					Soil and more sedentary arthropods					Non-arthropods				
				geometric mean /m^2	t	df	P	Sig	geometric mean /m^2	t	df	P	Sig	geometric mean /m^2	t	df	P	Sig
Derwent	04/05/00	OP	Control	937.80	3.8	22	<0.01	**	678.53	3.8	22	<0.01	**	319.35	-0.1	22	>0.05	NS
		SP	Disposal	266.78					335.35					294.86				
Teesdale1	18/04/00	OP	Control	170.78	0.85	22	>0.05	NS	300.41	1.93	22	>0.05	NS	175.35	3.44	22	<0.01	**
			Disposal	109.39					196.24					74.12				
Teesdale 1A Pre-disposal	15/05/00	OP	Control	500.57	-1.56	22	>0.05	NS	254.69	-1.5	22	>0.05	NS	46.37	-2.04	22	<0.05	*
			Disposal	843.10					332.41					92.41				
Teesdale 1A Post-disposal	11/07/00	OP	Control	491.76	0.34	22	>0.05	NS	405.55	-0.95	22	>0.05	NS	0.00	0	22	>0.05	NS
			Disposal	528.98					450.61					0.00				
Teesdale 2	18/04/00	OP	Control	364.73	1.14	22	>0.05	NS	295.18	-0.96	22	>0.05	NS	118.20	1.69	22	>0.05	NS
			Disposal	386.29					396.08					85.88				
Yorkshire 3	18/05/00	SP	Control	632.16	2.38	22	<0.05	*	555.43	3.96	22	<0.01	**	0.00	0	22	>0.05	NS
			Disposal	336.98					220.08					0.00				
Yorkshire 4	02/06/00	SP	Control	749.06	6.93	22	<0.01	**	462.04	5.45	22	<0.01	**	0.00	0	22	>0.05	NS
			Disposal	151.00					132.24					0.00				
Wales 2	24/05/00	SP	Control	530.29	-1.23	22	>0.05	NS	402.94	-1.99	22	>0.05	NS	40.82	-3.01	22	<0.01	**
			Disposal	1001.80					626.61					90.12				
Wales 3	24/05/00	SP	Control	732.41	-0.11	22	>0.05	NS	277.88	-1.8	22	>0.05	NS	32.65	-1	22	>0.05	NS
			Disposal	576.65					461.06					43.43				

Active Arthropods (mainly predators): carabids, staphilinids, other beetle adults, Diptera adults, ants, other Hymenoptera, spiders, harvestmen, centipedes
Soil and more sedentary arthropods: weevils, beetle larvae, tipulid larvae, all other fly larvae, Hemiptera, Lepidoptera and sawfly caterpillars
Non-arthropods: earthworms, slugs and snails. For complete Legend see Table 3.19

Spring 2000

Total Numbers of Invertebrates

In spring 2000, total numbers of invertebrates were at significantly lower densities on areas where disposal had taken place in autumn 1999 than on control fields at Derwent, Teesdale 1, Yorkshire 3 and Yorkshire 4 (Table 3.22). At Wales 2, however, the densities of invertebrates were significantly higher on the disposal than on the control area. At Teesdale 1A, densities were significantly higher on the disposal area than on the control area, before the dip had been applied ($t_{22} = -2.15$, $p<0.05$). Fourteen days after disposal, invertebrate densities had risen significantly (14%) on the control area comparing the difference in invertebrate densities between pre and post disposal ($\chi^2 = 7.2$, $p<0.05$) and significantly decreased (-22%) on the disposal area ($\chi^2 =33.4$, $p<0.05$).

Beetles, Flies and Tipulid larvae

The mean densities of beetles on the disposal sites at Derwent, Teesdale 1, Yorkshire 3 and Yorkshire 4 were about half those on the control sites and were significantly lower in each case (Table 3.23). At Teesdale 2, Wales 2 and Wales 3 the beetle densities on the disposal sites did not differ significantly from the control areas. At Teesdale 1A beetle density did not alter significantly on the control site between pre and post disposal sampling but there was a significant decrease (-17%) in beetles on the disposal site ($\chi^2 = 4.1$, $p<0.05$). Flies showed a similar pattern to beetles with significant differences at Derwent, Yorkshire 3 and Yorkshire 4. At Teesdale 1A fly densities increased significantly (69%) on the control area ($\chi^2 = 40.6$, $p<0.05$), and decreased significantly (-44%) on the disposal area ($\chi^2 = 95.1$, $p<0.05$) between pre and post dip disposal sampling. Yorkshire 4 was the only site where tipulid densities differed significantly on control and disposal areas, with densities four times higher on the control areas.

Active and Sedentary Invertebrates

When active and sedentary arthropods were compared, both groups were at significantly lower densities on the disposal areas at Derwent, Yorkshire 3 and Yorkshire 4. At Teesdale 1A, the densities of active invertebrates changed little on the control area but dropped significantly (-37%) on the disposal site after sheep dip application ($\chi^2 = 71.9$, $p<0.05$). Sedentary arthropod densities at Teesdale 1A increased significantly (59%) between pre and post disposal sampling in the control area ($\chi^2 = 34.5$, $p<0.05$) and also increased significantly (35%) in the disposal area ($\chi^2 = 17.8$, $p<0.05$). Neither active nor sedentary arthropods differed in density between control and disposal areas at the remaining sites (Table 3.24). The non-arthropod group (molluscs and earthworms) was significantly less abundant on the dip disposal area at Teesdale 1 but more abundant on the disposal area at Wales 2.

Table 3.25: Soil sample summary, comparing percentage differences in mean densities of active and sedentary arthropods on dip disposal and control areas, - denotes lower on disposal area, * p<0.05, ** p<0.01)

Site	Autumn 1999		Spring 2000	
	Active	Sedentary	Active	Sedentary
Wales 1	-6	-63	-	-
Wales 2	-25	-5	+89	+55
Wales 3	-	-	-21	+66
Yorkshire 1	-39	-92*	-	-
Yorkshire 2	+35	+40	-	-
Yorkshire 3	-	-	-47*	-60**
Yorkshire 4	-	-	-80**	-71**
Teesdale 1	-34	-69**	-36	-35
Teesdale 1A†	-	-	-37*	+35
Teesdale 2	+59	+81*	+6	+34
Derwent	-50**	-61**	-72**	-51**

† Teesdale 1A comparison is between pre- and post-disposal samples

These results are summarised for the two years in Table 3.25, which shows that on 7 of 15 sampling occasions significantly lower densities of arthropods were found on the disposal area compared to the control. These data are graphically displayed in Figures 3.2 and 3.3. At Teesdale 2 sedentary arthropods were at higher densities on the disposal area, which had a higher organic content than the control, in autumn 1999. The difference between the disposal area and the new control area was not significant in spring 2000. The three sites where it was known that multiple disposals had been made all showed significant density reductions on the disposal areas. Derwent, the "worst case" had significantly reduced numbers of both active and sedentary invertebrates in autumn 1999 and showed no recovery in spring 2000, despite the lack of disposal over winter. Yorkshire 4, which had been used as a disposal site for 30 years, showed a similar lack of recovery in spring 2000. However, Teesdale 1, where the disposal area had been used for 5 years, showed no significant difference in spring 2000 although there was significant reduction in sedentary arthropods after autumn disposal. Despite the variation between sites, comparison between control and disposal areas for all the farms showed a significant 32% reduction in the densities of total invertebrates on the disposal areas in comparison to the controls (paired $t_{14} = 2.18$, $p<0.05$).

There were no significant differences between the densities of worms on disposal and control areas and no overall significant difference comparing the farm differences (Table 3.26).

3.4.2.2 Surface active invertebrates

The mean numbers of invertebrates caught in pitfalls were similar on disposal and control areas and did not differ significantly in a paired comparison for all the farms (Table 3.26). The numbers of surface-active invertebrates taken by suction samples were also similar on disposal and control areas although the sedentary arthropods, which were caught in smaller numbers on the disposal areas, were close to the 0.05 significance level (paired $t_9 = 2.09$, $p<0.1>0.05$) (Table 3.26).

Table 3.26: Paired t-tests comparing total numbers of invertebrates caught using the different sampling methods found in control and disposal areas in all the study sites 1999-2000

Organisms sampled and method	Geometric mean		t-tests for total numbers of invertebrates			
	Control	Disposal	t	df	P	Sig
total soil invertebrates (Berlese extraction)	27.3 (25-30)	18.8 (16-21)	2.18	14	<0.05	*
surface invertebrates (totals) (suction sampling)	91.8 (89-94)	88.9 (87-91)	0.59	9	>0.05	NS
surface invertebrates (active) (suction sampling)	73.5 (72-75)	78 (76-80)	1.08	9	>0.05	NS
surface invertebrates (sedentary) (suction sampling)	15.3 (13-17)	9.6 (8-12)	2.09	9	>0.05	NS
worms (totals/m^2) (hand sorting)	270.5 (268-273)	280.1 (278-282)	0.86	3	>0.05	NS
surface active invertebrates (pitfall samples)	1126.2 (1124-1128)	1232.8 (1231-1235)	0.19	9	>0.05	NS
birds (area counts)	19 (17-21)	17 (15-19)	1.25	10	>0.05	NS

95% confidence limits are given in parentheses
P < 0.05 = Significant

3.4.2.3 Bird counts

A range of bird species was recorded utilising disposal areas including curlew, lapwing, golden plover, redshank and black grouse. Both direct and indirect toxic effects of sheep dip disposal could possibly affect these protected species.

Figure 3.2: Percentage differences in mean densities of active and sedentary arthropods from soil samples on dip disposal and control areas, Autumn 1999

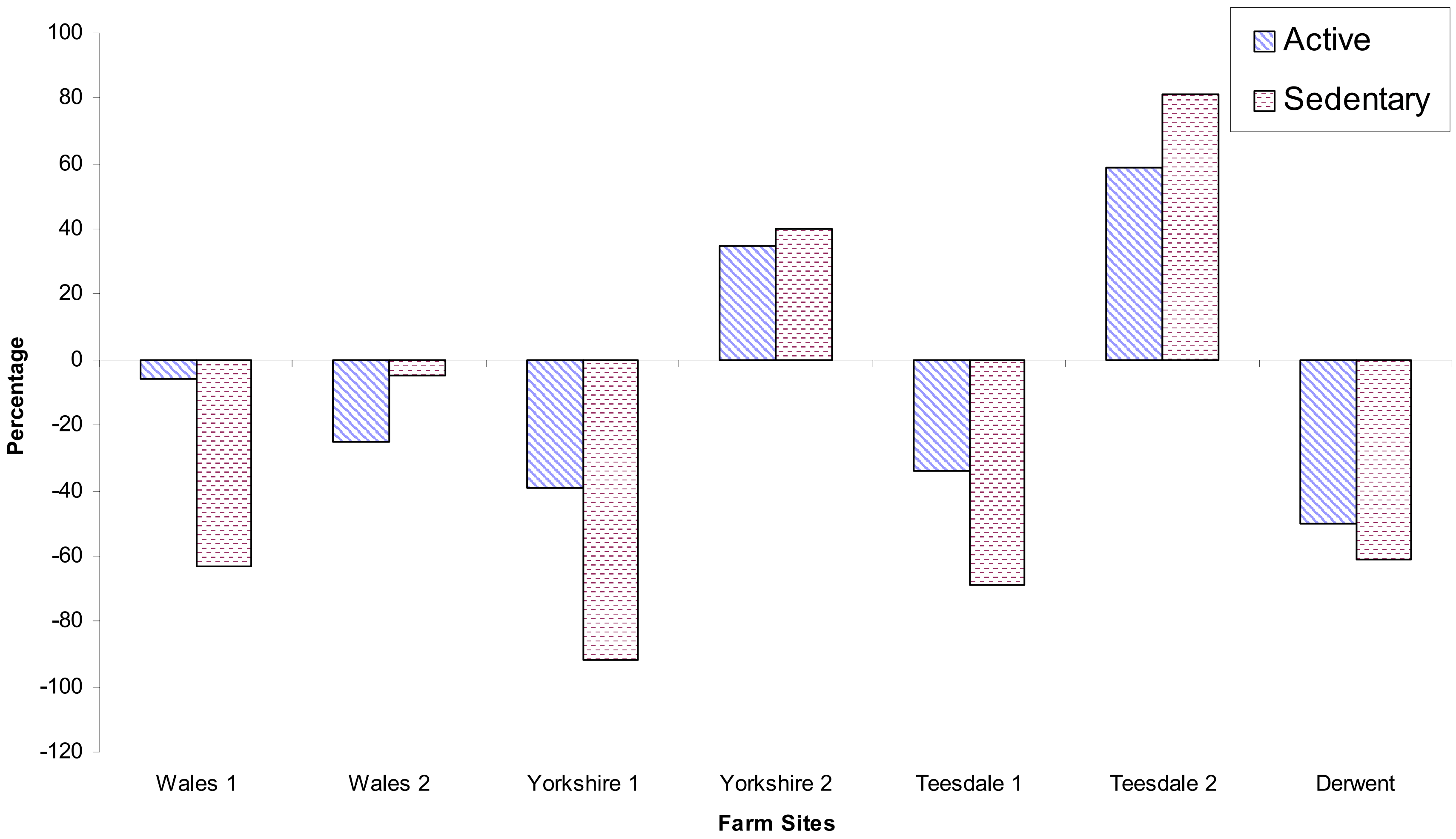
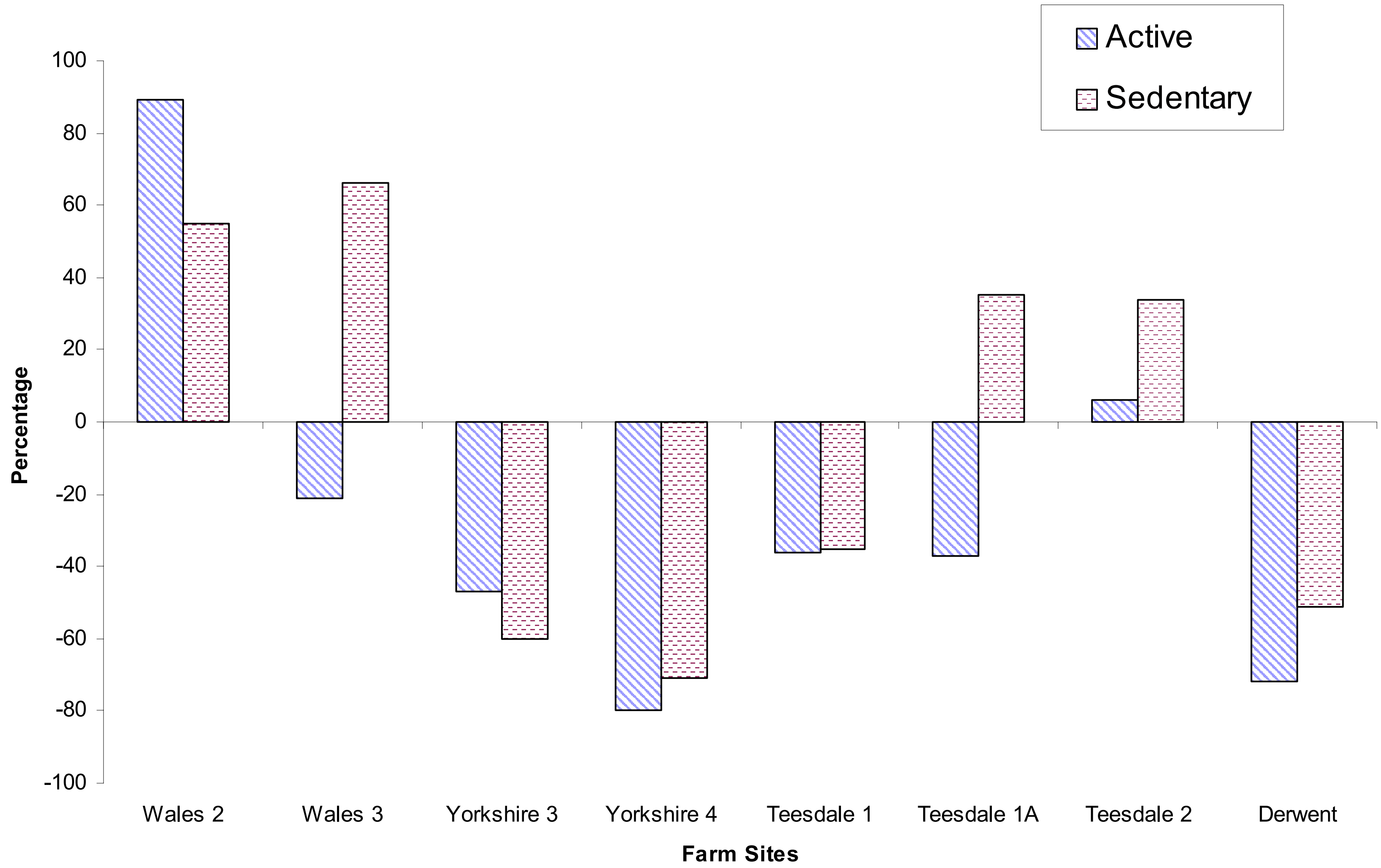


Figure 3.3: Percentage differences in mean densities of active and sedentary arthropods from soil samples on dip disposal and control areas, spring 2000.



3.4.2.4 Invertebrate species response - Ordination of pitfall catches

Introduction

There was no indication from the numbers of invertebrates caught in pitfall traps that dip disposal had had any effect on the combined density and activity of the surface active invertebrates (Table 3.26). However, disposal could have had differential effects on the survival of different species and altered community structure. This possibility was investigated by CANOCO analysis (Ter Braak 1988) carried out on the spider and ground beetle assemblages caught in the pitfall traps at the farm sites. "Canonical ordination is a combination of ordination and multiple regression. This leads to an ordination diagram of samples, species and environmental variables, which optimally displays how community composition varies with the environment" (Ter Braak 1988). The analysis quantifies the relative importance of the environmental variables contributing to the major axes of variation and is, therefore, an appropriate tool for identifying the effects of perturbations such as dip disposal.

Interpretation of ordination diagram

The CANOCO ordination axes represent environmental gradients indicated by the species distributions, constrained by the measured environmental parameters. Sites with similar species compositions have similar axis scores and lie close to each other within the ordination. Equally, when species distributions are plotted, species that occur together on the same sites have similar axis scores. Species that do not occur together are widely separated within the ordination space. Axis 1 represents the best fit, for both species and environmental variables, and comparison of eigenvalues indicates the relative power of the other axes. Environmental variables, contributing significantly to the axes, are represented by arrows on the diagrams. The degree of influence of the environmental variable on the species distribution is indicated by the length of the arrow and sites depicted as lying close to an arrow head are particularly associated with the variable; e.g. T1, T1A and T2 were hay meadows (Figure 3.5). The angle between arrow and axis indicates its importance to the axis; e.g. the altitudinal gradient contributes significantly to axis 1 whereas pH is the most important variable for axis 2 in Figure 3.4.

Ordination Results

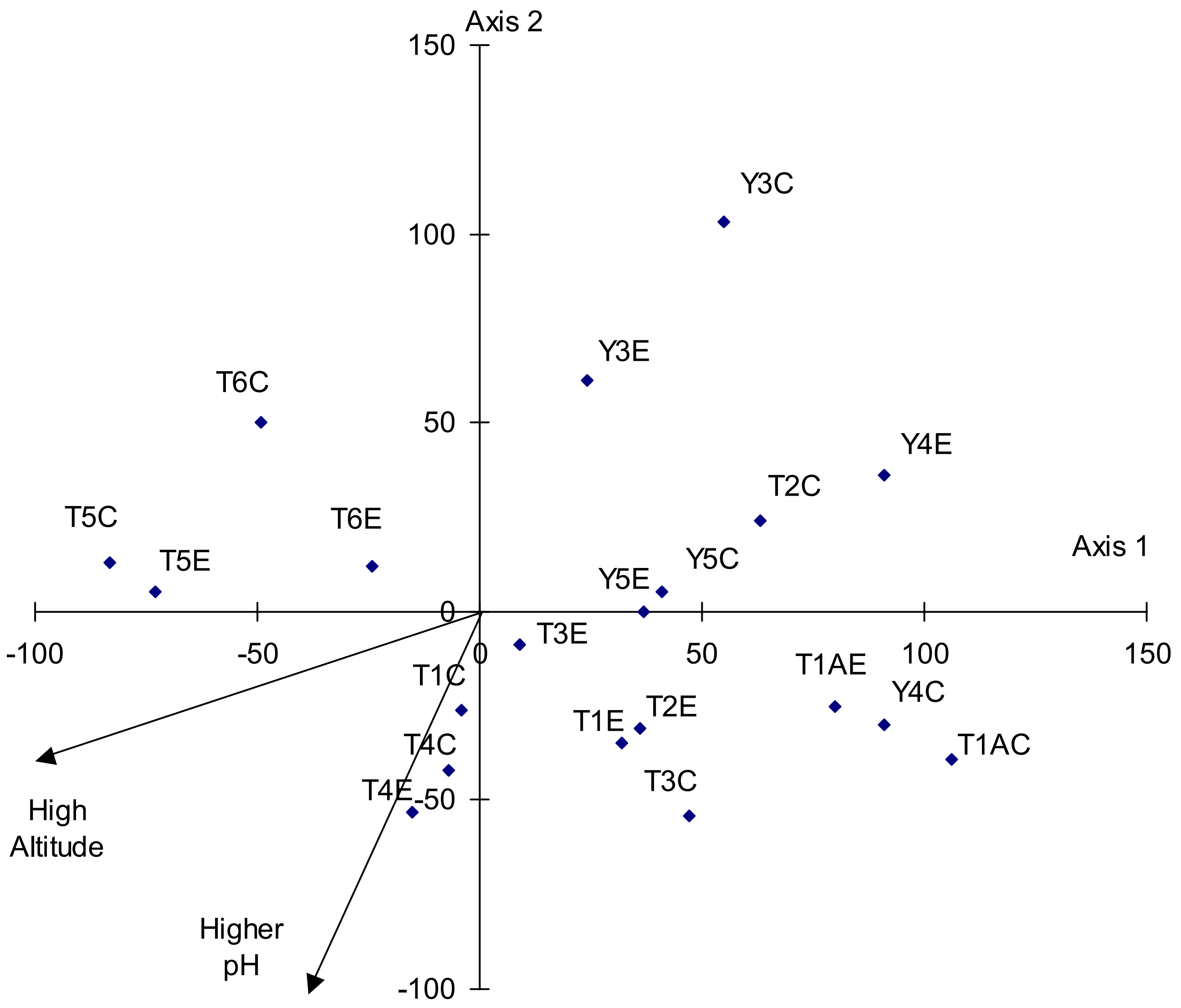
Spiders

CANOCO (Ter Braak 1988) indicated that the species distribution of spiders was significantly related to the environmental variables on axis 1 (Monte Carlo permutation test, $p<0.02$). Altitude was the most important variable, indicated by the high canonical coefficient (-4.00) and the relatively high exploratory t-value (4.4). pH made the strongest contribution to axis 2 but with an exploratory t-value of 2.5 only (Table 3.27). There is no consistent pattern in the relationship between the axis scores for paired control and disposal sites in the ordination (Figure 3.4). Further, the low values for the canonical coefficients representing dip disposal (Table 3.27) and the comparatively small biplot scores (Figure 3.4) indicate that dip disposal had little effect on species distribution.

Ground beetles

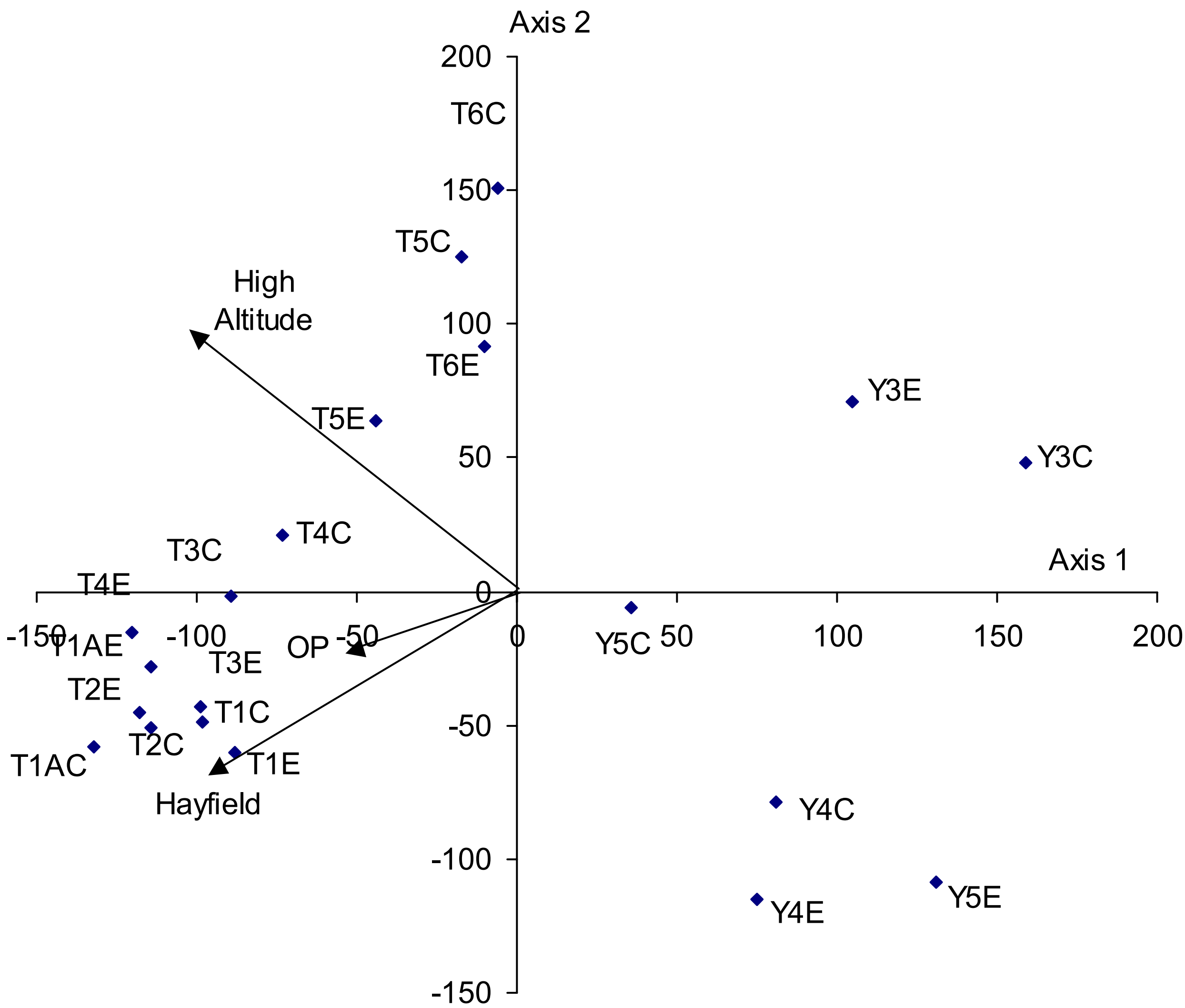
Field type and altitude were the most important influences on carabid distribution with axis 1 scores of –7.7 and 6.0 for altitude and hay meadow (exploratory t = 4.0 in both cases). Altitude and hay meadow also made an important contribution to axis 2, but here the influence of OP is indicated with a score of –2.75 (exploratory t = -3.14) (Table 3.27). In comparison with the low canonical scores for dip application in the spider ordination, the higher scores indicate a possible small significant effect of OP disposal on the carabid species distribution.

Figure 3.4: CCA ordination of farm sites based on the spider assemblages caught in pitfall traps in spring 2000



E = disposal site
C = control site

Figure 3.5: CCA ordination of farm sites based on the ground beetle assemblages caught in pitfall traps in spring 2000



E = disposal site
C = control site

Table 3.27: Eigenvalues and canonical coefficients (with "t" values) for the first two axes of CANOCO analyses on spider and ground beetle species assemblages, caught in pitfall traps, on control and disposal areas at the farm sites

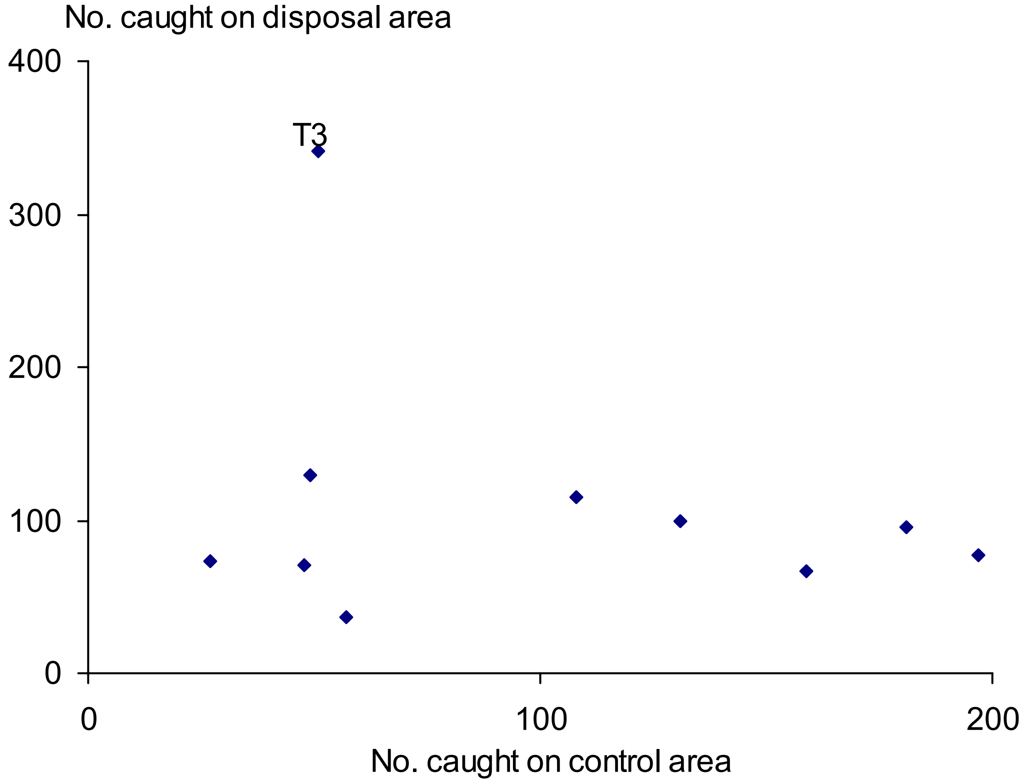
	Spiders				Ground beetles			
	Axis 1	t	Axis 2	t	Axis 1	t	Axis 2	t
Eigenvalue	0.169		0.135		0.472		0.352	
Cannonical coefficients								
Altitude	-4.00	-4.37	0.16	0.24	-5.99	-3.89	4.36	2.52
Hay field	1.41	1.02	-1.87	-1.78	-7.71	-4.04	-5.46	-2.55
pH	-0.50	-0.37	-2.48	-2.46	-1.48	-0.85	1.06	0.55
OP dip	0.34	0.55	-0.57	-1.23	0.09	0.11	-2.75	-3.14
SP dip	-1.13	-1.57	-0.15	-0.27	-0.50	-0.54	0.49	0.46

3.4.2.5 Relationship between numbers of species and numbers of individuals for spiders and ground beetles

Comparison between the numbers of spiders and ground beetles caught on control and disposal areas

The numbers of spiders caught in pitfalls on the disposal areas were significantly correlated with the numbers caught on the control areas (Figure 3.6a) whereas the numbers of ground beetles showed little relationship (Figure 3.6b). The high numbers of beetles caught on the disposal site at Teesdale 3 were contributed largely by a single species *Nebria brevicollis* with 295 individuals. *N. brevicollis* was present at all the farm sites and was caught in significantly greater numbers on disposal areas than on controls (paired $t_9 = 3.04$, $p<0.02$). However, the catches of the other ubiquitous ground beetle *Loricera pilicornis* did not differ significantly on control and disposal areas.

Figure 3.6b: Relationship between numbers of carabids caught in pitfalls on disposal and control areas



The number of species is dependent on the number of individuals caught and, when catches are relatively small and within the same habitat type, a double log plot is expected to give an approximately linear relationship. The spiders showed a significant relationship between the number of species and the number of individuals caught (Figure 3.7a) but the ground beetles did not (Figure 3.7b).

Figure 3.6a: Relationship between the numbers of spiders caught in pitfalls on disposal and control areas

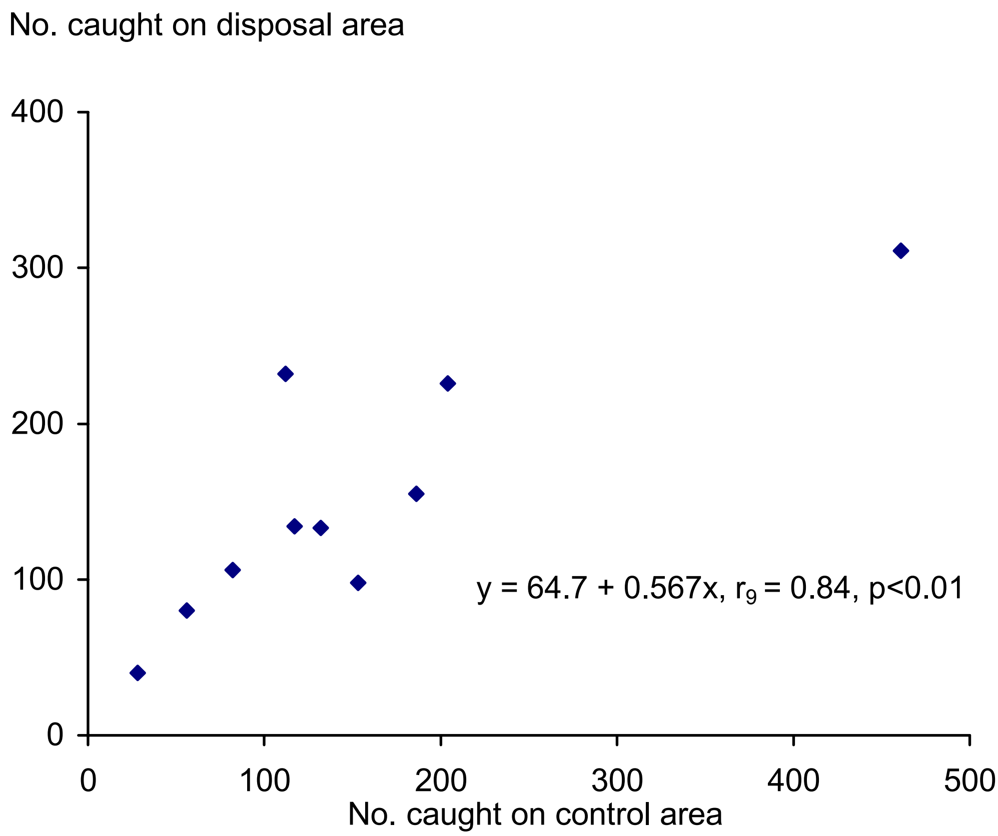


Figure 3.7a: Relationship between numbers of spider species and numbers of individuals caught

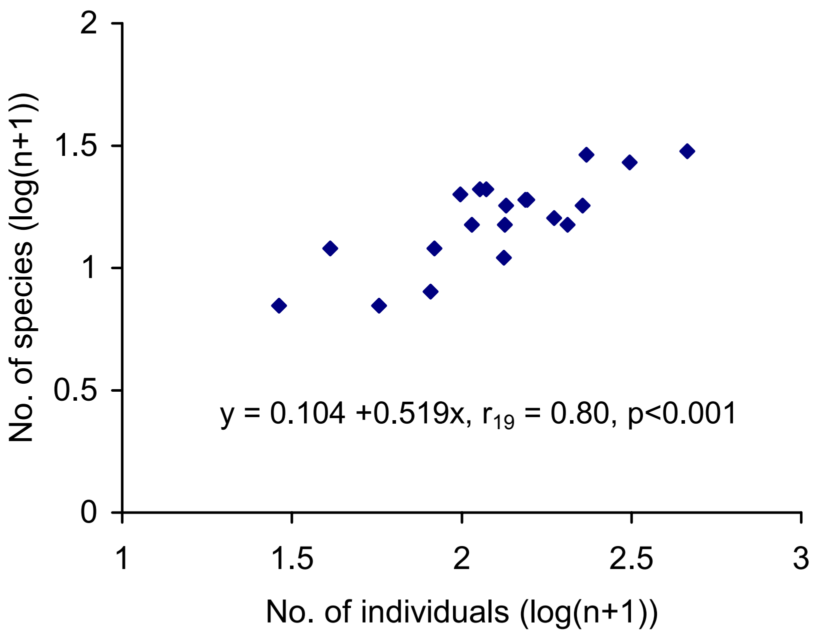
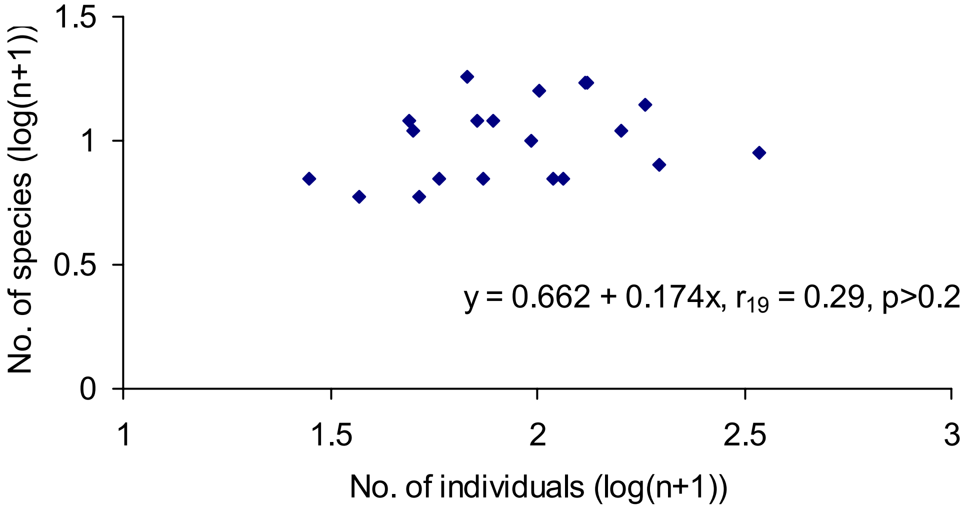


Figure 3.7b: Relationship between numbers of carabid species and numbers of individuals caught



Comparison between species diversity on control and disposal sites

Simpson's Diversity Index (D) which takes into account both species richness and equitability (Krebs 2001) showed no significant differences between spider diversities on control and disposal sites (Table 3.28) and diversities on disposal and control sites at each farm were closely correlated ($y = 1.06x - 0.18$, $r_9 = 0.973$, $p<0.001$). Ground beetle diversity, however, was significantly higher on disposal sites than controls, $t_9 = 2.51$, $p< 0.05$ (Table 3.28). This was mainly due to lower numbers caught and higher equitability on the disposal areas, though this trend was not consistent. The relationship between diversities on disposal and control sites at each farm was not significant ($y = 1.01x + 1.16$, $r_9 = 0.437$, n.s.).

Table 3.28: Simpson's diversity indices (D) based on pitfall catches of spiders and ground beetles at the farm sites.

	D (spiders)			D (ground beetles)		
Sites	Control	Disposal	C-D*	Control	Disposal	C-D*
Yorkshire 3	8.57	9.36	-0.79	3.5	6.62	-3.12
Yorkshire 3	2.97	3.94	-0.97	2.11	3.83	-1.72
Yorkshire 3	3.84	2.63	1.21	4.72	7.49	-2.77
Teesdale 1	5.12	4.3	0.82	3.24	2.61	0.63
Teesdale 1A	1.79	1.8	-0.01	3.24	2.27	0.97
Teesdale 2	3.52	4.39	-0.87	1.92	2.99	-1.07
Teesdale 3	3.93	3.91	0.02	1.52	1.33	0.19
Teesdale 4	11	11.6	-0.6	3.25	3.71	-0.46
Teesdale 5	6.34	6.49	-0.15	2.71	8.09	-5.38
Teesdale 6	6.05	6.24	-0.19	1.57	5.54	-3.97
mean difference			-0.153			-1.67
paired t			-0.67n.s.			-2.51 p<0.05

* Difference between control and disposal sites

3.5 Discussion of the Invertebrate Survey Results

3.5.1 Density response

Combining the results from all the farms, a significant 32% decrease in invertebrate densities was detected in the soil samples from the disposal areas compared to the controls. However, all the samples contributing to this figure were not independent (four of the farms were sampled in both autumn and spring) and the results from individual farms were highly variable. Teesdale 2 had significantly higher total densities of invertebrates on the disposal area in autumn 1999 and there were other instances where one or more invertebrate groups were sampled in significantly higher numbers on the disposal areas than on the controls. These examples of an apparently positive response to insecticide application could be the result of rapid recolonisation after insecticide use (Jepson 1989). However, there is no consistent pattern of progressive disappearance of significant effects with time (Tables 3.19 and 3.22) and the source of variation is more likely to lie in sampling error due to the patchy distribution of invertebrates. The farm soil survey has demonstrated the problems associated with sampling after an event has occurred.

There were many sources of variability in the use of the historic site information to determine any relationship between disposal activity and invertebrate abundance. Some of these are discussed in relation to the preliminary questionnaire. Other sources of variability included the interval between dip disposal and sampling, and saturation of the soil at the time of disposal. It was not possible to measure the latter but it will influence the rate at which dip penetrates the soil. Another major, potential source of variability lay in the matching of the disposal and control areas. Analyses of pH and organic content (Table 3.1) as well as qualitative analysis were used to confirm the disposal and control areas were comparable, but a range of other factors could lead to variability between fields in invertebrate populations. For example, site Teesdale 1A, despite having similar pH and organic content, was found to have higher invertebrate densities in the disposal area prior to dip disposal than the control area. Such pre-treatment differences would not have been apparent on the other sites with no pre-sampling, and results could wrongly be assumed to be either significant or non significant. This highlights the problem of finding comparable control and disposal areas within the same farm when individual fields have such pronounced differences in invertebrate fauna.

The most important source of variation, however, may have been in the location of the sampling area relative to the disposal area. On some sites, e.g. Wales 1 and Teesdale 2, the investigator was not confident that the area of disposal had been sampled while on others, e.g. Wales 2; the dip was bucketed on to the disposal area creating patches. From the point of view of assessing effects of dip disposal on the invertebrate diet for birds, this uncertainty about the disposal area suggests that the 32% average reduction on the disposal sites may be an under estimate of the actual reduction on areas which have received dip. On the other hand, it may represent a reasonable estimate for the allocated dip disposal areas in the short term. Fields, which had been used for multiple disposals, or over a long period (Derwent and Yorkshire 4), showed greater decreases in invertebrate densities (55 – 80%), which were still apparent six months after dip disposal. Although adult birds are unlikely to be affected by decreases of invertebrates within the relatively small areas represented by the disposal plots, decreases of this extent could contribute to pre-fledging mortality for the less mobile chicks. In the first week after hatching, wader chicks move short distances only and are dependent on invertebrates that are either on, or just below, the soil surface (Baines 1990, Galbraith et al. 1993, Whittingham et al. 2001).

No reduction in earthworm densities was observed on any of the disposal sites. In particular, the "worst-case" site at Derwent showed no significant difference between disposal and control area and it is concluded that the disposal of correctly diluted Cypermethrin and Diazinon is unlikely to have adverse effects on earthworm population densities. Other trials with similar pesticides support this conclusion (O'Halloran et al., 1999, for organophosphate based pesticide; Edwards and Brown, 1982, for synthetic pyrethroid studies).

Earthworms comprise a large proportion of the diet of adult lapwing in early spring (Baines 1990), which suggests that the pre-nesting food supply will be relatively unaffected by dip disposal. However, later in the season adult lapwing take surface-active arthropods, as do other adult waders and chicks of all species (Baines 1990, Galbraith et al. 1993, Whittingham et al. 2001). These birds may be at risk from depletion of their food supply and of direct exposure to treated invertebrates. The results of the spring bird counts show that the historic farm sites are used by many bird species, including lapwings, golden plover and curlews. Birds fed on disposal as well as control areas and thus could be exposed to contaminated prey on fields where there is spring sheep dip disposal. The invertebrate groups affected by dip disposal included abundant groups, e.g. beetles and flies, and sedentary arthropods, such as tipulid larvae, which all contribute to the avian diet.

3.5.2 Species response

CANOCO (Ter Braak 1988) indicated that the effects of dip application on the farms were negligible in the case of spiders and small, in relation to the first two variables (altitude and land use), for the carabids. Rushton et al. (1989) using a similar multivariate approach found an obvious decrease in carabid species richness associated with organophosphate (Chloropyrifos) application on large areas (2-11 ha) of upland pasture. As Diazinon has been recommended for control of the carabid strawberry pest *Harpalus rufipes* (Briggs and Tew 1969), OP application was expected to have adverse effects on ground beetle population densities. Further, in another study, Cypermethrin application in spring resulted in reduced catches of ground beetles for about a month while autumn application led to decreased densities of overwintering larvae of the common grassland species *Nebria brevicollis* (Cole et al. 1986). No effects were apparent in the next generation in the following year and it is likely that the plots were re-colonised by this active species. In the present study *N. brevicollis* was caught in significantly higher numbers on the farm disposal areas and, as catches of carabids other than *N. brevicollis* tended to be lower on the disposal areas, this may represent successful invasion of areas where competition has been reduced. On large areas, insecticide application is likely to have longer term adverse affects on the less active species, resulting from their limited ability to re-colonise the area (Rushton et al. 1989)

The present study has shown significant reduction in pitfall catches of lycosid spiders after cypermethrin application (Sourhope Latin Square, Section 4.3.2) but not of linyphiids. Insecticides, such as Dimethoate, have highly toxic effects on spiders when applied at field dosage rates (Vickerman and Sunderland 1977) but there is some evidence that the effects of some insecticides on spiders are not as long lasting as on ground beetles. Rushton et al. (1989) found Chloropyrifos application was detectable, as a factor within management intensification, acting on the ground beetles but concluded that spiders were probably responding more to the change in vegetation structure. The susceptibility of non-target organisms depends not only on the sensitivity of the species but also on the degree of exposure of the active stages to the insecticide. Plant-active linyphiid spiders were found to be adversely affected by pyrethroid application whereas ground-active species were not, suggesting persistence of the pyrethroid at the plant surface and rapid inactivation in the soil (Brown, White and Everett 1988). The recovery of populations after insecticide application depends largely on the capacity of the species to re-colonise the area. Although linyphiids may succumb to the immediate effects of insecticide, their capacity for rapid recolonisation means that they are at much lower risk of long-term population effects than carabids as a group (Jepson 1989).

Comparison of the relationship between the numbers of individuals caught in pitfall traps on disposal and control areas shows a high positive correlation for spiders whereas there is little relationship between the numbers of carabids caught on the paired areas (Figures 3.6a & 3.6b). It is possible that the non-significant relationship between the carabid pitfall catches reflects the taxon's natural variability but a further comparison of the relationships between numbers of species and numbers individuals caught shows a similar difference between carabids and spiders. Numbers of spider species caught were closely related to the total catch of individuals whereas the relationship was not significant in the case of the carabids (Figure 3.7a & 3.7b). The number of carabid species caught was less than the number of spiders and the difference in the relationships between numbers of species and individuals could be due to the pitfall catches differential contribution to the two species abundance curves, i.e. most carabid species were represented in relatively small catches whereas increased spider catches contributed further species. This possibility was tested by carrying out the same analysis on data from carabid catches, made during an upland invertebrate survey (Coulson and Butterfield 1979). Here, as with the spiders on the farm plots in the present study, the numbers of species were significantly related to the numbers of individuals caught ($y = 0.38 + 0.36x$, $r_{45} = 0.80$, $p<0.001$). The upland survey was carried out over a diversity of habitats and the rank abundance curves could be expected to differ between these habitats e.g. the catches were dominated by a few abundant species on blanket bog whereas species distribution was more equitable on grassland and low altitude moorland. This between habitat variability could undermine the relationship, between numbers of species and numbers of individuals caught, and the significant positive relationship here, suggests that relationship should hold for the, relatively, more homogeneous farm plots. The absence of the expected relationship between numbers of species and numbers of individuals suggests that dip disposal has a disruptive effect on the carabid community and supports the results of the CANOCO analysis, where an effect of OP was detected. In all but one case (Teesdale 1A) pitfalls were used on farms where dip had been disposed the previous autumn. Spider populations, although they could have been affected in the short-term (Vickerman and Sunderland 1977), had probably had time to recover.

Comparison of the similarity between spider diversities and the significant differences between ground beetle diversities on disposal and control areas (Table 3.28) also suggests an effect of dip application. However, the higher carabid species diversity detected on the disposal sites in this study, which is the opposite of the results found by (Vickerman and Sunderland 1977) was due to more than one effect. At Teesdale 5 and 6 and Yorkshire 3 and 4, fewer individuals were caught on the disposal areas, consistent with lowered population densities as a result of insecticide application, but at Yorkshire 5 more individuals and species were caught on the disposal area than on the control. The high diversity (Table 3.28) and low numbers of carabids caught at Teesdale 6 (Figure 3.6b) follows the general trend, suggesting that sampling had been on a correctly identified disposal area (see p. 38).

3.6 Conclusions

The many potential sources of error encountered in the farm site study mean that the results can only be viewed as indicative. However, total invertebrate densities, on the disposal areas as a whole, were significantly lower and about two thirds of the densities on the control areas. Both active and sedentary groups showed reductions and it can be assumed that recolonisation on the relatively large areas used for disposal at the farm sites is slow, even for active invertebrates. In spring 2000 invertebrate densities on three of the disposal areas were still significantly below the control areas following disposal in autumn 1999, with densities on the two sites that had been used for long-term disposal particularly depressed.

Although adult waders can move to new areas if they find one foraging area unprofitable, this may not be possible for young chicks. Invertebrate reductions of 55-80%, found at Derwent and Yorkshire 4, could impose severe restrictions on growth in the first few days when chicks can move short distances only.

The CANOCO analysis indicated a small but significant effect of dip disposal on the carabid species composition of the pitfall catches. The diversity of carabids was higher on the disposal areas than on the controls and the relationships between numbers caught on disposal and control areas and between numbers of species and individuals caught at each site were not significant. In contrast, spider species composition and diversity were not significantly related to dip disposal. Numbers caught on disposal and control areas were significantly correlated and the number of species was significantly related to the number of individuals caught. These differences between carabids and spiders indicate that disposal of sheep dip has a disrupting effect on species composition in carabid communities but that spiders are less vulnerable. The comparison suggests that not only do the major taxa differ in response to insecticide application but also that there are differences in response at the species level.

4. LATIN SQUARE EXPERIMENTAL DESIGN

4.1 Introduction

Dip was applied experimentally, using plots in a Latin Square design, at Sourhope Experimental Farm in spring 2000 to allow the short-term, direct effects of dip disposal to be assessed. Application of dip was also undertaken at Newton Rigg Experimental Farm in autumn 2001 using the same experimental design. This site was chosen to compliment the site at Sourhope Experimental Farm, sampled in 2000-2001, by representing more fertile inby land than the rougher grazing land previously sampled.

The farm sites (Chapter 3) gave very useful indicative results but the invertebrate survey suffered from problems locating the exact area of disposal on some of the farms. Difficulties were also encountered in finding appropriate replicate control sites at the farm scale. The purpose of experimental application was to avoid the uncertainties of the farm survey by carrying out a multifactorial replicated plot experiment to investigate the effects of different dilutions of SP and OP dip on invertebrate activity and abundance. The aim was to reflect the real situation on farms as far as possible, using widely available dips and applying the dip at the same dilution and volume per area, as the quantities per hectare specified in EA guidelines. The dilutions used at the experimental sites included made up dip diluted 1:3 with water, as recommended by EA guidelines, and made up dip without any further dilution, as the farm studies showed that the dip was not always diluted for disposal, at least not to specified levels.

The Latin Square design experimental method takes account of any possible environmental gradient effects e.g. slope or drainage. It uses a quadrat grid with equal numbers of columns and rows, set out so that no treatment occurs more than once in any row or column thus avoiding any uncontrollable factor influencing one treatment more than another and providing statistically tenable results. The disadvantage is that available space and manpower dictated a maximum plot size for application of 10 x 10 m. Each treated plot, therefore, represented only a small proportion of the plot size actually used for disposal on farms, the smallest of which was approximately equivalent to the entire experimental plot area. Rates of recolonisation, after any density reductions suffered as a result dip disposal, will therefore differ, and probably be more rapid, on the Latin square plots than in the real farm situations.

In addition to the main experiment at Newton Rigg 2002, a small supplementary study was carried out specifically designed to investigate the effects of dip disposal on smaller invertebrates, such as Collembola, which are generally accepted to be of high value to carabid beetles (Toft and Bilde 2002). Results from both farm sites and initial experimental plot work at Sourhope showed that the disposal of both organophosphate and synthetic pyrethroid sheep dips had a detrimental effect on some relatively large invertebrates including adult and larval Coleoptera. These invertebrates feature strongly in the diet of important wading bird species such as golden plover (Ratcliffe, 1976) and lapwing (Baines, 1990) for which several upland SSSIs have been designated, in particular those in Teesdale and Wales where part of the previous research was undertaken. It is therefore also important to know whether the smaller invertebrate prey species of some of the larger predatory species are also affected by dip disposal to farmland. The aim was to determine whether effects of the dip on the larger invertebrates were due simply to direct effects of the dip or whether they could have resulted from indirect effects of a drop in food supply. Long-term negative effects of pesticide regimes have been found previously on collembolan communities sampled by pitfall trapping as part of the SCARAB project on agricultural land (Holland, Frampton and Van Den Brink, 2002) and in other work on Collembola using suction sampling (Frampton, 2000, 2001).

4.2 Methods

4.2.1 Latin square set up at Sourhope

The experimental site at Sourhope (Plate 1) was representative of the type of rough grazing land that farmers typically choose for dip disposal, if it is available to them. As indicated by information gathered in the preliminary survey (Chapter 2) farmers, where possible, generally prefer not to use their best quality grazing land for disposal. The Sourhope site had an organic content of approximately 16.3% and a pH of approximately 4.5. The vegetation consisted mainly of long coarse grasses, often forming dense tussocks, interspersed with small numbers of thistles and other species.

The Latin Square was set up with five treatments and five replicates of each treatment; Cypermethrin at the recommended dilution for made up dip (SP), Cypermethrin, made up dip diluted 1:3 (SP dilute), Diazinon at the recommended dilution for made up dip (OP), Diazinon, made up dip diluted 1:3 (OP dilute) and control (water). The total plot size was 50m x 50m (constrained by available site dimensions), with individual plots therefore of 10m x 10m, and application rate was equivalent to 5000lha^{-1}. The treatments were applied on 15 June 2000. Disposal was carried out according to safety guidelines (Health and Safety Executive, 1998), using recommended protective clothing and methods for storage and transportation of the dip prior to disposal. The appropriate measure of dip for each plot was transported partly diluted and further dilution was carried out on site with maximum ventilation and minimum possible exposure to participants. Disposal was carried out using watering cans, since slurry tankers were inappropriate at this scale, and each treatment was spread to within 0.5m of the edge of each plot, effectively leaving a boundary of 1m between treatments.

4.2.2 Sampling

Soil sampling was carried out pre-disposal (15/06/00) and at 10 days (26/06/00), 20 days (04/07/00) and 40 days (24/07/00) after treatment application and in Spring 2001 (16/5/01). Sampling was carried out using the same method as used in the historic farm sampling (Chapter 3) but taking two smaller samples (12 cm x 12 cm) on each plot to reduce the possibility of taking single unrepresentative samples, such as those containing ant nests, that would provide misleading results at this scale.

Pitfall traps were also laid, one per plot (near the centre of the plot). These were in place prior to disposal but were destroyed by grazing sheep. The sheep were excluded before dip application and the pitfalls were replaced on the day the dip was applied. They were collected at 10, 20 and 40 days after the experimental treatment. A further 25 pitfalls were placed in similar positions, the following year (01/06/01). These were collected after 14 days (15/06/01).

Suction sampling was undertaken at 10 and 40 days after treatment application. Predisposal sampling on 15th June was considered too early in the season at such a northerly site for suction sampling to catch adequate numbers of surface-active invertebrates (i.e.adult insects) for meaningful analysis of results. At 20 days rainfall also prevented suction sampling. Sampling was carried out using the "Echo Blower-vacuum" with two 30 s suctions within each plot. Invertebrates obtained using suction sampling were identified to species level.

4.2.3 Latin Square set up at Newton Rigg in 2001

The experimental site at Netwon Rigg (Plate 2) was representative of the type of inby land, with good quality grazing, that many farmers use for dip disposal if they do not have access to a suitable alternative. The site had an organic content of approximately 18.8% and a pH of approximately 4.4. The vegetation consisted primarily of short cropped, heavily grazed grasses with a few small tussocks and isolated areas of rushes, indicating areas of high soil moisture content.

The Latin Square at Newton Rigg was set up with five treatments and five replicates of each treatment in the same way as at Sourhope (above). The total plot size was 25m x 25m (constrained by available site dimensions), with individual plots therefore of 5m x 5m, and application rate was equivalent to 5000lha^{-1}. The treatments were applied on 24/10/01. Each treatment was spread to within 0.25m of the edge of each plot, effectively leaving a boundary of 0.5m between treatments.

4.2.4 Latin Square set up in 2002

In spring 2002 a second Latin Square was set up (Site B), adjacent to the original site (Site A). Site B was set up in exactly the same way as Site A but with the treatment plot arrangement turned by 90 degrees. Site B was set up to create additional data and allow comparisons between the original site that was used for a second time in spring and the new site that was only used once for dip disposal. The treatments were applied on 24/5/02

4.2.5 Sampling in 2001

In 2001 soil sampling was carried out on Site A pre-disposal (11/10/01) and at 10 days (2/11/01) after treatment application. Further samples were not taken at 20 and 40 days after treatment application because many invertebrates overwinter in inactive stages and cannot be extracted. In order to determine densities of soil invertebrates, two soil samples were taken from each plot, each approximately 12cm x 12cm, from each individual plot. Mobile invertebrates were collected from each soil sample by heat extraction in Berlese funnels for one week. Invertebrates were sorted and identified to family level (or as precise a level as possible depending on the stage of development of the individuals).

A further soil sample of approximately 12cm x 12cm was taken from each plot for an investigation of densities of earthworms. These were sorted by hand on return to Durham.

Pitfall traps were also laid, one per plot (near the centre of the plot). These were in place prior to disposal but were destroyed by grazing sheep. The sheep were excluded before dip application and the pitfalls were replaced on the day the dip was applied. They were collected 10 days after the experimental treatment.

4.2.6 Sampling in 2002

In 2002 soil sampling was carried out both on the original site (Site A) and the adjacent Site B predisposal (24/5/02) and at 10 days (3/6/02), 20 days (13/6/02) and 40 days (2/7/02) after treatment application. The soil sampling and invertebrate extraction methods were the same as those used in 2001 (above).

Pitfall traps were not laid in 2002 as, following discussion of the 2001 results, the plot sizes were deemed too small to make this valuable.

Suction sampling for surface-active invertebrates was undertaken only at 50 days. Heavy rainfall on the earlier sampling occasions made vegetation too wet to sample. Suction sampling was carried out using an Echo "Blower-vacuum" with an extension sampling tube (aperture 0.01 m^2). Sampling was carried out for 6x10 second intervals within each plot (Macleod, A. *et al*, 1994).

4.2.7 Additional sampling for Collembola and Mites

Collembola are very numerous and can occur at densities between 10,000 and 100,000 individuals per square metre (Hopkin, 2000). They can be sampled using several different methods and have been present in samples from Berlese extraction in other parts of this work in numbers far too great to count. More time efficient methods include suction sampling (Frampton, 2000, 2001), pitfall sampling (Holland, Frampton and Van Den Brink, 2002) and small soil cores for extraction of the invertebrates using Tullgren Funnels (Southwood and Henderson, 2000). The last method was chosen for this study.

Sampling for Collembola was carried out on Site B at Newton Rigg, set up in Spring 2002 predisposal (24/5/02) and at 10 days (3/6/02), 20 days (13/6/02) and 40 days (2/7/02) after treatment application. From each plot a 0.001m^2 soil core was taken for extraction of the invertebrates in the laboratory using Tullgren Funnels. In Tullgren Funnels heat and light resulted in invertebrates being driven out of the cores to be collected into ethanol as the samples slowly dried out over 48 hours. All the invertebrates obtained using this method were then counted, identified and tested statistically. Numbers of total invertebrates that had also been extracted by this method were investigated in addition to the Collembola and, since they were relatively numerous in the samples, mites were also tested statistically.

4.2.8 Statistical analysis

Numbers of invertebrates were log-transformed and the results were analysed using ANOVA for Latin Squares because ANOVA is the most appropriate analysis for the randomised design. Tukey HSD tests were carried out where the ANOVA results had been significant to isolate which treatment types were significantly different to each other.

Plate 1: Field site at Sourhope, 2000-2001

Plate 2: Field site at Newton Rigg, 2001-2002

4.3 Results of the Experimental Field Trial at Sourhope

Lists of groups invertebrates were sorted into are in Appendix 2. The results of the statistical analyses of the data collected at Sourhope are listed in tables 4.1.1 to 4.3.4 in Appendix 5. These tables include geometric mean numbers of invertebrates for each treatment and results of ANOVA tests. Where ANOVA revealed significant heterogeneity between the plots, Tukey HSD tests were also carried out to determine between which treatments significant differences arose. Table 4.1 summarises the results showing the significant results of the ANOVAs and indicating which treatments were responsible for the significant reductions in densities of invertebrates on treated, compared to control, plots. All sampling methods indicated that some groups of invertebrates were at significantly lower densities on sheep dip disposal plots, compared to the control plots, at some time interval after application.

4.3.1 Soil fauna (soil samples)

Ten days after sheep dip application, the sedentary soil invertebrates were present at significantly lower densities in the plots where OP had been applied than in the controls, indicating an immediate effect (Table 4.1). At 20 days after application, the same pattern remained, with lower densities on the treated areas but the difference from the control areas was not statistically significant. At 40 days the pattern was no longer apparent. In the resample in spring 2001 the total invertebrate densities were significantly lower on the SP plots, whereas the SP (dilute), OP and OP (dilute) treated plots showed no significant difference from the control (Figure 4.1).

4.3.2 Surface invertebrates (pitfall traps)

The pitfall results showed significant effects of dip disposal in the 20 day sample (Table 4.1, Figure 4.2). Significantly lower numbers per pitfall were caught on the SP plots, compared to the controls. Different taxa showed differing responses to the dip applications. Lycosid spiders were most affected by SP and were at significantly lower densities on both SP and SP (dilute) plots than on the controls 20 days after application and remained significantly lower on the SP (undiluted) plots after 40 days (Table 4.1). Elaterid beetles, were significantly adversely affected by the undiluted OPs and undiluted SPs 10 days after application. Samples at 20 days showed significantly lower numbers for SP plots and at 40 days there were significantly lower numbers on OP plots. Carabid beetles showed no statistically significant differences in densities between control and treated plots until 40 days after dip application and then numbers were significantly higher on the SP (dilute) plots than on the controls. There were no significant differences between treated and control plots in the pitfall catches in the spring of 2001, the following year.

4.3.3 Surface invertebrates (suction samples)

The suction samples indicated that invertebrates at the soil surface and on the vegetation were severely depleted by dip application, with the diluted dip acting as adversely as the undiluted (Table 4.1). Ten days after dip application the numbers on the disposal plots were about 20% of those on the control plots. There was little recovery by 40 days and at both 10 and 40 days there were significantly lower numbers on all of the dip treatments compared with the controls (Figure 4.3). The bugs (Hemiptera) comprised more than 60% of the invertebrates taken in the suction samples and they showed the same trend with significantly lower numbers on all the disposal treatments at both 10 and 40 days. Two Hemiptera species were taken in sufficiently high numbers to analyse the influence of dip disposal at the species level. At 10 days *Hyledelphax elegantulus* was present at significantly lower densities on all dip disposal treatments compared with the controls. At 40 days *H. elegantulus* numbers had declined over the whole of the experimental area and it had been replaced by *Pachytomella parallela* which was also at significantly lower densities on all the disposal areas compared to the controls.

Table 4.1: Summary of treatments responsible for significant reductions in densities of invertebrates on treated, compared to control plots, in the Latin Square experiment at Sourhope 2000-2001.

	Time after sheep dip application			
Taxonomic group	**10 days**	**20 days**	**40 days**	**12 months**
Total soil invertebrates	NS	NS	NS	SP
Sedentary soil invertebrates	OP	NS	NS	NS
Total pitfall Invertebrates	NS	SP	NS	NS
Lycosidae (pitfalls)	NS	SP, SP dil.	SP	NS
Linyphiidae (pitfalls)	NS	NS	NS	NS
Elateridae (pitfalls)	OP, SP	SP	OP	NS
Carabidae (pifalls)	NS	NS	Control *	NS
Total suction invertebrates	OP, OP d., SP, SP d.	N/A	OP, OP d., SP, SP d.	N/A
Bugs (suctioned)	OP, OP d., SP, SP d.	N/A	OP, OP d., SP, SP d.	N/A
Hyledelphax elegantus	OP, OP d., SP, SP d.	N/A	(too scarce)	N/A
Pachytomella parallela	(too scarce)	N/A	OP, OP d., SP, SP d.	N/A

Key
OP = organophosphate
OP d. = organophosphate diluted
SP = synthetic pyrethroid
SP d. = synthetic pyrethroid diluted
N/A = not sampled
* = significantly less on control
NS = no significant differemces

N.B. Where treatment abreviation is listed, eg OP, SP, OP d., SP d., significant reduction occured due to that treatment

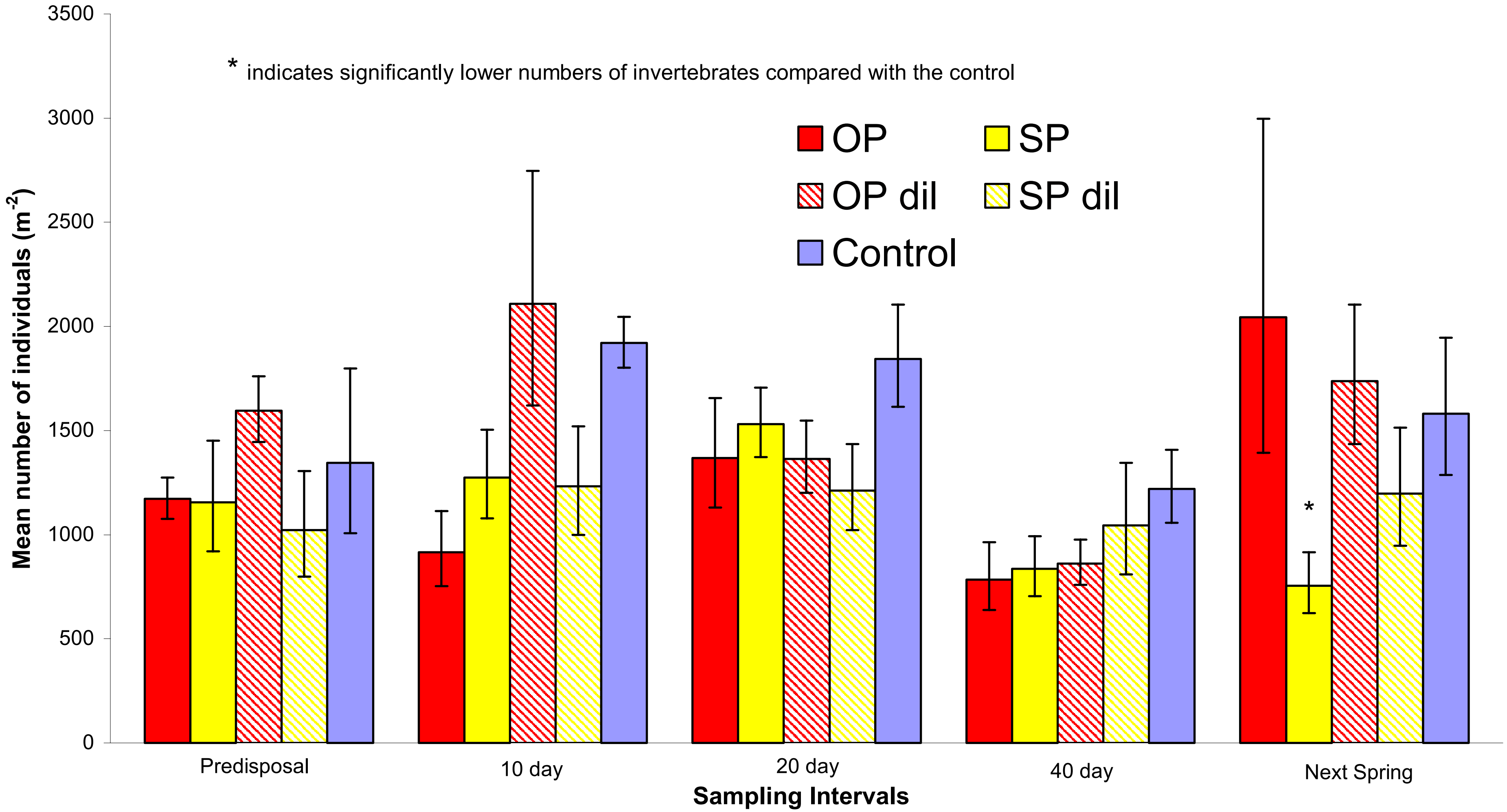


Figure 4.1: Geometric mean numbers, with standard errors, of invertebrates obtained by soil sampling at Sourhope before and at 10,20 and 40 day intervals and 12 months after treatment application, 2000-2001

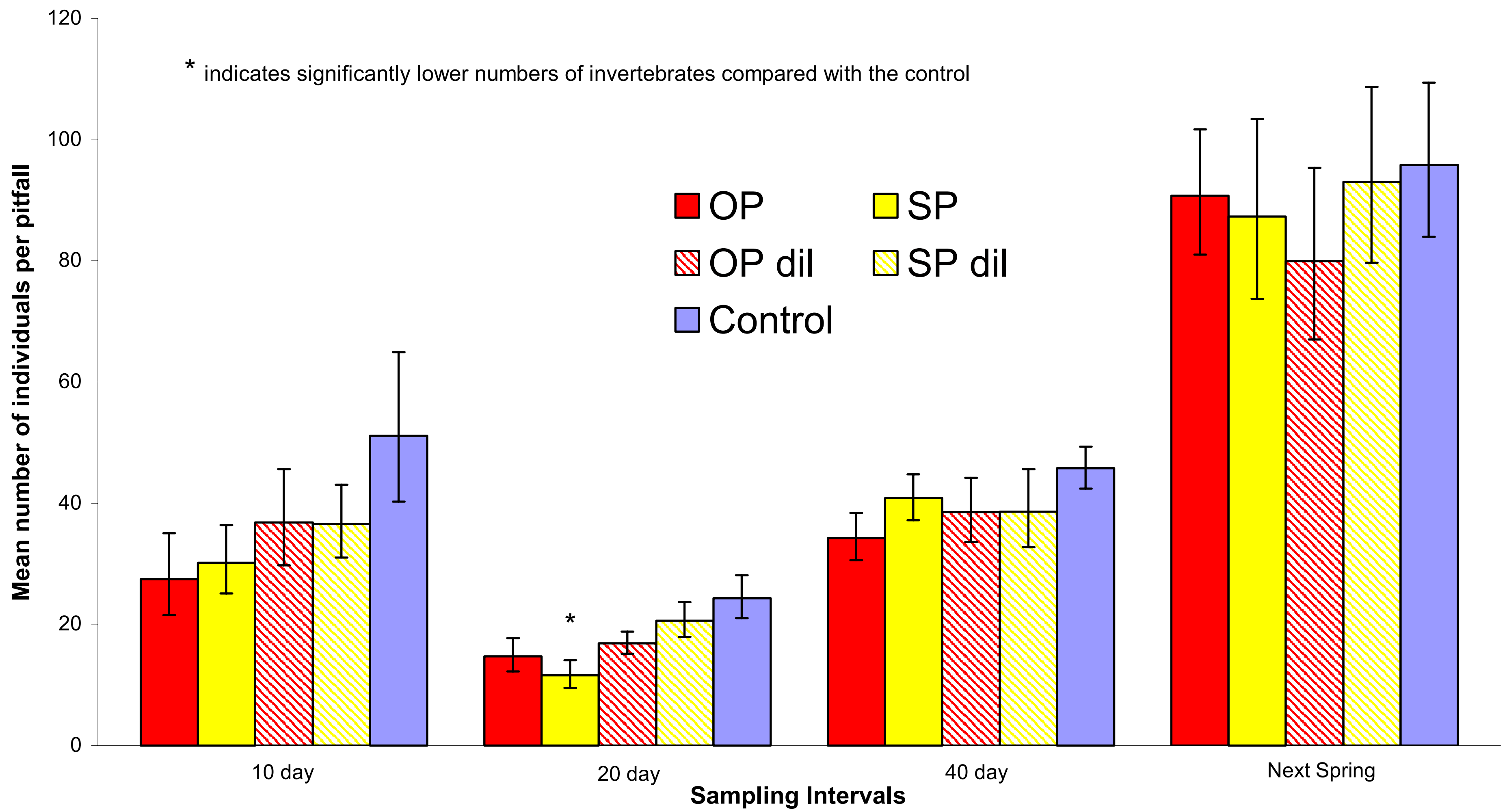


Figure 4.2: Geometric mean numbers, standard errors, of invertebrates obtained by Pitfall Traps at Sourhope before and at 10,20 and 40 day intervals and 12 months after treatment application, 2000-2001

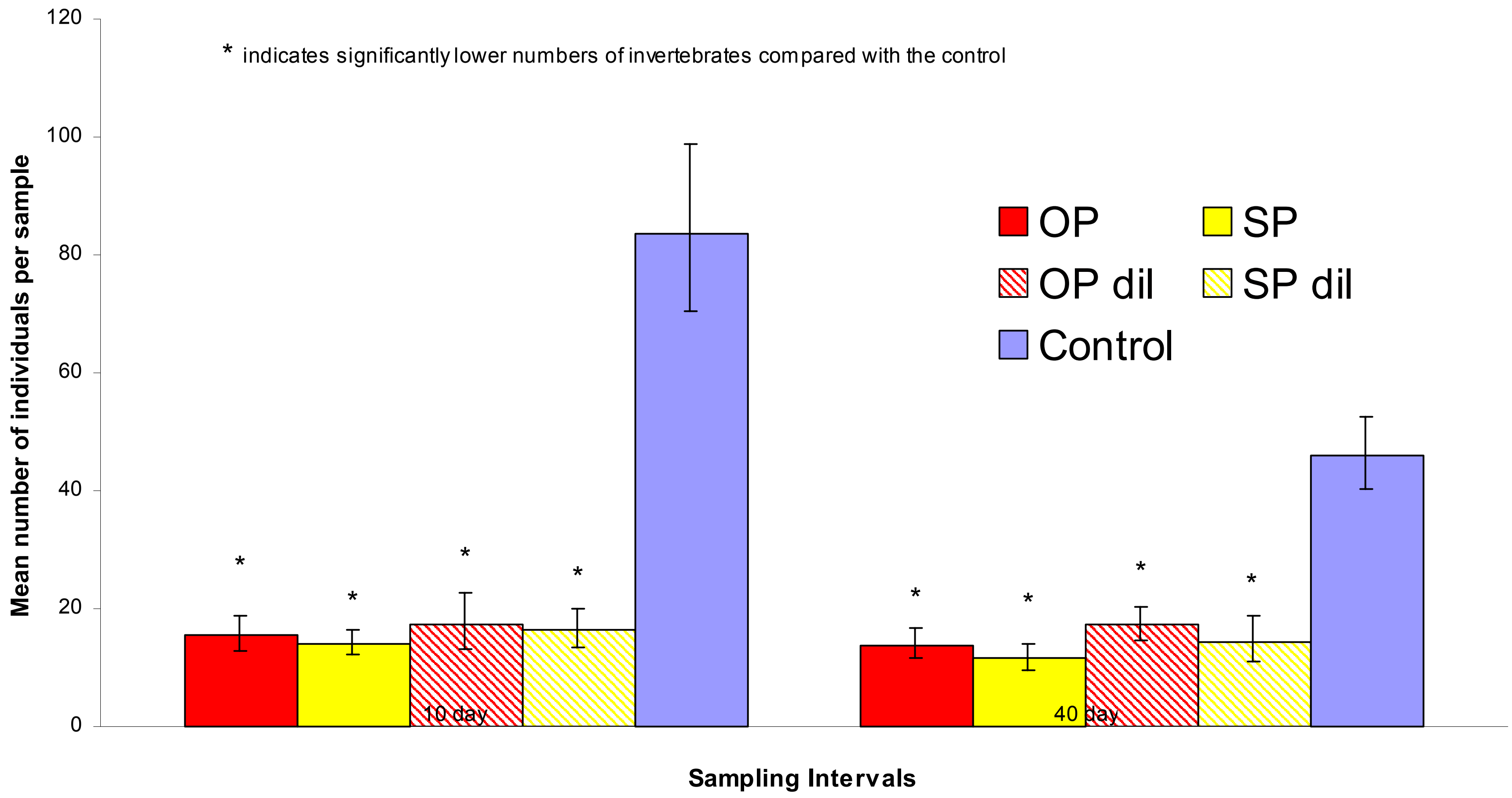


Figure 4.3: Geometric mean numbers, with standard errors, of invertebrates obtained by Suction Sampling at Sourhope at 10 and 40 day intervals after treatment application, 2000

4.4 Results of the Experimental Field Trial at Newton Rigg

Table 4.2 is a summary of treatments responsible for reductions in densities of invertebrates on treated, compared to control plots for all sampling methods in 2001 and 2002 at Newton Rigg.

Lists of groups invertebrates were sorted into are in Appendix 2. Appendix 5 (Tables 4.4.1 to 4.12.12) shows the results of the statistical analyses. These tables include geometric mean densities of invertebrates for each treatment and results of ANOVA tests on log transformed densities. Where ANOVA revealed significant heterogeneity between the plots, Tukey HSD tests were also carried out to determine between which treatments significant differences arose. Figures 4.4 to 4.6 show the results for total numbers of invertebrates extracted from soil samples. Figure 4.7 shows the results of the Collembola investigation.

4.4.1 Autumn Sampling 2001

4.4.1.1 Soil fauna (soil samples)

Predisposal samples showed no significant differences in invertebrate densities between plots used in the treatment regime. Ten days after sheep dip application, the total soil invertebrates were present at significantly lower densities in the plots where OP, SP had been applied than in the controls, indicating an immediate effect (Figure 4.4). This pattern was repeated in both sedentary invertebrates and active invertebrates although the latter also showed significantly lower densities on plots where diluted OP had been applied. The samples hand sorted for earthworms showed no significant differences between the plots before or after treatment application.

4.4.1.2 Surface invertebrates (pitfall traps)

The pitfall results did not show a significant reduction of total invertebrate activity 10 days after dip disposal and invertebrates were low on all plots (Appendix 5, Table 4.6.1).

4.4.2 Spring Sampling 2002

4.4.2.1 Soil fauna (soil samples)

4.4.2.1.1 Predisposal

On Site A, which had been treated in the previous autumn, there were no significant differences between predisposal samples in total, sedentary or active invertebrate densities in subsequently treated and control plots. On Site B, which had not previously been exposed to dip application, there were also no significant differences between predisposal samples in total, sedentary or active invertebrate densities predisposal.

4.4.2.1.2 Total Invertebrates

On Site A there were no significant differences in total invertebrates at 10 days but by 20 days total invertebrate densities were significantly lower on plots treated with SP, OP and diluted SP compared with the control. By 40 days there were no significant differences (Figure 4.5).

On Site B there were no significant differences in total invertebrates at 10 days but by 20 days SP, OP, diluted SP and dilute OP showed significantly reduced numbers of total invertebrates. By 40 days there were no significant differences (Figure 4.6).

4.4.2.1.3 Sedentary Invertebrates

At Site A there were no significant differences in sedentary invertebrates at 10 days but at 20 days there were significant reductions on all the treated plots compared to the controls. By 40 days there were still significant differences between the undiluted SP plots but not between the diluted SP or either of the OP applications when compared with the controls.

At Site B significant differences in sedentary invertebrates were found at 10 days when all the treated sites were compared with the control and at 20 days this pattern remained. By 40 days there were no significant differences between the treated and control plots for sedentary soil invertebrates.

4.4.2.1.4 Active Invertebrates

When tested independently of each other there were no significant differences in active invertebrates between the treated and control plots on any sampling occasion at either Site A or Site B. However, it was noted that the geometric means were far greater on the control plots post disposal than on any of the treated sites. This did not reveal statistically significant results because of the high standard errors produced due to the patchy nature of active invertebrate activity. Adding the results together from both sites, thereby creating a greater number of samples in the same statistical test, revealed significantly reduced active invertebrates at the 20 day sampling occasion on SP, OP and dilute SP treated plots compared with the control (Appendix 5, Table 4.9.2).

4.4.2.1.5 Earthworms

At Site A there were no significant differences until 40 days when significantly higher densities were found on SP, OP and dilute SP treated sites when compared with the controls. There were no significant differences in earthworms densities on any sampling occasion at Site B.

4.4.2.2 Surface invertebrates (suction samples)

At 50 days there were no significant differences in total invertebrates between the treated plots and the control at either Site A or Site B. There were also no significant differences in Collembola at either site. However, at Site A there were significantly decreased numbers of mites on SP, OP, dilute OP and dilute SP plots when compared with the control. There were no significant differences for mites at site B. Bugs and spiders were not caught in sufficient numbers to make statistical analyses of separate species valuable.

4.4.2.3 Collembola and mite study

Results of the Anova and Tukey HSD tests are in Appendix 5, Tables 4.12.1 to 4.12.12.

There were no significant differences between numbers of total invertebrates on the treated and control plots on any of the sampling occasions. However, at 20 days the number of Collembola was significantly greater on the control site than on the sites treated with OP, SP and dilute OP. There were no significant differences by 40 days.

There was a significant difference between the numbers of mites on the control area and the OP dilute treated area at 10 days. 20 days after treatment application there were still significant differences in numbers of mites on the control area compared with the OP dilute treated area and also with the undiluted SP treatment. By 40 days there were no significant differences between any of the treated plots and the control.

Table 4.2: Summary of treatments reponsible for significant reduction in densities of invertebrates on treated, compared to control plots, in the Latin Square experiments at Newton Rigg

	Autumn Application	Spring Application			
		Time after sheep dip application			
Taxonomic group	**10 days**	**10 days**	**20 days**	**40 days**	**50 days**
Site A					
Total soil invertebrates	OP, SP	NS	OP, SP, SP d.	NS	
Sedentary soil invertebrates	OP, SP	NS	OP, SP, OP d., SP d.	SP	
Active soil invertebrates	OP, SP, OP d.	NS	NS	NS	
Total pitfall Invertebrates	-	N/A	N/A	N/A	
Suction sample totals	N/A	N/A	N/A	N/A	NS
Suction sample collembola	N/A	N/A	N/A	N/A	NS
Suction sample mites	N/A	N/A	N/A	N/A	OP, SP, OP d., SP d.
Earthworms	NS	NS	NS	*	
Site B					
Total soil invertebrates	N/A	NS	OP, SP, OP d., SP d.	NS	
Sedentary soil invertebrates	N/A	OP, SP, OP d., SP d.	OP, SP, OP d., SP d.	NS	
Active soil invertebrates	N/A	NS	NS	NS	
Suction sample totals	N/A	N/A	N/A	N/A	NS
Suction sample collembola	N/A	N/A	N/A	N/A	NS
Suction sample mites	N/A	N/A	N/A	N/A	NS
Earthworms	N/A	NS	NS	NS	
Active invertebrates A+B	N/A	NS	OP, SP, SP d.	NS	

Key
OP = organophosphate
OP d. = organophosphate diluted
SP = synthetic pyrethroid
SP d. = synthetic pyrethroid diluted
N/A = not sampled
* = significantly less on control
NS = No significant differences

N.B. Where treatment abreviation is listed, eg OP, SP, OP d., SP d., significant reduction occured due to that treatment

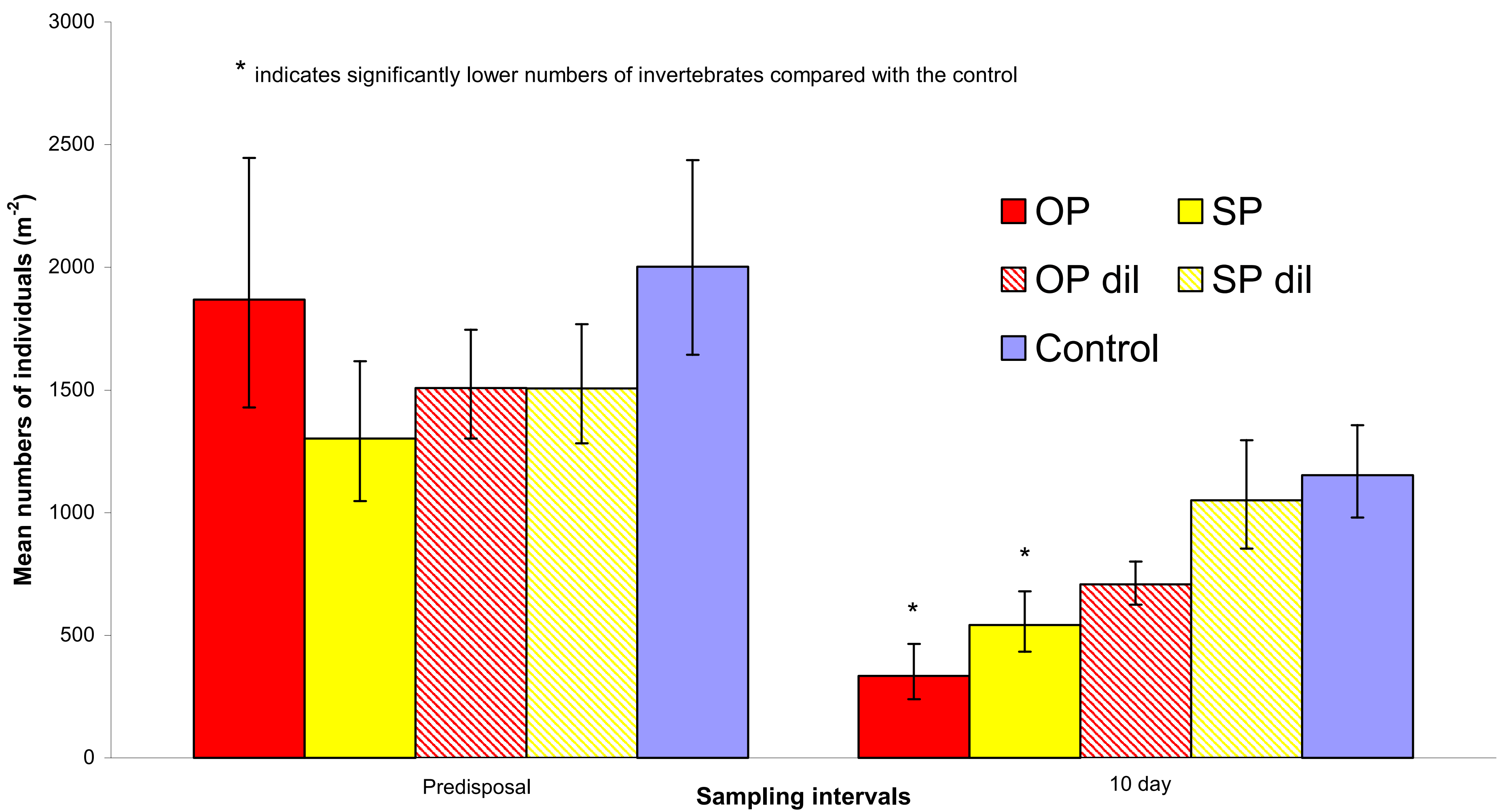


Figure 4.4: Geometric mean numbers, with standard errors, of total invertebrates obtained by soil sampling in Site A at Newton Rigg predisposal and 10 days after application in autumn 2001

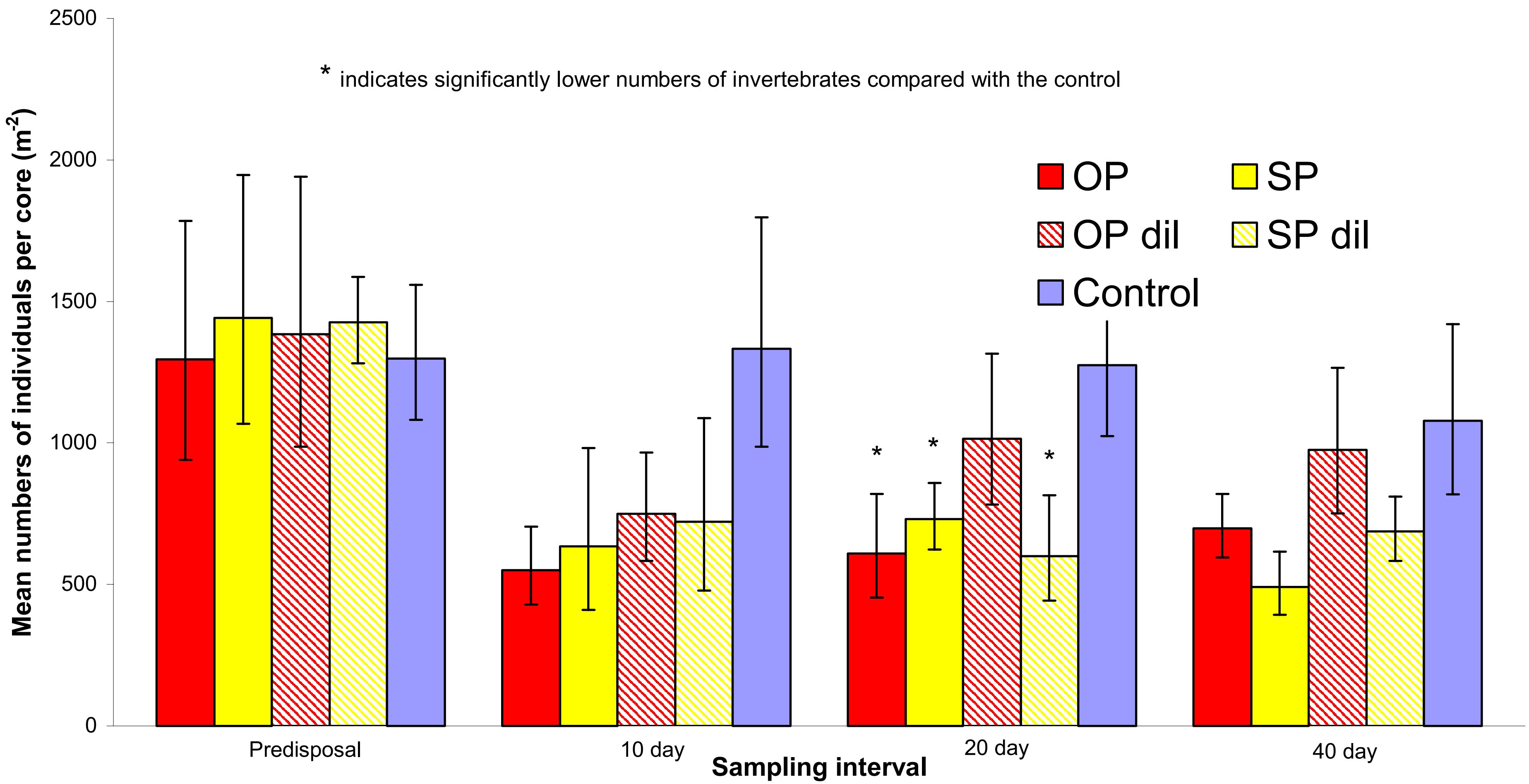


Figure 4.5: Geometric mean numbers, with standard errors, of total invertebrates obtained by soil sampling in Site A at Newton Rigg predisposal and at 10, 20 and 40 day intervals after application, 2002

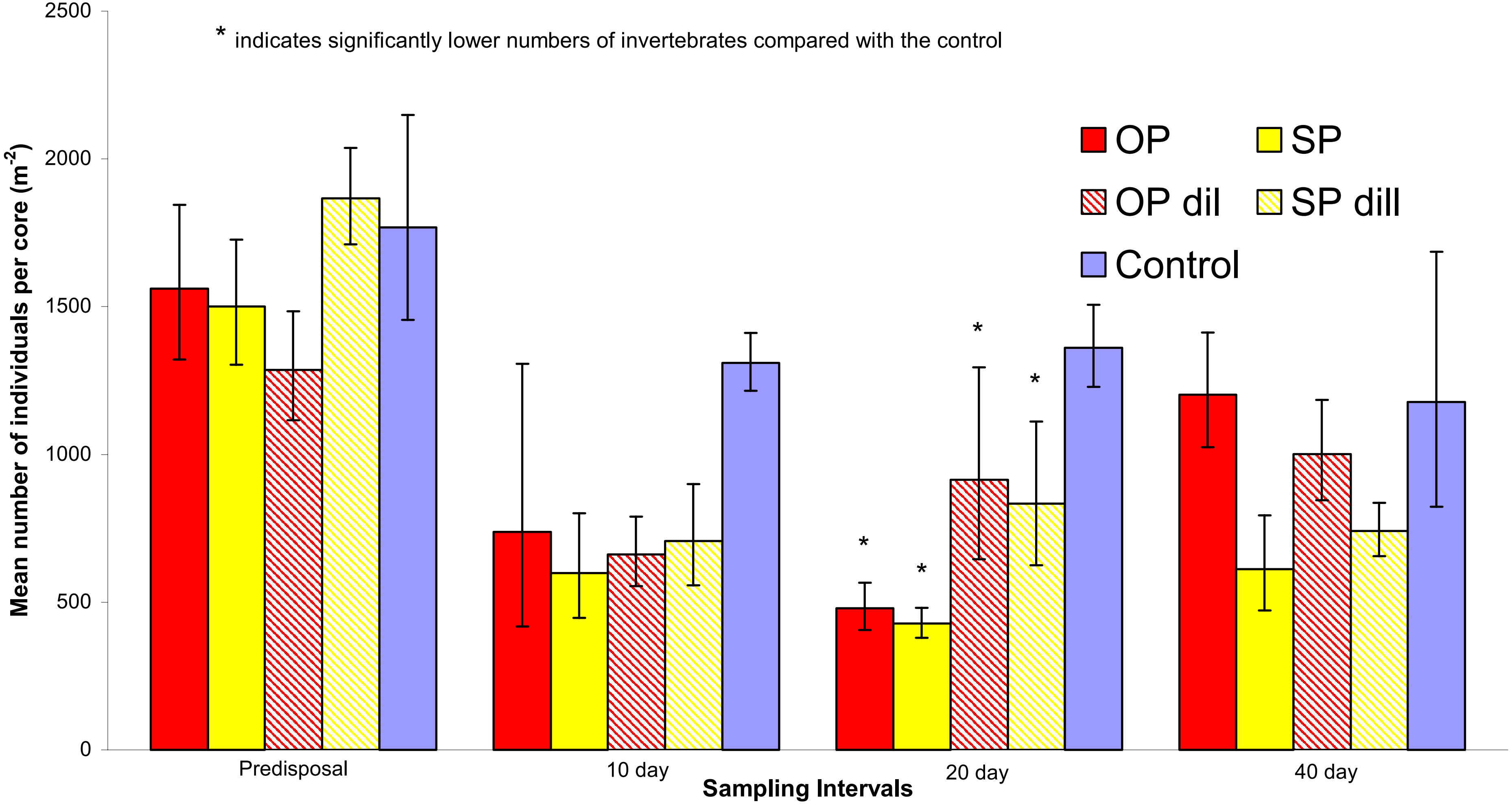


Figure 4.6: Geometric mean numbers, with standard errors, of total invertebrates obtained by soil sampling in Site B at Newton Rigg predisposal and at 10, 20 and 40 day intervals after application, 2002

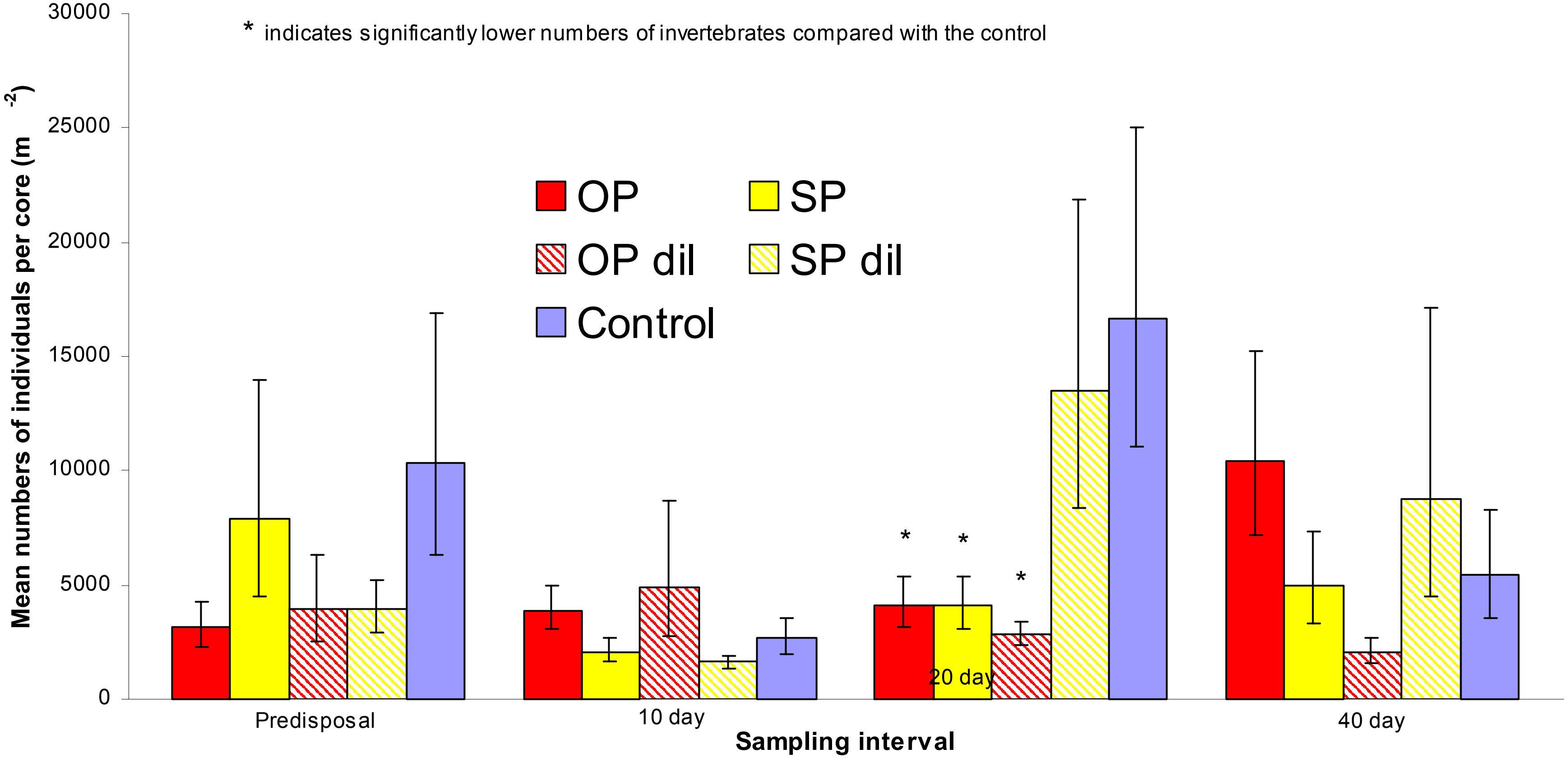


Figure 4.7: Geometric mean numbers, with standard errors, of Collembola obtained by soil sampling in Site B at Newton Rigg predisposal and at 10, 20 and 40 day intervals after application, 2002

4.5 Discussion

All sampling methods used in the Latin Square experiment at Sourhope indicated significant adverse effects of dip disposal on invertebrates. Sampling at Newton Rigg on fertile inby land also indicated a detrimental effect of sheep dip disposal on terrestrial invertebrates. The proportions of invertebrates in each taxon captured at Newton Rigg were differed from those on the rougher grazing land at Sourhope. In particular there were fewer bugs at Newton Rigg, possibly due to the shorter grass in the better quality grazing land providing less suitable habitat for many species. There was also a greater proportion of flies at Newton Rigg, probably due to the increased amount of manure in the more intensively grazed field. However, effects of the disposal of both undiluted dip and dip diluted to recommended specifications were still apparent in both sedentary and active invertebrates. In agreement with the experiment at Sourhope there were differences in intensity of the effects and differences in their timing e.g. there were significantly lower sedentary invertebrate densities on all treated sites compared to the control on Site A after 20 days but by 40 days only the SP treated plot had significantly lower densities. Also, at Site B significantly lower invertebrate densities were found on treated plots after 10 days, whereas these effects were only apparent on total invertebrates and grouped results for active invertebrates from both sites A and B after 20 days (Table 4.2). This is probably due not only to the differing susceptibilities between the taxa (Jepson 1989) but also to differences in exposure to the dip. For instance, sedentary invertebrates would not be expected to be able to escape an area affected by pesticides as fast as active invertebrates. In addition, soil dwelling arthropods may inhabit soil with pesticide residues remaining long after surface residues on vegetation have been washed away by precipitation, particularly since water is the recommended dilutant of both OP and SP based dips. The suction samples at Sourhope consisted largely of arthropods from the vegetation. These would have been directly exposed to the dip and it was not surprising that suction sampling indicated the most severe effects, with major reductions in densities for all insecticide treatments. In an experimental study in which a small carabid *Bembidion lampros* was caged on mature wheat leaves and at the soil surface 24 h after insecticide application, Cilgi, Jepson and Unal (1988) demonstrated much higher mortality on the wheat leaves. The lethal effects also persisted for longer on the vegetation. In the present study the contribution of persistence to the lack of recovery on the treated areas could not be estimated. The majority of arthropods caught by suction sampling were bugs. As these are relatively immobile and many have annual life cycles, recovery after a single, short-lasting lethal event would not be expected within the year. *Pachytomella parallela* adults, which showed reduced densities on the treated areas after 40 days, were most unlikely to have moved onto the plots after the dip application. *P. parallela* was the only mirid adult to be caught at 40 days and unidentified mirid nymphs were significantly depleted on the disposal plots at 10 days. As nymphs, bugs tend to remain on the same plant and even small areas would not be recolonised within a season. The reduction in Hemiptera densities after disposal may be of particular interest since bugs are important chick food for upland waders such as lapwing and redshank (Beintema, A.J. et al, 1991).

The pitfall catches at Sourhope indicated a drop in total numbers on the SP plots at 20 days and lycosid spiders, in particular, were susceptible to SP and not OP. At 40 days, total numbers did not differ significantly from the controls. This is consistent with a lack of persistence in the soil of either insecticide but it could also be explained by the pitfall catches consisting predominantly of active predatory arthropods. These run rapidly over the soil surface, covering considerable distances within a short time (Thiele 1977) and individuals, running into the treated plots from outside would have had little time to be adversely affected. In addition the vegetation coverage, in this type of disposal area with long grasses, may have afforded a considerable degree of protection to soil surface species, at the time of dip application. Elaterid beetles showed longer-term effects and this may reflect their association with the vegetation as well as their susceptibility (Cypermethrin is used to control *Agriotes* spp. (Jepson 1989)). Unlike any of the other groups, the ground beetles were caught in significantly higher numbers on treatment plot (SP dilute) after 40 days. This could be a statistical anomaly but invasive species are likely to colonise pasture following insecticide application (Rushton et al. 1989).

At Newton Rigg the effects on active invertebrates were significant when the results from both Site A and Site B were combined. The ANOVA results did not show significant results individually due to the high standard errors provided by the nature of the active invertebrates. The active invertebrates were comprised mainly of flies. These lay their eggs in clusters, causing group emergence that was seen predominantly in the control plots. The effects are therefore probably due to adults selecting breeding grounds without dip or the dip affecting the eggs/larvae, as seen in the sedentary invertebrate results.

The re-sample at Site A at Newton Rigg in the spring, prior to re-disposal, did not reveal significantly different invertebrate densities. However, at 20 days there were significantly fewer sedentary invertebrates on all of the treated plots when compared to the controls on both Site A and B but by 40 days recovery had occurred on all plot types apart from the undiluted SP on Site A. Despite no significant differences being detected in spring predisposal results for the previously used Site A at Newton Rigg, the soil sampling at Sourhope indicated there were long term effects of SP dip. In the autumn of 1999, although reductions in invertebrate densities occurred on all treated plots, the single significant reduction was in the sedentary invertebrates on the OP plots 10 days after application (Table 4.1). In Spring 2000, however, densities on the SP plots were significantly lower than on the control areas. It is unlikely that this is a statistical anomaly because both SP and SP dilute treatments show depressed numbers whereas densities on the OP plots are both similar to the controls. Additionally, 50 days after treatment application at Newton Rigg, despite repeated heavy rainfall post disposal, there remained a significant effect on numbers of mites on all treated plots obtained by suction sampling at Site A, but not at Site B, which might indicate a cumulative effect of the repeated dip disposal. Mites play a role in the decomposition and recycling of organic material (Pechenik, 1996). If mites feed on material containing pesticide residue it seems realistic that they could be adversely affected for as long as the pesticide remains in the soil and also highlights the possibility that if effects persist after repeated dip disposal, the essential decomposers and smaller organisms within the soil may be affected and eventually the soil itself would be altered. This would then play a more major role in affecting the larger invertebrates, by altering their habitat and removing some small prey items. There were no significant effects on Collembola using suction sampling but this may be due to reduced numbers due to waterlogging of the soil, since Collembola would be adversely affected by soil saturation if the soil pores that they inhabit were filled with water.

Any degree of long-term persistence in Cypermethrin has potentially serious consequences for terrestrial invertebrates, as it is one of the least selective insecticides (Thieling and Croft 1989). Roberts and Standen (1977;1981) revealed that Cypermethrin has half lives in different soils ranging from 1 to 10 weeks but unextractable residues were still found up to 52 weeks after the Cypermethrin was introduced to the soil. If all the dip residue is not removed by the time of the next disposal effects could be expected to be stronger and/or last longer than a single disposal. Such effects may build up over time and produce long-term decreases in the invertebrate populations, such as at the repeatedly used disposal sites of Derwent reservoir, Teesdale 1 and Yorkshire 4 (Chapter 3).

The additional investigation, using small soil cores, showed that both OP and SP based dips adversely affected Collembola but effects were not significant by 40 days after dip disposal. Unfortunately there were too few carabids caught at this site throughout the main investigation to be able to provide any links between Collembola and carabid activity. However, adverse effects on the Collembola could mean carabids may have to look to other sources of food on dip disposal sites or move to other areas.

Collembola and mite densities were investigated, using the additional small soil cores, only on Site B, which had not been treated with dip prior to the spring, so the possibilities of cumulative effects of dip disposal were not investigated in this part of the investigation. Relatively low numbers of Collembola were found on either site, possibly due to the waterlogged nature of the soil throughout the study period. This might have caused densities of Collembola, that usually inhabit soil pores, to be lower than in a drier year. Studies by Frampton (2000, 2001) and Holland et al, 2002 showed long term deleterious effects of pesticide regimes on Collembola if repeated for up to seven years. Since the regulations following the move to dispose of dip onto farmland limit farmers to specific areas for disposal, it is realistic to suppose certain areas will be used repeatedly over many years and this could have long term effects both on the Collembola populations and on the larger invertebrates that feed on them. Mites were also found to be adversely affected by the disposal of sheep dip using this sampling method at 10 and 20 days but showed recovery by 40 days.

The Latin Square Experiments at Sourhope and Newton Rigg both showed significant depletions of invertebrate populations post dip disposal and showed recovery in both surface active and soil invertebrates by 40 days. Although it might be expected that recolonisation would be more rapid on the smaller plots used at Newton Rigg there was no difference in recolonisation apparent between Sourhope and Newton Rigg during this study. However, at field scale (Chapter 3) multivariate analysis indicated that carabids at least were affected up to six months after dip application. The bugs at Sourhope did not recover or recolonise after exposure to dip because they are relatively immobile and have a yearly life cycle. Active invertebrates such as adult beetles and spiders often have a longer life cycle and can move over the surface faster than sedentary invertebrates such as beetle and fly larvae can move through the soil. Active populations would therefore be expected to recolonise more efficiently than sedentary invertebrates at a field scale. However, by 40 days the sedentary invertebrate population is likely to have been increased by active invertebrates such as adult diptera flying on to a disposal site some time after disposal but unable to detect the dip. They lay eggs that could hatch successfully if enough time had elapsed post disposal and by 40 days would be counted as larvae. It is therefore difficult to determine from the Latin Square investigations whether recovery or recolonisation is responsible at this scale.

Both closer cropped inby land and areas of rougher grazing land are used by wading birds for nesting and feeding (Appendix 6). The experiments detailed in this report have shown affects on a variety of land-use types and a variety of different invertebrates that are either prey items for wading birds or often prey items for the larger invertebrates, which are then taken by the birds. The apparent adverse effects of sheep dip on mites also indicates a possibility of disruption of important soil processes in disposal areas that, if allowed to persist by repeated dip disposal, could alter the soil fauna over a number of years.

5. EXPERIMENTAL EXPOSURE OF TIPULID LARVAE TO DIP APPLICATION

5.1 Introduction

The length of time that the dip remains toxic is an important factor in the assessment of detrimental effects of disposal on upland farms. There is evidence that arthropods exposed on plants to pyrethroid application are more at risk than species at ground level (Brown et al 1988) but it is not clear how much of this difference can be attributed to the greater exposure on the plant and how much to inactivation at the soil surface. *Bembidion lampros* exposed at the soil surface three days after Deltamethrin application and six days after Dimethoate application experienced no mortality Cilgi et al. (1988). However, there is evidence that Cypermethrin is more persistent, remaining detectable in the soil as long as seven months after application to control spruce bark beetles (Class 1992).

Tipulid larvae are an important component in the diet of both adults and chicks of wading birds on upland pastures (Baines 1990, Galbraith et al.1993, Whittingham et al. 2001) and these were used in a small preliminary trial on the toxicity and persistence of Diazinon and Cypermethrin applied to soil. The evidence of OP and SP toxicity to tipulids from the historic disposal sites on the farms was not clear. Yorkshire 4 and Teesdale 1 (in 1999), which received multiple applications of dip, showed significant reductions in tipulid larval densities on disposal areas but Teesdale 2, where the disposal area had a high organic content, and Yorkshire 2 had higher densities on disposal sites, compared with control areas. The present trial was designed to investigate whether dip applied to the soil and surface vegetation was toxic to larvae and to determine how long the effect persisted. The trial was not part of the original research contract but is reported here as relevant to the interpretation of the field study.

5.2 Methods

The main constraint on this toxicity trial was the sampling and extraction time required to collect an adequate supply of *Tipula subnodicornis* larvae from the field. Seventy larvae only were collected. Because there was no background knowledge of the length of time Diazinon or Cypermethrin might remain toxic to tipulids, it was decided to use these larvae to establish the appropriate time span for a study of persistent effects. In each trial six replicates only were used. This did not allow reliable LD_{50} estimates to be made but it did allow the larvae to be exposed to dip at a series of five time intervals from initial application.

Twelve cultures of leafy liverworts (Butterfield 1976), in ericaceous compost were set up in 10 cm diameter plastic plant pots on 13 July and 42 cultures on 31 October. Diazinon and Cypermethrin were applied to six pots each on 13 July and to 18 pots each on 31 October. Each pot received 100 ml of sheep dip applied at the disposal dilution for made up dip, equivalent to the full strength application at Sourhope. Six control cultures without dip application were also set up on 31 October and received 100 ml of water.

One *Tipula subnodicornis* larva was introduced to each of six Diazinon, six Cypermethrin and six control cultures on 31 October (day 0 after application). The top of each plant pot was covered by polythene secured with an elastic band and the pots were placed in plant trays outside. Six further Diazinon and Cypermethrin cultures set up on 31 October received a larva each on 1 November (day 1 after application) and on 7 November (day 8 after application). On 9 November, some of the larvae were not found in the cultures, so compost and liverworts were transferred from each of six Cypermethrin, six Diazinon and six control pots set up on 31 October to 50 ml screw-top vials. On 16 November (day 17 after application), one larva was placed in each vial. On 25 November (19 weeks after application) compost and liverworts were transferred to vials from the six Diazinon and Cypermethrin pots set up in July and one larva placed in each vial.

5.3 Results

Table 5.1: Percentage mortality of *Tipula subnodicornis* larvae exposed to Diazinon and Cypermethrin (at standard dip dilution) at different time periods after application. Probabilities in brackets represent comparisons between treatment and control based on Fisher's Exact Test.

Days after application	% mortality in treatment: Cypermethrin	Diazinon	Control
0	100 (p=0.005)	100 (p=0.005)	0
1	100 (p=0.005)	100 (p=0.005)	0
8	67* (p=0.05)	83* (p=0.01)	0
17	50 n.s.	83 (p=0.01)	0
133	33 n.s.	67 n.s.	0

* One larva not found

Tipulid larvae which were exposed on the day of application, or the day after, to either Diazinon or Cypermethrin, all died within two days (Table 5.1). There was no mortality in the controls (for each of the four comparisons with the controls p = 0.005, Fisher Exact Test). When larvae were introduced eight days after the dip application, mortality was not instantaneous in most cases and the disappearance of six of the larvae from the cultures indicated an active response in some individuals. All but one of the missing larvae in each set of dip cultures were found dead in the tray containing the plant pots, seven days after the larvae were introduced. One larva survived 14 days in the Cypermethrin cultures but no larvae survived in Diazinon, giving significant differences from the controls in both cases (p = 0.05 and p = 0.01 respectively, Fisher Exact Test). Larvae introduced to the cultures 17 days after application of Diazinon suffered significant mortality (p = 0.01, Fisher Exact Test) but not 17 days after the application of Cypermethrin. Even after 133 days, the cultures where dip had been applied appeared to retain some toxicity with four larvae dying in the Diazinon culture and two in Cypermethrin over a two week period (pooling dip cultures (N =12) and comparing with the six controls, p <0.05, Fisher Exact Test). The surviving larvae, and those remaining from the cultures set up on 16 November, were all alive 41 days later on 5 January 2001 but, in comparison with the six control larvae, the three larvae in the Diazinon cultures were unresponsive and thin with no fat reserves.

5.4 Discussion

These toxicity trials were carried out on small numbers of larvae and obviously need to be verified by being repeated on a larger scale and under experimental conditions that are more closely equivalent to the natural situation. In particular, the experiment should be repeated using larvae that have been allowed to establish themselves in burrows in grass turves before the insecticide application is made. It was not anticipated that larvae would escape from flowerpots, as the negatively phototactic, third instar larvae of *Tipula paludosa* can be reared in open boxes (Szewczyk and Langenbrush 1997). The small containers used for the 17 and 133 day trials did not have drainage holes and this may have contributed to the maintenance of high toxicity levels in the compost. Despite these reservations, the results suggest that both dips may remain toxic to soil invertebrates over longer periods than anticipated (Cilgi, Jepson and Unal 1988). The apparent lingering toxicity of Diazinon 19 weeks after application is particularly surprising and needs to be verified under more rigorous conditions. The mini-trial also suggested that the tipulids might have been behaving atypically after receiving the dip application, coming to the surface and moving out of the plant pots, before dying. Under field conditions, and if birds are present on the pastures, surface activity of dying tipulids could lead to contaminated individuals being eaten. The present study was not concerned with the direct effects of insecticide-contaminated prey poisoning birds. However, a decrease of 64% in cholinesterase activity was observed in shrews when they were fed earthworms which had been released into dimethoate treated soil (ChE activity in the worms was depressed by 90%), one day after application (Dell'Omo et al. 1999). The possibility of behavioural changes, following dip application, that make the invertebrate prey more attractive to birds needs further investigation.

6. GENERAL DISCUSSION

This study has shown significant reductions in the densities of both active and sedentary soil invertebrates on areas where sheep dip disposal has taken place, with the greatest reductions on areas that have been exposed to multiple disposals over a number of years. Although density decreases occurred as an immediate response to disposal, in some cases numbers of soil invertebrates remained lower on the disposal site than on the control area six months after the dip application. This suggests persistence of toxic effects or slow rates of re-colonisation by even relatively active species. Analysis of the species composition of samples taken from the Latin Square Experiment at Sourhope, 2000-2001, and of pitfall catches on the farm sites, indicated that the susceptibility of the invertebrates exposed to dip varied, both between major taxa and at the species level.

Although the broad conclusions above are probably justified, many problems were encountered in attempting to quantify the effects of dip disposal. In some cases the same problems have been found in other studies on the effects of insecticides on non-target organisms. At a farm scale, other studies have found that the detection of the effects of insecticide application depended on the size of plot studied. Plots smaller than 2 ha (larger than some of the disposal areas used in this study) were rapidly re-colonised by ground beetles and no effects of insecticide application could be detected in pitfall catches (Jepson 1989). On 2 ha plots decreases in densities, after Dimethoate application, were detected up to seven days only (Fischer and Chambon 1987). In the present study, sampling was delayed for at least 10 days after application in order to decrease risk to the investigator and, although this would depend on persistence, initial concentration of dip and susceptibility of different organisms, the evidence from Jepson's (1989) study suggests that this would allow time for reinvasion of the areas by mobile organisms. When pitfall catches were made on the farms in spring in the present study, one site only had received dip in the same year (and showed a significant decrease in density of invertebrates after dip disposal), the others had had no dip disposed since the previous autumn. The detection of adverse effects at the community level in pitfall catches of ground beetles, but not spiders, may reflect the capacity for rapid re-colonisation by the spiders (Wise 1993). Re-colonisation by the soil fauna as a whole may account for the apparent lack of significant effects in soil samples at some of the sites in spring 2000. However, soil samples were taken on all sites (except Wales 1) within 10 – 21 days of application in 1999, and here sedentary organisms would be expected to show reduced densities in response to dip application. Of the six sites where there had been autumn disposal, four had lower densities of either active or inactive invertebrates (both categories at Derwent) on the disposal area. At one site the differences between the two areas were not significant and at Teesdale 2 the numbers of sedentary invertebrates were higher on the disposal area. This last result does not imply a positive response to dip application, as densities could have been much higher on the disposal area before the dip was applied (as on Teesdale 1A in 2000), but it does highlight the problems of using paired samples when distributions are unlikely to be uniform (Southwood and Henderson, 2000).

Where sites had received multiple disposals or been in use for many years (Derwent and Yorkshire 4), the results were clear-cut, with marked reductions in densities of both sedentary and active soil organisms present in the spring six months after the last disposal. This is evidence indicating a long-term effect and Jepson (1989) speculated that this might be experienced by predatory arthropods if their food supply had been diminished by previous insecticide applications. Lowering of springtail densities after insecticide application (Frampton 1988) could adversely affect densities of the many ground beetles that prey on them, in particular the members of the *Leistus* and *Notiophilus* genera which are Collembola specialists (Hengeveld 1980).

From the point of view of upland wader populations, the distinction between long and short-term effects is important. The Latin Square Experiments demonstrated the lethal effects of both Diazinon and Cypermethrin to the arthropods exposed on the vegetation and at the soil surface. In the first few days after hatching, the chicks of waders are restricted in their movements and dependent on surface-active arthropods (Baines 1990, Whittingham et al. 2001). Dip should not be disposed during the period when young chicks are present as there are possible risks of both direct and indirect effects. The Farm Questionnaire revealed that by far the greatest proportion of the disposal areas were on rough pasture and, as this is favoured nesting habitat for many wader species (Stillman and Brown 1998) it is particularly important to avoid spring disposal on these fields.

The absence of detectable effects on earthworms populations in this work is supported by other studies (O'Halloran et al., 1999, for organophosphate based pesticide; Edwards and Brown, 1982, for synthetic pyrethroid studies). Despite evidence from laboratory studies showing reduced cholinesterase activity as a response to OP, no sublethal effects were detected in natural worm populations (Booth et al. 2000). The earthworm component of the diet of adult lapwing in early spring is unlikely to be adversely affected by the previous autumn's dip disposal. However, both lapwing and oystercatcher also feed to a large extent on leatherjackets (Baines 1980, Zwarts and Blomert 1996). *Tipula paludosa*, the dominant pasture species, is present in the early instars through autumn into winter and will be vulnerable to autumn dip disposal as found in the tipulid experiment (Chapter 5). Unfortunately, tipulid numbers were too low on the Latin Square Experimental sites to provide meaningful results for this group. In a laboratory trial on the dominant upland peat species *T. subnodicornis* this leatherjacket showed high mortality on exposure to both Diazinon and Cypermethrin. The effects persisted for some time, with Diazinon causing significant mortality 17 days after application and an indication of sublethal toxicity lasting even longer. The laboratory experiment was subject to a number of problems and far removed from a realistic field trial. Whether tipulid species below the soil surface receive a lethal dosage from disposal in the field situation needs to be determined. However, the OP Chlorpyriphos is used as a spray for leatherjacket control (Hill 1987) and there is no reason why the sheep dip application should be less efficient at soil penetration. Moreover the persistence of Diazinon is similar to Chlorpyrifos, with 50% remaining in non-sterile organic soil at 2 weeks and 2.5 weeks respectively (Verschueren 1996). It has already been suggested that dip disposal should not be made onto rough pasture where waders are nesting in spring, both because the invertebrates may be toxic and because the reduction in prey availability could be detrimental to the wader chicks. There are also grounds for suggesting that autumn disposal should not be made on improved ground where, typically, the larval densities of *T. paludosa* are higher than on the rough pasture. As *T. paludosa* has an annual life cycle there is no possibility of populations recovering before early spring, when large flocks of lapwing feed on improved pasture before dispersing to breed (Baines 1990). However, long-term disposal onto breeding areas, whether in autumn or spring is probably the most damaging option. The earthworms on the improved pasture provide an important component of the diet in early spring and their densities are not affected by disposal. However, arthropods assume much greater importance on the rough pasture. Although the persistence of both Diazinon and Cypermethrin is low and many active species can re-colonise disposal areas, the densities of sedentary species in direct contact with the dip will be reduced. As this has the potential to reduce predator populations (Jepson 1989), it is likely that the arthropod fauna as a whole will be affected, with a consequent reduction in food availability for birds.

6.1 Conclusions

Conclusions based on the findings of the investigation into the effects of sheep dip disposal on non-target invertebrates are listed below:

- Decreases in invertebrate population densities resulting from sheep dip disposal have been demonstrated both on farm sites (Chapter 3) and on the Latin Square experimental site (Chapter 4).
- Detrimental effects appear to be more long term on sites that have received multiple applications, with some sites showing significant reductions in invertebrate populations six months after disposal (Chapter 3).
- Earthworm densities do not appear to be adversely affected by current dip disposal practice
- Re-colonisation by active invertebrates could have occurred prior to the sampling at 10 days on any site, which could lessen the apparent significance of any detrimental effects of dip disposal on this group.
- Detrimental effects of dip disposal may have consequences for wading birds, shown to be using the disposal sites (Chapter 3), particularly for relatively immobile young chicks.

7. RISK ASSESSMENT

7.1 Introduction

Risk assessment of current dip disposal practice is necessary to aid best practice recommendations and is particularly important in assessing applications for authorisations to dispose on land in or adjacent to protected areas such as SSSIs and SPAs. Risk assessment must include both short and long term risks, direct and indirect effects of dip disposal onto farmland and take into account the very variable nature of current dip disposal practice as highlighted in the farm questionnaires (Chapter 2). Where possible the risk assessment should include information regarding not only the potential hazards to the terrestrial invertebrates themselves but also the possible resultant effects on the upland bird populations that feed upon them.

Short term effects are those that occur during any initial depletion of insect populations following disposal (Jepson, 1989) and are mainly due to direct toxicity of the dip. Recovery is usually apparent by the following season in relatively short term studies of effects of insecticides e.g. organophosphates (Vickerman and Sunderland, 1977) and pyrethroids (Cole and Wilkinson, 1985; Shires, 1985) but these do not determine whether recovery is due to recruitment from reproduction or recolonisation from adjacent untreated areas, which is important if insecticide application is widespread (Jepson, 1989).

Long-term risks arise as a result of repeated applications of short-persistence chemicals impeding any recovery that may occur after a single application, or a single application where recolonisation from adjacent land is poor (Burn, 1989). Delayed effects may occur in predatory species due to sublethal effects of the dip that may cause a reduction in activity, feeding (stimulus or capability) and consequently fecundity (Jepson, (1989). Direct effects resulting in depletion of populations of prey species, such as Collembola, may also cause indirect effects of dip disposal for predator species e.g. Carabidae. These indirect effects may be most apparent in subsequent seasons and are important but difficult to assess in longer term risk.

The potential risks of current dip disposal practices have been highlighted both in field tests on farms and in experimental trials. Indications that there were possible short and long term effects of disposal of both SP and OP dips were apparent from the historic farm site investigations (Chapter 3) where there were significant differences between control and disposal plots on some farms both in the same season as disposal and six months later. This was most apparent on sites that had been used as dip disposal sites repeatedly over previous years, such as Derwent, Teesdale 1 and Yorkshire 4. The bird observations in this study also provided confirmation that birds were feeding and nesting in fields that had been used for dip disposal. Some of these fields had significantly depleted invertebrate populations and therefore provided diminished invertebrate prey availability. The Latin Square experiments (Chapter 4), on areas that had not previously been used for dip disposal, also showed short term effects of both dip types at different known concentrations. There were also indications of longer term effects e.g. the SP treated plots did not show complete recovery of the invertebrate community after six months on the rough pasture at Sourhope.

The purpose of this risk assessment is to provide an overall evaluation of the impact of sheep dip disposal on terrestrial invertebrate populations and an assessment of the consequences for the birds, which use the invertebrates as a food source. The birds most relevant to this study are Curlew, Lapwing, Redshank, Snipe and Golden Plover as these are the wading birds that many upland SSSIs are designed to protect and would most likely be affected by the dip disposal process.

The basic estimates of risk are intended to be applicable over any area and subsequently used in conjunction with any specific relevant information available about the area. A worst case scenario can then be used to aid realistic best practice recommendations, assisting the assessment of applications for authorisation to dispose on land in or adjacent to SSSIs and SPAs. This risk assessment aims to include both long and short term risk, direct and indirect effects of dip disposal onto farmland. It must also take into account the variable nature of current dip disposal practice, as highlighted in the farm questionnaires (Chapter 2).

Adult birds can travel over great distances to feed and are therefore unlikely to be affected by a drop in invertebrate prey on the relatively small areas used for sheep dip disposal. Chicks, however, are more restricted in their movement and lapwing chicks have been reported to stay around the nest until the entire brood has hatched and often for the first day (Cramp, 1983). Chicks are therefore more likely to be affected by areas of depletion in prey availability and are the main focus for this risk assessment.

Detailed quantitative information about wading bird diets was sparse for chick diets compared to adult birds. However, it is generally accepted that chick diets are very similar to the adult diets, restricted only by the shorter bill length in the very young birds which allows for shallower probing in search of soil invertebrates. For example, young Lapwing chicks feed almost exclusively on surface active invertebrates, particularly carabid beetles (Baines, 1990). In addition, little conclusive work was available about the proportions of each invertebrate species that made up an average bird diet. Birds are opportunistic feeders and capitalise on the most abundant or accessible suitable prey in an area. A calculation of the overall biomass required is therefore the most important factor in terms of bird feeding requirements.

The risk assessment will comprise the following steps:

- Determine the different invertebrate taxa that comprise the diet of both adult wading birds and their chicks
- Calculate the reduction in biomass from experimental disposal areas when compared with controls
- Determine the size of disposal area (where reduction in invertebrate biomass has occurred as a consequence of dip disposal), which would adversely affect the wading birds as either chicks or adults.

7.2 Methods

7.2.1 Invertebrate bird food requirements

Information about the different invertebrate taxa that comprise the bird's diets for both adults and chicks was obtained by reviewing available literature. The result of this work is shown in Appendix 7.

7.2.2 Change in available biomass following sheep dip disposal

The overall change in available invertebrate biomass following sheep dip disposal was calculated using the invertebrate samples from rough grazing land from the first experimental farm site on rough grazing land at Sourhope. The invertebrates that had been extracted from all soil samples from predisposal and 10, 20 and 40 days and suction sampling at 10 and 40 days after disposal were dried to a constant weight at 70^{o}C. Dried samples were weighed using a balance accurate to three decimal places. An arithmetic mean of the results from each treatment type was calculated for each sampling occasion. The percentage change in biomass between predisposal sampling and 40 day sampling was calculated for each treatment type. Undiluted OP treated plots had decreased in available invertebrate biomass by 63%, undiluted SP had increased by 6%, dilute OP had increased by 6% and dilute SP had decreased by 12% between predisposal and 40 days. The biomass on the control plots increased by an average of 143%, which would be expected on untreated plots during this time. This data was then used in a calculation to determine the number of chicks treated areas can sustain.

An average of the predisposal biomass (0.9g/m^2) based on the invertebrate standing crop was used as a starting point. This was converted into energy using a conversion rate of 1g biomass to 25 KJ of usable energy to give initial energy (K). This conversion was an average of the KJ value per g of several important invertebrate species including tipulid larvae, Coleoptera spp, ants and Diptera spp.

The total energy available following the application of each different treatment type is KX, where X is the estimated change in biomass (X_{SP}, X_{OP}, X_{SPdil}, X_{OPdil}, $X_{control}$). KX values were calculated per hectare and represent a standing crop. A factor F indicates the percentage of invertebrates expected to be available to the chicks, i.e. on or close to the soil surface or vegetation. This was determined using the results of the soil and suction sampling at Sourhope in Phase 1. The proportion of surface invertebrates was calculated to be 44% of the total available invertebrates. Therefore we assume that KXF is the total energy from invertebrate material available to the chicks.

7.2.3 Distances travelled by broods to fulfil energy requirements

Detailed information about chick movement and energy requirements is incomplete for all the species in the study. However, the information for all the species was amalgamated to create an effective overall estimation.

Work on curlew chicks (Grant, unpublished) found that for broods studied to at least 22 days of age the mean maximum distances broods were recorded from their nests was approximately 197m. Other work supports this figure (Cramp, 1983) suggesting curlew chicks usually remain within 200m of the nest until fledging at four to five weeks. Lapwing chicks may move between 50 and 150m from the nest after the first week and up to 250m in the second week, but they have been found to remain close to the nest in the early days (Cramp, 1983). Smaller, younger chicks need to return to the nest more often and can move shorter distances than older chicks, which may not need to return to the nest at all. A linear relationship between distance travelled and time was assumed as a suitable means of breaking this information down. The distance of 197m (giving a maximum area coverable of approximately 120,000m^2) was therefore divided by 22 days to give a daily increase in possible distance moved from the nest. The maximum area within the range of the daily possible distance travelled was then calculated. It is assumed that the entire range over which the chicks can move is affected by sheep dip disposal to the same degree and they are not feeding on untreated land at any time.

7.2.4 Realistic foraging area within the range of the chicks

Chicks do not realistically feed over the entire area within the potential range, making repeated forays from the nest in search of food rather than searching over the whole area. Radio-tracking of 22 broods of Golden Plover (Whittingham, 2001) revealed an average of 0.157% of the potential home range was used for foraging (Whittingham, unpublished data, Appendix 8). KXF was multiplied by the calculated usable area in hectares (A) by the chicks to give a value of the estimated possible energy from invertebrate prey items available to the chicks of varying age and mass.

7.2.5 Calculation of daily energy requirements of the chicks

The daily energy requirements of chicks were calculated based on work by Schekkerman and Visser, 2001 on Lapwing chicks. The daily metabolised energy is proportional to the size of the chick and is calculated using the following equation:

$$ME = 4.365 \times M^{0.911}$$

where ME is Metabolised Energy and M is the mass of the chick

Assuming that the chick has an approximate starting mass of 20g upon hatching (Schekkerman and Visser, 2001 for Lapwing; Pearce-Higgins and Yalden, 2002 for Golden Plover), a mean increase of 5g per day was added using the average daily growth rate of lapwing chicks from Schekkerman and Visser, 2001 and assuming a linear relationship, which has been found to occur between at least five and thirty days (Baines, 1990). Lapwing chicks fledge at 70-80% of adult mass (Beintema and Visser, 1989a). The value of 202g for adult mass was taken from Schekkerman and Visser, 2001, giving an 80% fledging mass of 160g, after which point it can be assumed that the chicks are highly mobile and can move out of dip disposal areas for more abundant invertebrate supplies if necessary.

7.2.6 Extrapolation of calorific requirements of chicks in relation to availability on disposal areas

By dividing the possible available energy from the invertebrate food source by the metabolised energy a value for the number of chicks that can be supported with increasing age, mass of chick and mobility.

The complete calculation is therefore:

Where:
N is the number of chicks of a certain age and mass that can be supported on disposal land.
KXF is the total energy from invertebrate material available to the chicks.
A is the area the chick could use for feeding
ME is metabolised energy requirements of each chick

Using this equation, given a starting biomass and depletion rate for dip type applied, it is possible to calculate either the critical disposal area that may cause problems for young chicks or the size of chick that would cope with depletion give proposed affected area (see case studies).

An average clutch size for Lapwing chicks is 3 to 4 (Baines, 1988). Therefore, for the above calculation, if the area was found to be able to support less than 3 chicks it can be assumed that chicks may not have the optimum invertebrate food intake and fitness may suffer.

This model does not take into account any improved efficiency of feeding that may occur with age such as bill length increase that may allow probing for soil invertebrates at greater depths.

7.2.7 Summary of Assumptions

The above model uses the following assumptions:

- The nest, containing a clutch size of 3 to 4 chicks, is situated in a large disposal area. The chicks cannot move far enough at any stage prior to fledging to forage for invertebrates on untreated land.
- Total energy available is calculated using invertebrate data from the treated plots on rough grazing land at Sourhope and represents a standing crop, with the biomass remaining static over time. Total energy available might also be expected to differ depending on quality and type of land but this is not currently featured into the model. Different data could be input into the model for specific case studies wherever it is available.
- A linear relationship is assumed between age of chick and distance it can travel each day.
- 0.157% of the potential home range is used by chicks for foraging (Whittingham, unpublished, Appendix 8)
- Each chick has an approximate starting mass of 20g upon hatching and gains 5g per day. Energy requirements increase with mass.
- The model does not take into account competition between chicks or between adults and chicks and assumes no overlap in foraging.
- This model does not take into account any improved efficiency of feeding that may occur with age.

7.3 Results

The calculations refer only to the wader chicks as it is assumed the adult birds would be able to forage over such a large area that indirect effects of dip disposal by invertebrate prey depletion would be negligible. Figure 7.1 shows the number of chicks each treated area can sustain as the mobility, mass and energy requirements of the chicks increases with time. Appendix 9 shows the complete results of the numbers of chicks that can be supported at different mass/age on different treated areas. The control area, treated only with water, is the only treatment that could sustain 3 chicks for the first day, when a chick can cover an area of approximately 0.001ha, meaning it could probably support an average brood. By three days, the SP, SPdil, and OPdil treated areas could all support more than a single brood of chicks given the rapidly increasing mobility of the chicks and distance they can move from the nest. The OP treated site could not sustain a full brood until day four or five and this could therefore be expected to have the most deleterious impact on chick fitness and brood success.

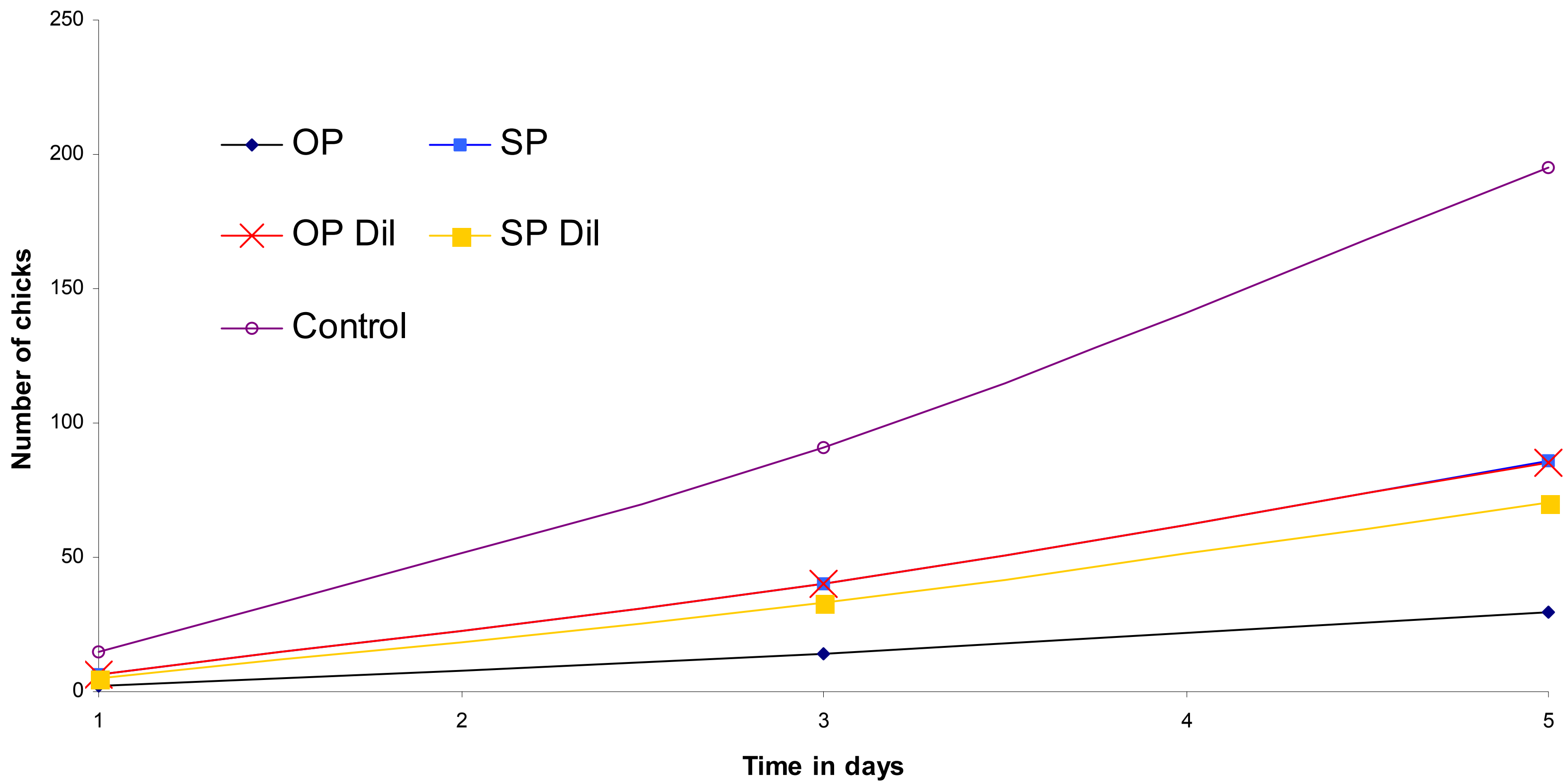


Figure 7.1: Number of chicks treated areas can sustain as the chicks develop over time, with increasing size and energy requirements, following a spring application of sheep dip to farmland

Table 7.1 is a summary of the results at three different stages for each treatment type. This includes the mass of chick, energy and equivalent invertebrate biomass requirements, distance the chick can travel, productivity of the land with different treatment types and the area the chick would need to cover to obtain the energy requirements from each treatment type. The results show the lowest productivity is in the OP treated area at 3.8KJ/m^2 and the control, treated only with water has the highest productivity at 24.8KJ/m^2. The information given is for a single chick so does not take into account competition from other chicks in a brood or the requirements of the adult birds.

Table 7.1: A summary of chick abilities, requirements and treated land productivity in terms of invertebrate food resources

Treatment Type	Age (days)	Mass (g)	ME (KJ)	Available Biomass (g/m^2)	Productivity (KJ/m^2)	Required Area (m^2)	Distance (m)	Possible Area (m^2)	No. of Chicks
OP	1	20	66.9	0.34	3.8	17.6	9.0	39.5	2
	3	30	96.7	0.34	3.8	25.5	26.9	355.8	14
	5	40	125.7	0.34	3.8	33.1	44.8	988.2	30
SP	1	20	66.9	0.97	10.9	6.1	9.0	39.5	6
	3	30	96.7	0.97	10.9	8.9	26.9	355.8	40
	5	40	125.7	0.97	10.9	11.5	44.8	988.2	86
OP dil	1	20	66.9	0.97	10.8	6.2	9.0	39.5	6
	3	30	96.7	0.97	10.8	8.9	26.9	355.8	40
	5	40	125.7	0.97	10.8	11.6	44.8	988.2	85
SP dil	1	20	66.9	0.80	8.9	7.5	9.0	39.5	5
	3	30	96.7	0.80	8.9	10.9	26.9	355.8	33
	5	40	125.7	0.80	8.9	14.1	44.8	988.2	70
Water	1	20	66.9	2.21	24.8	2.7	9.0	39.5	15
	3	30	96.7	2.21	24.8	3.9	26.9	355.8	91
	5	40	125.7	2.21	24.8	5.1	44.8	988.2	195

Age is the age of chick in days from hatching
Mass is the mass of the chick
ME is the energy the chick of a corresponding mass requires per day
Available Biomass is the average invertebrate biomass available per m^2 between disposal and 40 days
Productivity is the energy available in invertebrate matter in the treated areas
Required Area is the area a chick would need to occupy to get enough invertebrate food material
Distance is the distance a chick can move from the nest at a corresponding age and mass
Possible Area is the area a chick can forage over at the given age and mass, e.g. 0.157 of potential area
No. of Chicks is the number of chicks that can be supported for the given age and treatment type

7.4 Application of Results to Case Studies

Background information for case studies A and B, detailed below, was provided by the EA in September 2002. Maps of the areas, with the SPAs and buffer zone marked, are included in Appendix 10. The buffer zone is added to account for birds nesting in the SPA that may travel considerable distances to feed.

Case Study A - North Pennine Moors SPA

- Eight authorisations for dip disposal within SPA
- 62 authorisations for dip disposal within 1km SPA
- Area of SPA = 30810 hectares
- Area of 1km buffer = 22980 ha
- Area of buffer + SPA = 53790 ha
- Average dip area = 2.7ha

- Area of farmland that could receive dip within SPA is 21.6 ha
- Area of farmland that could receive dip within 1km buffer is 167.4 ha
- Area of farmland that could receive dip within SPA plus buffer is 189 ha
- Percentage of total area that could be used for dip disposal is 0.351 %

The above calculation assumes a worst case scenario that the entire area authorised for disposal will be utilised. Using the risk assessment equation: $\frac{KXFA}{ME} = N$ it can be established that a chick would have to be approximately 10 days old (approx.65g) to leave the disposal area if the nest is situated in the middle of the 2.7ha area, which means depending on the type and dilution of the dip applied it may not be able to move far enough at a younger age to obtain an optimum amount of invertebrates.

Case Study B - Elenydd-Mallaen SPA, Wales

- Eight authorisations for dip disposal within SPA
- 33 authorisations for dip disposal within 1km SPA
- Area of SPA = 30020 hectares
- Area of Buffer + SPA = 52170 ha
- Area of 1km buffer = 22150 ha
- Average dip area = 4.3ha

- Area of farmland that could receive dip within SPA is 34.4 ha
- Area of farmland that could receive dip within 1km buffer is 141.9 ha
- Area of farmland that could receive dip within SPA plus buffer is 176.3 ha
- Percentage of total area that could be used for dip disposal is 0.338 %

The above calculation assumes a worst case scenario that the entire area authorised for disposal will be utilised. Using the risk assessment equation: $\frac{KXFA}{ME} = N$ it can be established that a chick would have to be approximately 13 days old (approx. 80g) to leave the disposal area if the nest is situated in the middle of the 4.3ha area, which means depending on the type and dilution of the dip applied it may not be able to move far enough at a younger age to obtain an optimum amount of invertebrates.

The above details a worst case scenario with the entire dip disposal area being used each time. This may not be the case as a typical residual volume of dip for disposal is approximately 1200 litres. With fourfold dilution and disposal via a vacuum tanker this may only cover 0.25 ha, which would result, for example, in only 17.5 ha out of the 53790 ha that makes up the SPA plus buffer zone for case study A being affected. This is less than 10% of the possible disposal area and can be taken as a best case scenario. The nest may also not be central in the disposal area, leading to faster possible escape to areas that may support a greater invertebrate population.

The position of the disposal sites in relation to each other is also important. The maps (Appendix 10) show that sites are not adjacent to each other on either of the case study SPAs. This increases the chance of birds being able to leave a disposal area, if it has a depleted invertebrate population, and fulfil their dietary requirements elsewhere.

7.5 Discussion

The risk assessment has shown that young chicks, in an average brood of three, between one and three days from hatching might have difficulty in feeding over a large enough area to fulfil their daily metabolic energy requirements if their nests are within an area treated with OP based dips even if the dips are diluted to recommended levels (3 parts water to one part made-up dip). Although the disposal of undiluted sheep dip is a situation that should be avoided if EA recommendations are adhered to, it was apparent from answers to the questionnaires in Chapter 2 that dilution rates are not always accurately measured and can be greater or less than recommended levels depending on the disposal equipment a farmer has access to and the amount of dip to dispose of.

Although the results show that an average brood of three chicks might be able to collect enough food on any treatment site after the first few days from hatching, this does not take into account added pressure from the adult birds, any overlapping feeding areas from other nests or competition for surface invertebrates with other bird species and small mammals. The older the chick the greater its mass and also the greater its energy requirements, meaning it must move further in search of food. Therefore, with increasing age comes a greater chance of overlap with other feeding broods and increasing competition. The above model may therefore underestimate the possible negative effects on wading bird breeding success after the first few days of age. Baines, 1988 found an average Lapwing density to be 35.3 breeding pairs per 100ha on marginal grassland in N. England, which would not be spaced out evenly and some overlap in feeding areas would be expected. Lapwings commonly nest in loose neighbourhood groups of 4 to 10 pairs with nests between 10 and 150m apart in northern Scotland with nests more widely spaced where food supply is poor (Cramp et al, 1983).

The risk assessment results show that the depletion of available invertebrate biomass in disposal areas will necessitate chicks moving further and perhaps feeding for a longer time period in order to fulfil their dietary requirements. Baines, 1988, found that food availability had only a minor effect on breeding success when compared to predation, soil moisture content and clutch destruction by farm machinery but adds that invertebrate biomass had probably surpassed a critical threshold level for the chicks during the study. However, the extra difficulty of finding enough food may exacerbate the problematic effects of other factors such as climate through the breeding season (Beintema and Visser, 1989a, 1989b). Below a certain temperature, dependant on body size, a chick must return to the nest to be brooded by parents at intervals to maintain body temperature. This therefore presents a further restriction in the distance a chick could move from the nest and since foraging is done in dry hours feeding time can be severely limited. In the worst case in prolonged adverse weather conditions many Lapwing chicks die of starvation (Beintema and Visser, 1989a). Therefore any reduction in invertebrate density could affect chick growth rate and even mortality, particularly when coupled with other adverse conditions.

The risk assessment model was designed to be applied over any area. However, the data used in the example was for rough grazing land at Sourhope Experimental farm and the biomass starting point may not be the same for other land use types. The greater the starting biomass, the greater the proportion of invertebrate biomass available after dip disposal. It might therefore be important to assess the potential invertebrate biomass depending on area in the UK and land-use type and input data that is as accurate as possible for each scenario being investigated.

The above risk assessment does not take into account any possible direct effects of dip disposal. To avoid the possibility of direct poisoning by contaminated prey, spring disposal should not be made on areas known to be used by feeding waders, either chicks or adult birds) prior or during the breeding season.

7.6 Best Practice Recommendations

The following recommendations are a result of both Phase 1 and Phase 2 of this study into the effects of sheep dip disposal on terrestrial invertebrates and are intended to minimise possible detrimental effects to breeding waders, particularly young chicks, from depletion of the important invertebrate food supply.

- Dip at any dilution should not be disposed during, or for at least 40 days prior to, the breeding season of the relevant wading birds (approx. April to June). During this time there are possible risks of both direct and indirect effects.

- Rough pasture, commonly used for dip disposal, is favoured nesting and feeding habitat for many wader species and so should be avoided for spring dip disposal, particularly if it is a known nesting site.

- Dip for disposal should always be diluted to the recommended levels.

- If possible within the authorised disposal area, the same area should not be used for disposal in consecutive years to allow the maximum possible time for recovery of invertebrate populations and minimise the possibility of persistence due to cumulative effects.

- Autumn dip disposal is preferable to spring disposal, particularly where rotation of disposal areas is possible, as this is less likely to have long-term effects on invertebrate populations and therefore reduces the possibility of indirect effects on wading birds.

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APPENDICES

Appendix 1

Confidential Farm Questionnaire

1) Do you use sheep dip? (if no go to 18)

2) What is the name of the dip?

3) Is there any subsequent treatment; e.g. decontaminant used?

4) How many sheep are dipped?

5) Where is the dip disposed of ? e.g. on your own land, to a neighbour's land, mobile dip?

6) What is the method of application to land?

7a) What area is used for disposal e.g.
- i. acreage
- ii. part/whole
- iii. enclosed/open

7b) Why was the area chosen and how long has it been used for this purpose?

8) What is the quantity /dilution of the dip disposed of?

9) How often and what time of year is dip disposed of?

10) Is the dip mixed with slurry?

11a) What type of vegetation is on the disposal area? Improved pasture, rough grazing, hay meadow, other.

11b) What is the soil type of the disposal area?

12) Are there clumps of rushes on the disposal area?

13) Is the disposal area likely to have any wildlife value; e.g. do waders nest or feed on the land?

14) Do you use other chemical controls on the land i.e. insecticides for leatherjackets?

15) What guidance have you received about dip disposal and was it practical?

16) Would you be happy for me to come back and survey the vegetation and soil type on the disposal area?

17) Could I sample for invertebrates? This would involve taking 24 spadefulls of soil from the disposal area and from an adjacent field (to act as a control) in October and again next spring.

Secondary questionnaire for farmers who haven't applied for disposal licence

18) What alternative to sheep dip do you use to treat the sheep for pests and why?

19) Did you dip regularly before the current legislation came into force?

20) How did you dispose of the dip?

Appendix 2

Invertebrate Identification and Sorting

The following groupings were used for both the farm investigations in 1999-2000 and the Latin Square experiments 2000-2002.

Active Invertebrates (mainly predators)

Carabid Beetles
Staphilinid Beetles
Other Adult Beetles
Spiders
Adult Diptera
Ants
Other Hymenoptera
Harvestmen
Centipedes

Soil and more Sedentary Invertebrates

Weevils
Beetle Larvae
Tipulid Larvae
Other Fly Larvae
Sawfly Caterpillars
Hemiptera (bugs)
Lepidoptera
Millipedes

Other Invertebrates

Earthworms
Slugs
Snails

Appendix 3

Species lists of invertebrates found on farm sites

Species lists of Carabids and Spiders found on Farm Sites

Carabid species

Carabus problematicus
C. violaceus
Leistus rufescens
Nebria brevicollis
N. salina
Notiophilus aquaticus
N. biguttatus
N. substriatus
Elaphrus riparius
Loricera pilicornis
Dyschirius globosus
Clivina fossor
Miscodera arctica
Patrobus assimilis
P. atrorufus
Trechus obtusus
Bembidion aeneum
B. guttula
B. lampros
B. lunulatum
B. nigricorne
B. unicolor
Pterostichus adstrictus
P. diligens
P. madidus
P. melanarius
P. nigrita agg.
P. strenuus
Calathus fuscipes
C. melanocephalus
Synuchus nivalis
Agonum fuliginosum
A. muelleri
A. aenea
A. aulica
A. familiaris
A. lunicollis
A. plebeja
T. placidus

Spider species

Clubionidae	*Clubiona diversa*
	Clubiona neglecta
Linyphiidae	*Agyneta conigera*
	Bathyphantes gracilis
	Dicymdium nigrum
	Diplocephalus latifrons
	Erigone atra
	Erigone dentipalpis
	Erigonella haemalis
	Gonatium rubens
	Gongylidium vivum
	Lepthyphantes pallidus
	Lepthyphantes tenuis
	Lepthyphantes zimmermanni
	Maso sundevali
	Micrargus herbigradus
	Microlinyphia pusilla
	Monocephalus fuscipes
	Oedothorax fuscus
	Oedothorax retusus
	Pelecopsis parallela
	Silometopus elegans
	Tiso vagans
	Tricopterna thorelli
	Troxochrus scabricula
	Walckenaeria acuminata
	Walckenaeria antica
	Walckenaeria nudipalpis
Lycosidae	*Alopecosa pulverulenta*
	Pardosa agricola
	Pardosa pullata
	Trochosa terricola
Gnaphosidae	*Drassodes cupreus*
	Haplodrassus signifer
Tetragnathidae	*Pachygnatha degeeri*
Theriidae	*Robertus lividus*
Thomisidae	*Oxyptila trux*
	Xysticus cristatus

Species list of Bugs found on Farm Sites

	Bug species
Cercopidae	*unidentified nymphs*
	Neophilaenus lineatus
	Philaenus spumarius
Cicadellidae	*unidentified nymphs*
	Anoscopus albifrons
	Consanus obseletus
	Jassargus distinguendus
	Planaphrodes bifasciata
	Psammotettix sp.
	Streptanus marginatus
Delphacidae	*unidentified nymphs*
	Conomelus anceps
	Criomorphus albomarginatus
	Dicranotropis divergens
	Hyledelphax elegantulus
	Javesella discolor
	Javesella obscurella
	Muellerianella fairmairei
Miridae	*unidentified nymphs*
	Calocoris norvegicus
	Leptopterna ferrugata
	Pachytomella parallela
	Stenodema holsatum

Appendix 4

Chi-square analyses for Teesdale 1A pre and post disposal soil sample data

Total Invertebrates

	control	disposal
pre-disposal	737.48	1193.07
post disposal	844.04	926.92
percentage difference	14	-22
χ^2	7.2	33.4

Beetles

	control	disposal
pre-disposal	243.59	274.94
post disposal	239.02	229.55
percentage difference	-2	-17
χ^2	0.0	4.1

Active Invertebrates

	control	disposal
pre-disposal	500.07	843.10
post disposal	491.76	528.98
percentage difference	-2	-37
χ^2	0.1	71.9

Flies

	control	disposal
pre-disposal	231.84	758.86
post disposal	390.86	423.51
percentage difference	69	-44
χ^2	40.6	95.1

Sedentary Invertebrates

	control	disposal
pre-disposal	254.69	332.41
post disposal	405.55	450.61
percentage difference	59	35
χ^2	34.5	17.8

Tipulid larvae

	control	disposal
pre-disposal	40.82	83.59
post disposal	254.69	282.45
percentage difference	524	238
χ^2	154.8	108.0

Appendix 5

Results of ANOVA and Tukey HSD tests from the Latin Square Experimental Site, Sourhope 2000-2001

Results of ANOVA based on the total number of invertebrates found in soil samples predisposal and at 10, 20 and 40 days and 12 months after sheep dip disposal at Sourhope, 2000

4.1.1

Pre-disposal	means/ m^2	Anova $F_{4, 20}$	Anova Significant	10 day	means/ m^2	Anova $F_{4, 20}$	Anova Significant
sp dil	601.6	0.10	N/S	sp dil	656.0	2.34	N/S
op	521.6			op	396.8		
sp	492.8			sp	563.2		
op dil	560.0			op dil	816.0		
water	582.4			water	867.2		

4.1.2

20 day	means/ m^2	Anova $F_{4, 20}$	Anova Significant	40 day	means/ m^2	Anova $F_{4, 20}$	Anova Significant
sp dil	630.4	1.50	N/S	sp dil	432.0	0.94	N/S
op	601.6			op	336.0		
sp	684.8			sp	364.8		
op dil	508.8			op dil	396.8		
water	825.6			water	540.8		

4.1.3

12 month	means/ m^2	Anova $F_{4, 16}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	627.2	**3.68**	Yes	sp dil. vs op	**reject H_0**
op	1113.6		$P<0.05$	sp dil. vs sp	accept H_0
sp	483.2			sp dil. vs op dil.	**reject H_0**
op dil	1177.6			sp dil. vs water	accept H_0
water	1027.2			op vs sp	**reject H_0**
				op vs op dil.	accept H_0
				op vs water	accept H_0
				sp vs op dil.	**reject H_0**
				sp vs water	**reject H_0**
				op dil. vs water	accept H_0

Results of ANOVA based on the number of sedentary invertebrates found in soil samples predisposal and at 10, 20 and 40 days and 12 months after sheep dip disposal at Sourhope, 2000

4.1.4

Pre-disposal	means/ m^2	Anova $F_{4, 20}$	Anova Significant
sp dil	400.0	0.12	N/S
op	284.8		
sp	252.8		
op dil	336.0		
water	284.8		

4.1.5

10 day	means/ m^2	Anova $F_{4, 16}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	323.2	**3.39**	Yes	sp dil. vs op	accept H_0
op	160.0		$P<0.05$	sp dil. vs sp	accept H_0
sp	252.8			sp dil. vs op dil.	accept H_0
op dil	236.8			sp dil. vs water	accept H_0
water	483.2			op vs sp	accept H_0
				op vs op dil.	accept H_0
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	accept H_0
				op dil. vs water	accept H_0

4.1.6

20 day	means/ m^2	Anova $F_{4, 20}$	Anova Significant	40 day	means/ m^2	Anova F	Anova Significant
sp dil	342.4	1.52	N/S	sp dil	156.8	1.09	N/S
op	262.4			op	9.2		
sp	313.6			sp	9.6		
op dil	236.8			op dil	10		
water	518.4			water	17.2		

4.1.7

12 month	means/ m^2	Anova $F_{4, 20}$	Anova Significant
sp dil	451.2	2.31	N/S
op	806.4		
sp	326.4		
op dil	822.4		
water	697.6		

Results of ANOVA based on the total number of invertebrates caught in pitfall traps at 10, 20 and 40 days and 12 months after sheep dip disposal at Sourhope, 2000

4.2.1

10 day	means/ sample	Anova $F_{4, 20}$	Anova Significant
sp dil	33.6	1.39	N/S
op	25.2		
sp	28.8		
op dil	36.6		
water	48.0		

4.2.2

20 day	means/ sample	Anova $F_{4, 16}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	19.6	**4.24**	Yes	sp dil. vs op	accept H_0
op	13.4		$P<0.05$	sp dil. vs sp	accept H_0
sp	10.4			sp dil. vs op dil.	accept H_0
op dil	15.6			sp dil. vs water	accept H_0
water	23.0			op vs sp	accept H_0
				op vs op dil.	accept H_0
				op vs water	accept H_0
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	accept H_0

4.2.3

40 day	means/ sample	Anova $F_{4, 20}$	Anova Significant
sp dil	39.6	1.10	N/S
op	33.0		
sp	39.6		
op dil	34.6		
water	44.6		

4.2.4

12 months	means/ sample	Anova $F_{4, 20}$	Anova Significant
sp dil	84.6	0.38	N/S
op	89.0		
sp	85.6		
op dil	84.4		
water	94.0		

Results of ANOVA based on the number of Linyphiidae caught in pitfall traps at 10, 20 and 40 days after sheep dip disposal at Sourhope, 2000

4.2.5

10 day	means/ sample	Anova $F_{4, 20}$	Anova Significant
sp dil	4.0	2.10	N/S
op	5.0		
sp	1.4		
op dil	4.0		
water	6.0		

4.2.6

20 day	means/ sample	Anova $F_{4, 20}$	Anova Significant
sp dil	2.0	1.28	NS
op	2.0		
sp	0.2		
op dil	2.0		
water	1.6		

4.2.7

40 day	means/ sample	Anova $F_{4, 20}$	Anova Significant
sp dil	5.60	2.46	NS
op	2.60		
sp	2.20		
op dil	3.00		
water	3.80		

Results of ANOVA based on the number of Lycosidae caught in pitfall traps at 10, 20 and 40 days after sheep dip disposal at Sourhope, 2000

4.2.8

10 day	means/ sample	Anova $F_{4, 20}$	Anova Significant
sp dil	0.8	2.64	NS
op	1.4		
sp	3.0		
op dil	4.4		
water	7.0		

4.2.9

20 day	means/ sample	Anova $F_{4, 12}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	0.2	**25.37**	Yes	sp dil. vs op	**reject H_0**
op	1.0		P<0.01	sp dil. vs sp	accept H_0
sp	0.2			sp dil. vs op dil.	**reject H_0**
op dil	1.4			sp dil. vs water	**reject H_0**
water	2.2			op vs sp	**reject H_0**
				op vs op dil.	accept H_0
				op vs water	**reject H_0**
				sp vs op dil.	**reject H_0**
				sp vs water	**reject H_0**
				op dil. vs water	accept H_0

4.2.10

40 day	means/ sample	Anova $F_{4, 16}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	0.6	**5.19**	Yes	sp dil. vs op	accept H_0
op	2.6		P<0.01	sp dil. vs sp	accept H_0
sp	0.0			sp dil. vs op dil.	accept H_0
op dil	2.0			sp dil. vs water	accept H_0
water	2.2			op vs sp	accept H_0
				op vs op dil.	accept H_0
				op vs water	accept H_0
				sp vs op dil.	**reject H_0**
				sp vs water	**reject H_0**
				op dil. vs water	accept H_0

Results of ANOVA based on the number of elaterids caught in pitfall traps at 10, 20 and 40 days after sheep dip disposal at Sourhope, 2000

4.2.11

10 day	means/ sample	Anova $F_{4, 20}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	5.0	**2.94**	Yes	sp dil. vs op	**reject H_0**
op	0.6		P<0.05	sp dil. vs sp	accept H_0
sp	2.8			sp dil. vs op dil.	accept H_0
op dil	6.2			sp dil. vs water	accept H_0
water	8.0			op vs sp	**reject H_0**
				op vs op dil.	**reject H_0**
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	accept H_0

4.2.12

20 day	means/ sample	Anova $F_{4, 20}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	1.4	**3.09**	Yes	sp dil. vs op	accept H_0
op	0.6		P<0.05	sp dil. vs sp	accept H_0
sp	0.2			sp dil. vs op dil.	accept H_0
op dil	1.8			sp dil. vs water	accept H_0
water	3.6			op vs sp	accept H_0
				op vs op dil.	accept H_0
				op vs water	accept H_0
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	accept H_0

4.2.13

40 day	means/ sample	Anova $F_{4, 12}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	2.2	**4.11**	Yes	sp dil. vs op	accept H_0
op	0.4		$P<0.05$	sp dil. vs sp	accept H_0
sp	0.6			sp dil. vs op dil.	accept H_0
op dil	2.4			sp dil. vs water	accept H_0
water	3.6			op vs sp	accept H_0
				op vs op dil.	accept H_0
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	accept H_0
				op dil. vs water	accept H_0

4.2.14

10 day	means/ sample	Anova $F_{4, 20}$	Anova Significant
sp dil	2.0	0.51	N/S
op	0.2		
sp	0.8		
op dil	1.2		
water	1.4		

Results of ANOVA based on the number of carabids caught in pitfall traps at 10, 20 and 40 days after sheep dip disposal at Sourhope, 2000

4.2.15

20 day	means/ sample	Anova $F_{4, 20}$	Anova Significant
sp dil	2.0	1.53	N/S
op	0.6		
sp	1.6		
op dil	1.0		
water	0.6		

4.2.16

40 day	means/ sample	Anova $F_{4, 12}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	4.6	**4.02**	Yes	sp dil. vs op	accept H_0
op	2.6		$P<0.05$	sp dil. vs sp	accept H_0
sp	3.4			sp dil. vs op dil.	accept H_0
op dil	1.4			sp dil. vs water	**reject H_0**
water	0.2			op vs sp	accept H_0
				op vs op dil.	accept H_0
				op vs water	accept H_0
				sp vs op dil.	accept H_0
				sp vs water	accept H_0
				op dil. vs water	accept H_0

sp contains more carabids than the water treatment where the Tukey test rejects H_0

Results of ANOVA based on the total number of invertebrates caught by suction sampling at 10 and 40 days after sheep dip disposal at Sourhope, 2000

4.3.1

10 day	means/ sample	Anova $F_{4, 12}$	Anova Significant	Tukey test Comparison	conclusion	40 day	means	Anova $F_{4, 12}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	17.8	**17.48**	Yes	spd vs op	accept H_0	sp dil	16.4	**17.50**	Yes	spd vs op	accept H_0
op	14.2		P<0.05	spd vs sp	accept H_0	op	12.6		P<0.05	spd vs sp	accept H_0
sp	13.0			spd vs opd	accept H_0	sp	10.4			spd vs opd	accept H_0
op dil	11.8			spd vs water	**reject H_0**	op dil	12.4			spd vs water	**reject H_0**
water	81.2			op vs sp	accept H_0	water	44.6			op vs sp	accept H_0
				op vs opd	accept H_0					op vs opd	accept H_0
				op vs water	**reject H_0**					op vs water	**reject H_0**
				sp vs opd	accept H_0					sp vs opd	accept H_0
				sp vs water	**reject H_0**					sp vs water	**reject H_0**
				opd vs water	**reject H_0**					opd vs water	**reject H_0**

Results of ANOVA based on the total number of bugs caught by suction sampling at 10 and 40 days after sheep dip disposal at Sourhope, 2000

4.3.2

10 day	means/ sample	Anova $F_{4, 12}$	Anova Significant	Tukey test Comparison	conclusion	40 day	means	Anova $F_{4, 12}$	Anova Significant	Comparison	conclusion
sp dil	5.0	**20.55**	Yes	sp dil. vs op	accept H_0	sp dil	9.8	**15.35**	Yes	sp dil. vs op	accept H_0
op	5.4		P<0.05	sp dil. vs sp	accept H_0	op	3.0		P<0.05	sp dil. vs sp	accept H_0
sp	3.6			sp dil. vs op dil.	accept H_0	sp	4.0			sp dil. vs op dil.	accept H_0
op dil	4.8			sp dil. vs water	**reject H_0**	op dil	4.0			sp dil. vs water	**reject H_0**
water	54.4			op vs sp	accept H_0	water	32.6			op vs sp	accept H_0
				op vs op dil.	accept H_0					op vs op dil.	accept H_0
				op vs water	**reject H_0**					op vs water	**reject H_0**
				sp vs op dil.	accept H_0					sp vs op dil.	accept H_0
				sp vs water	**reject H_0**					sp vs water	**reject H_0**
				op dil. vs water	**reject H_0**					op dil. vs water	**reject H_0**

Results of ANOVA based on the number of *Hyledelphax elegantulus* caught by suction sampling at 10 days after sheep dip disposal at Sourhope, 2000

4.3.3

10 day	means/ sample	Anova $F_{4, 20}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	6.4	**2.96**	Yes	sp dil. vs op	accept H_0
op	1.0		P<0.05	sp dil. vs sp	accept H_0
sp	0.6			sp dil. vs op dil.	accept H_0
op dil	1.0			sp dil. vs water	**reject H_0**
water	12.2			op vs sp	accept H_0
				op vs op dil.	accept H_0
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	**reject H_0**

Results of ANOVA based on the number of *Pachytomella parallela* caught by suction sampling at 40 days after sheep dip disposal at Sourhope, 2000

4.3.4

40 day	means/ sample	Anova $F_{4, 20}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	7.0	**32.95**	Yes	sp dil. vs op	accept H_0
op	1.4		P<0.01	sp dil. vs sp	accept H_0
sp	3.4			sp dil. vs op dil.	accept H_0
op dil	3.4			sp dil. vs water	**reject H_0**
water	28.2			op vs sp	accept H_0
				op vs op dil.	accept H_0
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	**reject H_0**

Results of ANOVA and Tukey HSD tests from the Latin Square Experimental Site, Newton Rigg 2001-2002

Re**sults of ANOVA based on the total number of invertebrates found in soil sampl**
predisposal and at 10 days after sheep dip disposal at Newton Rigg, 2001

4.4.1

Pre-disposal	means/ m^2	Anova $F_{4, 16}$	Anova Significant
sp dil	1505.40	0.54	N/S
op	1869.04		
sp	1301.82		
op dil	1507.78		
water	2001.76		

4.4.2

10 day	means/ m^2	Anova $F_{4, 16}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	1051.05	**8.65**	Yes	sp dil. vs op	**reject H_0**
op	333.65		$P<0.05$	sp dil. vs sp	**reject H_0**
sp	542.53			sp dil. vs op dil.	accept H_0
op dil	707.59			sp dil. vs water	accept H_0
water	1153.22			op vs sp	**reject H_0**
				op vs op dil.	**reject H_0**
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	accept H_0

Results of ANOVA based on the number of sedentary invertebrates found in soil samples predisposal and at 10 days after sheep dip disposal at Newton Rigg, 2001

4.4.3

Pre-disposal	means/ m^2	Anova $F_{4, 16}$	Anova Significant
sp dil	468.99	0.37	N/S
op	637.33		
sp	414.85		
op dil	440.06		
water	769.30		

4.4.4

10 day	means/ m^2	Anova $F_{4, 16}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	265.25	**7.88**	Yes	sp dil. vs op	**reject H_0**
op	86.48		P<0.05	sp dil. vs sp	accept H_0
sp	190.37			sp dil. vs op dil.	accept H_0
op dil	251.10			sp dil. vs water	accept H_0
water	437.95			op vs sp	**reject H_0**
				op vs op dil.	**reject H_0**
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	accept H_0

Results of ANOVA based on the number of active invertebrates found in soil samples predisposal and at 10 days after sheep dip disposal at Newton Rigg, 2001

4.4.5

Pre-disposal	means/ m^2	Anova $F_{4, 16}$	Anova Significant
sp dil	832.89	0.77	N/S
op	843.14		
sp	511.37		
op dil	609.42		
water	1110.75		

4.4.6

10 day	means/ m^2	Anova $F_{4, 16}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	644.97	**4.41**	Yes	sp dil. vs op	**reject H_0**
op	126.47		P<0.05	sp dil. vs sp	**reject H_0**
sp	247.99			sp dil. vs op dil.	**reject H_0**
op dil	281.41			sp dil. vs water	accept H_0
water	487.89			op vs sp	**reject H_0**
				op vs op dil.	**reject H_0**
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	**reject H_0**

Results of ANOVA based on the total number of earthworms found in soil samples predisposal and at 10 days after sheep dip disposal at Newton Rigg, 2001

4.5.1

Pre-disposal	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	761.74	0.66	N/S
op	1082.15		
sp	1131.08		
op dil	1192.52		
water	894.36		

4.5.2

10 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	600.54	0.81	N/S
op	380.29		
sp	594.32		
op dil	645.15		
water	730.02		

Results of ANOVA based on the total number of invertebrates caught in pitfall traps at 10 days after sheep dip disposal at Newton Rigg, 2001

4.6.1

10 day	means/ sample	Anova $F_{4, 12}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	15.16	**4.05**	Yes	sp dil. vs op	accept H_0
op	27.93		P<0.05	sp dil. vs sp	accept H_0
sp	13.89			sp dil. vs op dil.	accept H_0
op dil	21.73			sp dil. vs water	accept H_0
water	19.99			op vs sp	**reject H_0**
				op vs op dil.	accept H_0
				op vs water	accept H_0
				sp vs op dil.	**reject H_0**
				sp vs water	accept H_0
				op dil. vs water	accept H_0

Results of ANOVA based on the total number of invertebrates found in soil samples predisposal and at 10, 20 and 40 days after sheep dip disposal at Newton Rigg Site A, 2002

4.7.1

Pre-disposal	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	1426	0.22	N/S
op	1295		
sp	1441		
op dil	1384		
water	1298		

4.7.2

10 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	722.00	1.39	N/S
op	550.00		
sp	634.00		
op dil	750.00		
water	1332.00		

4.7.3

20 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	601	**4.02**	Yes	sp dil. vs op	accept H_0
op	610		$P<0.05$	sp dil. vs sp	**reject H_0**
sp	732			sp dil. vs op dil.	**reject H_0**
op dil	1015			sp dil. vs water	**reject H_0**
water	1275			op vs sp	accept H_0
				op vs op dil.	**reject H_0**
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	accept H_0

4.7.4

40 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	687	2.06	N/S
op	699		
sp	491		
op dil	975		
water	1078		

Results of ANOVA based on the number of sedentary invertebrates found in soil samples predisposal and at 10, 20 and 40 days after sheep dip disposal at Newton Rigg Site A, 2002

4.7.5

Pre-disposal	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	731	0.38	N/S
op	634		
sp	806		
op dil	680		
water	606		

4.7.6

10 day	means/ m^2	Anova $F_{4, 16}$	Anova Significant
sp dil	152	2.88	N/S
op	200		
sp	288		
op dil	303		
water	439		

4.7.7

20 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	207	**9.56**	Yes	sp dil. vs op	accept H_0
op	206		$P<0.05$	sp dil. vs sp	**reject H_0**
sp	92			sp dil. vs op dil.	accept H_0
op dil	308			sp dil. vs water	**reject H_0**
water	415			op vs sp	**reject H_0**
				op vs op dil.	**reject H_0**
				op vs water	**reject H_0**
				sp vs op dil.	**reject H_0**
				sp vs water	**reject H_0**
				op dil. vs water	**reject H_0**

4.7.8

40 day	means/ m^2	Anova $F_{4, 16}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	500	**3.49**	Yes	sp dil. vs op	accept H_0
op	490		P<0.05	sp dil. vs sp	**reject H_0**
sp	284			sp dil. vs op dil.	accept H_0
op dil	538			sp dil. vs water	accept H_0
water	437			op vs sp	**reject H_0**
				op vs op dil.	accept H_0
				op vs water	accept H_0
				sp vs op dil.	**reject H_0**
				sp vs water	**reject H_0**
				op dil. vs water	accept H_0

Results of ANOVA based on the number of active invertebrates found in soil samples predisposal and at 10 , 20 and 40 days after sheep dip disposal at Newton Rigg Site A, 2002

4.7.9

Pre-disposal	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	767	0.12	N/S
op	637		
sp	715		
op dil	745		
water	713		

4.7.10

10 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	632	0.14	N/S
op	352		
sp	296		
op dil	488		
water	878		

4.7.11

20 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	416	2.36	N/S
op	441		
sp	626		
op dil	718		
water	890		

4.7.12

40 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	223	1.08	N/S
op	231		
sp	242		
op dil	558		
water	673		

Results of ANOVA based on the total number of invertebrates found in soil samples predisposal and at 10, 20 and 40 days after sheep dip disposal at Newton Rigg Site B, 2002

4.8.1

Pre-disposal	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	1867	0.76	N/S
op	1561		
sp	1501		
op dil	1287		
water	1768		

4.8.2

10 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	707	2.05	N/S
op	739		
sp	598		
op dil	661		
water	1309		

4.8.3

20 day	means/ m^{-}	Anova $F_{4, 16}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	833	**5.70**	Yes	sp dil. vs op	**reject H_0**
op	479		P<0.05	sp dil. vs sp	**reject H_0**
sp	427			sp dil. vs op dil.	accept H_0
op dil	913			sp dil. vs water	**reject H_0**
water	1361			op vs sp	accept H_0
				op vs op dil.	**reject H_0**
				op vs water	**reject H_0**
				sp vs op dil.	**reject H_0**
				sp vs water	**reject H_0**
				op dil. vs water	**reject H_0**

4.8.4

40 day	means/ m^{-}	Anova $F_{4, 12}$	Anova Significant
sp dil	740	1.41	N/S
op	1202		
sp	612		
op dil	1001		
water	1177		

Results of ANOVA based on the number of sedentary invertebrates found in soil samples predisposal and at 10, 20 and 40 days after sheep dip disposal at Newton Rigg Site B, 2002

4.8.5

Pre-disposal	means/ m^{2}	Anova $F_{4, 12}$	Anova Significant
sp dil	1047	0.30	N/S
op	898		
sp	1016		
op dil	912		
water	982		

4.8.6

10 day	means/ m^2	Anova $F_{4, 16}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	283	**5.88**	Yes	sp dil. vs op	**reject H_0**
op	226		P<0.05	sp dil. vs sp	accept H_0
sp	237			sp dil. vs op dil.	**reject H_0**
op dil	135			sp dil. vs water	**reject H_0**
water	733			op vs sp	accept H_0
				op vs op dil.	accept H_0
				op vs water	**reject H_0**
				sp vs op dil.	**reject H_0**
				sp vs water	**reject H_0**
				op dil. vs water	**reject H_0**

4.8.7

20 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	308	**8.49**	Yes	sp dil. vs op	**reject H_0**
op	221		P<0.05	sp dil. vs sp	**reject H_0**
sp	188			sp dil. vs op dil.	accept H_0
op dil	260			sp dil. vs water	**reject H_0**
water	632			op vs sp	accept H_0
				op vs op dil.	accept H_0
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	**reject H_0**

4.8.8

40 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	441	1.75	N/S
op	589		
sp	331		
op dil	732		
water	612		

Results of ANOVA based on the number of active invertebrates found in soil samples predisposal and at 10 , 20 and 40 days after sheep dip disposal at Newton Rigg Site B, 2002

4.8.9

Pre-disposal	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	862	2.46	N/S
op	679		
sp	521		
op dil	433		
water	792		

4.8.10

10 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	448	1.31	N/S
op	395		
sp	456		
op dil	566		
water	656		

4.8.11

20 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	622	2.18	N/S
op	299		
sp	262		
op dil	686		
water	767		

4.8.12

40 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	329	1.14	N/S
op	635		
sp	315		
op dil	283		
water	781		

Results of ANOVA based on the number of active invertebrates found in soil samples 10, 20 and 40 days after sheep dip disposal at Newton Rigg Site A+B, 2002

4.9.1

10 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	1018	1.79	N/S
op	637		
sp	606		
op dil	1002		
water	1465		

4.9.2

20 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	936	**4.48**	Yes	sp dil. vs op	accept H_0
op	729		$P<0.05$	sp dil. vs sp	accept H_0
sp	843			sp dil. vs op dil.	**reject H_0**
op dil	1360			sp dil. vs water	**reject H_0**
water	1574			op vs sp	**reject H_0**
				op vs op dil.	**reject H_0**
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	accept H_0

4.9.3

40 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	509	1.91	N/S
op	828		
sp	494		
op dil	655		
water	1288		

Site A: Results of ANOVA based on the total number of earthworms found in soil samples predisposal and at 10, 20 and 40 days after sheep dip disposal at Newton Rigg, 2002

4.10.1

Pre-disposal	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	414	1.25	N/S
op	426		
sp	381		
op dil	523		
water	310		

4.10.2

10 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	295	0.29	N/S
op	351		
sp	273		
op dil	299		
water	352		

4.10.3

20 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	285	0.93	N/S
op	191		
sp	199		
op dil	259		
water	214		

4.10.4

40 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	282	**3.56***	Yes	sp dil. vs op	**reject H_0**
op	176		$P<0.05$	sp dil. vs sp	accept H_0
sp	242			sp dil. vs op dil.	accept H_0
op dil	264			sp dil. vs water	**reject H_0**
water	183			op vs sp	accept H_0
				op vs op dil.	**reject H_0**
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	**reject H_0**

NB * denotes significantly higher numbers on the treated sites than the control (water)

Site B: Results of ANOVA based on the total number of earthworms found in soil samples predisposal and at 10, 20 and 40 days after sheep dip disposal at Newton Rigg, 2002

4.10.5

Pre-disposal	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	565	0.99	N/S
op	449		
sp	493		
op dil	434		
water	568		

4.10.6

10 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	429	0.24	N/S
op	377		
sp	300		
op dil	428		
water	377		

4.10.7

20 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	321	2.00	N/S
op	232		
sp	285		
op dil	301		
water	340		

4.10.8

40 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	304	0.38	N/S
op	244		
sp	271		
op dil	183		
water	176		

Results of ANOVA based on the total number of invertebrates found in suction samples 50 days after sheep dip disposal at Newton Rigg Site A, 2002

4.11.1

50 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	936	0.98	N/S
op	786		
sp	751		
op dil	648		
water	916		

Results of ANOVA based on the total number of invertebrates found in suction samples 50 days after sheep dip disposal at Newton Rigg Site B, 2002

4.11.2

50 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	1157	0.83	N/S
op	1151		
sp	988		
op dil	1340		
water	1292		

Results of ANOVA based on the number of collembola found in suction samples 50 days after sheep dip disposal at Newton Rigg Site A, 2002

4.11.3

50 day	means/ m^{-}	Anova $F_{4, 12}$	Anova Significant
sp dil	1406	1.56	N/S
op	1000		
sp	2077		
op dil	996		
water	1736		

Results of ANOVA based on the number of collembola found in suction samples 50 days after sheep dip disposal at Newton Rigg Site B, 2002

4.11.4

50 day	means/ m^{-}	Anova $F_{4, 12}$	Anova Significant
sp dil	585	0.25	N/S
op	244		
sp	406		
op dil	553		
water	512		

Results of ANOVA based on the number of mites found in suction samples 50 days after sheep dip disposal at Newton Rigg Site A, 2002

4.11.5

50 day	means/ m^{-}	Anova $F_{4, 20}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	778	**6.73**	Yes	sp dil. vs op	**reject H_0**
op	1450		$P<0.05$	sp dil. vs sp	accept H_0
sp	863			sp dil. vs op dil.	**reject H_0**
op dil	1381			sp dil. vs water	**reject H_0**
water	3548			op vs sp	accept H_0
				op vs op dil.	accept H_0
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	**reject H_0**

Results of ANOVA based on the number of mites found in suction samples
50 days after sheep dip disposal at Newton Rigg Site B, 2002

4.11.6

50 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	899	2.28	N/S
op	1859		
sp	781		
op dil	2508		
water	1166		

Results of ANOVA based on the total number of invertebrates found in soil cores
predisposal and at 10, 20 and 40 days after sheep dip disposal at Newton Rigg Site B, 2002

4.12.1

Pre-disposal	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	17837	0.14	N/S
op	19213		
sp	30327		
op dil	18821		
water	25893		

4.12.2

10 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	9953	1.9	N/S
op	22030		
sp	9517		
op dil	12468		
water	9984		

4.12.3

20 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	22706	0.82	N/S
op	19746		
sp	17445		
op dil	15809		
water	28726		

4.12.4

40 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	21258	0.35	N/S
op	23060		
sp	15590		
op dil	12495		
water	20513		

Results of ANOVA based on numbers of collembola found in soil cores
predisposal and at 10, 20 and 40 days after sheep dip disposal at Newton Rigg Site B, 2002

4.12.5

Pre-disposal	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	3920	1.10	N/S
op	3125		
sp	7928		
op dil	3976		
water	10329		

4.12.6

10 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	1629	0.83	N/S
op	3908		
sp	2077		
op dil	4925		
water	2667		

4.12.7

20 day	means/ m^{-}	Anova $F_{4, 16}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	13532	**3.54**	Yes	sp dil. vs op	**reject H_0**
op	4119		P<0.05	sp dil. vs sp	**reject H_0**
sp	4086			sp dil. vs op dil.	**reject H_0**
op dil	2827			sp dil. vs water	accept H_0
water	16654			op vs sp	accept H_0
				op vs op dil.	accept H_0
				op vs water	**reject H_0**
				sp vs op dil.	accept H_0
				sp vs water	**reject H_0**
				op dil. vs water	**reject H_0**

4.12.8

40 day	means/ m^{-}	Anova $F_{4, 12}$	Anova Significant
sp dil	8800	1.28	N/S
op	10427		
sp	4941		
op dil	2060		
water	5412		

Results of ANOVA based on the number of mites found in soil cores predisposal and at 10, 20 and 40 days after sheep dip disposal at Newton Rigg Site B, 2002

4.12.9

Pre-disposal	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	5547	0.53	N/S
op	6835		
sp	11835		
op dil	7177		
water	7349		

4.12.10

10 day	means/ m^2	Anova $F_{4, 20}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	4528	**2.89**	Yes	sp dil. vs op	accept H_0
op	5839		P<0.05	sp dil. vs sp	accept H_0
sp	6600			sp dil. vs op dil.	**reject H_0**
op dil	2670			sp dil. vs water	accept H_0
water	4772			op vs sp	accept H_0
				op vs op dil.	**reject H_0**
				op vs water	accept H_0
				sp vs op dil.	**reject H_0**
				sp vs water	accept H_0
				op dil. vs water	**reject H_0**

4.12.11

20 day	means/ m^2	Anova $F_{4, 16}$	Anova Significant	Tukey test Comparison	conclusion
sp dil	5917	**3.22**	Yes	sp dil. vs op	accept H_0
op	5872		P<0.05	sp dil. vs sp	**reject H_0**
sp	5564			sp dil. vs op dil.	**reject H_0**
op dil	2303			sp dil. vs water	accept H_0
water	7474			op vs sp	accept H_0
				op vs op dil.	**reject H_0**
				op vs water	accept H_0
				sp vs op dil.	**reject H_0**
				sp vs water	**reject H_0**
				op dil. vs water	**reject H_0**

4.12.12

40 day	means/ m^2	Anova $F_{4, 12}$	Anova Significant
sp dil	6100	1.40	N/S
op	6159		
sp	5444		
op dil	3452		
water	4029		

Appendix 6

General habitat requirements of five species of upland wading birds

Bird Species	General habitat requirements	Nesting requirements	Chick rearing requirements	Out of breeding season
Golden Plover	Unenclosed upland moors and peatlands, above natural tree-line. Terrain over which it can easily run, e.g. no steep slopes or dense vegetation. Raised places for lookouts. Patchy habitat, usually in transition, e.g. where heather burning occurs.	Close to trees, shrubs or low walls. (Glutz et al, 1975)	Areas of increased food resources Shelter Less disturbance	Close-grazed open grassland and farmland of open character. (Fuller & Youngman, 1979)
Lapwing	Moist ground to give ready access to surface and sub-surface inverts. Unenclosed terrain, relatively flat or gently undulating ground, easy to walk on.	Short vegetation	Increased food resources	Some stay within 100km of nesting site, others move further south and west
Snipe	Areas of impeded drainage. Access to shallow water. Tall or dense vegetation separated by open ground, clumps of vegetation as lookout posts. Soft ground for probing.	Dry areas close to wetter zones for feeding	Areas of impeded drainage Access to shallow water	Moves widely to areas of good food supply
Curlew	Wet and dry patches of terrain. Open landscapes with low or sparse vegetation, typically managed moorland.	Rough grass fields Dry nesting sites	Damp feeding areas	Moves to marine env.
Redshank	Moist or wet grasslands. Open or gently sloping ground. Mounds for lookout facilities.	Open areas, only sparse, short, vegetation near wet feeding areas	Moist ground of high invert. biomass availability.	Coastal

(predominantly sourced from Cramp et al, 1983)

Appendix 7

The main foods taken by five species of adult wading birds (predominantly sourced from Cramp et al, 1983)

Invertebrates	Golden Plover	Lapwing	Snipe	Curlew	Redshank
Beetles (adults and larvae)	√	√	√	√	√
Lepidoptera (adults and larvae)	√	√	√	√	
Tipulids (adults and larvae)	√	√	√		√
Other flies	√	√	√	√	√
Other fly larvae	√	√			
Bugs	√	√	√	√	√
Froghoppers	√				
Ants	√	√		√	√
Dragonflies and Mayflies	√	√	√	√	√
Caddisflies and larvae		√	√	√	√
Damselflies		√			
Orthopterans	√	√		√	√
Earwigs	√	√		√	√
Spiders	√	√	√	√	√
Millipedes	√	√			
Snails	√				
Molluscs and Crustaceans	√	√	√	√	√
Harvestmen		√			
Woodlice		√		√	
Slugs	√				
Weevils		√			
Leeches			√		
Earthworms	√	√		√	√
Other worms e.g. Nereids			√		
Small amts. other inverts	√	√	√	√	√
Vertebrates and other food					
Frogs		√	√	√	√
Fish		√		√	√
Vegetation (seeds, grass etc.)	√	√	√	√	√

NB.There is less detailed information about chick diet but it is generally accepted that chicks eat a similar diet to that of the adults, a theory supported by Boyle, 1956, who found that Lapwing chicks less than 2 weeks old can successfully probe for food.

The table is not intended to be a definitive list of bird foods but an indication of the important food types regularly taken. The opportunistic nature of bird feeding has resulted in different proportions of the invertebrates occurring in different studies on the same species. Different species of invertebrates are consumed at various times of the year due to availability and the dietary requirements of the birds e.g. during the breeding season. This will be discussed further in the main text.

Appendix 8

The following data is presented with the permission of the author.

Golden Plover Chick Foraging Areas (Whittingham, unpublished data)

WD=Widdybank
CF=Chapel Fell

Site	Brood no.	Potential home range	MCP	Area used with potential home range MCP/Potential
WD	1	55.6	7.28	0.130935252
WD	2	21.7	4.32	0.199078341
WD	3	45.48	2.44	0.053649956
WD	4	4.94	1.88	0.380566802
WD	5	51.36	18.8	0.366043614
WD	6	35.32	2.32	0.065685164
WD	7	14.28	3.84	0.268907563
WD	8	29.24	3.84	0.131326949
WD	9	16.56	4.76	0.287439614
WD	10	146.72	12.12	0.082606325
WD	11	18.08	1.76	0.097345133
CF	1	114.04	6.04	0.052963872
CF	2	113.96	9.8	0.085995086
CF	3	20.44	4.12	0.201565558
CF	4	27.48	3.84	0.139737991
CF	5	21.88	5.72	0.26142596
CF	6	54.88	10.16	0.185131195
CF	7	30.2	3.52	0.116556291
CF	8	96.8	1.64	0.016942149
CF	9	25.44	6.42	0.252358491
CF	10	118.76	7.28	0.061300101
CF	11	84.8	1.4	0.016509434
				Mean % area 0.15700322

MCP are minimum convex polygons, created by joining outer radio locations from radio tracked chicks with a straight line.

Potential Home Range is calculated by drawing a circle of radius around the nest site, radius length being the maximum recorded distance each chick moved from the nest.

(Methodological details in Whittingham et al., 2001)

Appendix 9

The effects of different treatment types on invertebrate prey requirements of chicks

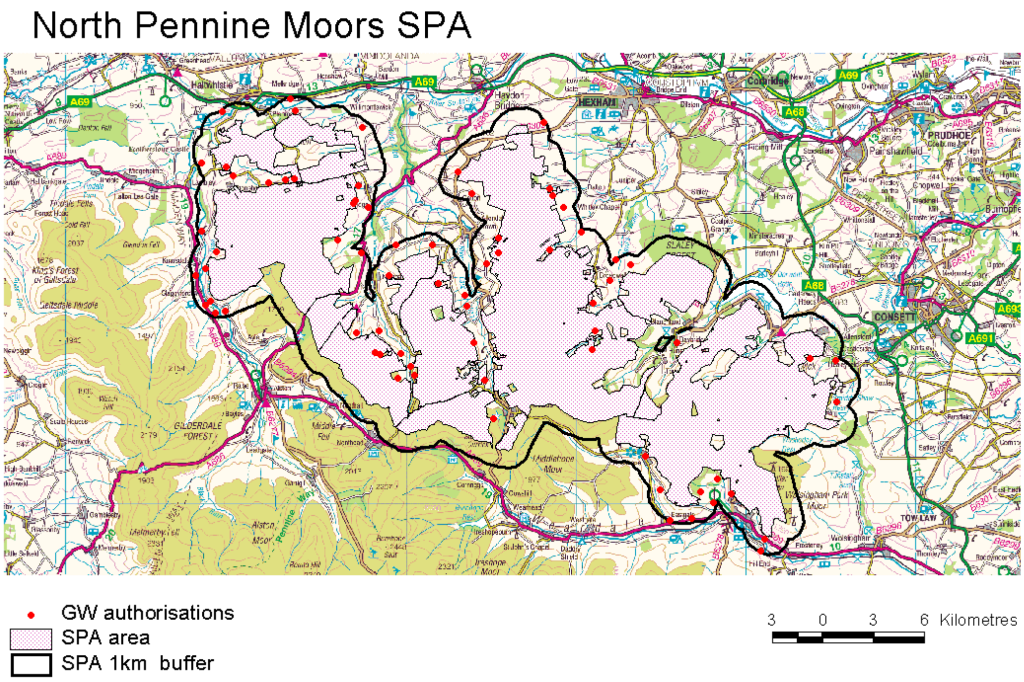
OP, pre - 40 day						SP, 40 day					OP dil, 40 day				
time (days)	Mass (g)	ME (KJ)	Area (ha)	KXF (KJ)	no. of chicks	Mass (g)	ME (KJ)	Area (ha)	KXF (KJ)	no. of chicks	Mass (g)	ME (KJ)	Area (ha)	KXF (KJ)	no. of chicks
1	20	67	0.004	150	2	20	67	0.004	431	6	20	67	0.004	428	6
3	30	97	0.036	1350	14	30	97	0.036	3877	40	30	97	0.036	3851	40
5	40	126	0.099	3749	30	40	126	0.099	10768	86	40	126	0.099	10697	85
7	50	154	0.194	7349	48	50	154	0.194	21105	137	50	154	0.194	20967	136
9	60	182	0.320	12148	67	60	182	0.320	34889	192	60	182	0.320	34659	191
11	70	209	0.478	18146	87	70	209	0.478	52117	249	70	209	0.478	51775	247
13	80	236	0.668	25345	107	80	236	0.668	72792	308	80	236	0.668	72314	306
15	90	263	0.889	33743	128	90	263	0.889	96913	368	90	263	0.889	96276	366
17	100	290	1.142	43342	150	100	290	1.142	124479	430	100	290	1.142	123661	427
19	110	316	1.427	54140	171	110	316	1.427	155491	492	110	316	1.427	154469	489
21	120	342	1.743	66137	193	120	342	1.743	189949	555	120	342	1.743	188701	552
23	130	368	2.091	79335	216	130	368	2.091	227852	619	130	368	2.091	226355	615
25	140	394	2.471	93732	238	140	394	2.471	269201	684	140	394	2.471	267433	679
27	150	419	2.672	101380	242	150	419	2.672	291168	695	150	419	2.672	289255	690
29	160	445	2.882	109329	246	160	445	2.882	313997	706	160	445	2.882	311933	702

	SP dil, 40 day					Water				
time (days)	Mass (g)	ME (KJ)	Area (ha)	KXF (KJ)	no. of chicks	Mass (g)	ME (KJ)	Area (ha)	KXF (KJ)	no. of chicks
1	20	67	0.004	352	5	20	67	0.004	980	15
3	30	97	0.036	3172	33	30	97	0.036	8817	91
5	40	126	0.099	8812	70	40	126	0.099	24493	195
7	50	154	0.194	17271	112	50	154	0.194	48006	312
9	60	182	0.320	28550	157	60	182	0.320	79356	436
11	70	209	0.478	42649	204	70	209	0.478	118544	566
13	80	236	0.668	59567	252	80	236	0.668	165570	700
15	90	263	0.889	79306	301	90	263	0.889	220434	837
17	100	290	1.142	101864	352	100	290	1.142	283135	977
19	110	316	1.427	127242	403	110	316	1.427	353674	1119
21	120	342	1.743	155439	454	120	342	1.743	432050	1263
23	130	368	2.091	186457	507	130	368	2.091	518264	1409
25	140	394	2.471	220294	560	140	394	2.471	612316	1555
27	150	419	2.672	238270	568	150	419	2.672	662281	1580
29	160	445	2.882	256951	578	160	445	2.882	714205	1607

KXF is the energy available to the chicks from invertebrate prey
ME is the energy required by the chicks at a certain mass
Area is the area that the chicks could cover in search of their invertebrate prey requirements
No. of chicks are those that can be supported given the distance they can move at certain mass/age

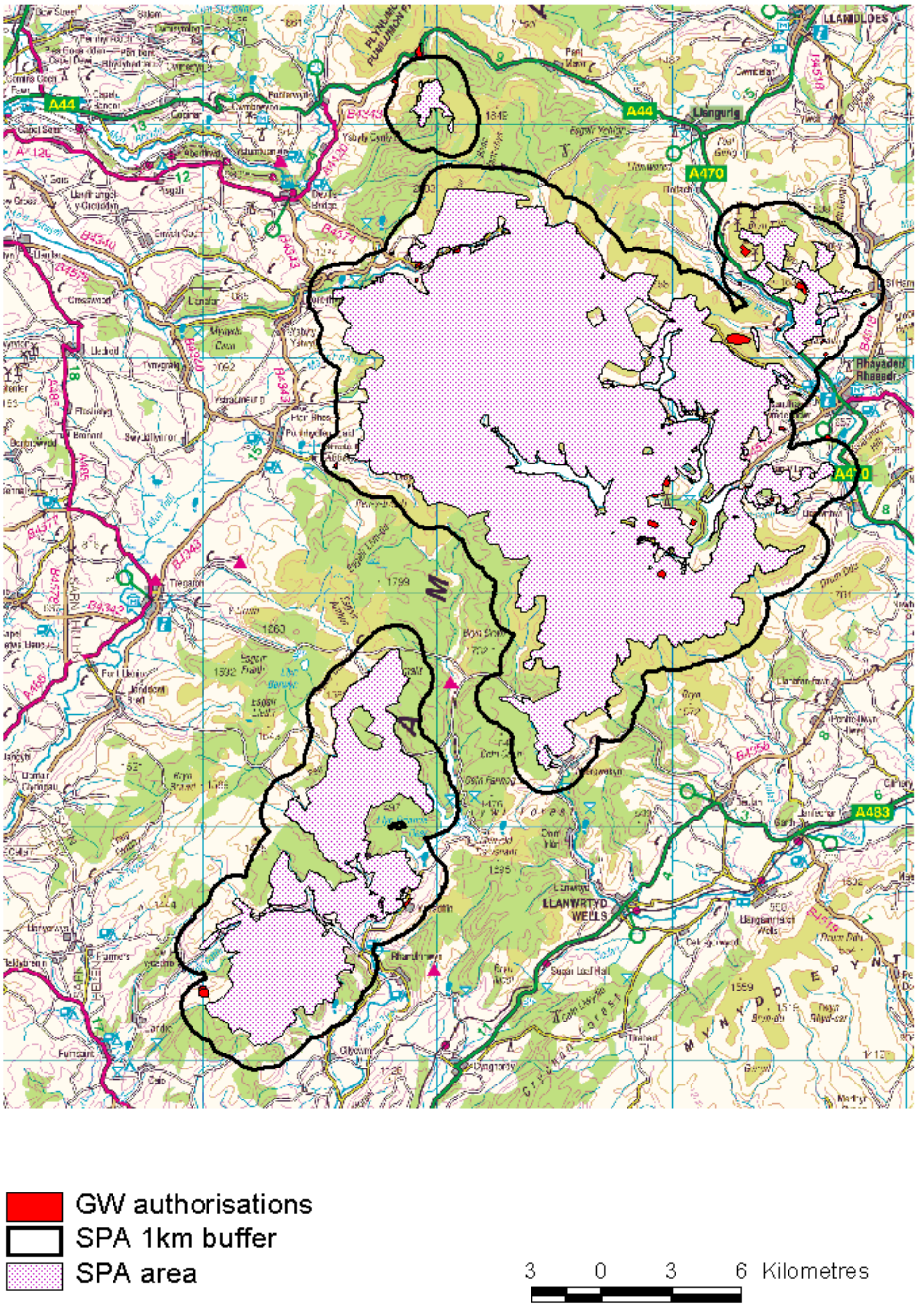
Appendix 10

Case Study A:



Case Study B:

Elenydd-Mallaen SPA



Appendix 11

Alternatives to Traditional Sheep dipping and Limitation of Possible Harmful Effects to the Environment

Sheep dipping, involving full immersion of the sheep, has been traditionally used by farmers to control harmful insect pests. One of the merits to the farmer of using sheep dip is the treatment of a broad range of pests including blowfly strike, ticks, lice and, very importantly to the hill sheep farmer, sheep scab mites. Blowfly strike results in loss of appetite and condition as the infected animal is literally eaten alive and can result in death in as little as three days. Lice cause severe skin irritation and ticks transmit debilitating diseases including tick borne fever (Cooper and Thomas, 1983). Sheep scab is highly contagious and is a predominant issue where farmers share common grazing rights to rough grass and moorland, where sheep that may have been missed in the gathering at dipping time can infect 'clean' flocks. Since sheep graze the common land for months at a time it is important that they are protected from the scab mites. Scab mites cause highly irritating lesions that cause the sheep to rub and gnaw the infected area. Severe crusting over large areas and wool loss can culminate in secondary bacterial infection, immaciation and eventual death.

Alternatives to traditional dipping include pour-ons and injectables. Pour-ons involve pouring a measured amount of chemical along the back of each animal and uses less chemical than full immersion dipping. It is widely used to treat ticks and lice. However, anecdotal evidence from the questionnaire in Phase 1 of this work suggests this technique is not popular in areas where sheep scab is a problem since some farmers believe the scab mites can escape the treatment. Injectables are another alternative but often farmers do not like having to carry out this treatment, if done incorrectly it can cause significant discomfort to the animal and many customers prefer meat that has not been injected.

There are several drawbacks to the traditional dipping method. The first is that it is relatively time consuming. Dipping guidelines recommend that each sheep is immersed for at least 1 minute with two complete immersions, including the head, during that time. This results in a second drawback, which is inevitable stress to the sheep. The cost of the dip plus dipping licence and then disposal licence and equipment is also considerable. Finally, and most pertinently, the possibilities of detrimental effects on the environment during disposal of the spent dip are very important, as discussed in Phase I and Phase II reports of this research.

However, there are possibly a number of ways to ameliorate the drawbacks of the full immersion sheep dipping method. The first is to add a chemical to the used dip at the end of the dipping process to speed up degradation of the active ingredients. In the case of Young's OP based sheep dip, for example, which contains the active ingredient Propetamphos, the manufacturer recommends adding sodium hypochlorite solution (10%) to the sheep dip wash. They claim this "rapidly degrades the OP insecticide within 24 hours." For these OP dips, which were widely used in the study in Phase I of this work, the solution should be added and mixed at the rate of 25 litres per 1000 litres of spent dip. The dip manufacturers also claim that hypochlorite solution is available at many animal health and dairy distributors. For non OP dips containing High-cis Cypermethrin (SP) Young's recommend adding 5kg of sodium hydroxide and 5 litres of surfactant per 1000 litres of spent dip, which should degrade the insecticide within 12 hours. At the time of printing Young's Sheep Dipping Guide this disposal system was only available via the manufacturer. The claims of this and other dip manufacturers have not been tested as part of this investigation. However, if the claims of the manufacturer are realised in real life situations on farms this could be very important. Unfortunately, such choices currently rely on the purchaser of the sheep dip and their willingness to go to the additional expense of the degradation system in a process where the costs per head of sheep are already considerable. Hardy hill sheep are often not worth more than a few pounds each. A costly dipping process soon becomes prohibitive if it cuts too greatly into an already tiny profit margin.

Mobile sheep dipping is an increasingly used alternative to the full immersion dipping process. mobile dips create less waste dip and allow many sheep to be dealt with at the same time, leading to much faster throughput. For example, the "Monsoon" Mobile Sheep Shower, available from T.W. & L.A.Wilson won the 2002 Lloyds TSB Award for Economic Merit from the Royal Agricultural Society of England Award Scheme. This is a typical mobile system and allows a throughput of up to 225 sheep per hour. The sheep are first herded from an open pen into the main trailer-like enclosed holding pen a few at a time. Dip is sprayed at them from all angles for a set amount of time, after which they are released into an open holding pen that allows dip from the sheep to drain back into the system. The sheep can then be returned to the fields. The dip water becomes less soiled than in a traditional bath since any solid muck falling off the sheep is contained in the trailer and can be removed, rather than contaminating the dip water. Therefore fewer preservatives need to be added to stop bacterial growth etc. When a set number of sheep have been 'showered' the holding tank is topped up with more dip concentrate. When the amount of made-up dip in the holding tank reaches a minimum level it is topped up with both dip and fresh water from a clean water holding tank if more sheep await treatment.

At the end of a dipping session as little as 20 litres of spent dip can remain. This can either be disposed of onto farmland, or in the case of contractors or co-operatives can be incorporated into the next batch of freshly made-up dip, with waste disposed of only at the end of the dipping season. In this way the contractors T.W and L.A.Wilson mobile dipped more than 110,000 sheep on contract in one year, which saved the combined disposal of approximately 5,200 tonnes of spent dip from over 400 farms. The cost of purchasing a mobile sheep shower is £6,500 plus VAT for a "Monsoon" model in 2002, whereas the traditional dip baths can cost more than £10,000 for a permanent, watertight system sunk into the ground. Since less dip has to be used in the mobile system and disposal is minimal, running costs are lower as well, so to set up a new system the mobile shower would seem the most cost effective choice. The problem arises when farmers already have a traditional bath set-up and don't want the extra expense of starting something different. To this end co-operatives are occurring where several farmers will get together and purchase a mobile system, sharing costs and again cutting down on disposal. For example, the National Trust have set up a trial scheme in Cumbria incorporating 8 farms with land unsuitable for dip disposal due to possible contamination of adjoining bodies of water. If, as anecdotal evidence suggests, the mobile dipping system is as effective as the traditional dip bath method at protecting flocks, this might prove an excellent method of allowing effective animal husbandry whilst keeping any risk to the environment from disposal of the pesticide at an absolute minimum.