CONTROL OF NORWAY RATS IN THE AGRICULTURAL ENVIRONMENT- ALTERNATIVES TO RODENTICIDE USE

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CONTENTS

Abstract

The control of Norway rat populations on farms in the UK currently relies heavily on the use of anticoagulant rodenticides, and many infestations are safely and effectively controlled in this way. However, rodenticide use can represent a risk to non-target animals, and the emergence of 'hotspots' of resistance to anticoagulant rodenticides has led to concerns over the long-term viability of a rodenticide-biased approach.

This study investigated some non-rodenticide approaches to rat control on farms. Small mammals potentially compete with rats for resources, and managing the habitat to encourage them could indirectly solve rat problems. Field margin surveys were conducted to examine the distribution of small mammals, and identify habitat characteristics that are associated with rat populations. The results were inconclusive, although there was some evidence that dense ground vegetation favours some small mammal species and discourages rat colonisation. In later trials, reducing cover and harbourage around farm buildings reduced rat activity and survival, and compared well with rodenticide use in terms of efficacy and labour input.

By reducing cover around farm buildings, good results were achieved within a short space of time. However, the technique is likely to be more useful as part of a long term strategy, whereby greater consideration is given to making the farm environment less suitable for rats, without reducing the quality of the habitat for other species. It is unlikely that a resource management approach would not include the use of other methods, including limited use of traps and rodenticides where necessary. However, less emphasis on rodenticides could potentially offer long-term benefits in the form of reduced risks to non-target wildlife and help to limit the spread of resistant rat populations.

1. General introduction

1.1. The origin and distribution of rats in Britain

Two species of rat are found in Britain; the black rat (*Rattus rattus*), which is also referred to as the ship rat (**Figure 1.1**) and the Norway rat (*Rattus norvegicus*), which is also known as the common rat or brown rat (**Figure 1.2**). Black rats are native to the southeast Asian mainland, the islands of Indonesia, and the Philippines (Brooks, 1973), and until relatively recently it was assumed that they were absent from western Europe until the early Middle ages (Corbet and Southern, 1977). However, the discovery of black rat bones in Roman deposits in York (Rackham, 1979) and subsequently from stratified Roman deposits at other archaeological sites in England (Armitage *et al*., 1984), suggests that they have been present in Britain for at least 2000 years. More recently, it has been suggested that black rats may have been introduced to Britain on more than one occasion, as they have been found from deposits dated to the Roman and Viking periods, but not from deposits between those periods (O'Connor, 1991). Certainly, by the 13th and 14th centuries, black rats were common in most cities in Western Europe, and were indirectly responsible for the devastating spread of bubonic plague throughout medieval Britain, although this was not recognised until many years later. Black rats were once widespread throughout the British Isles, but are now limited to a few small populations, such as that on the island of Lundy in the Bristol Channel (Smith *et al.*, 1993), the subject of a recent control operation to eradicate all rats from the island.

Figure 1.1. The black rat (*Rattus rattus*), also known as the ship rat.

The Norway rat is a much more recent introduction, and can be distinguished from the black rat by its smaller ears, shorter tail, and blunt snout. Coat colour is not always a reliable means of identification, as black rats can be much lighter in colour than Norway rats, as well as darker. The Norway rat is thought to be native to the Steppe lands and grassy plains of Central Asia, and was not recorded in England until 1728 (Brooks, 1973). Exactly how Norway rats arrived in England is unclear, and for a while there was speculation that they had been introduced, as their name suggests, from Norway (Twigg, 1975). However, there is no evidence that Norway rats were present in that country before they were found in England. Its arrival coincided roughly with that of George I in 1714, and for a while the Norway rat became known as the Hanoverian rat, some were even convinced that the ‘new’ rat had been conveyed in the same ship as the monarch.

Whatever its means of arrival, once in Britain the Norway rat spread rapidly. By 1762, it had reached Anglesey, where it is said to have eaten the standing corn while men were reaping it, and by 1776 Norway rats were reported to be tunnelling under houses in Selkirk to such an extent that the residents were concerned for the safety of the buildings (Twigg, 1975). For a while Norway rats existed alongside black rats, although historical accounts suggest that there was a degree of spatial separation between the two species. In 1768 Robert Smith, who was the official rat-catcher to Princess Amelia in London, noted in ‘The universal directory for taking alive and destroying rats and all other kinds of four-footed and winged vermin in a method hitherto unattempted: calculated for the use of the Gentleman, the farmer and the warrener’ that the black rat lived in ceilings, but brown ones in sewers (Twigg, 1975). Despite living in such close proximity it was clear that the two species were not equally matched in combat, and the Norway rat certainly appeared to be more aggressive. Having caught Norway rats in the cellar of a house, and black rats in the attic, the Royal rat-catcher placed them in a large cage to provide evidence of his work to his employer, whereupon the Norway rats are said to have killed and ate the black rats immediately. Thus it has often been suggested that Norway rats were responsible for the decline of the black rat through persecution. However, other authors have noted that the two species will co-exist in relatively close proximity, each occupying its slightly different niche. Barnett (1955) reported that wild-caught adult male rats could be maintained in mixed species colonies, and that black rats would share nest boxes with Norway rats. Hence it seems that the decline of the black rat in Britain may not have been

directly due to aggression from the Norway rat, but from indirect activity, such as interference competition, or from a change in the environment that favoured the Norway rat over the black rat. The black rat is probably less well adapted to environmental conditions in the UK due to its tropical origins, and may well have been simply out-competed by the Norway rat, which is better adapted to life in temperate regions.

Whether the decline of the black rat was directly or indirectly due to the spread of the Norway rat is still a matter of conjecture. However, if environment was the reason why *R. norvegicus* was able to prosper while *R. rattus* declined, the range of the latter may expand in future if climate change shifts the balance of favour. Whatever the reason for its success, the spread of the Norway rat in Britain must count as one of the most rapid of any introduced species. Norway rats are distributed throughout almost all parts of the UK, although they are absent from some offshore islands and mountainous regions. Accurate population estimates are difficult to obtain on a national scale, and recent reports of 60 million rats in the UK are likely to be an overestimate. However, some evidence suggests that the number of rats in Britain is still increasing. In recent surveys carried out by the National Pest Technicians Association, many Local Authorities reported a recent rise in the number of rat infestations (Sheard, 2000; Sheard, 2001; Sheard, 2002) although whether this reflects short-term fluctuations or a sustained increase is still unclear.

Figure 1.2. The Norway rat (*Rattus norvegicus*) also referred to as the common rat, or brown rat.

1.2. Links between the ecology and control of Norway rats on farms

Norway rats in the UK are predominantly commensal, in both rural and urban areas. Their close association with man means that rats are an important pest for both economic and public health reasons. Rat populations on farms cause economic losses through spoilage of stored crops, damage to farm equipment, and even damage to the farm buildings in the longer term. Norway rats also carry a variety of parasites, viruses and bacteria, which represent a potential health hazard for the farmer, farm workers and livestock. In a survey of rat populations on farms in Oxfordshire, Webster

and MacDonald (1995) found 13 zoonotic and 10 non-zoonotic parasitic species in Norway rats, including *Cryptosporidium parvum*, *Pasteurella spp.*, *Listeria spp.*, *Yersinia enterocolitica*, *Coxiella burnetii* and *Hantavirus*. Farms can support particularly large numbers of rats (**Figure 1.3**) and landowners are obliged under the Prevention of Damage by Pests Act (1949) to ensure that their premises are kept rat-free. The need to control rat populations has driven research into many different aspects of Norway rat ecology, and much of the behavioural work on wild rat populations has been carried out from a control perspective. Therefore, much of what we know about the ecology of wild rats is related to the efficacy of rodenticide treatments on farms. It is not within the scope of this thesis to provide a complete account of the ecology of the Norway rat, but an overview of some aspects relevant to control may be useful.

Early work focussed on the ecology of populations. Middleton (1954) and Brodie (1981) observed populations of rats in the agricultural environment and found that arable field margins often become infested with Norway rats, especially during late summer and early autumn when cereal crops are ripening. Furthermore, Huson and Rennison (1981) found that rat populations on farms are rarely static; infestation levels around farm buildings tend to fluctuate throughout the year, probably in response to food availability.

Figure 1.3. Norway rats congregating at night to drink rainwater from the valley gutter of livestock sheds.

Technological advances in the late 1970s and early 1980s lead to the use of radio-transmitters to gather data on the movement patterns of individual rats on farms. A pilot study demonstrated the usefulness of this technique, and confirmed the dynamic nature of rat populations; some rats were found to cover large distances within a relatively short space of time, one male rat moved 3.3 km at speeds of 0.5 - 1.1 km hr^{-1} in a single night (Taylor and Quy, 1978). Furthermore, Taylor (1978) found that rats living in field margins frequently alternated between several home sites, and some rats regularly

covered large distances. The average home range length of male rats was found to be 660 m, almost twice that of females. On average, males changed their home site every seven days, more frequently than females who changed home site every 14 days. Rats living near artificially maintained food sources in the field margins had much smaller home ranges than other rats, and rarely moved more than 30 m. Surprisingly, when the artificial food sources were removed, rats did not migrate to nearby farm buildings, as earlier studies predicted, possibly because of antagonism from rats already resident in those areas. Instead, rats adhered to areas that were familiar to them, even in times of apparent food deprivation, but expanded their range to include other food sources. A subsequent study (Hardy and Taylor, 1979) confirmed that rats living near food sources had smaller home ranges than rats in open farmland. It was also found that rats do sometimes migrate to farm buildings, as a male rat, which had made foraging trips to farm buildings, established a nest site there, displacing a smaller male. Later work by MacDonald and Fenn (1995) reinforced the view that rats in resource-rich areas occupy smaller home ranges.

Fenn *et al*. (1987) used radio tracking to monitor the behaviour of a population of rats on a farm in Oxfordshire, and found that a better understanding of rat movements on the farm enabled them to carry out a targeted and efficient control program. It was found that a single bait point, placed at a focus of rat activity, gave a high level of control. More recently, studies using passive integrated transponder (PIT) tags have revealed

information about the behaviour of individual rats at bait points. PIT tags are small enough to be implanted quickly and easily into juvenile and adult rats in the field, and can be used to identify individual animals passing through an energised reader. Using a system of PIT tag readers and data loggers, Quy *et al.* (2003) were able to monitor the activity of individual rats as they fed from a bait container and baited burrows in the field. Most rats made very short visits to the bait box; the median visit length was just 14 seconds for male rats and 18 seconds for females. Curiously, rats feeding alone made shorter visits to the bait box than those feeding in groups. This is important from a control perspective as small bait containers that discourage group feeding are likely to reduce visit length, leading to lower bait uptake, and higher rates of bait transfer.

Studies of rats living in semi-natural enclosures have also provided useful information on particular aspects of rat behaviour. The reluctance of rats to approach novel objects such as bait containers, and their cautious sampling of novel foods, often referred to as neophobia, is well documented, and may cause control problems in the field (Shepherd and Inglis, 1987; Cowan *et al*., 1994; Brunton, 1995).

Much has been learned about the ecology of rats in the agricultural environment, although there are still many gaps in our knowledge. An understanding of the ecology of rat populations, and of course the behaviour of individuals within those populations, is crucial when interpreting

rodenticide efficacy data, and is the key to developing control approaches that are both effective and environmentally sensitive.

2. Control options in the agricultural environment

2.1. The use of rodenticides

Lethal chemical control agents have been used to control rodent populations for hundreds, if not thousands of years. The earliest rodenticides were probably of botanical origin, obtained from plants such as henbane (*Hyoscyamus niger*) and hemlock (*Conium maculatum*). Red squill, a rodenticide derived from the bulbs of the Mediterranean plant *Urginea maritima,* was widely used as a rodent control agent in parts of Europe during the nineteenth century, although it may have been in use as long ago as 1500 B.C. (Freeman, 1954). Scillirocide, the active compound, is a highly toxic cardiac and nerve glycoside (Buckle, 1994), which is regarded as effective against Norway rats and house mice (*Mus domesticus*), although black rats appear to be less susceptible (Meehan, 1984). At concentrations lower than those used in rodenticide baits, red squill is unpalatable to most domestic species (Fitzpatrick, 1952) and usually induces vomiting. For these reasons, scillirocide is regarded as a relatively safe rodenticide, and it therefore scores well against Brooks' (1973) eleven criteria for an ideal rodenticide:

- It should be lethal in a normal amount of food
- It should be palatable to rodents
- The onset of symptoms should be slow to avoid bait shyness
- It should be specific to the target species

- There should be no difference in susceptibility to the compound due to variation in age, sex or strain
- There should be no secondary poisoning hazard
- Resistance should not develop
- There should be no danger to man and domestic animals
- It should be inexpensive
- It should be easily degraded in the environment
- It should be easily formulated

However, non-target animals that lack the emetic response are vulnerable to accidental poisoning. The main mode of death following a lethal dose of scillirocide is usually heart failure, although other symptoms of poisoning include convulsions, paralysis of the hind limbs and diarrhoea. The use of red squill is therefore regarded as inhumane, and its use as a rodenticide was banned in the UK under the Animal (Cruel Poisons) Act 1963. Another important disadvantage of scillirocide is its rapid mode of action. Onset of symptoms can be within two hours, and death usually follows within 24-48 hours (Meehan, 1984). It is therefore classed as an acute rodenticide, and can induce 'bait shyness' (Freeman, 1954). Rats lack an emetic response, and are therefore more vulnerable to poisoning than species that can expel toxic foods. Instead, rat feeding behaviour has evolved such that novel foods are sampled in small amounts, and in the context of rodenticide bait this will almost certainly represent a sub-lethal dose. If the onset of poisoning symptoms is rapid, rats associate the symptoms with the novel food and may avoid the food, or even the place where the food was

encountered, for months. Therefore, acute rodenticides only give good results if used after a lengthy pre-baiting period during which unpoisoned bait is used. Once the rats are feeding from the unpoisoned bait the rodenticide bait is introduced, in the hope that the rats will ingest a lethal dose before the onset of illness. Pre-baiting often takes 14 days or longer, and is therefore expensive. Furthermore, acute rodenticides will still give poor results if rats detect a difference between the unpoisoned and poisoned baits, or if any other changes are made following the pre-bait period, such as the position of bait containers. Consequently, acute rodenticides are now rarely used and the only acute rodenticide currently available for rat control on farms is ergocalciferol, vitamin D_2.

The problem of bait-shyness was overcome with the introduction of anticoagulant rodenticides, which are slow acting, and do not require pre-baiting. Warfarin was the first widely available anticoagulant rodenticide and was discovered following the isolation of a haemorrhagic compound from spoiled sweet clover hay (Link, 1944). Other similar hydroxycoumarin compounds such as coumatetralyl, and a series of indane-diones including diphacinone and chlorophacinone, were subsequently developed for rodent control (Buckle, 1993) all of which have a similar mode of action to warfarin. Because of their slow mode of action, anticoagulant rodenticides are considered relatively safe, as there is usually enough time to administer the antidote, vitamin K_1, if accidental poisoning is suspected. However, all anticoagulants are non-specific, and the widespread use of such toxic compounds represents a risk for non-target wildlife. Even when every

reasonable effort is made to prevent other animals from feeding on rodenticide baits, non-target species may still be at risk during control treatments. When used in the agricultural environment, rodenticide baits may be eaten by non-target animals such as voles or mice (Cox and Smith, 1990), these then represent a potential secondary-poisoning risk to predators or scavengers. Recent reports from the Defra Wildlife Incident Investigation Scheme (WIIS) suggest that a range of such species are exposed to anticoagulant residues during the course of rodent control operations, including red kites (*Milvus milvus*), buzzards (*Buteo buteo*), foxes (*Vulpes vulpes*), and badgers (*Meles meles*) (Barnett *et al*., 2002a; Barnett *et al*., 2002b). It was concluded that in many of these cases, the consumption of poisoned rodents was the most likely route of exposure. The number of incidents where the cause of death can be firmly attributed to anticoagulants is relatively small, and it is unclear what effect, if any, rodenticides are having at the population level. However, anticoagulant residues have been detected in British barn owl (*Tyto alba*) and polecat (*Mustella putorious*) carcasses (Newton, *et al*., 1990; Shore *et al*., 1999), causing concerns for the future of these species.

Anticoagulants revolutionised rodent control, and almost all rodenticide baits now contain an anticoagulant rodenticide. However, such widespread use has exerted strong selection pressures on rodent populations and therefore it is not particularly surprising that resistance has developed. Resistance to the first-generation anticoagulants emerged less than 10 years after warfarin was first introduced, and rats resistant to warfarin are now found in many

parts of the UK (MacNicoll and Gill, 1987; MacNicoll *et al*., 1996). In response to this, more potent 'second-generation' anticoagulant rodenticides such as bromadiolone and difenacoum were developed (Hadler and Shadbolt, 1975). However, in some areas resistance to these compounds has also been detected (Quy *et al.,* 1995). Anticoagulant resistance is a heritable trait (Greaves and Ayres, 1967) and so continued use of anticoagulants is likely to favour the spread of resistance through the selection pressures exerted. Resistance to the second-generation anticoagulant rodenticides is not yet widespread, although it is a problem that will become increasingly common with continued use. Resistant animals may also represent a greater secondary poisoning hazard to predators, as they are potentially carriers of rodenticide residues for longer periods than susceptible animals.

These problems have led to a re-evaluation of rodent control approaches, and a desire to develop environmentally benign, effective and humane alternatives to rodenticides. In tropical regions, great success has been achieved with non-chemical management techniques in recent years (Singleton *et al*., 1999) based on the concept of 'ecologically-based pest management' or EBPM (National Research Council, 1996). For example, synchronous planting of rice crops, in order to reduce the length of time that food is available to the pest species, is recommended as a way of controlling the rice-field rat (*Rattus argentiventer*) in Indonesia (Leung *et al*., 1999). Buckle (1999) argues however that the reluctance to use rodenticides may now be verging on ‘chemophobia’, and that some of the

‘environmentally friendly’ approaches may also have detrimental effects on a wide range of non-target taxa. Much has been done in recent years to improve the efficacy of rodenticide formulations. For example, the development of the more potent second-generation anticoagulants, such as difenacoum and bromadiolone, overcame some of the control problems caused by physiological resistance to the first generation anticoagulants such as warfarin. Some of the safety issues have also been addressed. The human taste deterrent Bitrex^{TM} is now added to many commercially available rodent baits for example, and the use of 'tamper-proof' bait boxes is becoming increasingly widespread. Despite the problems caused by resistance, and the potential threat to non-target animals, rodenticides undoubtedly have a place in practical rodent control programs; they are widely available and can often provide quick, albeit temporary results. However there are still many concerns regarding the ecological implications and long-term viability of an approach that relies entirely on the use of toxic compounds. There is therefore a need to explore alternative control methods that could form part of an integrated strategy in order to reduce reliance on rodenticides.

2.2. A non-rodenticide approach to Norway rat control on farms

The primary aim of pest management should be to reduce damage, rather than kill the pest (Smith, 1994) and a great deal of research effort has been directed at non-lethal rodent control methods, including the use of repellents and reproductive inhibitors. The use of ultrasonic rodent-repellent devices is particularly appealing, as in theory this approach offers a clean, safe long-lasting non-lethal solution. However, Meehan (1984) and Lund (1988) concluded that there is no convincing evidence that ultrasonic devices are effective, as any initial aversion is often overcome, especially if there are no attractive alternative habitats nearby. Chemical and biological inhibitors of reproduction have also produced relatively poor results in efficacy trials, usually because it is difficult to administer the fertility-suppressing agent to a sufficiently high proportion of the population. The delivery of immunosterilants by virus vectors is a novel approach that has met with some success (Singleton and Redhead, 1991) although public approval for the wide-scale release of modified viruses is unlikely.

Aside from environmental concerns, and issues associated with anticoagulant resistance, there are other, more fundamental, problems with rodenticide use and all other lethal control methods. The high reproductive output of rats means that any survivors can quickly re-populate a site following a partially successful rodenticide treatment. Also, given the ability of rats to migrate over long distances, immigration to a cleared site often occurs from surrounding populations. Even if complete elimination of the

pest population is achieved, it is very likely that re-invasion will occur if nothing is done to change the conditions that allowed the infestation to become established. This means that lethal rodent control measures have to be regularly repeated, which is undesirable for both economic and environmental reasons.

In order to find a more effective and economic long-term solution, we need to target the factors that allow rats to thrive in the agricultural environment. Given the high reproductive output of rats, and their ability to adapt to a variety of environmental conditions, why do they not inhabit every piece of available space on every farm in the land? We should ask why some habitats appear unsuitable for Norway rats, and identify the factors that limit rat populations. The limiting factors are likely to include key resources such as food, water and shelter, which to some extent can be controlled by rodent proofing, good hygiene and sanitation. In many cases however, rodent proofing is not economically viable, or possible without disruption of normal farming practices. The work outlined in this thesis was carried out in order to examine some alternative resource management strategies for rat control on farms. There are two main experimental themes;

1) Indirect resource management. Other small mammals in the agricultural environment may compete with Norway rats for resources such as food and shelter. Managing the farm environment to the advantage of a ‘less undesirable’ competitor species might offer an indirect means of controlling rats, especially in areas where large

numbers of potential competitors already exist, such as in field margins. In Chapter 3, work was conducted to identify the factors that influence the distribution of rat populations in field margins in order to formulate habitat management recommendations for these habitats.

2) Direct resource management. Removal of key resources such as food is an obvious, but generally impractical way of controlling rat populations. In Chapters 5 and 6, an alternative 'habitat management' approach was investigated whereby harbourage was selectively reduced. The impact of this approach on the survival and behaviour of rats was assessed.

In the final phase of the study, an assessment of habitat management techniques as a longer-term rat control strategy was conducted, and a resource management approach was compared with rodenticide use in terms of efficacy and labour input.

3. Competitive displacement as a rodent management tool

3.1. Background

The geographical range of a species is ultimately limited by its powers of dispersal within its physical environment. Within those physical limits, the range may be restricted through interactions with predators, parasites or competitive interactions with other animals. Competition may come from animals within the same species, intra-specific competition, or from members of a different species, inter-specific competition. Where two species have abutting, but non-overlapping ranges, a situation referred to as contiguous allopathy, it is usually assumed that the species involved are too similar in their ecological requirements for coexistence in the same area to be possible. Where the ranges of two similar species overlap, differences in habitat utilisation often occur, and in some cases it has been proposed that this segregation is caused by competitive exclusion, a concept introduced by Volterra (1926), Lotka (1932) and Gause (1934). For example, where voles of the genera *Microtus* and *Clethrionomys* occur, *Microtus* species tend to occupy grassland areas, whereas *Clethrionomys* species are usually confined to areas of forest or scrubland (e.g. Partridge, 1978). Cameron (1964) noted that this habitat segregation is maintained in areas where both genera are represented by at least one species, such as on the mainland of North America where *Microtus pennsylvanicus* is essentially a grassland dweller, and *Clethrionomys gapperi* inhabits forested areas. On islands off the coast of North America, Cameron (1958) found that in the absence of *C.*

gapperi, *M. pennsylvanicus* was found frequently in woodland areas, as well as its normal grassland habitat. It was suggested therefore, that the segregation of the two species on mainland North America was maintained by competitive exclusion. Evidence for this argument comes from Morris (1969) who removed *C. gapperi* from outdoor enclosures, and found that *M. pennsylvanicus* readily moved into the wooded areas. Conversely, when *M. pennsylvanicus* was removed from outdoor enclosures, *C. gapperi* moved into grassland, from which it had previously been absent (Grant, 1969). *M. pennsylvanicus* has also been shown to exclude another competitor, the prairie deer mouse (*Peromyscus maniculatus*) from grassland in the field (Hallet *et. al.*, 1983) and in enclosures (Grant, 1971). In other areas of North America, *P. maniculatus* is excluded from grassland by other microtines; *Microtus townsendii* in British Columbia (Redfield *et. al.*, 1977), and *Microtus ochrogaster* in Colorado (Abramsky *et. al*., 1979).

Two species of *Microtus* occur in Britain. *Microtus arvalis*, the Orkney vole, is confined to the Orkneys and the island of Guernsey, while *Microtus agrestis*, the field vole, is found throughout mainland Britain and on some of the Hebridean Islands. The genus *Clethrionomys* is represented by only one species in Britain; the bank vole (*C. glareolus*) which occurs throughout England, Wales and parts of Scotland. In mainland Britain, bank voles occur chiefly in woodlands, hedgerows and areas of low shrubs whereas field voles are found mainly in rough pasture and grassy field margins. It has been suggested that like their North American counterparts, *M. agrestis* excludes *C. glareolus* from grassland in Britain, although Löfgren (1995)

found that, at least in Sweden, there was little evidence for competition between the two species. As microtines have been shown to influence the distribution of several small mammal species in North America, it seems reasonable to ask whether they influence the distribution of other species in Britain. Although many studies have provided useful information on the habitat preferences of small mammals in Britain however, very few studies have sought to examine the influence of inter-specific competition on the distribution of those species. Bellamy *et. al.,* (2000) examined the role of road verges as habitat for small mammals in Britain and looked at how the density of several small mammal species in road verges was influenced by a number of habitat variables, including the presence of other small mammal species. They found only a weak negative correlation between the density of bank voles and field voles, and a weak positive correlation between field voles and wood mice (*Apodemus sylvaticus*). There was a strong positive association between the number of bank voles found and the number of wood mice.

In the farmed environment, very little is known about the relationship between field voles and other small mammal species. Taylor (1975) suggested that the absence of *M. agrestis* on islands off the coast of Britain might be one explanation for the quite different distribution of Norway rats on those islands, in the same way that the absence of *C. gapperi* on islands off the coast of North America allows *M. pennsylvanicus* to inhabit woodland. Taylor (1975) made particular reference to the Isle of Man where field voles are absent, and Norway rats occur frequently in hedges, banks

and ditches on pasture land. On mainland Britain rats are seldom found in hedges, banks or ditches on pasture land, possibly because field voles exclude them. Of course it is unlikely that field voles would be able to exclude Norway rats by physical aggression, however aggression is not the only means by which one species excludes another. For example there are several instances of exclusion between rodent species where interference with reproduction has been implicated. Lidicker (1966) reported that the spread of *Microtus californicus* to Brooks Island in San Fransisco Bay disrupted the normal reproductive activities of house mice (*Mus domesticus*) leading to the elimination of *Mus* from the island within 15 months. Similarly Barnett and Spencer (1951) found that a confined colony of black rats began to decline when Norway rats were introduced to the enclosure. Aggressive encounters were rarely seen and the decline of the black rats was attributed to the disruption of normal feeding and reproductive behaviour by the Norway rats. Black rats have not given way to Norway rats throughout their entire range however, as in tropical regions black rats are regarded as the superior competitor indicating that the ecological relationships between these two species are not clear-cut.

If field voles were found to influence the distribution of Norway rat populations by some means, it could offer the possibility of controlling Norway rat numbers by managing areas of the farmed environment specifically to encourage *Microtus*. This would be particularly useful in arable field margins, which often become infested with Norway rats during the summer months (Middleton, 1954; Brodie, 1981). Many of these rats

leave the fields after the harvest, although some field margins remain infested with small numbers of rats throughout winter. These scattered colonies exist as a potential source of autumn and winter re-infestation of cleared farm premises (Drummond, 1970; Huson and Rennison, 1981) and are often overlooked by pest controllers.

The ecology of some small mammal species within the agricultural environment has been studied in great detail, but interactions between species have been largely ignored. In particular, very little is known about the way in which Norway rats and other small mammals interact within the farm environment. The aim of this part of the study was to determine whether Norway rats and other small mammal species in Britain exhibit spatial separation within the agricultural environment. As the first study of the distribution of Norway rats in relation to that of other small mammal species within this environment, field margins in a variety of arable and pasture habitats were surveyed. If spatial separation between species were found during these surveys, further work would be required to identify which species were excluding the other. Of course it is important not to attribute segregation between species to competitive exclusion when the difference in distribution is simply due to different habitat preferences, therefore the physical and floral characteristics of the field margins were also surveyed.

It was hypothesised that Norway rats and other small mammal species would exhibit spatial separation in their distribution. Accordingly, the null hypotheses were that;

- Norway rats and other small mammal species would show no spatial separation within or between field margins.

- Norway rats and other small mammal species would be homogeneously distributed throughout the field margin environment regardless of changes in habitat characteristics such as hedgerow dimensions and vegetation.

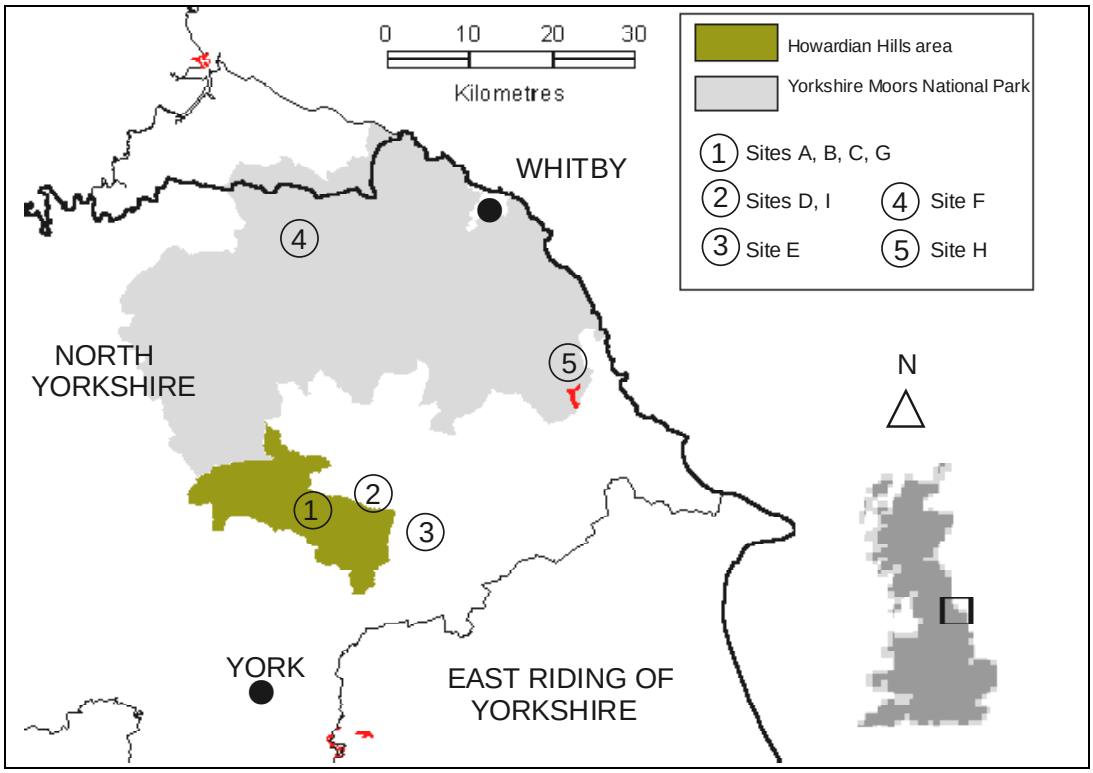
3.2. Materials and methods

3.2.1. Description of field sites

Sections of nine field boundaries were surveyed between June 1998 and October 1999. These were chosen to give a range of habitats within arable and pasture environments. Six of the sites were re-surveyed at intervals throughout the year to examine seasonal effects, whilst the three extra sites were surveyed only once and were included to give a greater range of habitats within the sample. **Figure 3.1** shows the locations of the nine field boundaries, which were on five farms in North Yorkshire. Boundaries A, B, C and G were on a mixed livestock and arable farm in the Howardian Hills 22 km north of York. Boundaries A and B ran along the southern and eastern edges of a 9.3 hectare arable field **(Figure 3.2)** and although these sites were close together, they differed in several respects. Boundary A **(Figure 3.3)** had a relatively narrow field margin and a discontinuous

hedgerow, consisting mainly of Hawthorn *(Crataegus monogyna)* with occasional Common Ash *(Fraxinus excelsior)*, Elder *(Sambucus nigra)* and Dog Rose *(Rosa canina)*, which had been cut within the last two years. Boundary B **(Figure 3.4)** consisted of a ditch, a relatively wide field margin, and a large, unmanaged hedgerow of Hawthorn, Blackthorn *(Prunus spinosa)*, Crab Apple *(Malus sylvestris)*, Hazel *(Corylus avellana)* and Common Oak *(Quercus robur)*. The ditch associated with boundary B rarely held water due to the slope of the land, although a shallow pond, fed by natural springs, drained into it towards the eastern corner of the field. Boundary C, approximately 0.5 km from the intersection of boundaries A and B, ran along the western edge of a 6.5 hectare arable field adjacent to a meadow grazed by sheep **(Figure 3.5)**. A narrow margin separated the arable field from an unmanaged hedgerow, consisting mainly of Hawthorn with occasional Elder, Alder *(Alnus glutinosa)*, Blackthorn and Common Oak **(Figure 3.6)**.

Figure 3.1. The location of field sites A - I



Field boundary G, approximately 250 m east of the intersection of boundaries A and B, ran along part of the western and northern edges of an 8.5 hectare arable field **(Figure 3.2)**. Along the section surveyed, the boundary consisted of a field margin, ditch and stock-proof fence along the western edge **(Figure 3.7)**, and a field margin, ditch and hedgerow mainly of Hawthorn along the northern edge. The ditch associated with the northern edge continuously drained water from springs in adjacent fields, although the ditch associated with the western edge was dry throughout the summer.

Field boundary D, 26 km north east of York, lay between a meadow, which was cut annually for hay, and a path adjoining a field of free range pigs **(Figure 3.8)**. The dense hedgerow consisted mainly of Hawthorn, with

Elder, Common Ash, Dog Rose, Dogwood *(Thelycrania sanguinea)*, Hazel, Blackthorn and Gooseberry *(Ribes uva-crispa)* **(Figure 3.9)**. Boundary I, approximately 250 m east of site D, ran along the southern and eastern sides of a 2.8 hectare arable field **(Figure 3.8)**. A dense hedge, mainly of Elder, with Blackthorn, Hawthorn, Hazel, Dog Rose, Dogwood and Common Ash, ran along most of the section surveyed.

Field boundary E, near the eastern edge of the Yorkshire Wolds, lay between an 8.9 hectare arable field, and 8.5 hectares of cattle pasture **(Figure 3.10)**. A stock-proof fence separated the two fields and a discontinuous hedgerow, mainly of Hawthorn, with occasional Dog Rose, Elder and Blackthorn, ran along most of the section surveyed. A strip of deciduous woodland adjoining the pasture consisted mainly of Elder and contained several pheasant feeders, which were filled with wheat from autumn through to spring. Field boundary F, on the North Yorkshire Moors, lay between cattle pasture and an uncultivated meadow for approximately half of the section surveyed, and between cattle pasture and arable land for the remainder. The meadow and pasture were separated by a dry stone wall **(Figure 3.11)** while the arable field was separated from the pasture by a tall, unmanaged hedgerow of Hawthorn, Dog Rose, and Elder **(Figure 3.12)**. Field boundary H, on the eastern edge of North Yorkshire Moors, lay between two 4.5 hectare arable fields **(Figure 3.13)**. A dense hedge, mainly of Hawthorn, and narrow field margin separated the fields **(Figure 3.14)**.

Figure 3.2. The position of field boundaries A, B, C and G.

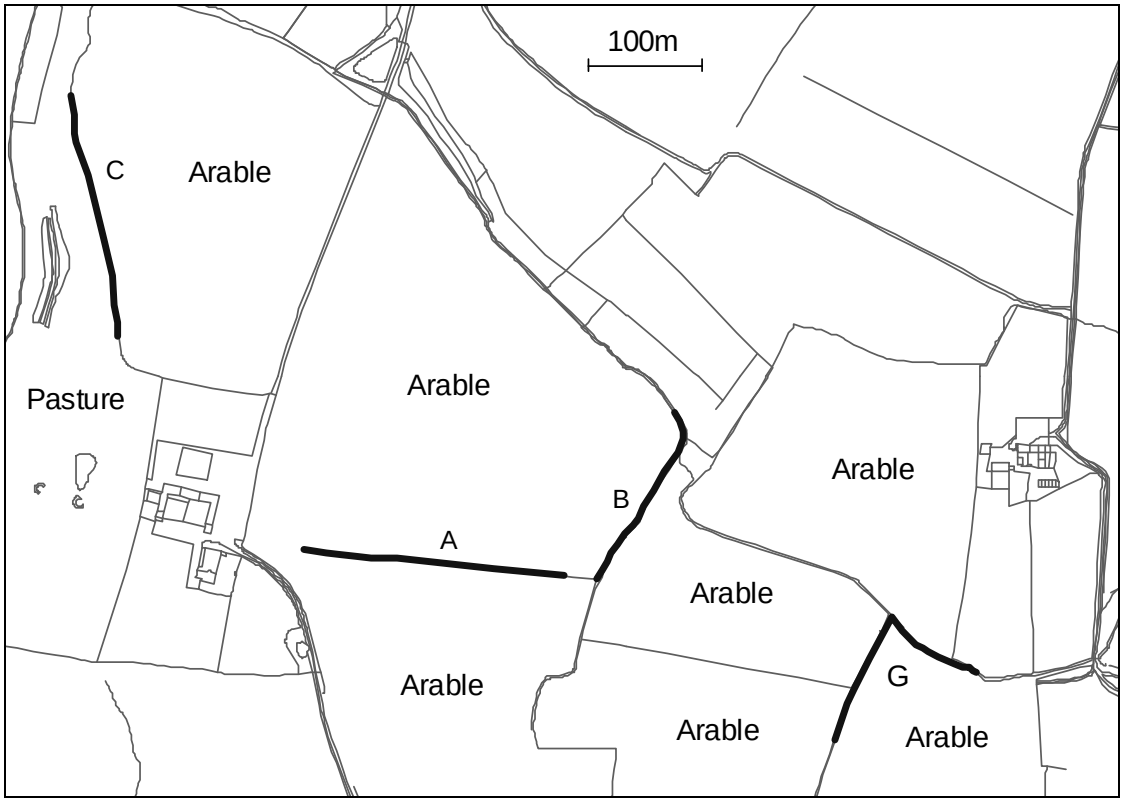


Figure 3.3. Site A, northern side, during early spring.

Figure 3.4. Site B, from the south, during early spring.

Figure 3.5. Site C, western side, during summer.

Figure 3.6. Site C, eastern side, during early spring.

Figure 3.7. Site G, from the north, during autumn.

Figure 3.8. The position of field boundaries D and I.

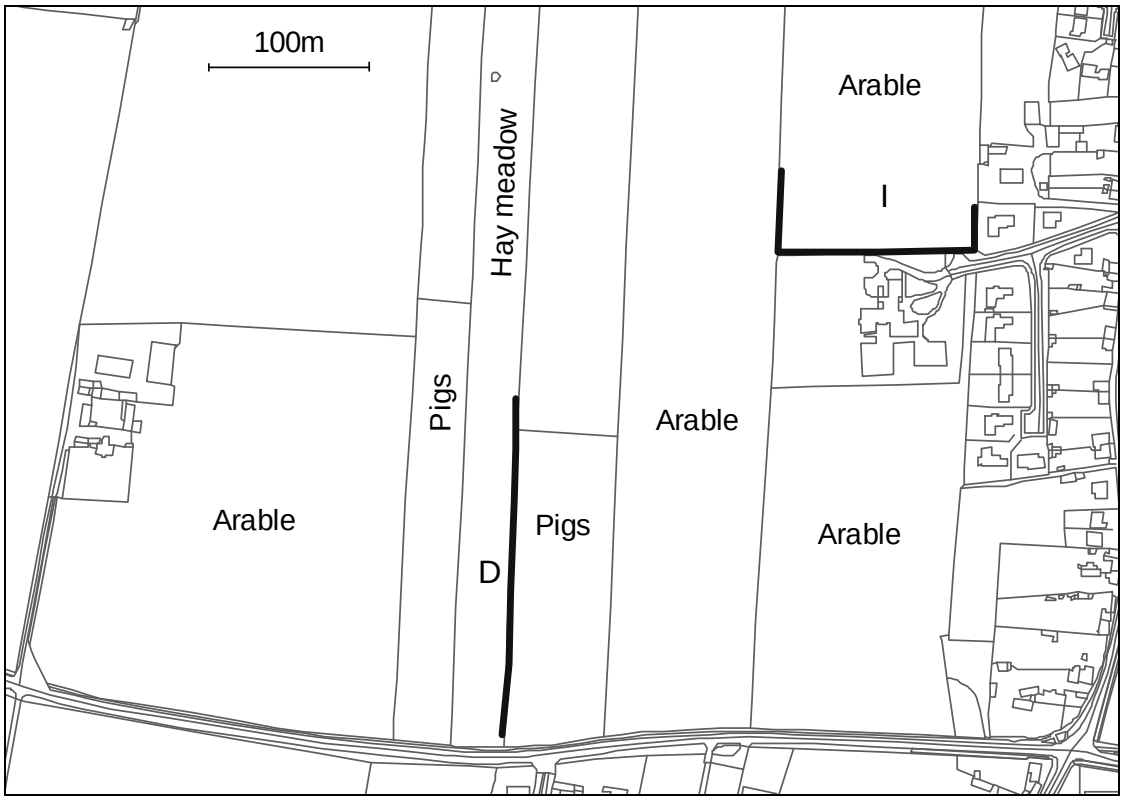


Figure 3.9. Site D, western side, during late summer.

Figure 3.10. The position of field boundary E.

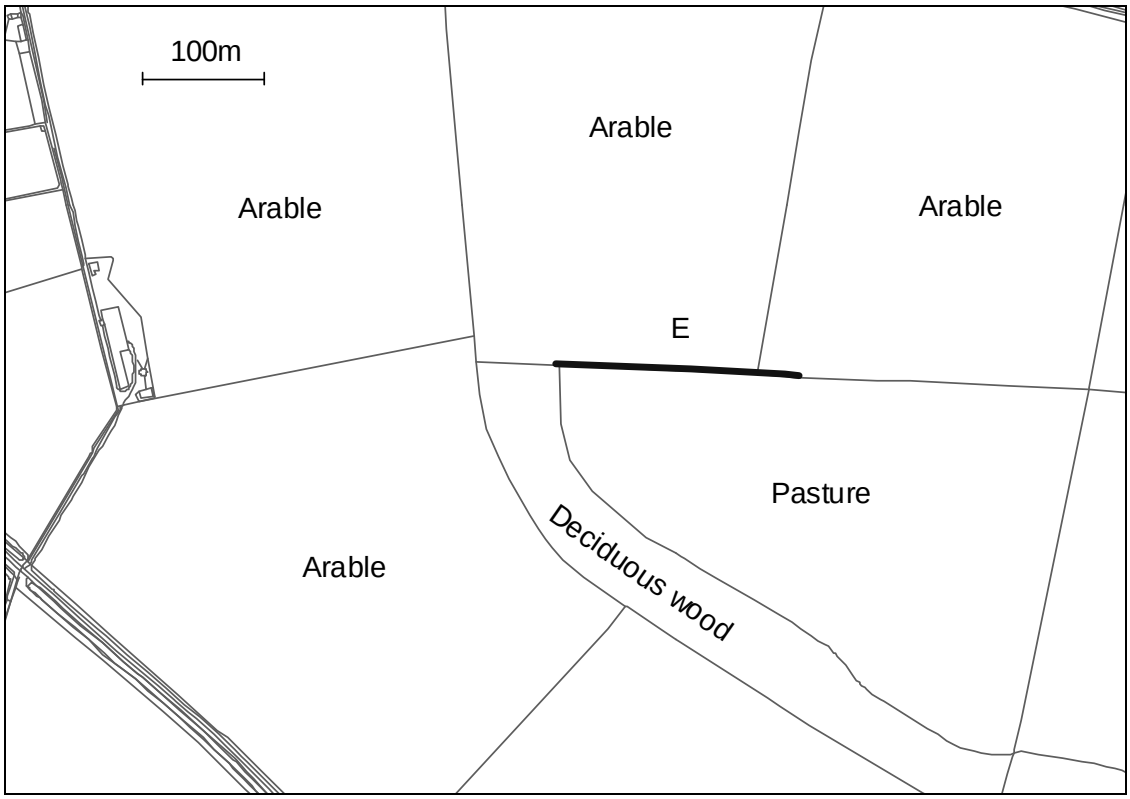


Figure 3.11. Site F, from the west, during summer.

Figure 3.12. Site F, from the north, during summer.

Figure 3.13. The position of field boundary H.

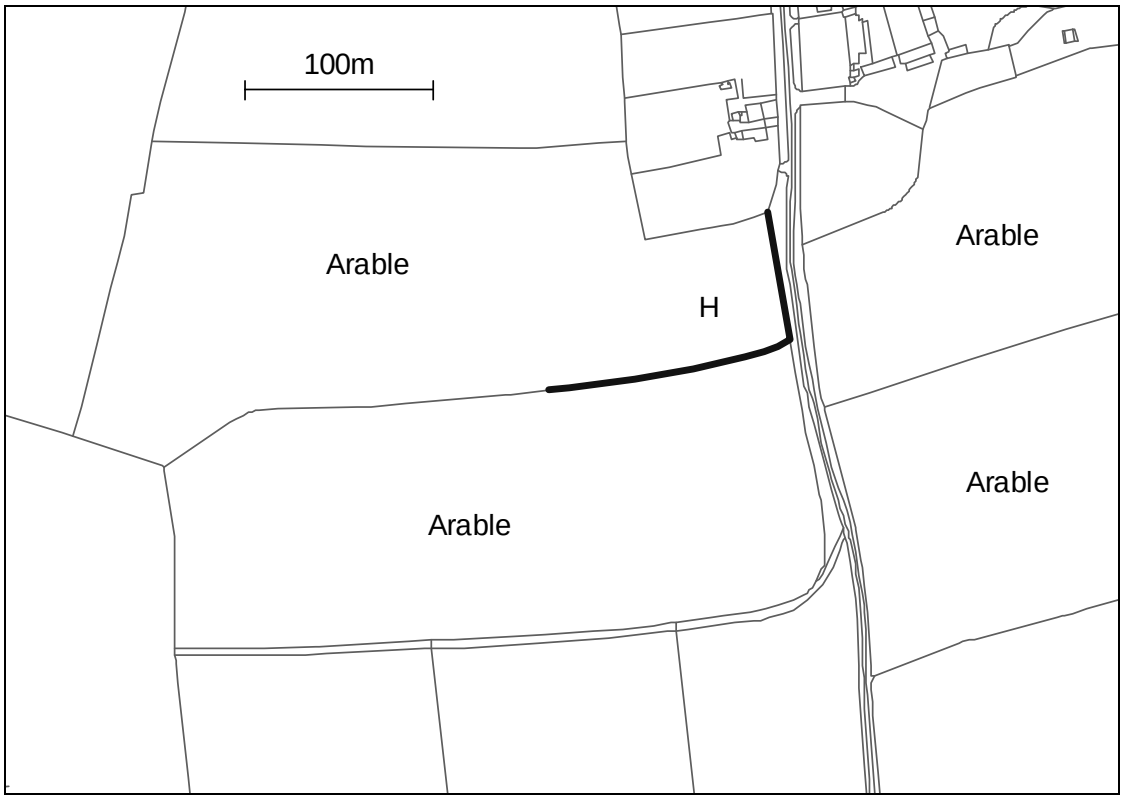


Figure 3.14. Site H, from the east, during autumn.

3.2.2. Sampling small mammal populations

On each site, small mammals were trapped over four consecutive nights (a trapping session) using pairs of Longworth live-traps at 5 m intervals (trap points) along a section of the non-crop boundary. Although the same density of traps was used at each of the nine sites (two traps every 5 m, i.e. 400 traps km^{-1}), the length of the boundaries surveyed varied from 170 m (68 traps) at site B, to 230 m (92 traps) at sites A and D. The lengths of the other boundaries surveyed were; site C 86 traps (215 m), site E 82 traps (205 m), site G 84 traps (210 m), sites F, H and I 80 traps (200 m). Trapping at sites A-D was carried out during summer 1998, and repeated during autumn 1998, winter 1998/1999 and spring 1999. Trapping was carried out at sites E and F in winter 1998/1999, spring 1999, summer 1999 and autumn 1999. Sites G, H and I were surveyed once only; site G in winter 1999/2000, site H in autumn 1999 and site I in summer 1999. The number of traps used, multiplied by the number of nights that they were set, gave a total trapping effort of 8,976 trap nights.

Gurnell and Flowerdew (1982) provided a detailed introduction to the use of Longworth traps, forming the basis of the procedures used here. Whole wheat and blowfly pupae were used as food in the traps and fresh hay was provided as bedding. The traps were set with the entrances angled slightly downwards to prevent the ingress of rainwater. Even so, the bedding sometimes became damp due to condensation and was changed as necessary. The distribution of small mammals within a field boundary is

likely to reflect the heterogeneous nature of these environments. For example, we might expect that species that are generally associated with woodland habitats, such as the wood mouse, would be caught more frequently in traps positioned near to the hedgerow, and less frequently in ones away from the hedgerow in the grassy field margin. Therefore, care was taken to avoid this possible sampling bias by not positioning disproportionately high numbers of traps in either the hedgerow or field margin component of the boundary.

The traps were checked twice daily. A trap with a closed door was placed unopened onto a portable electronic balance (Ohaus, Pine Brook, New Jersey, USA) and the weight recorded. The trap was then opened into a large, clear polythene bag so that the contents could be inspected. In order to reduce handling stress, shrews were released after identification, other species were carefully scruffed, sexed, given a fur-clip and then released. The bedding and uneaten food were then returned to the trap, which was weighed for a second time. Subtraction of this figure from the initial weight gave the weight of the small mammal, which was recorded along with the species, sex and trap number. All field data were recorded on waterproof paper (Gilling and Manwarring, Newark, Nottingham, UK). A handful of wheat and blowfly pupae were then added, and the trap returned to its original position and reset. The traps were washed using a mild solution of detergent, rinsed thoroughly and dried between trapping sessions, but not washed during trapping sessions.

3.2.3. Determining the size and distribution of rat populations

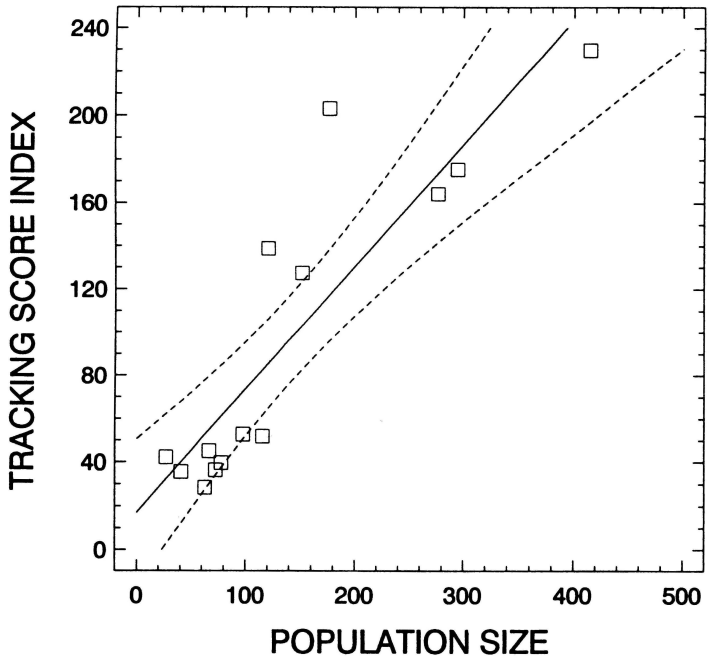
For rats, the capture-mark-recapture (C-M-R) census technique may cause disruption to the study population, as traps require a pre-baiting period to overcome neophobia. This may attract rats from outside the study area, distorting the census; therefore indirect methods that measure changes in levels of rodent activity are preferred (Taylor *et al*., 1981). Quy *et al.* (1993) refined earlier attempts at using tracking plates to monitor Norway rat activity and calibrated the technique against rat populations of known size on farms in central southern England. In the calibration study, carbon coated tracking plates were used at a density of 400 plates ha^{-1} and scored over four consecutive nights using a four-point system. An assessment was made of the proportion of the tracking plate covered in rat footprints; no prints = 0, 1-25% of the plate covered = 1, 26-95% covered = 2 and 96-100% covered = 3. The scores were then summed to give a daily total and the average of these totals over the four nights gave an index of activity. The Norway rat population on each of the 14 farmsteads was then trapped out to determine the actual population size. There was a significant relationship between the activity index and the actual population size and a linear regression ($r^2 = 0.78$, $p \leq 0.0001$) was fitted to the data giving;

$$y = 1.77x - 30.21$$

Where; y is the population size, and x is the tracking score based on the four-point scoring system. The tracking plate technique was hence

calibrated for populations of between 20 - 400 rats and 95% confidence limits were calculated which suggest that the technique is most accurate for populations in the middle of these limits. A tracking score index of 120 for example gives a population estimate of 182 ± 40 rats **(Figure 3.15)**.

Figure 3.15. Calibration data from Quy *et al*., (1993); the relationship between tracking score index and population size of Norway rats in southern England, 1985-1988.



In practice, this equation leads to negative estimates of population size for populations of less than 27 animals. The regression was therefore recalculated through the origin (as zero populations inevitably produce a zero tracking plate score) giving a line with the equation $y = 1.56x$. Hence, estimated population size (y) is simply the tracking plate score (x) multiplied by 1.56.

For the present study, tracking plates were made by applying clear, self-adhesive film (available from stationary suppliers as book-binding film) to 100 mm by 200 mm pieces of light-coloured vinyl floor tile. Activated carbon powder (Lancaster Synthesis Ltd., Morecambe, Lancashire, UK) suspended in industrial methylated spirit (~25 g litre^{-1}) was then brushed onto the plastic coated side of the tile. This was done in a dry atmosphere, ensuring adequate ventilation when indoors. The methylated spirit then evaporated to leave a thin layer of carbon powder on the tile, which was weather proof once dry. Two tracking plates were placed at each trap point in positions where they were most likely to record rat activity, i.e. at the entrances to rat burrows or on rat runs where possible, but usually within 1 m of a Longworth trap. The plates were inspected daily during each trapping session and repainted as necessary. In total, 8,976 tracking plates were deployed.

In the present study, tracking plates were placed near the Longworth traps to indicate the presence or absence of rats at each trapping point. The probability of capture next to a marked tracking plate *p* (m) was calculated for each small mammal species as;

$$p\,(\mathrm{m}) = \frac{n}{r}$$

Where; *n* is the number of individuals (including recaptures) caught next to tracking plates marked by rats at sites A-I, and *r* is the number of tracking plates marked by rats at sites A-I.

The probability of capture next to an unmarked tracking plate *p* (u) was then calculated for each species as;

$$p\,(\mathrm{u}) = \frac{N}{U}$$

Where; *N* is the number of individuals (including recaptures) caught next to unmarked tracking plates at sites A-I, and *U* is the number of unmarked tracking plates at sites A-I.

As the plates were used at the density for which the technique was calibrated (four plates 100 m^{-2}, i.e. 400 plates ha^{-1}) the data were also used to give an estimate of the Norway rat population size for each trapping session. The tracking plates were scored each day during the trapping session using the four-point system devised by Quy *et al.* (1993). The scores were then summed to give a daily total and the mean daily score gave an index of rat activity. This was converted to an estimate of the number of Norway rats per kilometre of field margin (*y1*) using the formula;

$$y1 = \frac{1.56x}{b}$$

Where; *x* is the index of activity, and *b* is the length of field boundary surveyed (km).

3.2.4. Assessing field margin characteristics

Hedgerow height, hedgerow width, the total field boundary width and percentage ground cover were recorded at 10 m intervals along the non-crop boundary at sites A-D during summer 1998, and at sites E, F and I in summer 1999. Most measurements were taken using a 30 m surveyor's tape, although ranging poles were necessary for measuring the taller hedgerows. At the same time, a botanical survey was conducted at these seven sites by laying the surveyor's tape across the field boundary and identifying each plant species along the transect. Dicotyledonous plants and shrubs were identified to species level with the aid of Rose (1981), trees were identified to species level using Mitchell and Wilkinson (1988) and grasses were identified to at least genus level using Hubbard (1984). A full list of the species found at the seven sites is given in appendix A. Measurement of the physical characteristics was repeated during autumn 1998, winter 1998/1999 and spring 1999 at site A, winter 1998 and spring 1999 at sites B, C, D and during spring 1999 and autumn 1999 at sites E and F.

3.3. Results

In total, 1,195 small mammals were caught. With 8,976 trap-nights, this gave an overall trap success of 13.31%. Recaptures accounted for 40.6% (485) of the total, giving a maximum of 707 individuals from nine species of small mammal, not including rats. Excluding recaptures, 287 wood mice (*Apodemus sylvaticus*) and 145 bank voles (*Clethrionomys glareolus*) were caught, representing 40.6% and 20.5% of the catch respectively. Only 17 field voles (*Microtus agrestis*) were caught, two of these were recaptures. Three species of shrew were caught, 230 common shrews (*Sorex araneus*), 19 pigmy shrews (*Sorex minutes*) and five water shrews (*Neomys fodiens*), all including recaptures. Seven house mice (*Mus domesticus*) were caught including three recaptures, two harvest mice (*Micromys minutus*) and one weasel (*Mustela nivalis*). Three juvenile rats were also caught. **Table 3.1** gives the number of small mammals caught during each trapping session and the estimated number of Norway rats. For Wood mice, bank voles and field voles, the figures were calculated by dividing the number of unmarked individuals captured during the trapping session (the minimum number alive, MNA) by the length of boundary surveyed, giving MNA km^{-1}. The figures given for common shrews were calculated in the same way but recaptures could not be excluded, therefore the true population sizes are likely to be lower than those shown. For Norway rats, the figures shown are the tracking plate estimates of population size divided by the length of field boundary surveyed.

Where rats were encountered, well-defined footprints were often recorded on the tracking plates **(Figure 3.16)**. Of the 8,976 tracking plates deployed, 1,897 (21.1%) were marked by rats, 7,074 (78.8%) were unmarked, and 5 (0.1%) were unreadable. Of the marked plates, 75.2% (1,427 plates) were scored as category 1 (1-25% coverage), 24.2% (460 plates) were scored as category 2 (26-95% coverage) and 0.5% (10 plates) scored as category 3 (96-100% coverage). Rats were present throughout the year in three of the field boundaries (B, D and E) and present intermittently in two of the boundaries (A and C). Norway rats were absent throughout the year in field boundary F.

Figure 3.16. Tracking plate *in-situ* showing Norway rat footprints.

Table 3.1. The estimated numbers of small mammals (Longworth traps) and Norway rats (tracking plates) per kilometre of field boundary. For information on confidence limits associated with tracking plate estimates see section 3.2.3. Figures for shrews include recaptures, for other species recaptures are excluded. See over for key to species names.

Field margin	Season	*As*	*Cg*	*Ma*	*Sa*	*Nf*	*Sm*	*Mm*	*Rn*
	Spring	4	0	0	222	0	4	0	0
A	Summer	22	4	4	39	0	0	0	2
	Autumn	52	26	0	26	0	0	4	539
	Winter	30	13	22	9	0	0	0	0
	Spring	24	59	0	35	12	0	0	209
B	Summer	18	41	24	35	0	0	0	60
	Autumn	229	118	0	65	18	18	6	349
	Winter	112	47	12	6	0	18	0	603
	Spring	5	19	0	65	0	14	0	0
C	Summer	116	0	0	28	0	0	0	0
	Autumn	158	28	0	60	0	0	0	36
	Winter	51	23	0	33	0	0	0	0
	Spring	0	0	0	0	0	9	0	203
D	Summer	4	0	0	4	0	0	0	171
	Autumn	17	13	0	0	0	0	0	495
	Winter	26	0	0	0	0	4	0	273
	Spring	0	0	0	0	0	0	0	209
E	Summer	29	15	0	59	0	0	0	21
	Autumn	88	15	0	0	0	0	0	177
	Winter	20	0	0	0	0	0	0	226
	Spring	75	70	0	135	0	15	0	0
F	Summer	25	35	0	85	0	5	0	0
	Autumn	75	75	0	60	0	10	0	0
	Winter	50	95	0	45	0	0	0	0
G	Winter	48	29	14	5	0	0	0	562
H	Autumn	130	0	0	10	0	0	0	380
I	Summer	30	25	0	90	0	0	0	0

Key to Table 3.1.

As - *Apodemus sylvaticus*, wood mouse.

Cg - *Clethrionomys glareolus*, bank vole.

Ma - *Microtus agrestis*, field vole.

Sa - *Sorex araneus*, common shrew.

Nf - *Neomys fodiens*, water shrew.

Sm - *Sorex minutes*, pygmy shrew.

Mm - *Micromys minutus*, harvest mouse.

Rn - *Rattus norvegicus*, Norway rat.

Figure 3.17 shows the seasonal changes in Norway rat abundance in boundaries A-F. Most activity was recorded in autumn and least in summer. A similar pattern was seen in bank vole abundance, while wood mice were most abundant in autumn and least abundant in spring **(Figure 3.18)**. Common shrews were caught most frequently in spring and least often in winter. Field voles were only caught during the summer and winter surveys. **Table 3.2** gives the Pearson product-moment correlation coefficients for comparisons within the data set. Using this analysis, a value of 0 indicates no association, values approaching +1 indicate a strong positive association and values approaching –1 indicate a strong negative association. The correlation coefficients were compared with tables in Cohen and Holliday (1982) to determine whether the associations were statistically significant.

Figure 3.17. Mean number of Norway rats (*Rattus norvegicus*) in six field boundaries (A-F) in North Yorkshire 1998-1999. The number of rats in each field boundary was estimated by the tracking plate method. For information on confidence limits associated with tracking plate estimates see section 3.2.3

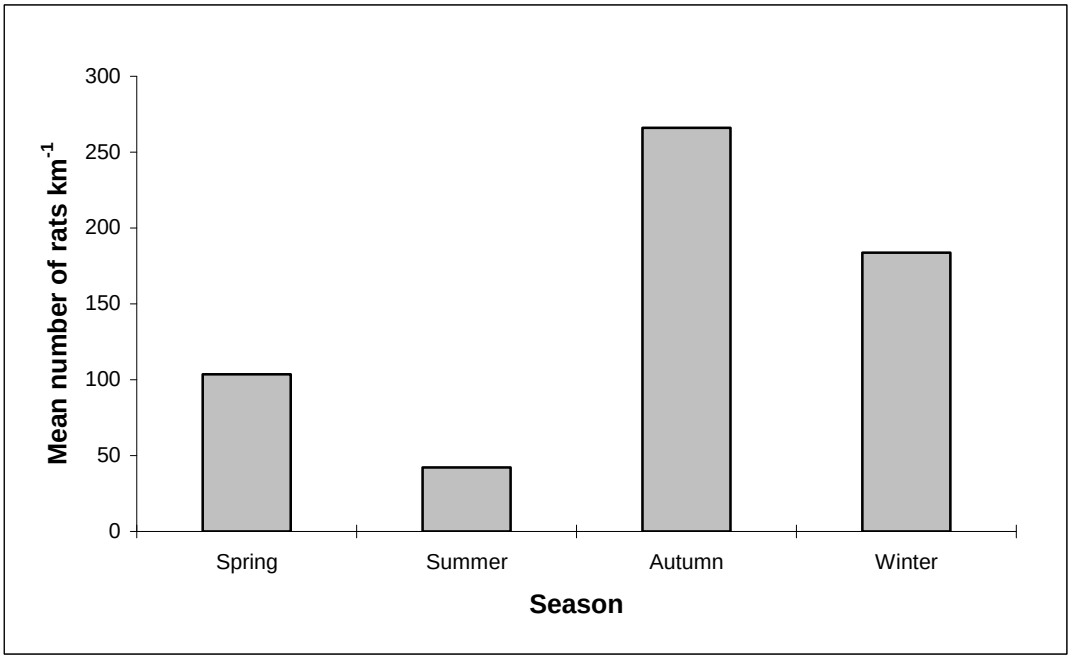
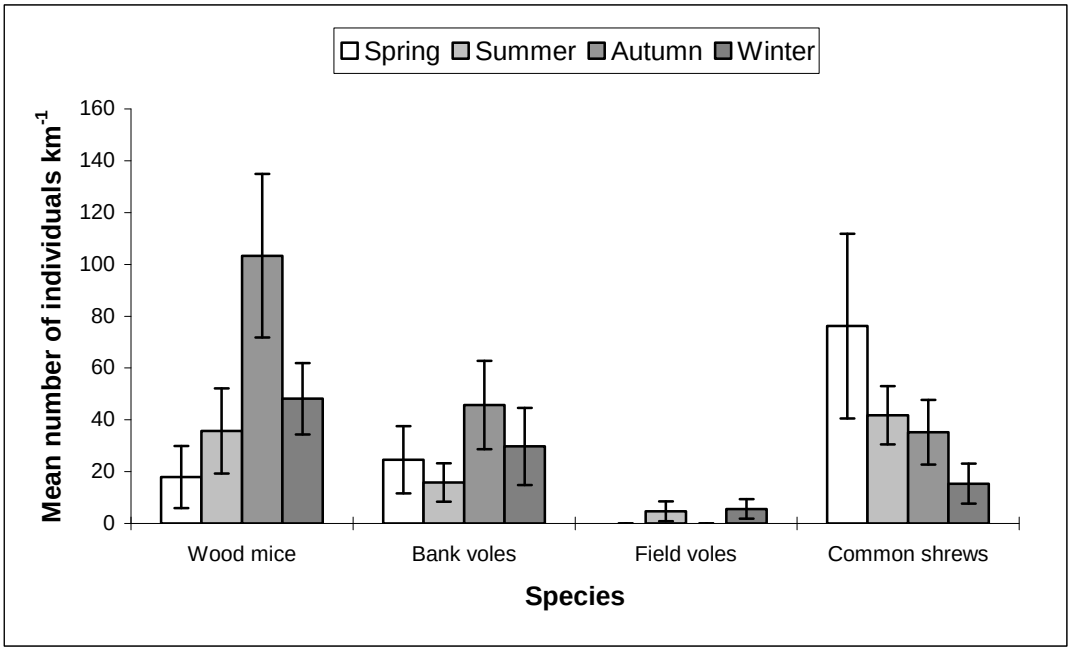


Figure 3.18. Seasonal variation in estimated small mammal abundance (from Longworth tapping) in six field boundaries (A-F) in North Yorkshire 1998-1999. Common shrews were not fur-clipped and therefore recaptures are included, for other species recaptures are excluded. Bars indicate ± 1 standard error of the mean.



The number of field voles per kilometre was not significantly correlated with any of the measured habitat variables. Wood mice were positively associated with taller, wider hedgerows ($r = 0.400$, $p \leq 0.05$ and $r = 0.453$, $p \leq 0.05$ respectively) and the number of plant species recorded ($r = 0.433$, $p \leq 0.05$). Bank voles were also correlated with taller, wider hedgerows ($r = 0.558$, $p \leq 0.05$ and $r = 0.500$, $p \leq 0.05$ respectively) but not with the number of plant species found. There was a strong positive association between bank voles and the total field boundary width ($r = 0.775$, $p \leq 0.01$). There was also a strong positive association between wood mouse and bank vole distribution ($r = 0.500$, $p \leq 0.01$). There appeared to be no association between the distribution of Norway rats and either wood mice or

bank voles. Common shrews were positively associated with ground cover (r = 0.471, $p \leq 0.05$) and negatively associated with Norway rats (r = -0.486, $p \leq 0.05$), which were negatively associated with ground cover (r = -0.505, $p \leq 0.01$). Where rats were present all year round, the number of common shrews caught was significantly lower than at sites where rats were absent for some or all of the year (**Figure 3.19**).

For wood mice, bank voles, field voles and pygmy shrews the probability of capture next to a marked tracking plate was not significantly different from the probability of capture next to an unmarked tracking plate. For common shrews the probability of capture next to a marked tracking plate was over five times smaller than the probability of capture next to an unmarked tracking plate **(Table 3.3)**.

Figure 3.19. The relationship between the presence or absence of Norway rats, and the estimated abundance (from Longworth trapping) of small mammals six field boundaries (A-F) in North Yorkshire 1998-1999. Common shrews were not fur-clipped and therefore recaptures are included, for other species recaptures are excluded. Bars indicate ± 1 standard error of the mean.

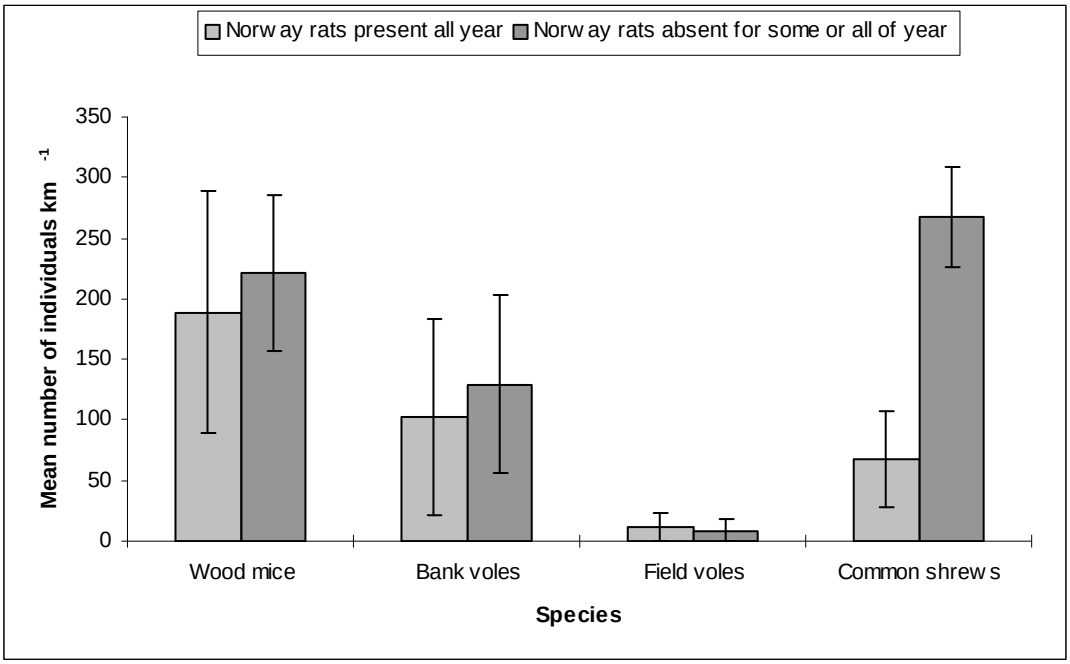


Table 3.3. The relationship between Norway rat distribution and the probability of capture for five small mammal species in nine field boundaries (sites A-I) in North Yorkshire; *p* (m) is the probability of capture next to a tracking plate marked by rats, *p* (u) is the probability of capture next to an unmarked plate.

	Wood mouse	Bank vole	Field vole	Common shrew	Pygmy shrew
p (m)	0.085	0.034	0.002	0.006	0.003
p (u)	0.067	0.030	0.002	0.031	0.002

3.4. Discussion

Two null hypotheses were generated at the beginning of this chapter. Firstly that Norway rats and other small mammal species would show no spatial separation within or between field margins. There was no association between Norway rat abundance and the size or distribution of wood mouse, or bank vole populations. However, common shrews were caught less frequently in field margins that had rat populations all year long, and were caught less frequently in traps next to tracking plates marked by Norway rats. We can therefore reject the first null hypothesis, as spatial separation between species was detected.

Common shrews and Norway rats would seem unlikely competitors, and any segregation between them is more likely to be related to differences in habitat preference. Large populations of common shrews were found to be associated with high levels of ground cover, while the reverse was true for rats. It is not clear whether the activities of rats reduce ground cover or whether they selectively colonise hedgerows with low levels of such cover; it may be argued that, for rats, digging burrows is easier on bare soil than if a dense mat of vegetation is present and movement is unobstructed. Provided a dense canopy of shrubs is present to protect them from the attentions of predators, habitats with low ground cover may be more attractive to rats. Norway rats and common shrews also showed seasonal differences in their abundance in field margins, so they were separated temporally as well as

spatially. Norway rats were more abundant in autumn and winter, while common shrews were more abundant in spring and summer. Shrews were not fur-clipped in this study, and recaptures cannot be excluded from the data. The higher abundance in spring and summer may be partially due to higher trapability at this time of year, although other studies have also recorded high densities in summer and low densities in winter for this species (Kotzageorgis and Mason, 1997; Churchfield, 1991). In the present study, wood mice and bank voles were more abundant in the autumn trapping sessions, indicating that both species use the arable fields to some extent, and retreat to the field margins following harvest.

The second null hypothesis generated at the start of the chapter was that Norway rats and other small mammal species would be homogeneously distributed throughout the field margin environment, regardless of changes in habitat characteristics such as hedgerow dimensions and vegetation. This hypothesis can also now be rejected, as several aspects of the hedgerow structure were found to significantly influence small mammal distribution. Wood mice and bank voles were positively associated with taller, wider hedges while common shrews were not. This is probably a reflection of the different feeding habits of these species. Tree seeds and rose hips from the hedgerow provide an important food resource for wood mice (Mallorie and Flowerdew, 1994; Pollard and Relton 1970) and bank voles (Eldridge, 1969) while common shrews feed almost exclusively on invertebrates (Churchfield, 1991). Bellamy *et al.* (2000) also reported a positive association between hedge height and the abundance of both wood mice and bank voles at

roadside study sites in Cambridgeshire. However, in a study of 23 arable hedgerows in Essex, southern England, Kotzageorgis & Mason (1997) found that the abundance of wood mice, but not bank voles, or common shrews was associated with taller hedges. They found no association between bank voles and hedge height during most of the year, and a negative association with hedge height in late autumn. They also found that bank voles were strongly associated with dense ground cover, and suggested that hedgerow height reduces ground cover by shading, thereby reducing the quality of habitat for bank voles. In the present study there was a fairly strong (but not significant) positive association between bank vole abundance and ground cover, and only a weak association between hedge height and ground cover. This suggests that bank voles prefer taller hedges as long as dense ground cover is available. Good ground cover was also found to be an important habitat requirement for common shrews, a finding reported from previous studies (Tew, 1994a). Wood mice were not associated with dense ground cover in the present study (also reported by Kotzageorgis and Mason, 1997), which is not surprising as this species is traditionally associated with woodland habitat. Wood mice are trapped in arable fields far more frequently than either common shrews or bank voles, which are confined to the field margins for most of the year (Tew, 1994b; Pollard and Relton, 1970). Despite the different associations with levels of ground cover seen in this and other studies, bank voles and wood mice exhibit significant niche overlap due to their similar diets. In the present study, there was a significant positive correlation between the abundance of bank voles and wood mice (also reported by Bellamy *et al.*, 2000). Time

partitioning may reduce interference competition between these two species (Gurnell, 1985), as the wood mouse is strictly nocturnal, whereas bank voles are active at least as much during the day as at night.

Field voles were not associated with any of the habitat features measured, which reflected their universally low abundance in all of the field margins surveyed. Sites C, D and F provided, at least in places, what appeared to be suitable habitat for *Microtus*. The reason why field voles were not found at any of these sites throughout the study may be due to the cyclic nature of microtine rodent populations. Petty *et. al.* (2000) reported that in Kielder Forest, northern England, field vole populations fluctuate on a three to four year cycle of abundance, a similar periodicity to fluctuations in central Fennoscandia (Hanski et. al., 1991). It seems therefore, that the current study, which had the main aim of investigating the relationship between field voles and Norway rats in field margins, may have coincided with a transitory period of low field vole abundance. During summer 2000, a study of small mammal populations in recently planted deciduous plantations near sites G and E of the present study, also found very low field vole densities (Banks, 2000). At first, this seemed unfortunate, but it could be viewed as a natural removal experiment. If habitat segregation depends on inter-specific interactions, the disappearance of competitors should involve a competitive release, leading to niche expansion and increased population size of the remaining species. Conversely, if habitat segregation is due to different habitat requirements, there should be no effect on population size and niche breadth (Grant, 1972; Keddy, 1989; Pianka, 1981). If Taylor (1975) was

correct in proposing that Norway rats are excluded from pasture in mainland Britain by competition from *Microtus*, the absence of field voles in the current study should have allowed Norway rats to expand into the areas from which they had been excluded. This did not appear to be the case at two field margins adjoining pasture in this study; site C, where Norway rats were absent for all but the autumn trapping session, and at site F, where rats were absent all year. This seems to suggest therefore, that other factors apart from field voles make pasture unsuitable for Norway rats in mainland Britain. In the absence of field voles, rats were present at site D throughout the year, a field margin separating a meadow, which was cultivated for hay, and a field of free-range pigs. Observations made at the time of the trapping sessions, suggested that rats in this field margin were feeding extensively from pig food hoppers in the adjacent field, and probably not utilising the meadow to any great extent. This suggests that Norway rats will live in areas adjoining grassland, but need a supplementary food source. Potentially, food resources such as seeds and invertebrates do exist in grassland to support small populations of Norway rats, which apparently survive on these resources in the Isle of Man and elsewhere. Populations of Norway rats living in coastal areas appear to survive quite well on a diet of invertebrates and vegetable matter (Drummond, 1960). The reason why rats do not exploit these resources on grasslands in mainland Britain, an apparently marginal, but adequate habitat, therefore remains unresolved.

The data presented in this chapter suggest that field margins in the agricultural environment should be managed to increase levels of ground

cover in order to deter colonisation by Norway rats. If possible, a dense and wide grassy field margin should be maintained. This practice is recommended in the Code of Practice for the Safe Use of Pesticides on Farms and Holdings (1985) to provide a buffer zone to absorb pesticide and fertilizer run off from arable fields, as well as encouraging higher numbers of common shrews, bank voles and potentially field voles. These species are well adapted the field margin environment, which may enable them to ‘mop up’ resources that would otherwise allow Norway rats to thrive.

4. The response of Norway rats to field vole odours

4.1. Background

In the previous chapter, no evidence was found for spatial separation between wood mice, or bank voles and Norway rats in arable field margins. As very few field voles were found however, it was not possible to look for direct segregation or overlap between these two species. If spatial separation does occur between Norway rats and field voles in the farm environment, one way in which this separation might be maintained is through odour cues. Odour cues are used by many rodent species to avoid predators and maintain spatial separation between their competitors. Field voles for example avoid traps marked with weasel (*Mustela nivalis*) or red fox (*Vulpes vulpes*) odours (Dickman and Doncaster, 1984; Stoddart, 1976), while the role of scent marking in competition between rodents of the same species has been extensively studied (e.g. Hurst, 1987). However, there have been few studies of the role of scent marking in maintaining spatial separation between rodents of different species. As the first investigation of the response of Norway rats to field vole odour, a series of trials was conducted in indoor enclosures to monitor the feeding behaviour of two colonies of Norway rats when field vole odours were introduced. Wood mouse odour was used as a positive control, as the previous chapter found no evidence for spatial separation between wood mice and Norway rats.

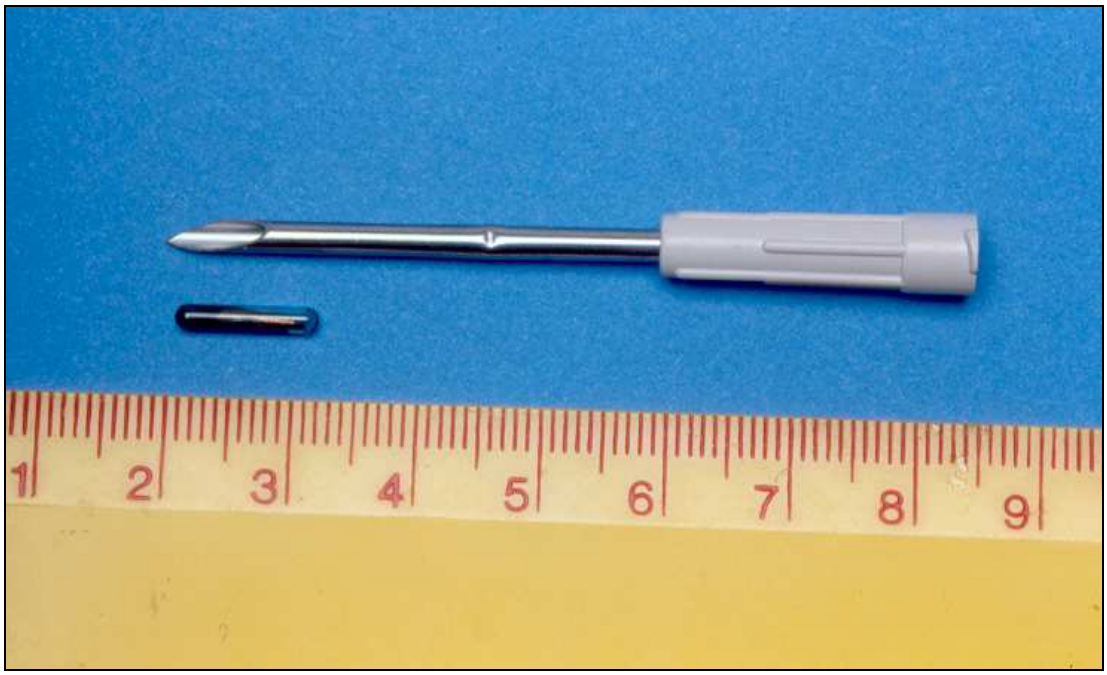
4.2. Materials and methods

Passive integrated transponder (PIT) tags were chosen to individually identify the rats, as they are a reliable, long-lasting and relatively low cost way of marking animals. The tag, consisting of a microchip and antenna encased in a biocompatible glass capsule, is implanted under the skin of the animal, using a sterile needle **(Figure 4.1)**. The individual identity code of the tag, set during the manufacturing process, can then be read using a hand-held reader, or other suitable equipment. PIT tags have been used in a variety of marking applications including the identification of pets and valuable livestock, and in wildlife research for marking mammals, fish, birds, reptiles and amphibians. The tags have no moving parts and no power source (they are inactive until energised by the reader) hence they need no maintenance and can last for many years. For some species, PIT tagging appears to be less reliable than existing marking methods (Rogers *et. al.,* 2002), although in many cases the technique is superior (Kerth and König, 1996; Parmenter, 1993). For rats the technique is particularly useful as external marking methods (such as ear tagging) are generally unreliable. Furthermore, large numbers of animals can be marked, as a large number of identity codes (more than 34 billion) are available (Nietfield, Barret and Silvy, 1996). The tags can also be used to study the movements of individual animals. In this case, a permanently energised array of readers in a fixed position, connected to a logging device, was used to record the identity code of any tagged rat passing within range. This equipment was

used to monitor the behaviour of two colonies of rats before and after the introduction of a field vole odour source.

Each trial was conducted using a family group of Norway rats living in an indoor enclosure measuring 12 m x 3 m. Introducing a group of adult wild-caught rats to the enclosures was not possible because of possible aggression between unfamiliar males or females. In each enclosure therefore, the family group was derived from three wild caught rats, one male and two females. The offspring of the wild-caught adults would not have been exposed to the odour of field voles or wood mice; therefore the experimental protocol relied on an innate response from the captive bred animals. This is not an unreasonable assumption, as there are many instances of innate responses to odour cues, especially where those cues have a strong biological relevance, such as sexual pheromones, or predator odours. Orkney voles (*Microtus arvalis*) avoid red fox and stoat (*Mustela erminea*) odours, despite geographical isolation from all mammalian predators other than the otter (*Lutra lutra*) since Neolithic times (Calder and Gorman, 1991; Gorman, 1984). After the first litter was weaned, the parents and their offspring were each injected with a PIT tag (Sokymat, Switzerland), which was implanted under the skin between the shoulder blades. This procedure was carried out under short-term general anaesthesia using Isoflurane (Abbott Laboratories Ltd., Queenborough, Kent, UK). Subsequent litters were removed from the enclosure.

Figure 4.1. PIT tag and needle.



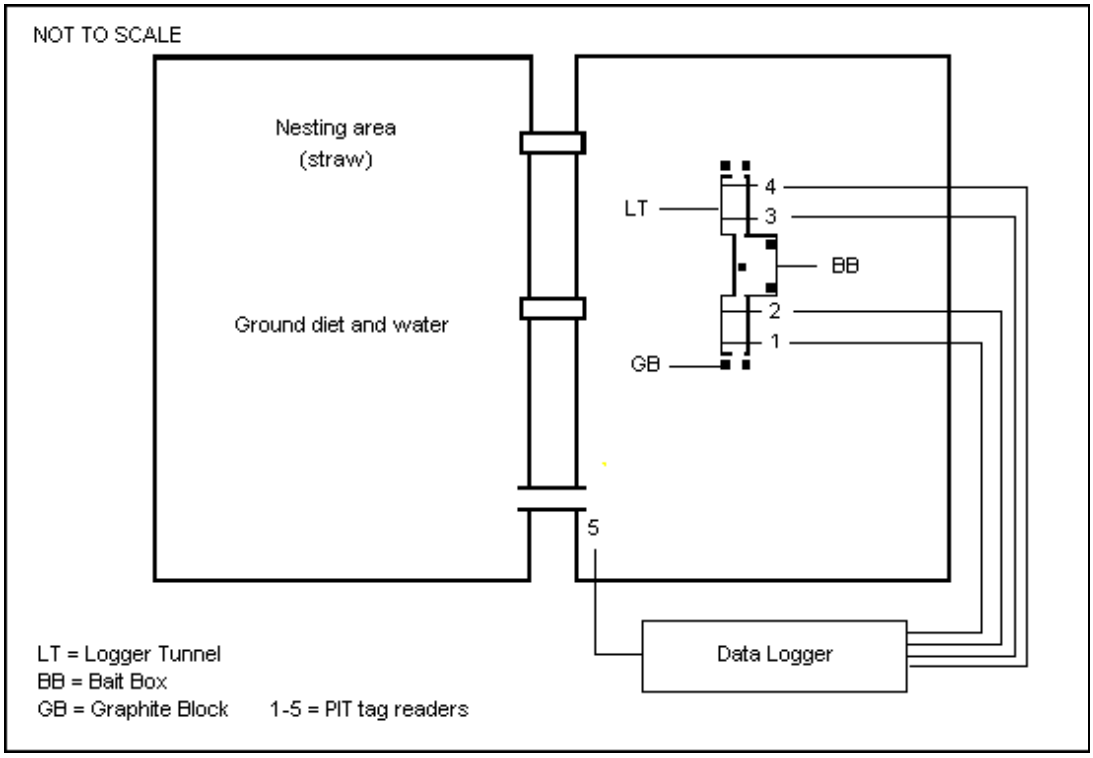
A drinking fountain and a tray containing ground GR3EK diet (Special Diet Services; SDS, Witham, Essex, UK) was provided near the centre of the enclosure, and hay was provided for bedding **(Figure 4.2)**. In an adjoining enclosure, a wooden bait box was fitted with two logger tunnels, each containing two PIT tag readers (Francis Scientific Instruments, Cambourne, UK). A fifth reader was placed at the entrance to the interconnecting tunnel to monitor the movements of rats from one enclosure to the other, each reader was then connected to a separate channel of a remote data logger **(Figure 4.3)**. The logger recorded the PIT tag identification code, channel number and time (to within 1/16 of a second) each time a rat passed within range of a reader. To enter the bait box, which contained whole wheat, the rats had to pass through one of the two logger tunnels, triggering a series of records on the data logger. From the timing of these events, it was possible

to track the movement of rats in order to establish which rats had entered the bait box, and how long they had stayed.

Colony A was allowed access to the second enclosure each day during the trial from late afternoon until the following morning. During an acclimation period, it was found that the rats readily entered the second enclosure and visited the bait box to gain access to the wheat, a favoured food. Once the logger records showed that every rat in the colony had entered either of the two logger tunnels, baseline data was collected over three consecutive nights.

Figure 4.2. Indoor enclosure for housing Norway rats.

Figure 4.3. For the arena trials, a wooden bait box, with two PIT tag readers enclosed in a wooden logger tunnel at each end, was placed in one of two indoor enclosures. Each night the interconnecting tunnel was opened to give rats access to the bait box.



For the baseline phase, seven clean graphite blocks were placed in and around the bait box **(Figure 4.4)**. Two blocks were placed 10 cm away from the entrance of each logger tunnel, and three blocks were placed inside the bait box. At the time of the trial, Colony A consisted of eight male rats and seven females. The males weighed between 350 g – 575 g, and the females weighed between 240 g – 390 g.

The blocks and bait box were removed each day and replaced with items of the same size and design that had been washed in a solution of mild detergent, rinsed and dried overnight. The positions of the bait box, logger

tunnels and graphite blocks were marked on the floor of the enclosure so that they could be replaced each day in the same positions.

Figure 4.4. Bait box, logger tunnels and graphite blocks

The blocks inside the bait box were also replaced in the same positions each day. On the fourth day, the graphite blocks were replaced with blocks that had been in cages with field voles for seven days. This was repeated on days five and six, replacing the bait box with a cleaned one each day. Seven pairs of adult field voles had each been given three blocks, giving the 21 scent marked blocks that were required. On days seven, eight and nine, clean blocks, and a clean bait box, were used for a second baseline phase. On days 10, 11 and 12, the graphite blocks were replaced with blocks that had been in cages with wood mice for seven days. Again, seven pairs of

adult wood mice had each been given three blocks, giving the 21 scent marked blocks that were required. Wood mouse scent was used as a control odour as the field margin surveys indicated that Norway rats do not avoid this species. On each day, the whole wheat was weighed and replaced with fresh grain from the same source.

The reaction of the rats to the two inter-specific odours was investigated by examining four response variables, the bait take, the number of visits to the bait box, the length of visits to the box and the latency of approach to the box. When an individual rat entered the bait box, a sequence of events was stored on the logger. In this case, for a single visit, the order of channel numbers would read either 1-2-3-4, 1-2-2-1, 4-3-2-1 or 4-3-3-4, depending on which direction the rat entered and left the box. In practice, these sequences often contained more records as the tag was recorded 16 times for every second it stayed within the field generated by the reader. For instance, the first of the above sequences might appear as 1-1-1-1-2-2-2-3-3-3-4-4-4-4, and the second sequence might appear as 1-1-1-2-2-2-2-2-1-1-1-1. **Figure 4.5** shows a small section of the output from a data logger connected in the same way as that in **Figure 4.3**.

The first record indicates that one of the male offspring, with the hexadecimal identity code 2A 21, was logged at the entrance to the arena (CH 5). The time that this event occurred can be calculated from the figures in columns T1, T2 and T3, which show time increments in multiples of 62.5 milliseconds, 16 seconds and 4096 seconds respectively. The value of 3 in

column T3, for instance, indicates that 3 x 4096 seconds had elapsed since the logger was started. This is added to the value in column T2 (23 x 16 seconds) and the value in column T1 (2 x 62.5 milliseconds) to give a total of 12656 seconds, or 3 hours, 30 minutes and 56 seconds after the logger was started. The same rat is recorded at an outer tunnel reader (CH 4) 33 minutes and 4 seconds later, and then at an inner reader (CH 3) 20 minutes after that. The rat then leaves the box the same way it went in, past CH 4.

The data for each night was analysed to determine how many valid channel sequences appeared for each rat, and hence the number of visits made to the bait box. The length of visit was taken as the time between the first and last events recorded at the inner readers for each visit. Hence, in the sequence shown in **Figure 4.5,** the visit length was taken as the time between the first and last records on channel 3, 1 minute and 20 seconds. The latency of approach to the bait box was calculated for each rat each night. This was taken as the time elapsed between the first record on CH 5 for each rat (i.e. at the entrance to the enclosure) and it's first record at either the inner or outer reader of either logger tunnel, 33 minutes and 4 seconds in the sequence shown in **Figure 4.5**.

Figure 4.5. Output from a data logger attached to an array of PIT tag readers

PIT TAG ID-TIME LOGGING SYSTEM F.S.I (C) DEC 1998 REV 4.3

ID-TIME LOGGER DATA 2001/ 6/14 12: 4:00

T1=0-255 x 62.5mS T2=0-255 x 16 secs T3=0-255 x 4096 secs

CH	HRS	T1	T2	T3	ID4	ID5
5	3.4	2	23	3	42 33	2A 21
4	3.4	2	147	3	42 33	2A 21
4	3.4	2	150	3	42 33	2A 21
3	3.4	2	225	3	42 33	2A 21
3	3.4	1	229	3	42 33	2A 21
3	3.4	2	230	3	42 33	2A 21
4	6.8	3	241	3	42 33	2A 21
4	2.3	3	242	3	42 33	2A 21
4	2.3	5	242	3	42 33	2A 21

Much of the data analysis was carried out using automated routines in SPSS/PC+ (SPSS Inc., USA) and Microsoft® Excel 2000 (Microsoft Corporation, USA), although for some of the analyses, such as calculating latency of approach, examination of individual records was necessary.

Comparisons were made between the four odour groups on the untransformed data using One-way ANOVA if the data were normally distributed according to the Kolmogorov-Smirnov test for normality. If the data were not normally distributed, Log_{10} transformations were performed and comparisons made between the four odour groups using One-way ANOVA. If the Log_{10} transformation did not normalise the data, between-group comparisons were made using the Kruskal-Wallis One-way ANOVA on ranks. Post-hoc comparisons on all treatment pairs were made using either the Holm-Sidak method (following One-way ANOVA) or Dunn's Method (following Kruskal-Wallis One-way ANOVA on ranks).

The trial was repeated using the second colony of rats (colony B) following the same experimental protocol but with the order of presentation of the two inter-specific odours reversed. The data from the first trial suggested that the acclimation phase allowed for colony A may not have been of sufficient duration, therefore for colony B, the acclimation phase continued until the number of visits to the bait box per night had levelled out. At the time of the trial, colony B contained seven male rats (145 g – 440 g) and nine females (130 g – 350 g).

4.3. Results

Over the 24 nights of the two trials (not including data collected during the acclimation phases) a total of 680,752 events were logged, 391,396 for colony A, and 289,356 for colony B. Colony A made 4,095 visits to the bait

box and colony B made 4,590 visits. **Figures 4.6 and 4.7** show the amount of bait eaten by the two colonies during the trial. **Table 4.1** shows the results of between-group comparisons for each of the two colonies. **Table 4.2 (a-c)** and **Table 4.3 (a - c)** show the results of post-hoc comparisons between the four odour groups.

Figure 4.6. The mean nightly amount of grain taken by Norway rats (colony A) from a logged bait box when no odour (Control), wood mouse (*Apodemus*) odour or field vole (*Microtus*) odour was applied near the entrance to the bait box.

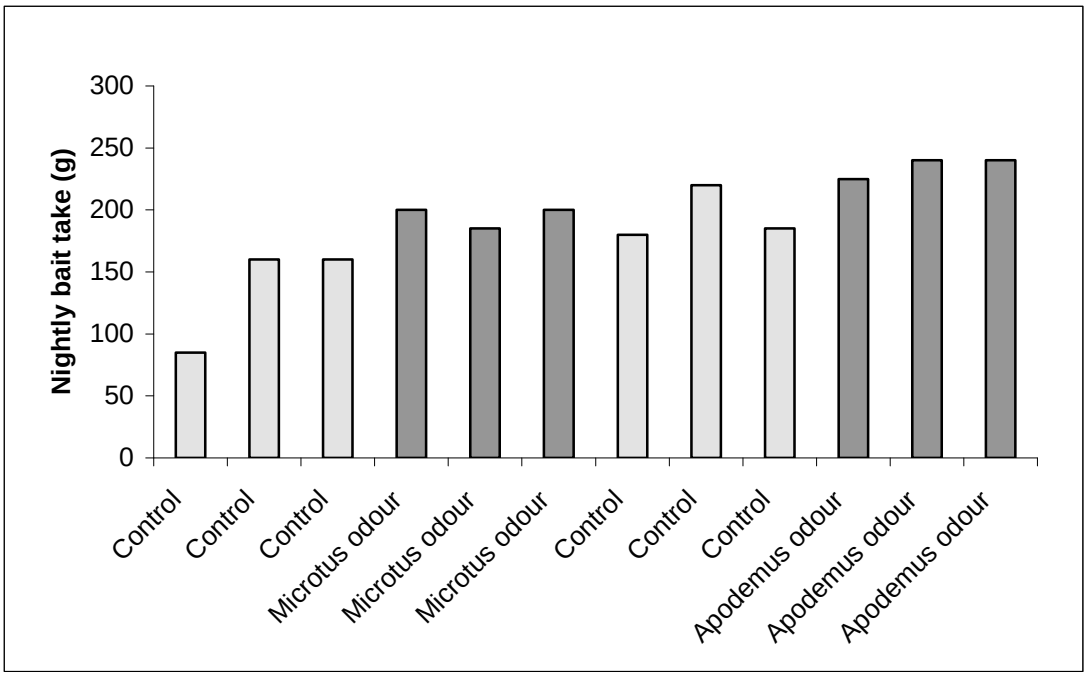


Figure 4.7. The mean nightly amount of grain taken by Norway rats (colony B) from a logged bait box when no odour (Control), wood mouse (*Apodemus*) odour or field vole (*Microtus*) odour was applied near the entrance to the bait box.

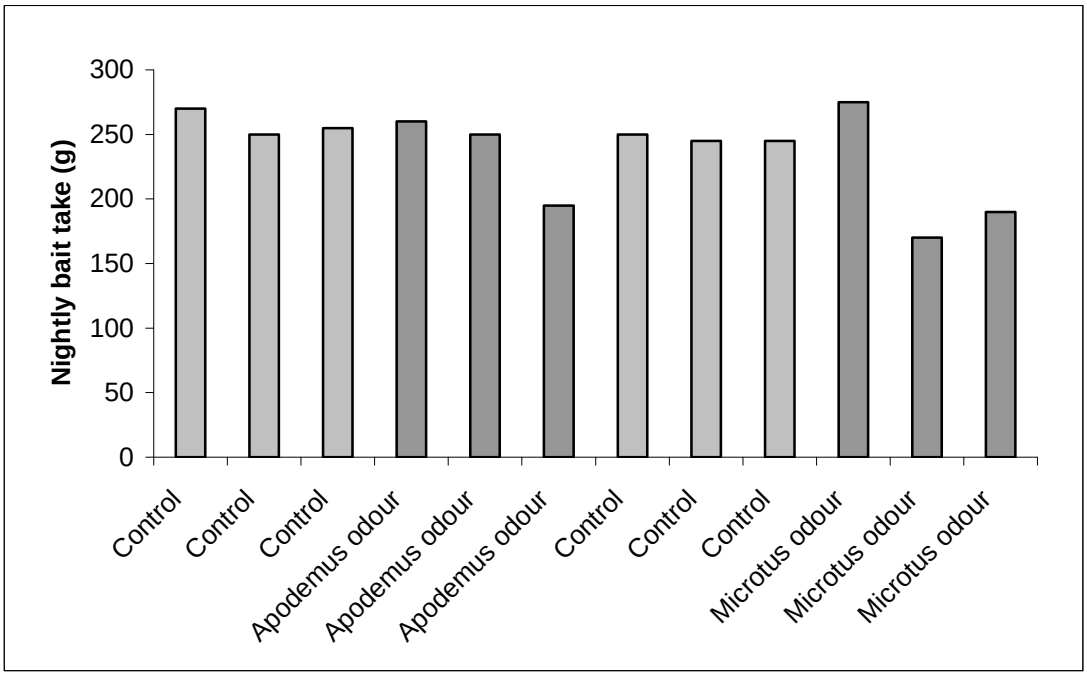


Table 4.1. The effect of inter-specific odour on the number of visits, length of visits and latency of approach to a logged bait box for two colonies of Norway rats in indoor enclosures when either wood mouse (*Apodemus*) odour or field vole (*Microtus*) odour was applied near the entrance to the bait box. Significant differences between the means are denoted by $p \leq 0.05$ and $p \leq 0.01$, ns indicates no significant difference

	Colony A		Colony B	
	Males	Females	Males	Females
Number of visits	ns [a]	ns [c]	$p \leq 0.05$ [c]	$p \leq 0.001$ [a]
Visit length	$p \leq 0.01$ [c]	ns [c]	$p \leq 0.05$ [c]	$p \leq 0.01$ [c]
Latency of approach	$p \leq 0.001$ [b]	ns [b]	ns [*]	ns [b]

[a] One-way ANOVA on untransformed data

[b] One-way ANOVA on Log_{10} transformed data

[c] Kruskal-Wallis One-way ANOVA on ranks

* Significant difference using One-way ANOVA on untransformed data, but data narrowly failed normality test.

Table 4.2 (a-c). Post-hoc comparisons between the four odour groups for colony A using either the Holm-Sidak method (following One-way ANOVA) or Dunn's Method (following Kruskal-Wallis One-way ANOVA on ranks). C1 = First control phase, *Ma* = Field vole odour, C2 = Second control phase, *As* = Wood mouse odour. Significant differences between the means are denoted by ***** ($p \leq 0.05$) and ****** ($p \leq 0.01$) - indicates that the data violated the assumptions of Dunn's Method, ns indicates no significant difference.

a) Number of visits

	Males				Females			
Ma	ns				*Ma*	ns		
C2	ns	ns			C2	ns	ns	
As	ns	ns	ns		*As*	ns	ns	ns
	C1	*Ma*	C2			C1	*Ma*	C2

b) Visit length

	Males				Females			
Ma	ns				*Ma*	ns		
C2	*****	-			C2	ns	ns	
As	-	-	ns		*As*	ns	ns	ns
	C1	*Ma*	C2			C1	*Ma*	C2

c) Latency to enter bait box (Log $_{10}$ transformed data)

	Males				Females			
Ma	******				*Ma*	ns		
C2	ns	ns			C2	ns	ns	
As	**	ns	**		*As*	ns	ns	ns
	C1	*Ma*	C2			C1	*Ma*	C2

Table 4.3 (a-c). Post-hoc comparisons between the four odour groups for colony B using either the Holm-Sidak method (following One-way ANOVA) or Dunn's Method (following Kruskal-Wallis One-way ANOVA on ranks). C1 = First control phase, *Ma* = Field vole odour, C2 = Second control phase, *As* = Wood mouse odour. Significant differences between the means are denoted by ***** ($p \leq 0.05$) and ****** ($p \leq 0.01$) - indicates that the data violated the assumptions of Dunn's Method, ns indicates no significant difference.

a) Number of visits

	Males				Females			
As	-				*As*	**		
C2	ns	-			C2	**	ns	
Ma	-	-	-		*Ma*	**	ns	ns
	C1	*As*	C2			C1	*As*	C2

b) Visit length

	Males				Females			
As	ns				As	*		
C2	-	-			C2	ns	-	
Ma	-	-	-		Ma	-	ns	-
	C1	As	C2			C1	As	C2

c) Latency to enter bait box

	Males				Females			
As	ns				*As*	ns		
C2	ns	ns			C2	ns	ns	
Ma	ns	ns	ns		*Ma*	ns	ns	ns
	C1	*As*	C2			C1	*As*	C2

For colony A, the only pair-wise post-hoc comparisons that were statistically significant were the mean visit length and the latency to approach the bait box for male rats. Male rats in colony A made more visits to the bait box per night during the nights when either the field vole or wood mouse scent marked blocks were used compared to the first control phase (**Figure 4.8**) although the differences were not significant. The average length of all visits made to the bait box by rats in colony A during the trial was 124.09 seconds (range 0.19 s – 1455.25 s). Males made, on average, slightly longer visits (143.83 s, range 0.19 s – 1455.25 s) than females (105.35 s, range 0.19 s – 1295.50 s). The visit length data was not normally distributed (**Figure 4.9**) with 59.66% of visits lasting for less than 60 seconds, and 88.57% lasting for less than 360 seconds. The small number of long visits tended to distort the mean visit length and therefore the data were $\log_{10}$ transformed resulting in a more normal distribution (**Figure 4.10**). For the visit length data, this did not result in a statistically normal distribution however, and so non-parametric analyses were used. These revealed that for males in colony A, visit length was lower in the second control phase compared to the first control phase (**Figure 4.11**). The data for latency to approach the bait box were not normally distributed either, but in this case a $\log_{10}$ transformation resulted in a statistically normal distribution, and parametric statistical analyses were used. This revealed that the latency to approach the bait box by male rats in colony A was significantly higher during the first control phase compared to the field vole or wood mouse odour treatments, and

higher for the second control phase compared to the wood mouse odour (**Figure 4.12**).

There were significant differences between the odour groups for the number of visits made and length of visit for both male and female rats in colony B. The only post-hoc test that could be carried out for the number of visits made to the bait box by male rats in colony B showed that there was no significant difference during the first and second control phases. Females in colony B made significantly more visits during the first control phase than the wood mouse, second control or field vole odour phases. Rats in colony B spent an average of 111.68 seconds (range 0.18s – 2633s). Males spent an average of 102.3 seconds in the bait box (range 0.19s – 2633s) compared to 115.28 (range 0.18s – 2303s) for females. Again, the majority (58.13%) of visits to the bait box lasted for less than 60 seconds. For males in colony B, visit length fell slightly when the wood mouse odour was introduced, but was very similar during the first control, second control and field vole odour phases (**Figure 4.13**). The difference between the first control phase and the field vole odour was not significant but other post-hoc tests could not be conducted. Females in colony B spent more time in the bait box when the blocks with wood mouse odour were used than they did during the first control phase (**Figure 4.14**). For males in colony B, latency to enter the box increased following the first control phase (**Figure 4.15**) although the difference was not statistically significant. Females in colony B responded similarly to the males (**Figure 4.17**) but again the differences were not significant.

Figure 4.8. The mean number of visits made to the bait box by males in colony A. Bars indicate ± 1 Standard Error of the mean.

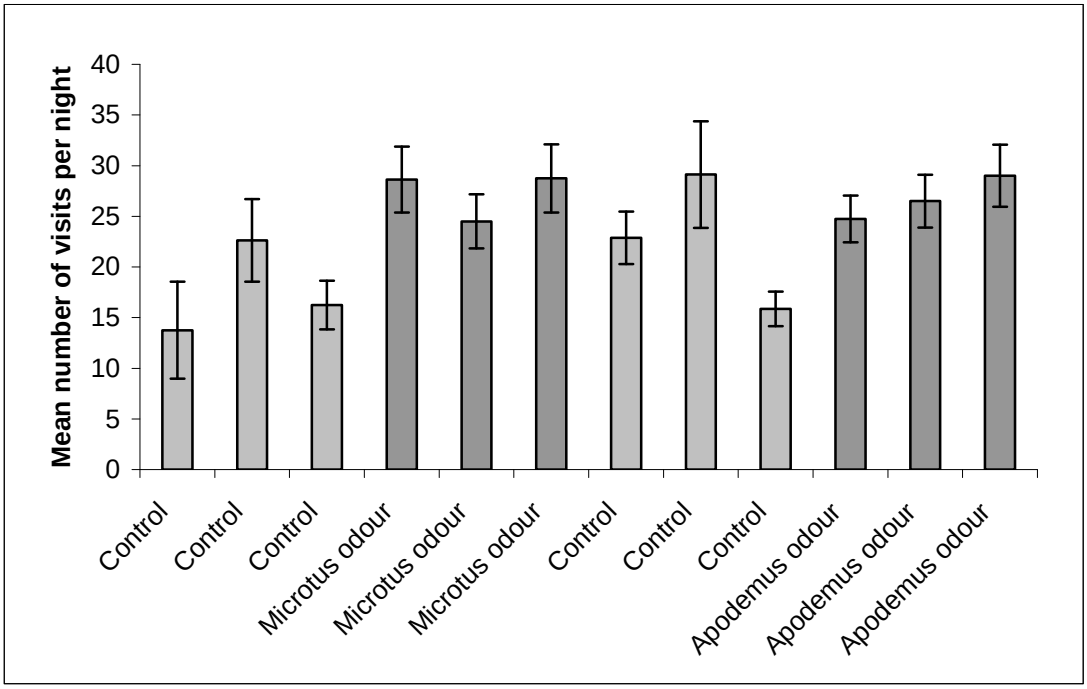


Figure 4.9. The distribution of visit length data for all visits to the bait box made by rats in colony A.

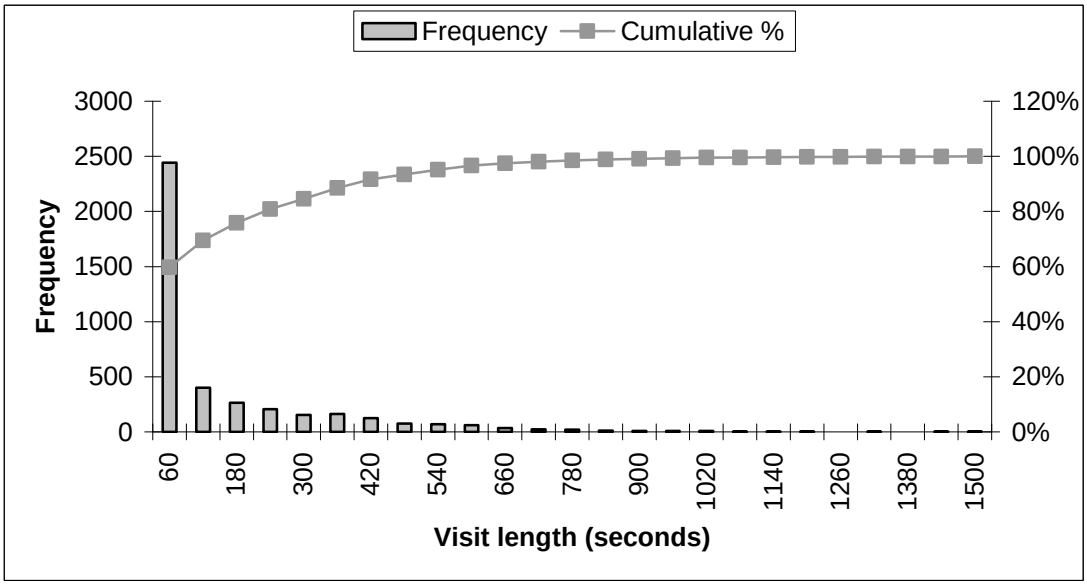


Figure 4.10. Log_{10} transformed visit length data for colony A

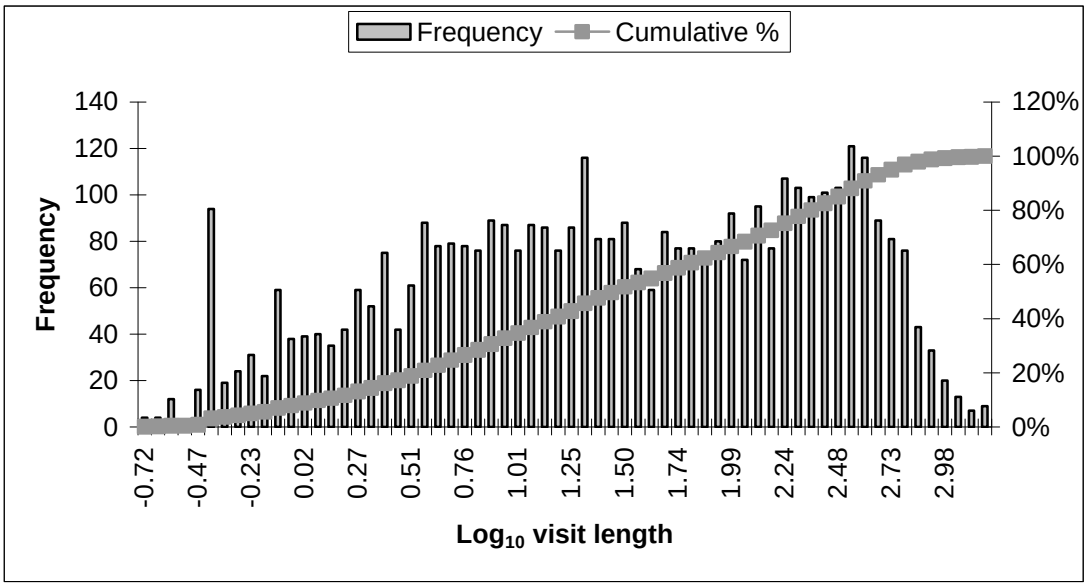


Figure 4.11. The mean time spent in the bait box by male rats in colony A for the four odours (log_{10} transformed data).

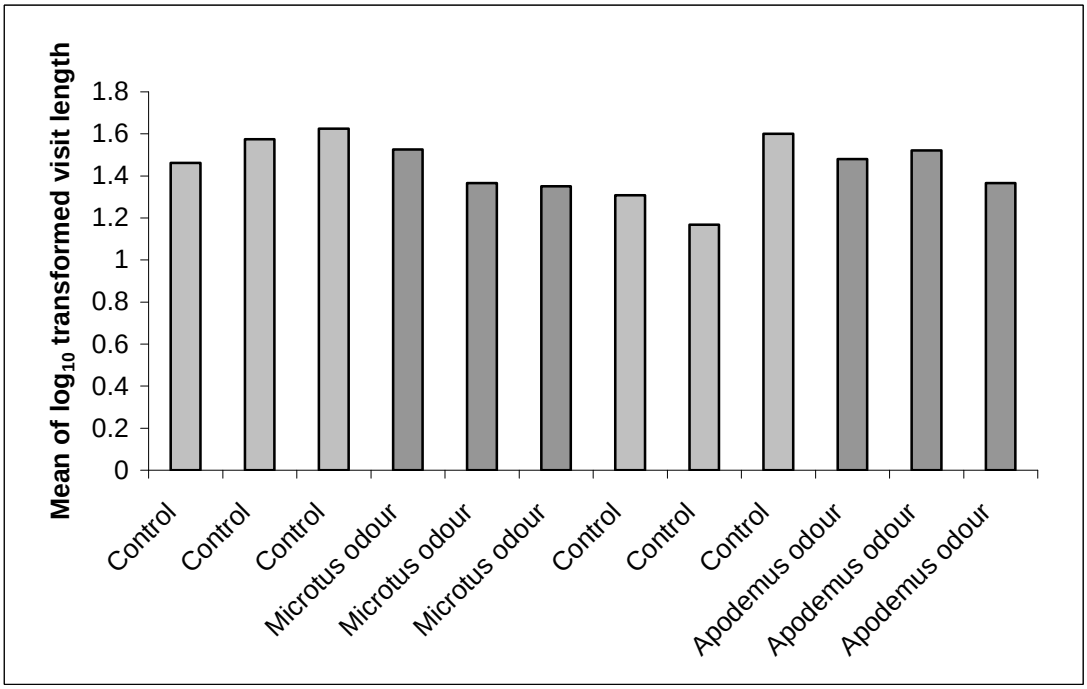


Figure 4.12. The mean time delay (latency) between first entering the enclosure and entering a logger tunnel attached to the bait box. Male rats, colony A. Bars indicate ± 1 Standard Error of the mean.

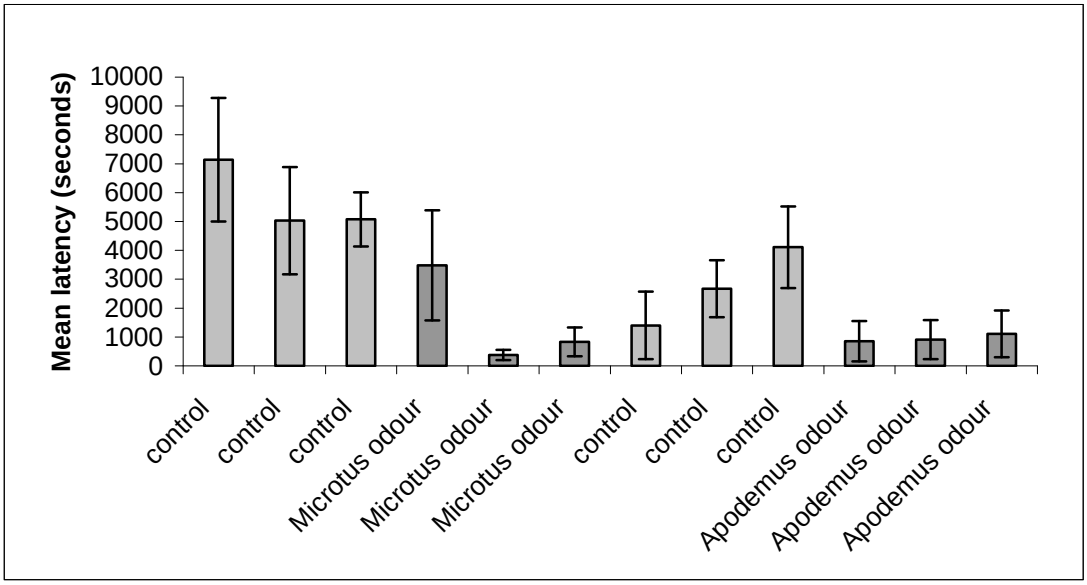


Figure 4.13. The mean time spent in the bait box by male rats in colony B for the four odours (log_{10} transformed data).

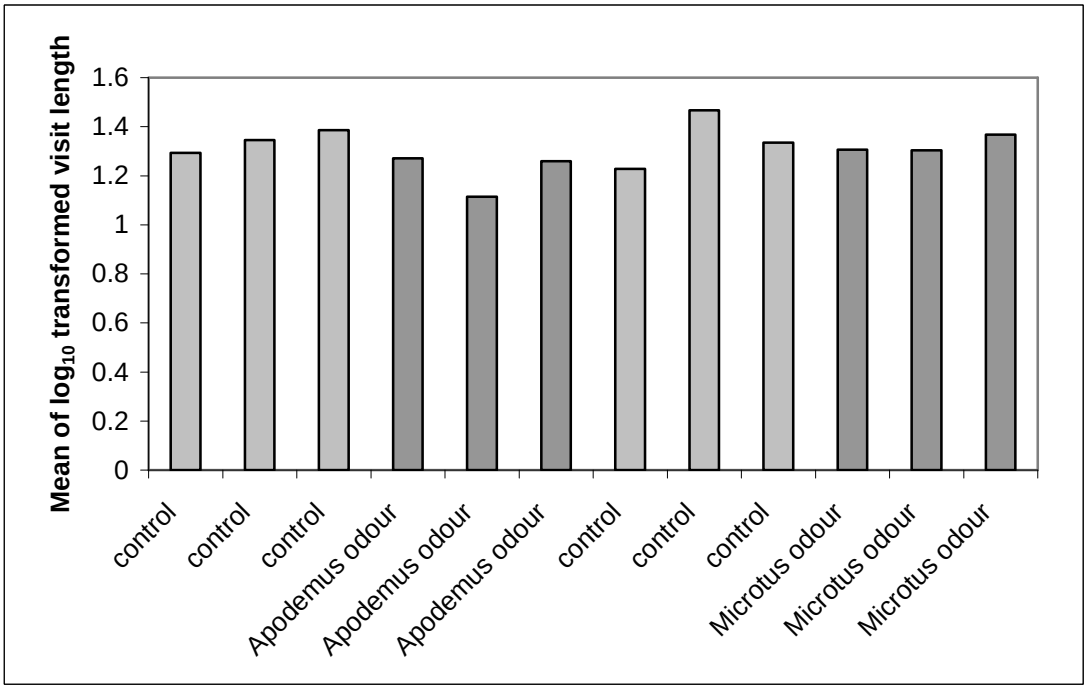


Figure 4.14. The mean time spent in the bait box by female rats in colony B for the four odours (log_{10} transformed data).

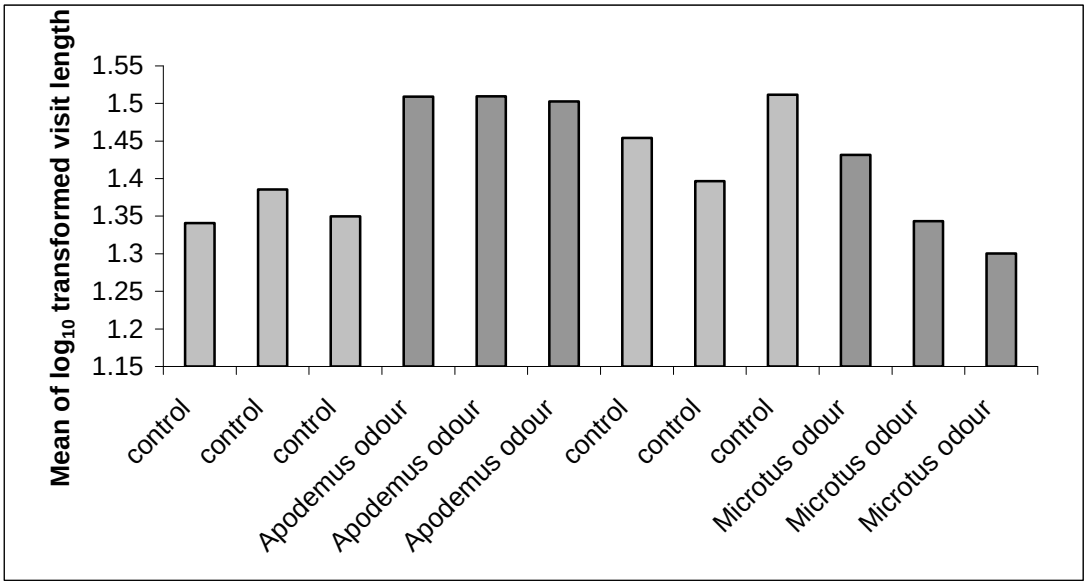


Figure 4.15. The mean time delay between first entering the enclosure and entering a logger tunnel attached to the bait box. Male rats, colony B. Bars indicate ± 1 Standard Error of the mean.

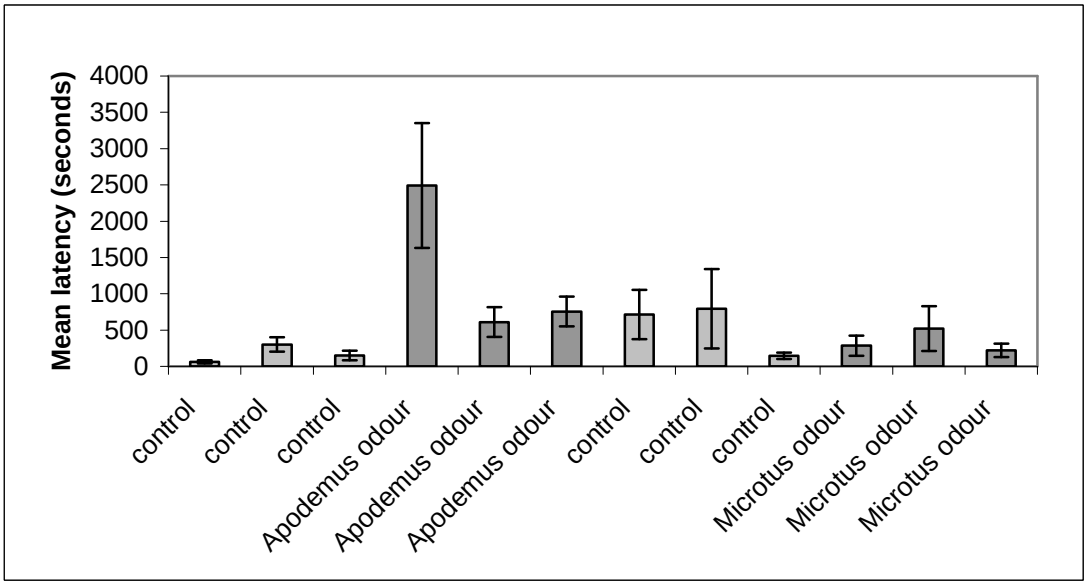
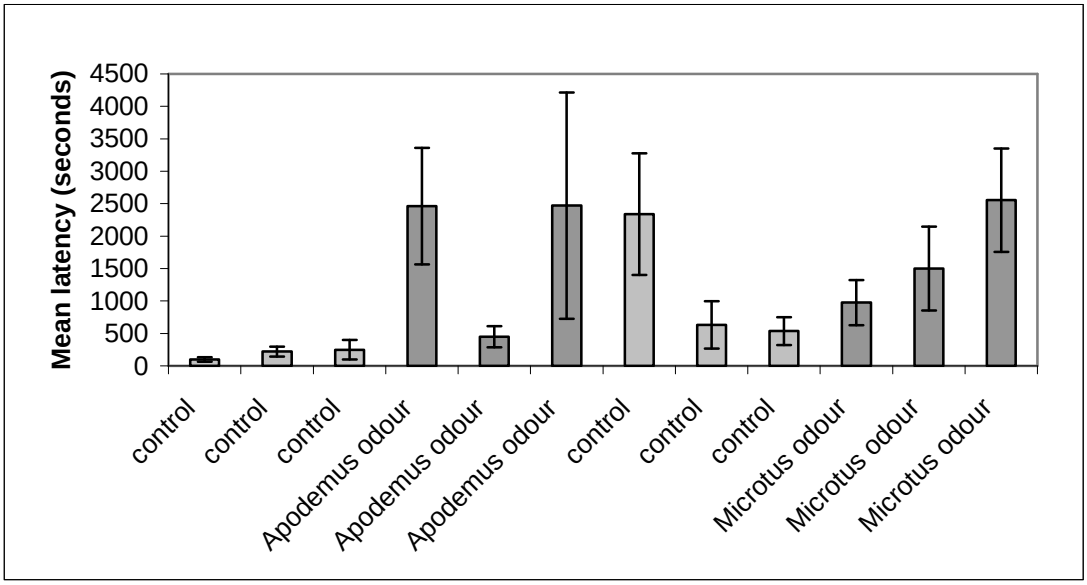


Figure 4.16. The mean time delay between first entering the enclosure and entering a logger tunnel attached to the bait box. Female rats, colony B. Bars indicate ± 1 Standard Error of the mean.



4.4. Discussion

The amount of bait taken from the logged bait box by rats in colony A doubled between the first and second nights, which suggests that not enough time was given during the acclimation phase for rats in colony A to overcome their initial reluctance to enter the bait box. Norway rats are often reluctant to approach any novel object that they encounter, and even though all rats had been logged at the bait box at least once before the first control phase was started, it appears that the acclimation phase for this colony was too short. This is probably the reason for the fall in latency to enter the bait

box during the early stages of the trial, rather than an attraction to the field vole odour.

The acclimation phase for colony B lasted until the number of visits per night had stabilised. Bait take from the box for this colony remained relatively stable during the three nights of the first control phase, indicating that the acclimation phase given for this colony was long enough for the rats to overcome their initial reluctance to enter the box. Latency to approach the bait box remained relatively stable during the first control phase for males and females in colony B, again evidence that the acclimation period had been of sufficient duration for this colony. With a mean latency of just 170.8 seconds for males, and 189.4 seconds for females, they were showing very little hesitation in approaching the bait box each night. When the wood mouse odour was introduced, the mean latency to approach the bait box rose for both males and females in colony B, although the difference was not statistically significant for females and only marginally significant for males. Female rats in colony B also made significantly fewer visits to the bait box when the wood mouse odour was introduced. Wood mouse odour was used as a positive control during these trials, as the field margin surveys indicated that Norway rats do not avoid this species. We would expect that Norway rats would not show aversion towards wood mouse odour, and therefore, the increase in the time taken to approach the bait box, and the reduction in the number of visits made to the box by females was probably due to the novelty of the odour. The associated increase in visit length may be due to a negative correlation between number of visits

and visit length, or may indicate investigative behaviour after the initial aversion was overcome. The number of visits to the bait box made by female rats in colony B was also lower for the field vole odour phase compared to the first control phase, but there was no significant difference between the number of visits made during the wood mouse and field vole odour treatments. This indicates that there was no aversion to the field vole odour over and above the aversion shown towards a novel odour.

In summary, there was no evidence that Norway rats showed any aversion to the field vole odour as it was presented in this trial. However, rats scent mark copiously, and tend to pay particular attention to novel objects, it is possible therefore that over-marking obscured the field vole odour. It is also possible that the field vole odour dissipated too quickly to have any significant impact on the behaviour of the rats. If the odour was maintained, it may be that any aversive effects beyond the initial aversion of a novel odour would be seen.

5. A habitat management approach

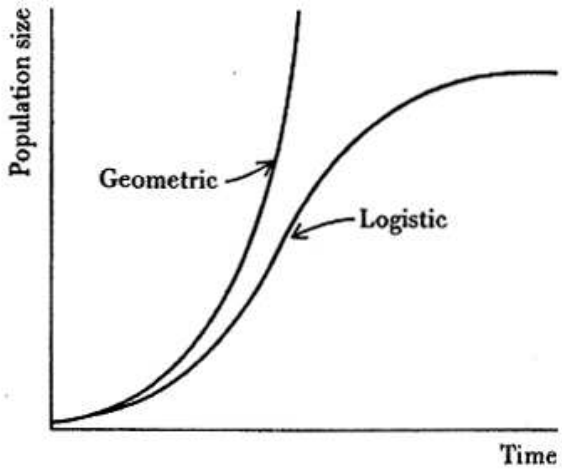
5.1. Background

The capacity for increase of all animal populations is exponential, and in the absence of competition this potential may be realised, albeit temporarily. This is demonstrated by the speed with which non-native animals and plants can spread following their introduction to a new continent. The muskrat (*Ondatra zibethicus*) for example, was absent from Europe until 1905, when five animals were released near Prague. From that original population, the muskrat, which is native to North America, subsequently spread at a rate of around 15 km per year (Elton, 1958) and it is now widely distributed throughout Europe and Asia. Mammalian introductions to islands such as New Zealand, where competition is from native mammals is virtually absent, are often particularly successful. The European hedgehog (*Erinaceus europaeus*) was introduced to New Zealand towards the end of the nineteenth century, and is now abundant, reaching much higher densities than in Europe (Brockie, 1960). In Australia, cane toads (*Bufo marinus*) have spread rapidly following the introduction of 101 individuals from Hawaii in 1935. Their introduction was deliberate, in an attempt to control Frenchi and Greyback beetles in sugarcane. However, the cane toads have ignored their intended prey, and are now considered a serious pest, as they deprive native frogs of food, and are toxic to predators. The spread of the Norway rat from its native Asia is also an example of rapid colonisation; it is now

regarded as cosmopolitan, although in the tropics it tends to be limited in its range to coastal areas (Meehan, 1984).

The spread and ecological damage caused by alien species can be dramatic. However, the availability of resources eventually limits the growth of the population, and the habitat cannot support any more individuals. At this point, known as the carrying capacity, recruitment through reproduction, and losses through mortality are effectively in balance, therefore population growth ceases. The population will theoretically remain constant until the availability of resources either increases or decreases. Rapid expansion of a population, followed by a sustained period of stability, is described by the logistic growth curve, **Figure 5.1**.

Figure 5.1. Population growth. Geometric growth in an unlimited environment, and logistic growth in a limited environment. After Krebs, 1972.



This concept, introduced by Verhulst (1838) is a useful, but rather simplistic view, as natural populations are rarely static. All populations tend towards the carrying capacity, but in reality the carrying capacity frequently changes due to a number of factors, such as competition with other species. Thus, the size of natural populations tends to fluctuate and is constrained by the limited supply of resources. Individuals must compete for these resources and at lower densities there is less competition, leading to higher reproductive rates and lower mortality. At higher densities, there is greater competition for resources, accompanied by lower reproductive rates, and higher mortality. A sudden reduction in population size may reduce competition among the survivors, leading to a rise in the growth rate. This is the fundamental flaw in any attempt to manage wildlife populations by culling. Following the cull, reproductive rates rise, mortality falls, and the population again tends towards the carrying capacity. In species with a high reproductive potential, such as rodents, recovery may be very rapid. In the case of Norway rats, even a small number of survivors can quickly repopulate cleared premises following a rodenticide treatment. Therefore, in the long term, modification of the environment to reduce its capacity to support rat populations might offer a better solution (Jackson, 1972).

Studies of urban rat populations in Baltimore, USA, in the 1940s revealed that uncontrolled rat populations increase to the capacity of a given environment, and essentially remain at this level unless their habitats are modified (Davis, 1972). Studies of the population dynamics and behaviour of the Baltimore rats showed that poisoning or trapping had only temporary

effects. When the control measures were relaxed, the population quickly recovered to the carrying capacity of the habitat. Following these studies, a successful integrated rat control strategy based on habitat management principles was developed, prior to the availability of synthetic organic rodenticides. The system included large-scale co-ordination of sanitation and habitat modification, such as removal of refuse from alleys, and blocking of access to sewers. Monitoring indicated that the rat population within the cleared areas was virtually eliminated within a relatively short time, and an increase in rat numbers during a refuse collectors strike in 1948 provided further evidence of the effectiveness of the habitat management approach (Jackson, 1998). Unfortunately the program was not maintained because the lack of political and personal will to maintain environmental standards (Colvin and Jackson, 1999) and the habitat management approach was eventually abandoned in favour of rodenticide use.

More recently, damage caused by *Rattus rattus* to macadamia nut crops in Australian orchards was found to be greatest in plantations near undisturbed, structurally complex habitats, such as areas of scrub vegetation (White *et al*., 1997). When scrub vegetation was cleared to a distance of 20 m from the edge of three orchards, and herbicides were used to prevent scrub regeneration through summer, damage was reduced by 65% relative to two control sites (White *et al*., 1998). The technique was also found to be cost effective, as the value of the crop saved from damage was more than double the cost of carrying out the work. In theory, the same

effect could be achieved on farm premises by restricting access to cover and nest sites. On farms in the UK, rats find cover in unused areas between and around the buildings, which become overgrown with weeds such as the common nettle (*Urtica dioica*) and fast growing shrubs or trees such as elder (*Sambucus nigra*). These ‘dead spaces’ are often used for storing redundant farm machinery, old pallets, and other items. This makes an environment in which a substantial population of rats might go unnoticed, or might be difficult to control due to inaccessibility.

Norway rats are taken by several species of predators such as stoats (*Mustela erminea*) and weasels (*Mustela nivalis*) (Day, 1968), foxes (*Vulpes vulpes*) (Lever, 1959) cats (*Felis catus*) (Carss, 1995) and domestic dogs (*Canis familiaris*) (Brodie, 1988). Rats actively avoid these predators, and prefer to stay close to cover when moving between their nest sites and feeding sites (Taylor, 1978; Taylor and Quy, 1978). Rats may also change their activity patterns to avoid predators. Fenn and Macdonald (1995) suggested that the largely diurnal behaviour of a population of rats on an Oxfordshire farm refuse tip was due to the nocturnal activity of red foxes (*Vulpes vulpes*) at the site. It has been also been suggested that subordinate rats are more vulnerable to attack from predators because they are forced to occupy marginal habitats, such as areas with less cover (Brodie, 1988; Jackson, 1972) or are forced to feed at times that allow them to avoid dominant individuals (Berdoy and Macdonald, 1991). Harbourage for nesting and shelter from predators are key resources that may limit the size of rat populations; manipulation of these resources may therefore

provide a means of control. Harbourage, shelter and access to food sources can, to some extent, be controlled by rodent proofing and good hygiene, but in many cases rodent proofing is not economically viable, or possible without disruption of normal farming practices. However, ensuring that areas near food sources are free from harbourage and shelter provided by overgrown areas and discarded machinery and other debris may reduce nesting opportunities, and expose rats to a greater risk of predation. This 'habitat management' approach could potentially offer long-term benefits in the form of reduced rodenticide usage and may have the potential to limit the spread of resistant populations. In the present study, six field trials were conducted to examine the impact on rat populations of reducing cover in selected areas of the farm environment. It was predicted that the effects of reducing cover would be seen in the ranging behaviour, size and survival of rat populations. Accordingly, three null hypotheses were generated, such that following reduction of cover in rat-infested areas;

1) There would be no change in the survival rates of individual rats in cleared areas compared to those in un-cleared control areas

2) There would be no change in the home range size or home site location of individual rats in cleared areas compared to those in un-cleared control areas

3) There would be no change in the size of rat populations in cleared areas compared to those in un-cleared control areas

5.2. Materials and methods

5.2.1. Description of field sites

Field trials were carried out between July 1998 and May 2000 at six study sites where field signs indicated the presence of Norway rat infestations. The availability and distribution of resources within the farm environment is likely to influence the size and distribution of rat populations, therefore sites were selected to encompass different habitat types. Three of the rat infestations were located in and around farm buildings on livestock units, the other three were away from farm buildings, in field margins, ditches and near other cover such as straw bales. **Figure 5.2** shows the location of the study sites, which were in North Yorkshire (sites J, K, M and N), East Yorkshire (site L) and Durham (site O). Sites J, L and O consisted of three main farm buildings, and associated yards, of mixed livestock and arable farms where pigs were housed in buildings of various size and age. Site O was the largest of these, with agricultural buildings and associated yards covering an area of 10,190 m^2. Site L, was the second largest, with buildings and yards covering an area of 7,870 m^2, and site J was the smallest, with buildings and yards covering 7,660 m^2. All three sites were mainly surrounded by arable land, although at site J, sheep were grazed in fields close to the farm buildings. Free-range pigs were reared in fields approximately 250 m from site L. Each of these three sites had overgrown areas between and around the farm buildings, with vegetation consisting

mainly of fast growing shrubs such as elder (*Sambucus nigra*) and weeds such as common nettle (*Urtica dioica*). At each site these 'dead spaces' were often used to store farm machinery, equipment and other items such as discarded pallets and building materials **(Figures 5.3 and 5.4)**. Fresh signs, such as droppings and active runs, indicated that a population of rats was present at each of these sites.

Figure 5.2. The location of field sites J-O.

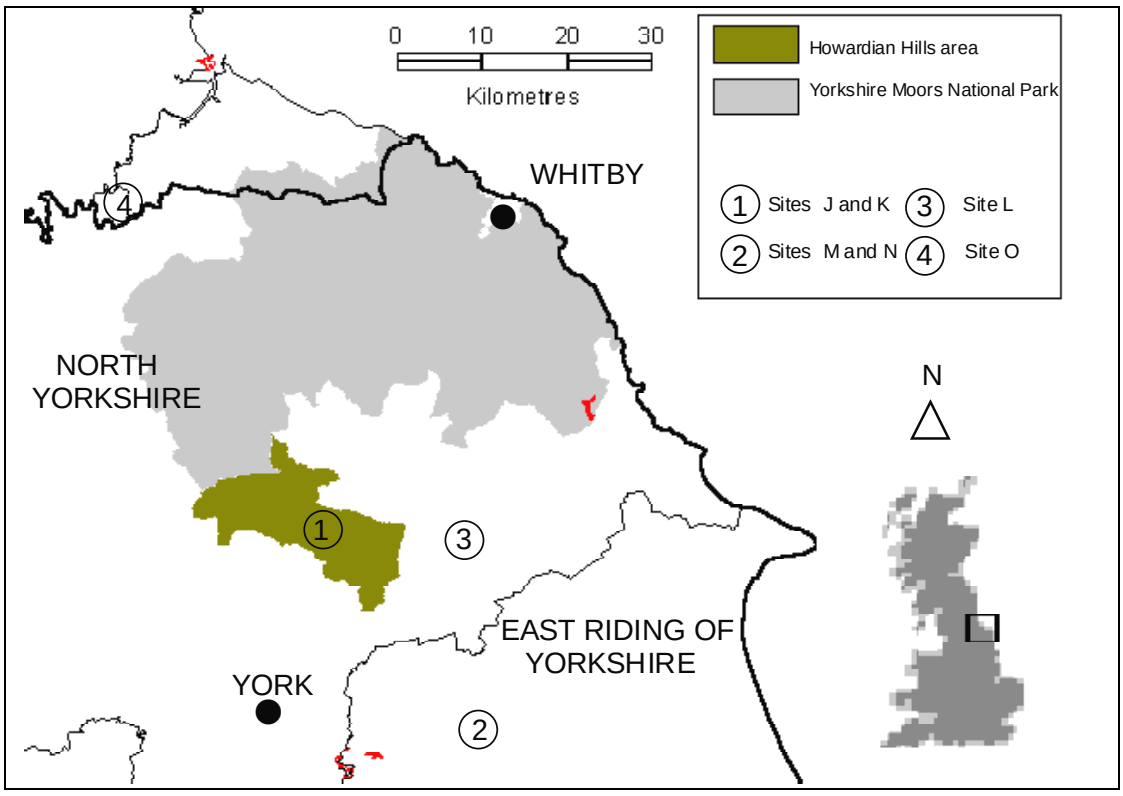


Figure 5.3. Site J. Discarded farm equipment providing cover for rats.

Figure 5.4. Site L. Vegetation between buildings providing cover for rats.

Site K, which was 175 m from the nearest farm buildings, consisted of a 2.7 ha field of kale, bordered on its eastern and northern sides by ditches that took rainwater run-off from the surrounding fields, **Figure 5.5**. Fresh rat signs indicated the presence of rats living along the banks of both ditches, which were overgrown with bramble (*Rubus fruticosus*), common nettle and other weeds, **Figure 5.6**. The kale served as a cover crop for game birds, and dry whole wheat was provided at two pheasant feeders positioned 100 m apart. Site M, which was 250 m from the nearest farm building, consisted of a 2.1 ha field, which had recently been planted with spring cereals. The field contained two rows of large round bales. One row of bales, which was 25 m long, ran parallel to the western field margin, the other row, which was 50 m long, ran parallel to the northern field margin, **Figure 5.7**. The bales, and a strip of uncultivated land between each row of bales and the hedgerow, served as cover for game birds. Dry whole wheat was provided in a single pheasant feeder at the western end of the northern row of bales. Fresh signs, including burrows and runs near both rows of bales, indicated that the cover and food source supported a population of rats. Site N, 500 m from the nearest farm buildings, was similar to site M, with round bales as cover, and a single source of dry whole wheat for game birds. The single row of bales ran parallel to the western edge of a 14.7 ha field of cereal stubble, **Figure 5.8**. A track (4 m wide) with a dense hawthorn hedgerow running along each side separated the stubble field from the fields of cattle pasture and recently sown cereals to the west. Again, evidence of a population of rats could be seen around the bales near to the food source.

Figure 5.5. Site K.

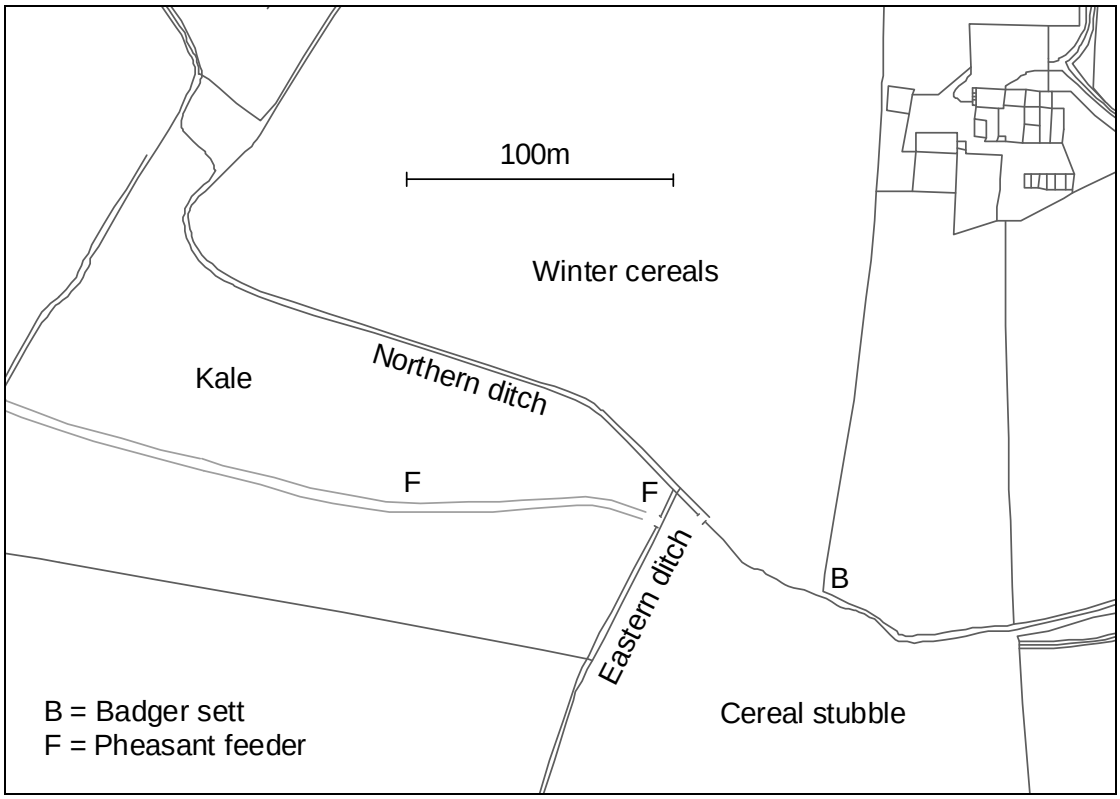


Figure 5.6. Brambles and other vegetation providing cover for rats along the eastern ditch at site K.

Figure 5.7. Site M.

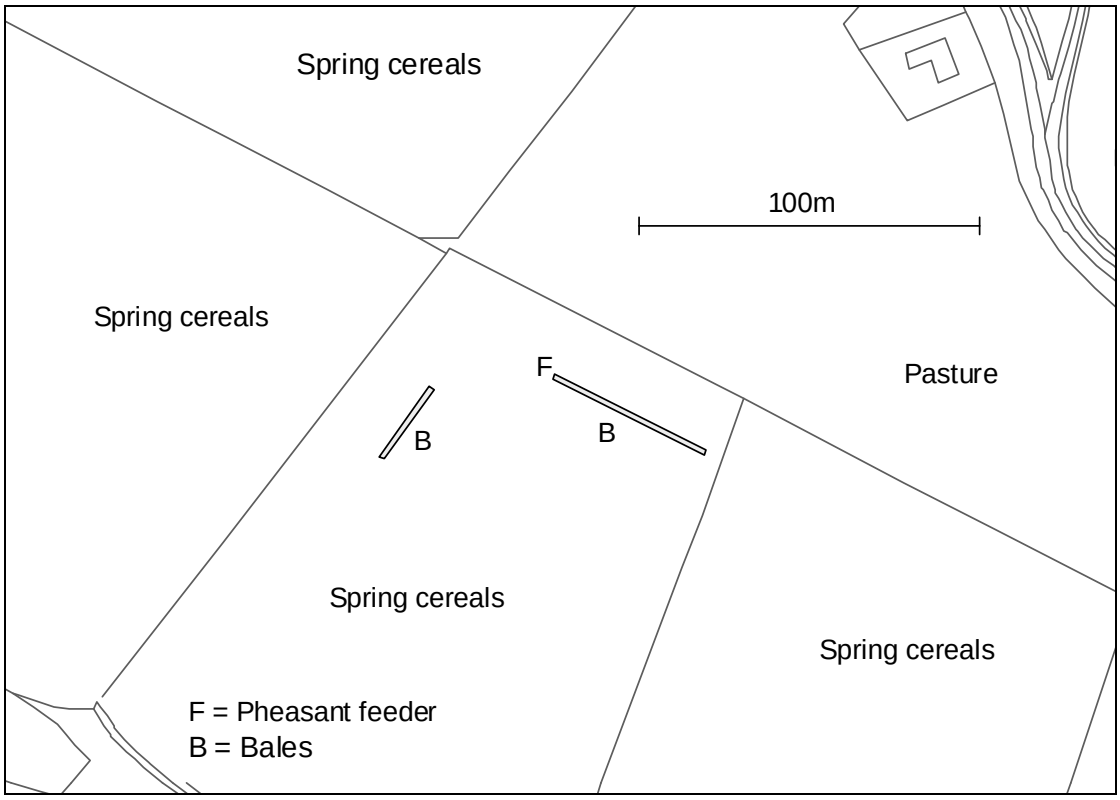
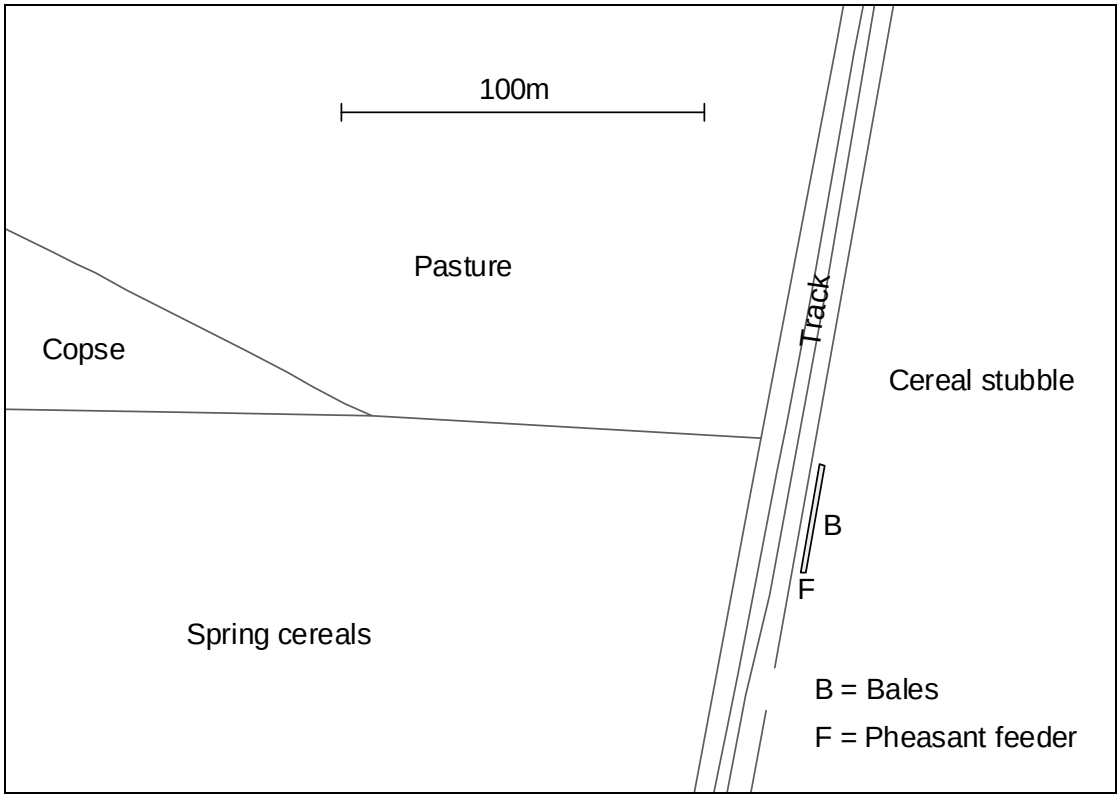


Figure 5.8. Site N.

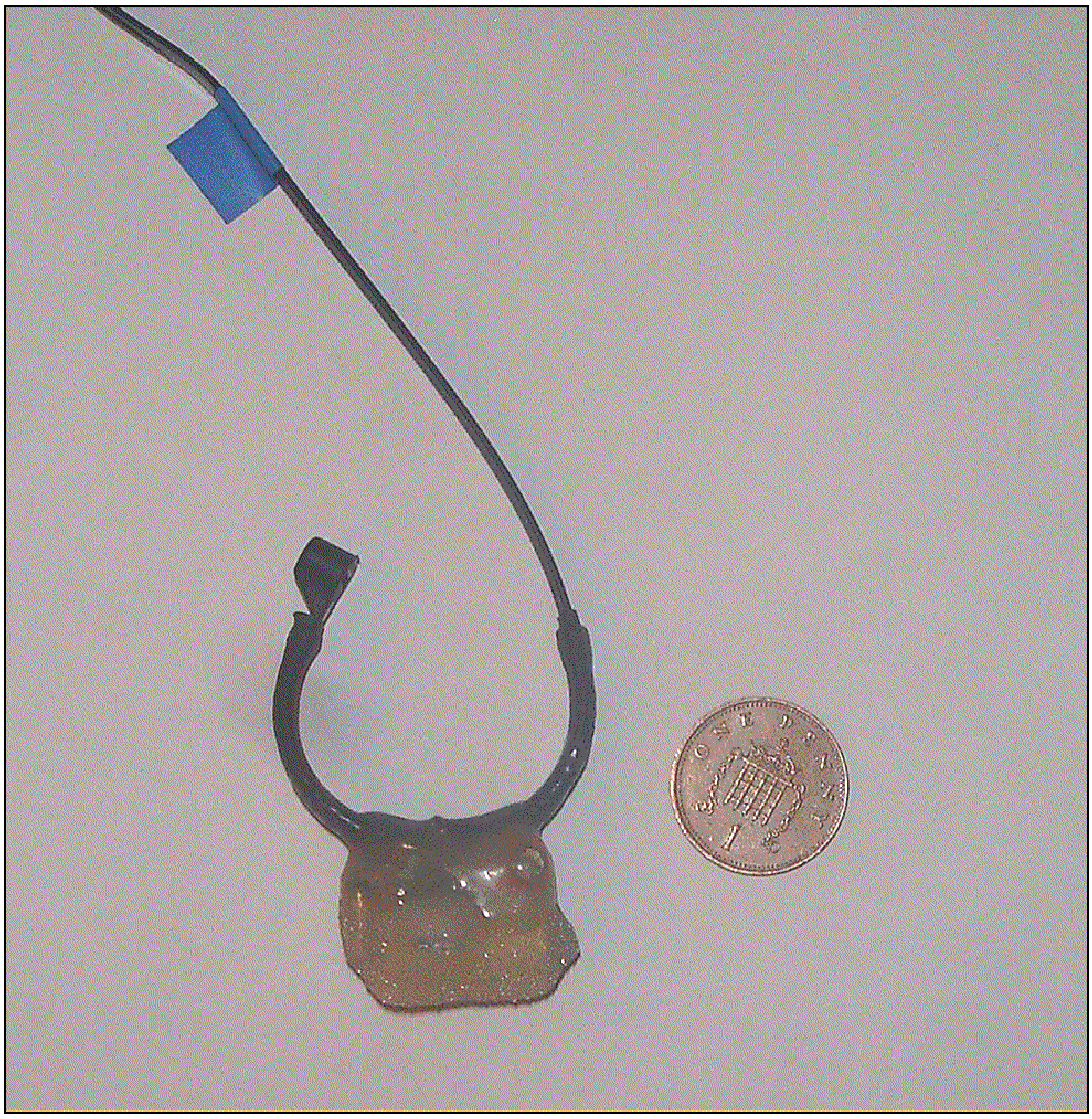


5.2.2. Radio-tracking and population monitoring

At each site, approximately 20 single-capture cage traps were positioned near to fresh rat signs and pre-baited for up to three weeks with dry, whole wheat. The traps were then set in late afternoon or early evening, and inspected on the following morning. The captured rats were visually examined, and each healthy animal was transferred to an inhalation chamber and anaesthetised using isoflurane. Each rat was then sexed, and weighed using a top pan balance (Salter, West Bromwich, UK). Rats over 250g were fitted with a temperature sensitive model T3 radio transmitter (Biotrack Ltd., Wareham, UK) (**Figure 5.9**) held in place around the neck by a plastic collar.

These transmitters weighed approximately 10g each, and had a maximum range of 1000m over flat, open ground. In practice however, this range was usually much reduced by obstructions produced by the terrain and other obstacles such as buildings. The rate of radio pulses emitted by the transmitter was temperature dependent so that a 'cold' pulse rate indicated that the rat was either dead or had lost its collar. The transmitters were factory set with a unique frequency between 173.000 - 174.999 Mhz allowing the identification of individual rats in the field. The tagged rats were then returned to their cage traps to recover from the effects of the anaesthetic, and subsequently released at their capture location.

Figure 5.9. Biotrack model T3 radio transmitter.



In order to track the movements of the tagged rats, each site was visited twice daily. A ‘discontinuous’ radio-tracking regime was used such that at each visit, each tagged rat was located in turn using a Televilt RX900 hand-held radio receiver (Televilt, Lindesberg, Sweden) connected to a three-element antenna (Yagi, UK). The location of each rat was then recorded on a map of the site. A discontinuous radio-tracking regime was used because the observer needed to approach to within a few metres of the rat to pinpoint its precise location. Usually the rat then ceased to exhibit normal behaviour,

and headed for the nearest cover, making continuous radio tracking inappropriate. Video recordings made by the author as part of another study however, showed that radio-tagged rats quickly resume their normal behaviour following the departure of the observer; one rat emerged from cover after just three minutes.

The times of the visits were varied each day, with one visit during daylight hours to establish nest site location, and the other at night to observe ranging behaviour. Rat location data were then plotted onto digital site maps using ArcView GIS 3.2 software (ESRI, California, USA) and analysed using the Animal Movement 1.0 program (Hooge and Eichenlaub, 1997) in order to calculate the home range size for each animal using the minimum convex polygon (MCP) method. The MCP method was selected because it is the most widely used and easily interpreted approach, however the data were also analysed using the kernel method for comparison. During this period, an estimate of the rat population size at sites K-O was made, using the tracking plate method described in section 3.2.3. Subsequent data analyses and statistical procedures were conducted using Microsoft® Excel 2000 (Microsoft Corporation, USA).

5.2.3. Selective removal of harbourage

Between 11 and 30 nights after the first rat had been fitted with a transmitter, harbourage was removed from part of each site, leaving the remainder of the site as an un-cleared control area. Heavy items, such as

bales, farm machinery and pallets were moved using lifting equipment and removed from the site. Lighter items were moved by hand, whilst vegetation was cut to near ground height using a petrol driven strimmer. **Figures 5.10**, **5.11** and **5.12** show the extent of the areas cleared at sites J, L and O. At site J, harbourage reduction was carried out over an area of 908 m^2. At site L, 1415 m^2 was cleared and at site O, 1160 m^2 was cleared. **Figures 5.13** and **5.14** show sites J and L after the reduction of harbourage. Compare these to **figures 5.3** and **5.4**, which show the same areas before clearance.

At site K, brambles, nettles and other vegetation was removed from a 60 m length of the ditch (128 m^2) along the eastern side of the field, exposing the rat runs and burrows underneath, **Figure 5.15**. Compare this to **figure 5.6**, which shows the same area before clearance. At site M, the northern row of bales was removed (84 m^2), leaving the remaining row as the control area, and at site N, the single row of bales was removed (48 m^2), leaving the area between the bales and the track as the control area. Following the removal of harbourage, visits were made to each site in order to locate the tagged rats, and hence examine the impact of the reduced cover on home range size and nest site location. At sites K-O, a further estimate of the rat population size in the cleared and control areas was made using the tracking plate technique three weeks after harbourage removal.

Figure 5.10. Site J. Harbourage was removed from the hatched area.

Figure 5.11. Site L. Harbourage was removed from the hatched area.

Figure 5.12. Site O. Harbourage was removed from the hatched area.

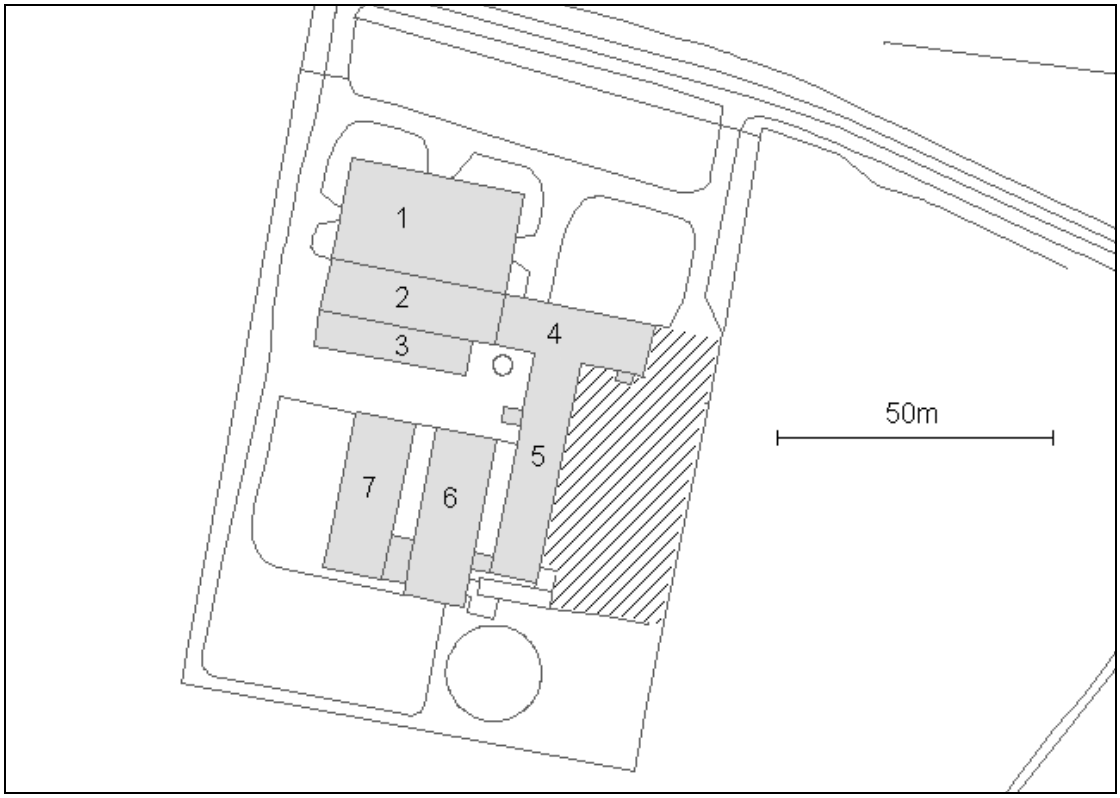


Figure 5.13. Site J following reduction of harbourage.

Figure 5.14. Site L following the reduction of harbourage.

Figure 5.15. Site K following the reduction of harbourage.

5.3. Results

5.3.1 Mortality

Of the 48 rats fitted with radio collars, six were lost (the signal could not be found) before the harbourage reduction was carried out. A further 10 rats either died or lost their radio collars before the harbourage was removed. Three of these 10 animals were recovered dead with collars still in place (one was accidentally killed by the farmer, one had been killed by a farm dog and the other had no obvious wounds). Five either died or lost their collars in cavity walls or roof voids and could not be recovered. The remaining two collars were recovered without any trace of the wearers, one was intact and had presumably slipped off, but the other had been gnawed through. Another collar appeared to be faulty and gave an intermittent signal.

This left 31 rats still active at the time of harbourage clearance, 13 of which were living in areas that were cleared, and 18 in the un-cleared control areas. A significantly smaller proportion of rats from the cleared areas were still alive and active in the same area 30 days after the cover was reduced compared to the un-cleared areas ($p < 0.05$, z - Test for comparison of proportions; Glantz, 2002). Therefore we can reject the first null hypothesis that predicted that there would be no change in the survival rates of individual rats in cleared areas compared to those in un-cleared control areas. A higher proportion of rats in the cleared areas died from predator attack (0.23) compared to un-cleared areas (0.06) although the difference

was not statistically significant ($p > 0.05$, z - Test for comparison of proportions). **Table 5.1** summarises the fate of the 31 rats for 30 days after clearance.

Table 5.1. The effect of selective harbourage removal on Norway rat survival (30 days after treatment) at farm sites in North Yorkshire, East Yorkshire and Durham (sites J-O) 1998-2000.

N	Cover	Remained alive 'in situ'	Moved to adjacent area	Died (predator kills)	Left study area	Fate not known
13	Cleared	1 (8%)	3	6 (3)	1	2
18	Un-cleared	10 (56%)	1	6 (1)	1	0

5.3.2. Home range data

From the radio-tracking data gathered before any harbourage reduction was carried out, there were two main trends. Rats living in field margins (sites K, M and N) occupied larger home ranges than rats living near farm buildings (sites J, L, and O) and within these two groups male rats occupied larger home ranges than females (**Table 5.2**). Pair-wise comparisons were made for these data using Single Factor ANOVA to examine differences in home range size, home range length and maximum distance travelled between successive observations for male and female rats living near farm buildings or in field margins (**Table 5.3 a-c**). Six rats were lost before their home range could be calculated and are excluded from the analyses. Male rats living in field margins had significantly larger home range sizes and covered

larger distances than male or female rats living near farm buildings. Female rats living in field margins covered greater distances than male or female rats near farm buildings. They also had larger home range sizes than female rats living near farm buildings. The pre-treatment home range data for rats at site J is shown in **Figure 5.16**. Compare this with the much larger pre-treatment home ranges occupied by rats at site K, which are shown in **Figure 5.17**.

Table 5.2. Pre-treatment home range data for rats living close to farm buildings (sites J, L and O) or in field margins (sites K, M and N) at farm sites in North Yorkshire, East Yorkshire and Durham 1998-2000.

	Sites J, L and O		Sites K, M and N	
	Males (n=15)	Females (n=15)	Males (n=7)	Females (n=5)
Mean home range (MCP) area (m^2)	304.5 (9.0 - 1056.6)	140.4 (3.6 - 667.5)	4987.8 (19.5 – 14571.0)	612.35 (38.5 - 1694.7)
Mean home range length (m)	35.2 (5.8 - 85.3)	25.4 (3.1 - 54.0)	160.8 (56.9 - 368.2)	131.6 (43.7 - 291.3)
Mean daily range (m) [a]	27.5 (5.7 - 49.0)	21.7 (3.1 - 50.7)	130.9 (56.9 – 222.0)	112.3 (43.7 - 207.3)

[a] Maximum distance between successive observations

Table 5.3 (a-c). Pair-wise comparisons (Single Factor ANOVA) between male and female rats living near farm buildings (JLO) or in field margins (KMN) for MCP home range size, home range length and maximum distance travelled between successive observations. From radio-tracking data collected before reduction of cover. Significant differences between the means denoted by ***** ($p \leq 0.05$), ****** ($p \leq 0.01$) and *** ($p \leq 0.001$). No significance difference denoted by ns.

a) MCP Home range size (m^2)

Females JLO	ns		
Males KMN	**	**	
Females KMN	ns	*	ns
	Males JLO	Females JLO	Males KMN

b) Length of home range (m)

Females JLO	ns		
Males KMN	***	***	
Females KMN	**	***	ns
	Males JLO	Females JLO	Males KMN

c) Maximum distance travelled between successive observations (m)

Females JLO	ns		
Males KMN	***	***	
Females KMN	***	***	ns
	Males JLO	Females JLO	Males KMN

The furthest distance moved between consecutive observations by an individual rat was a minimum of 490 m, when rat N3 moved overnight from its established nest site to a vacant burrow close to the main farm buildings. By the most likely route taken, staying close to hedgerows and field margins, the distance travelled would have been 650 m. N3 did not return to its original nest site, which was in a copse 200 m from where it was initially captured, and therefore its pre-treatment home range was calculated on the basis of its movements before it moved to the buildings.

Rats generally moved within, or close to hedgerows, along fences or other cover such as standing kale. The regular route taken by rat K5 is shown in **Figure 5.18**. This rat, an adult male, used two home sites that were 80 m apart. One of these was in a hedgerow under an old apple tree, and the other in an active badger sett. Rat K5 always stayed close to cover, moving along hedgerows or a well-worn path through the standing kale to reach a pheasant feeder. Three other rats fitted with radio collars at this site also used the badger sett as a home site.

Following the reduction of harbourage, rats still living in the cleared areas at sites J, L and O occupied a significantly reduced home range area, and smaller home range length ($p \leq 0.01$, Single Factor ANOVA). Therefore we can reject the second null hypothesis that predicted that there would be no change in the home range size or home site location of individual rats in cleared areas compared to those in un-cleared control areas. Rats living at sites JLO also had shorter home ranges following the reduction of cover

($p \leq 0.05$, Single Factor ANOVA). Over the same period at the same sites, there was no significant change in the mean home range size or mean home range length for rats living in the un-cleared areas, **Table 5.4**. Six of the 10 rats in the cleared areas were male, whereas in the un-cleared areas four of the 10 were male. There was just one rat (M2) resident in the cleared areas at sites K, M and N at the time of harbourage reduction. Rat M2 expanded its home range considerably following the reduction of harbourage, from 38.5 m^2 to 5824.6 m^2. For rats living in the un-cleared areas at sites K, M and N, there was no significant change in the mean home range size following the reduction of harbourage. Further details for individual rats are given in Appendix B.

Table 5.4. Pre and post-treatment home range data for rats living close to farm buildings (sites J, L and O). Data for rats that were lost before the harbourage reduction was carried out are excluded. Six of the 10 rats in the cleared areas were male, whereas in the un-cleared areas four of the 10 were male. Significant difference following harbourage reduction denoted by * ($p \leq 0.05$) and ** ($p \leq 0.01$).

	Cleared areas (n=10)		Un-cleared areas (n=10)	
	Before	After	Before	After
Mean home range (MCP) area (m^2)	395.1**	83.3**	46.8	15.1
Length of home range (m)	40.5*	21.0*	20.4	17.5
Maximum distance travelled (m) [a]	29.0	20.8	19.4	15.0

[a] Maximum distance between consecutive observations

Figure 5.16. The pre-treatment home range data (plotted as a minimum convex polygon, MCP) for all rats fitted with radio collars at site J. Males are shown in dark shading, females in light shading. Scale, 1:2000.

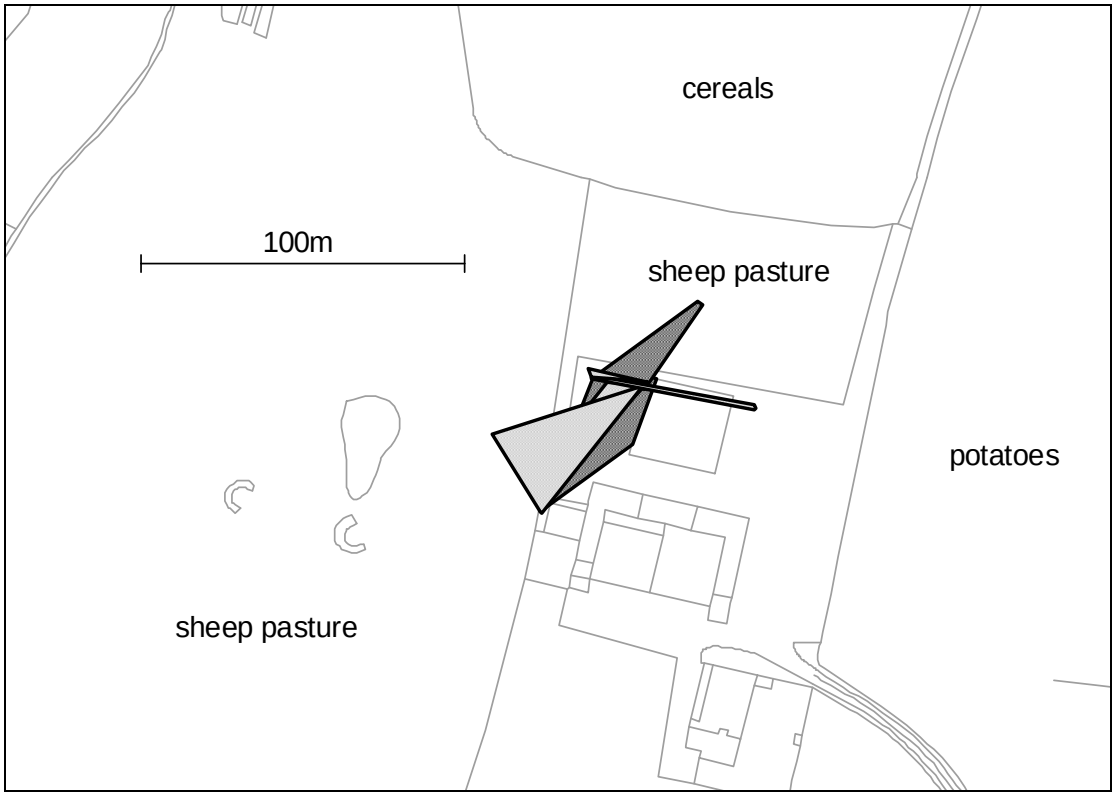


Figure 5.17. The pre-treatment home range data (plotted as a minimum convex polygon, MCP) for all rats fitted with radio collars at site K. Males are shown in dark shading, females in light shading. Scale, 1:2000.

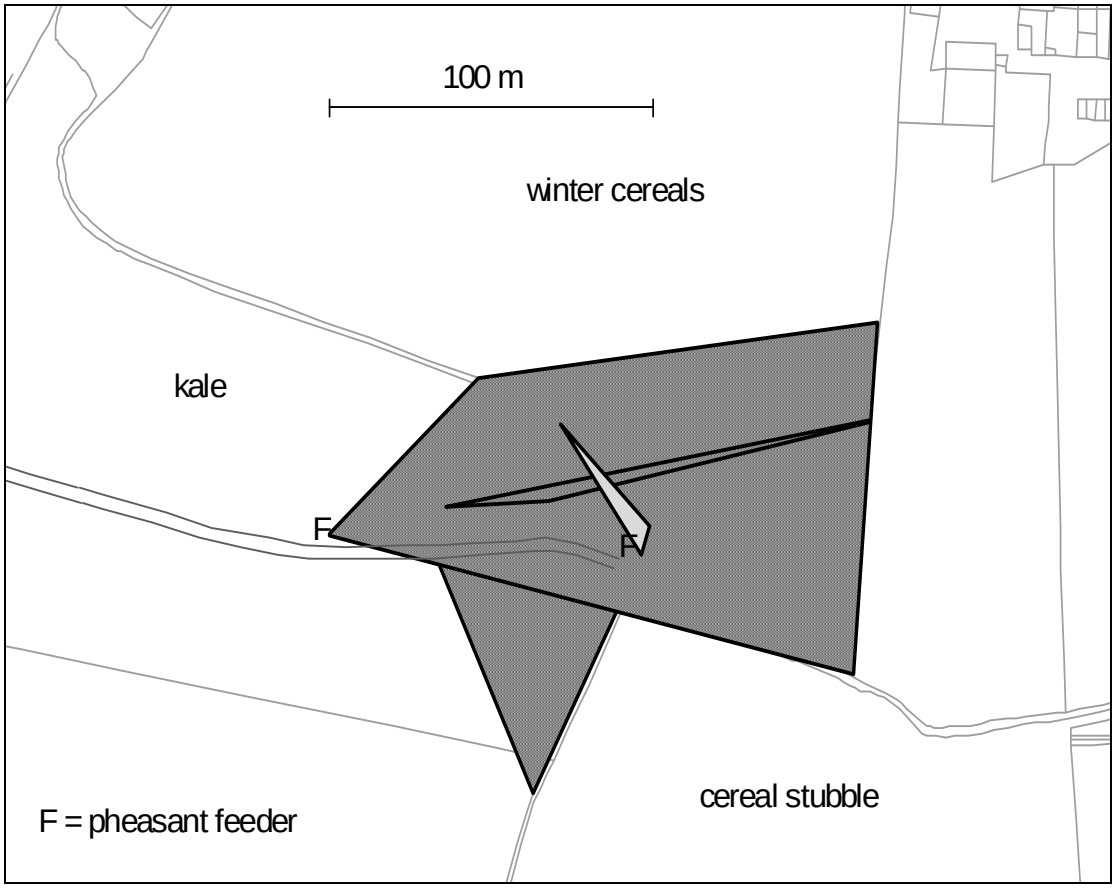
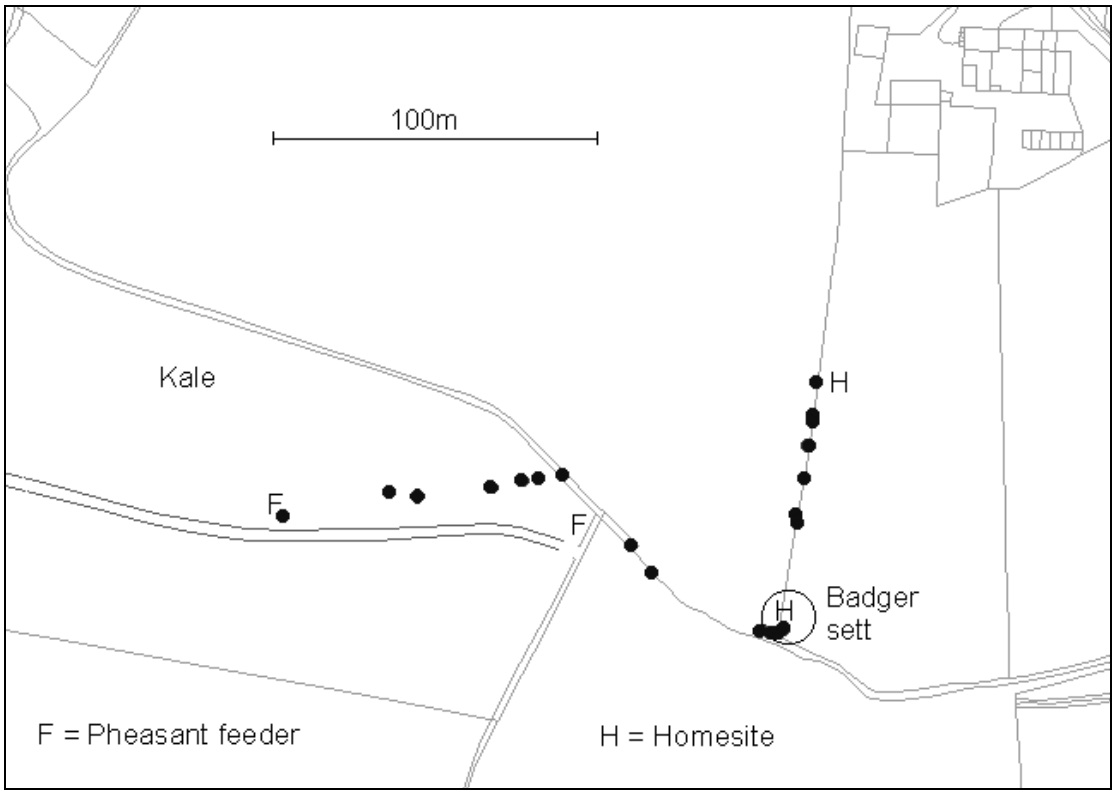


Figure 5.18. The movement of rat K5 between its two home sites, and the main food source, a pheasant feeder. Like most rats, movement was along hedgerows and other cover. The data were collected during 47 visits to the field site, each black dot indicates one location record. Scale, 1:2000.



5.3.3. Movement of individual rats near farm buildings

Figure 5.19 shows the pre-treatment home ranges for all 16 rats at site L plotted as a minimum convex polygon (MCP). This site had the highest rate of pre-treatment losses. The signal from rat L3 was lost within 24 hours, either through predation or transmitter failure. A further two rats were killed before the treatment, L16 by the farmer and L9 by a farm dog. Two either died or lost their collars in roof spaces and could not be recovered (L11 and L4), and one collar was chewed through with rat teeth marks clearly visible (L5). This left 10 rats with radio collars still alive at site L at the time of the treatment. Two of these animals (L13 and L15) lost their collars within 24 hours of the harbourage reduction and hence no post treatment home range data was available. This left eight rats at site L, four in the cleared area (rats L8, L10, L12 and L14) and four in the un-cleared area (L1, L2, L6 and L7). The pre-treatment home range data for the four rats in the cleared area is shown in **Figure 5.20**, and their corresponding post-treatment home range data is shown in **Figure 5.21**, both figures are drawn at a scale of 1:650. Only one of these rats (L8) survived for more than 30 days, the female shown near the top of **Figure 5.21**. Following the removal of cover, rat L8 moved to a different nest site, under a concrete path between two buildings and was subsequently not found away from the buildings. Like L8, rat L14 stayed in the cleared area following harbourage removal, and moved to a new nest site. Initially, it moved into the roof void of building 5, from where it continued to make feeding visits to the pig food hoppers in building 4. However, unlike L8, L14 abandoned its new nest site 11 days later, and

excavated a new burrow under a hedgerow 15 m from the nearest buildings, near to its original nest site. L14 continued to make foraging visits to the pig food hoppers during the night, crossing 15m of open ground to reach the buildings, and was killed by a farm dog less than 5 days later. L10 and L12 also stayed in the cleared area, but stayed in their original nest sites. They continued to make visits across the cleared area to gain access to pig food hoppers in building 4. L10 was found dead five days after the harbourage removal. From the condition of the remains, it was apparent that a cat, or small mustelid predator was responsible. L12 either died or lost its collar in the roof space of building 4 between 20 and 24 days after treatment.

All four of these rats occupied smaller home ranges after the cover was reduced. Their mean pre-treatment home range size was 338.6 m^2, compared to 81.0 m^2 afterwards, a reduction of 74%. The post-treatment home range of rat L8 was 6.0 m^2, less than 10% of her pre-treatment home range of 61.4 m^2.

By contrast, rats in the un-cleared area at site L occupied very similar home ranges throughout the trial. Their mean pre-treatment home range size was 31.0 m^2, compared to a mean post-treatment home range size of 28.7m^2. Rats L1 and L2 were never located outside the workshop where they had harbourage and access to stored pig food. They were sometimes seen in the roof space of the workshop where they could find access to rain water in the gutters of the building.

Figure 5.19. Pre-treatment home range data (plotted as a minimum convex polygon, MCP) for the 16 rats fitted with radio collars at site L. The male rats are shown in dark shading, and the females in light shading. Scale, 1:850.

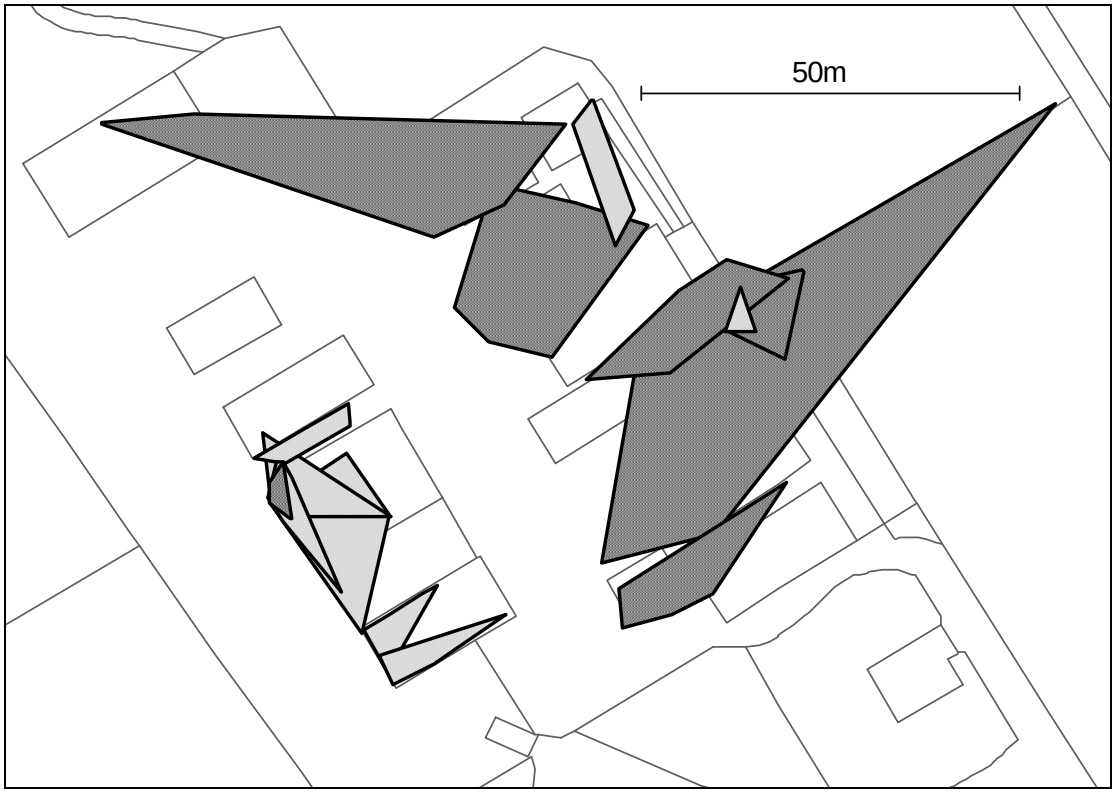


Figure 5.20. The pre-treatment home range data (plotted as a minimum convex polygon, MCP) for rats L8, L10, L12 and L14 living in the cleared area at site L. Males are shown in dark shading, the female in light shading. Scale, 1:650.

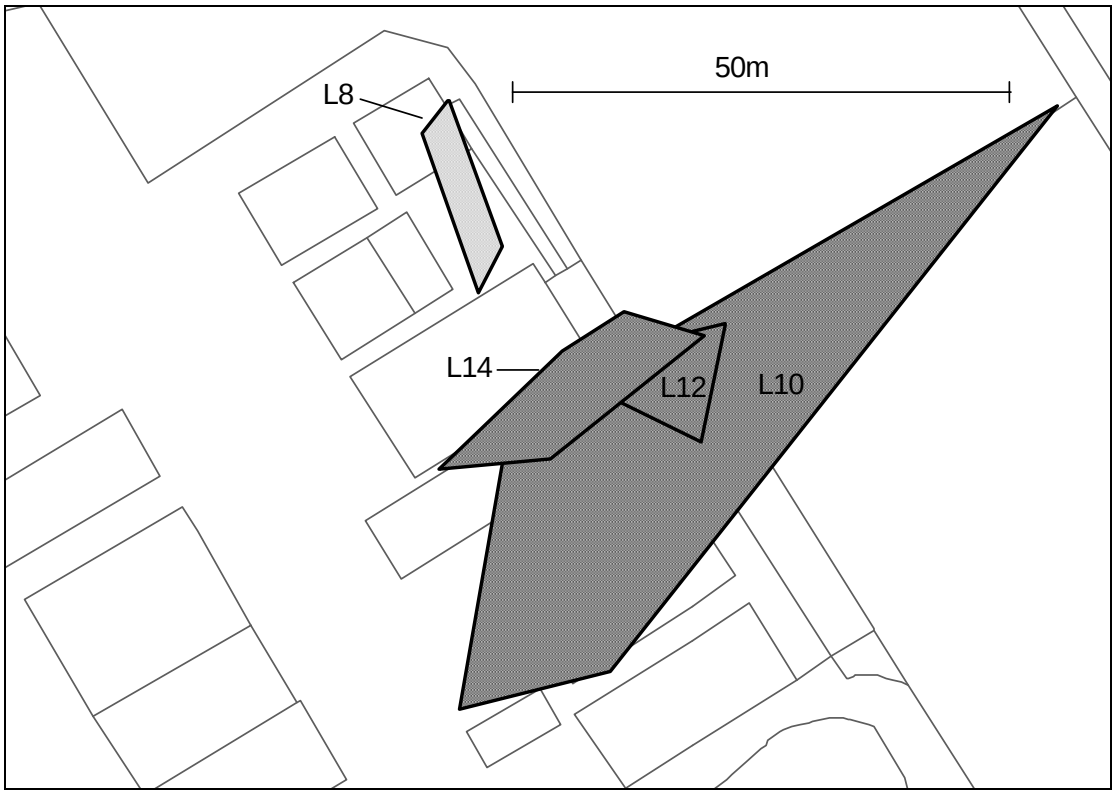
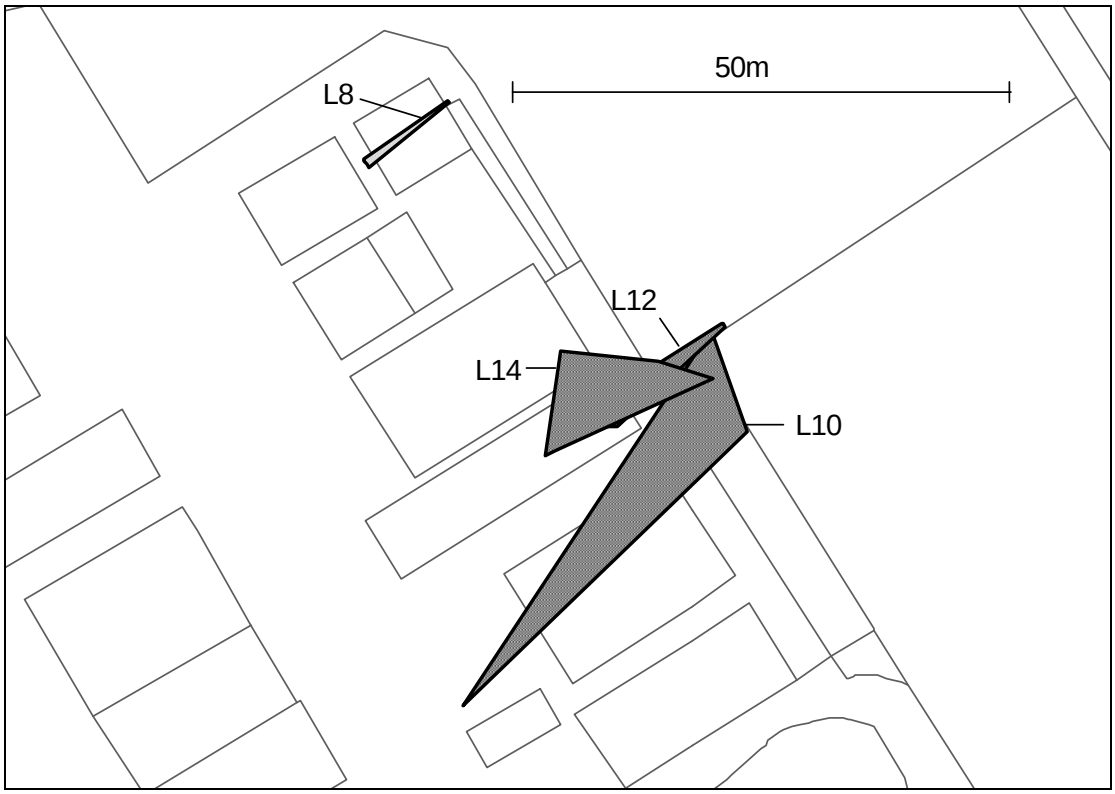


Figure 5.21. The post-treatment home range data (plotted as a minimum convex polygon, MCP) for rats L8, L10, L12 and L14 living in the cleared area at site L. Males are shown in dark shading, the female in light shading. Scale, 1:650.



5.3.4. Movement of individual rats in field systems and margins

Figure 5.22 shows the pre-treatment home ranges for both rats at site M. Before any harbourage was removed, rat M2 was never found away from the eastern row of bales. Rat M1 was also found frequently at the eastern row of bales, but her most frequently used nest site was located in the western row. Both rats were found near to the pheasant feeder on several occasions.

The post-treatment home ranges for rats M1 and M2 are shown in **Figure 5.23**. Following the removal of the eastern row of bales, M2 moved across to the western row, and also frequented a second nest site, 150m away, in an area of scrub vegetation near the south west corner of the field. M2 was not seen near the pheasant feeder after the eastern row of bales was removed, unlike M1, who continued to make visits to the pheasant feeder, across open ground. M2 was found dead between the western row of bales and the hedgerow, 53 days after the removal of the eastern bales. The condition of the remains indicated that rat M2 was probably killed by a cat, or other small mammalian predator. Rat M1 was found dead between the western bales and the pheasant feeder 22 days after the bales were removed, and had been shot.

Figure 5.22. Pre-treatment home range data (plotted as a minimum convex polygon, MCP) for the two rats (both female) fitted with radio collars at site M. Scale, 1:1600.

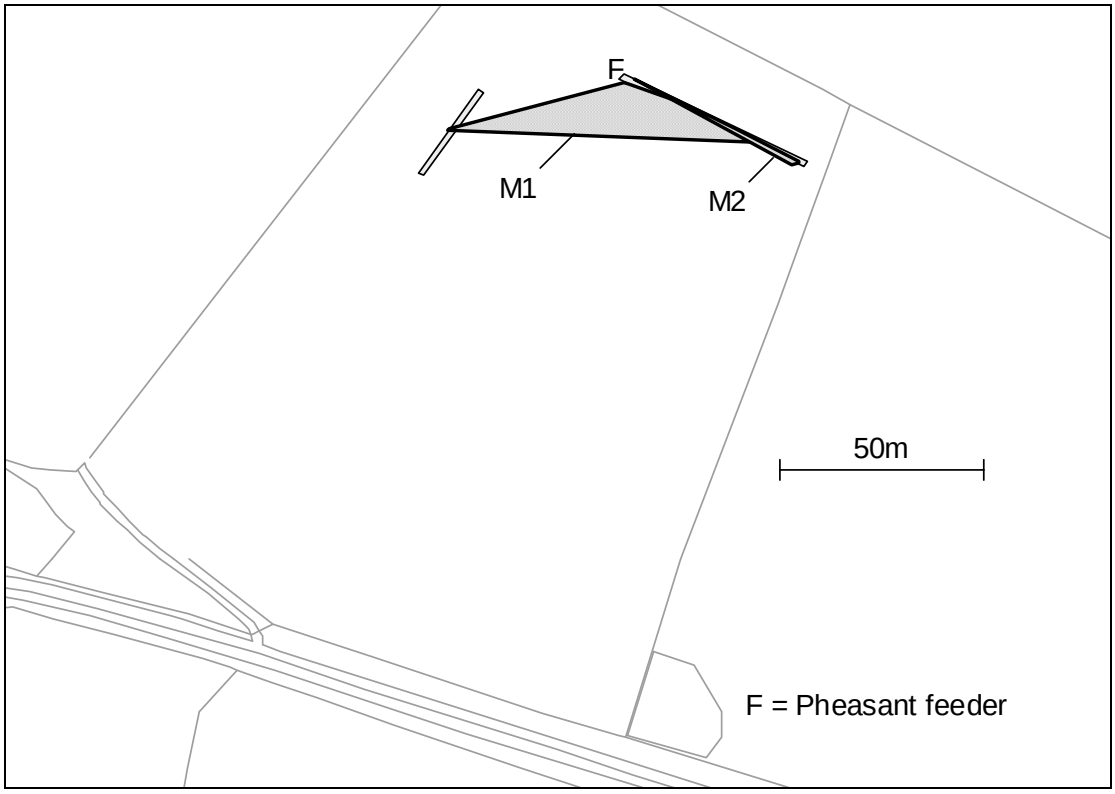
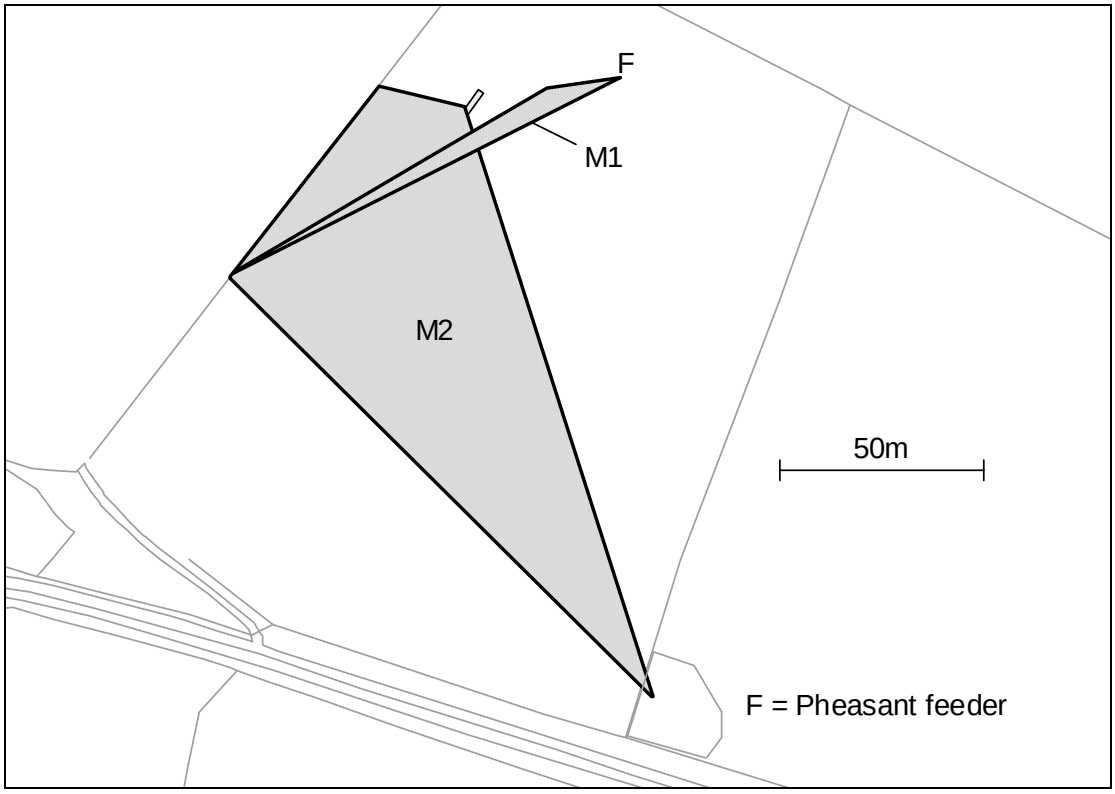


Figure 5.23. Post-treatment home range data (plotted as a minimum convex polygon, MCP) for the two rats (both female) fitted with radio collars at site M. Scale 1:1600.



5.3.5. Comparisons between MCP and kernel analysis

For the analyses thus far, the Minimum Convex Polygon (MCP) method has been used to examine the home range data. The MCP method has been widely used in radio-tracking studies of other species. It is a non-parametric method and is therefore easily interpreted; the output is simply a polygon enclosing the extremities of the home range data. For some species however, the MCP method tends to overestimate the size of the home range. The error will be greatest for species with a multi-modal, or 'clumped'

home range configuration, where large areas between the ‘core’ areas are not utilized. This might apply to Norway rats in some circumstances, for instance where rats are utilising two perpendicular field margins, but not the adjoining field. At site K for example, the radio-tracking data for a male rat (K5) suggested that it was moving between its nest site and a pheasant feeder on a regular basis, mainly along field margins. Along a field margin where the adjoining field of recently sown winter cereals afforded little cover, the rat appeared not to venture into the field, but it was frequently found in the mature kale crop that afforded good cover. The MCP method therefore overestimated the home range for this rat, as a portion of the winter cereal field, into which the rat apparently did not venture, was included. **Figure 5.24** shows the post-treatment (after harbourage reduction) MCP for rat K5.

Alternative methods of home range analysis are available including other non-parametric methods such as Dirichlet tessellation, and parametric methods such as kernel analysis. Wray *et. al*. (1992) found that MCP analysis overestimated the home range size for European hares (*Lepus europaeus*) by up to 73% compared to the harmonic mean, kernel and Dirichlet tessellation methods. Similarly it was found that the MCP method overestimated the size of badger home ranges by up to 46%. Kernel analysis is an appealing alternative to the MCP method and has been applied to home range data for a wide range of species. Contours, or ‘isopleths’ of habitat usage are generated, usually to include 50%, 75% or 95% of the radio fixes. The contours are generated according to a number of assumptions and are modified by a smoothing factor (h) which is often

calculated by Least Squares Cross Validation (LSCV) of the mean integrated square error Silverman (1986). Smaller multiples of h produce tight contours around locations, whereas higher multiples of h produce smooth contours, generating larger home ranges. LSCV can be applied on a range-by-range basis, but this makes the size of individual ranges dependent not only on the area covered by the locations, but also on how they are distributed within that area. **Figure 5.25** shows the fixed (bivariate normal density) kernel (Worton, 1989) for the home range data presented in **Figure 5.24**. The smoothing factor (h) generated by Least Squares Cross Validation was 10.998. The habitat utilization for this rat was very similar before treatment (harbourage reduction), yet partly because less radio-fixes were collected, LSCV produced a larger smoothing factor (h = 30.447) leading to an over-estimated home range (**Figure 5.26**). To overcome this problem, the median LSCV smoothing factor was calculated using the pre-treatment data for all rats, giving h = 3.753. The median smoothing factor was then applied to all rats using the kernel analysis (Kenward *et al*., 2003). This gave more 'realistic' estimates of the home range size for rat K5, which are shown in **Figure 5.27** (post-treatment) and **Figure 5.28** (pre-treatment).

The pre-treatment home range data using the median LSCV smoothing factor (h = 3.753) for all rats at site K are shown in **Figure 5.29**, indicating that all five tagged rats largely avoided the recently sown winter cereal and stubble fields, but were often found in the kale field that afforded better cover. The mean pre-treatment h by LSCV for all rats at sites J-O was

8.612, with most of the larger values arising from rats at sites K, M and N (mean h = 21.491, range 0.00 – 57.711) rather than those at sites J, L and O (mean h = 3.210, range 0.00 – 11.395). The mean home range calculated by kernel analysis (using the median LSCV smoothing factor) for rats living near farm buildings and in field margins is shown in **Table 5.5**, home ranges calculated by the MCP method are shown for comparison. Pair-wise comparisons were made for these data using Single Factor ANOVA to examine differences in home range size (95%, 75% and 50% kernel contours) for male and female rats living near farm buildings or in field margins (**Table 5.6 a-c**). 95%, 75% and 50% kernel probability contours for rats living in cleared areas near farm buildings (sites J, L and O) were significantly smaller after cover was reduced. 95% and 75% kernel probability contours for rats living in un-cleared areas near farm buildings were significantly smaller after cover was reduced (**Table 5.7**).

Figure 5.24. The home range of a male rat (K5) on arable land in North Yorkshire (site K) calculated by the Minimum Convex Polygon (MCP) method.

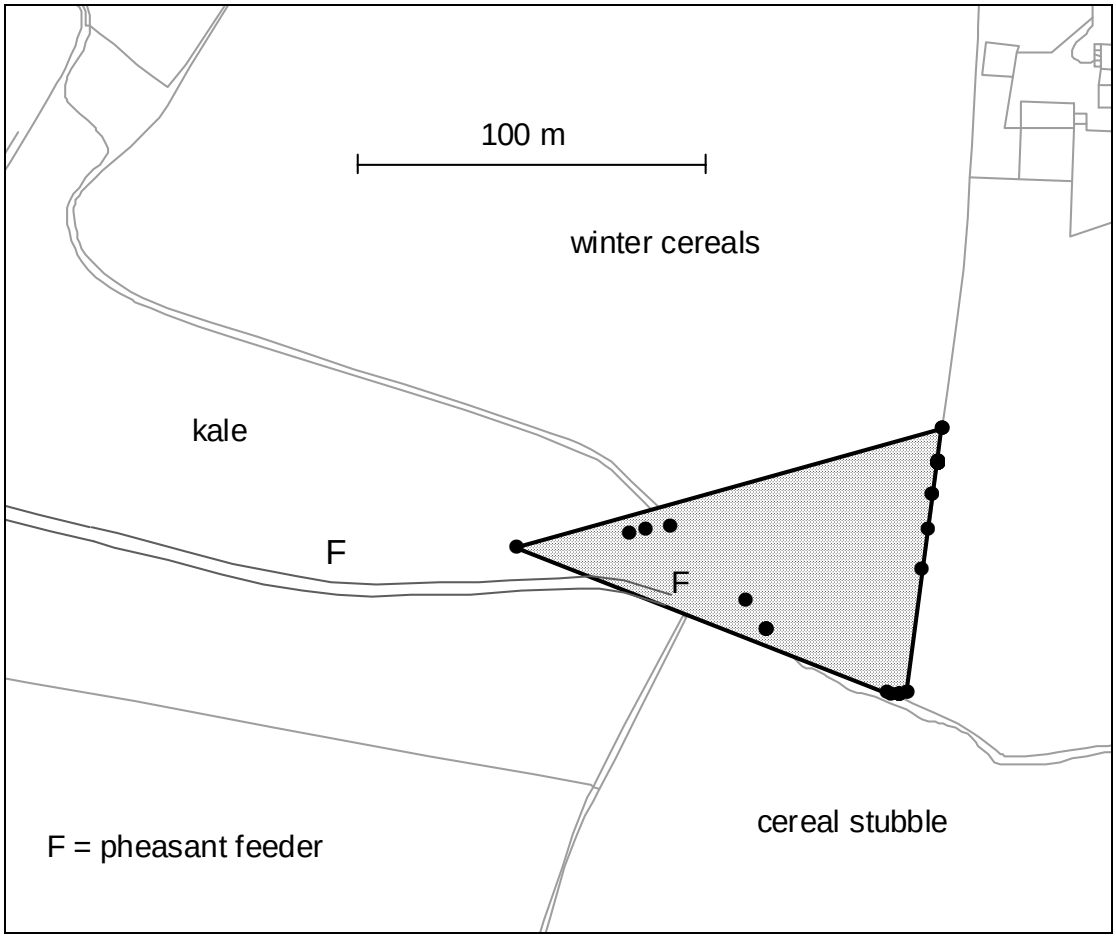


Figure 5.25. The post-treatment home range of a male rat (K5) on arable land in North Yorkshire (site K) calculated by the kernel method. The smoothing factor (h = 10.998) was generated by the Least Squares Cross Validation technique. 95% (outer) 75% (middle) and 50% (inner) probability contours are shown.

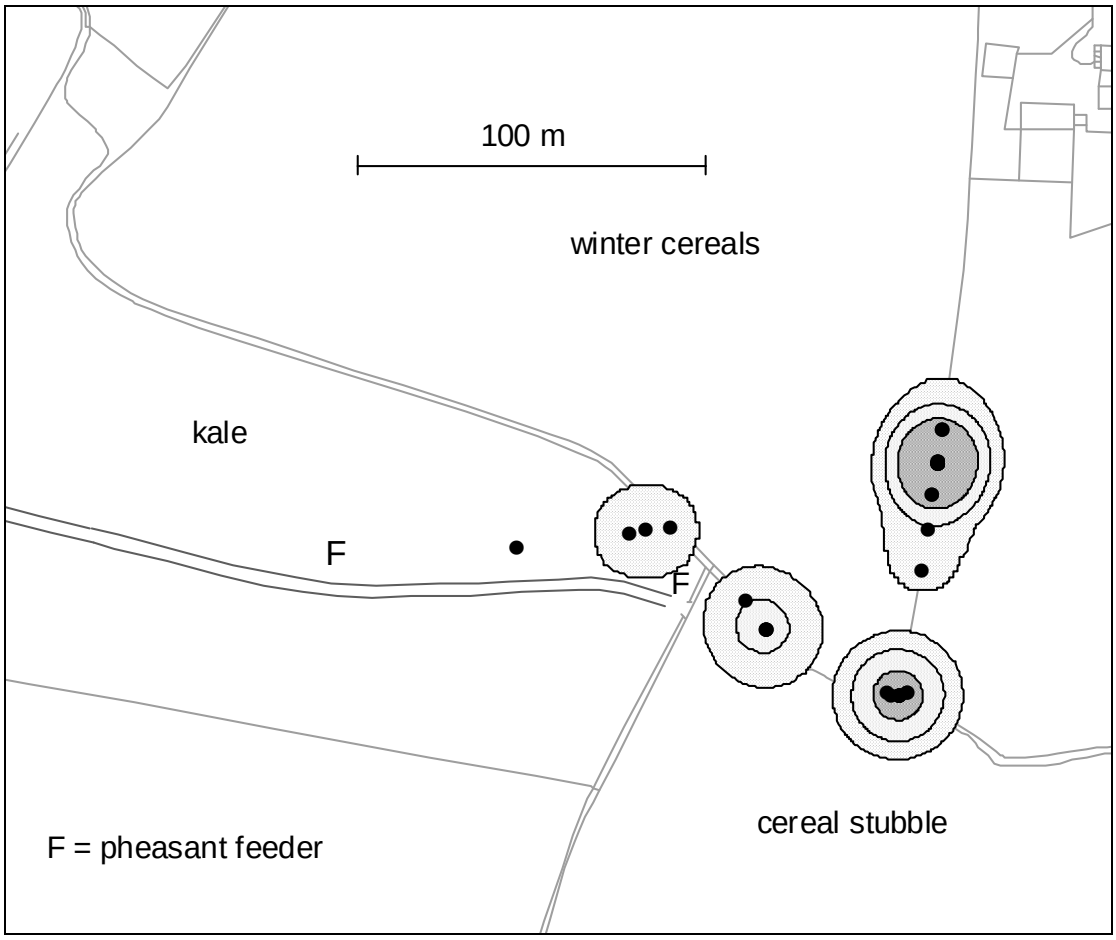


Figure 5.26. The pre-treatment home range of a male rat (K5) on arable land in North Yorkshire (site K) calculated by the kernel method. The smoothing factor (h = 30.447) was generated by the Least Squares Cross Validation technique. 95% (outer) 75% (middle) and 50% (inner) probability contours are shown.

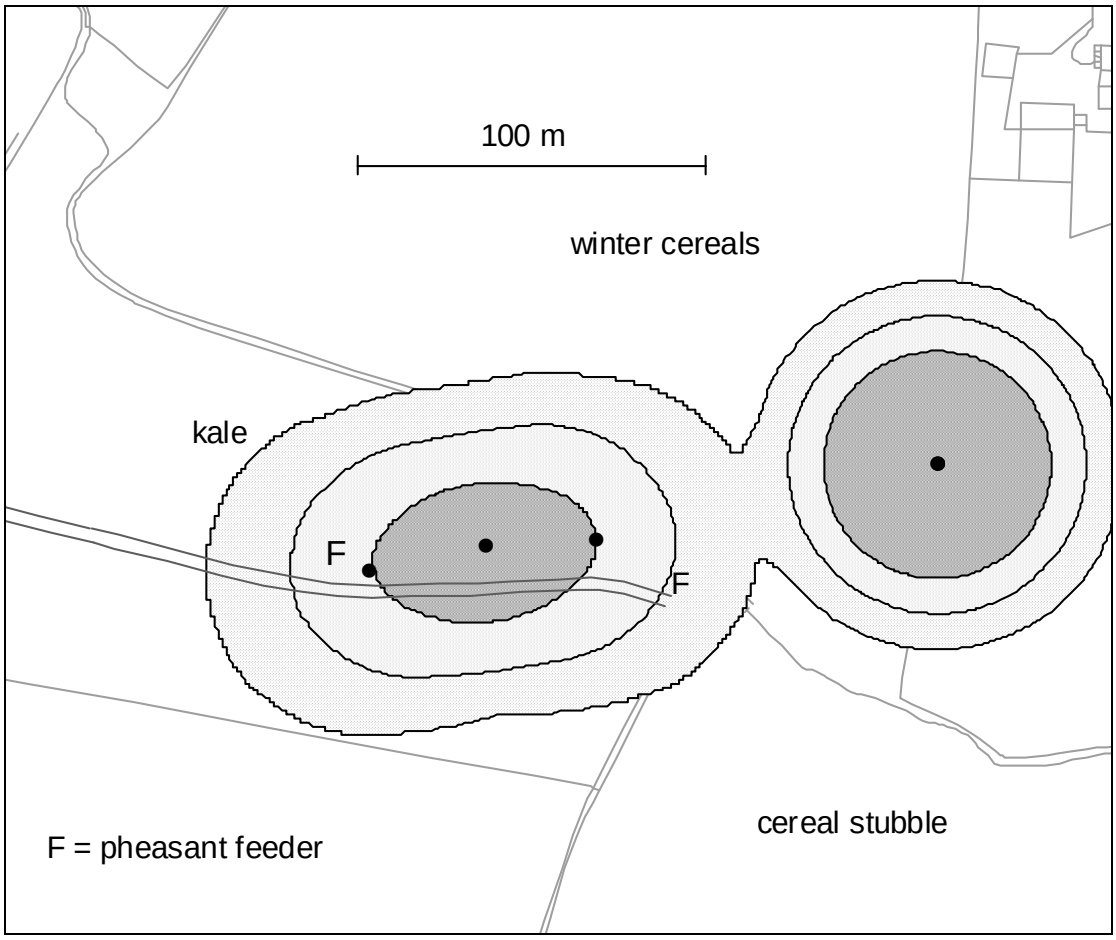


Figure 5.27. The post-treatment home range of a male rat (K5) on arable land in North Yorkshire (site K) calculated by the kernel method using the median LSCV smoothing factor (h = 3.753). 95% (outer) 75% (middle) and 50% (inner) probability contours are shown.

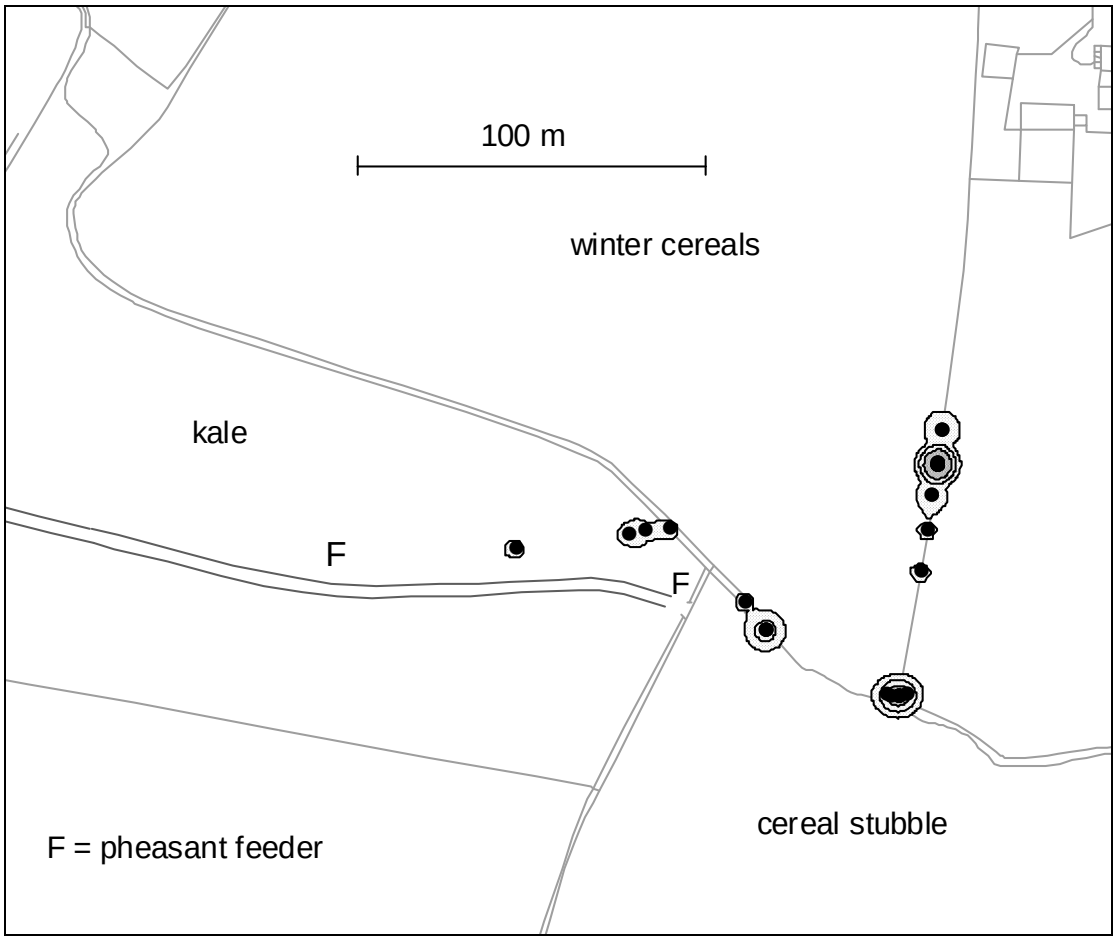


Figure 5.28. The pre-treatment home range of a male rat (K5) on arable land in North Yorkshire (site K) calculated by the kernel method using the median LSCV smoothing factor (h = 3.753). 95% (outer) 75% (middle) and 50% (inner) probability contours are shown.

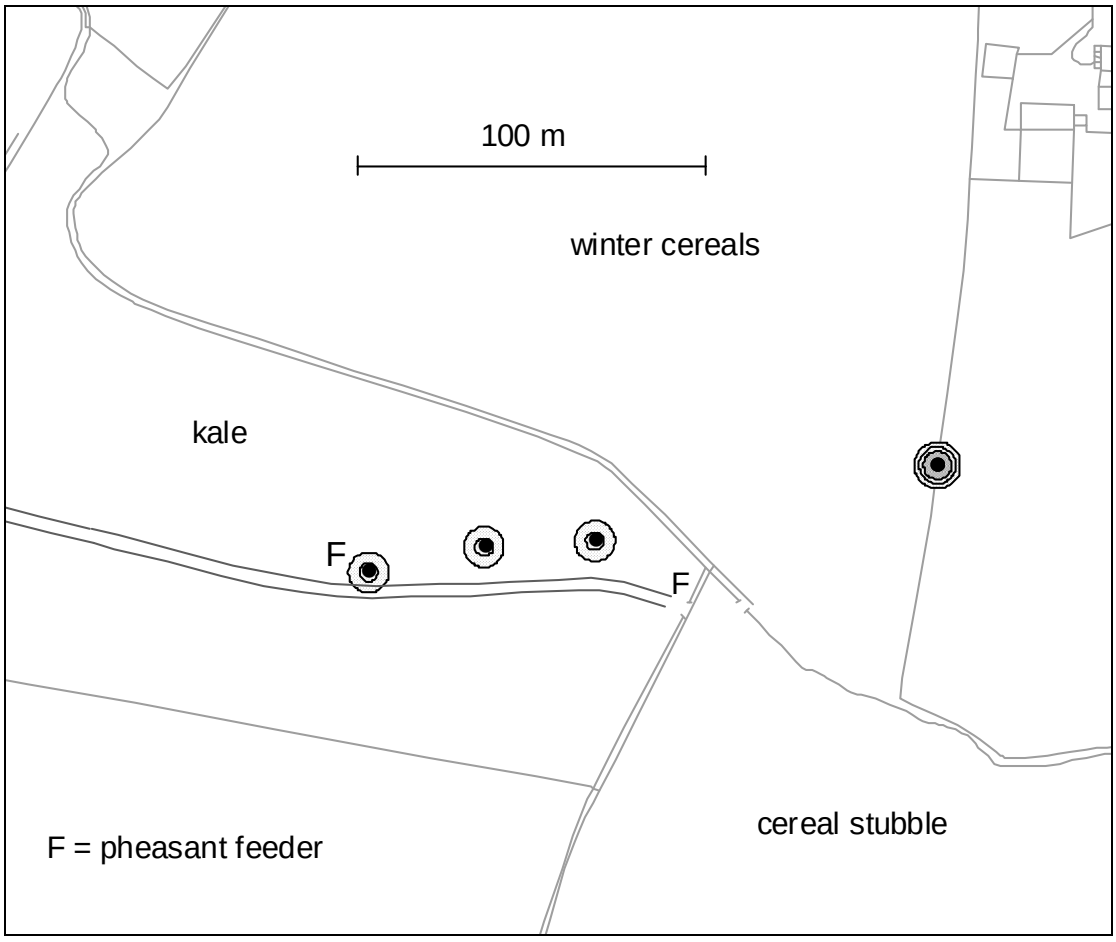


Figure 5.29. The pre-treatment home ranges of five rats (four males and one female) on arable land in North Yorkshire (site K) calculated by the kernel method using the median LSCV smoothing factor (h = 3.753). Male rats are shown in dark shading, and females in light shading. 95% (outer) 75% (middle) and 50% (inner) probability contours are shown (Scale 1:2000).

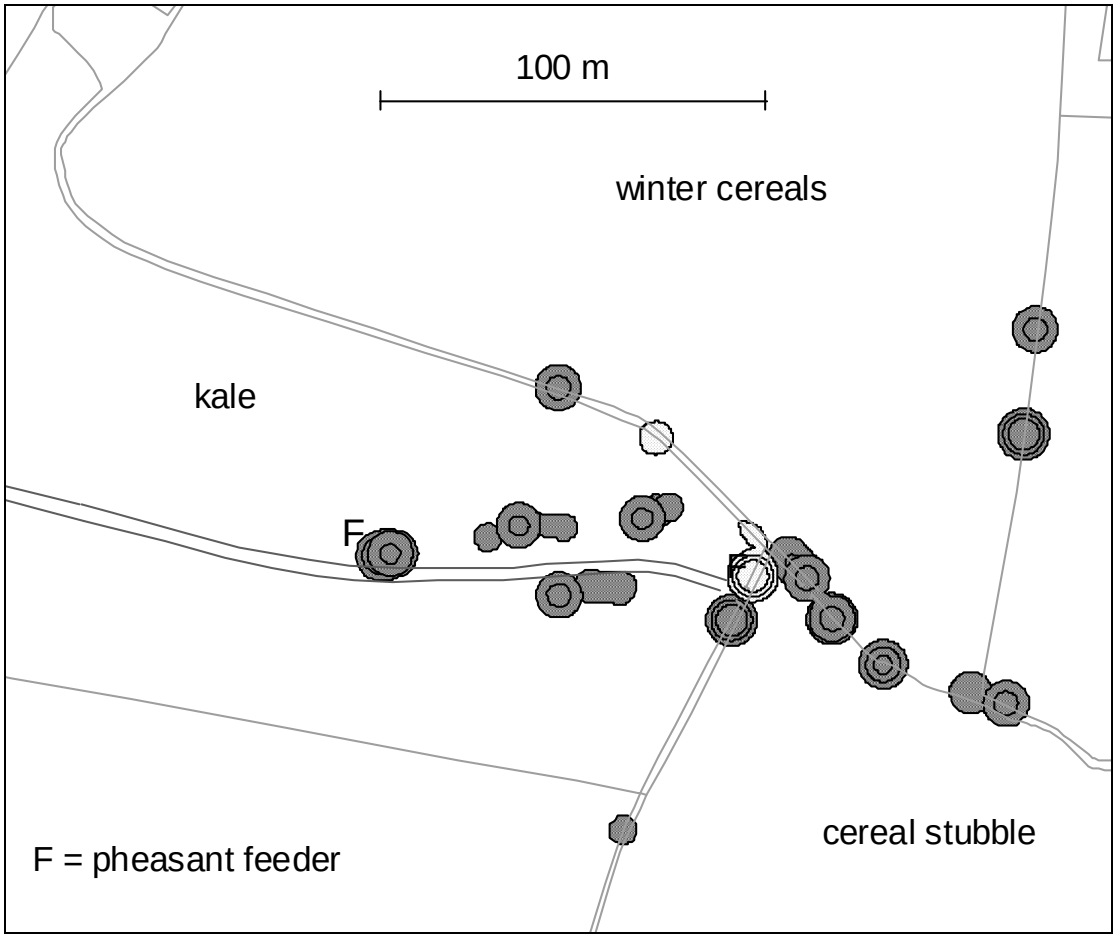


Figure 5.30. The pre-treatment home ranges of 16 rats (eight males and eight females) on a pig unit in East Yorkshire (site L) calculated by the kernel method using the median LSCV smoothing factor (h = 3.753). Male rats are shown in dark shading, and females in light shading. 95% (outer) 75% (middle) and 50% (inner) probability contours are shown. Scale 1:950.

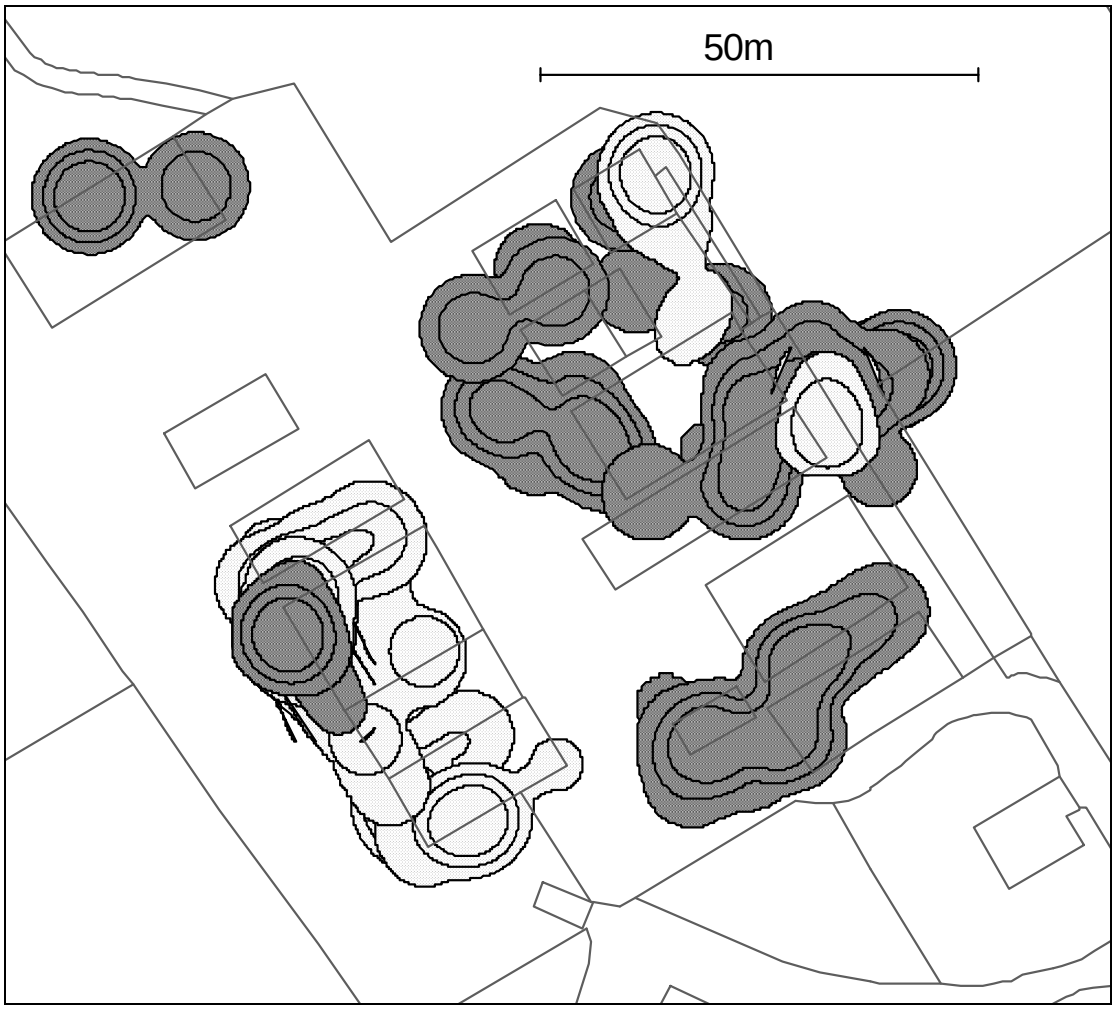


Table 5.5. Pre-treatment home range data for rats living close to farm buildings (sites J, L and O) or in field margins (sites K, M and N) at farm sites in North Yorkshire, East Yorkshire and Durham 1998-2000. Kernel analyses were performed using the median LSCV smoothing factor (h = 3.753).

	Sites J, L and O		Sites K, M and N	
	Males (n=15)	Females (n=15)	Males (n=7)	Females (n=5)
Mean home range (MCP) area (m^2)	304.5 (9.0 - 1056.6)	140.4 (3.6 - 667.5)	4987.8 (19.5 – 14571.0)	612.35 (38.5 - 1694.7)
95% kernel (m^2)	407.5 (90.4 – 803.4)	293.7 (23.6 – 577.4)	493.4 (274.4 – 944.5)	490.9 (234.4 – 746.2)
75% kernel (m^2)	176.8 (53.6 – 327.6)	118.4 (0.4 – 175.0)	159.7 (87.6 – 302.2)	239.2 (89.0 – 443.9)
50% kernel (m^2)	77.9 (5.15 – 187.8)	55.0 (0.0 – 92.3)	55.4 (50.0 – 68.4)	121.5 (51.6 – 251.6)

Table 5.6 (a-c). Pair-wise comparisons (Single Factor ANOVA) between male and female rats living near farm buildings (sites JLO) or in field margins (sites KMN) for 95%, 75% and 50% probability contours generated by kernel analysis of radio-tracking data collected before reduction of cover. Kernel analyses were performed using the median LSCV smoothing factor (h = 3.753). Significant differences between the means denoted by ***** ($p \leq 0.05$), ****** ($p \leq 0.01$) and *** ($p \leq 0.001$). No significance difference denoted by ns.

a) 95% probability contour (m^2)

Females JLO	ns		
Males KMN	ns	*	
Females KMN	ns	*	ns
	Males JLO	Females JLO	Males KMN

b) 75% probability contour (m^2)

Females JLO	*		
Males KMN	ns	ns	
Females KMN	ns	**	ns
	Males JLO	Females JLO	Males KMN

c) 50% probability contour (m^2)

Females JLO	ns		
Males KMN	ns	ns	
Females KMN	ns	**	ns
	Males JLO	Females JLO	Males KMN

Table 5.7. Pre and post-treatment home range data for rats living close to farm buildings (sites J, L and O) using kernel analysis. Kernel analyses were performed using the median LSCV smoothing factor (h = 3.753). Data for rats that were lost before the harbourage reduction was carried out are excluded. Six of the 10 rats in the cleared areas were male, whereas in the un-cleared areas four of the 10 were male. Significant difference (paired t - test) following harbourage reduction denoted by * ($p \leq 0.05$) and ** ($p \leq 0.01$).

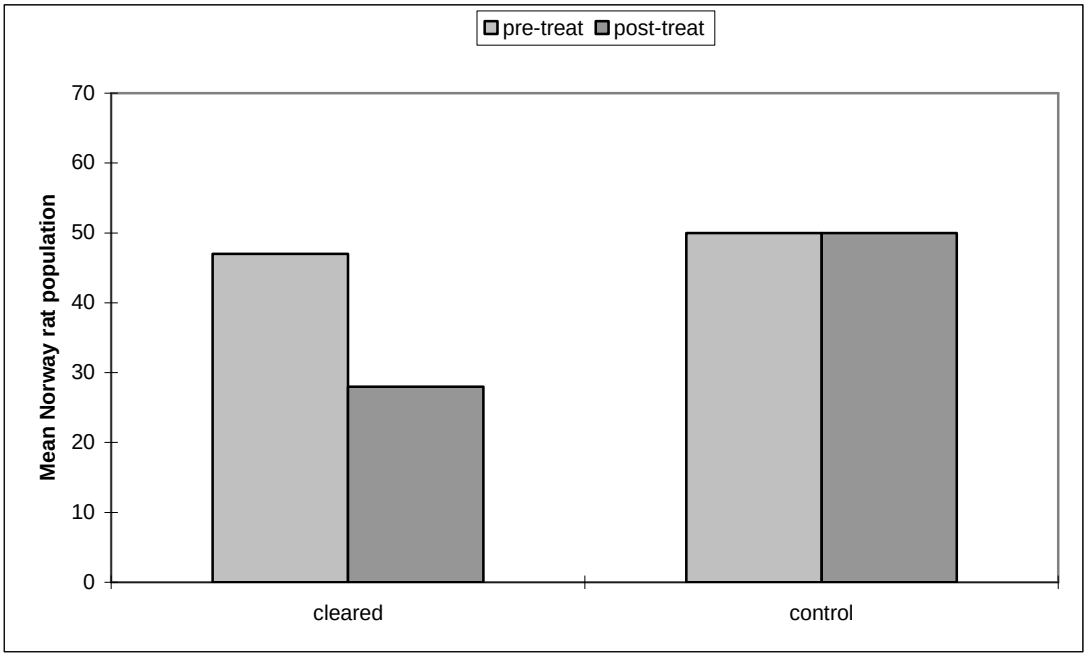
	Cleared areas (n=10)		Un-cleared areas (n=10)	
	Before	After	Before	After
95% kernel	423.5 *	255.1 *	239.9 **	162.7 **
75% kernel	163.6 *	116.1 *	110.4 *	80.0 *
50% kernel	76.0 **	46.2 **	49.8	39.1

5.3.6. Census data

Before any harbourage was removed, an index of rat activity was obtained at sites K-O over four consecutive nights using carbon coated tracking plates. An estimate of rat numbers at these five sites was then obtained from the mean of the four activity indices, as described in section 2. This was repeated three weeks after the reduction of harbourage. **Figure 5.31** shows the estimated number of Norway rats at sites K-O before and after selective removal of harbourage. In areas where harbourage was reduced, there was an overall reduction in the rat population estimate of 40.7% (single factor ANOVA, $p \leq 0.01$) In areas where harbourage was not

reduced there was an overall reduction of 0.5%. Hence we can reject the third null hypothesis that predicted that there would be no change in the size of rat populations in cleared areas compared to those in un-cleared control areas

Figure 5.31. The estimated size of Norway rat populations at five sites K-O in North Yorkshire, East Yorkshire and Durham 1998-2000. In the 'cleared' areas, cover such as weeds, old machinery and other debris was removed, and in 'control' areas the habitat was unmodified.



5.4. Discussion

5.4.1. General observations and MCP analyses

In this study, home range length for rats at the livestock sites was generally much smaller than that of rats at the arable sites. On livestock farms, food is generally available for rats throughout the year, and rats with home sites near to the buildings do not need to move far. This is consistent with observations made by Taylor (1978) who found that on agricultural land, rats living near to a reliable food source rarely moved more than 30 m from their home sites. In that study, food sources were artificially maintained near to hedgerow rat populations. When the food was removed, rats living nearby expanded their range considerably. Here, the mean home range length for male and female rats living near livestock farms was very close to the 30 m reported by Taylor for rats living near their artificially maintained food sources. In the present study, some of the rats at the arable sites did have small home ranges centred on the pheasant feeders. However, most of the rats at sites K, M and N had large home ranges that incorporated more than one food source. This may have been because they were unable to monopolise a single food source due to antagonism from other rats. The pheasant feeders represented a discrete, high value food resource, and observations made at site K revealed that there were large numbers of rats using each of the two feeders. Antagonistic encounters were observed on a regular basis near one of the feeders, although at the other, rats were frequently seen feeding together. At the livestock sites, the food was easily

available and distributed over a much wider area, probably leading to fewer antagonistic encounters, and allowing a greater density of rats to live within a short distance of the buildings.

Thus it seems that the distribution and size of the food resource probably has a strong influence on the size of the home range occupied by wild rats in the agricultural environment. However, other factors, such as breeding behaviour may also be important. Using the Minimum Convex Polygon (MCP) method, male rats in this study occupied larger home range areas than females, approximately twice as large at the livestock sites, and eight times larger at the arable sites. The length of home range of male rats was also greater than that of females, but the difference was not statistically significant. Taylor (1978) also reported that the home range length of male rats in field margins was greater than that of females, 660 m for males compared with 340 m for females. These observations may reflect the different mating strategies of the two sexes, male rats are highly promiscuous, and probably move further than females in search of potential partners. Within these distinctions, there was some considerable variation. Most rats living near farm buildings had small home ranges as they had no need to travel long distances in search of food and mating opportunities. Some of these rats appeared to have taken extreme risk avoidance strategies; two rats living in a workshop in the un-cleared area at site L apparently never ventured outside, even to the extent of climbing into the roof space to gain access to rain water in the gutters. Some rats however

appeared to be ‘risk takers’ and sometimes made long excursions from their home site for no apparent reason.

Using the Minimum Convex Polygon (MCP) and kernel methods, the home range area, and home range length of rats living near livestock farms in this study were significantly smaller following the reduction of harbourage at those sites. Most of the rats that were resident (i.e. occupied nest sites) in the cleared areas, stayed there following harbourage reduction. Only three of the thirteen rats present when the harbourage was reduced moved to an adjacent un-cleared area. From the rats that stayed in the cleared areas, only one was still alive after 30 days. A much higher proportion of rats (10 out of 18) survived for 30 days or more in the un-cleared areas. The reluctance of rats to move into the un-cleared areas was again probably due to antagonism from other rats already occupying nest sites in those areas. Taylor (1978) found that there was no tendency for rats living in field margins to move to nest sites near farm buildings, even at times of apparent food deprivation. In that study, some of the 21 rats tracked regularly visited farm buildings, and included the buildings in their home range, but none of them became established there. Taylor suggested that this might have been due to antagonism from rats living near the buildings, although no antagonistic encounters were observed. This is contrary to the widely held belief that rats leave field margins when food becomes scarce in winter, and move into farm buildings. It rather suggests that visits to the farm buildings from field-dwelling rats may increase during the winter months, but that they will not take up residence unless the resident population is removed, by a

rodenticide treatment for example. Before harbourage reduction at site N, rat N3 moved overnight from its established nest site to farm buildings nearly 500 m away. It became established near a grain store, in a burrow, which had been baited with rodenticide 4-6 weeks earlier as part of another trial. This was the only tracked rat that moved from the field margins to farm buildings, and is good evidence that immigration from outlying populations of rats does occur following a rodenticide treatment.

Although rats were trapped and fitted with radio collars in the areas due to be cleared at sites K, M and N, only one was found to be resident in those areas. For the other rats at those sites, the cleared area was usually a small part of a much larger home range; therefore their home range size was largely unaffected. The one rat that was resident in a cleared area at the arable sites expanded its home range following harbourage reduction. This was at site M, where removal of the harbourage, a row of straw bales, revealed shallow nests just under the bales with no burrows into the ground. Removing the bales therefore removed the nest site of this rat, forcing it to move elsewhere. It subsequently expanded its range, found two new nest sites, and never returned to its previous feeding site in the cleared area.

The tracking plate census at sites K-O revealed that rat activity was significantly reduced in the cleared areas following harbourage reduction. Given that home range size was also reduced at the livestock sites, it is possible that this reflected a change in rat behaviour, rather than a change in population size. However, predators in the cleared areas took three rats

soon after harbourage was reduced. This suggests that the reduction in the activity index may have been due to two factors; a reduction in the rat population, and lower activity of the remaining rats, possibly in response to a greater threat of predation. A reduction in rat activity, as measured by tracking plates, was observed in the cleared areas regardless of the type of habitat. Harbourage reduction is therefore likely to lead to lower rat activity, and by inference, fewer rats, in field margins and around farm buildings. However, as a rodent control strategy, habitat management is likely to be more practical and more effective near farm buildings, due to the smaller home ranges of rats in that environment. A cleared area of 30 m around farm buildings, corresponding to the mean home range length of rats in that habitat, would probably be sufficient as a harbourage free zone, and may also act as a barrier to reinvasion.

5.4.2. Comparisons between the MCP and kernel approaches

Minimum Convex Polygons provided an easily interpreted method of analysing Norway rat home range data. However, the home range was overestimated for some rats, especially rats living in field margins that appeared to have a multi-modal home range with several core areas. Kernel analysis of the home range data was not straightforward, and Least Squares Cross Validation of the data also lead to exaggerated home range sizes for some animals living in field margins, especially where the number of location fixes was small. This was a particular problem here as the number of location fixes often varied between pre-treatment and post-treatment data

sets. Rather than exclude useful data from the analyses, the pre-treatment median LSCV smoothing factor was calculated and then applied to all rats pre-treatment and post-treatment. This resulted in more ‘realistic’ home range descriptions for rats in field margin environments. However the smoothing factor was a compromise value, biased towards the larger number of rats living near farm buildings. The median smoothing factor may therefore have underestimated the home range size of rats in field margin environments, and blurred the distinction between ‘field populations’ and ‘farm populations’ found during the MCP analysis. Even so, some of these differences were still apparent using kernel analyses, as were the differences between male and female rats, and the differences between ‘cleared’ and ‘control’ areas.

6. A comparison of rodenticide and non-rodenticide approaches

6.1. Background

In the previous chapter, a one-off reduction in cover around farm buildings led to a significant reduction in rat activity within three weeks. This suggests that cover is an important resource for rats and reducing it may lower the carrying capacity of the farm environment. If cover can be maintained at low levels, recovery of rat populations may be impeded following control operations, leading to a reduction in the need for rodenticides over the longer term. This would have two main benefits; a reduction in the selection pressure that has led to the emergence of anticoagulant resistant rat populations, and a reduction of risks to non-target species from accidental poisoning. Rodent control guidelines often recommend improving standards of hygiene, tidying the site and rodent proofing following rodenticide treatments, and this can help to minimise future problems. The final phase of this study goes a step further by attempting to evaluate the effects of establishing and maintaining low levels of cover around farm buildings by monitoring the recovery of rat populations following initial control measures on two groups of farms. On one group of farms a ‘habitat management’ approach was implemented; on the other group of farms, anticoagulant rodenticides were used to control the rat populations. To be acceptable to farmers and contractors, control of rat infestations by habitat management should be as cost-effective in the long-term as control using conventional rodenticide-based methods. Therefore, the non-rodenticide control strategy

was compared with the use of commercially available anticoagulant baits, in terms of time and effort required, as well as efficacy.

6.2. Materials and methods

6.2.1. Description of study sites

Five field trials were carried out between June 2000 and October 2002, although the collection of data was interrupted by access restrictions imposed during the Foot and Mouth Disease (FMD) outbreak, which began in February 2001. **Figure 6.1** shows the location of the study sites, which were in east Yorkshire (site P), north Yorkshire (sites Q-S) and Durham (site T). The main farming activity at sites P and Q was pig rearing and fattening. Site P covered an area of 7 870 m^2, with buildings of relatively modern design (less than 20 years old), while site Q covered an area of 7 206 m^2 with mainly older style brick built structures. A mix of arable and pastureland (**Figure 6.2** and **Figure 6.3**) surrounded both of these sites. At site R the yards and farm buildings covered an area of 2 360 m^2, and the main farming activity was cattle rearing and fattening. This site was adjacent to residential land to the north, east and south, with a mix of arable and pastureland to the west (**Figure 6.4**). At site S the main activities were arable production, sheep farming, and pig fattening. The buildings and yards at this site were surrounded by a mix of arable and pastureland, and covered an area of 7 660 m^2. At site T the sole farming activity was pig fattening, in buildings surrounded by arable fields. This site covered an area of 10 190 m^2. Work at sites Q, R and T was started in June 2000, and at sites P and S in July

2000. Work at a sixth site was started in October 2000, but insufficient data was collected before the outbreak of FMD in February 2001.

Sites P, S and T were previously used in the habitat modification trials described in chapter 5, and are referred to in that chapter as sites L, J and O respectively. At site P, eight months had elapsed between the habitat modification trial and the beginning of this trial, at site S 23 months had elapsed, and at site T three months had elapsed. During that time, the harbourage levels in the cleared areas at those three sites had been allowed to return to levels similar to those seen before the previous work. At the start of this trial, all six sites had areas of harbourage such as vegetation, redundant farm machinery and building materials in close proximity to the farm buildings, and all six sites had signs of a rat infestation.

Figure 6.1. The location of field sites P-T.

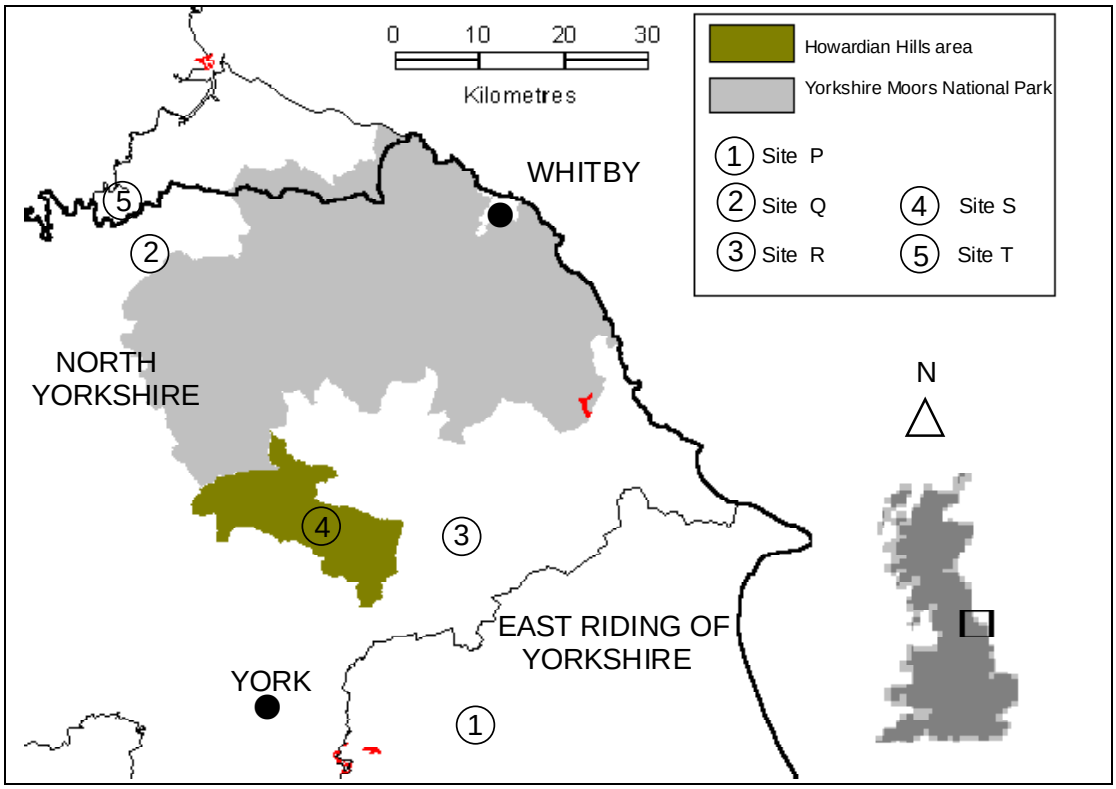


Figure 6.2. Site P. Scale 1:2000.

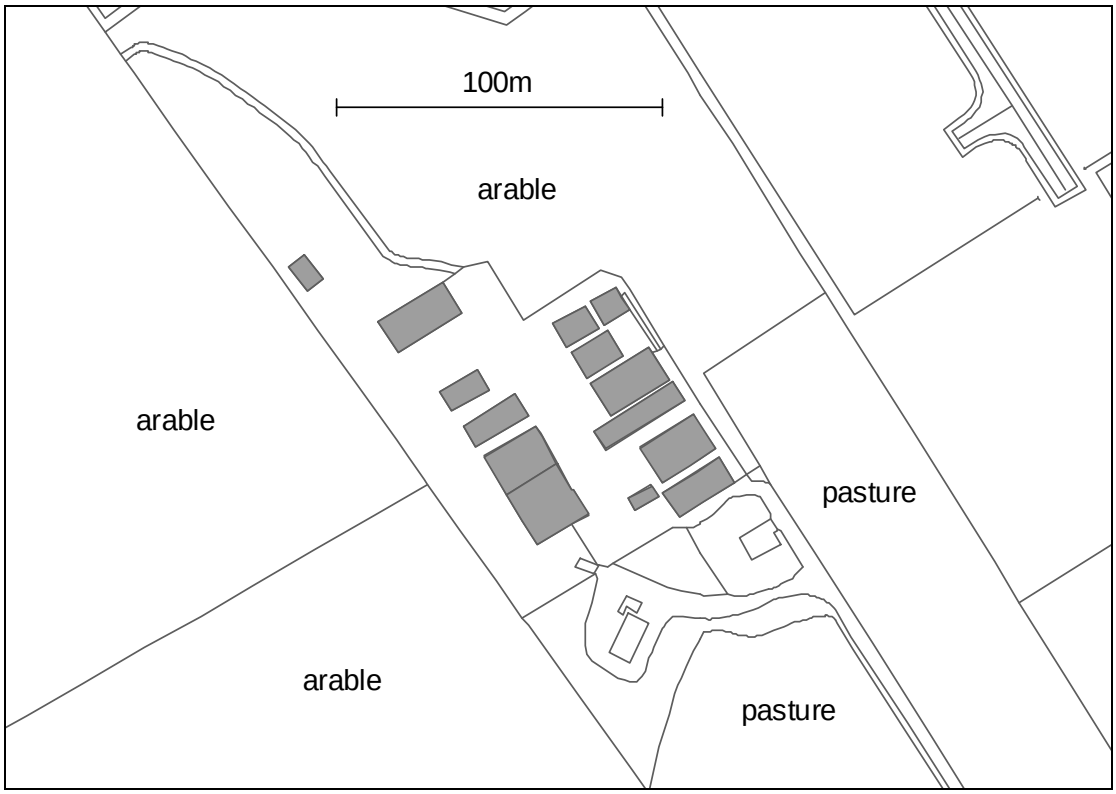


Figure 6.3. Site Q. Scale 1:2000.

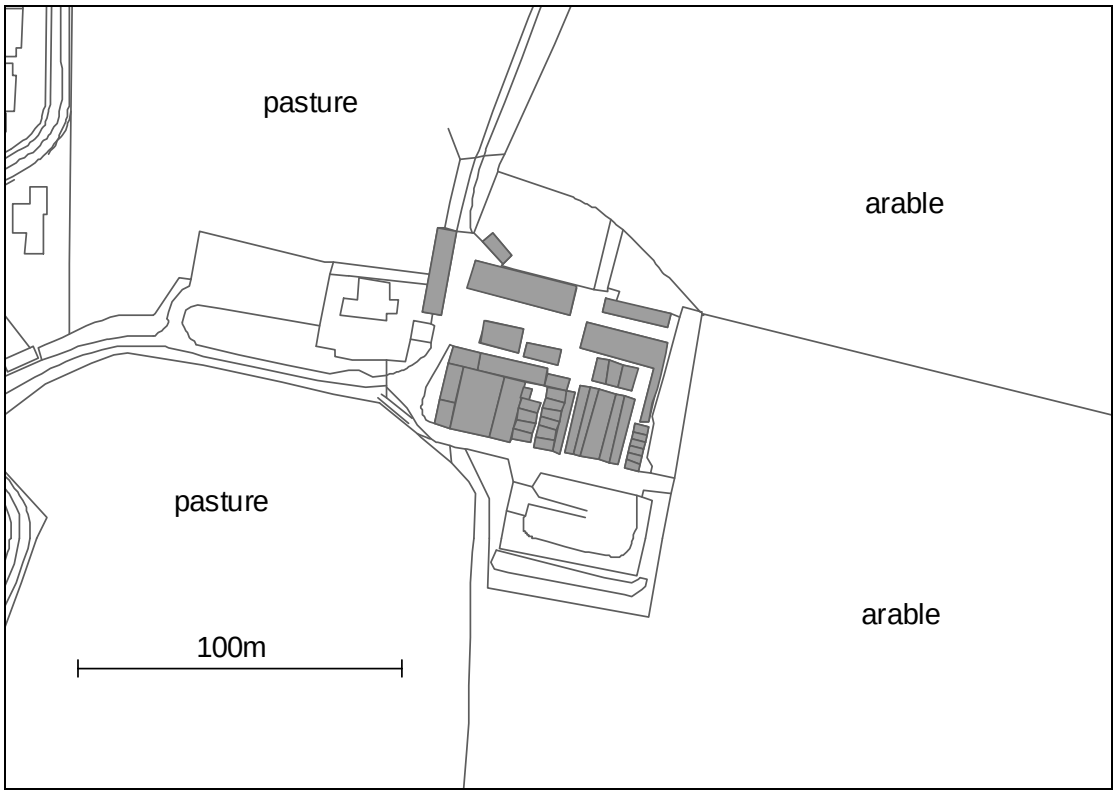


Figure 6.4. Site R. Scale 1:2000.

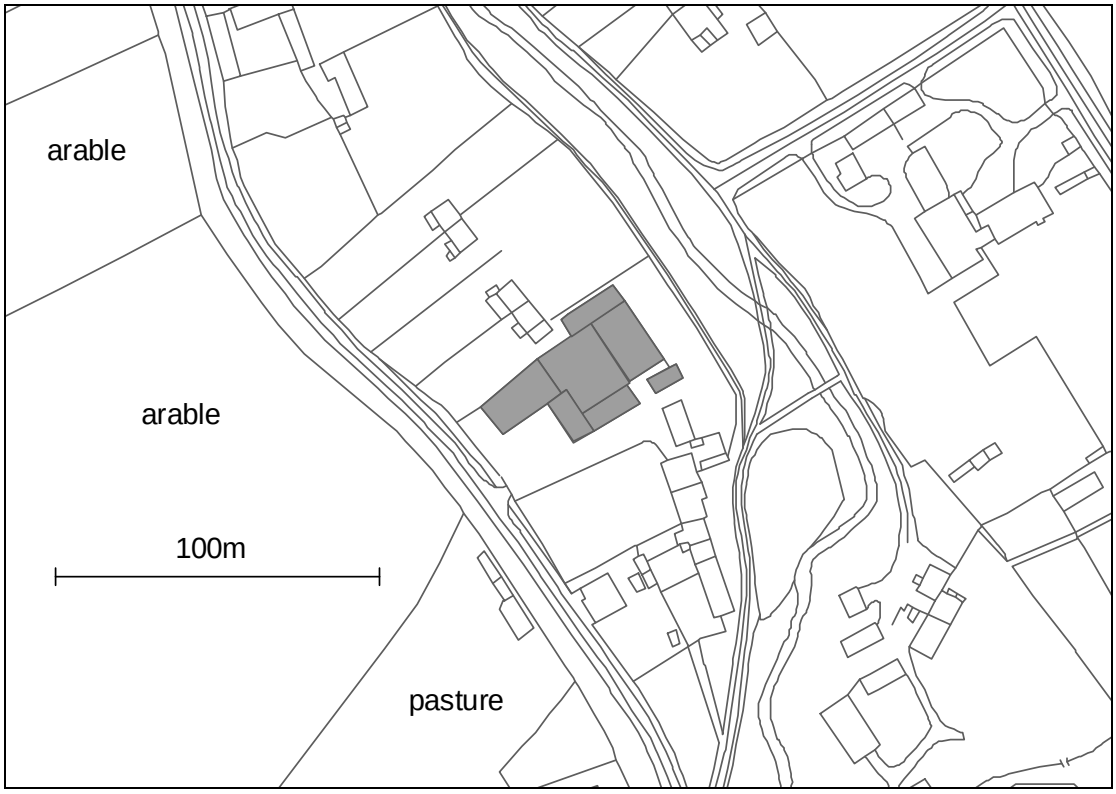


Figure 6.5. Site S. Scale 1:2000.

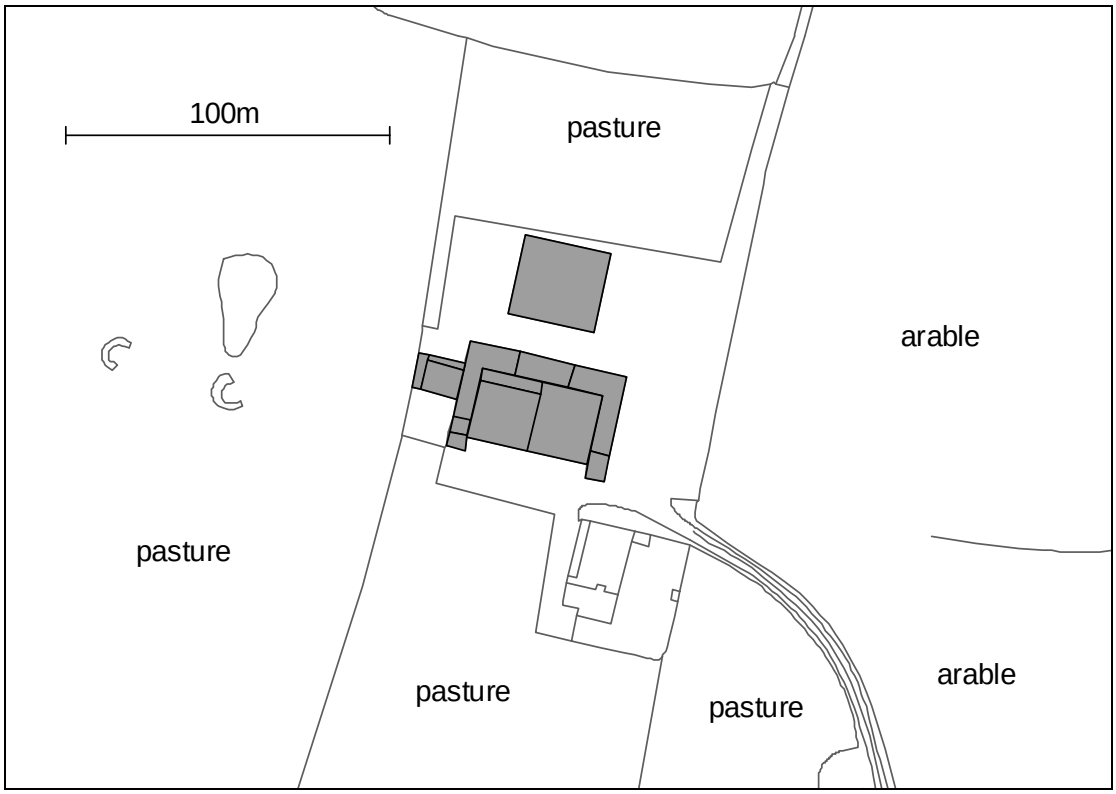
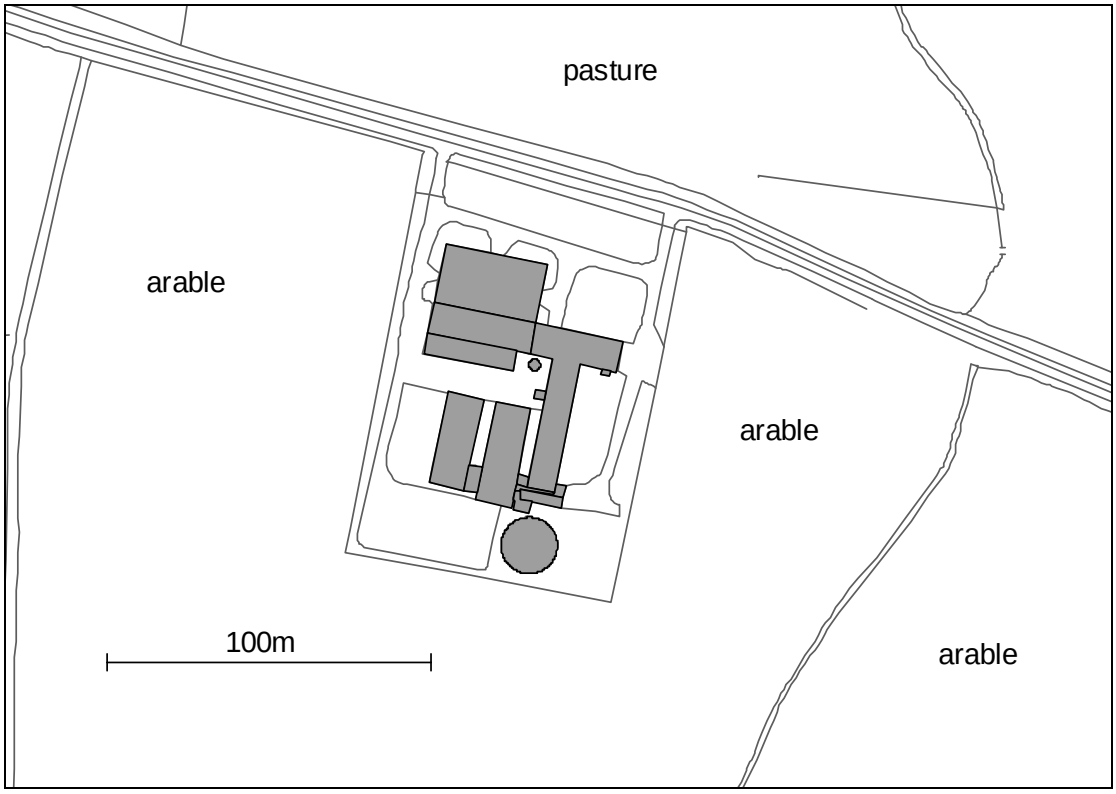


Figure 6.6. Site T. Scale 1:2000.



6.2.2. Control strategy

Each of the five sites was randomly allocated to one of two treatment groups, rodenticide use (group R) or habitat modification (group H). Sites P, Q and T were allocated to group H; sites R and S were allocated to group R. A detailed plan of each site was drawn and the size of the rat population was determined using carbon-coated tracking plates evenly distributed around the infested areas at a density of 400 plates ha^{-1}, as described in section 3.4. For three weeks after the initial census, an intensive effort was made to reduce the size of the rat infestations, using methods appropriate to each treatment group, in order to obtain a common starting point. After this, tracking plates were used to monitor the size of each rat infestation at six-weekly intervals.

Control on farms allocated to the rodenticide treatment group was carried out using commercially available anticoagulants (warfarin, bromadiolone, difenacoum) formulated into whole grain baits. Baits were mainly presented in wooden bait containers with a waterproof metal lid (**Figure 6.7**) placed inside and outside buildings near to signs of rat activity. A single tracking plate was positioned at the entrance to each bait container to record visits by rats. The bait containers were left in their original positions throughout the trial, unless the distribution of rats changed, in which case the bait containers were moved accordingly. Burrow baiting was also carried out whenever active burrows were found, hence the number of baited burrows varied according to the size and distribution of the rat infestation at any

particular time. A long handled baiting spoon was used to dispense the bait as far as possible into the rat burrow, then the entrance of each baited burrow was lightly blocked with hay or grass. Regular visits (2-3 times per week) were made to each site to record bait takes and ensure that a surplus of bait was available, unless the census data indicated that the rat population had declined to less than 10% of its original level, in which case the bait was removed.

Control on farms in the non-rodenticide (habitat modification) treatment group was carried out indirectly by regular reduction of cover such as weeds, stacks of old pallets and other general debris, usually within a 30m radius of the farm buildings. Weed cover was reduced initially using hand tools and a petrol driven strimmer. Thereafter, weed cover was reduced to a height of 5-10 cm every 2-3 weeks during the growing season using a petrol driven strimmer. Efforts were also made to deny rats access to harbourage such as the drainage system, by fitting metal drain covers at surface level, and block routes to food sources by using wire mesh to close holes in masonry and woodwork. At site T it became clear during the study that rats were living in the drainage system and the roof void of one of the pig sheds. To remove this source of harbourage was beyond the scope of this study, therefore traps were set for one night every 2-3 weeks under an inspection cover to the main drain and in the roof void in an attempt to control rats in these areas. Traps were not set at the other sites.

Figure 6.7. Wooden bait container with metal lid, as used at sites R and S.

6.2.3. Anticoagulant resistance testing

It was necessary to determine the anticoagulant resistance status of the rat population at each farm before and after the field trials so that any change in resistance levels under the two control regimes could be detected. It is also likely that the resistance status of the rats at sites R and S would affect the outcome of the rodenticide treatments at those sites. Before the initial three weeks of control, a sample of live rats was trapped using single-capture traps at farms R and S, and at two farms in group H (sites Q and T). These were taken to a laboratory and maintained in a constant environment for at least three weeks before being tested for resistance to warfarin using the blood clotting response (BCR) test (MacNicoll and Gill, 1993). Briefly, the resting blood clotting time and percentage clotting activity (PCA) were

established for each animal before administration of a sub-lethal dose (5 mg kg^{-1} body weight) of sodium warfarin by oral gavage. Menadione sodium bisulphate (vitamin K_3) was also administered at a dose of (1 mg kg^{-1} body weight) to minimise any variation in the initial vitamin K status of the animals. A second blood sample was taken and analysed 24 hours later, and any animal with more than 17% PCA relative to day 0 was classified resistant. Following the lifting of restrictions imposed during the 2001 FMD outbreak, a second sample of rats was taken from sites Q-T and the process of resistance testing was repeated.

6.3. Results

6.3.1. Impact on rat populations and resources used

The census data for five farms are summarised in **Figure 6.8**. At all census points during the trial, the estimated average number of rats on each farm did not differ significantly between the two treatment groups ($p > 0.05$, Single Factor ANOVA). Although the changes were not statistically significant, the proportion of the population active outside the farm buildings fell considerably between weeks five and 29, while the proportion of rats outside at the rodenticide treated farms remained nearly unchanged over the same period (**Figure 6.9**). In general, both methods failed to completely eliminate the infestations, although rat activity was reduced to zero at site P by week 23 (**Figure 6.10**).

In total, 10,220g of warfarin bait, 34,305g of difenacoum bait and 32,465g of bromadiolone bait was eaten by rats in the rodenticide treatment group (Table 6.1). To service the bait points at the two rodenticide farms, a total of 118 visits were made, lasting a total of 59 hours. Therefore an average of 59 visits was made to each farm, with an average visit length of 30 minutes. To keep vegetation short and remove objects offering cover to rats at the three habitat modification farms, a total of 58 visits were made, lasting a total of 85 hours and 28 minutes. Therefore, to implement and maintain the non-rodenticide control strategy took an average of 19 visits per farm, lasting an average of 88 minutes per visit.

6.3.2. Anticoagulant resistance status

In total, 48 rats trapped on farms Q-T during the initial three weeks of the trial were tested for resistance to warfarin. Of these, 24 rats retained over 17% PCA 24 hours after administration of the rodenticide, and were therefore classified resistant (**Table 6.2**). At farm R, where control was carried out with rodenticides, no rats from the pre-treatment sample were found to be resistant to warfarin. At the other rodenticide site (S) 60% of the rats tested were found to be resistant. At sites Q and T, where control was carried out using the non-rodenticide approach, the pre-treatment level of resistance to warfarin was found to be 67% and 71% respectively. The post-treatment sample of 39 rats was collected between 14 and 28 months after the pre-treatment sample, and 29 of these were found to be resistant. The trial had been halted by the FMD outbreak sometime before the pre-

treatment sample was collected (6-20 months), during which time a single rodenticide treatment was carried out using an unknown quantity of warfarin bait at site Q, although no rodenticides were used at site T. At site R, no further rodenticide use took place between the end of the trial and the post-treatment sampling, while at site S, the farmer continued to use rodenticides. At site S, the frequency of warfarin resistance increased by 32% to 92%, while at site T the frequency fell by 17% to 54%, although these changes were not statistically significant ($p > 0.05$, z - Test for comparison of proportions; Glantz, 2002). At sites Q and R, the level of warfarin resistance was almost unchanged relative to the pre-treatment sample. Details of the BCR tests for individual rats are given in Appendix D.

Figure 6.8. The change in rat numbers over a 29 week period on five farms in north east England where either rodenticides or a habitat modification control strategy was used. Week one was the pre-treatment census preceding an intensive period of control to obtain a common low starting point for the two farm groups.

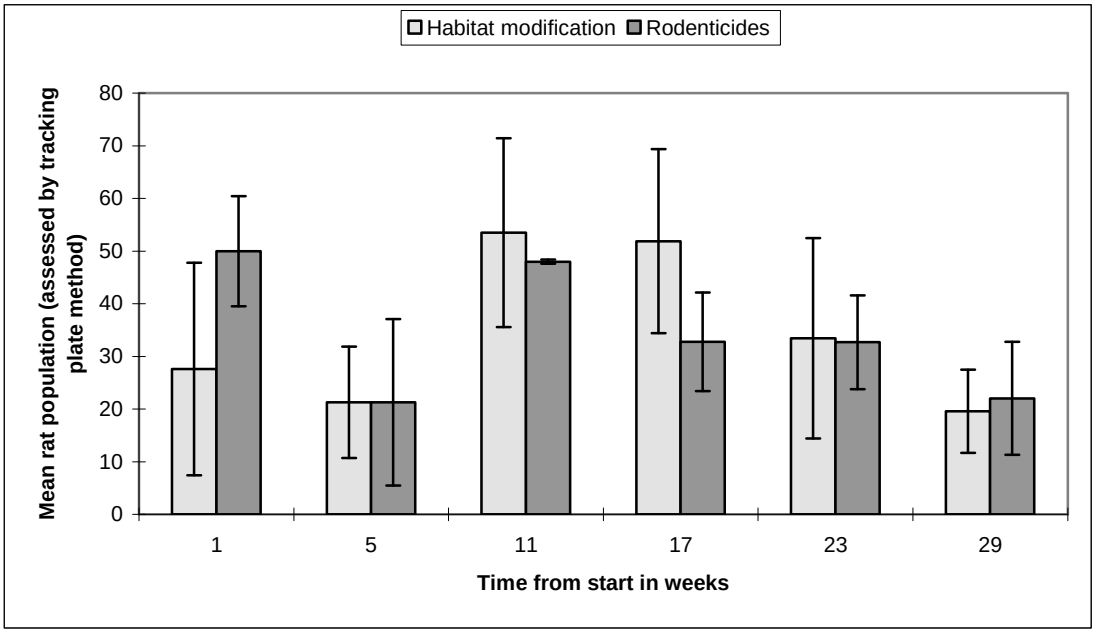


Figure 6.9. The proportion of the rat population active outside of the main buildings on five farms in north east England, where either rodenticides or a habitat modification control strategy was used. Week one was the pre-treatment census preceding an intensive period of control to obtain a common low starting point for the two farm groups.

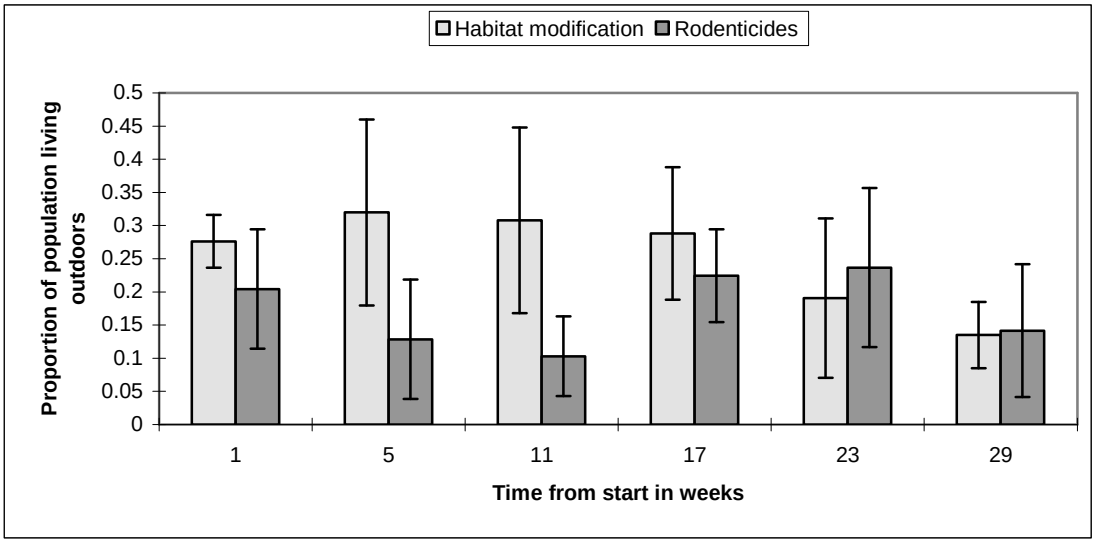


Figure 6.10. The change in rat numbers over a 29-week period on a single livestock farm (site P) in East Yorkshire where a habitat modification control strategy was used. Week one was the pre-treatment census preceding an intensive period of control to obtain a common low starting point for the two farm groups.

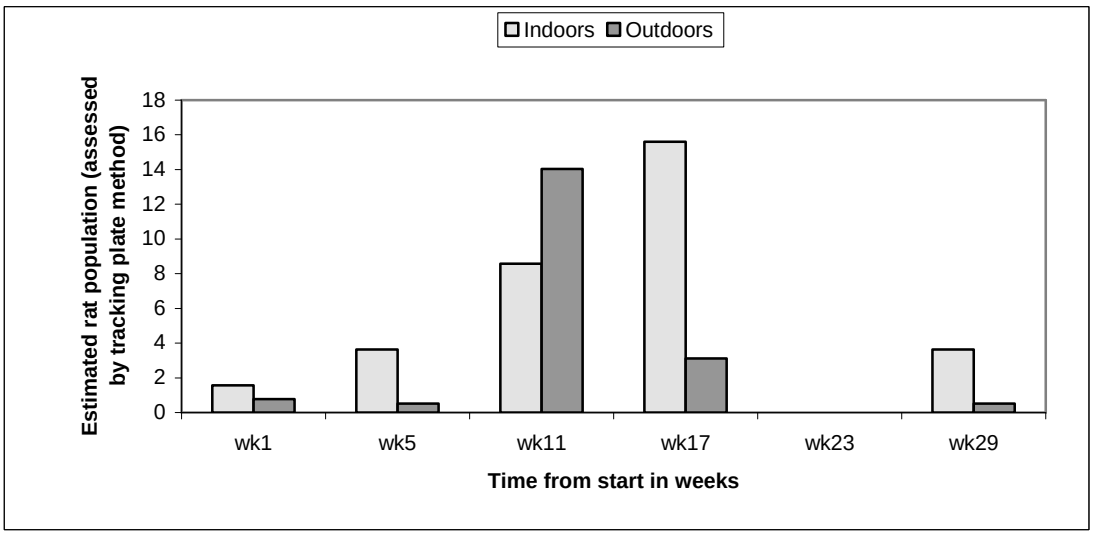


Table 6.1. The resources used, and changes in rat population size, during a 29-week control period on five farms in north Yorkshire. Control was carried out using anticoagulant rodenticides (R) or habitat modification (H).

Site	Control method	Number of visits [1]	Mean visit length (minutes) [1]	Number of bait points	Total bait take	Rat population size range
P	H	6	55	0	0	0-23
Q	H	13	76	0	0	13-59
R	R	61	32	15-23 [2]	53 520 [3]	11-48
S	R	57	28	10-18 [2]	23 470 [4]	5-60
T	H	39	99	0	0	30-85

[1] Not including visits made to collect census data

[2] Number of points in use simultaneously, Including baited burrows

[3] 10 220g of warfarin, 29 560g bromadiolone and 13 740g difenacoum bait

[4] 2 905g of bromadiolone and 20 565g difenacoum bait

Table 6.2. The change in warfarin resistance status of four farm rat populations in north Yorkshire after control by either habitat manipulation (H) or rodenticide use (R).

Site	Control strategy	No. resistant pre-treatment (%)	No. resistant post-treatment (%)	Time elapsed (months) [-1]
Q	H	6/9 (67)	9/13 (69)	21 [2]
R	R	0/12 (0)	0/1 (0)	24 [3]
S	R	6/10 (60)	11/12 (92)	28
T	H	12/17 (71)	7/13 (54)	14

[1] Between pre-treatment and post-treatment samples

[2] A single rodenticide treatment was carried out by the landowner between the end of the trial and the post-treatment sampling

[3] No rodenticides were used between the end of the trial and the post-treatment sampling

6.4. Discussion

During the comparative trial, rats were not eliminated from either of the farms in the rodenticide treatment group, while the habitat manipulation approach failed to eliminate rats from two out of three farms (sites Q and T). However, some degree of control was achieved at all sites, and habitat manipulation appeared to be no less effective in controlling rat populations on livestock farms than rodenticide use. Furthermore, it required a comparable level of input. Habitat manipulation was most effective at site P, where a family of feral cats (*Felis catus*) had taken up residence shortly before the start of the trial. The cats were successful predators, and were

frequently seen taking adult, as well as juvenile rats. An influx of rats at the site, shortly after the surrounding fields were harvested in the autumn, was soon reduced to low levels. As a control method in their own right, opinion on the usefulness of farm cats is divided. Davis (1957) claimed that farm cats could keep a rat population under control, whereas Elton (1953) reported that cats were unlikely to eradicate an established rat colony. In this study, the cats were established before the autumn influx of rats from the surrounding fields, and were perhaps aided by the regular reduction of cover. Predators were seen at the other habitat manipulation sites; cats at site Q, and cats and a fox (*Vulpes vulpes*) at site T, but were present at much lower densities than at site P. This suggests that as a control method, habitat manipulation is likely to be more successful where there are greater numbers of predators. Of course, there are disadvantages in encouraging generalist predators such as feral cats, such as the potential impact on wildlife, and the consequences of any future rodenticide use. At site P, the farmer reported cats taking juvenile rabbits, and also an unidentified raptor, when rat numbers were low. However, predators such as the barn owl (*Tyto alba*) and polecat (*Mustella putorius*) that have recently been under threat from rodenticide poisoning (Newton, *et al*., 1990; Shore *et al*., 1999) would almost certainly benefit from a move towards a habitat management approach to rat control on farms.

As a control approach, habitat management might be particularly useful where populations of rats resistant to warfarin, bromadiolone or difenacoum are encountered, as any move towards reducing reliance on anticoagulant

rodenticides may in the long term help to reduce the selection pressures that have lead to the spread of resistance (Kerins *et al.*, 2001). At the one site where rodenticides were not used between the pre-treatment and post-treatment resistance testing the frequency of resistance within the sampled population fell by 17 %. At the site where anticoagulants were used throughout the period between the pre-treatment and post-treatment sampling resistance rose by 32 %. Although not statistically significant, the direction of these changes may be an indication that the habitat manipulation approach favoured susceptible rats, which have been reported to have a physiological advantage over resistant rats in the absence of anticoagulant use (Greaves *et al*., 1977; Smith *et al*., 1991).

It was not within the scope of this project to completely eliminate harbourage from the three study sites. Indoor harbourage was generally left undisturbed in order to minimise disruption to farming practices, and to test the theory that rats could be controlled just by manipulation of the outdoor environment. This appeared to be reflected in the rat census data, in that at the habitat manipulation sites, there was a significant fall in the proportion of the rat population living outdoors. At site T, large numbers of rats were known to be residing in the roof space of one particular pig unit to which access was restricted, although these animals were probably not immigrants displaced during the habitat manipulation procedure, as the radio-tracking study carried out in the previous chapter showed that the majority of rats do not abandon their nest site when harbourage around it is reduced. This indoor component of the population, which was inaccessible to predators,

may have been providing a stable nucleus for the infestation, and also the majority of recruitment to the population. Hence, habitat management as a rodent control strategy should ideally take into account of harbourage inside buildings where possible, as well as that outside. Localised clearing of old building materials and surplus stored items inside one building at site Q was carried out, and appeared to effectively reduce the number of rats in that area. If habitat manipulation is only carried out around the farm buildings, as it was here, some other form of control inside buildings will probably be necessary. This might take the form of localised trapping, or occasional rodenticide use, which is likely to be safer than outdoor use of rodenticides due to the reduced risk of non-target poisoning. In particular, rats resistant to bromadiolone or difenacoum can be controlled by the use of the more toxic compounds flocoumafen and brodifacoum, which under current UK legislation, are only cleared for indoor use. Hence harbourage reduction around farm buildings, supplemented by indoor use of brodifacoum or flocoumafen where necessary, would probably be an effective resistance management strategy in areas where control with less toxic compounds is no longer possible.

7. Data collected from Cumbria during the 2001 FMD outbreak

7.1. Background

The Foot and Mouth Disease (FMD) outbreak began in February 2001, eight months after the series of trials described in Chapter 6 was initiated. Norway rats were implicated in the spread of the FMD virus as mechanical and biological vectors, although early work failed to show that Norway rats could be infected by exposure to the virus. Arkwright *et al.* (1925) reported that intramuscular and intradermal inoculation of large doses of virus failed to produce foot lesions in wild rats, although superficial tongue lesions were seen in a small number of cases. However, improvements in virus assay and serological techniques eventually showed that Norway rats can become infected with foot and mouth disease, although they are less susceptible than many other rodents (Capel-Edwards, 1970). It was also found that, although most rats do not develop the clinical symptoms of FMD after inoculation with infected bovine material, they continue to excrete virus particles for many months. Along with their ability to travel long distances and act as mechanical vectors, this means that wild rats have considerable potential for the transmission of FMD virus between infected farm premises. Steps were therefore taken by the Ministry of Agriculture Fisheries and Food (MAFF) to control rat infestations on infected farm premises (and those regarded as having had ‘dangerous contact’) throughout England and Wales. Through these control operations, an opportunity was taken by the

author to collect data on the relationship between harbourage levels and the size of rat populations on a sample of livestock farms in Cumbria.

7.2. Materials and methods

In addition to the information provided by all staff during rodent control operations on infected farms, rodent control operators from the Rural Development Service (RDS) and the Central Science Laboratory (CSL) working at the Penrith office were asked to complete a questionnaire for each site that they visited (Appendix C). Members of staff were asked to provide subjective assessments of the harbourage availability, the severity of the rat infestation, and details of existing (pre-outbreak) arrangements for control. The questionnaire was designed to be easy to complete, and therefore a small number of categories for each variable was chosen. The severity of the rat infestation was rated as none, light, moderate or severe. For data analysis, these categories were given a score from 0-3 respectively. Harbourage was rated as none (buildings well maintained, no cover available), low (clean and tidy but one or two limited areas of cover available), average (generally tidy but several areas of weeds, pallets etc.), high (overgrown areas between most buildings, piles of rubble etc.) or very high (large amounts of cover such as tyres, old pallets, etc.). For data analysis, these categories were given a score of 0-4 respectively. The relationship between the severity of the rat infestation and harbourage was examined by calculating the Pearson product-moment correlation coefficient (*r*). This was compared against tables in Campbell (1974) to

determine whether the association was statistically significant. Other statistical tests described in section 7.3 were carried out by Single Factor ANOVA using Microsoft ® Excel 2000 (Microsoft Corporation, USA).

7.3. Results

A small number of questionnaires were returned with missing information; these were excluded, leaving 156 valid returns. Of these, 35 farms were rated as having no rats, 87 had a light infestation, 29 had a moderate infestation, and 5 had a severe infestation. Of the 141 forms that could be attributed, 51 were returned by RDS staff and 90 by CSL staff. Average ratings between these groups were not significantly different for rat infestation ($p = 0.09$) and harbourage availability ($p = 0.87$). This indicates a good degree of inter-operator agreement, as it is likely that the range of farms encountered by staff from the two organisations were broadly similar. There was a significant positive correlation between harbourage availability and severity of rat infestation ($r = 0.52$, $p \leq 0.001$, 154 d.f.), **Figure 7.1**. Farms rated as having low harbourage availability had significantly lower rat infestation ratings than farms rated as having either average harbourage availability ($p \leq 0.01$), high harbourage availability ($p \leq 0.0001$) or very high harbourage availability ($p \leq 0.0001$). The existing (pre-outbreak) arrangements for control appeared to have relatively little influence on the severity of the infestation. Only private contractors appeared to have any impact, **Figure 7.2**.

Figure 7.1. The relationship between harbourage availability and rat infestation size. The data was collected from 156 farms in Cumbria during the 2001 FMD outbreak.

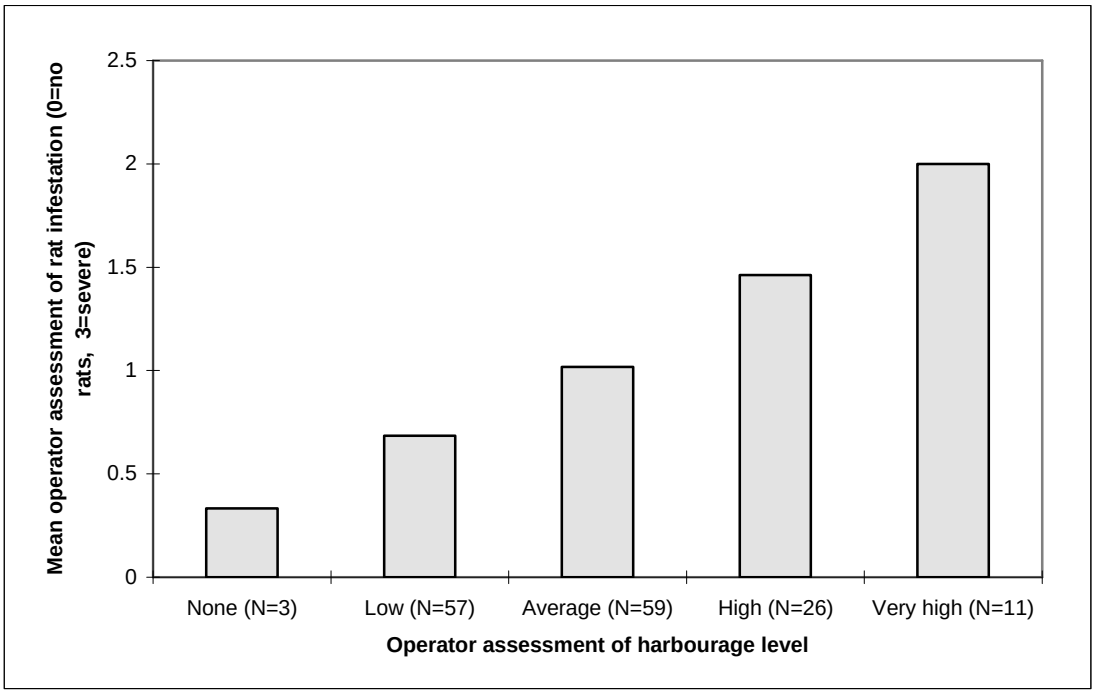
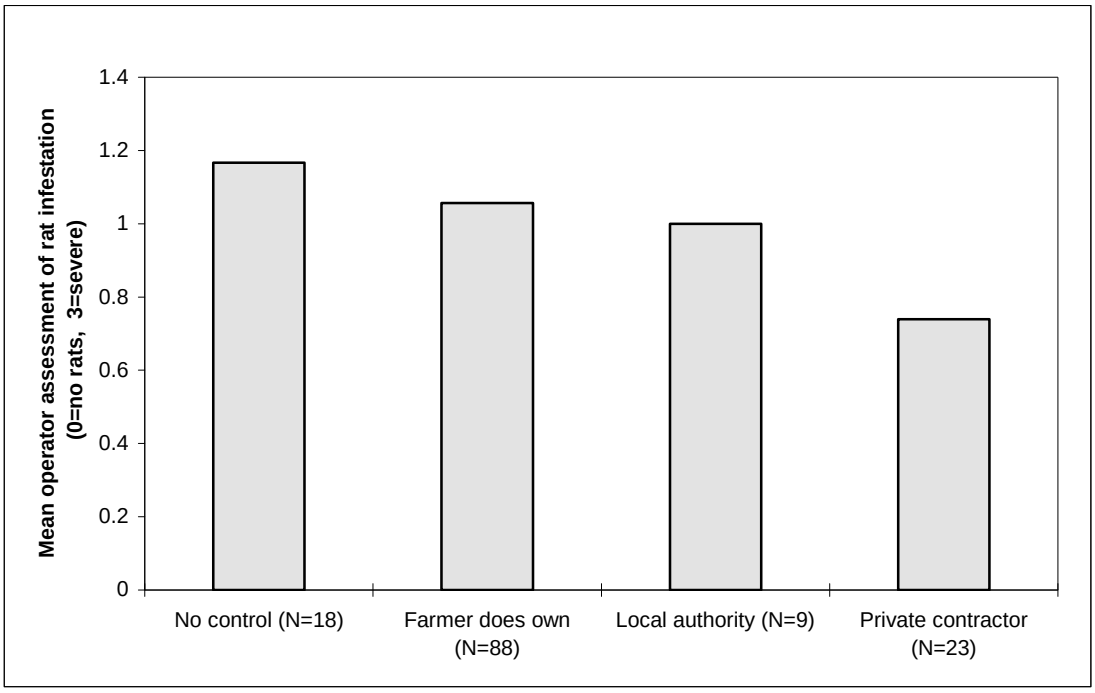


Figure 7.2. The influence of previous (pre-outbreak) control arrangements on rat infestation size. The data was collected from 156 farms in Cumbria during the 2001 FMD outbreak.



7.4. Discussion

The assessment of infestation severity and harbourage levels was subjective and the judgement of operators may have been influenced by their previous experience. An inexperienced operator may be inclined to rate a 'moderate' infestation as 'severe' if they had not yet encountered a very large infestation. However, the majority of the operators employed on these duties had previous experience of rodent control on farms and a background in wildlife management, or were working with experienced members of staff. Their judgement can probably be considered reliable, and the data collected

in Cumbria during the FMD outbreak therefore reinforced the link between harbourage and the size of rat infestations discussed in Chapter 6. There was a strong correlation between high levels of harbourage and large numbers of rats, further evidence that cover is an important resource for farm rat populations. Interestingly, there was only a weak link between previous control arrangements and the severity of rat infestations. Only farms that had pest control arrangements with private contractors had less severe rat infestations than those farms with no previous control. However, this result is confounded by the likelihood that farms that generally did not have problems with rats did not need to carry out control, and therefore had no previous control arrangements. Only farms with persistent rat problems would have previous control arrangements in place. Unfortunately it was not possible to identify these farms in the dataset, therefore it may be incorrect to conclude that the actions of landowners or Local Authority contractors had no impact on rat infestations.

8. General discussion

Since the introduction of warfarin in 1950, anticoagulant rodenticides have been widely used for rat control, almost to the total exclusion of any other methods. However, resistance to anticoagulants is already a problem in some areas, and there are very few viable alternatives. This has led to concerns over the long-term future of an approach that relies almost exclusively on anticoagulant use. Secondary poisoning of wildlife is also a matter for increasing concern. The spread of resistance to warfarin and other first generation anticoagulants has led to a shift in recent years towards the use of the more toxic 'second generation' compounds bromadiolone and difenacoum, which pose a greater threat to non-target animals. These issues would be less important if rodenticide use gave long-lasting results. However, rodenticides and all other direct lethal control methods usually have to be repeated on a regular basis due to the high reproductive potential of survivors following partially successful treatments, reinvasion from nearby untreated rat populations, or both. A resource management approach potentially offers a long-term environmentally sensitive control strategy by selectively targeting the resources that are important to farm rat populations, without reducing the quality of the habitat for other species.

The work presented in this thesis was carried out in order to investigate two resource management based rat control strategies. Firstly, the possibility of indirectly limiting resources by encouraging inter-specific competition

between Norway rats and small mammals was investigated in Chapter 3. Small mammals potentially compete with Norway rats for resources, and may be better adapted to environmental conditions in field boundaries, a marginal habitat for rats. The distribution of Norway rats in relation to other small mammals in field boundaries was therefore examined. Field voles, the primary candidate competitors, were found infrequently or not at all throughout the study and therefore the results were equivocal. There was some evidence from the data that a high density of small mammals may reduce the habitat quality for rats in field boundaries, although this may be less limiting for rats living in the arable environment, especially when standing cereal crops are available. During laboratory trials, there was no conclusive evidence that rats avoided field vole odours (Chapter 4) although if segregation in the field does occur, other cues may be important. The search for a competitor species was therefore inconclusive, although this study adds significantly to our understanding of small mammal ecology in the agricultural landscape.

One of the most important factors influencing the distribution of rats and small mammals in field margins was found to be ground cover. Large populations of common shrews and bank voles were associated with high levels of ground cover while the reverse was true for rats. It is likely that large rat populations create areas of low ground cover due to trampling. However, less ground cover may also be attractive to rats living in field margins as burrowing is easier, and there is less obstruction to movement between nest sites and food sources, which are often widely dispersed in

the agricultural landscape. But as discussed later on, rats tend to favour habitats with that provide adequate shelter from predators. This suggests that an ideal field margin from a rat's perspective might be one with a dense hedgerow canopy providing protection from avian predators, above areas of sparse ground cover. Field margins in the agricultural environment should therefore be managed to increase levels of ground cover, as this would deter rats and encourage a greater density of other small mammal species. This could be achieved by clipping the hedge to reduce shading and encourage the growth of understorey vegetation. This is already practiced by some farmers, who cut the hedge every one or two years, usually in the autumn, to a box-section of 1-2m high to maintain a more effective barrier to livestock. Combined with a dense, grassy field margin, this type of hedge may deter colonisation by rat populations and encourage other small mammals that are positively associated with ground cover, in particular common shrews, bank voles and potentially field voles.

Maintaining hedgerows to reduce the canopy size may however disadvantage wood mice and bank voles, which are associated with taller, wider hedges. It is important therefore that suitable habitats for these species, such as the woodland habitats and small copses that exist in many agricultural landscapes are maintained. Hedgerows provide important corridors for small mammal dispersal between these habitats, but also provide corridors for rats moving between resource rich areas. Rats of course will inhabit small copses and woodland areas if adequate food supplies exist locally, such as pheasant feeders. In game rearing areas,

populations of rats often build up around pheasant feeders during autumn and winter, and have the potential to invade farm premises at the end of the pheasant season when the feeders become redundant. Indeed, the heterogeneous nature of many agricultural landscapes has the potential to support many small ‘sub-populations’ of rats, which may act as one ‘meta-population’ connected by corridors such as hedgerows. Removing a single sub-population allows the meta-population to persist, with any gaps created by control operations quickly filled by immigration from surrounding sub-populations. Maintaining field margins in ways that discourages rat colonisation may slow down movement between sub-populations, but would probably not prevent it. In Malaysia and the Philippines a ‘trap-barrier system’ consisting of traps inserted at regular intervals in a rat-proof barrier has provided a novel and effective method of interrupting the transmission of rats between resource-rich patches (Singleton and Petch, 1994). This is an interesting approach that has potential for use in Western agricultural environments whereby an artificially maintained food resource such as a sacrificial ‘trap crop’ could be used as a lure surrounded by a trap-barrier system to intercept rats along main dispersal routes, breaking the transmission cycle. Suitable trap-crops include sugar beet, maize or even a stack of bales and a pile of unwanted grain.

Cutting back overgrown hedgerow canopies not only reduces shading and encourages the growth of understorey vegetation, it may also facilitate predation. In tropical oil palm and cocoa plantations, avian predators are aided by the provision of hunting perches and provided with nesting boxes

adjacent to crops vulnerable to rodent attack (Lee, 1997). This is a technique that could be adapted to the Western agricultural environment by the provision of suitable perches at intervals along field margins. The impact of these field margin management recommendations should be a priority for further investigation. Managing field margins to discourage rat colonisation may have other benefits for the environment. The creation of wider, grassy field margins for example provides buffer zones to absorb pesticide and fertilizer run off from arable fields and is recommended in the Code of Practice for the Safe Use of Pesticides on Farms and Holdings (1985), also known as the Green Code. There may also be negative impacts however, such as increased predation on non-target species from higher predator numbers. Any change in agricultural practice should only be implemented after thorough investigation of the positive, and negative ecological implications.

Increasing levels of rat predation is a control technique that may have considerable potential in other areas of the farm environment, such as around farm buildings where high-density rat populations sometimes build up where resources are easily available. A key resource for rats is harbourage, which provides shelter from predators and opportunities for nesting. In this study, the removal of harbourage and shelter provided by weed growth, redundant machinery and other debris from around farm buildings led to a substantial reduction in rat activity within three weeks (Chapter 5). The number of rats taken by predators was higher in areas where cover was reduced. Again, avian predation could be further facilitated

by provision of nest boxes and suitable perches near farm buildings. Where predators are encouraged to take rats in this manner, it should be remembered that any further rodenticide use should be very carefully executed to keep the risk of secondary poisoning to a minimum.

The radio-tracking data collected for Chapter 5 suggested that there is considerable variation in the behaviour of rats in the farm environment. Most rats living near farm buildings had small home ranges, presumably because they had no need to travel long distances in search of food and mating opportunities. Some of these rats appeared to have adopted extreme risk avoidance strategies, and never ventured outside, even to the extent of climbing into roof spaces to gain access to rain water from gutters. These rats presumably would be the most difficult to control using rodenticides as they would be least likely to encounter bait points. They would provide a stable core for the population, and a basis for repopulation of a farm site following a partially successful rodenticide treatment. A small number of rats living near farm buildings appeared to be ‘risk takers’ and sometimes made long excursions from their home site for no apparent reason, while rats in ‘field populations’ where food sources are often widely distributed, generally had larger home ranges and travelled further than rats living near farm buildings. Rats with larger home ranges are most likely to encounter bait points or predators, but they are also the animals that are most likely to transfer between populations and reinvade cleared premises or populate new areas. Clearly the ecology of rats in the agricultural environment is

highly complex, and there are many factors that need to be taken into account during control programs.

In the final phase of the project (Chapter 6) the habitat management approach was found to be no less effective than rodenticide use around farm buildings. Furthermore it required a similar level of labour input. However, it is unlikely that removal of cover around farm buildings would lead to a quick elimination of a large established rat population, and this approach is probably more useful as a means of limiting the growth of rat populations following control by lethal methods. In Chapter 6, the habitat management strategy was implemented during the summer, in advance of the autumn peak in rat numbers, following an initial three-week period of intensive control. A component of the population was unaffected by the outdoor habitat management approach used here, and it is likely that an effective integrated strategy would incorporate other methods where necessary, such as limited trapping or occasional and well-targeted rodenticide use. The habitat management approach is likely to be more effective on farms with a healthy population of predators, therefore rodenticides should be used sparingly, and only when considered absolutely necessary.

Maintaining a ‘clear zone’ between areas of harbourage and food sources makes life difficult for rats, and easier for their predators. Habitat management has the potential to reduce the amount of bait required to control rat populations on farms, and should always be considered as part of

an integrated approach, supplemented by well targeted rodenticide use, or other methods such as trapping if necessary. Implemented on a national scale, this integrated approach would lead to a significant reduction in rodenticide use, reducing the risks to non-target animals, and alleviating some of the selection pressure that has led to the spread of anticoagulant resistant populations. It is unlikely that rodenticides will ever be abandoned entirely, as they are often a useful and quick, albeit temporary, solution to a worldwide problem. However, using rodenticides as the first, last, and only resort is expensive, environmentally damaging and unsustainable.

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10. Appendices

Appendix A - vegetation species lists from field margin surveys

Field boundary A (summer 1998)

Annual Meadow-grass *(Poa annua)*
Barley *(Hordeum sp.)*
Barren Brome *(Bromus sterilis)*
Bramble *(Rubus fruticosus)*
Broad-leaved Dock *(Rumex obtusifolius)*
Cleavers *(Galium aparine)*
Cocksfoot *(Dactylis glomerata)*
Common Ash *(Fraxinus excelsior)*
Common Chickweed *(Stellaria media)*
Common Nettle *(Urtica dioica)*
Creeping Soft-grass *(Holcus mollis)*
Dog Rose *(Rosa canina)*
Elder *(Sambucus nigra)*
False Oat-grass *(Arrhenatherum elatius)*
Fescue *(Festuca sp.)*
Germander Speedwell *(Veronica chamaedrys)*
Hawthorn *(Crataegus monogyna)*
Hogweed *(Heracleum sphondylium)*
Meadow Thistle *(Cirsium dissectum)*
Perennial Rye-grass *(Lolium perenne)*
Red Dead-nettle *(Lamium purpureum)*
Wheat *(Triticum sp.)*
Yorkshire Fog *(Holcus lanatus)*

Field boundary B (summer 1998)

Annual Meadow-grass *(Poa annua)*
Barley *(Hordeum sp.)*
Barren Brome *(Bromus sterilis)*
Blackthorn *(Prunus spinosa)*
Bramble *(Rubus fruticosus)*
Broad-leaved Dock *(Rumex obtusifolius)*
Cleavers *(Galium aparine)*
Cocksfoot *(Dactylis glomerata)*
Common Chickweed *(Stellaria media)*
Common Mallow *(Malva sylvestris)*
Common Nettle *(Urtica dioica)*
Common Oak *(Quercus robur)*
Common Poppy *(Papaver rhoeas)*
Common Reedmace *(Typha latifolia)*
Common Vetch *(Vicia sativa)*
Cow Parsley *(Anthriscus sylvestris)*
Crab Apple *(Malus sylvestris)*
Creeping Buttercup *(Ranunculus repens)*
Creeping Soft-grass *(Holcus mollis)*
Creeping Thistle *(Cirsium arvense)*
Crosswort *(Galium cruciata)*
Cut-leaved Crane's-bill *(Geranium dissectum)*
Fescue *(Festuca sp.)*
Field Bindweed *(Convolvulus arvensis)*
Germander Speedwell *(Veronica chamaedrys)*
Gooseberry *(Ribes uva-crispa)*
Greater Stitchwort *(Stellaria holostea)*
Green Figwort *(Scrophularia umbrosa)*
Ground-elder *(Aegopodium podagraria)*
Hawthorn *(Crataegus monogyna)*
Hazel *(Corylus avellana)*
Hedge Woundwort *(Stachys sylvatica)*

Hogweed *(Heracleum sphondylium)*
Horse tails (*Equisetum sp*.)
Long-stalked Crane's-bill *(Geranium columbinum)*
Perennial Rye-grass *(Lolium perenne)*
Pineappleweed *(Matricaria matricarioides)*
Red Campion *(Silene dioica)*
Rosebay Willowherb *(Chamaenerion angustifolium)*
Rough chervil *(Chaerophyllum temulentum)*
Spear Thistle (*Cirsium vulgare*)
Water Forget-me-not *(Myosotis scorpioides)*
Water-cress *(Rorippa nasturtium-aquaticum)*
Wood-sorrel *(Oxalis acetosella)*
Yorkshire Fog *(Holcus lanatus)*

Field boundary C (summer 1998)

Alder *(Alnus glutinosa)*
Annual Meadow-grass *(Poa annua)*
Barren Brome *(Bromus sterilis)*
Barren strawberry *(Potentilla sterilis)*
Betony *(Betonica officinalis)*
Black Knapweed *(Centaurea nigra)*
Blackthorn *(Prunus spinosa)*
Bristly Oxtongue *(Picris echioides)*
Broad-leaved Dock *(Rumex obtusifolius)*
Bugloss *(Anchusa arvensis)*
Cleavers *(Galium aparine)*
Cocksfoot *(Dactylis glomerata)*
Common Bird's-foot-trefoil *(Lotus corniculatus)*
Common Chickweed *(Stellaria media)*
Common Eyebright *(Euphrasia nemorosa)*
Common Field Speedwell *(Veronica persica)*
Common Gorse *(Ulex europaeus)*
Common Mallow *(Malva sylvestris)*

Common Mouse-ear *(Cerastium holosteoides)*
Common Nettle *(Urtica dioica)*
Common Oak *(Quercus robur)*
Common Poppy *(Papaver rhoeas)*
Common Quaking-grass (*Briza media*)
Common Sorrel (*Rumex acetosa*)
Cow Parsley *(Anthriscus sylvestris)*
Creeping Buttercup *(Ranunculus repens)*
Creeping Thistle *(Cirsium arvense)*
Crested Dog's-tail *(Cynosurus cristatus)*
Crosswort *(Galium cruciata)*
Daisy *(Bellis perennis)*
Dandelion *(Taraxacum officinale)*
Dog's Mercury *(Mercurialis perennis)*
Dutch clover *(Trifolium repens)*
Elder *(Sambucus nigra)*
Fescue *(Festuca sp.)*
Field Bindweed *(Convolvulus arvensis)*
Field Forget-me-not *(Myosotis arvensis)*
Field Penny-cress *(Thlaspi arvense)*
Garlic Mustard *(Alliaria petiolata)*
Germander Speedwell *(Veronica chamaedrys)*
Greater Plantain (*Plantago major*)
Ground Ivy *(Glechoma hederacea)*
Hawthorn *(Crataegus monogyna)*
Herb-Robert *(Geranium robertianum)*
Hogweed *(Heracleum sphondylium)*
Ivy *(Hedera helix)*
Lady's Bedstraw *(Galium verum)*
Lesser Stitchwort *(Stellaria graminea)*
Meadow Crane's-bill *(Geranium pratense)*
Mugwort *(Artemisia vulgaris)*
Nipplewort *(Lapsana communis)*
Perennial Rye-grass *(Lolium perenne)*

Potato *(Solanum tuberosum)*
Rape *(Brassica napus)*
Red Campion *(Silene dioica)*
Red Clover *(Trifolium pratense)*
Red Dead-nettle *(Lamium purpureum)*
Rough Chervil *(Chaerophyllum temulentum)*
Shepherd's-purse *(Capsella bursa-pastoris)*
Smooth Sow-thistle *(Sonchus oleraceus)*
Spear Thistle (Cirsium vulgare)
White Campion *(Silene alba)*
Wild pansy (Viola tricolor)
Yarrow *(Achillea millefolium)*
Yorkshire Fog *(Holcus lanatus)*

Field boundary D (summer 1998)

Annual Meadow-grass *(Poa annua)*
Black bryony *(Tamus communis)*
Blackthorn *(Prunus spinosa)*
Bramble *(Rubus fruticosus)*
Broad-leaved Dock *(Rumex obtusifolius)*
Cleavers *(Galium aparine)*
Cocksfoot *(Dactylis glomerata)*
Common Ash *(Fraxinus excelsior)*
Common Nettle *(Urtica dioica)*
Cow Parsley *(Anthriscus sylvestris)*
Creeping Thistle *(Cirsium arvense)*
Dog Rose *(Rosa canina)*
Dogwood *(Thelycrania sanguinea)*
Elder *(Sambucus nigra)*
Field Bindweed *(Convolvulus arvensis)*
Germander Speedwell *(Veronica chamaedrys)*

Gooseberry *(Ribes uva-crispa)*
Greater Plantain (Plantago major)
Ground Ivy *(Glechoma hederacea)*
Hawthorn *(Crataegus monogyna)*
Hazel *(Corylus avellana)*
Herb-Robert *(Geranium robertianum)*
Ivy *(Hedera helix)*
Meadow Thistle *(Cirsium dissectum)*
Perennial Rye-grass *(Lolium perenne)*
Spear Thistle (*Cirsium vulgare*)
White Campion *(Silene alba)*
Yorkshire Fog *(Holcus lanatus)*

Field boundary E (summer 1999)

Annual Meadow-grass *(Poa annua)*
Barren Brome *(Bromus sterilis)*
Bramble *(Rubus fruticosus)*
Cleavers *(Galium aparine)*
Common Field Speedwell *(Veronica persica)*
Common Nettle *(Urtica dioica)*
Common Poppy *(Papaver rhoeas)*
Creeping Thistle *(Cirsium arvense)*
Dandelion *(Taraxacum officinale)*
Fescue *(Festuca sp.)*
Field Bindweed *(Convolvulus arvensis)*
Field Forget-me-not *(Myosotis arvensis)*
Greater Stitchwort *(Stellaria holostea)*
Hawthorn *(Crataegus monogyna)*
Hedge Bindweed *(Calystegia sepium)*
Hogweed *(Heracleum sphondylium)*
Lesser Burdock *(Arctium minus)*
Perennial Rye-grass *(Lolium perenne)*
Pineappleweed *(Matricaria matricarioides)*

Prickly Sow-thistle *(Sonchus asper)*
Rosebay Willowherb *(Chamaenerion angustifolium)*
Rough chervil *(Chaerophyllum temulentum)*
Smooth Hawk's-beard *(Crepis capillaris)*
Spear Thistle *(Cirsium vulgare)*
2 x unidentified umbelliferous spp.
White Campion *(Silene alba)*

Field boundary F (summer 1999)

Annual Meadow-grass *(Poa annua)*
Black Bent *(Agrostis gigantea)*
Black Knapweed *(Centaurea nigra)*
Bramble *(Rubus fruticosus)*
Broad-leaved Dock *(Rumex obtusifolius)*
Bulbous buttercup *(Ranunculus bulbosus*)
Cleavers *(Galium aparine)*
Cocksfoot *(Dactylis glomerata)*
Common Nettle *(Urtica dioica)*
Common Sorrel *(Rumex acetosa)*
Common Vetch *(Vicia sativa)*
Creeping Buttercup *(Ranunculus repens)*
Creeping Thistle *(Cirsium arvense)*
Crested Dog's-tail *(Cynosurus cristatus)*
Dandelion *(Taraxacum officinale)*
Dog Rose *(Rosa canina)*
Dutch clover *(Trifolium repens)*
Elder *(Sambucus nigra)*
False Oat-grass *(Arrhenatherum elatius)*
Foxglove *(Digitalis purpurea)*
Germander Speedwell *(Veronica chamaedrys)*
Greater Plantain *(Plantago major)*
Hawthorn *(Crataegus monogyna)*
Hogweed *(Heracleum sphondylium)*

Perennial Rye-grass *(Lolium perenne)*
Red clover *(Trifolium pratense)*
Red Dead-nettle *(Lamium purpureum)*
Rosebay Willowherb *(Chamaenerion angustifolium)*
Selfheal *(Prunella vulgaris)*
Small-leaved Timothy-grass *(Phleum bertolonii)*
Yorkshire Fog *(Holcus lanatus)*

Field boundary I (summer 1999)

Barren Brome *(Bromus sterilis)*
Black-bindweed *(Polygonum convolvulus)*
Blackthorn *(Prunus spinosa)*
Cleavers *(Galium aparine)*
Common Ash *(Fraxinus excelsior)*
Common Chickweed *(Stellaria media)*
Common Nettle *(Urtica dioica)*
Cow Parsley *(Anthriscus sylvestris)*
Creeping Buttercup *(Ranunculus repens)*
Creeping Thistle *(Cirsium arvense)*
Dandelion *(Taraxacum officinale)*
Dog Rose *(Rosa canina)*
Dogwood *(Thelycrania sanguinea)*
Elder *(Sambucus nigra)*
False Oat-grass *(Arrhenatherum elatius)*
Fat-hen *(Chenopodium album)*
Field pansy *(Viola arvensis)*
Greater Plantain *(Plantago major)*
Groundsel *(Senecio vulgaris)*
Hawthorn *(Crataegus monogyna)*
Hazel *(Corylus avellana)*
Hedge Bindweed *(Calystegia sepium)*
Hedge Woundwort *(Stachys sylvatica)*
Hogweed *(Heracleum sphondylium)*

Ivy *(Hedera helix)*

Knotgrass *(Polygonum aviculare)*

Perennial Rye-grass *(Lolium perenne)*

Pineappleweed *(Matricaria matricarioides)*

Red fescue *(Festuca rubra)*

Redshank *(Polygonum persicaria)*

Rosebay Willowherb *(Chamaenerion angustifolium)*

Scarlet pimpernel *(Anagallis arvensis)*

Smooth Sow-thistle *(Sonchus oleraceus)*

White Dead-nettle *(Lamium album)*

Yorkshire Fog *(Holcus lanatus)*

Appendix B – pre-treatment and post-treatment home range data for rats in cleared (C) and uncleared (UC) areas.

Livestock sites (J, L and O)

Rat	MCP 1	MCP 2	M 1	M 2	L 1	L 2	Treatment	Sex	Weight
J1	195.9	20.9	22.8	23.3	31.9	23.3	C	F	475
J2	270.4		36.5		39.5		UC	M	350
J3	62.9	15.3	50.7	51.1	52.3	51.1	UC	F	540
J4	667.5	2.2	43.9	6	50.1	6	C	F	375
J6	628.2		47.5		54.2		C	M	365
J7	20.1		17.5		18.4		C	F	265
L1	37	3.7	11.9	8.1	13.6	8.1	UC	F	320
L2	42.2	7.6	17.6	5	18	7.1	UC	F	275
L4	184.9		21		24		UC	F	390
L5	84.6		15.8		20.3		UC	F	380
L6	12.9	2.3	5.7	2.5	8	4.2	UC	M	500
L7	31.8	101.1	12.3	19.6	14.9	33.4	UC	F	300
L8	61.4	6	9.6	10.4	19.5	10.5	C	F	400
L9	354		20.7		28.2		C	M	420
L10	1056.6	195.3	45.4	45.2	85.3	45.2	C	M	355
L11	11.8		6.2		6.2		C	F	275
L12	98.4	34.3	16	19.2	16.3	19.2	C	M	310
L13	129.7		22.1		28.9		C	M	260
L14	138.1	88.6	14.5	17.8	29.9	18.7	C	M	460
L15	41.6		18.7		19.4		UC	F	425
L16	528.4		49		61.2		C	M	325
O1	9	5.9	5.8	3.9	5.8	4.8	UC	M	550
O2	734.1	226.2	39.8	37.3	44.8	38.3	C	M	430
O3	208.5	259	27.9	33.5	35.5	33.5	C	M	540
O4	187.9	0	29.6	0	37.4	0	C	M	440

Livestock sites (J, L and O) continued

Rat	MCP 1	MCP 2	M 1	M 2	L 1	L 2	Treatment	Sex	Weight
O5	192.5	9.2	25.6	16.2	26	22.9	UC	M	410
O6	602.6	0	40.3	15	54	15	C	F	370
O7	18	1.8	26.9	15.1	27.1	15.1	UC	M	375
O8	3.6	3.6	3.1	3.1	3.1	3.1	UC	F	290
O9	58.1	0.4	34.3	25.6	34.8	25.6	UC	F	-

Arable sites (K, M and N)

Rat	MCP 1	MCP 2	M 1	M 2	L 1	L 2	Treatment	Sex	Weight
K3	2985.2	4443.1	66.6	69.1	85.4	133.2	UC	M	500
K5	267.1	4656.5	132.7	124.3	133.1	127.6	UC	M	325
K6	1501.2	2811	70.6	76.3	101.9	79.3	UC	M	545
K7	153.9	464.5	43.7	68	43.7	83.7	UC	F	410
K9	10314		166.1		178.6		UC	M	550
M1	562.3	330	66.7	56.9	77.5	107.2	UC	F	475
M2	38.5	5824.6	44.3	165	46.2	165	C	F	410
N1	14571	12.6	222	12.7	368.2	12.7	UC	M	470
N2	5256.6		201.2		201.2		UC	M	450
N3	1694.7	0.3	199.3	42.9	199.3	42.9	UC	F	360
N4	19.5		56.9		56.9		UC	M	540
N6			207.3		291.3		UC	F	325

Key

MCP 1	Home range area (Minimum Convex Polygon) before treatment
MCP 2	Home range area (Minimum Convex Polygon) following treatment
M 1	Maximum distance between successive points before treatment
M 2	Maximum distance between successive points following treatment
L 1	Length of home range before treatment
L 2	Length of home range following treatment

Farm Name

Case No.

1. Rat infestation (please tick one box)

- ❑ None
- ❑ Light
- ❑ Moderate
- ❑ Severe

2. Harbourage availability (please tick one box)

- ❑ None (buildings well maintained, no cover available)
- ❑ Low (clean and tidy but one or two limited areas of cover available)
- ❑ Average (generally tidy but several areas of weeds, pallets etc.)
- ❑ High (overgrown areas between most buildings, piles of rubble etc.)
- ❑ Very high (large amounts of cover such as tyres, old pallets, etc. etc.)

3. Previous control

- ❑ None
- ❑ Farmer does own
- ❑ Local authority contract
- ❑ Private contractor
- ❑ Don't know

4. Comments (e.g. harbourage type, products used for previous control, other factors, such as farm cats etc.)

Appendix D – BCR data collected during warfarin resistance testing of wild rats. A percentage clotting activity (PCA) of less than 17% on day 1 indicates physiological resistance. Missing data indicate that no sample was taken, or the sample clotted.

Pre-treatment sample

Site	Intake date	PCA day 0	PCA day 1
Q	31/08/00	80.6	63.7
Q	31/08/00	40.7	33.7
Q	31/08/00	50.3	51
Q	22/09/00	32.4	15.4
Q	22/09/00	68.2	2.2
Q	04/10/00		6.3
Q	04/10/00	54.3	26.4
Q	04/10/00	52.2	44
Q	04/10/00	48.4	35.5
R	08/06/00		2.9
R	08/06/00		5.8
R	08/06/00	83.6	4.3
R	09/06/00	30.9	9.2
R	20/06/00	40	12.1
R	20/06/00	89.2	15.4
R	20/06/00	48.1	5.1
R	20/06/00	63.1	15
R	20/06/00	72.7	8.5
R	20/06/00	32	13.2
R	20/06/00	36.5	6
R	20/06/00	41.8	3
S	30/06/00	60.8	7.1
S	30/06/00	35.5	31.8
S	30/06/00	40.7	26.1

Pre-treatment sample continued

Site	Intake date	PCA day 0	PCA day 1
S	30/06/00		11.9
S	30/06/00	82.6	94.3
S	06/07/00	83.6	71.1
S	06/07/00	46.4	36.3
S	12/07/00		5.7
S	14/07/00	46.4	21.9
S	14/07/00	60.2	2.3
T	30/06/00	66.9	26.2
T	30/06/00	52.6	29.3
T	30/06/00	66.9	84.7
T	30/06/00	36.9	14.2
T	30/06/00	167.7	21.4
T	30/06/00	51.8	47.4
T	14/07/00	44.8	12.9
T	14/07/00	67.5	55.2
T	14/07/00	94.3	41.2
T	14/07/00		32.9
T	14/07/00	35.2	26.5
T	14/07/00	71.1	86.9
T	14/07/00	51.4	
T	14/07/00	57.1	64.3
T	14/07/00		2.6
T	14/07/00	50.3	49.5
T	14/07/00	21.1	12.5

Post-treatment sample

Site	Intake date	PCA day 0	PCA day 1
Q	09/05/02		32.2
Q	09/05/02		29.3
Q	09/05/02	43.5	16.6
Q	09/05/02		3.1
Q	09/05/02	34.6	24.4
Q	09/05/02	40.9	16.6
Q	09/05/02	54.4	23.8
Q	09/05/02		19.4
Q	09/05/02	45.9	23.4
Q	09/05/02	49.2	43.3
Q	09/05/02		25.6
Q	09/05/02	65.1	5.5
Q	09/05/02	55.5	26.3
R	24/05/02	40.3	3.8
S	24/10/02	17.5	
S	24/10/02	17.7	33.35
S	24/10/02	19.1	29
S	18/10/02	21.3	28.35
S	09/10/02	20.1	27.7
S	18/10/02	18.15	27.4
S	09/10/02	22.05	24.9
S	18/10/02	16.55	23.9
S	09/10/02	21.85	22.35
S	24/10/02	20.5	21.45
S	18/10/02	20.35	21
S	09/10/02	19.85	17.65

Post-treatment sample continued

Site	Intake date	PCA day 0	PCA day 1
T	30/08/01	74.21	2.14
T	30/08/01	63.39	3.33
T	30/08/01	74.92	2.84
T	30/08/01		2.02
T	30/08/01	46.46	3.83
T	30/08/01		58.2
T	30/08/01	64.97	26.94
T	30/08/01		51.33
T	30/08/01		26.49
T	30/08/01		4.31
T	30/08/01	47.59	26.58
T	30/08/01	43.85	2.95
T	30/08/01	40.66	30.52
T	30/08/01		26.31

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