

**RATS IN AN AGRICULTURAL LANDSCAPE:  
POPULATION SIZE, MOVEMENT AND CONTROL**

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by

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## ABSTRACT

### **Rats in an Agricultural Landscape: Population Size, Movement and Control**

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This research investigated the effects of coordinating rodent control across areas up to 400 ha, using conventional and alternative strategies, to see if it was possible to reduce rat numbers and to keep them at a lower level compared with uncoordinated control. The aims were to reduce the rat numbers, reduce the amount of rodenticide used over time and to reduce the risk of secondary poisoning of non-target animals. Rodenticide loads in rat carcasses were investigated using historical and new samples from Berkshire, Leicestershire and Yorkshire in order to quantify risk to non-target predators of rats. Movement was also studied to see if rats were moving into farmyards in the autumn and out in the spring as is generally assumed.

Analysis of radio-tracking data showed that the majority of rats tracked stayed within a small home range, two moved and stayed away from the trap site and only one moved into a farmyard. Analysis of the movement of the rats caught in traps showed that the movement towards and away from farms was in roughly equal numbers.

The rodenticide analysis showed that rats from areas of rodenticide resistance carried a far greater body load of poison than those from non-resistance areas. Thus resistance increases the risk of a predator or scavenger of rats ingesting a lethal dose more quickly in areas of rodenticide resistance.

The coordinated rat control was broadly successful over a period of two to three years. Rat numbers varied greatly between Yorkshire and Leicestershire, with Yorkshire having the larger numbers. Rat control in the coordinated areas showed a decreasing trend over the period. Bait take also generally showed a decline over the period. The results revealed an apparent delayed synchrony in rat numbers between coordinated and uncoordinated areas in Yorkshire that requires further investigation to explain.

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## **CHAPTER 1. INTRODUCTION**

### **1.1. THE HISTORY OF RATS IN THE UK**

There are two species of rat in the UK, the rare black rat (*Rattus rattus* L. 1758) and the brown rat (*Rattus norvegicus* Berkenhout 1769). Both species have a series of common names; the black rat is also known as the ship or roof rat and the brown rat as the common or Norway rat. The two species originate from two different areas of the world. Black rats come from the Far East, the southeast Asian mainland, the islands of Indonesia and the Philippines (Brooks, 1973). The brown rat originates from the steppes of Central Asia (Brooks, 1973; Lund, 1994). The common names of both species, the black and brown rat, are not good descriptors of their appearance. The brown rat ranges in colour from brown to grey and the black rat can be both lighter and darker in colour than the brown rat. The black rat can be distinguished from the brown rat by larger ears, a more pointed nose and relatively longer tail.

The brown rat first appeared in the UK in the early 18<sup>th</sup> century. Brooks, (1973) specifies a date of 1728, though the origin of the first introduction is not known. Confusingly, brown rats appear to have been associated with being introduced from Norway and, thus, were given the name of the Norway rat, though there is no evidence to prove that it naturalised in Norway any earlier than in the UK; the earliest recording of a brown rat in Norway is put at 1762 (Twigg, 1975). Twigg (1975) indicates that the brown rat's arrival in the UK may have been as early as 1714, and was popularly thought to have arrived in the same ship as George I, with the result that it was also given the name of the Hanoverian rat.

Following its introduction the brown rat spread quickly across the UK. By 1762 it was known to have reached the island of Anglesey where brown rats were reported to be eating the standing corn as it was being cut. Brown rats had reached Selkirk in

Scotland by 1776 where they were reported to be tunnelling under houses, with householders concerned for the safety of their properties. Records show that both the brown and black rats were present in the UK during the mid-18<sup>th</sup> century, though they seem to have occupied different habitats, the brown rat in the sewers and the black rat in the rafters of buildings (Twigg, 1975). The brown rat is a commensal rodent, living in close proximity to man, either in human habitations or associated buildings where there is a plentiful supply of food and water. During the 18<sup>th</sup> Century buildings were largely constructed of wood or wattle and daub, construction materials that would have made it easy for rats to gain access to food sources.

The date of the arrival of the black rat into the UK is unknown. This species was, however, known to have been present in western Europe by the end of the 12<sup>th</sup> century and was thought to have arrived in the ships of the crusaders between 1095 and 1191. The first recorded reference in the UK to rats is made by Giraldus Cambrensis in the 12<sup>th</sup> century (Twigg, 1975). Subsequent archaeological research has shown that the black rat may have been present in the UK during Roman times (Armitage *et al.*, 1984; Rackham, 1979). Thus, it would appear that black rats could have been in this country for over 2000 years and it is likely that they were widespread for much of their history in the UK. O'Connor, (1991) concluded that there was a period between the 5<sup>th</sup> and 8<sup>th</sup> centuries (the Dark Ages) during which there are no records of black rats and that there is a possibility that they were introduced twice into this country, firstly prior to the arrival of, or coinciding with, the arrival of the Romans and then again by Scandinavian settlers in the 9<sup>th</sup> century. Black rats were common in most of the cities of western Europe by the 13<sup>th</sup> and 14<sup>th</sup> centuries and their fleas are thought to have been responsible for the bubonic plague (Black Death) that spread throughout the UK in both the 14<sup>th</sup> and 17<sup>th</sup> centuries.

Black rats are now restricted in their UK distribution, being confined to islands, such as Lundy (Smith *et al.*, 1993), although this population has been the subject of an eradication programme (Anon, 2006), the Shaint Islands in the Outer Hebrides (Anon) and to major seaports such as London, Glasgow and Liverpool (Figure 1.1). However, the 10 km grid map from the National Biodiversity Network Gateway for the black rat would suggest that distribution of the species is not as limited as maybe thought (Figure 1.1) (Anon, 2004).

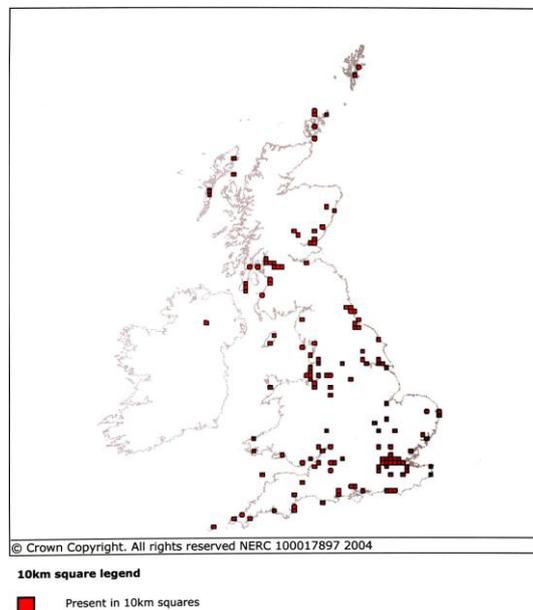


Figure 1.1 10 km squares records for *Rattus rattus* in Great Britain and Ireland

The decline of the black rat in the UK has been attributed to direct competition from the larger more aggressive brown rat. In 1768, Robert Smith, (the official rat-catcher to Princess Amelia) placed live black rats caught in the upper parts of a house and brown rats caught in the cellars together in a cage to show a gentleman the effectiveness of his labours and he reports that “*the Norway rats killed the black rats immediately and devoured them in my presence*” (Twigg, 1975). There is, however, evidence that the two species can co-occur. Barnett, (1955) put wild caught adult male animals of both

species into the same cage where nest boxes were shared by the two species without mortalities and generally without injury over a 22 week period. Placing males in the same cage as females of the same species will evoke aggression and result in death, usually by fatigue rather than injury, of all but the largest males, the females generally being unaffected (Barnett, 1955). Therefore, it would seem that the decline of the black rat in the UK may not wholly be a consequence of direct aggressive encounters with brown rats as has been suggested. Instead, the black rat, which originates in the warmer climate of the Far East, may be less well adapted to the UK environment and performs poorly under competition from the brown rat, which originated in the Asian steppes, where the environment more closely matches that of the UK.

Being a commensal animal in both urban areas and the countryside, the brown rat is a pest in terms of the both economic damage that it does and the possible health problems that it can cause. Rodents, particularly the brown rat, cause a great deal of damage with their constant chewing and in all buildings where there are rats there is the possibility of damage to cables and pipe work with the consequent risk of fire and flooding (FAO, 1983). Drummond, (2001) quotes a somewhat contradictory report for the American insurance industry, (Anon, 1957), where it was estimated that 25% of fires with an *undetermined* cause were caused by rats! Indeed, if electrical cables are gnawed through, there is the possibility of a shorting out of the circuit and this can cause a fire but it is not easy to prove that it was rat damage, as the evidence will most likely have disappeared in any fire. Damage as the result of chewed water pipes that result in flooding can on the other hand be seen and the cause properly identified.

In both the agricultural and commercial sectors, damage is caused by rats to products stored in bags and boxes. As well as gaining access to and possibly damaging the contents, the shredded material that results from this serves another purpose for the

rat as it can be used as nesting material (Drummond, 2001; Lund, 1994). This sort of activity does not just represent the damage to the product being stored but to the additional costs involved in replacing or when possible, cleaning, and repackaging the damaged material.

In the agricultural environment rats are a major cause of damage to stored grain where they eat and spoil the grain with their faeces, urine and hair. As a result of this damage the value of the grain in the marketplace is reduced, sometimes making the grain unsaleable, with the resultant loss of income. In one trial 10 - 26 brown rats were given access to a ton of wheat for 12 – 28 weeks. Only 4.4% of the wheat was eaten, but more than 70% was fouled and had to be cleaned before it could be used (Meehan, 1984). Meehan also quotes figures from the USA of 76% of corn samples being contaminated by rodent droppings. Some studies have shown that up to 23% of uncleaned samples and 12% of cleaned samples of grain intended for human consumption have been contaminated (Dykstra, 1954 quoted in Meehan 1984) but other studies put the degree of contamination at a lower figure (Harris *et al.*, 1952 quoted in Meehan 1984). In Scotland, 4000 tons of grain were examined and in an average 10 lb sample there were on average 96 mouse droppings (range 0 – 962) and 14 rat droppings (range 0 – 212). Only 2% of the samples taken were clear of any contamination (Kent, 1958 quoted in Meehan 1984).

Agricultural premises, particularly if they house livestock, can support very large numbers of rats and indeed it has been known for rats to damage and destroy farm buildings to the extent that the farmer has been forced to quit (M. Lambert Pers. Comm.). Rats can and sometimes do cause damage to farm machinery by chewing on cables and pipe work, which results in expensive repairs being necessary (P. Jarvis Pers. Comm.).

Rodents worldwide are known to carry a wide variety of diseases (Gratz, 1994). In one survey of 510 brown rats caught on farms in the UK, it was shown that rats carried 13 zoonotic and 10 non-zoonotic parasites (Webster & MacDonald, 1995). Brown rats carry ectoparasites (fleas, lice, mites and ticks) and endoparasites (helminths) in addition to bacteria such as *Salmonella* spp., *Leptospira* spp. (Weil's disease), *Listeria* spp., and viruses such as *Hantavirus* and Cowpox virus. The ectoparasites, with the exception of the ticks, are restricted to rats but the majority of the other parasites, bacteria and viruses detected can be found in and cause illness in both humans and livestock (Webster & MacDonald, 1995). Plague is caused by *Yersinia pestis* and is still a problem in the Americas, Africa and south Asia. Although the disease is passed to humans through the bite of an infected flea (the secondary carrier), the rat is the primary carrier (FAO, 1983; Lund, 1994). There is therefore a need to control rats and indeed landowners in England and Wales are obliged to do so under the terms of the Prevention of Damage by Pests Act (1949), although farmers enjoy a degree of exemption.

Rats may be controlled by non-chemical (Smith, 1994) or chemical means (Buckle, 1994) and rat damage may be minimised using non-lethal methods (Smith, 1994). In practice, chemical control is most commonly used to reduce infestations of rats. The delayed action of anticoagulant rodenticides represent the main mode of action employed because they overcome the phenomenon of conditioned bait aversion or bait shyness (see Section 1.6.1).

## 1.2 THE HUMANENESS OF RODENT CONTROL

There are several alternatives to the use of rodenticides in the control of rats, methods such as poisoning (other than anticoagulants) using zinc phosphide and calciferol, snap or break-back traps, glue traps, electrocution traps, rat proofing, gassing and live trapping with euthanasia (Mason & Littin, 2003; Meehan, 1984). Some are considered more humane and others less humane than the use of anticoagulant rodenticides. Indeed, some rodenticides are considered more humane than the anticoagulant poisons. Several ultrasonic and electromagnetic devices have also been developed that are designed to repel rodents away from particular areas but these would appear to have been of limited success as they are not to be found nowadays on the shelves in agricultural merchants.

### 1.2.1 Acute poisons.

There are several poisons that could be used to control rodent populations. Zinc phosphide is the most commonly used chemical to control rats after anticoagulants and is most widely used in the developing world. It is an acute poison, killing after the ingestion of a single dose and kills by the production of phosphine gas in the stomach (Meehan 1984). Death occurs as the result of cardiac and respiratory failure and can be in as little as five hours (or less) or up to 72 hours after ingestion (Mason and Littin 2003).

Calciferol is a sub-acute poison that produces physiological symptoms within about half a day and is a form of Vitamin D ( $D_2$  or  $D_3$ ) that at high concentrations affects the stability of calcium in the body. The calcium in the bones is mobilised and is taken up in the gut and causes the calcification of soft tissues, particularly the blood vessels. Death is caused by hypocalcaemia or kidney failure. Rodents that have

ingested calciferol show signs of pain and dysfunction such as lethargy or hunched posture and large doses can cause tremors and coma. Rats are likely to become ill within 24 – 48 hours of ingestion and death will occur within 1 – 13 days (Meehan 1984).

### 1.2.2 Traps.

There are three different types of trap commonly available, the live capture trap, the snap trap and the glue trap, and of these only one will kill the animal outright if caught in it. Under UK laws, there are at least three different types of snap trap allowed: the BMI trap, the Fenn trap and the enlarged mouse trap. All are designed to kill, the large mouse trap by the sprung arm trapping the rat across the neck between the bar and the wooden base of the trap and the BMI and the Fenn kill in the same way, by crushing the animal between powerful spring loaded jaws, however, they operate in different ways. The BMI trap cannot be hidden as it has to be set vertically in the place it is to operate (Figure 1.2a below) and this presents problems for the people doing the rodent control in that, because it cannot be hidden, the rats will exhibit their normal neophobic reaction to new objects in their home range, and avoid it or as pictures have shown, walk across the top of the traps rather than through them (Chapter 5 Figure 5.8). The Fenn trap on the other hand is set horizontally and is set just below ground level and can be lightly covered with grass, or straw, depending on where it has been set, to hide it (Figure 1.2b below). This is obviously not possible if the trap is set on to a solid surface such as concrete, as it may be around a farm yard, and in these circumstances the trap needs to be placed under some form of cover to try to prevent non-target species gaining access.



Figure 1.2a. BMI Trap in the set position      Figure 1.2b. Fenn Traps in the sprung (left) and in the set (right) positions  
Pictures by Courtesy of <http://www.thefieldsportsdebate.co.uk/traps/>

Both of these traps can kill an animal caught in them very quickly and with very little distress (Mason & Littin, 2003). During the course of this research however, both types of trap have been shown to catch rats but not kill them, which is obviously not humane (see Chapter 5). Some rats caught but not killed, depending on how they have been trapped, have released themselves by chewing off a paw or part of their tail, and we therefore have a maimed animal that is in great distress; this cannot be described as humane.

Glue traps or sticky traps are another type of trap used to capture rats. They are used widely in America and work by trapping the animal by its feet and/or fur. These traps are not designed to kill the animal, merely to trap it, and have the advantage of being able to capture several animals at once. Animals thus caught are liable to predation as they are unable to move but it also places the predator in jeopardy of becoming stuck. Neither Meehan (1984) nor Mason and Littin (2003) assess glue traps as humane.

Live trapping seems to be a humane way of catching rats and is another method of removing them from the ecosystem, but like the glue traps all the animals caught have to be killed by the operator, which, depending on the individual, may or may not

be by humane methods. Methods of killing range from the humane by the use of a gassing chamber where the animal is given an excess amount of anaesthetic and it just never wakes up, to being put into a bag and hit on the head or just being placed in a tank of water in the trap and drowning. Being given an overdose of anaesthetic is a very humane way to be killed but death by drowning certainly is not. Being hit on the head can be humane provided the animal is killed outright but using this method can also cause a lot of suffering if the blow is not applied accurately. Being confined in a trap may also be very stressful and so live trapping may not be humane.

Trapping in any of its forms is a labour intensive method of rodent control and all the traps need to be inspected daily and all animals removed and where necessary killed humanely. Unfortunately this does not always happen and live animals are left in traps to die before the carcass is removed. There may be an aversion to handling live animals and also to having to kill them, particularly on the part of the general public who may be using some or all of these types of trap. However, there is no excuse for this to happen on farms where rodent control is conducted either by a professional operator or by one of the farm staff. Unfortunately traps are not always cleared on a daily basis and as a result suffering is caused to those animals that are not killed outright.

### 1.2.3 Fumigation.

There are several gases that are in use to fumigate rat burrows, including sulphur dioxide, carbon dioxide and cyanide although not all are available in the UK. Meehan (1984) assesses fumigation as the most efficient method of rodent control, providing it is carried out correctly, but it is also the most expensive. Fumigation has several advantages over the other methods described, in that all the animals within a burrow are

killed at the same time, providing sufficient gas is applied, otherwise there is the risk of some animals receiving a sub-lethal dose. In terms of humaneness, young that are still in the nest and dependent on their mothers for food are killed at the same time rather than being left to starve to death (Mason and Littin 2003).

Gassing rats is likely to cause the animal major discomfort, whichever gas is used. Sulphur dioxide ( $\text{SO}_2$ ) will convert into sulphuric acid ( $\text{H}_2\text{SO}_4$ ) on contact with moist surfaces such as the mucus membranes and likewise carbon dioxide ( $\text{CO}_2$ ) will convert to carbonic acid ( $\text{H}_2\text{CO}_3$ ), both of which will cause irritation to airways and lungs, resulting in burning and choking sensations. Animals not killed by either of these two gases are likely to be left permanently damaged, sulphur dioxide damaging mucus membranes and carbon dioxide causing brain damage due to the lack of oxygen. Death from sulphur dioxide is not preceded by unconsciousness and can take from 20 minutes up to five hours. Carbon dioxide on the other hand causes unconsciousness in rats within two – three minutes at 100% concentration. At lower concentrations (50%) it can take 16 minutes to induce unconsciousness and 2 – 24 hours to kill (Meehan 1984; Mason and Littin 2003). Both these gases would therefore appear to be inhumane as a means of killing rats except for carbon dioxide used at very high concentrations, which under field conditions may not be achievable.

Phosphine (hydrogen phosphide,  $\text{PH}_3$ ) is produced when aluminium or magnesium phosphide comes into contact with water. The effect of phosphine is to produce respiratory and eye irritation, convulsions and hind limb paralysis. Symptoms do not appear until 30 minutes after exposure and death occurs within the range 50 minutes to three hours after exposure. There appear to be no ill effects to animals that survive and recover (Mason and Littin 2003).

Cyanide is another gas used in the fumigation of burrows and its effect on rats depends on the concentration that can be achieved in a burrow. Magnesium or calcium cyanide powder is placed into the burrow and hydrogen cyanide (HCN) gas is released on contact with water but it can only be used where the soil is “suitable”, i.e. not on sandy or loose soils, otherwise the gas will permeate through the soil and out into the atmosphere (Meehan 1984). It is thought that cyanide gas will render rats unconscious very quickly and cause some brief and mild to moderate distress and will kill without causing pain (Mason and Littin 2003).

All these fumigants need to be used at high concentrations to be completely effective otherwise there is the risk of animals surviving. A benefit of fumigation is in the fact that if used in high enough concentrations then all the animals will die underground and not become prey for predators and scavengers and thus expose them to the risk, maybe only through cyanide, of secondary poisoning.

#### 1.2.4 Proofing and Hygiene.

Making a building rat proof (Meyer, 1994) has to be one of the most humane methods of controlling rats. If rats cannot get into a building then they cannot damage the contents, breed in safety from predation and depending on the building contents, have unrestricted access to food. This does not cause the animal any harm directly, although of course preventing access to food would indirectly cause starvation. Rat-proofing does not in itself control rodents; it controls damage by preventing access to a particular site or area and may move the problem to somewhere else. Other measures need to be taken in addition to rat-proofing to control a rat population, like removing all old rubbish such as tyres and old machinery and clearing the vegetation from around building so that they have to cross open ground to get to buildings and thus open

themselves up to predation. Lambert (2003) has shown that good hygiene can be as cost effective as poisoning.

#### 1.2.5 Anticoagulants.

The use of anticoagulants is by far the most widely used form of rodent control, McDonald & Harris, (2000) quotes Thomas & Wild, (1996) as contributing 92% of rodent control on UK arable farms. There are two groups of anticoagulants, known as first and second generation anticoagulants (Buckle, 1994), and all work by blocking the vitamin K cycle in the liver, as indicated below (see Section 1.3). Rats have developed resistance to warfarin and there are now well-established pockets of resistance to second generation rodenticides in the UK. Poisoned rats may show external signs of bleeding from the mouth, nasal passages and anus and blood can be seen in the faeces. When autopsied, signs of internal bleeding are also found in the muscles and intestinal tract. Bleeding itself is not a painful process but the effect of bleeding into a closed cavity, such as a joint can be extremely painful. Time to death depends on the rodenticide used and on the dose consumed; it may be less than 24 hours but is more typically between 4 – 8 days (Mason and Littin 2003). In research on the pre-lethal effects of anticoagulant rodenticides Cox & Smith, (1992) found that all their test animals (18) died within 120 hours of consuming the poisoned pellets. Although anticoagulant rodenticides are generally effective in controlling rat populations, except where resistance has built up, I do not think it can be said that they are humane. They probably cause some animals considerable pain over an extended period of time if there is bleeding into the joints and, along with alterations in behaviour, they place predators and scavengers at risk of secondary poisoning.

### 1.3 THE PHYSIOLOGICAL EFFECTS OF RODENTICIDES

Anticoagulant rodenticides are the most commonly used poison because of their delayed action which prevents the development of bait shyness (section 1.6.1). All anticoagulant rodenticides act in the same manner by blocking the vitamin K cycle in the liver. There is now a wide range of first and second generation anticoagulant rodenticides and they all have differing binding affinities and persistence in the liver. Huckle *et al.*, (1988) in their research on the metabolism, toxicity and hepatic binding of the second generation rodenticide flocoumafen, were able to show that the rodenticide accumulated in the liver but that it was not until all the specific binding sites were saturated that it became lethal. As the rodenticide is carried by the blood stream it will also be stored in other parts of the body besides the liver and Huckle *et al.*, (1988) showed that it was also stored in the kidney, skin, muscle fat and blood. Rammel *et al.*, (1984) conducted research on the effects of brodifacoum, another second generation rodenticide, on a target pest species, (the rabbit *Oryctolagus cuniculus* L. 1758) and non-target species and found that the rodenticide had accumulated in the rabbit liver, fatty tissue and muscle.

#### 1.3.1 Normal behaviour of rats

Rats are by nature nocturnal (Berdoy & Macdonald, 1991; Taylor *et al.*, 1991; Whishaw *et al.*, 1992) and protect themselves from predators by moving about under cover when it is available. When it is not available, rats show thigmotactic behaviour by moving close to protective barriers, such as walls (Cox & Smith, 1992; Hardy & Taylor, 1980) that limit exposure to predators. Feeding is carried out during the hours of darkness. Should they not be able to feed sufficiently in the hours of darkness,

maybe because they are not able to gain access to the food because of dominant rats feeding (Adams & Boice, 1983), then they will feed during daylight hours (Berdoy & Macdonald, 1991; Shepherd & Inglis, 1987). Shekarova *et al.*, (1995) have noted that, if there is little disturbance or predation, then rats will feed during daylight hours. Wishaw *et al.*, (1992) found that when feeding in the open and therefore more likely to predation, rats spent less time at the food source than when feeding under cover or in darkness.

One of the major defence characteristics that rats exhibit is neophobia or fear of novelty, exhibiting this not just to new objects within their home range but also to new foods (Berdoy & Macdonald, 1991; Inglis *et al.*, 1996; Shepherd & Inglis, 1987). Rats are not the only animals to exhibit this tendency and it has been shown to be present in a range of commensal rodents, some bird species, domesticated animals such as cats, dogs, and pigs, gorillas and humans, particularly children (Brigham & Sibly, 1999). Rats are able to detect a new substance i.e. a rodenticide in a familiar food source, following a pre-baiting period (M. Lambert Pers. Comm.). Once a new food becomes familiar and is accepted, their consumption of it increases (Berdoy & Macdonald, 1991; Buckle *et al.*, 1987). This is important because of the phenomenon known as bait shyness (section 1.6.1).

### 1.3.2 Effect of Rodenticide on rats

Pesticide treatments have been shown to produce behavioural changes in some vertebrate species (Hart, 1990; Hooper *et al.*, 1990), and others have shown that the behaviour of rats changes in the pre-lethal stages of rodenticide poisoning (Cox & Smith, 1992; Cox, 1991; Smith *et al.*, 1994). Such changes occur within 24 hours of

rodenticide bait consumption and may last for up to five days before the rat dies (Cox, 1991; Shepherd & Inglis, 1987; Smith *et al.*, 1994).

The changes that can occur in rat behaviour are such that it puts the rat in danger of predation and exposes the predator or scavenger to the risk of secondary poisoning. The changes are an increased tendency to move from nocturnal to daytime activity and feeding and also to lose the thigmotactic response and to frequent more open spaces. Rats will also lose the fight or flight response and just sit in the open (freeze) when approached by a predator (Cox & Smith, 1992; MacVicker, 1998). Cox and Smith (1992) and MacVicker (1998) demonstrated that the males and females exhibit different effects to rodenticides in that males will stagger about whilst the females appeared drowsy. Rats that are resistant to rodenticides may also show an aversion (enhanced neophobia) to a rodenticide bait because it has made them feel ill, but not killed them, following its consumption (Berdoy & Macdonald, 1991; Brunton *et al.*, 1993). This conditioned aversion to a rodenticide may be passed on to juveniles through socially induced food preferences (Galef & Whiskin, 1994).

#### 1.4 A REVIEW OF SECONDARY POISONING BY PESTICIDES OF RAPTORS AND OTHER NON-TARGET ANIMALS

The use of pesticides has grown rapidly since 1944 when there were 63 pesticides in use in the UK and, by 1976 this number had risen to 819. By 1996 there were 3400 pesticides registered under the Food and Environment Protection Act 1985 (Johnson, 1996). These included herbicides, insecticides, rodenticides, fungicides and animal repellents. The earliest specific anticoagulant rodenticide to be manufactured was warfarin. This poison was developed as the result of farmers in the 1920s in North Dakota, USA and Alberta, Canada observing cases of cattle bleeding to death. Local vets diagnosed the condition as haemorrhagic septicaemia. Research by F. W. Schofield, and L. M. Roderick in the 1920s and early 1930s showed that the source of the septicaemia was stacks of mouldy sweet clover hay upon which animals had fed (Link, 1944). The condition was subsequently named “sweet clover disease”. In his lecture, given on 20 January 1944 as part of the Harvey Series Lectures, Link (1944) described the discovery and extraction of 3,3'-Methylenebis (4-Hydroxycoumarin) from spoiled sweet clover hay, which proved to be the causative agent for the haemorrhagic septicaemia observed by farmers. The identification of this compound opened the way for the development of coumarin-based anticoagulant rodenticides.

Warfarin was the first anticoagulant rodenticide to be developed from research on coumarin. All subsequent anticoagulant rodenticides that are currently licensed for use are derived from coumarin or indane-dione structures (Buckle, 1994). Lethal doses vary widely among anticoagulant poisons; in general the halogenated molecules are the most toxic.

It was recognised as far back as 1950 that there was a secondary poisoning risk to mammals from the use of the ubiquitous anticoagulant rodenticide, warfarin (Hayne

& Gaines, 1950). Meehan, (1984) observed that death in rats occurred between four and nine days after ingestion of a lethal dose of anticoagulant poison. The length of the period from ingestion to death has implications for raptors, since they prey chiefly on rodents and are liable to consume prey that is dead or dying or that shows altered behavioural patterns that make it more prone to capture as the result of ingesting rodenticides (Cox & Smith, 1992). There are also implications for other animals that may hunt in and around farmyards, for example mustelids; polecats (*Mustela putorius* L. 1758), stoats (*M. erminea* L. 1758) and weasels (*M. nivalis* L. 1758), and domestic animals such as cats (*Felix* spp.) and dogs (*Canis familiaris* L. 1758).

In order to understand the impacts of rodenticides on raptors and other non-target animals it is necessary to define two terms used in the context of pesticide use. *Hazard* is used to denote the potential for a compound to cause harm, while *risk* refers to the chances of actual harm resulting from the patterns of use of a pesticide and exposure to it. Risk is a function of both hazard and exposure. A further term is *secondary poisoning*. Mineau *et al.*, (1999) defines secondary poisoning as: “The passing of residues assimilated into one animal tissue into another animal,” which will be the definition used here. The LD<sub>50</sub> is another term used when measuring the toxicity of a substance. The standard convention is to quantify the amount of the substance, measured in mg of toxin per kg of animal tissue, that kills 50% of the test population over a prescribed period of time under defined conditions (Calow, 1998). The LC<sub>50</sub> is a similar measure that measures concentration rather than dose.

The aim of this review is to summarise the use, action and possible impacts on non-target species of rodenticides and other chemicals used in the agricultural environment. Pesticides not intended to kill rodents will be considered first for comparison with the rodenticides that are widely used in agriculture today.

In the following review there are two sources of data referred to: on the one hand is the feeding of dosed food to captive animals and on the other is analysis of non-target species to determine the cause of death following the use of pesticides under approved or recommended conditions of use.

## 1.5 PESTICIDES RATHER THAN RODENTICIDES

### 1.5.1 Organophosphates and Organochlorines

Organophosphates are a large group of organic compounds that were developed as agricultural insecticides; the first, parathion, was developed by G. Schrader in 1944 (Calow, 1998). These compounds, like organochlorines, attack the nervous function and are known generically as anticholinesterases.

Hunt *et al.*, (1991) investigated the effect of fenthion, an organophosphorus avicide that was originally developed as an insecticide, on American kestrels (*Falco sparverius*). Fenthion is used to control pest bird species, such as the house sparrow (*Passer domesticus* L. 1758), the rock dove (*Columba livia*) and the European starling (*Sturnus vulgaris* L. 1758), in urban and agricultural areas. All these bird species are potential prey of the American kestrel. Fenthion is applied to specially prepared perches that are placed in roosting sites. Previous studies showed that fenthion is at least three times more toxic to kestrels than to house sparrows with an acute oral LD<sub>50</sub> values of 1.0 mg kg<sup>-1</sup> and 5.6 mg kg<sup>-1</sup> respectively (Schafer *et al.*, 1964; Schafer & Cunningham, 1965; Schafer *et al.*, 1969 quoted in Hunt *et al.*, 1991).

Hunt *et al.*, (1991) used 14 male kestrels and male house sparrows in secondary poisoning trials. Treatment of sparrows in the study involved their being confined in a perching box containing a fenthion treated perch for five minutes. Kestrels were starved for 48 hours before having the treated sparrow released into its aviary in an attempt to simulate natural predation.

The only recorded effect of fenthion on house sparrows was to induce paralysis. 11 kestrels however died within a day of their killing and at least partially consuming a treated sparrow. Time to death ranged from 1 hour to 15.5 hours. Two kestrels died on day two of the trial after killing and partially consuming a second treated sparrow and

the remaining bird died on the third day after partially consuming a third treated sparrow. Reduction in the cholinesterase activity in the 11 birds that died on Day 1 was 81.3% (brain) and 96.6% (plasma). The two birds that died on Day 2 of the experiment showed reduction in cholinesterase activity of 77.9% (brain) and 96.6% (plasma) and the last bird to die on Day 3 showed reductions of 92% (brain) and 96% (plasma). Residues of fenthion found by Hunt *et al.* (1991) on and in the kestrels ranged from 1.4 – 14.3  $\mu\text{g g}^{-1}$  in the gastrointestinal tract and 2.4 – 19.2  $\mu\text{g g}^{-1}$  on the feet.

Blus, (1996) reviewed the effects of pesticides on owls in North America and noted the death of 18 owls from 5 species between 1982 and 1991 as the result of organochlorine or carbamate poisoning (anticholinesterase pesticides), 13 great horned owls (*Bubo virginianus*), one barn owl (*Tyto alba*), one eastern screech-owl (*Otus asio*), two short-eared owls (*Asio flammeus*) and one snowy owl (*Nyctea scandiaca*), one animal was not identified. All the deaths were the result of poisoning by a single chemical, but the chemical was not identified in the case of three of the deaths. Blus also reported that a variety of organochlorines were responsible for the deaths of 44 owls of 3 different species between 1968 and 1990 (33 great horned owls, six barn owls, and five eastern screech-owls, one animal was not identified). Most instances were the result of poisoning by a single chemical but in 11 cases two or more chemicals were found to be present.

### 1.5.2 Carbamates

Studies have been carried out on the effects on predators during the routine use of carbamates used as insecticides and nematicides. Several carbamates are very toxic to birds. Dietrich *et al.*, (1995) studied the effect of carbofuran, a carbamate insecticide-nematicide on the common buzzard (*Buteo buteo*), red kite (*Milvus milvus*)

and black kite (*M. migrans*). It is known that buzzards and kites prey on earthworms (*Lumbricus terrestris* L. 1758) during rainy days in spring. Birds of prey were found either dead or seriously ill in or close to fields that had recently been sown with either fodder beet or sugar beet where carbofuran had been applied in the furrow following planting. Examination of the crop contents of these birds showed that they had consumed earthworms and carbofuran and it was hypothesised that they had died through secondary poisoning of contaminated earthworms.

Dietrich *et al.*, (1995) also conducted laboratory and field experiments on the effects of carbofuran on earthworms. They started to collect earthworms from a 0.5 ha field on 7 April 1992, 3 days before it was sown with fodder beet and the simultaneous application of carbofuran at typical levels ( $30 \text{ kg ha}^{-1}$ ). For the field experiments earthworms were collected from 8 sites, four at the edge and four in the middle of the field and from 10 April 1992 they were collected at irregular intervals over the following 143 days. Live and dead worms were taken from the soil surface or from five cm below the surface, with the sample size ranging from 4 – 10 worms per location. All samples collected were frozen and stored prior to analysis. In the laboratory, 250g soil samples were mixed with 50 ml of water and 0, 0.125, 0.25 or 0.5 g carbofuran granules and placed in perforated beakers with 3 or 4 worms in each beaker. It is not stated where these earthworms used in the laboratory experiments came from. The worms were removed from the soil every hour and placed back on the respective soil surface to test for viability. This procedure was halted when either two or more worms had died or after 24 hours. This laboratory study allowed estimation of the toxicity of carbofuran to earthworms and the amount of toxin carried by earthworms to their predators.

Weather conditions influenced results from the field experiment. High levels of carbofuran were found in the earthworms on the day following its application when the soil was damp but not damp enough to allow the carbofuran granules to dissolve. There was no rain on the following 17 days with no change in the appearance of carbofuran granules and no carbofuran was found in four further samples of earthworms taken during this time. Following rain the carbofuran granules dissolved and in subsequent samples of worms  $2.7 \text{ mg kg}^{-1}$  carbofuran was detected in pooled samples. Laboratory results showed that 25, 50 and  $100 \text{ mg kg}^{-1}$  carbofuran concentrations were acutely toxic to worms. From both experiments, worms with high levels of carbofuran were found on or close to the soil surface, showing that they would be readily available to predators.

In the field experiments carried out by Dietrich *et al.*, (1995), it was shown that the earthworms contained carbofuran concentrations ranging between  $<0.2 \text{ mg kg}^{-1}$  and  $3.2 \text{ mg kg}^{-1}$  where the estimated concentration of carbofuran applied was 10.6 ppm. In the laboratory experiment earthworms were exposed to 25 – 100 ppm carbofuran, and levels in earthworm tissue were  $15 - 20 \text{ mg kg}^{-1}$ , considerably more than was found under the field conditions. Crop contents from the buzzards were taken for analysis but no tissue samples were taken from any of the raptors as it has been shown that carbofuran is metabolised rather rapidly (De Lavour *et al.*, 1991, quoted in Dietrich *et al.*, 1995). Analysis of the crop contents of five buzzards that contained earthworm remains showed total carbofuran levels ranging between 3 and  $1100 \mu\text{g}$ .

Elliott *et al.*, (1997) reported the deaths and poisoning of raptors in a study of phorate from Canada. In January/February 1992 and between December 1993 and March 1994, nine raptors (there is a discrepancy in the numbers in the paper) from the Fraser River Delta, Canada, (eight bald eagles (*Haliaeetus leucocephalus*) and a red-

tailed kite (*Buteo jamaicensis*), were found dead or debilitated. The lower Fraser Valley is an important wintering area for bald eagles and other raptors where they feed on the waterfowl that gather in the area. The area is intensively farmed for vegetable crops and the waterfowl depend on the agricultural land for feeding. The soil type in the Fraser Valley is an acidic clay and is subject to seasonal flooding and puddling. These conditions do not lend themselves to the degradation of the granular phorate and along with the fact that phorate is normally applied directly into the furrow when potatoes are planted means that there is a build up in the soil. In normal agricultural practice under these conditions the granules can account for up to 60% of the phorate residues 4.5 months later. The deaths and sub-lethal effects on these raptors occurred about 10 months after the normal recommended spring application time.

Analysis of blood and the contents of their crops showed that phorate was the cause of the poisoning (Elliot *et al.*, 1997). Sick birds that were captured, (all were bald eagles), showed symptoms of clenched talons, poor co-ordination, twitching eyes, convulsions, and smelly and swollen crops; all symptoms indicate poisoning by an anticholinesterase agent. Dead specimens also had swollen crops. Elliott and his team did not record levels of phorate in the tissues of the birds that they were sent. They did record the levels of phorate found in the crop contents and these ranged from none detected ( $<50 \mu\text{mol min}^{-1} \text{ l}^{-1}$ ) to a maximum of 24 ppm (Elliott *et al.*, 1997).

In Britain the Wildlife Incidents Investigation Scheme (WIIS) is a unique system that monitors adverse effects of pesticides on wildlife (see the Pesticides Safety Directorate web page <http://www.pesticides.gov.uk/environment.asp?id=58> for more information). Recent WIIS reports have highlighted rodenticide incidents but have also shown that carbamates can cause avian deaths, including the death of a red kite in Norfolk, following ingestion of just a few granules of compounds such as Aldicarb,

(Barnett *et al.*, 2004). Rodenticides are therefore by no means the only pesticides that cause non-target mortality.

## 1.6 PRE – 1970 RODENTICIDES

### 1.6.1 Acute Toxicants

The first rodenticides to be used were referred to as “acute toxicants” because they have a rapid acute effect and include compounds such as zinc phosphide, Red Squill and 1080 (Table 1.1). Rodents, and particularly rats, are notoriously wary of anything new in their environment, including food, exhibiting what is termed neophobia, “the extreme or irrational fear or dislike of anything new, novel or unfamiliar” (Pearsall, 1999). In addition, rats are unable to vomit (Fitzpatrick, 1952), and therefore usually eat only a small amount of any new food item with which they are presented (Macdonald & Fenn, 1994). If they suffer any adverse reaction to a new food they will subsequently avoid it, possibly for the rest of their lives, showing conditioned bait aversion or ‘bait shyness’ (Brooks, 1973; Fenn & Macdonald, 1987; Smith, 2001 ). When using acute poisons, such as zinc phosphide, it was necessary to practice what is known as prebaiting, putting down the unpoisoned cereal bait base for several days before replacing it with the same bait base containing the zinc phosphide. Prebaiting helped to overcome neophobia and also bait shyness. With a sub-acute toxicant such as Calciferol and the first generation anticoagulants, prebaiting was not necessary as their effect was somewhat slower, although several meals of the poisoned bait were necessary over a period of days in order to achieve the death of the animal (Whisson, 1996). Pre-baiting to encourage rats to consume bait might also encourage non-target species to consume the bait. The effects of acute rodenticides on non-target wildlife however, has hardly been studied

## ACUTE TOXICANTS

Rodenticide	Chemical formula	Liver Half Life (days)	Rat Oral LD <sub>50</sub> (mg kg <sup>-1</sup> )	Date Introduced	Trade Names
Red Squill	C <sub>32</sub> H <sub>44</sub> O <sub>12</sub>		0.43 - 0.7		
Zinc phosphide	Zn <sub>3</sub> P <sub>2</sub>		45.7		
1080	C <sub>2</sub> H <sub>2</sub> FNaO <sub>2</sub>		1		
Calciferols* (Vitamins D <sub>2</sub> & D <sub>3</sub> )	C <sub>27</sub> H <sub>44</sub> O		352 - 619	1974 <sup>(4)</sup>	Deerat, sorex Fatal, Sorex C

\*Calciferols are often referred to as sub-acute poisons because there is some delay in the appearance of physiological effects

## FIRST GENERATION RODENTICIDES

Warfarin	C <sub>19</sub> H <sub>16</sub> O <sub>4</sub>	7 – 10 <sup>(1)</sup>	3 – 186	1950 <sup>(4)</sup>	Warfarin, Rat and Mouse bait
Diphacinone	C <sub>23</sub> H <sub>16</sub> O <sub>3</sub>		2.3	1952 <sup>(4)</sup>	Sorex CD3, Ditrac, Tomcat
Foumarin					Fumasol, Krumkil, Rat-a-way, Tomarin
Coumatetralyl	C <sub>19</sub> H <sub>16</sub> O <sub>3</sub>	55 <sup>(2)</sup>	1.08 – 16.5	1956 <sup>(4)</sup>	Bio Racumin, Racumin, Townex
Chlorophacinone	C <sub>23</sub> H <sub>15</sub> ClO <sub>3</sub>		3.15	1961 <sup>(4)</sup>	Drat, Endorats, Karate, Rout
Pindone	C <sub>14</sub> H <sub>14</sub> O <sub>3</sub>		50		Pival, Pivalyn

## SECOND GENERATION RODENTICIDES

Difenacoum	C <sub>31</sub> H <sub>24</sub> O <sub>3</sub>	182	1.8 – 2	1975	Deosan, Difenard, Endem, Fentrol, Neokil, Neosorex
Bromadiolone	C <sub>30</sub> H <sub>23</sub> BrO <sub>4</sub>	170	1 – 3	1980	Bromard, Contrac, Deadline, Endorats, Luxan, Ratta, Rodine
Brodifacoum	C <sub>31</sub> H <sub>23</sub> BrO <sub>3</sub>	157	0.37 – 0.68	1982	Erasor, Klerat, Talon, Vertox, Havoc
Flocoumafen	C <sub>33</sub> H <sub>25</sub> F <sub>3</sub> O <sub>4</sub>	222 <sup>(3)</sup>	0.4	1986	Storm,

Table 1.1. Rodenticides

<sup>(1)</sup> (Thijssen, 1995)

<sup>(2)</sup> (Parmar *et al.*, 1987)

<sup>(3)</sup> (Huckle *et al.*, 1988)

<sup>(4)</sup> (Buckle, 1994)

### 1.6.2 First Generation Rodenticides: Warfarin

The first and second generation anticoagulant rodenticides are poisons specifically developed to control rodents and were all developed following the initial discovery of coumarin by Link in 1944 (Link, 1944).

The secondary toxicity of warfarin to birds was investigated by Townsend *et al.*, (1981) who fed warfarin dosed mice to captive Tawny owls (*Strix aculo* L. 1758) in two experiments. Four owls were fed dosed mice on alternate days for three months and all survived. At the end of this time blood samples were taken from all four test birds. Two control birds and one male and one female test bird were killed for body tissue analysis. The remaining two test birds were fed undosed mice for three weeks and then fed mice that had been dosed with warfarin at 10 – 20 times the previous dosage for 28 days. Both survived this period. Again blood samples were taken from the test and control birds and the two test birds killed for body-tissue analysis.

During the first phase of this experiment all the owls increased in weight by an average of 14%, as did the control birds. Moulting of the primary wing feathers in one of the test animals started two weeks before the start of the experiment, which lasted for 120 days. This individual was not affected by the warfarin in the diet and no bleeding was observed. No observations are recorded of any effect of the warfarin in the second phase of the experiment. Pellet and faecal analysis showed that 10% of the warfarin was excreted in the first phase but in phase 2 excretion of warfarin was less than 10% of that ingested.

From the analysis of the body tissue conducted by Townsend *et al.*, (1981) similar levels of warfarin were found in the tissues of the pair of owls used in the first phase of their feeding experiment. The analysis of the tissue from the second pair (Phase 2) showed much greater variation, the owl that had the highest level of warfarin

in its liver, with the exception of body fat, also had higher levels of warfarin in the other types of body tissue analysed (kidney, heart, brain and muscle). In both pairs the highest levels were in the liver, 0.49 and 0.46 ppm for the phase 1 birds and 0.90 and 0.75 ppm for the phase 2 birds.

Warfarin is regarded as relatively harmless to birds and there is little concern about its non-target effects, although many mammals are susceptible to warfarin. It is often assumed that other first generation anticoagulants are also benign with respect to birds, but the annual WIIS reports (entitled Pesticide poisoning of Animals and produced by the Pesticides Safety Directorate) show that fatalities do occur because of exposure to first generation compounds (<http://www.pesticides.gov.uk/environment.asp?id=1861>).

## 1.7. POST 1970 (SECOND GENERATION) RODENTICIDES

Second generation rodenticides were developed and first marketed between 1975 and 1985, because rodents, principally rats, had become resistant to first generation compounds (Cowan *et al.*, 1995). Second generation poisons include difenacoum, bromadiolone, brodifacoum and flocoumafen. They are 100 – 1000 times more toxic to rats than first generation rodenticides such as warfarin and are also toxic to birds. They also have long biological half lives (Table 1.1), in organs such as the liver where they are principally stored after they are ingested (Newton *et al.*, 1999). The combination of these factors means that they have greater potential to cause secondary poisoning in predators than first generation rodenticides.

Eadsforth *et al.*, (1996) carried out field research in southern Eire where they monitored the levels of rodenticides in the pellets of wild barn owls. No dead owls were found during the 13-day period when pellets were collected and no mention is made of any target rodent species being found dead. Analysis of 89 of the 139 pellets collect showed that 97% contained no detectable trace of the 3 rodenticides brodifacoum, difenacoum and flocoumafen (analysis limits 0.01 – 0.02 mg kg<sup>-1</sup>), and the remaining 3% would appear to be the result of contamination by co-extracted material. Eadsforth *et al.*, (1996) found no dead owls during their survey so it was impossible to obtain residue levels in body tissue.

### 1.7.1 Difenacoum

Difenacoum was the first of what became known as the “second generation” anticoagulant rodenticides and was launched in 1975 (Newton *et al.*, 1999). Its effects have been studied in a variety of animals and birds, but mainly in polecats and barn owls, because these are animals that often hunt near farmyards where the vast majority

of rodenticides are used and where they are more likely to detect animals that have been affected by rodenticides.

Gray *et al.*, (1994) conducted feeding experiments on captive barn owls using difenacoum, brodifacoum and flocoumafen. Of the 12 owls tested, four died within 14 and 16 days from the commencement of the trial. Two died after having been fed flocoumafen and one each after consuming brodifacoum and difenacoum. There were no observations of any changes in the behaviour of the birds. Analysis of pellets showed that of the amounts of rodenticide consumed, 29%, 26% and 21% respectively of brodifacoum, difenacoum and flocoumafen were regurgitated in the pellets. No analysis of the body tissue of the four owls that died during the experiments was carried out by Gray *et al.*, (1994). It was concluded that within 15 days post treatment, the levels of all 3 rodenticides had declined to about 1% of the level during treatment.

A series of three studies were carried out on the carcasses of polecats (Shore *et al.*, 2003; Shore *et al.*, 1999; Shore *et al.*, 1996); the majority had died as the result of road accidents, while the remainder had either been trapped or found dead. In the first study of 29 animals, analysis was carried out on livers and stomach contents. Of the 24 livers and five stomachs analysed, only seven livers and two stomachs contained rodenticide. Difenacoum was the most frequently detected rodenticide (28% of the animals). Bromadiolone was found in 10% and brodifacoum in 3% of the animals. In the second and third studies, only the livers were analysed.

In the second study an analysis of the livers of 24 animals showed that six contained second generation rodenticides. Like the first study, difenacoum and bromadiolone were the predominant poisons, being found in 16% and 14% of the animals respectively. In a third study of 50 animals, 18 of the livers contained rodenticides. As with the first two studies difenacoum and bromadiolone were the most

frequently found, present in 28% and 10% of the animals. Brodifacoum was only found in three animals in total and flocoumafen was not detected at all in any of the three studies.

In all studies there were some animals that contained at least two poisons and in the final study one animal was found to contain all three rodenticides (brodifacoum, bromadiolone and difenacoum). Of the 100 livers that were analysed it would appear that both sexes are equally likely to be poisoned, males 22 out of 71 (30.96%), females 9 out of 29 (31.03%).

In another study of mustelids that had either been shot or trapped McDonald *et al.*, (1998) found rodenticide residues in nine out of 40 stoats and in three out of 10 weasels.

### 1.7.2 Brodifacoum

Following the successful eradication of the Kiore (*Rattus exulans* Peale 1848) on the Lady Alice Islands, New Zealand (Ogilvie *et al.*, 1997), brodifacoum was used to attempt to eradicate Brown rats from Langara Island, a sea bird colony, off the north-western tip of British Columbia, Canada (Howald *et al.*, 1999). Howald *et al.*, (1999) monitored secondary poisoning of avian predators during this rat-control exercise. Langara Island is a seabird-nesting colony that at one time held an estimated 500,000 seabirds. By 1993 one species, Ancient murrelets (*Synthliboramphus antiquus*), had declined to 10% of their historical population size. The avian predator species susceptible to poisoning were identified using rat carcasses monitored by cameras with motion sensors. The chief predators were identified as bald eagles, ravens (*Corvus corax*) and north-western Crows (*Corvus caurinus*).

Wild rats were live trapped by Howald and his team and four adult males, five adult females, five juvenile males and five juvenile females were captured. Each individual was tagged, weighed and fitted with a radio collar. The rats were released and were located at least once each day. Poisoning was conducted in two phases, a six-week intensive phase followed by a two-year period of limited baiting, using 3848 bait stations.

Of the 19 rats that were radio collared by Howald and his team, 15 were recovered dead of which 13 had died under ground and, therefore, were not available to bird predators. Death of the rats occurred between three and nine days from the start of intensive poisoning using brodifacoum. A total of 35 other rat carcasses were recovered above ground from an estimated population of 3000 rats. No bald eagles or north-western crows were found dead during the poisoning, although 13 ravens were found dead during the intensive baiting period. A sample of 23 bald eagles was captured and blood samples taken for analysis. In addition, 27 north-western crows were caught and killed and their livers taken for analysis. From the blood samples, only three plasma samples showed the presence of brodifacoum, ranging from 0.037 – 1.74 mg l<sup>-1</sup>. A pooled sample of three crow livers also showed traces of brodifacoum, at a concentration of 0.019 mg kg<sup>-1</sup>. The livers of ravens were also assessed for the level of brodifacoum and ranged between 0.98 mg kg<sup>-1</sup> to 2.52 mg kg<sup>-1</sup>.

### 1.7.3 Bromadiolone

Berny *et al.*, (1997) conducted a 4-year investigation in France into the secondary poisoning of foxes (*Vulpes vulpes* L. 1758) and buzzards by the anticoagulant rodenticide, bromadiolone. Bromadiolone is used away from buildings only by official pest control operators to control the field vole (*Arvicola terrestris* L.

1758) and coypu (*Myocaster coypus* Molina 1782). The corpses of 17 different species of animals suspected of being poisoned were collected by hunters, including red fox, common buzzard, brown hare (*Lepus capensis* L. 1758), wild boar (*Sus scrofa* L. 1758), rock dove and black kite. Analysis of specimens showed 97 of 101 were confirmed as having been poisoned, 59 were poisoned by bromadiolone and the remainder by chlorophacinone; in some cases both poisons were detected. A total of 28 specimens were derived from one site following a poisoning event in which carrots were treated with bromadiolone over a 3-month period in an area of high field vole density ( $>300 \text{ ha}^{-1}$ ). All 28 specimens came from within 5 km of the treated area. All the 31 foxes and 15 of the 16 buzzards were confirmed as having been poisoned.

In the study carried out by Berny *et al.*, (1997) liver tissue was analysed to determine the levels of bromadiolone poison remaining in the body. They found that in foxes levels ranged from  $0.8 \mu\text{g g}^{-1}$  to  $6.9 \mu\text{g g}^{-1}$  and in the buzzard from  $0.2 \mu\text{g g}^{-1}$  to  $1.3 \mu\text{g g}^{-1}$ .

#### 1.7.4 Flocoumafen

Newton *et al.*, (1994) carried out feeding trials with five barn owls using the second-generation rodenticide flocoumafen. All of the test birds used in the experiment had previously been used in experiments with other second-generation rodenticides (difenacoum, bromadiolone and brodifacoum), which may have affected the outcome of the experiments. The birds were fed contaminated mice in three phases, one day (three mice), three days (six/seven mice) and six days (9 – 12 mice) with 24 days between phases one and two and 45 days between phases two and three.

All birds survived the period of the trials but one died after the end of the six-day trial. None of the birds showed any signs of haemorrhaging during the one and

three day feeding trials. Before the six-day feeding trial began two owls (one of which subsequently died) started to moult and both bled from the growing flight feathers. An analysis of pellets produced by the experimental owls showed that on average 27% of the flocoumafen ingested was excreted in the pellets; almost three times greater than that found by Townsend *et al.*, (1981) for warfarin excretion. Blood coagulation times were also measured after the one-day trial and found to be variable. The blood of one bird, taken the day following the trial, had a normal coagulation time, but a sample from the same bird nine days later failed to coagulate. Blood from two other birds would not coagulate two and three days after the trial, but other samples taken nine days after the trial had normal coagulation times. Blood samples from the four surviving birds after the six-day trial did not coagulate.

The surviving owls used by Newton *et al.*, (1994) were killed 73 and 267 days after the end of the trials and their livers analysed for flocoumafen. Those killed at 73 days contained an average of  $0.49 \text{ mg kg}^{-1}$  and those killed at 267 days had  $0.06 \text{ mg kg}^{-1}$ . The owl that died following the 6-day trial had an average  $0.90 \text{ mg kg}^{-1}$  of flocoumafen in its liver. The liver was divided into three pieces that were then analysed separately and it is notable that the flocoumafen was not distributed evenly in the liver, the three parts containing  $0.25 \text{ mg kg}^{-1}$ ,  $1.15 \text{ mg kg}^{-1}$  and  $1.15 \text{ mg kg}^{-1}$ . This uneven distribution of the toxin in the liver has also been noted with other rodenticides. It was estimated from the decrease in flocoumafen levels over time and the excretion through the pellets that 97% of the flocoumafen was excreted in one form or another within the first two days of ingestion.

#### 1.7.5. Patterns of rodenticide use and exposure

Rodenticides are toxic by design to rodents and most are more or less toxic to all vertebrates. Mode of application is therefore critical in determining exposure of non-target animals to these intrinsically hazardous compounds. Because rats do not readily take poisons, two methods have been developed for applying anticoagulant rodenticides in the agricultural and domestic environment, the saturation and the pulsed methods. The saturation method involves the poison being left out continuously for a long period to allow rats to become familiar with it and to consume substantial quantities. This method is used mainly with first generation rodenticides where ingestion over several days is necessary to achieve lethal dosing. The pulsed method is where the bait is placed out in smaller quantities and replenished only at intervals (e.g. seven days) for a limited period (i.e. 21 days) then removed. Pulsed baiting is used with second-generation rodenticides, because of their higher toxicity. The pulse method was developed by A. C. Dubock and is supposed to reduce non-target exposure as well as costs. There is some evidence that pulsed baiting reduces mean body loads of anticoagulant compared with saturation baiting (Dubock, 1982).

## 1.8. EFFECTS OF ANTICOAGULANTS ON WILDLIFE

From the field studies that have been carried out that are reported in these papers there are relatively very few predators, relative to numbers in the population, that have succumbed to secondary poisoning and there are very few reports of the primary target species being found dead. This means that maybe few of the target species of the poison are dying above ground (in rats there is conflicting evidence on this), or that they are dying above ground, but are being removed before or soon after death by other opportunistic scavengers.

In experiments using brown rats Cox & Smith, (1992) found that death occurred between five and eight days in males and five to eleven days in females following ingestion of an anticoagulant (brodifacoum, R. H. Smith Pers. Comm.). An effect of anticoagulant poisoning observed by Cox & Smith, (1992) was an alteration in rat behaviour. Within forty-eight hours of consuming poison bait more time was spent by rats during the hours of darkness in nest boxes and more time during daylight in the open, a reversal of normal patterns of activity. Rats also began to lose their thigmotactic behaviour, spending time out in the open, with a change in their startle behaviour from bolting to freezing. As a consequence of this change in behaviour, poisoned rats would be more at risk from diurnal predators than normal, thereby increasing the susceptibility of predators to secondary poisoning.

Only Cox and Smith, (1992) have described behavioural side effects of rodenticides that might made exposure of non-target species more likely; no other studies have been reported that indicate whether certain pesticides are more liable to encourage higher levels of predation of poisoned individuals.

Studies indicate what effect poisoning episodes have on the individuals of non-target species exposed to pesticides. For individuals, exposure to secondary poisoning

frequently results in death, but for local populations the risk may be small. For example, in the River Fraser delta in Canada where large numbers of wildfowl and raptors over-winter and there were high concentrations of phorate in the soil there were few raptors found dead relative to the total numbers of birds (Elliott *et al.*, 1997).

Studies of secondary poisoning usually confine results to the often limited numbers of animals examined or tested and none attempt to extrapolate findings to the population level. Those animals that have succumbed to secondary poisoning often contain high levels of poison, which may be the result of the way that predators, particularly raptors, eat. Red kites will eviscerate a rat and eat just the organs (Brakes, 2003), starting with the liver and stomach, with the result that they are liable to ingest large quantities of rodenticide that might be stored in the liver of their prey or from any poisoned bait that remains in the stomach. Other animals will eat the whole animal, including the stomach and intestines, again, which could contain large quantities of poison. In either case, large quantities of rodenticide are liable to be ingested, either as pure rodenticide that has been removed from the bait by the prey animals' digestive system or as the result of eating bait that has already been ingested by the prey animal.

It may be that predator populations as a whole are not at great risk from secondary poisoning, since predators are likely to feed on a range of prey species not all of which will be subject to control measures that could result in secondary poisoning. However, individuals foraging in areas where poisoning is ongoing may be at high risk. Predators at most risk are those that also readily scavenge, such as the red kite, as they are most likely to feed selectively on prey that has received high concentrations of poison. Brakes (2003) studied the removal of rat carcasses from around a pig farm and found that a variety of species including red kite, badger (*Meles meles* L. 1758) and fox

scavenged dead rats (although cannibalisation by other rats was one of the commonest means of removal of carcasses).

Even for predator species that rely heavily on prey species, such as rats, that are the direct targets of poisoning, the direct impacts of secondary poisoning may not always be great since poisoning is often highly localised and often of short duration. In addition, some predators might be able to tolerate poisons. For example, studies on barn owls have shown this species is able to eliminate the majority of the poisons it ingests and is relatively tolerant of exposure to rodenticides. However, some predator species may be at risk from secondary poisoning, especially if a species is rare or at risk for other reasons. For example, where red kites have been introduced into the UK from captive breeding programmes, populations may be more at risk because numbers are low and introduced birds may rely heavily on scavenging because they lack hunting skills.

## 1.9 POPULATION STRUCTURE

The number of rats in any given population fluctuates, whether as the result of the natural conditions or as the result of man's actions. Rats are density dependent and under natural conditions a population size fluctuates around a number, the carrying capacity, depending on the conditions pertaining at the time. These fluctuations are the result of births and deaths within a colony but also as the result of immigrations into and emigrations out of the colony. When man interferes with this balance, such as applying rodenticides, the carrying capacity remains the same but there are fewer rats and so one or two things can happen. Firstly, the females within the remaining population breed more rapidly because there are proportionately more resources available or rats move into the area to fill the void created. If a building or store is cleared out in which rats are living, this reduces the available resources, habitat and/or food and this reduces the carrying capacity and therefore some animals will have to leave and face predation or starvation.

Rats may be concentrated in a small area because the conditions, available habitat, food and water, allow them to be, or the same number of animals may be spread out over a larger area in smaller groups but still with contact between the groups. On a larger scale these groups may be in adjacent farms, detached building such as field barns, in hedgerows or in woodland. The smaller the scale over which a colony is spread the more contact there will be between members of that colony but it has been shown that rats will move a considerable distance, (Chapter 3). As a result, even over the larger scale, there is likely to be contact between separated groups, (Figure 1.3).

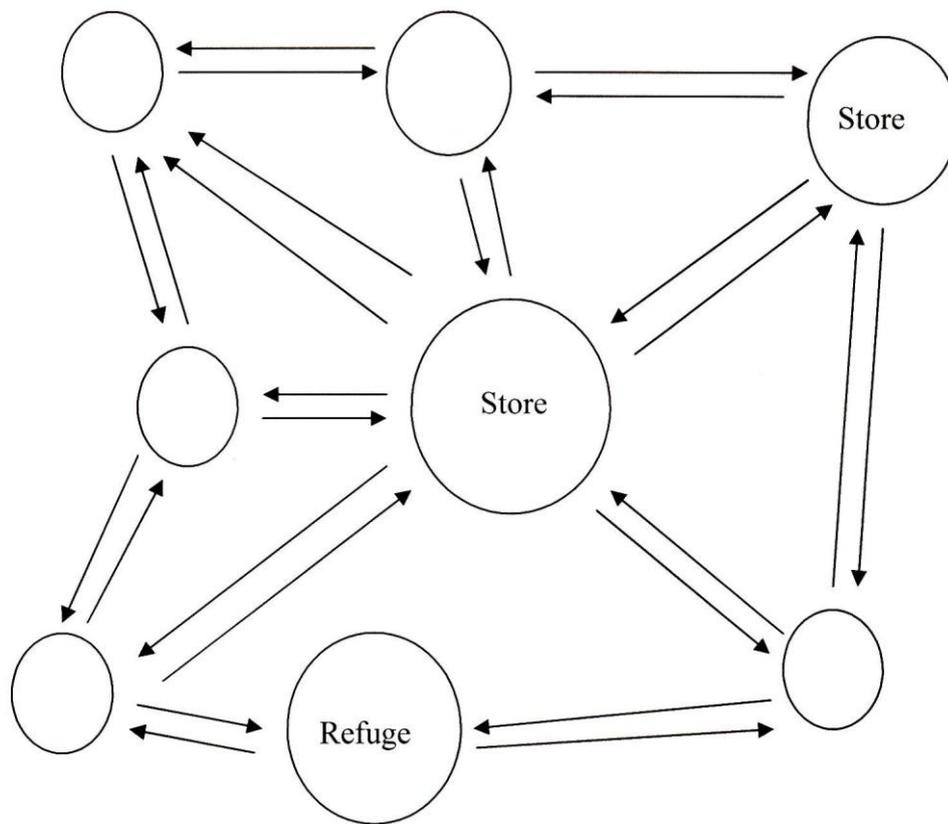


Figure 1.3. The metapopulation structure. The arrows indicate the movement of rats between small populations and sources of food (after (Smith, 1994))

If man interferes with these dynamics, for example by applying rodenticide in an uncoordinated manner by only placing bait in one area (i.e. the farmyard) then there will be a vacuum created in that particular area which will allow other rats to move in, assuming no other treatment, i.e. hygiene measures such as clearing overgrown areas and removing old machinery are carried out. Coordinating the rodenticide treatment across several or all of the rat populations should have a more lasting effect as there will be fewer rats to repopulate the area. Those areas in the middle of the treated area should benefit most as it will take more time for rats to move into them.

These separated populations within a particular area where there is movement between the different groups, comprise what is now termed a metapopulation, a larger population comprised of several smaller populations. This then begs the question of

how big is a metapopulation. Rats are not confined by boundaries and so each individual population will have contact with several other populations in the vicinity. If a circle is drawn around an area then all the individual rat populations within that area may be considered as a single metapopulation, however, those populations on the outside of the circle will not have contact with all those populations within the circle and some of their contacts will with populations outside the circle. This logically can be extended to the boundaries of any land mass and so all the rats within that land mass could be considered as part of one very large metapopulation. In reality this is not very sensible and so metapopulations are more logically thought of as comprising those populations within any given area that are sufficiently close to each other that there can be contact between the different groups.

This is in contrast to a patchy environment where populations are defined by the environmental suitability of the habitat. If the habitat is suitable over a wide area then the population will be spread across the whole area, and there may be several such populations within any given area but separated by areas that are unsuitable or form a barrier. Under these circumstances there is no contact between the different populations and they are described as living in a patchy environment. Extinction of any one of these patchy populations is just that, as there is no movement between them and therefore there will be no recolonisation. This is in contrast to a metapopulation where there may be an extinction of any given population within it but there will be a recolonisation of that habitat because of the continuous movement of rats between the different smaller populations that make it up.

## 1.10. AIMS OF THE PROJECT

This research project had one aim and four specific objectives:

The aim was to develop ecologically-based management strategies that will reduce the reliance on rodenticides. The purpose of this is to overcome concerns about humaneness and the adverse effects on wildlife.

The four specific objectives were:

- a. To investigate whether or not rats from areas of known rodenticide resistance carry a higher rodenticide load than those from areas where there is no known rodenticide resistance (Chapter 2).
- b. To investigate whether rats migrate into farmyards in the winter time, as is commonly supposed, in order to test whether trapping during migration can be used as the basis of ecologically-based rat management (Chapter 3).
- c. To investigate whether or not it is better to coordinate rodent control over a large area (up to 400 ha or 1000 acres), rather than the existing system where rodent control is conducted only in or around the farmyard (<1 ha), without coordination (Chapter 4).
- d. To investigate whether it is possible to set up a trapping system similar to the trap barrier system used in the Far East and whether or not this can have an effect on rat numbers around farm buildings (Chapter 5).

## CHAPTER 2. ANTICOAGULANT RODENTICIDE LOADS IN RATS AND THE RISK OF SECONDARY POISONING

### 2.1 INTRODUCTION

The length of the half-lives in livers of second-generation anticoagulant rodenticides (Table 1.1), show that they represent a substantial hazard of secondary poisoning to predators and scavengers. A rat that has been subject to a baiting episode and has consumed poisoned bait will have the poison in its gut or its tissue or both and so anything that predares or scavenges on it will consume rodenticide.

In order to be able to assess the risk of secondary poisoning to predators and scavengers it is necessary to quantify the amount of anticoagulant rodenticide that is carried by rats following a poisoning episode. Rats are a food source for many predators and scavengers, and alterations in the behaviour of rats caused by anticoagulant rodenticides may make them more susceptible to predators, which in turn may face an incremental risk of secondary poisoning (Cox & Smith, 1992).

All the anticoagulant rodenticides work in the same way, by blocking the vitamin K cycle in the liver. Different rodenticides contain compounds that differ in their persistence and their level of binding affinity. Field trials with brodifacoum showed that anticoagulant concentrations in rabbit tissue were highest in the liver, less in muscle and least in fatty tissue (Rammel *et al.*, 1984). Huckle *et al.*, (1988) conducted experiments to examine the retention and elimination of a single dose of flocoumafen and found that the half-life of flocoumafen in rats was 222 days in the liver (the lengths of the half-lives of other rodenticides are summarised in Table 1 of Chapter 1). Huckle *et al.*, (1998) also carried out experiments to determine the relationship between metabolism and the toxicity of flocoumafen. The major route of elimination of flocoumafen was via the faeces, which for animals receiving the lower level of dose ( $0.02 \text{ mg kg}^{-1} \text{ week}^{-1}$ ) was a mean of 28% of a single dose, approximately

half of which was eliminated in the 24 hours after exposure. In animals receiving a higher dose ( $0.1 \text{ mg kg}^{-1} \text{ week}^{-1}$ ), elimination via the faeces during the first four weeks rose from 18% to 42% of a single dose and reached a peak of 63.5% after 10 weeks following exposure. During the experiment it was apparent that elimination on the second and third day increased relative to the first day, suggesting that the flocoumafen was being metabolised and that detoxification mechanisms were perhaps induced by the toxins. As the result of the analysis of the various body tissues, Huckle *et al.*, (1989) showed that the flocoumafen was stored in tissue in the rank order liver > kidney > skin > muscle > fat > blood, regardless of the level of dose received. After six weeks of dosing, the concentration of rodenticide found in the livers was more than five times that found in the kidneys. After 10 weeks of dosing and then a 222 day recovery period the amount in the livers was more than seven times that stored in the kidneys. The level of flocoumafen increased in all body tissues except for the liver, during the period of the experiment. They found that at the higher level of dose the concentration in the liver increased during weeks one to four but not between weeks four and six. This result showed that the binding sites became saturated prior to the onset of anticoagulant toxicity, which was observed six weeks after the start of the study.

## 2.2 SOURCE OF VARIATION IN TOXICITY: DIFENACOUM IN RATS

Difenacoum is the agreed name for 3-(3-biphenyl-4-yl-1,2,3,4-tetrahydro-1-naphthyl)-4-hydroxy-coumarin ( $C_{31}H_{24}O_3$ ) (Figure 2.1 – Bromadiolone has been included for comparison of chemical structure) and was the first of a series of compounds, synthesised in 1975, to be developed commercially (Buckle, 1994; Hadler & Shadbolt, 1975). Studies on difenacoum reveal two main sources of variation in  $LD_{50}$ , sex and population. Both these sources affect not only the efficacy of a compound in different situations but also the risk to predators and scavengers of rats.

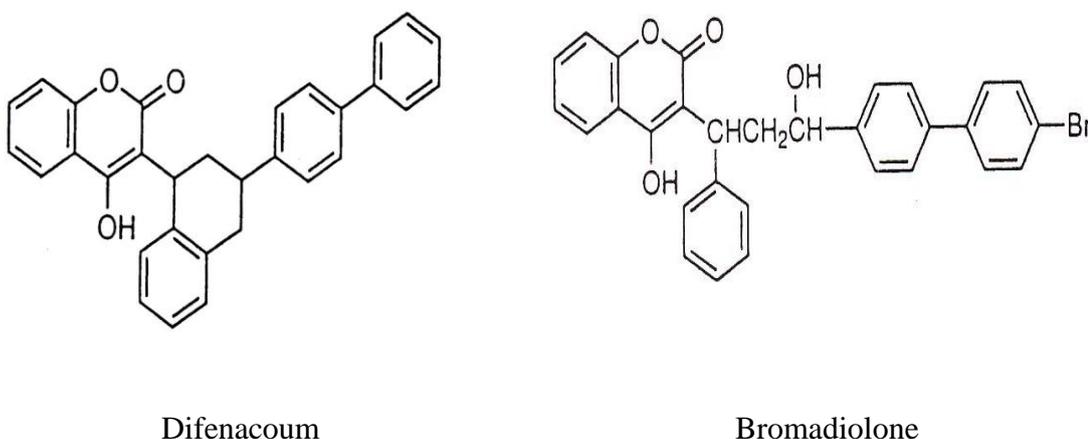


Figure 2.1 The chemical structures of difenacoum (WHO, 1995) and bromadiolone (WHO, 1996)

In 2000 difenacoum was the most widely used rodenticide on arable farms in the UK. It was estimated to be used on 44% of farms and estimated to account for 34.6% (by weight) of all the rat bait applied (Dawson *et al.*, 2001). This compares with 48% of farms and 39.5% of all bait applied in 1998 although the amount of bait applied was less than in 2000 (Banks & Garthwaite, 2001). In 1996 the figures were 44% of farms and 46.9% of all bait applied and again the estimated total amount of bait applied was less than applied in 1998 (De'Ath *et al.*, 1999). By comparison with farms, difenacoum was used on 27% of game estates that responded to a survey in 1998 (McDonald & Harris, 2000).

The acute oral LD<sub>50</sub> for difenacoum for rats has been established as 1.8 mg kg<sup>-1</sup> (WHO, 1995). This would appear to be for rats that show no resistance to rodenticides because other research has found different LD<sub>50</sub> levels in rats where there is known rodenticide resistance. Buckle, (1993) gives 1.8 mg kg<sup>-1</sup> for non-resistant rats and 3.4 mg kg<sup>-1</sup> for rats with resistance. Other researchers give a far greater range and provide figures for non-resistant rats (male 1.5 mg kg<sup>-1</sup> and female 3.4 mg kg<sup>-1</sup>) and also for rats from different areas of known resistance. These range from Welsh male rats with an LD<sub>50</sub> of 1.9 mg kg<sup>-1</sup> through to female rats from Hampshire with an LD<sub>50</sub> of 14.0 mg kg<sup>-1</sup> (Greaves & Cullen-Ayres, 1988). Using only the four difenacoum resistant wild rats from Hampshire (one male and three female) and their difenacoum resistant F2 descendants and back-crosses Greaves and Ayres-Cullen, (1988) established a closed colony and from this stock produced female animals that showed even greater resistance to the rodenticide (LD<sub>50</sub> 29.3 mg kg<sup>-1</sup>), although the males from this stock showed a lower tolerance (LD<sub>50</sub> 5.5 mg kg<sup>-1</sup>) when compared to the original four wild captured animals. From the work by Greaves and Ayres-Cullen, (1988) it is interesting to note that in all cases, from those rats that show no resistance, through the Welsh, Scottish and Hampshire populations where there is known resistance to second generation rodenticides, the males have a lower LD<sub>50</sub> to difenacoum than the females. The mechanism underlying this sex-specific variation is not known.

## 2.3 AIMS AND OBJECTIVES

The specific aim of this chapter was to investigate whether or not rats from areas of known resistance carry a higher rodenticide load than those from areas where there is no known resistance. From this specific aim come two further objectives:

- a. To test the extent to which, as the result of primary poisoning, the rodenticide load carried by rats represents a hazard to predators and scavengers through secondary poisoning.
- b. To test whether rats from areas where there is known rodenticide resistance present a greater threat (higher residues) than those from areas of no known resistance

Thus two predictions were tested:

1. Rats poisoned with anticoagulant rodenticide present a threat of secondary poisoning to predators and scavengers.
2. Rats from areas of known rodenticide resistance present a greater threat of secondary poisoning than rats from areas of no known anticoagulant resistance, because resistant rats accumulate higher levels of toxin.

These predictions were to be tested using two sources of material:

1. Contemporary material collected in Yorkshire and Leicestershire.
2. Historical samples collected in Berkshire and Leicestershire by MacVicker (1998). The aim being to extend the small number of samples (10) analysed for coumatetralyl by MacVicker (1998).

## 2.4 MATERIALS AND METHODS

### 2.4.1 Collection and preparation of rat carcasses.

Carcasses were obtained either as the result of trapping, using Fenn Mk 3 traps (Killgerm) or were picked up following a poisoning campaign, where it was assumed that they had died as the result of the poison. Of the 71 carcasses used here, 35 had been found dead and 36 were the result of trapping. The rats from East Yorkshire (formerly Humberside) were collected during a trial to rid a pig farm of rats where the farmer had tried for some long time to clear his land of rats using normal commercial baits. The rats were present in such large numbers that they were to be seen around the farm buildings at all hours of the day and were causing extensive damage to the buildings (M. Lambert. Pers. Comm.). Staff of the Central Science Laboratory (CSL) at York were asked to help and formulated their own bait using pinhead oatmeal, sugar, corn oil and bromadiolone or calciferol; it did not contain Bitrex, a bittering agent, or colouring. Live rats were caught and tested for rodenticide resistance, by the staff at CSL, specifically for resistance to warfarin, bromadiolone or difenacoum using blood clotting response (BCR) tests (Gill *et al.*, 1993, 1994; MacNicoll & Gill, 1993). Briefly, the resting blood clotting time and percentage clotting activity (PCA) were established for each animal (at day 0) before administration of a sub-lethal dose of rodenticide by oral gavage. Subsequent blood samples were then taken to determine PCA in relation to day 0, and animals were classified as susceptible or resistant in accordance with the published guidelines. The 10 rats from Leicestershire that were used for comparison came from Farm B (see Site descriptions in Chapter 4), an area of no known resistance. They were collected during the final census period in 4 – 6 January 2006 following the last baiting session that was conducted over the period 28 November – 16 December 2005. The rats that are discussed under the heading

“Historical samples collected in Berkshire and Leicestershire” (Section 2.6.1) came from the farms used by MacVicker (1998) (see pages 39 – 46), A1 – A9 were from the East Midlands where there is no known resistance and B1 – B9 came from Berkshire where there is known rodenticide resistance to both bromadiolone and difenacoum.

After collection carcasses were frozen at  $-20^{\circ}\text{C}$  until required. They were then partially thawed, the tail and feet were cut off and the body weighed. The tail and feet were removed as they do not mince easily and it was assumed that the rodenticide would not have accumulated significantly in these parts of the body. The liver was removed, weighed (fresh mass) and stored in a labelled Sterilin screw-topped container. The body cavity contents (lungs, heart, stomach, intestines, reproductive organs, bladder and urinary duct) were also removed and disposed of so that any rodenticide remaining within the gut would not be included in the analysis. The carcass was then reweighed and refrozen. Carcasses were partially thawed for about 20 – 30 minutes and cut into small pieces prior to mincing. Initially the carcasses were cut into pieces with a meat cleaver. This method was found to be labour intensive as the skin and hair of the rat have very strong mechanical properties and the cleaver needed to be sharpened after every 4 or 5 rats. The feet and tail had been removed using a pair of kitchen scissors that are designed to cut bone and these scissors were then used to cut the carcasses into pieces. This was found to be much more effective and considerably quicker than using the cleaver. The pieces from each rat were kept together in a labelled plastic bag prior to mincing.

The rat pieces were minced using a domestic hand mincer as this had been found to be the most effective method of homogenising the carcass (MacVicker, 1998). The resulting mince was then fed through the mincer a second time to ensure that the sample was fully homogenised and stored in a clean, labelled plastic bag at  $-20^{\circ}\text{C}$

before rodenticide extraction. To prevent cross contamination among the rats, all equipment was thoroughly scrubbed, rinsed and dried between samples.

#### 2.4.2 Extraction and preparation of rodenticide residues

The method of rodenticide extraction and analysis used was that of (Jones, 1996), which was a variation of the original method of (Hunter, 1983).

Rodenticide was extracted from the liver and homogenised body material using a solvent extraction method. The method for extraction from both the liver and the whole body samples was identical. A one gram sample ( $\pm 0.01$  gm) was allowed to thaw at room temperature for 20 minutes. The sample was mixed in a stone mortar with 10 gm ( $\pm 0.01$  gm) of anhydrous sodium sulphate and ground with a pestle until it comprised a uniform, free-flowing powder. This step was to remove moisture and to provide the maximum surface area to be exposed to the chemical solvent extractant. The liver mixture formed the powder very easily but it was more difficult to produce the uniform powder with the whole body samples because of the hair and small pieces of skin in the sample. The powder was placed into a 100 ml screw-topped conical flask and left for 30 minutes. 15 ml of the extraction solvent, acetone in dichloromethane (30:70 v/v), were added to the flask and shaken for one hour on an oscillating platform (model: Gallenkamp Orbital Shaker) at 300 oscillations per minute to aid the extraction process. After shaking, the liquid, approximately 10 – 12 ml, was transferred into a 25 ml centrifuge tube and spun at  $3000 \text{ revs min}^{-1}$  for 10 minutes (Centrifuge model: MSE minor 'S'). The supernatant was poured into a 25 ml volumetric flask. A further 10 ml of extraction solvent was added to the conical flask and this was shaken for a further 30 minutes, again at  $300 \text{ oscillations min}^{-1}$ , to ensure full extraction of the rodenticide. The liquid was again poured off into a centrifuge tube and spun at  $3000 \text{ revs min}^{-1}$  for

10 minutes, the supernatant being added to the 25 ml volumetric flask. The supernatant in the flask was made up to 25 ml with extraction solvent and placed into a screw-topped universal and sealed with laboratory sealing film (Whatman). This extraction process not only removes the rodenticide, but also other unwanted material such as fatty acids and lipids. Therefore samples had to be cleaned up to remove all the unwanted material, leaving only the rodenticide for analysis. The clean-up process was carried out using disposable neutral alumina Sep-Pak cartridges (Waters). This extraction process separates the analyte (rodenticide) from the other material. The cartridge was conditioned with 10 ml of dichloromethane using a 10 ml glass syringe, passing the fluid through in one minute. 10 ml of the sample extract was passed through the cartridge at the rate of 3 – 5 ml min<sup>-1</sup>. The cartridge was washed with 10 ml of the original extraction solvent and 2 ml of acetone:dichloromethane (75:25 v/v). The rodenticide was washed out with 5 ml of a 5% solution of acetic acid in methanol into a 7 ml screw-topped glass vial. This screw-topped glass vial was placed in a water bath at 70 - 80° C for up to an hour to evaporate the contents to dryness. The resulting crystals were then redissolved using 0.5 ml of methanol, the lid was screwed on and sealed with laboratory film (Whatman). The sample of rodenticide extract was then stored in a fridge at 4° C before high performance liquid chromatography (HPLC) analysis. Rodenticide extraction on all the 71 samples was completed in nine days.

All the solvents were of HPLC grade, the dichloromethane was supplied initially by Sigma Aldridge, Gillingham and subsequently by Fisher Chemicals, Loughborough who supplied all the other solvents. The anhydrous sodium sulphate was formulated for pesticide residue analysis and supplied by Fisher Chemicals, Loughborough. The Alumina N Sep-Pak cartridges (1850 mg) were supplied by Water Ltd, Watford.

### 2.4.3 HPLC theory

HPLC is a system that allows a sample to be separated into individual components and for those components to be identified and, given a standard, for them to be quantified. HPLC uses a coupled detection system and works by putting the sample through a narrow column containing a microparticulate, the stationary phase, in a solvent medium under high pressure (up to 5000 psi), the mobile phase. The sample is injected into the flow of solvent immediately prior to the mixture entering the column. Each analyte in a sample has its own specific polarity and it is this polarity that allows the analytes to be separated. The polarity of an analyte determines its interaction between the stationary and mobile phases and also the amount of time that it stays in the column. The separation of the components can be improved by changing the polarity in the mobile phase along the solvent gradient. Each analyte has its own specific time that it will stay in the column, the retention time, and is then identified and the amount quantified using direct fluorescence detection measured against the standard. This works by the detector responding to the presence of an analyte and producing an electric signal, which relates to the quantity of the analyte present (Kealey & Haines, 2002).

The system is calibrated by passing through it known concentrations of known analytes in solution, in this case rodenticides. This allows the retention times to be determined and to measure the strength of the signal produced. These together identify the analyte and its strength.

Sample chromatograms of liver and whole body samples and mixed rodenticide standard from the analysis carried out by CSL are shown at Figures 2.2, 2.3 and 2.4.

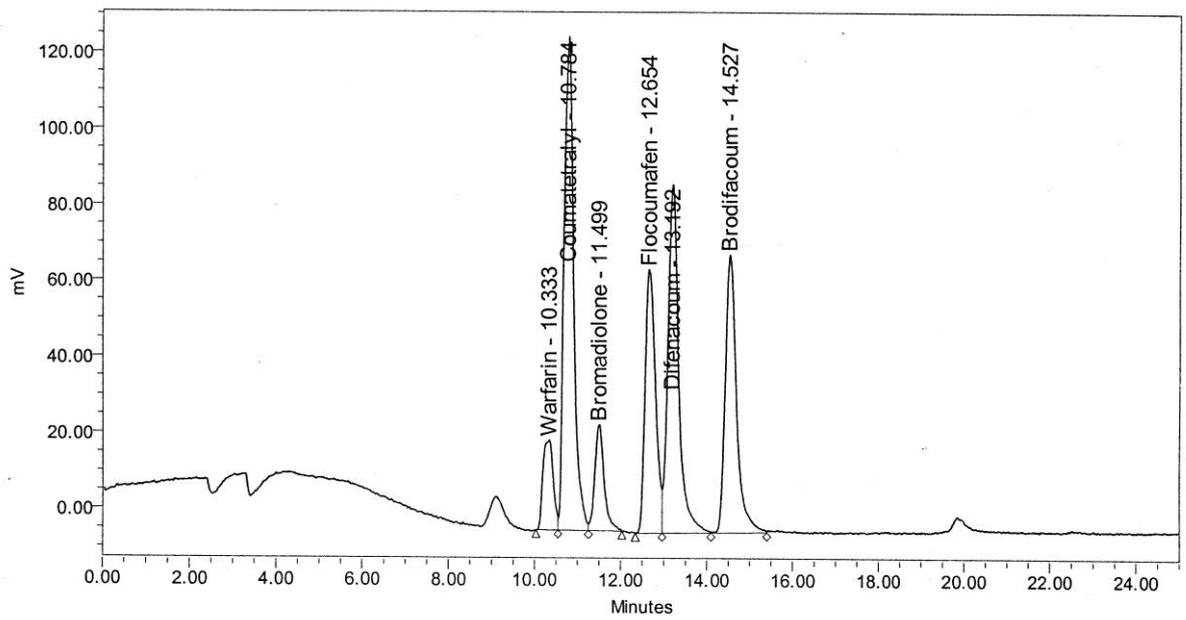


Figure 2.2. Chromatogram of a mixed rodenticide standard

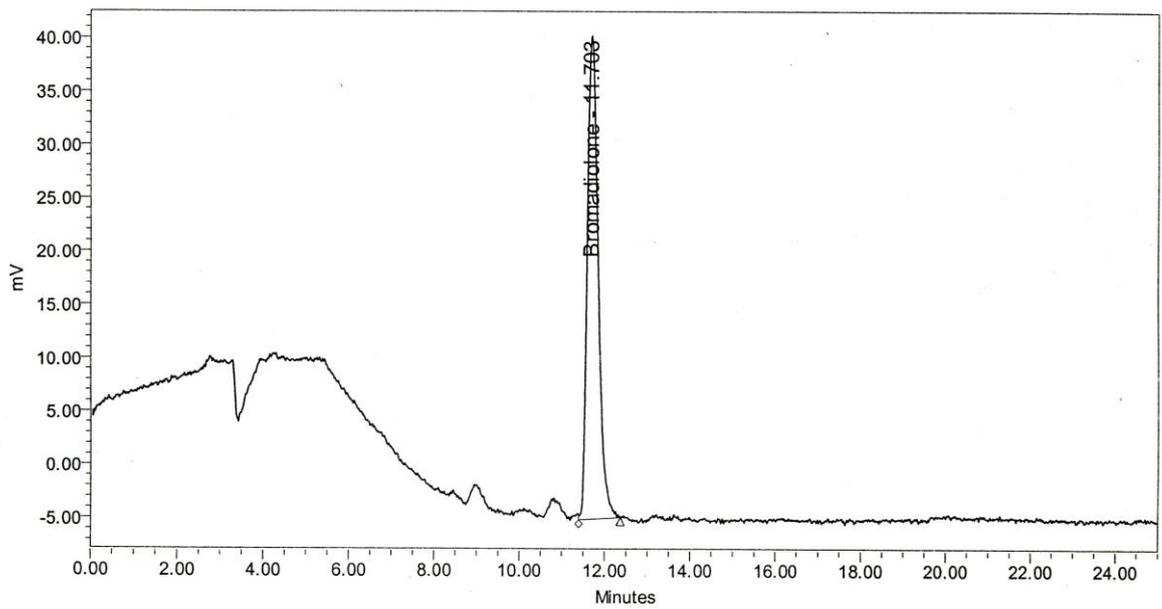


Figure 2.3. Chromatogram of bromadiolone from a liver sample

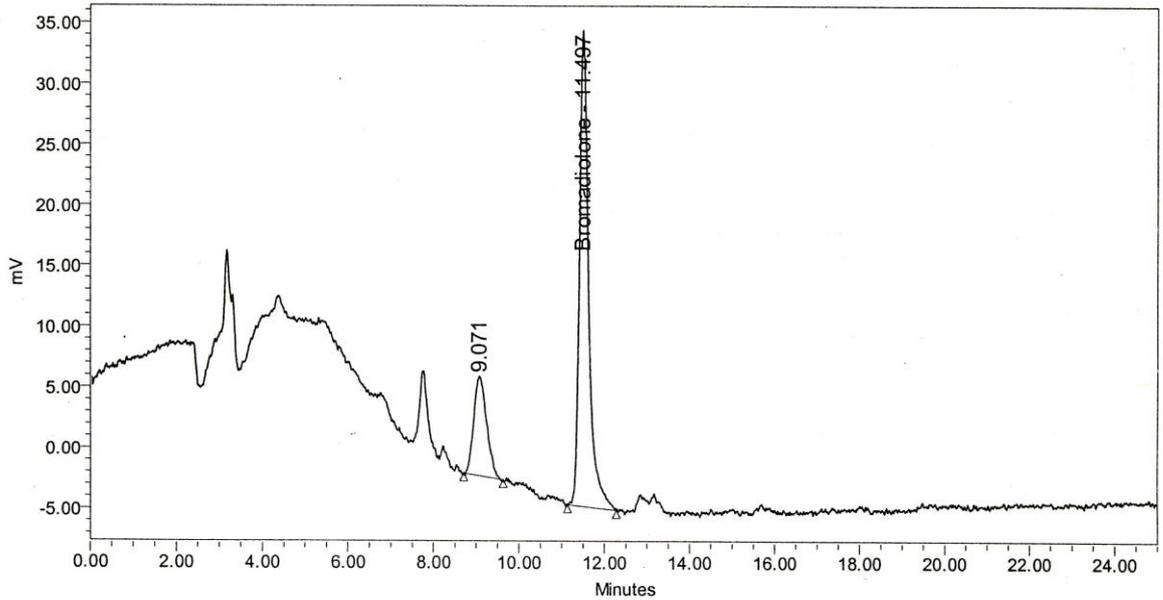


Figure 2.4 Chromatogram of bromadiolone from a whole body sample

Figure 2.2 shows the retention times and peaks for the six rodenticide standards, two first generation rodenticides warfarin (10.333 mins) and coumatetralyl (10.785 mins) and the four second generation rodenticides, Bromadiolone (11.499 mins), Flocoumafen (12.654 mins), Difenacoum (13.192 mins) and Brodifacoum (14.527 mins). Figures 2.3 and 2.4 show the peaks and retention times for a sample of liver and a sample of whole body tissue. It can be seen from these two chromatographs that the peaks are of different heights indicating that these two samples contained different levels of rodenticide.

#### 2.4.4 Analysis of rodenticide residues using HPLC

The Central Science Laboratory (CSL) at Sand Hutton, York runs the national Wildlife Incident Investigation Scheme (WIIS) where all the suspected cases of wildlife poisonings by pesticides are investigated. The Pesticides and Veterinary Medicines Department there conducts the analysis of animal tissue for anticoagulant rodenticide content on a routine basis. Analysis of all the samples extracted and used for

comparison in the present study was carried out at CSL York under the standard operating procedure (SOP) “PGD/001: determination of anticoagulant rodenticide residues in samples”. A further set of samples was analysed at the Biocentre at the University of Leicester using the same SOP.

The HPLC system at CSL is fully automated and uses Waters equipment. It comprises an autosampler (model: Waters 717 Plus) and a fluorescence detector (model: Waters 474). The pumps for the mobile phases are Waters 515 and the pump for the PCR is a Waters 510. The system is managed by a personal computer running Waters Millennium software, which controls the autosampler, solvent pressure, flow rate and gradient and also measures the detector signals. In the Leicester Biocentre the system comprised of an autosampler (model: Varian Pro-Star 410) and fluorescence detector (model: Waters 470). The system was managed using Varian Pro-Star chromatography (Ver. 6.20) software. The conditions for measuring anticoagulant rodenticides using HPLC are shown in Table 2.1.

It was decided to use the laboratory at CSL to conduct the rodenticide analysis because they do this type of work on a day to day basis. They routinely prepare rodenticide standards against which to measure rodenticide loads and it is where all the animals that are suspected of being of being killed by poisons in England are sent to determine the cause of death. It was felt that they were best qualified to conduct the analysis if the samples prepared during this research.

Parameter	Conditions		
Column	Spherisorb ODS2, 5 $\mu$ m, 250 x 4.6 mm with guard column (reverse phase)		
Solvent A	0.25 % (v/v) acetic acid in water		
Solvent B	0.25 % (v/v) acetic acid in methanol		
Flow rate	0.8 ml min <sup>-1</sup>		
Gradient	Time (min)	%A	%B
	0	75	25
	5	5	95
	20	0	100
	21	75	25
	25	75	25
Post-column reagent	6 % (v/v) ammonia solution		
Flow Rate	0.6 ml min <sup>-1</sup>		
Detector:	Excitation wavelength	310 nm	
	Emission wavelength	390 nm	

Table 2.1. HPLC parameters for the analysis of tissue extracts

## 2.5 DATA ANALYSIS

All data were tested for homogeneity of variance with a Bartlett test and for normality using a Kolmogorov-Smirnov test. In the experiment examining the difference between rodenticide resistant and non-resistant areas, a Mann-Whitney Test was carried out. In the two experiments where the differences between 1998 and 2006 analysis results were examined, a one-sample Wilcoxon test was used.

## 2.6 RESULTS

In total 66 rats were analysed for rodenticide. These were split into three groups.

### 2.6.1 Historical samples collected in Berkshire and Leicestershire

In Helen MacVicker's (1998) study, a non-metabolisable bait marker (hexachlorobiphenyl (HCBP)) was incorporated into the poison bait and analysis of this was used to calculate the total consumption of poison bait by individual rats. The method of bait marker analysis used was based on an unpublished method supplied by MAFF, Central Science Laboratory. The bait marker (HCBP) was extracted from the prepared sample of minced rat using a soxhlet condenser and gas chromatography with mass spectrometry was used to measure the amounts of HCBP in each sample. The full explanation of her extraction method and measurement of the HCBP can be found in MacVicker (1998), sections 4.2.ii and 4.2.iii (pages 141 – 145). In total she carried out analysis on 156 animals by this method. In addition, 10 of these 156 animals were

selected for rodenticide analysis using identical methods as described in Section 2.4 in this chapter.

For all the animals selected for reanalysis it was only possible to obtain results for the whole body as the liver had not been retained separately. From these 156 animals originally analysed by her, 36 were randomly selected (Minitab – Calculations – Random Data – Sample from columns) for reanalysis to be able to make a comparison between Berkshire (an area of known rodenticide resistance) and Leicestershire (an area of no known rodenticide resistance) for rodenticide load. The results for rodenticide residues were compared with the results for rodenticide load calculated by her using bait-marker analysis. A highly significant difference in rodenticide load was found (Wilcoxon  $W = 548$ , d.f. = 35,  $p < 0.001$ ). Based on her results, an eight-fold difference would have been expected (12% of rodenticide consumed absorbed into tissue). The complete set of data for these samples is in Table 2.2. A histogram of the mean rodenticide loads is at Figure 2.5.

Ref No	Location	Species (Rat/Mouse)	Trapped / Found dead	Rodenticide (Coumatetralyl / Brodifacoum)	Gross Weight (gm)	Net Weight (gm)	Whole body load (mg/kg) MacVicker	Whole body load (µg/ml) Leicester
17	Berkshire	R	T	Coumatetralyl	78	66	67.47	0
19	Berkshire	R	T	Coumatetralyl	194	165	51.12	0
20	Berkshire	R	D	Brodifacoum	44	37	88.9	0.19
21	Berkshire	R	T	Coumatetralyl	120	102	15.5	2.63
31	Berkshire	R	T	Coumatetralyl	74	63	60.12	0.07
38	Berkshire	R	T	Coumatetralyl	70	60	22.84	0.45
53	Leics	R	FD	Coumatetralyl	80	68	0.2	0.51
59	Leics	R	FD	Brodifacoum	58	49	8.53	0
66	Leics	R	FD	Brodifacoum	112	95	17.87	0.11
79	Berkshire	R	FD	Brodifacoum	80	68	0	0
80	Berkshire	R	FD	Brodifacoum	108	92	15.7	0
82	Leics	R	T	Coumatetralyl	80	68	102.25	0
84	Berkshire	R	T	Coumatetralyl	38	32	27.43	0.37
85	Berkshire	R	FD	Brodifacoum	32	27	48.23	0.01
89	Berkshire	R	FD	Brodifacoum	82	70	22.3	0
103	Leics	R	T	Coumatetralyl	84	71	14.1	2.94
104	Leics	R	FD	Brodifacoum	140	119	10.98	0
111	Leics	R	T	Coumatetralyl	472	401	39.05	0
112	Berkshire	R	FD	Brodifacoum	146	124	0.24	0
126	Berkshire	R	T	Coumatetralyl	386	328	13.33	0
127	Berkshire	R	T	Coumatetralyl	32	27	45.95	0.09
129	Leics	R	FD	Brodifacoum	308	262	0.1	0
131	Leics	R	FD	Brodifacoum	17	14	36.98	0
137	Berkshire	M	T	Coumatetralyl	18	15	0.9	0.06
138	Berkshire	M	T	Coumatetralyl	20	17	63.63	0
143	Berkshire	M	T	Coumatetralyl	13	11	0	0
144	Berkshire	M	T	Coumatetralyl	19	16	122.02	0
145	Leics	M	T	Coumatetralyl	16	14	23.58	0
147	Leics	M	FD	Coumatetralyl	12	10	0	2.52
148	Berkshire	M	T	Coumatetralyl	17	14	26.12	0
150	Leics	M	FD	Coumatetralyl	16	14	4.19	0.43
152	Leics	M	FD	Brodifacoum	18	15	29.26	0
157	Berkshire	M	T	Coumatetralyl	19	16	0	0
158	Leics	M	FD	Coumatetralyl	18	15	0	0.8
205	Leics	R	FD	Brodifacoum	100	85	15.78	0.01
209	Leics	R	FD	Brodifacoum	138	117	3.27	0
Berkshire mean				Brodifacoum	82	69.7	29.2	0.0333
Berkshire Standard Error				Brodifacoum	17	14.5	14	0.0314
Berkshire mean				Coumatetralyl	78.4	66.6	36.89	0.262
Berkshire Standard Error				Coumatetralyl	27.3	23.2	9.12	0.186
Leicestershire Mean				Brodifacoum	111.4	94.5	15.35	0.015
Leicestershire Standard Error				Brodifacoum	32.9	28.1	4.46	0.0136
Leicestershire Mean				Coumatetralyl	97.3	82.6	22.9	0.9
Leicestershire Standard Error				Coumatetralyl	54.8	46.5	12.4	0.414

Table 2.2. Data from a sample of 36 rat carcasses collected 10 years previously and analysed 10 years apart using two different methods.

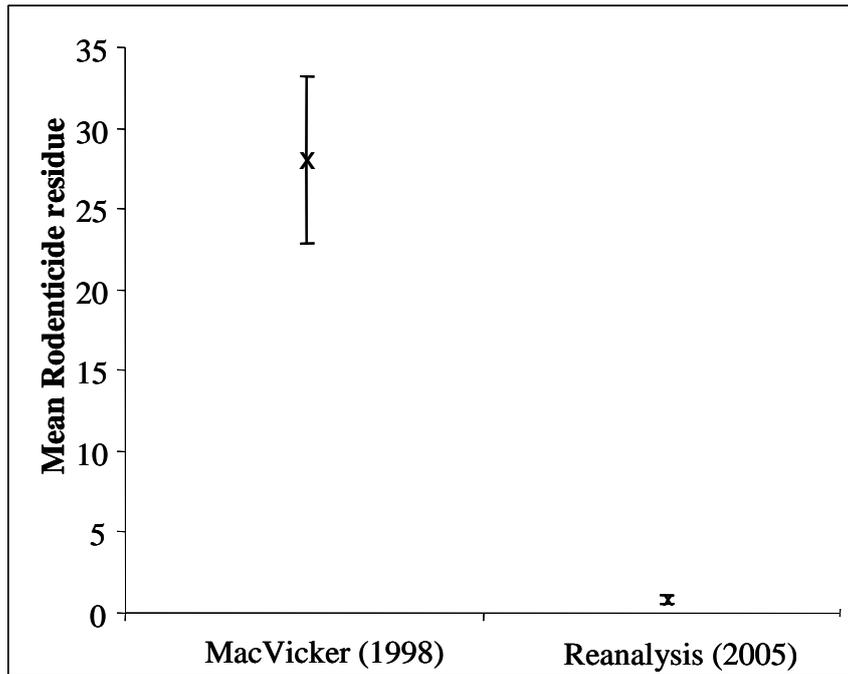


Figure 2.5 Comparison of the mean rodenticide loads from 36 carcasses collected 10 years ago.

Because of the unexpectedly large difference, it was decided to reanalyse the 10 samples that she has analysed differently and to have the analysis carried out at CSL as they do this type of work routinely. The analysis showed that there was a significant difference in the rodenticide load in the same samples when done 8 – 10 years apart (Wilcoxon  $W = 55$ , d.f. = 19,  $p < 0.05$ ). The results from the three different analyses are shown in Table 2.3a. There was also a very poor correlation between analyses carried out in the different laboratories (Table 2.3b), whereas in Brakes (2003) the correlation between CSL and the Biocentre results was  $>0.9$ .

Ref No	Location	Trapped / Died	Rodenticide	Gross Weight (gm)	Net Weight (gm)	Whole body load (mg/kg) (MacVicker)	Whole body load (µg/ml) (Leicester)	Whole body load (µg/ml) (CSL)
12	Berks	T	Coumatetralyl	468	398	83.29	0.0488	0.0370
24	Berks	T	Coumatetralyl	196	167	106.67	0.0189	>0.5
28	Berks	T	Coumatetralyl	446	379	47.94	0.0	0.0230
47	Leics	FD	Coumatetralyl	256	218	17.40	0.0857	0.1670
55	Leics	FD	Coumatetralyl	138	117	17.77	0.0	0.4330
58	Leics	FD	Coumatetralyl	326	277	5.95	0.0245	0.0
63	Leics	FD	Coumatetralyl	368	313	4.55	0.0	0.0150
65	Leics	FD	Coumatetralyl	308	262	29.90	0.0	0.0
107	Berks	T	Coumatetralyl	166	141	61.51	0.0	0.0300
203	Berks	T	Coumatetralyl	430	366	51.50	0.1597	0.3130

Berkshire Means	341.2	290.2	70.2	0.0455	0.1806
Berkshire Standard Error	69.9	56.0	11.0	0.0299	0.0969
Leicestershire Mean	279.2	237.4	15.11	0.022	0.1230
Leicestershire Standard Error	39.6	33.7	4.62	0.0166	0.0837

Table 2.3a. The results of the reanalyses of 10 samples for rodenticide residues

	MacVicker (1998)	Biocentre Leicester	CSL
MacVicker (1998)		r = 0.096 p = 0.792	r = 0.362 p = 0.304
Biocentre Leicester			r = 0.266 p = 0.457
CSL			

Table 2.3b. Pearson correlation coefficient between whole body load determination at different times and at different laboratories

### 2.6.2. Contemporary carcass collection

The contemporary collection comprised 20 carcasses, 10 of which came from Yorkshire (an area of known rodenticide resistance) and 10 came from Leicestershire (an area of no known rodenticide resistance). All carcasses had been kept deep frozen before being prepared for analysis. With these 20 animals a comparison was carried out between the two areas, of the rodenticide loads in the livers and those in the whole bodies as defined above, excluding livers. The complete set of data for these samples is at Table 2.4. Plots of the differences in the mean rodenticide loads in the livers and whole bodies are at Figures 2.6 and 2.7.

	Location	Rodenticide recently used and analysed	Died / Trapped	Gross weight (gm)	Net weight (gm)	Liver weight (gm)	Rodenticide load – liver (µg ml-1)	Rodenticide load – WB (µg ml-1)
1	Yorks	Bromadiolone	T	203	148	9	0.223	0.125
2	Yorks	Bromadiolone	T	488	407	23	0.015	0.01
3	Yorks	Bromadiolone	FD	496	409	25	8.5	0.084
4	Yorks	Bromadiolone	FD	369	306	17	5.72	0.127
5	Yorks	Bromadiolone	FD	479	364	23	10.3	0.095
6	Yorks	Bromadiolone	FD	390	319	17	4.7	0.066
7	Yorks	Bromadiolone	FD	377	310	18	26.52	0.01
8	Yorks	Bromadiolone	FD	550	470	18	0.279	0.01
9	Yorks	Bromadiolone	FD	472	370	32	4.16	0.08
10	Yorks	Bromadiolone	FD	506	426	23	6.36	0.058
11	Leics	Difenacoum	T	422	323	21	0.01	0.01
12	Leics	Difenacoum	T	520	360	39	0.01	0.01
13	Leics	Difenacoum	T	273	210	8	0.01	0.01
14	Leics	Difenacoum	T	244	176	16	0.050*	0.01
15	Leics	Difenacoum	T	380	306	13	0.067	0.042
16	Leics	Difenacoum	FD	206	148	10	0.027	0.032
17	Leics	Difenacoum	T	333	252	18	0.01	0.01
18	Leics	Difenacoum	T	158	109	7	0.01	0.01
19	Leics	Difenacoum	T	495	302	30	0.01	0.01
20	Leics	Difenacoum	T	306	232	10	0.01	0.01
Yorkshire: Means				433	352.9	20.5	6.68	0.0665
Yorkshire: Standard Error				31.9	28.8	1.95	2.47	0.0142
Leicestershire: Means				334	241.8	17.2	0.0214	0.0154
Leicestershire: Standard Error				38.1	25.9	3.28	0.0065	0.0037

Gross Weight (mass): Entire animal

Net weight (mass): Less feet, tail & body cavity contents, including the liver

T: Trapped FD: Found dead

WB: Whole body - less feet, tail, body cavity contents and liver

\* interfering peak in chromatogram at the retention time of difenacoum therefore difficult to say whether difenacoum is present or not.

Limit of detection = 0.01 i.e. present at very low levels

Table 2.4. Data for contemporary carcasses analysed for rodenticide body load at the Central Science Laboratory

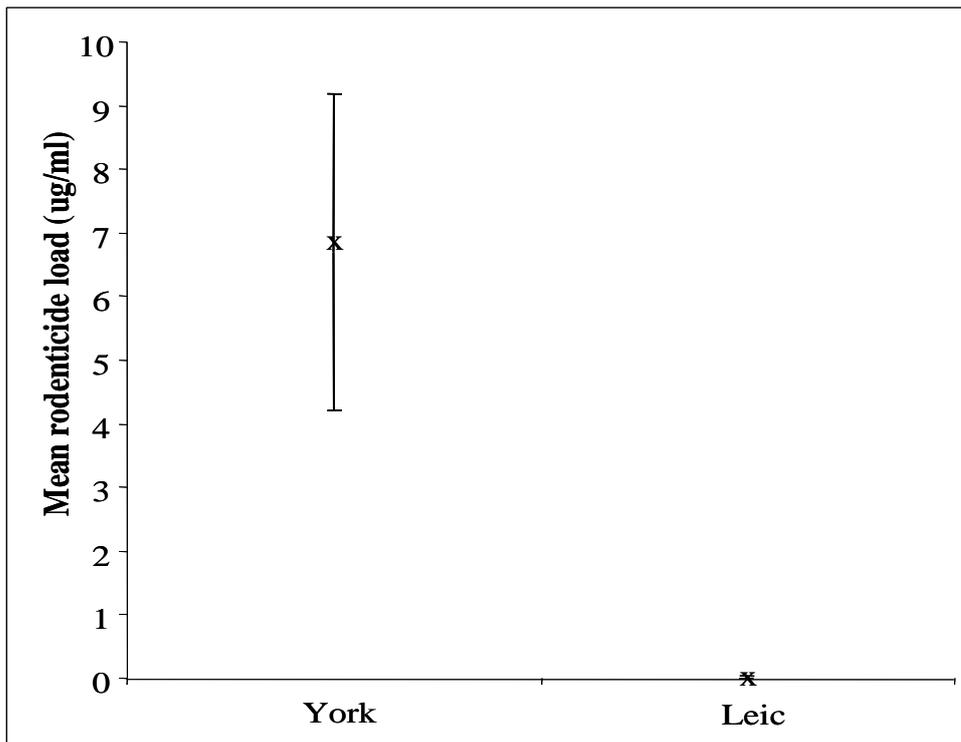


Figure 2.6 Comparison of the mean liver rodenticide loads in samples of 10 rats from Yorkshire (bromadiolone) and Leicestershire (difenacoum).

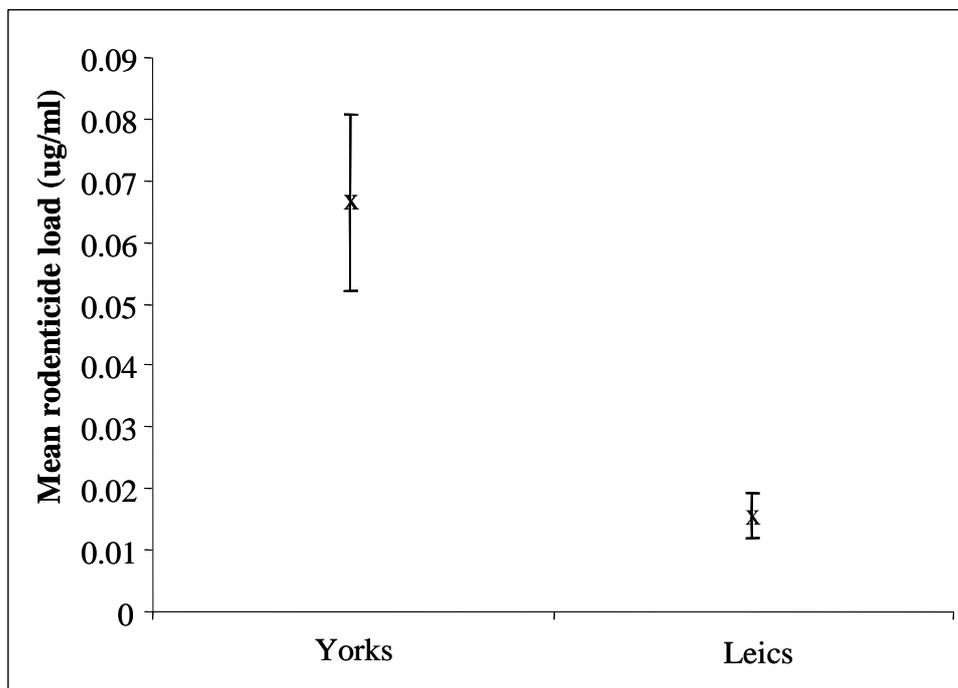


Figure 2.7 Comparison of the mean whole body rodenticide loads on rats collected in Yorkshire and Leicestershire (The Mann Whitney U test was used, the data was not normal.)

The results for the liver analysis showed that there was a significant difference in the mean rodenticide load carried by the rats from Yorkshire compared with the rats from Leicestershire (Mann-Whitney  $W = 152.0$ , d.f. = 18,  $p < 0.001$ ). The results for the whole body analysis also showed that there was a significant difference in the load carried by the rats from Yorkshire than that carried by the rats from Leicestershire (Mann-Whitney  $W = 149.0$ , d.f. = 18,  $p = 0.001$ ). The raw means ( $\pm$ s.e.) of the liver concentrations ( $\mu\text{g ml}^{-1}$ ) were  $6.68 (\pm 2.47)$  for Yorkshire and  $0.0214 (\pm 0.0065)$  for Leicestershire.

## 2.7 DISCUSSION.

The result from the analysis of rats taken from rodenticide resistant and non-resistant areas has major implication for predators and scavengers that range over the area where there is rodenticide resistance. This study has confirmed that rats in a rodenticide resistant area that have been subjected to a poisoning episode are able to carry a far greater rodenticide load than those rats in a non-resistant area (MacVicker 1998). The comparison here is complicated by the fact that the Yorkshire rat carcasses were collected during a rat control trial while the Leicestershire rats were collected after treatment was complete. Thus the residues in the Leicestershire rats, which were generally at the limit of detection, represent what is left in animals that had not consumed a lethal dose of poison. The Yorkshire rats were killed by the calciferol in the bait rather than the bromadiolone and were carrying substantial bromadiolone body loads. In terms of secondary poisoning this is significant as it puts predators and scavengers of rats at far greater risk of ingesting a lethal dose of rodenticide from rats in areas with resistance. Shore *et al.*, (2005(b)) put the potentially lethal dose of second generation anticoagulant rodenticides in predatory birds at  $>0.1 - .02 \mu\text{g g}^{-1}$  wet weight.

It has been thought for a long time that the second generation rodenticides were stable compounds, and the long half lives shown in Chapter 1 would tend to support this. However, the reanalysis of samples that have been in frozen storage for about 10 years would suggest that this theory does not hold for residues in dead rats stored for several years. These samples, both those that were analysed using identical methods and those where a comparison of different methods of analyses was carried out, produced very low residues. In both cases the difference in rodenticide found in the samples was statistically significant, with the reanalysis showing significantly lower levels of rodenticide than that found when the original analysis was carried out. This

particular result is relevant where samples are kept frozen for long periods of time before analysis is undertaken and may produce misleading results. Because the CSL and Biocentre analyses are not consistent, it is possible that breakdown products interfered with the analysis.

### 2.7.1 Risk Assessment

Assessing the risk of secondary poisoning to non-target species is not a precise science and is based on data determined using similar animals, such as quail (*Coturnix coturnix*) or other chemicals and then extrapolating those results to other animals such as the red kite (Brown *et al.*, 1996).

In order to be able to say whether or not the rodenticide loads that are carried by rats pose any sort of risk to other animals, a risk assessment needs to be carried out. In order to do this we need to know what are the lethal rodenticide loads for any animals that scavenge or predate on rats. Unfortunately this information is not readily available as scientists and researchers are quite rightly averse to feeding animals poisons, (unless they are specifically bred for just this purpose i.e. Wistar strain rats, and are required by law to provide LD<sub>50</sub>s for the target species). The raptors that predate or scavenge on rats do not exist in any great numbers and in a lot of cases are protected species under the terms of the Wildlife and Countryside Act 1981, and to use even captive bred animals for this purpose is not seen as ethical. A good example here is the Red kite (*M. milvus*) which has recently been reintroduced into this country and their numbers, although rising, are still at quite low levels, they scavenge carrion and are therefore particularly at risk of secondary poisoning. Buzzards (*B. buteo*) and peregrine falcons (*Falco peregrinus*) are other examples of raptors known to be at risk of poisoning; sometimes poisoning may be deliberate as they are seen by gamekeepers as a threat to

their game birds (Barnett *et al.*, 2005). The manufacturers of rodenticides do not conduct research to determine the LD<sub>50</sub> for animals other than the target species of their pesticides (J. Sampson, Sorex Ltd, Pers. Comm.). The only information available is through organisations such as the Central Science Laboratory (CSL) at York and the Scottish Agricultural Science Agency (SASA) in Edinburgh who conduct the analyses on animals, under the WIIS scheme, that are thought to have died from causes other than natural death. They do not have LD<sub>50</sub> values but are able to indicate levels of poisons that have killed these individual animals and have been able to provide the following information (Table 2.5) for the rodenticides difenacoum and bromadiolone (V. Jowett CSL York and E.Sharpe SASA Edinburgh, Pers. Comm.):

<b>Rodenticide</b>	<b>Species</b>	<b>Lethal Level (mg kg<sup>-1</sup>)</b>
Difenacoum	Red kite	0.292
Brodifacoum	Weasel	0.48

Table 2.5 Levels of rodenticides considered to be lethal found in a single non-target animal submitted to the WIIS scheme for analysis.

Red kites are essentially scavengers of carrion and only occasionally will they take live prey. Research has been conducted into the diet preferences of the Red kite (Ntampakis & Carter, 2005), and this showed that from a selection of carrion provided at a feeding station, (common rats of various sizes (large: 450 g, medium: 150 g and small: 50 g), house mice (*Mus domesticus*) (25 – 30 g), rabbits (*Oryctolagus cuniculus*) (1.2 – 2.0 kg) and birds ,mainly rooks (*Corvus frugilegus*) (25 – 300 g)), the preference was in the order medium rats, small rats, house mice, large rats, rabbits and finally crows. The medium and small rats and house mice were generally taken in flight. Only when the carcass was too large for them to pick up from the air would they land and break up the carcass into manageable pieces. They were reluctant to land and dismember carcasses when there were only a small number of birds about (Ntampakis

and Carter 2005). Ntampakis and Carter (2005) also placed rat carcasses close to farm buildings and these were taken mostly within a few hours of having been placed and almost always within two days. Red kites took all the carcasses taken in daylight and several of those left overnight were taken by foxes (*Vulpes vulpes*).

In the English Nature report on the reintroduction of the Red kite (Carter & Grice, 2002), analysis of the regurgitated pellets indicated that in the breeding season the lagomorphs, particularly rabbits, formed the largest part of the diet (16 – 64%) and brown rats represented 3 – 27% of the diet. Other vertebrate species found were field voles, sheep and deer, these latter two on only a few occasions and must have been taken as carrion. Game birds mostly pheasants, and pigeons were the most important bird species in the diet at this time and the remains of young corvids, especially rooks and crows were also found at nest sites. Outside the breeding season lagomorphs were again the main source of food, followed by brown rats and then small mammals such as wood mice and field voles. A total of 38 different mammal species were recorded as making up the diet of the Red kite in winter, indicating that it will scavenge or predate almost any carcass that is available. Carter and Grice (2002) indicated that the red kite was dependant on the activities of humans for a large part of its diet. Road kills would appear to form an important part of the diet as do carcasses left after pest control operations such as the shooting of rabbit and wood pigeon to protect crops and rodent control in and around farmyards

These differences between these two reports of the diet preference in the Red kite are likely to reflect differing availability of food. In the case of Ntampakis and Carter (2005), their research was carried out in the breeding season and they provided food at feeding stations and smaller prey are easier to carry away and for nestlings to eat. The Red kites in the area that their research was carried out in are used to being fed

at feeding stations as there are one or two farms that allow the public in to watch them being fed. Some of the local population also feed the red kites by putting food out in their back gardens. In both these cases the carrion provided is mostly poultry. Carter and Grice (2002) on the other hand were observing what happens in the wild and their conclusions were based on the analysis of the contents of the regurgitated pellets found in and around the nest or roosting site. The results therefore reflect the availability of food and it would seem to me to be the more likely diet.

Brakes, (2003), in his research of the feeding preference of red kites where he observed three wild bred and one captive bred kites, showed that when presented with a rat carcass the kites will open the carcass in the thoracic-abdominal region. The feeding preference was shown to be in the order small intestines > liver > and urinogenital organs. For a rat that has consumed rodenticide the intestines may still contain that rodenticide and it is known that the liver is the primary storage organ for the rodenticide once it is in the animal's system. Therefore, the observed method of feeding on rat carcasses means that the red kites are particularly vulnerable to secondary poisoning. We also know that poisoned rats in the main do not die above ground and are therefore not available to be scavenged by the kites. Red kites are at risk when they scavenge the odd rat that does die above ground or predate a poisoned rat that is suffering from sub-lethal anticoagulant toxicosis and has lost its thigmotactic behaviour and its fight or flight response as the result of the poison it has consumed. However, with both the weasel and the red kite requiring so few livers or whole bodies to provide a lethal dose of rodenticide both animals are at serious risk of secondary poisoning and death as a result if their main food source is rats. In the case of red kites, they range over a wide area in search of food and are therefore more likely to take a wider range of prey or carrion which will reduce, but not eliminate, the likelihood of receiving a lethal dose of

rodenticide. Weasels on the other hand are limited in the area in which they can forage (home range males 7 – 15 ha; females 1 – 4 ha) and are therefore at a greater risk if they are hunting in or around farms that conduct sustained rodent control and where the rats and other small rodents would be much easier to catch. They have a more limited range of prey with small rodent comprising between 60 – 80 % of their diet, with birds, eggs in season, rabbits and water vole making up the remainder (Macdonald & Barrett, 1993).

The results of the rodenticide analysis were provided in the form of  $\mu\text{g ml}^{-1}$  and needed to be converted into the same units ( $\text{mg kg}^{-1}$ ) as the results of the body analysis carried out by CSL and SASA. The formula used was provided by CSL (V. Jowett Pers. Comm.) and is given below:

$$\text{Mg kg}^{-1} = \frac{\text{the analysis result } (\mu\text{g ml}^{-1}) \times \text{final volume (0.5 ml)}}{\text{extracted volume taken (10 ml)} \times \frac{\text{total volume extracted (25 ml)}}{\text{weight of liver or whole body used (1g)}}$$

This resulted in the analysis results being multiplied by 1.25 to convert them to  $\text{mg kg}^{-1}$ . The calculations carried out are shown at Annex A. The results of the rodenticide loads in the whole bodies were very similar, Yorkshire (bromadiolone)  $0.083 \text{ mg kg}^{-1}$  and Leicestershire (difenacoum)  $0.046 \text{ mg kg}^{-1}$  but the liver loads showed no relationship, Yorkshire (bromadiolone)  $8.35 \text{ mg kg}^{-1}$  and Leicestershire (difenacoum)  $0.059 \text{ mg kg}^{-1}$ . As would be expected with the liver being the main storage site for rodenticides, the Yorkshire results are in line with expectation, the liver having 100 times the concentration of rodenticide than the rest of the body tissue. The two results from Leicestershire are even closer than the liver results from Yorkshire and Leicestershire, which is somewhat surprising and suggests that these animals had not recently

consumed much rodenticide, in this case difenacoum, because if they had they would most likely have died.

Only the results of the analyses from two animals (Nos 15 and 16 in Table 2.2) are used for the Leicestershire results because of the 10 animals analysed, seven livers and eight whole bodies produced results that were not detectable below 0.01245 mg kg<sup>-1</sup> and the tenth liver result had an interfering peak in the chromatogram at the retention time of difenacoum and it was therefore difficult to say whether difenacoum was present or not. The calculations for numbers of rats needed to be eaten to produce a lethal dose are shown in Table 2.6 and are broken down into whether the liver only, body tissue only or liver and body tissue is eaten.

	Liver only	Body tissue only	Whole body
Female weasel (bromadiolone)	1.5	8.6	1.3
Male weasel (bromadiolone)	2.8	16.1	2.4
Female red kite (difenacoum)	3539.8	230.8	216.2
Male red kite (difenacoum)	4070.8	265.4	248.6

Table 2.6. The numbers of livers, whole bodies or complete rats needed to be eaten by a weasel in Yorkshire and a red kite in Leicestershire in order to consume a lethal dose of rodenticide. (Note: These figures are extrapolated from the rodenticide loads found in the rats from Yorkshire and Leicestershire (Table 2.2) and the data provided by CSL and ESA on lethal levels found in predators (Table 2.5) and are for illustration purposes only. They are not to be considered definitive.)

The female weasel in Yorkshire is at far greater risk of secondary poisoning needing only to consume a maximum of 1.5 rat livers or whole bodies to receive a lethal dose of rodenticide. The male weasel needs only to consume a maximum of three livers or whole bodies to receive a lethal dose of rodenticide. If only body tissue is consumed then the female needs to eat nine rats and the male 17 rats. The red kite in

Leicestershire is at virtually no risk of secondary poisoning, with the female needing to consume the body tissue and livers of 217 rats. If only the livers are eaten then this number jumps dramatically to 3538. This would suggest that the steady state levels of difenacoum in rats that consumed only a little of the rodenticide bait would not be a problem to the kite. Red kites, as is known are scavengers, and will take any carrion that is available and therefore they are unlikely to consume this number of rats over a short period of time.

If it is assumed that bromadiolone and difenacoum have similar toxicity then the risk can be calculated to red kites in Yorkshire and weasels in Leicestershire. The figures are shown in Table 2.7.

	Liver only	Body tissue only	Body and liver
Female weasel (difenacoum)	371.1	24.2	22.7
Male weasel (difenacoum)	696.2	45.4	42.5
Female red kite (bromadiolone)	14.0	81.9	12.0
Male red kite (bromadiolone)	16.1	94.0	13.7

Table 2.7. The numbers of livers, whole bodies or complete rats needed to be eaten by a weasel in Leicestershire and a red kite in Yorkshire in order to consume a lethal dose of rodenticide. (Note: These figures are extrapolated from the rodenticide loads found in the rats from Yorkshire and Leicestershire (Table 2.2) and the data provided by CSL and ESA on lethal levels found in predators (Table 2.5) and are for illustration purposes only. They are not to be considered definitive.)

This shows a somewhat different picture, with the weasels needing to consume many more rats that had eaten difenacoum and the red kites needing to consume far fewer rats that had eaten bromadiolone. If the red kites eat rats as has been indicated (Brakes, 2003), then they are at far greater risk of secondary poisoning, a female kite needing only 14 and a male kite 16 livers to receive a lethal dose of rodenticide. Even fewer rats are necessary if they eat the body tissue as well.

If on the other hand published LD<sub>50</sub>s are used to conduct the risk assessment, the picture is somewhat different. Rat LD<sub>50</sub>s for bromadiolone and difenacoum are 1.125 mg kg<sup>-1</sup> (WHO, 1996) and 1.8 mg kg<sup>-1</sup> (WHO, 1995) respectively and using the liver weights from the analysis, gives rodenticide loads of 0.0231 mg for bromadiolone and 0.0207 mg for difenacoum. These figures were then used to calculate the number of livers needed to provide a lethal rodenticide dose they can then be compared with the data above, see Table 2. 8.

	Results from liver analysis		Results using published LD <sub>50</sub>	
	Bromadiolone	Difenacoum	Bromadiolone	Difenacoum
Female weasel	1.5	371.7	10.9	12.2
Male weasel	2.8	696.2	20.5	22.8
Female red kite	14.0	3539.8	104.1	115.9
Male red kite	16.1	4070.8	119.7	133.3

Table 2.8. Comparison of the numbers of rat livers required to produce a lethal dose of rodenticide in weasels and red kites using the data from the livers analysed and published LD<sub>50</sub> figures. (Note: These figures are extrapolated from the rodenticide loads found in the rats from Yorkshire and Leicestershire (Table 2.2) and the data provided by CSL and ESA on lethal levels found in predators (Table 2.5) and are for illustration purposes only. They are not to be considered definitive.)

This shows that, using the published LD<sub>50</sub> figures, these predators need to consume more livers of rats that have consumed bromadiolone, thus reducing the risk of secondary poisoning. However, the LD<sub>50</sub> results published by the WHO are for laboratory rats and not wild rats from areas where there is known to be rodenticide resistance. Therefore the wild rats that were analysed were probably able to carry a far greater bromadiolone rodenticide load because they were resistant to it and did not die until the calciferol was applied. The bromadiolone rodenticide load found in these rats from Yorkshire is 7.4 times greater than the published LD<sub>50</sub>. When considering difenacoum the results are reversed, far fewer rat livers are needed to provide a lethal

dose. For the weasel, using the LD<sub>50</sub> results, the numbers of rats required are broadly similar for both bromadiolone and difenacoum. For the red kite many more bromadiolone poisoned rats are required and considerably fewer difenacoum poisoned rats when compared to the numbers that resulted from the analysis conducted in this piece of research, but these are still quite large numbers of rat livers required.

## 2.8 CONCLUSIONS

The evidence presented here shows that the rats that were taken from the farm site in East Yorkshire carried a high level of bromadiolone rodenticide ( $8.35 \text{ mg kg}^{-1}$ ) in their livers when compared to both the results found in Leicestershire for difenacoum ( $0.059 \text{ mg kg}^{-1}$ ) and to the  $LD_{50}$ s published by the WHO (bromadiolone:  $1.125 \text{ mg kg}^{-1}$  and difenacoum:  $1.8 \text{ mg kg}^{-1}$ ). For bromadiolone the rodenticide load found here is 7.4 times that of the published  $LD_{50}$  and indicates a high level of resistance to the rodenticide. The level of difenacoum in the Leicestershire rats is very low and is only 3.2% of the  $LD_{50}$  for difenacoum indicating that these animals had not consumed much rodenticide at the last baiting session. For the raptors that may prey on poisoned rats from these areas these represent the opposite ends of a scale: the Leicestershire rats represent not threat to birds like the red kite, which would have to consume vast numbers of animals to take in a lethal dose, but more of a threat to the weasel. Neither animal is likely to eat only rats and the weasel will also predate other small rodents and ground nesting birds if it can, thus reducing the risk of secondary poisoning. The rats in Yorkshire do present a risk to predators, particularly the weasel as it only requires a maximum of two livers to provide a lethal dose for a female and 3 livers for a male weasel. If only the body tissue is consumed, then the picture is somewhat better, with a female needing to eat nine and a male 17 rats to take in a lethal dose. For the red kite the number of poisoned rat livers needed to ingest a lethal dose of rodenticide are 14 and 17 for the female and male respectively. Slightly smaller numbers are needed if body tissue is consumed in addition to the liver.

What was not expected were the very large differences in rodenticide load found in the rats that had been stored for about 10 years. It was presumed that the rodenticide

was stable and would not be degraded whilst in store but this small element of the research casts some doubt on this supposition.

## CHAPTER 3. THE MOVEMENT OF RATS IN AN AGRICULTURAL LANDSCAPE

### 3.1 INTRODUCTION

Several researchers report differences in the numbers of rats in farmyards during late autumn and winter compared with spring and summer (Brodie, 1981; Clark & Summers, 1980; Drummond & Rowe, 1960; Fenn & MacDonald, 1987; Hardy & Taylor, 1980; Harris *et al.*, 1995; Huson & Rennison, 1981; Middleton, 1954; Twigg, 1975; Villafane *et al.*, 2001). Neither Middleton, (1954) nor Drummond and Rowe, (1960) assessed the size of any of the populations that they were looking at but merely noted that, when surveys were carried out at different times of the year, the signs of rats in a particular location varied with the time of year. This suggests a population structure of the metapopulation type (Smith, 1999) with seasonal movements.

Drummond and Rowe, (1960) surveyed different types of crop, such as cereals, kale, winter corn and ploughed land, and also buildings found around a farm, (the main farm yard, isolated barns and farm cottages), between August and November and again between February and March and counted the numbers of fields and structures that had rat infestations. They concluded that in the autumn the rats were living around cereal fields but that in the winter they gathered around discrete food sources such as pigsties, cowsheds and corn ricks.

Twigg, (1975) stated that rats colonised corn ricks (stacks of unthreshed cereals) before November and left them in April. He also cites evidence of movement of rats from Wisconsin, USA where the rats were “sporadically distributed” around corn (probably maize) fields in the summer some considerable distance from buildings but that in winter the rats made for human habitations. In the spring the reverse movement was noted, the outdoor areas were repopulated and the buildings were vacated. He also stated that in the UK, where the winters are less severe than in Wisconsin, farms acted

as focal points for rats as food was more readily available there than in the fields. As further evidence of rat movement during the autumn, Twigg, (1975) cites the evidence from Fairley, (1967) of the diet of the long-eared owl (*Asio otus*) in north-east Ireland as being comprised of 6% rats in the summer but that in the autumn this figure rose to 50%, the reason was thought to be the “change of home between summer and winter” as cover was reduced and the rats were moving into unfamiliar territory looking for food and heading for the farm buildings and ricks.

Hardy & Taylor, (1980) followed the movements of 36 radio collared rats in various habitats, 21 rats on open farmland in Hampshire, 10 from around farm buildings on an arable and dairy farm in Surrey and five juveniles on a mixed farm in Surrey. Of the 21 rats trapped on arable land Hardy and Taylor record only two males that regularly visited the farm buildings that were 500 m away but they did not become established there. This is presumably because the resident animals did not allow them to become established as has been indicated may happen (Smith & Greaves, 1987; Taylor, 1978)

Huson & Rennison, (1981) studied the changes in rat populations from data collected from 1584 farms by Ministry of Agriculture Fisheries and Food (MAFF) staff (now the Department of the Environment, Farming and Rural Affairs (Defra)) in Powys and Shropshire during 1976 – 1977 as the result of work to try to prevent the spread of warfarin resistance. In total 2168 farms were visited and all rat infestations were treated. These data showed that during April to July there was a marked decline in the rat population in farm buildings “probably to surrounding fields”, which they presumed to be caused by the increasing abundance of natural foods and growing crops. They suggested that the majority of the resident population had left the buildings by July because cattle over wintered in the buildings had been turned out into the fields and

there was therefore a lack of available food. They noted that between August and November the population in the buildings began to rise as fields of cereals were harvested and the supply of natural food diminished. Again no population counts were carried out, the size being assessed on the increasing signs of rats in the buildings. One of the authors of this paper (D. B. Rennison) in attempting to eradicate rats from farms and dwellings in a 16 km square in the same area of Powys, found that between January and September the farms were disinfested but that they became reinfested in October. It is stated that the rats could only have come from populations in the surrounding fields.

Fenn & MacDonald, (1987) in their review of field studies looked how field work contributed to stored product rodent control. Stored grain is a concentrated source of food for rodents and as a result there is little need for the animals living near to accessible grain stores to move very far. They found that there was a large movement of rats, following harvest, to other food sources such as around the pheasant feeders in woodland that were there to ensure a good crop of game birds for shooting. They assessed the risk of immigration into grain stores or other suitable storage areas as significant if the rats were living within 0.5 km (590 yds). They said that the potential for reinfestation was probably enhanced by the greater mobility of field rats after harvest. Errington, (1935), cited in Fenn and Macdonald, (1987), said that as the winter progressed, the rats on Wisconsin farmland moved from the fields into corn ricks and buildings.

Clark & Summers, (1980) looked at the number of observations of rats that were reported and treated by council staff of the East Hertfordshire District Council for the two years September 1975 to August 1976 and September 1976 to August 1977. The area covered by the Council is mainly rural and intensively farmed with 54 country

towns. In total 1690 treatments were carried out during this time but this included house mice (*Mus musculus* now *M. domesticus*) as well. The data showed an increase in both years in the number of reports of rodents around buildings at the beginning of winter in October and November, with rat sightings producing the greater number of calls.

Brodie, (1981) looked at rats in the cereal stubble fields after the cereals had been harvested in two consecutive winters in east-central Scotland. He recorded active rat burrows and runs on four fields, two of barley and two of oats before harvest. After harvest the fields were inspected on 3 days each week for signs of post harvest rat activity. Crystals of the blue dye, Rhodamine B, were placed in selected burrows from which the direction of movement could be determined from observations of the stained straw and vegetation. Fresh droppings were examined each week for signs of cereals and other plant material. Rats moving into the farm buildings and a refuse tip were trapped during the period of the study, summer 1976 – spring 1978. The oats were harvested about three weeks after the barley each year. After the barley harvest there was an immediate increase in rat activity in the fields of oats and they also began to invade the refuse tip and farm buildings. Harvesting of the oats saw another increase in the numbers of rats arriving at the tip and farm buildings. After harvest there was up to 0.1 tonne ha<sup>-1</sup> of spilled grain lying on the ground and runs were found that extended 30 m into the fields. After harvest no signs of grain consumption were found in the fields of stubble although small piles of the remains of fresh grain were found under the grass at the edges of the fields. As autumn progressed rat activity in the field decreased on the stubble but increased on the field margins where a range of plant species were attacked and eaten, denoting a change in the rat's diet. As the result of harvest, it would appear that rats cannot survive in their new, less protected surroundings and so move to

more suitable habitat where there is available food and better cover. From this evidence Brodie concluded that a reservoir of rats existing outdoors and surviving on the spilled grain of harvest was unlikely.

Villafane *et al.*, (2001) looked at rodent infestations on poultry farms in Argentina and like the research in the UK they found that there was an increase in the population on the farms in late autumn and winter with a dramatic drop in numbers in the spring. Again no numbers are given for populations of the various rodents studied which included *Rattus* spp.

This evidence of movement into and out of farmyards at different times of year is countered by Bishop & Hartley, (1976). Whilst studying a population of rats that were resistant to warfarin they noted that they saw “transient adults” moving through their research area. They trapped rats in the field margins around the two farms they were studying and marked them by toe clipping. Following a poisoning treatment with zinc phosphide a substantial number of rats were removed from a set of buildings and they stated that this had very little effect on the hedgerow population because few rats from the hedgerow entered the buildings. This finding of limited movement from field sites to farm buildings was also found in further work carried out by Hartley & Bishop, (1979). They were studying the home range size of warfarin resistant rats at the same farms as their previous 1976 work. Here they trapped and marked 386 rats in field sites and from this number only recaptured 27 from the 576 rats trapped within the farm buildings. Of those 27 only 9 had travelled more than 100 m. They also stated that the allele for warfarin resistance increased within the farm population but not within the field population and from these two pieces of evidence concluded that rates of migration into or out of the buildings was low.

It is only in this last work, Hartley and Bishop (1979) that any numbers of rats are given and these are the numbers trapped. None of the above researchers attempted to quantify the rat population and, although this may be evidence of movement into or out of farm buildings at different times of year, it is no more than most farmers will tell you anyway.

Other evidence of movement of rats is to be found in the research conducted into the spread of rodenticide resistance. Warfarin was introduced as a rodenticide in the 1950s and the first recorded case of resistance to it was in 1958 in Scotland; subsequently outbreaks of resistance have been found in Wales, England and on continental Europe (Greaves & Ayres, 1967). Whether the spread of resistance represents independent occurrences or is the result of rat movement it is not possible to say, but considering the distances involved it was unlikely that rat movement was the cause. Recent work using sequencing of a segment of the *VKORC1* gene, (the gene identified as being responsible for conferring warfarin resistance), in resistant strains of laboratory brown rats, house mice and wild-caught brown rats from several sites across Europe, suggests that there were at least seven independent genetic mutation events of this gene across Europe (Pelz *et al.*, 2005). Only in Yorkshire were two mutations found in the same population and this suggested mixing of resistant populations from Scotland and Denmark.

Work done by Bentley & Rennison, (1966) quoted in Drummond, (1970) showed that the spread of the resistance from the outbreak 5 km south-west of Welshpool in 1960 was radial at the rate of 4.6 km year<sup>-1</sup> in the three years 1962 – 65. This is less than the rate of spread of rats into completely new territories found by Ecke, (1954) and Harmston & Wright, (1960), quoted in Drummond (1970), who both found that it was about 6 km year<sup>-1</sup> and probably reflects selection against vitamin K deficient

resistant rats (Smith & Greaves, 1987). Fenn & MacDonald (1987) quote Kozlov, (1979) who was looking at the rat population of northern Kazakhstan where he found that rats had moved into unpopulated areas 60 km from their starting point within a year. (Lund, 1988a) found that from an initial outbreak of warfarin resistance in one municipality (a local authority area) in Jutland, Denmark in 1962 it had spread to 34 municipalities (12.2%) by 1987. Between 1970 and 1980 there were eight further outbreaks of resistance that were classified as “of no practical importance”. By 1987 the first cases of resistance had been found on the islands of Funen and Zealand. Lund believed that the resistant populations on these two islands developed independently and therefore, by implication, that the spread of resistance from the original site was by rat movement, although this is not stated in the paper.

Other reasons have been found why rats will move from one location to another. The harvesting of a crop alongside which they have been living (Cowan *et al.*, 2003; Fenn & MacDonald, 1987) and the removal of harbourage (Davis, 1953; Hardy & Taylor, 1980; Jackson, 1972; Lambert, 2003; Recht, 1988) have both been shown as causes for rats to move away from an area. It has also been shown that rats live in a hierarchical society (Macdonald & Fenn, 1994), and that they are also density dependent in their breeding and/or feeding (Baker *et al.*, 2006; Brodie, 1988; Davis, 1972, 1988; Jackson, 1972, 1998; Macdonald & Fenn, 1994). The high status male rats will drive out those of lower status, which prevents them breeding with the resident females; alternatively the lower status animals, both male and female may leave because of a lack of food in the area (Kendall, 1984).

In the present study we sought to examine movement patterns of rats on agricultural land throughout different times of the year. Previous research has shown that rats can move considerable distances and have the potential to re-populate farms following rodenticide treatments. Information on rat movement patterns would enable those involved in control operations to 'intercept' rats in transit between farms, and so reduce the frequency of re-population, and hence reduce the need for repeated rodenticide treatments.

### 3.2 AIMS AND OBJECTIVES

The overarching aim of this element of the research was to investigate whether rats migrate into farmyards in the winter time in order to test whether trapping during migration can be used as the basis of ecologically-based rat management. The data collected from the radio collaring allowed two null hypotheses to be tested:

1. The rats will not move from the field into the farm buildings in the autumn.
2. There will be no difference in the home range size of male and female rats.

### 3.3 FARM SELECTION AND SITE DESCRIPTIONS

The farms over which this research was conducted were not in the real sense selected. The criteria was that all the farms that were used in the four separate areas necessary, (Yorkshire / Leicestershire, coordinated / uncoordinated), had to be within a contiguous 400 ha area. It was therefore not a process of selecting farms, but finding a group of farmers that were within a contiguous 400 ha area, that were prepared to admit that they had a rat problem, that would allow the researchers free access to all the land and buildings and allow us to conduct the research as we wished.

Plans of the radio-tracking trapping sites showing the initial trapping points for all the rats are in Annex B.

#### 3.3.1 Leicestershire.

All rats that were fitted with radio collars came from one farm, Farm A, within the coordinated control area. Rats were trapped on two sites, separated from each other by approximately 200 m (Sites 1 and 2). Another site was trapped (Site 3), on Farm B, again within the coordinated area, but none of the animals caught was of sufficient size to be fitted with radio collars.

Site 1. Site 1 was used as a burning area and was on the embankment of a disused railway line, with the embankment rising away from the level of the railway line on both sides. All sorts of flammable rubbish was dumped here, including the cleanings from the grain drier, old sacks, wood and the used netting, plastic sheeting and baler twine from the large bales used on this farm . The area of the embankment inhabited by rats was about 10 – 20 m wide and the full height of the bank, approximately 10 m. The angle of the bank was approximately 1:1, and it was covered in trees and undergrowth. The embankment on the opposite side was as steep and was

originally similarly covered, but has now been clear felled. The material produced from the felling had been burnt on the railway line. This was a good site for rodents, the material was tipped up the bank and the burning process was never a complete burn so there was always food available as well as material suitable for bedding. The farmyard was just across the road on the opposite bank to the burning area, approximately 75 m distant. At the farm there was always food available. In the late autumn, winter and early spring the Devon Red cattle were housed in the yards and there was cattle cake available. In the summer and early autumn the yards were used to store grain that was in excess of the silos' capacity and all year round in the grain drier there was spilled grain. Behind the grain drier was another enclosed building that held grain, usually from harvest (August) until late spring (May), to which rats had easy access.

Site 2. Site 2 was a dumping ground for all the non-flammable material no longer required for use on the farm. Here was found old piping, tanks, timber, fencing material, hardcore, old trailers and many other items. Recently the site has started to be covered with unwanted soil from a building construction site on the farm. This environment makes an ideal home site for rats as it provides readymade runs and cavities for nest sites and sleeping quarters. In addition, there was a stream adjacent to the site on one side, which if followed upstream for 100 – 150 m, would take the animals to within 50 m of the farmyard, and on the other side was an arable field as a food source for a large part of the year. Indeed, once harvest had been completed and before it was manured in the early winter and ploughed, rat holes and runs were visible in the field. On the far side of the stream were grass fields, used for sheep for the majority of the year, and during the winter, in the run up to lambing and following lambing, they were fed supplementary food which, if not totally cleared, was available to the rats.

Site 3. Site 3 was an area of trees and hedgerow, bounded on one side by a farm track and beyond that a pasture field and on the other by an arable field. The site was an area that has some mature trees but the majority were young ash that had been planted over the last few years. There was a grass track through the site leading to a bridge giving access to a cover crop that divided the arable field in two. Within this immediate area there was a pheasant feeder and behind it in the hedgerow were rat tracks and burrows. About 30 m along the hedgerow moving towards the farm buildings on the arable field side was another pheasant feeder and around that there were again rat signs. Under both of the feeders there was usually spilled grain, either as the result of pheasants feeding or spillage when the container was filled.

### 3.3.2 Yorkshire.

The rats fitted with radio collars in Yorkshire came from four sites. Two sites were located on farm 1 (sites 4 and 5) and the other two were on farm 7 (Site 6) and on farm 8 (Site 7).

Site 4. Site 4 was the area of the farm buildings and included a hedgerow about 50 m from the farmyard that ran almost due east from the farmyard for about 150 m. Within the farmyard all the trapping was carried out around the buildings that housed the pigs.

Site 5. Site 5 was located about 670 m south-south-west of the farm in a valley around a pheasant feeder at the southern edge of a small deciduous copse. Close by was a drainage ditch that took water into a stream that ran approximately east-west across the study area along the bottom of the valley. Surrounding this site were arable and pasture fields.

Site 6. Site 6 was located along a farm track. The track was below the level of the fields on either side and the banks were covered in scrub with a few mature trees. Rat activity could be found on both sides of the track, but the majority of the activity was to be found on the left hand side when looking away from the farm. This is because of the location of several large pheasant feeders on the field margin adjacent to the track. These feeders were 40 gallon oil drums that had had large holes cut into the bottom on the side of the drum and were filled with whole grain wheat. Rats had no problem accessing the grain as large quantities were spilled on the floor and they could just walk in as the drums become empty. The banks were covered with rat runs and there were many rat burrows to be seen. To the right of the track were several fields and small pieces of woodland. On the boundary of an arable field adjoining two areas of woodland were three pheasant feeders, again 40 gallon oil drums. All the pheasant feeders at this site were within a circle of approximately 240 m radius.

Site 7. Site 7 was a piece of land, approximately 1060m north-east of Site 6, in the corner of one field with hedgerows on two sides that was used to store the large bales of straw that are now to be found on the majority of farms. Again this was an ideal site for the rats as they had access to food within the bales and the bales provided good harbourage. Within the hedgerows there were also signs of rat activity, runs and burrows. The adjacent hedgerows provided cover for the rats when they moved away from this area into the nearby farms. The surrounding fields were pasture and were used to graze sheep. During the winter the sheep were fed mangolds distributed across the fields to supplement the meagre grass; immediately prior to and during the lambing period, the ewes were given supplementary food in the form of pellets, some of which was spilled, and both mangolds and pellets were available to the rats.

### 3.4 MATERIALS AND METHODS

#### 3.4.1 Trapping and Radio Collaring

Single, live capture traps (Bethel Rhodes, Keighley, West Yorkshire, UK) were set out on the sites and were baited with whole wheat grain. They were left *in situ* for approximately two weeks in the set safe position to allow the rats to become acclimatised to them. Bait was replaced as necessary. They were set with the open mouth of the trap facing on to rat runs. After this period the traps were set to trapping position and left overnight and checked the following morning for captures. In Leicestershire two non-target species were trapped, both on the same site, a grey squirrel (*Sciurus carolinensis* L 1758) and a common magpie (*Pica pica* Gmelin 1788).

All captured rats were assessed visually at the capture site for size and condition, and those that were obviously juveniles, under 250 g or in a poor condition were released immediately. The remainder were taken from their capture site to the vehicle to be weighed and if of sufficient size, collared. Only rats over 250 g were considered suitable for collaring. All animals were placed under the vehicle and a large piece of card or sack was placed over the traps to keep the rats as calm as possible whilst all the animals were dealt with.

Rats were removed individually from the traps by placing a thick black cotton bag over the trap mouth and then opening the trap door. Under these conditions rats will instinctively go to the darkest area they can find for safety. Once in the bag the rat was shaken to the bottom and the trap removed with the mouth of the bag being held closed. The rat was then manoeuvred into the centre of the bag and the bag held at both ends. The bag with the rat in was placed inside the anaesthetic chamber with the closed end outside. Holding the lid down, the bag was then gently pulled out of the chamber leaving the rat inside. The anaesthetic used was Halothane, which is relatively short

lasting. The anaesthetic chamber was made of transparent plastic and came in two parts. The upper part had a lid and a perforated plastic floor and held the rat and the lower half had cotton wool in it to absorb the anaesthetic which evaporated and passed through the perforated floor to the rat. Additional anaesthetic could be fed down a tube into the base of the chamber as necessary. The rat was watched once it was put in to the chamber and to ensure that the rat was asleep it was gently rolled around in the chamber before removal.

Once anaesthetised, the rat was removed and placed on a set of scales to ensure it was >250 g. If it was not, it was returned to the trap to recover. If it was in excess of 250 g it was sexed and its weight and condition noted. The collar was then fitted. The radio collars (Biotrak, Wareham, Dorset, UK) each had a unique frequency in the range of 173.000– 174.999 kHz, which was factory set to three decimal places and this allowed the rats to be individually identified in the field. The collars were fitted with a battery that had a life of approximately 3 months. The collars weighed 10 g. The collar was held on with an electrical cable tie and tightened so that the tip of the little finger would just fit between the collar and the neck. This allowed enough room for growth and also meant that it could not be pulled off. Should the rat start to wake up whilst this work was being carried out it could be returned to the anaesthetic chamber and be reanaesthetised without any harm. Figure 3.1 is a picture of one of the collars and Figure 3.2 shows an anaesthetised rat with a collar fitted but before the excess tie was removed. The red cylinder towards the front feet is the battery.



Figure 3.1. Radio collar – this one was fitted to a rat but became dislodged



Figure 3.2. Rat fitted with a radio collar

Once the collar was fitted, the excess cable tie was cut off using a pair of cable snips and the rat returned to the trap to recover. The recovery period was normally about 10 – 15 minutes, but they remained in the traps until all the animals trapped had been dealt with. They were then taken back to the point of capture, which was recorded accurately using a Garmin Etrex personal navigator 12 channel global positioning system (GPS) (Garmin (Europe) Ltd, Romsey, UK), and released. The GPS was set to provide readings using the Ordnance Survey grid reference system and provided a 10 figure reference. In order to be able to use this with the site plans the prefix number was added to each of the two sets of five numbers. The GPS also provided a measurement

of accuracy for each reading (range 5 – 40 m: mean 8.7 m: median 7 m), which depended on the location of the animal. To provide accurate reading the GPS requires a clear view of the sky, the more restricted this view the less accurate the reading.

#### 3.4.2 Radio Location

Radio locating was carried out using a Televilt RX-900 (Televilt, Lindesberg, Sweden) and a three element antenna (Yagi, UK). Locating was carried out daily subject to the requirement of other field work, Monday to Friday, at various times over the 24 hours although only one full night of locating was carried out as the terrain made it very hazardous. The starting point for the search was always the location at which the animal had last been found. The range over which the signal could be heard was approximately 1000 m under ideal conditions where the ground was clear and flat, but where there were obstructions such as a growing crop, undulations in the ground or buildings, the range of the signal was considerably reduced, down to as little as 50 m. With this equipment, providing the ground cover was suitable, it was possible to locate the animal precisely. Once the specific signal had been picked up, it was then a matter of determining in which direction the signal was coming from. By moving the antennae in an arc the signal volume rose or fell and by pointing the antennae in the direction of the greatest volume gave the direction in which to move. Walking down this line the signal increased in volume until there was no change. The antennae could then be pointed downwards and moved round in a circle to find where the greatest volume was, which gave the precise location of the animal. If the cover was not suitable, such as in a growing crop, then the location of the animal was determined using triangulation. All locations were recorded using the GPS. The dates and times of the location of each rat in Leicestershire are given in Table 3.1. It is not possible to provide similar information

for Yorkshire as although times that the rats were located varied throughout the day, no record was kept of when each rat was located. The antenna was very good providing one was close to the animal being tracked, but if it was at a distance the arc over which a signal could be picked up was quite wide. Some of the ground over which the rats roamed was growing arable crops and understandably the farmers were not keen on people walking through their crops, so triangulation had to be used to provide a location.

The rate of the pulse given off by the transmitter is temperature dependant which meant that, should the animal die or the collar come off, the rate of the pulse emitted changed. Whilst the collar was on a live rat it was kept warm and the rate of pulse was slow, but once the collar became cold, the rate of pulse emitted became faster.

The rats were not tracked on a continuous basis as one needed to be within a few metres of the location of the rat to obtain a precise fix of their position. It was likely that once the animal became aware of the presence of the tracker it would go to the nearest cover. However it has been shown that rats that have been radio tagged will quickly resume normal behaviour once the tracker has departed the location (Lambert, 2003).

Date 2004	Rat 1	Rat 2	Rat 3	Rat 4	Rat 5	Rat 6	Rat 7
12-May	10.30	11.30	11.30	11.30			
13-May	11.00	9.30	11.12	9.45			
17-May	15.50	15.40	15.30	15.30			
18-May	18.00	17.50	17.45	17.30			
19-May	12.15	11.42	11.50	11.36			
20-May	19.10	18.42	19.25	18.30			
21-May	5.38	5.50		5.56			
24-May	20.38			20.55			
26-May	20.00			20.16			
27-May	8.36			9.01			
01-Jun	14.41			15.06			
02-Jun				21.46			
03-Jun	4.00			4.25			
06-Jun	Collar recovered			Collar located			
07-Jun					10.42	11.15	11.30
08-Jun					15.30	15.50	14.50
09-Jun					8.45	9.15	9.00
10-Jun					10.10	9.50	9.25
11-Jun					20.15	210.50	20.36
17-Jun		13.05	11.40		13.30		10.45
18-Jun		9.00	11.30				10.45
21-Jun		13.50	13.00		11.40	12.05	12.35
22-Jun		11.30			12.00	13.10	13.15
23-Jun					11.10	12.00	12.15
24-Jun		12.15	13.30		11.25		
25-Jun		13.40	12.40			20.40	12.15
26-Jun		19.55					
29-Jun			20.55		No signal		20.16
30-Jun							
01-Jul		20.54	20.00				20.25
06-Jul		9.25	10.05				10.45
09-Jul		10.25	10.00				NF
14-Jul		10.48	10.15			10.25	9.40
16-Jul							11.25
19-Jul							NF
21-Jul						13.20	13.40
23-Jul		12.50	12.17				11.55
28-Jul		10.20	9.40			9.40	9.10
02-Aug		NF	10.10				9.50
04-Aug		9.30	9.50			9.45	10.15
05-Aug						Collar found	
06-Aug		9.40	9.15				8.55
07-Aug							10.55
09-Aug		11.35	11.55				
13-Aug		8.40	8.50				9.10
16-Aug		5.15	5.25				5.40
20-Aug		8.20	8.25				NF
25-Aug		21.35	22.00				22.10
26-Aug							9.40
28-Aug		10.15					
22-Sep			No signal				
18-Oct		10.42					10.42
19-Oct		No signal					11.20
08-Nov							14.35
							Killed

Table 3.1. Dates and times the Leicestershire rats were located. (Blanks indicate animal not located that day).

### 3.4.3 Triangulation

This was done using the antenna to provide a direction and then a compass bearing was taken along the direction of the antenna. The location of the point of the bearing was taken with the GPS. The bearing of the signal was then taken from a second position, and the location recorded. The location of the rat was found using the GPS readings and the bearings by plotting them on graph paper and reading off the intersection of the lines to obtain a location. This produced variable results as can be seen from the plot of the locations of Leicestershire rats one, where the locations are relatively close together, and six, where they are well spread out, (maps 1 and 3 in Annex C). On map 3 the positions at the bottom of the map were all in a field of oil seed rape, which it was not possible to walk through, and several locations were obtained using triangulation. After the field had been harvested the collar was located and was lying on the ground, probably where it had been for the majority of the time. The collar for rat one was found under a pile of metal sheeting and old machinery close to the area that the animal had been trapped in. The error in these locations using triangulation, as calculated from the location of the collar when found, ranged from 11.3 m to 149.5 m.

If, after several tracking sessions, the location of the signal was always in the same place and the rate of pulse had become faster then it was assumed that the animal had died or the collar had come off and the collar was retrieved, if this was at all possible. Several collars were recovered and reused but in a few cases it was not possible. Figure 3.3 shows a hole that is in excess of 120 cm deep and the collar had still not been reached.



Figure 3.3. Hole dug to retrieve a radio collar – the measure in the hole is 122 cm in length

### 3.5 DATA ANALYSIS

The GPS data were entered into Microsoft® (MS) Excel and saved as a database file that was then used to produce the necessary maps and provide the data for analysis. The locations of the rats were plotted onto digital Ordinance Survey maps of the relevant areas from the database files using ArcView GIS v3.2 software (ESRI, California, USA) and the analysis was carried out using Animal Movement v1.0 software (Hooge & Eichenlaub, 1997). Using this program it was possible to estimate home ranges for all the animals using both the minimum convex polygon (MCP) and kernel methods.

The MCP method is one that has been extensively used in studies of other animals that have used radio tracking. It is easily interpreted as it is a non-parametric method with the output being simply a polygon that is drawn by connecting the outside points of the home range data. This method can produce an overestimate of the home range and is at its greatest when the data is clumped and therefore the polygon produced includes areas between the clumps that are not utilised (Lambert, 2003). When radio tracking the European brown hare, it was found that the MCP method overestimated the home range area by up to 73% when compared with three other methods of home range estimation (Wray *et al.*, 1992). The data from the MCP method also provided minimum and maximum distances moved over the data set as well as the home range area.

The kernel method however, produces a home range area that has smooth lines because it is assumed that an animal will forage around any one point. With the kernel method it is possible to produce contours, based around the radio fixes obtained, representing different percentages of a home range, usually set at 50, 75 and 95%. As a result, two types of contour can be produced; one where the area is continuous, (as in

Figure 3.4a below) and the other where the area is not always continuous and for any given animal this may produce several areas (see Figure 3.4b below).

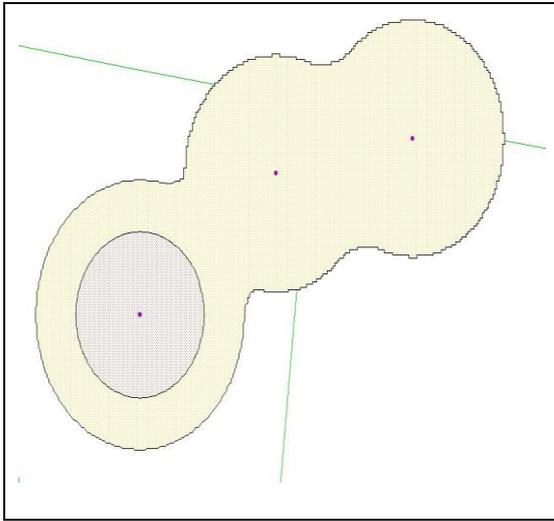


Figure 3.4a. Continuous kernel



Figure 3.4b. Discontinuous kernel

The generation of the contours is based on a number of assumptions and contours are modified by a smoothing factor ( $h$ ), which was calculated using the Least Squares Cross Validation of the mean integrated square error (Silverman, 1986). When plotting the home range for each rat,  $h$  is calculated on the basis of the individual data set and a wide range of values for  $h$  can be obtained across all the animals plotted, range 1.6 – 101.6. A small value of  $h$  produces a small home range and a high  $h$  value produces a larger home range area. The value of  $h$  depends on the number of radio fixes obtained, a small number of fixes producing a larger value for  $h$ , and therefore a larger home range, than a larger number of fixes that cover the same area but which produce a smaller home range (Lambert, 2003). This problem can be got round by using the median of all the values for  $h$  and then applying this to the whole kernel analysis which then produces a more realistic estimate of the home range (Kenward, 2001).

Comparisons of the home range areas and distances moved were carried out using MS Excel or Minitab v 14. None of the base data were of normal distribution or of equal variance. The only transformation where normality and equality of variance

could be obtained was by ranking the data. This transformation was then used in ANOVA to compare the three different areas and when comparing the three locations against MCP area, minimum and maximum distances moved, and the Kernel 50%, 75% and 95% home range areas.

### 3.6 RESULTS

At Annex C are the details of the 33 animals fitted with radio collars, along with what is known to have happened to them. At Annex D are the maps showing the recorded locations of all the radio-collared rats. The number of recorded locations ranged from one rat with only three locations to one rat with 43. 14 of the rats had nine or less recorded locations, 14 had between 10 – 19 and only five had 20 or more recorded locations. In only seven cases of the rats radio tracked were there no duplicated locations, the remaining 26 rats having at least one duplicate and nine of the animals had two or more duplicated locations. This would indicate that the majority of rats were recorded as being in their “home” burrow(s) on several occasions. In total 26 radio collars were used and 16 were lost or could not be recovered. Of the 10 collars that were recovered five were reused, four twice and one three times.

At Table 3.1 are the data obtained from the MCP and Kernel calculations.

Rat No	Sex	Number of times located	Site	Home Range Measurements						
				Minimum Convex Polygon			Kernel			
				Area (m <sup>2</sup> )	Min Dist (m)	Max Dist (m)	h	50% (m <sup>2</sup> )	75% (m <sup>2</sup> )	95% (m <sup>2</sup> )
1	M	12	1	501	12.5	31.6	7.6	404.1	1105.4	1889.7
2	F	29	1	30636	2.2	556.5	72.8	19914.9	42748.4	101071
3	F	26	1	45631	2.8	686.7	66.9	17597.4	34056.9	92064.8
4	F	13	1	82	0	11.2	1.6	35.8	109.4	175.5
5	F	10	1	26926	9.8	436.3	45.6	8612.3	15562.5	38689.6
6	M	13	1	102428	10.3	622.3	75.9	21747	81277.7	206149
7	F	30	1	31897	0	372.8	46	8437.1	15369.6	38446.3
0	M	9	2	465.5	0	114.8	14	936.7	1853.8	4036.9
1	F	15	2	17	0	34	2.8	29.3	50.3	93.7
1a	M	6	2	385.5	0	30.5	7.2	191.9	592.6	1610.9
2	M	10	2	939.5	1	105.2	16	1065.9	2526.2	7113.2
2a	F	6	2				8.7	276.5	472.9	1181.8
3	M	14	2	742.5	0	173.6	16.2	1057.3	2756.4	7102.5
3a	M	5	2				6.9	172.3	294.4	767.6
4	F	11	2	26721	0	286.4	38.5	5421.5	9321.6	25923.5
4a	F	3	2	7	3.2	57.7	19.5	1389.3	3787.5	6741.8
5	M	43	2	18800	0	161.2	14.9	1793.7	3465.8	12183.2
6	M	8	2	5550	0	143.2	23.2	2146.1	3729.6	13584.1
7	F	9	2	367.5	0	29.4	4.9	93.2	258.5	385.9
13	M	10	2	24900	0	220.9	42.3	7191.9	19263.5	48859.8
14	F	5	2	750	0	111.8	21.8	1736.5	4916.8	11111.6
15	F	5	2	500	0	141.4	26.7	2602.9	4466.8	11761.3
16	F	4	2	550	0	120.8	32.3	7531.9	12965	20283
17	F	5	2	1000	0	51	11.7	825	2304.3	4022.6
8	M	19	3	670	0	44.7	4.3	157.3	398.7	1080.3
9	F	18	3	146	0	38.1	5.2	133.8	322.5	605.2
10	M	16	3	21893	0	264.2	31.2	6188.6	19450.7	50054.5
11	F	13	3	1140	0	85.4	9.5	324.8	690.5	1880.2
12	M	32	3	5999	0	193.1	13.3	1764.3	4127.7	10682.4
19	M	7	3	11500	10	707.1	101.4	37485.5	64297.2	155381
20	F	14	3	6000	0	233.5	20.6	2403.9	4437.4	9546.2
21	M	6	3	2800	20	89.4	16.1	1287.9	3592.9	7709.3
22	F	6	3	2250	22.4	98.5	15.6	1666.5	3658.9	7054.1

Table 3.2. MCP and Kernel data for all the radio collared rats. (Site code: 1 – Leicester coordinated area, 2 – Yorkshire uncoordinated area, 3 – Yorkshire coordinated area).

The reason for there being no MCP area data for two of the Yorkshire rats (numbers 2a and 3a) is because they were only recorded as being in two different locations and therefore the MCP is just a straight line (No 2a had 7 records and No 3a had 5 records). Also in the MCP, the minimum distance moved is 0 (zero) because these animals were recorded at the same location on more than one occasion. Below at Table 3.2 are the means of the MCP and Kernel calculations for the different habitat types.

	Minimum Convex Polygon			Kernel		
	Area (m <sup>2</sup> )	Min Dist (m)	Max Dist (m)	50% (m <sup>2</sup> )	75% (m <sup>2</sup> )	95% (m <sup>2</sup> )
<b>Farm yards only</b>	408.0	0.0	41.4	145.6	360.6	842.8
<b>Farm yards &amp; Field</b>	14778.2	0.0	240.8	3251.7	8773.7	21994.0
<b>Field only</b>	12171.1	3.6	209.5	5263.6	11714.3	26485.6

Table 3.3. The means of the MCP and Kernel estimates of home range for both Yorkshire and Leicestershire for the different habitat types occupied by the rats.

As would be expected, with both MCP and Kernel methods of home range measurement, the animals that occupied only farm buildings, (n = 2), covered the smallest area and moved the shortest distances. It is not possible to obtain distance-moved information from the Kernel method of analysis so it is not possible to compare the two methods of analysis in this respect. It is however, interesting to note, that when using the MCP method to calculate the mean home range area for the animals that occupied both farmyard and field sites (n = 3), it produced a larger home range and longer maximum distances moved than for the animals occupying purely a field habitat (n = 28). In contrast to this, the Kernel method at 95% shows that a field rat had a larger home range than one that occupied both the farm buildings and field habitat.

This increased home range using the Kernel method ranged from 32.8% to 54.0% larger than the MCP calculations. This difference may be the result of the way that the home range is drawn. In the MCP method the outer points are connected and it is presumed that the animal does not go outside this area. For the Kernel method of home range calculation it is presumed that the animal will forage in an area around any given location at which it is recorded.

Analysis of the data, when looking at the three different areas in which the rats were trapped and then radio tracked (Leicester coordinated area and Yorkshire coordinated and uncoordinated areas), shows that the MCP area in which the animal trapped was statistically significant ( $p = 0.045$ ), as was the minimum distance moved ( $p = 0.022$ ). None of the other comparisons were statistically significant ( $p = >0.15$ ). The Leicestershire MCP areas were the significant factors in this with the Leicestershire region mean ( $34014 \text{ m}^2$ ) being more than 5.8 times that of the Yorkshire region coordinated ( $5446 \text{ m}^2$ ) and uncoordinated area ( $5822 \text{ m}^2$ ) means. The mean of the minimum distance moved was statistically significant with Yorkshire uncoordinated area having a mean of 0.25 m. At Figure 3.5 is a plot of the means of the MCP home range areas for the three regions in which the rats were radio tracked.

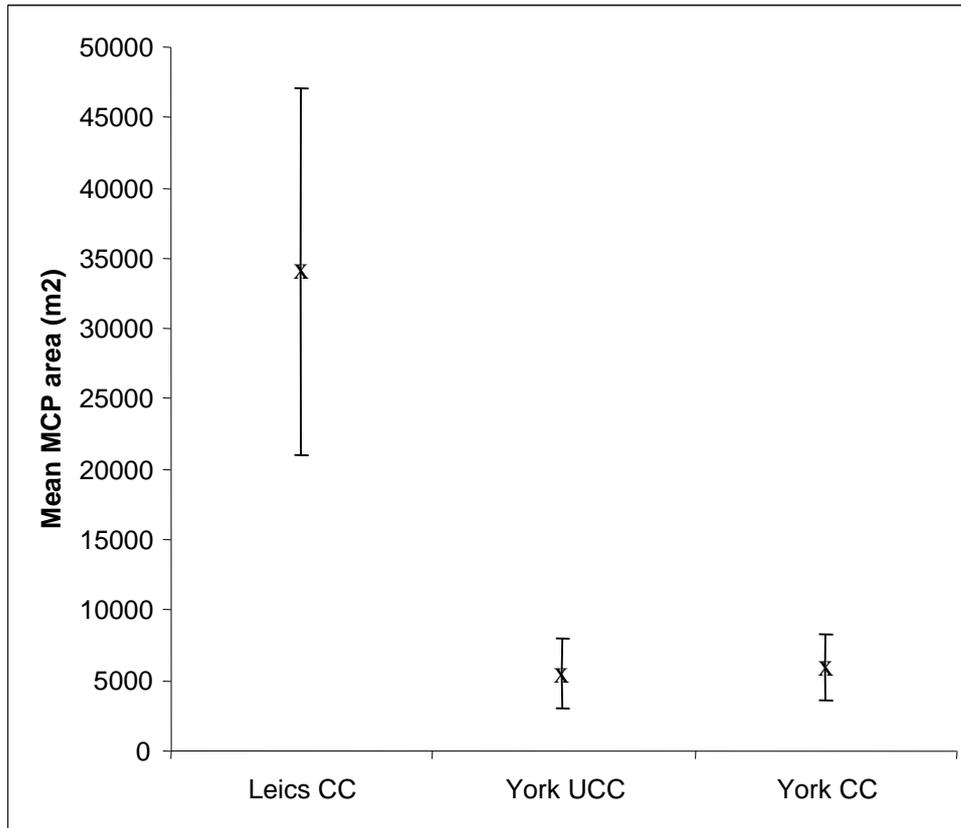


Figure 3.5 The mean MCP areas (plus SEM) for the three regions in which rats were radio tracked (CC – coordinated area, UCC – uncoordinated area)

When looking at the analysis of the data for home range size in relation to the sex of the animal, the sex is not significant for either method of measurement, MCP or Kernel ( $p = 0.438$ ). Therefore the null hypothesis can be accepted, that there was no statistically significant difference in the home range size of male and female rats. At Table 3.4 are the mean and median home range areas for male and female rats.

	<b>MCP Mean (m<sup>2</sup>)</b>	<b>MCP median (m<sup>2</sup>)</b>	<b>Kernel 50% Mean (m<sup>2</sup>)</b>	<b>Kernel 50% Median (m<sup>2</sup>)</b>	<b>Kernel 75% Mean (m<sup>2</sup>)</b>	<b>Kernel 75% Median (m<sup>2</sup>)</b>	<b>Kernel 95% Mean (m<sup>2</sup>)</b>	<b>Kernel 95% Median (m<sup>2</sup>)</b>
<b>Male</b>	14112	4175	5958	1526	14888	3529	37674	9196
<b>Female</b>	10272	1000	4391	1702	8639	4112	20613	8300

Table 3.4. Mean and median home range data for MCP and Kernel methods of home range measurement for male and female rats from both areas.

Only one rat, rat seven in Leicestershire, was seen to move into a farmyard from the 28 rats that were trapped and radio tracked that lived purely in field sites (see map 4

in Annex D). This shows that animals will move into farmyards but it is not conclusive that many do.

As far as the distances travelled by individual animals is concerned, the furthest distance any one rat moved was by a rat (number 19) in the Yorkshire coordinated area that went 707 m from its trap site, (see map 8 in Annex D). There is only one recording of this particular rat (probably more correctly the collar) at this distance, as only the collar was at this location, although a live rat was seen nearby. Rats two and three in Leicestershire moved 556 m and 686 m respectively to new home sites and remained there for the remainder of the time that the batteries lasted and then the signal was lost. Rat two moved across a field of oats to a small wood in which there was a pheasant rearing pen where it stayed until the signal was lost, probably due to battery failure (see map 1 in Annex D). Rat three moved down scrub land on the edge of two fields to an area of scrub land on the top of a small valley and was recorded as foraging in the adjacent field of oil seed rape and in the scrub land. It remained there until the signal was lost, again probably due to battery failure (see map 3 in Annex D). The rat in Yorkshire and the two rats in Leicestershire lived essentially in small areas and only moved the once away from the home site. The two from Leicestershire remained in relatively small areas once they had moved away.

Leicestershire rat five had one reading that was different from the rest and indicated that it was in a small wood 436 m from its home site on the burning pit (see map 2 in Annex D). The corridor along which it had moved was a hedgerow. The signal received at this location was different from the normal live or dead/removed signals and would not have been as strong as it was at this distance from the home site, so it was very likely at this location. It was not found for several days afterwards but was subsequently recorded as being back at its normal home site. Rat six moved from

its home site on the tip area once onto the disused railway track and then in the opposite direction into a field of oil seed rape (see map 3 in Annex D). The measurement of it having moved 622 m (from MCP calculations) is probably inaccurate and the actual distances moved, as measured using ArcView, were 395 m south-west and 375 m in an easterly direction with the distance between these two locations being 700 m. The last five recorded locations (in the south-west corner of map 3 at Annex D) were calculated using triangulation and, as can be seen from the map, are rather spread out. The collar was eventually found after the field had been harvested, which may say something about the accuracy of the bearings taken to do the triangulation.

In the Yorkshire coordinated area there are two rats that bear examination. Rat 10 was trapped on Farm 1 and was recorded over a wide area, with a home range estimate of 21892 m<sup>2</sup> (MCP) and 50054 m<sup>2</sup> (95% Kernel) (see map 5 in Annex D). This animal was recorded as being in the farmyard and in the two adjacent fields with no clumping in any one area although it was recorded at one site on more than one occasion. Rat 12 was trapped in the hedgerow adjacent to Farm 1 and it was subsequently recorded as being in a triangle formed on two sides by the trap location and the hedgerow that ran down the side of the farmyard and an area of the field these hedgerows bounded (see map 7 in Annex D). It is interesting to note the many recorded locations that are in or adjacent to the hedgerows showing linear movement with the occasional foray out into the field.

On the uncoordinated site in Yorkshire there are two rats are worth examining. Rat four is recorded as being in the main at one location based around a pheasant feeder in as small area of woodland on Farm 7, but there are two recorded locations that show that it moved away twice from its home site once to the north-east and once to the south but returned to its home site (see map 12 in Annex D). Rat five was trapped on land

used to store large bales on Farm 8. Unlike the majority of the other rats radio tracked this particular animal was recorded as being at many locations across the field (see map 16 in Annex D). The other rats tracked in the main have a clump of recordings, presumably around the “home site” whereas Rat five certainly has two recorded locations that are in the same place, because it has a minimum distance moved of zero, but the vast majority are spread out across the field.

### 3.7 DISCUSSION

This small piece of research into the movement of rats confirmed what has already been found in other studies, that rats in the main have a tendency to stay within a small area providing that there are the necessary requirements for them to live and breed. It is not possible to say from this research why two of the rats in Leicestershire moved 686 and 556 m from the trap site and made their homes at these distant locations (Annex E for the maps). The cause may have been a lack of food to support the number of animals at the tip area or they may have left because of the numbers of animals on site and there were insufficient suitable nests sites, both animals were female. The analysis of the rat population estimates (see Chapter 4, Section 4.5.2) indicates that the rat populations in all areas (coordinated, uncoordinated and both farmyard and field locations) were not density dependant. Whatever the cause, neither returned to the trap site once they had established a new home range.

Only one rat, No. seven from Leicestershire, moved from the trap site, where it had spent all summer and into the middle of October, into the farmyard where it remained until it was killed in early November. As can be seen from the map at Figure 3.6 this animal was recorded moving in a series of three stages away from its home range and into the farm yard. Unfortunately it was killed by the farm dogs in the yard within a month of establishing a new home range within the yard which prevented us from seeing how long this animal might have stayed in the yard. It had been hoped that more animals from both trap sites on Farm A would have moved into the farmyard once food had become scarce on the field sites as this had been one of the objects of this radio tracking, to try and confirm that rats moved from field sites into farmyards in the winter.

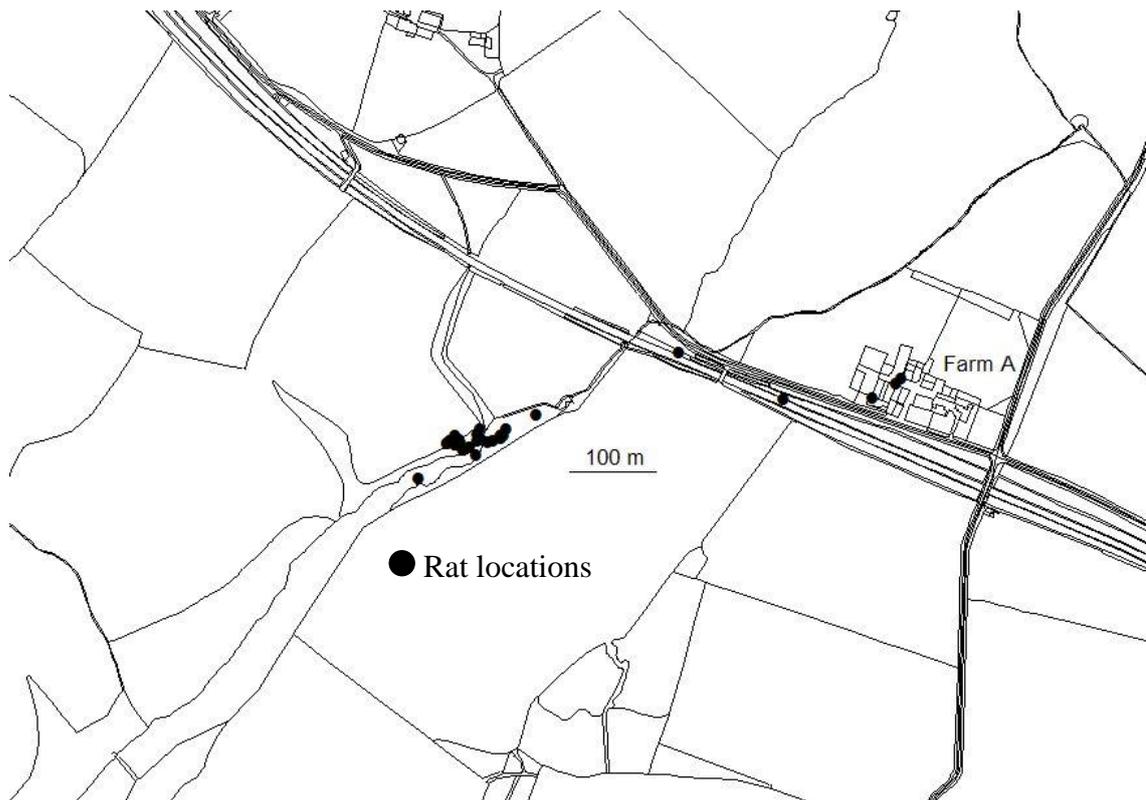


Figure 3.6. Map of the area over which Leicestershire rat seven moved. (North is at the top of the map).

Why Leicestershire rats should have such a much larger MCP mean home range size than either of the two areas in Yorkshire is not known. It may be that there is more food available for them in Yorkshire and therefore there is less need to move over a wide area. Another explanation may be that 14 of the 26 rats radio tracked in Yorkshire had nine or fewer locations recorded and of those 14, nine had six or fewer locations recorded, thus bringing down the mean home range size. More than half of the rats that were tracked in Yorkshire died after being collared, seven from rodenticide poisoning, two as the result of being predated (remains of the carcasses were found), four died of unknown causes, two were humanely killed by the researcher, one after having been retrapped and found to have an open sore where the collar had rubbed and the last one was found comatose (cause unknown). Of those 15, five had nine or fewer locations recorded. The signal from eight rats in Yorkshire was lost, of which five had fewer than nine locations recorded. The loss of signal may be caused by one of a number of

factors: loss of battery power if the collar was one that has been reused, predation of the collared rat and the carcass, with collar, taken some distance away or the rat may have migrated out of the area. The terrain in both areas was such that it would have been very difficult to relocate the collared animals without covering very large areas and without knowing in which direction to go would have taken some considerable time. It has to be borne in mind that the researched at CSL had other duties to perform in addition to the work for this research and therefore the necessary time was not available to trace these missing animals.

Radio tracking is a useful tool for studying short-term movements of individual rats. It is, however, extremely time consuming and analysis of the data is controversial (Hemson *et al.*, 2005). It was therefore decided to use extensive trapping along potential corridors of movement to quantify the extent of migration into and out of farms at different times of the year (see Chapter 5).

### 3.8 CONCLUSIONS

The only real conclusion that can be drawn from the data collected here is that male and female rats do not have statistically significant differences in their home range size, whichever method of measurement was used (MCP or Kernel). It has also been shown that in general rats tend to stay within a relatively small area but may move considerable distances (> 620 m) to a new home site.

It has also been shown that rats (one) do migrate from a field site into a farmyard, which is what had been hoped, and that this migration occurred in the autumn and early winter period, again as had been expected. It had been hoped that more animals from both Yorkshire and Leicestershire would have moved onto farms from the fields to show that there is a major migration during the autumn and early winter periods but this did not happen and one animal does not prove this theory.

The majority of the rats stayed within a relatively small area but several of them showed other patterns of behaviour. A pair of rats in Leicestershire showed this behaviour but it occurred in two different locations, before and after their long distance moves. The most normal type of behaviour of these was that of the rat in Yorkshire that moved generally in a linear manner along the two hedgerows, showing the thigmotactic behaviour associated with rats, with the occasional journey out into the adjacent field. A single rat in Yorkshire showed the greatest variation of this limited range behaviour and ranged over the whole field in which it had first been trapped. There would therefore appear to be a range of behaviours exhibited by rats in terms of the way that they live.

## CHAPTER 4 – LANDSCAPE SCALE MANAGEMENT OF RAT POPULATIONS: ASSESSMENT OF THE COORDINATED SITES VERSUS UNCOORDINATED SITES CONTROL EXPERIMENT

### 4.1 INTRODUCTION

As things stand at present, rodent control, certainly in the agricultural community, and most probably within the community at large, is carried out at an individual level and within the confines of the property boundaries of that individual. Farmers will only bait, if they bait at all, within the confines of their land as one would expect, and generally this is restricted to the extent of their farm buildings. They may occasionally bait along the hedgerows adjacent to the farmyard. They certainly do not liaise with their neighbours to develop a coordinated baiting strategy across a wider area. Rodent control operatives, if they are contracted to several farms in one area, may bait across that area in a coordinated fashion, but purely for economic reasons to reduce their travelling time, not specifically with the intention of preventing reinvasion, and again generally within the confines of the farmyard.

In other countries, however, coordinating control across smallholdings and controlling in both farm buildings and fields has proved very cost effective (Richards, 1988). Several researchers have conducted research where large areas of land have been used (Richards & Buckle, 1986; Smith & Nott, 1988). Richards and Buckle, (1986) conducted rat control across 1141 ha of rice fields in Bukateja, Indonesia. Smith and Nott, (1988) used one ha plots of cacao trees in Equatorial Guinea which each contained 900 trees, to assess and to control the damage caused by rodents to cacao pods and proposed coordinated control over larger areas. Others have looked at methods of rodent control that can be applied relatively cheaply to a small area but have an effect over a much larger area (Singleton *et al.*, 1999b), (this will be examined in more detail in Chapter 5). These are just some examples of where researchers have

started to look at a wider picture rather than concentrate on controlling rodents in relatively small areas.

Rats generally do not move far from their home nest site, and movement in a night can be as little as 3.1 m (Lambert, 2003), but one animal has been shown to travel a round journey distance of 3.3 km within a 24 hour period and the same animal also travelled 1.8 km in a round journey in a single night (Taylor & Quay, 1978). In research conducted by Lambert (2003), where he was comparing home range size pre- and post-harbourage removal, he found that for rats occupying farm buildings (n = 30; cleared area n = 16, uncleared areas n = 14) the maximum distance moved between points on successive nights, pre-harbourage removal ranged between 3.1 – 50.7 m and post-harbourage removal ranged between 6 – 45.2 m (n = 10) on cleared areas and 2.5 – 51.1 m (n = 10) in uncleared areas. When examining the home ranges of rats occupying field sites (n = 12; cleared areas n = 1; uncleared areas n = 11) he found that the maximum distance moved between successive nights pre-harbourage removal ranged between 43.7 – 368.2 m. Following the removal of harbourage on only one site, the maximum distance moved between successive nights for the one rat there was 165 m and on the uncleared sites ranged between 12.7 – 124.3 m (n = 7). Rats were lost to death or predation or collars were removed, which accounts for the different numbers of rats at each site pre- and post-harbourage removal.

The assumption that brown rats migrate seasonally into and out of farm buildings is based on first hand experience of farmers and landowners of the increased number of rats around farm yards in the autumn and winter, and also on the experience of field workers (Huson & Rennison, 1981). As yet no firm proof has been put forward in the scientific literature to support this (reviewed in Chapter 3). It has been shown however, that rats will congregate in available harbourage once the supply of food in

the hedgerows and fields has been exhausted (Leslie *et al.*, 1952). Leslie *et al.*, (1952) looked at the rat populations in hay ricks and showed that the ricks were invaded within a few weeks of them having been built and that these rats migrated in from the adjacent hedgerows. We no longer have hay and corn ricks, except on the odd farm that uses the old threshing machines for exhibition purposes, but we do have barns filled annually with straw and hay and also the modern equivalent of the corn ricks, but without the heads of grain still attached, the stacks of large bales of straw, hay and silage that are left out in the field or stored on the margins and other suitable areas. Both of these storage areas become infested with rats.

## 4.2 AIMS AND OBJECTIVES

This element of the study was set up to examine whether it was possible to reduce the rodent population over a large area (350 – 400 ha) by controlling both the farm populations and any field populations within the experimental area. To this end four 400 ha plots were found where the farmers were willing for researchers to come onto their properties to conduct this research. There were two areas located in Leicestershire and two areas in Yorkshire. One area in each county was designated the coordinated area and the remaining areas were designated the uncoordinated areas. In the coordinated areas the researchers would conduct the rodent control and in the uncoordinated areas the farmers would be free to do whatever rodent control they considered necessary. The reason that there were only two replicates, a coordinated and an uncoordinated area each in Leicestershire and Yorkshire, was purely practical. It was felt that trying to manage more than this with only two researchers was not a realistic option. Firstly it had proved difficult to find four groups of farmers in any one 400 ha location that was within reasonable travelling distance of the researchers base who would allow the research to be carried out and secondly, with the number of farms within each area it was thought that this would be big enough task monitoring the populations and conducting the control measures as well as the other elements of the research. The study practical elements of the research commenced in September of 2003 and concluded in January of 2006. The team at the Central Science Laboratory, York, was comprised of Dr D Cowan, overall Project Director, Roger Quy, and Dr Mark Lambert who carried out all the field work.

The following predictions were tested:

1. Coordinated control will reduce rat the population more than uncoordinated control.

2. Coordinated control will lead to less use of rodenticide bait over time.
3. Predictions one and two will apply in different areas, (i.e. not specific to Leicestershire or Yorkshire). This will be tested with a Location\*Treatment interaction.
4. It is predicted that changes in numbers in field populations will be different from changes in numbers in farm building populations if there is movement between field and farm.

#### 4.3 DESCRIPTION OF FIELD SITES.

Field surveys were carried out between September 2003 and January 2006 at four study sites, two in Leicestershire and two in Yorkshire. Each site, comprising a number of farms, covered between 350 and 400 hectares (875 – 1000 acres). All the farms on the study sites had signs of the presence of Brown rats. All the farmers agreed to allow this research to be carried out on their land providing that neither they nor their land was not identified. Therefore all the farms are identified only by letters or numbers and no grid references are given. At Figure 4.1 is a map showing the locations of all the research areas.



Figure 4.1. Map showing all the research areas in relation to each other

##### 4.3.1 Leicestershire Site Descriptions

Figure 4.2 shows the locations of the research areas in Leicestershire in relation to Leicester. The Coordinated site was situated approximately 20 miles east of the City

of Leicester and the uncoordinated site approximately 10 miles southeast of the city. The coordinated site comprised 3 farms (farms A, B and C) and the uncoordinated site comprised 6 farms (farms D, E, F, G, H and I) and an additional area of arable land that was leased to another local farmer whose farm was outside the research area. Within the coordinated area there was a small hamlet comprising a dozen houses and at the northwest and southeast ends of the uncoordinated site were two villages. Plans showing the layouts of the farmyards are at Annex F.

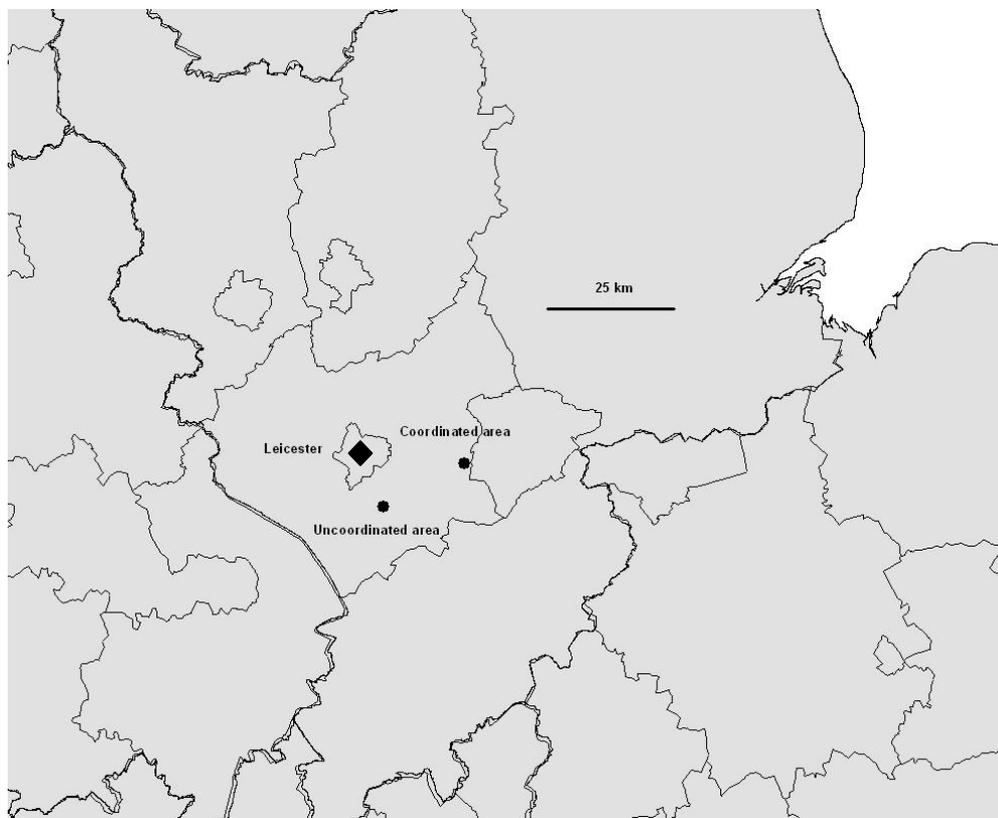


Figure 4.2 The two Leicestershire research areas in relation to Leicester

#### Coordinated area.

Farm A ran a herd of pedigree Red Devon beef cattle and grew grain and beans, both for sale and as cattle feed for during the winter. The farm yard comprises the farmhouse and garden, a workshop, grain dryer and silos, covered cattle yards (used to store excess grain during harvest), a large Dutch barn for hay and straw and a large

silage clamp (now used to store silage bales). The yard has a road running down its length on one side and is surrounded by pasture land on its remaining sides.

Farm A also had two field sites (FS) where there were rat populations.

Field site (FS) A – 1 was on the side of an old railway line on the embankment opposite the farm. The gradient of the bank at this point is approximately 1:1. Here all the unwanted burnable material was deposited up the bank and burnt. A large proportion of the waste dumped was the tailings from the grain drier and spoilt grain, also unwanted bags, both paper and woven material, used baler twine and empty containers of various materials, so it was an ideal site for rats to colonise. The old stone bed of the railway was used as a track for the tractors and trailers and both sides were littered with stacks of bricks/blocks, old machinery, corrugated tin sheets and the whole area was very overgrown providing ideal cover. This did not prevent tawny owls (*Strix aluco* L. 1758) hunting along the railway line and owls were, on occasion, seen taking rats from the site. Since finishing field work the length of the railway cutting has been cleared of the scrub although all the old material that is stored there still remains.

FS A – 2 was a site that was used by the farm to dispose of unwanted unburnable material, such as old pipes, washing machines, sheet metal and old building materials. It was located on the side of an arable field and an access track ran from the road around the field to the tip. There was a flat area adjacent to the track and beyond that a bank falling away from the field down which the material was tipped and then down to a stream. Like the burn area (FS A- 1) the tip became very overgrown during the spring and summer and none of it was ever cleared. Attempts have been made to cover up the tip with spoil from the foundations of a building project on the farm but all the underlying material remains and provides excellent harbourage for the rats.

Farm B was mainly an arable farm but ran a flock of ewes for lamb production. In addition the farm, in conjunction with the Game Conservancy Trust, conducted research into practical ways of farming that would also benefit the game birds that breed on the farm. The game-bird management has the added bonus of benefiting the farmland birds such as the skylark (*Alauda arvensis* L. 1758) (in 2001 there were 37 breeding pairs on the farm) and also many other species of which 49 species were recorded as breeding in 2001 (Stoate & Leake, 2002). The yard comprised two purpose built grain stores and associated drying unit, a lean-to for fertiliser and seed storage, a Dutch barn for hay and straw storage, a workshop, two open fronted covered barns that were used for lambing and storage at other times and six corrugated iron grain silos with two air blower units for grain drying. There was also a large open fronted shed that was used for storage plus the necessary sheep handling pens.

Farm B also had a field site where there was a rat colony.

FS B – 1 was located approximately 100 m from the farm buildings and was a long thin area known as the Ash Belt because of the ash (*Fraxinus excelsior* L) trees that were there or have relatively recently been planted. It is approximately 150 m by 10 m and is essentially a scrub area. Within this area were three pheasant feeders hung on posts that were in use from October to May. There was originally an 80 gallon oil drum within the area that was used to feed the pheasants (*Phasianus colchicus* L. 1758), again this was supported on posts. It was not filled during the time of this work and was subsequently removed.

Farm C has now become entirely pasture. It has grown cereals in the past but has now gone over completely to running a flock of ewes and rams for lamb production. The lambs are slaughtered and dressed off the farm and is then either sold to local butchers or is sold directly to the public off the farm. The yard comprises the farm

house that runs the complete length of the yard, a purpose built grain store that was also used for lambing, an open fronted barn that is used for storage and lambing, a Dutch barn for hay and straw storage (and lambing), a Dutch barn for storage and a stable complex. Running alongside the grain store are the sheep handling pens.

Figure 4.3 shows the coordinated site with the farms and field sites

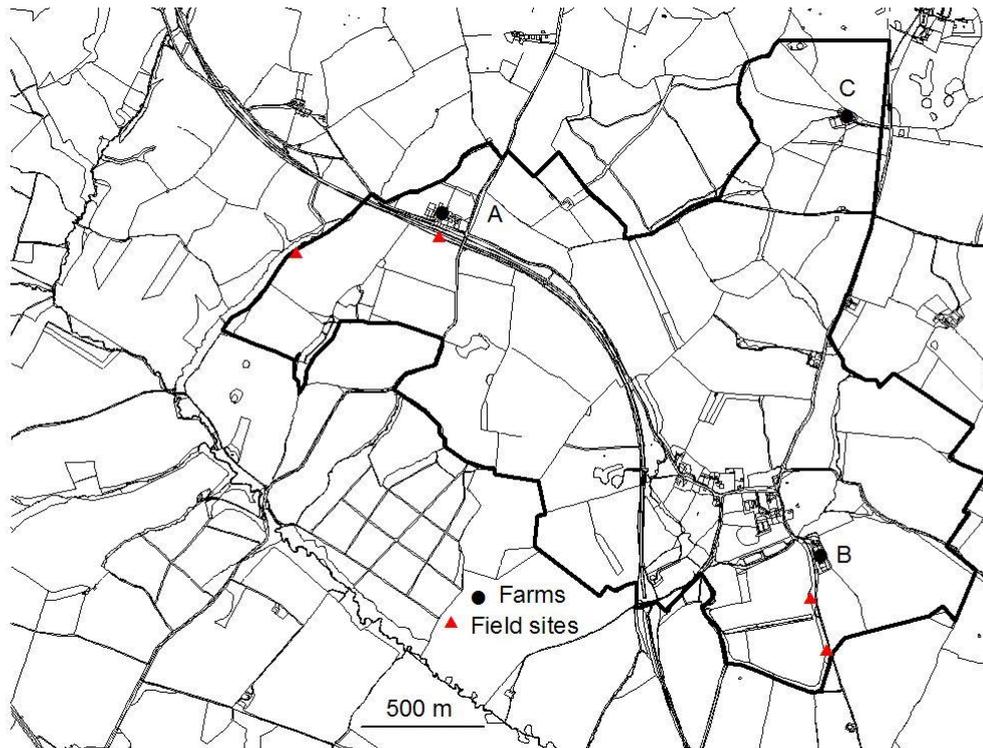


Figure 4.3 Map of the Leicestershire Coordinated area with the farms and field sites. (North is at the top of the page).

### Uncoordinated Area

Farm D was a County Council small holding and is run as a dairy unit, with a herd of Friesian cows and the calves bred go for beef production. The land was all pasture for grazing and for the production of silage and hay. The yard comprised the farmhouse, the milking parlour and dairy with adjoining bedding and feed yards for the dairy herd, three barns for cattle rearing, and a barn for storage. There were two feed silos (only one in use) and two earth walled silage clamps as well as a timber enclosed yard that was used to store the muck from the yards prior to spreading on the fields. In

addition there was a barn that was let to a local garden contractor and three open topped, feed storage areas that are used by the farmer to store brewer's grains (used malted barley grains, used as a cattle feed) and the garden contractor to store materials or rubbish prior to disposal. On some waste ground adjacent to the yard was a wood pile and hardcore heap.

Farm E was also a County Council small holding and is also run as a dairy unit, milking mainly Friesian cows. Again the farm was totally pasture land for grazing and silage and hay production. The yard comprised the farmhouse, the milking parlour and dairy, four open fronted buildings for calving and cattle rearing, three of which form two sides of the collecting yard and a separate cow yard. There were also two Dutch barns for fodder storage and two open fronted barns both of which are used for storage, plus two stables that were used as workshops. In addition there was a separate corrugated iron building and yard that were not in use.

Farms F and G were on the same site, separated by an access road and for the purposes of the rat censuses are considered to be one farm. Farm F was wholly a livestock farm, running a flock of ewes for lamb production, fattening a few beef animals and rearing day old chicks for poultry. The majority of the buildings, including the farmhouse, were of brick construction and formed three sides of a large concrete yard. The buildings around this yard, other than the farmhouse, were used to raise the poultry or as stables. Behind the yard were three barns, the largest of which was fully enclosed and used as sheep pens. A second barn was also enclosed on three sides and was used to house the beef animals in winter and sheep during lambing. The third barn was for hay and straw storage. Two of the barns and the back of some of the brick buildings also formed another open yard that was used as a feeding area for the sheep during lambing. An open area behind the farmhouse was used to store silage bales.

Farm G was also wholly livestock, but ran a herd of Friesian dairy cows and also raised the calves born on the farm for beef. There were a few brick built buildings that were used for the dairy parlour and storage but the majority of buildings comprised five large barns for housing the cattle and fodder storage. There was a large, purpose built muck pit and leading off from this was a large slurry pit. The contents of both these pits were applied to the farm land.

Farm H was a mixed farm that ran a flock of sheep for lamb production and also grew some cereals, mainly for winter animal feed. During the winter, in the run up to Christmas, turkeys were reared from day old for sale to the local population off the farm and through commercial outlets. The farm yard consisted of two farm houses and a small cottage that formed the three sides of a courtyard. There was one enclosed building that was used as a tool store and small workshop for the farm but the larger part was used by a local carpenter as his workshop. There were four barns, the smallest of which was a machinery and general store; the remaining three were used to store fodder and to house the livestock at the appropriate times.

Farm I was a part time small holding rented from the local landowner and consisted of a range of building and three fields. The tenant ran a small flock of sheep for commercial lamb production and a second flock of Jacob sheep, which were shown at the local and regional farm shows. The Jacob lambs were either kept for breeding or sold on to other enthusiasts. In with the commercial sheep were run a few beef animals. A few poultry were also kept for egg production. The farmer worked as a tractor driver for other local farmers. The yard consisted of two cottages and the original farmhouse with the original brick built barn and cattle yard. The yard was used for housing the sheep during lambing and the remainder was used for general storage. There were also three large barns that housed the sheep during lambing, the cattle during the winter and

hay and straw. There were also 11 corrugated steel grain silos, the majority of which were no longer used.

No field populations of rats were found within this uncoordinated area. At Figure 4.4 is the plan of the uncoordinated site

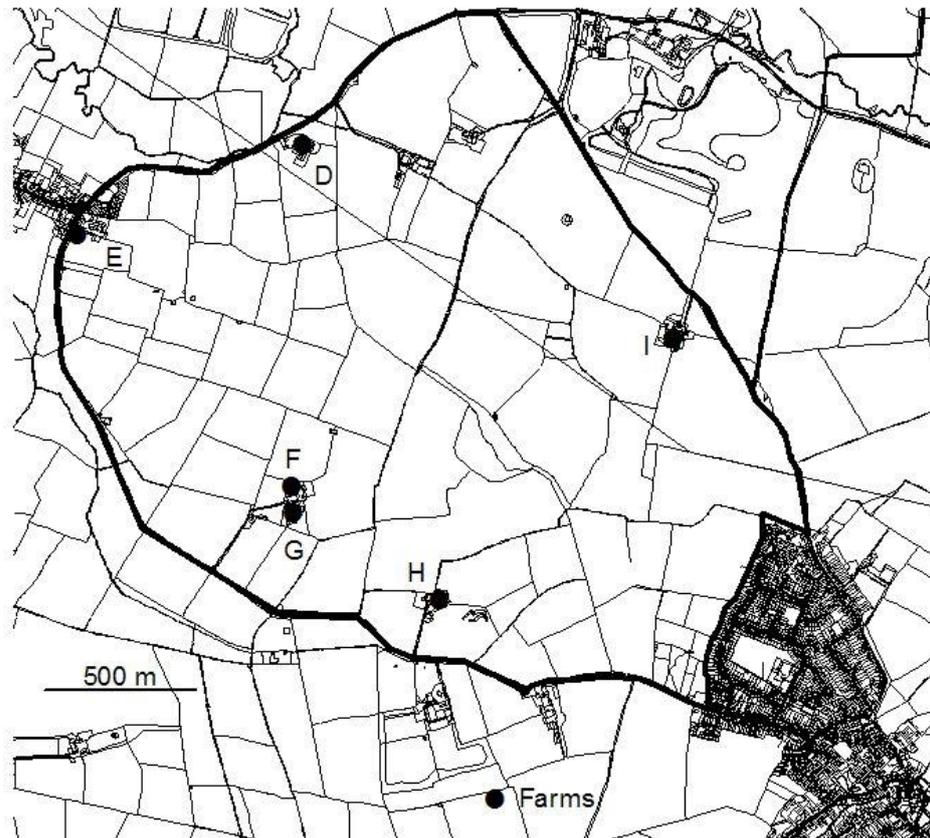


Figure 4.4. Map of the Leicestershire Uncoordinated area showing the farms. (North is at the top of the page).

#### 4.3.2 Yorkshire Site Descriptions

Figure 4.5 shows the locations of the research areas in Yorkshire in relation to York. The Coordinated site was situated 22 km NNE of the city of York, and the uncoordinated site 15 km to the east, 29 km NE of the city. The coordinated site comprised six farms (farms 1 – 6) and the uncoordinated site comprised four farms (farms 7 – 10). Within some of the farms there were also field sites where a rat population existed. Plans showing the layouts of the farmyards are at Annex G.

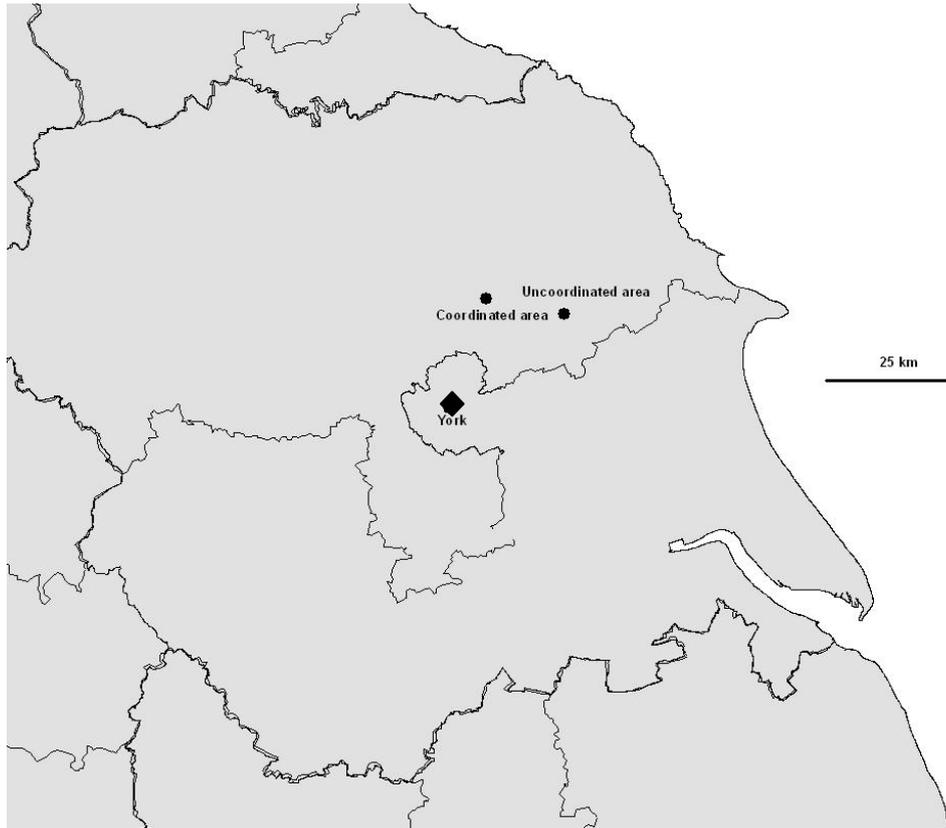


Figure 4.5. Map of the two Yorkshire research areas in relation to York. (North is at the top of the page).

### Coordinated Area

Farm 1 was a mixed farm that fattened pigs, grew potatoes and grain and had a limited amount of pasture for a flock of sheep. The major buildings in the farm, the farmhouse and a large barn were constructed from local stone; the remaining buildings were modern steel structures. The stone barn was divided into sections with an L-shaped workshop forming one full side and half the front side. There were also two large pig-pens and pens that were used for lambing. On the outside barn were the sheep handling pens. Pigs were also housed in two side-by-side open-ended Dutch barns with a large lean-to built down one side. There was a Dutch barn for fodder storage and a newly built enclosed barn for potato and grain storage.

Two field populations were found on farm 1.

FS 1 – 1 was the site of an old building that has long since disappeared except for two small pieces of wall. The area was used to store slurry pipes and surplus fodder bales.

FS 1 – 2 was a section of drainage ditch at the intersection of three arable fields with several pheasant feeders nearby.

Farm 2 was a mixed farm that ran a flock of sheep and also grew cereals. The farm therefore had a mixture of pasture and arable land. The farm-yard consisted of the house, two open fronted sheds for housing sheep during lambing, a large barn that had several uses, a lambing shed, a fodder store and when space was available a machinery store. There was also a Dutch barn for fodder storage and a small shed for poultry. Behind the poultry house was an area where there were polytunnels and beyond that another barn, all used for the sheep.

Farm 3 was a mixed farm with a flock of sheep, a large herd of pigs and a large flock of poultry. The land was part pasture for grazing and the production of hay/silage and part arable. The pigs were housed in a range of barns and there was a small shed for cattle. In addition there was a Dutch barn for fodder storage and a purpose built enclosed barn that was used as a machinery shed. There was also a grain drier, a grain store and a grain silo. The poultry were housed in sheds in an adjacent field where they ranged during the day.

Farm 4 had not been used as a farm for some considerable time but the buildings had been maintained by the landowner and had been rented out as a domestic and commercial property. The land was still actively farmed by the land owner. The farm was at least a mile from the nearest road and approached down a farm track. The complex comprised a separate house and range of red brick built buildings the majority of which adjoin. The larger part of the farmyard consisted of a barn with a separate

grain store above, a smaller barn, an open yard with small cattle yards leading from it and three stables. Beyond this was a further yard with a building that was divided into small sections, one of which had originally been a dairy, forming one side. The complex was being converted into domestic accommodation for the owner.

Farm 5 was not a farm, but livery stables. The site consisted of an open yard around which were situated the stables on three sides. Behind the stables on the right-hand side was a poultry house and in front of the stables on the left-hand side was a feed store. Across part of the open side of the yard was the farmhouse and garden.

Farm 6, like Farm 4, was no longer a working farm and was mainly domestic accommodation and stables. The buildings in this complex were set in a square with an open area in the middle into which the entrance road came with a track exiting to the adjacent farm-land. Some of the original farm buildings had been converted into domestic accommodation and some into stables.

At Figure 4.6 is a map of the Yorkshire coordinated area showing the farms and field sites.

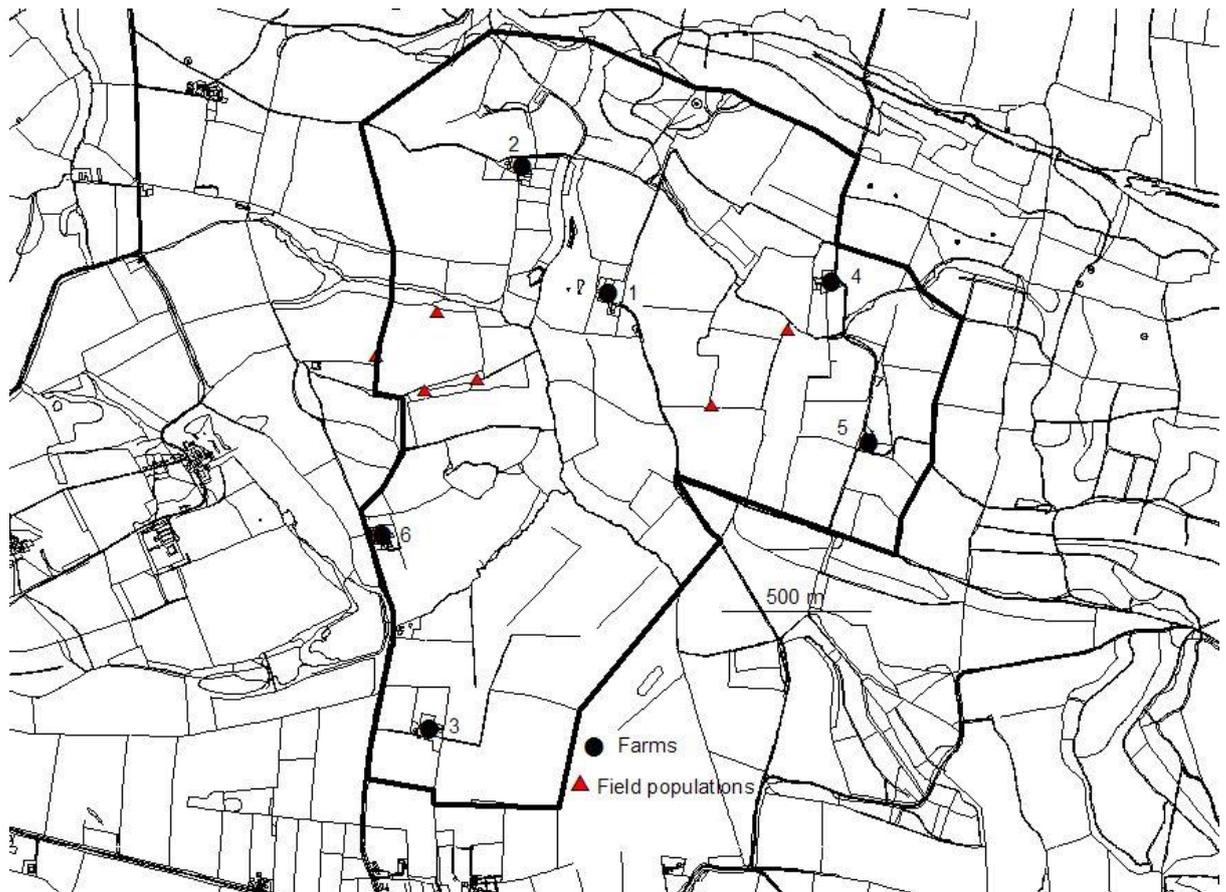


Figure 4.6 Map of the Yorkshire Coordinated area showing the farms and field sites. (North is at the top of the page).

#### Uncoordinated Area

Farm 7 was situated up a track about 50 m from the main road. It was a mixed farm, having a flock of sheep for lamb production and producing beef cattle. Geese were also raised. The arable land was used for the production of cereals and sugar beet. On the left-hand side of the entrance was a large barn that housed the grain drier and also some of the beef cattle. On the right-hand side of the entrance was the farmhouse garden and beyond that the farmhouse. Behind the farmhouse was a wood store and garage. At the top of the yard was another cattle yard with a feed mill inside. The silo for feeding to the mill was outside the barn.

Farm 7 had several field populations of rats all of which were located around pheasant feeders.

FS 7 – 1 to 5 were located along the farm track about 500 m from the farm and were located around pheasant feeders. The pheasant feeders were all 40-gallon oil drums that were stood on the ground. The drums had large holes cut in the bottom and were then filled with wheat, which as a result spilled out onto the ground. The drums had been placed on the far side of the hedgerow from the track, adjacent to the track in the field. The farm track at this point was below the level of the fields and the banks were peppered with the entrances to rat burrows and rat runs.

FS 7 – 6 was a site that at one time had been used to store large round straw bales, the remains of which were still visible, and had become the dumping ground for the waste bale netting and other material from the farm. This site was about 150m away from sites FS 7 – 1 to 5.

FS 7 – 7 to 9 were on the right-hand side of the farm track next to a hedge line. Like other field sites at this farm these populations were centred on pheasant feeders, 40-gallon oil drums and of similar construction to those at FS 7 – 1 to 5.

Farm 8 was a rather dilapidated collection of buildings, the majority of which were built from the local stone. All the farm buildings were on the left hand side of the yard with domestic accommodation, probably originally the farm workers' cottages, and a garage on the right hand side. Immediately on the left there was a raised grain store with an adjoining wood faced cattle yard and facing the entrance off the road was an open fronted machinery shed. Behind that was a chemical store and behind both of these was a large, enclosed cattle yard, beyond which was another barn that had not been in use for some considerable time. In front of this barn was a wood store.

Farm 8 had a field site with a population of rats.

FS 8 – 1 was situated across the road through the village, about 100 m from the farm. It was the corner of a grass field where large round bales of straw had been

stored for some considerable time. The bales were stacked on two groups along the two hedgerows nearest the farm at 90° to each other.

Farm 9 was a mixed farm that ran a flock of sheep for lamb production and grew cereals. The yard was long and thin with the entrance bounded by a general store on the right-hand side and a chemical store on the left. Behind the general store was the farmhouse. Beyond the chemical store was a woodwork shop and beyond that a large barn that acted as a grain store and sheep shed; behind this barn were the sheep handling pens. At the far end of the yard was a Dutch barn used for fodder storage. Behind the house were garages and a further workshop.

Farm 10 was a mixed farm growing arable crops. It also had a flock of sheep, beef cattle and some horses. The majority of the farm buildings were on the left-hand side of the track that ran through the yard. The farm-house was set back behind some stables and storage sheds. In the middle of the yard was a large square Dutch barn used for fodder storage, and around the yard were cattle sheds. On the right-hand side of the track was another house and garden and beyond that, a large grain store and drier complex.

Farm 10 had a field population of rats.

FS 10 – 1 was a located on a disused railway line beyond the farm down the track that ran through the farmyard. It was a dumping site for unwanted material from the farm, included in which were all the tailings from the grain drier and spoilt grain. The railway line was situated on an embankment and all the farm waste was tipped down the bank on the side opposite to the stream.

At Figure 4.7 is a map of the uncoordinated area showing farms and field sites.

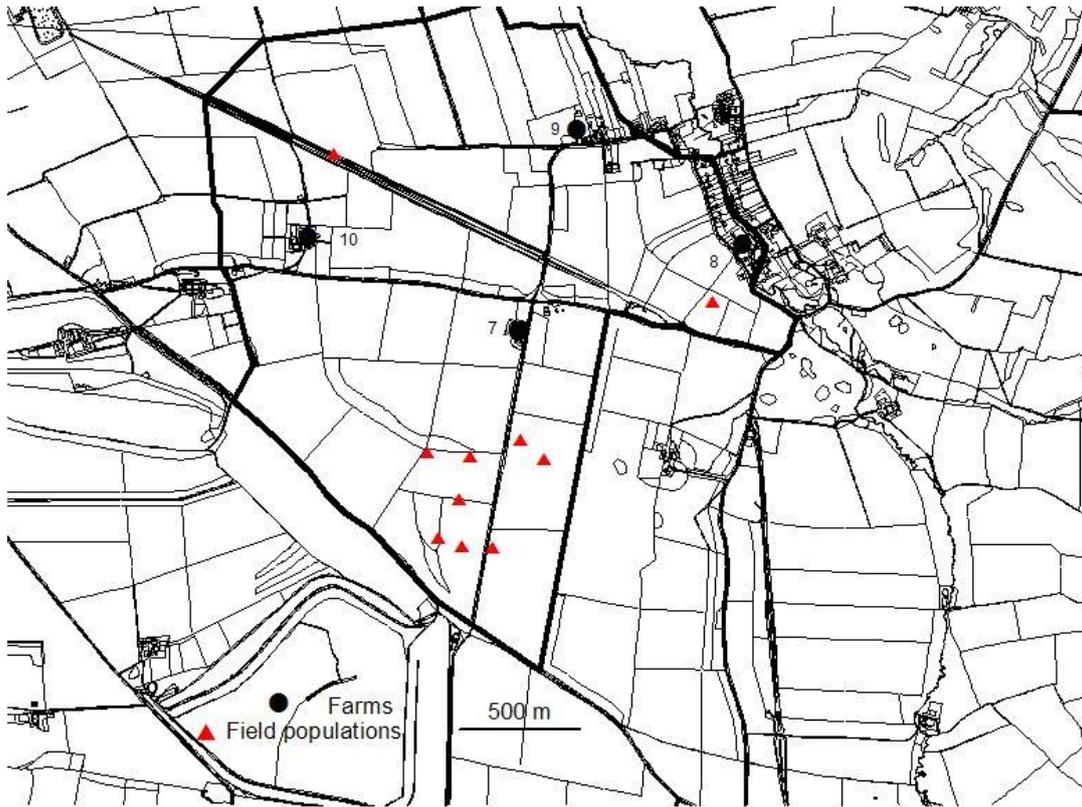


Figure 4.7 Map of the Yorkshire uncoordinated area showing farms and field sites. (North is at the top of the page)

## 4.4 MATERIALS AND METHODS

### 4.4.1 Rat Census

Rat censuses were carried out initially every six weeks and then changed to every eight weeks. Censuses (critically speaking, population estimates) were carried out in accordance with the indirect method devised by (Quy *et al.*, 1993). This method records rat's footprints on carbon-coated tracking plates, 200 x 100 mm, that were cut from Marley floor tiles (four from a 300 mm x 300 mm tile). Before cutting, the tiles were covered with a self-adhesive plastic sheeting (ESPO, Leicester, book covering material), the plastic covering was trimmed to size and then rubbed with a scouring pad to produce a matt surface. The tiles were cut using a homemade jig and a Stanley knife. They were then painted with a suspension of carbon, activated, Norit powder (Lancaster Synthesis, Morecambe, England) in 100% Industrial Methylated Spirit (IMS) (40 g in one litre). The IMS evaporated within a minute or two, or sooner in hot weather leaving the carbon powder adhering to the matt plastic surface. The plates can be left out in all weathers because they are waterproof (Shepherd & Greaves, 1984). The carbon was only washed off if the plate is left under a constant drip or outflow from a broken drainpipe. An example of a rat marked tracking plate is at Figure 4.8.



Figure 4.8. Example of rat foot prints on a tracking plate (Picture courtesy of C. R. Brakes)

Site maps were prepared for all the Leicestershire farmyards being used, taking the plan from Magic Interactive map site (<http://www.magic.gov.uk/website/magic/>). This was enlarged with a photocopier to produce an A4 sized plan that was then traced to produce a fine line plan. On this was overlaid a 10 x 10 meter grid, using the scale bar that came with the original site plan (enlarged with the original plan). For the Yorkshire farms, already available Ordnance Survey material was used to produce similar site plans. An example of a site map is at Annex H.

The tracking plates were laid out, using the gridded plans, with four plates to a 10 x 10 meter square which gave a density of 400 plates hectare<sup>-1</sup>. Not all squares would have contained plates, which were only put down if there were definite signs of rats, such as trails, droppings or grease smears along walls, or if the area was one in which one would expect to find rats, such as in a grain drier or around fodder bales. The plates were left out for approximately 24 hours and then inspected. If there were signs of any animal having trodden on the plate it was replaced with a fresh one. All plates with rat footprints on were scored daily, using the scoring system devised by Quay *et al.*, (1993). All marked plates were repainted with the IMS/carbon powder suspension and reused. The plate scoring system was as follows:

Unmarked plates	0
Plates with less than 25% coverage of rat prints	1
Plates with between 26 and 95% coverage of rat prints	2
Plates with more than 96% coverage of rat prints	3

Plates were placed out for three or four consecutive nights (Monday to Friday) and then collected in. The scores for all plates out in a yard or field site were totalled for each day and at the end of the three or four nights data collection the totals were added together; that total was divided by three or four, depending on whether the census lasted for three or four days, and then multiplied by 1.56 to produce a population estimate for that yard or field site (Quy *et al.*, 1993). This calibration procedure was validated by Quy *et al.*, (1993) on farms in southern England. The minimum length of time that a census could last to get a valid figure was 3 days but the ideal time was 4 days. For the purposes of this thesis, population estimates were carried out from September 2003 through to January 2006, although they will continue to be carried on by staff of the Central Science Laboratory (CSL) in Yorkshire until the end of the Defra funding of the project in 2007.

#### 4.4.2 Rodent Control

In the uncoordinated sites, the farmers were left to do their own rodent control as they had always done it, with no direction from the researchers. Rodent control was carried out on the coordinated sites in Leicestershire by the author and in Yorkshire by Dr Mark Lambert, a member of staff at CSL. A baiting session was triggered when the current census indicated that there was a population in excess of 30 rats on any one farm. In Leicestershire a baiting session was carried out over the three farms in both

farm buildings and field sites. In Yorkshire a population in excess of 30 on a farm only triggered a baiting on that farm, or if there was more than one farm with this size of population then the baiting was conducted over those farms. The reason for the difference was that in Leicestershire there were fewer rats and therefore there were fewer bait boxes used (86) which could be all got round and replenished as necessary in a day. In Yorkshire, with considerably more rats, there were many more bait boxes used (135) and it was not physically possible to get round all the boxes and replenish as required in a day, and therefore the decision was made to only bait those individual farms where the population was above 30 rats.

Using the census data to gauge the number of boxes required, bait boxes were set out on all the sites where rats were present in any numbers. It was not possible to put bait boxes at every site as for example there were some 150 pheasant feeders on farm B alone and there were signs of rats at all of them, but plates indicated that the numbers of animals at each feeder were limited to less than five at the feeders that were sampled ( $n = 20$ ). The decision was therefore taken not to bait at the pheasant feeders.

The boxes were made in the Biology department workshops to a design from CSL and were much more “rat friendly” than a normal commercial bait box, having one large bait holding area and two entrances; this allowed a rat feeding in the box to escape, should a dominant rat enter, without having to pass the dominant rat as would be the case with the commercial bait box. At Figure 4.9 are photographs of the CSL bait box and a commercially designed bait box.



Figure 4.9a. CSL designed bait box



Figure 4.9b. Commercial bait box

The boxes used (Fig 4.9a) were made from plywood and fitted with a galvanised steel lid, they measured 340 mm (l) x 240 mm (w) and 130 mm (h) (internal measurements)

The bait boxes were set out at least three days before baiting began to allow the rats to become acclimatised to them. At the end of the session they were left *in situ* wherever possible. If that was not possible they were moved to another location where they could continue to weather and take up the normal smells of a farm so that at the next baiting session the rats would at least be familiar with their smell. It was not always possible to put moved boxes back to the same location for subsequent baiting sessions but leaving the boxes out around the farm seemed to work very well as bait take in moved boxes seemed to be no different from those that had remained in the same location. Leaving the boxes *in situ* did have other effects. The rats became so familiar with them that some of them were used as nest boxes (Figure 4.10a). The only other problem encountered with these boxes was that in one or two locations the wood mice (*Apodemus sylvaticus*) covered the bait with grain heads, leaves, twigs and or stones (Figure 4.10b).



Figure 4.10a. Rat nest in bait box



Figure 4.10b. Wood mouse filled bait box

The baiting was carried out over a three week period, which is the industry standard period for control using anticoagulants. This time period was used because modern anticoagulant rodenticides do not act immediately and the rats therefore do not associate illness, i.e. feeling ill or bleeding, with the bait ingested. Social interactions prevent all rats from feeding at bait simultaneously (Dubock, 1982). Three weeks baiting is needed for a fatal dose of the rodenticide to be eaten by most rats in the local population. The bait used was a 0.005% difenacoum mixture that was made up by CSL staff (9 kg pinhead oatmeal (Killgerm, Osset, West Yorkshire), 500 g castor sugar (ASDA), 250 g corn oil (ASDA) and 250 g of 0.2% liquid concentrate Difenacoum (Sorex)) mixed in a commercial bakery mixer for 15 minutes. This mixture was known from experience at CSL to be more palatable to rats than the normal commercial bait as there was no bittering agent (i.e. Bitrex) and it was the same colour as whole grain, which helped reduce the neophobic reaction to the bait.

A standard unit of 200 g of bait was placed in each bait box at the start of baiting period and a tracking plate was placed at one of the entrances. Every box was checked on alternate days, (Monday, Wednesday and Friday) and if there were signs of bait having been taken, the remaining bait was weighed and the weight made up to 200 g. If all the bait had been taken then 400 g of bait was placed in the box. A record

was kept of the bait taken and what had been into the box, as seen by the evidence from the tracking plate, which was replaced with a fresh plate if it was marked at all. At the end of the baiting period, all the bait and plates were removed and the bait boxes were left out *in situ* and used in the same location for subsequent baiting sessions, if appropriate. Farms are constantly changing, and certainly during a three week period during the winter there could be quite considerable change occurring, which meant that occasionally bait boxes had to be moved during a session. If the situation had changed at a bait station between baiting sessions, such as the removal of bales which left the bait box exposed, then the bait box was relocated one week before the next baiting session began. This allowed the rats to become familiar with the box in its new location before baiting began for the following session.

#### 4.4.3. Density dependence

The population estimates were converted onto a value using the formula  $(N_{t+1})/N_t$ , where  $N_t$  is the population estimate and  $N_{t+1}$  is the following population estimate. This produced a value,  $R$ , and this was plotted against  $N_t$ . A trend line was drawn and if this had a negative slope it would show that density dependence was controlling the size of the population. Graphs were drawn for the whole areas, Yorkshire and Leicestershire coordinated and uncoordinated sites and then for the farm buildings and field sites within each area.

#### 4.4.4 Bait take

Records were maintained of the amount of bait taken and whether it was rats or mice entering each box. Graphs were plotted of total bait take from all farms during each baiting session. In Leicestershire this was six sessions during the period of the

study and in Yorkshire there were 18 baiting sessions in total, up to March 2006. On average the farms in the York region were baited seven times (range 2 – 12) during the research period, however, there were two farms that were only baited six times in total (one four times and one twice). Farm four had only four baiting sessions before they were stopped because the owner was due to commence building work on the site to convert it into living accommodation and for health and safety reasons work there could not be continued. Baiting on Farm five was discontinued after only two baiting sessions because the owner there was very conscientious about rodent control and as soon as he saw a rat or rat signs he set bait. It was agreed between the owner and Mark Lambert, the member of the CSL staff, that only the owner would conduct rodent control on these premises. These two farms have therefore been removed from the data set. When this was done the average number of baiting sessions on the remaining farms increased to eight (range 6 – 12).

In order to analyse trends in bait take the year was divided into two halves, a winter period (October – February) and a summer period (March – September). If rats move into farms in autumn, during the winter periods bait consumption within the farmyards should be at its highest. Graphs were drawn for both the coordinated sites using all the data from the farm buildings and field sites to see if there was any pattern visible in rodenticide take.

#### 4.5 DATA ANALYSIS

The raw population estimates are at Annex I. In the first instance graphs were drawn, using all the raw census data plotted against census date to see if there were any trends visible in the populations produced by the censuses. For Leicestershire this was with 16 and for Yorkshire 17 sets of census data.

For a comparison of the effects of the different treatments between the two areas to be made, adjustments were made to the two sets of data to be able to tie in the census dates. For the Leicester data the first census was removed and for the Yorkshire data the last two censuses were removed, giving 15 sets of census data for each area. This then brought the two sets of data into line as far as census date was concerned. There were a large number of zeros on individual farms in the Leicester data and so all the data for both areas were grouped by census period, producing six time periods, (January / February, March / April .....November / December).

The adjusted census data were tested for normality using the Kolmogorov-Smirnov test and for homogeneity of variance. No sets of data were normal or of equal variance so the data were then transformed, either by ranking, square root,  $\log_{10}$ , or  $\log_{10} + 1$  to produce sets of data that were approximately normal and of equal variance. All data were then compared using ANOVA with three factors being used, Location, (York or Leicester), Treatment (Coordinated or Uncoordinated), Month (as set out above). Three two-factor interactions were examined: Location \* Treatment, Location \* Month and Treatment \* Month. A comparison was also carried out of the data between York and Leicester identical treatments; here the factors were Location and Month (both as shown above), and again ANOVA was used.

## 4.6 RESULTS

### 4.6.1 Population Trends

Figures 4.11 and 4.12 are the graphs of the census data for the Leicestershire Coordinated and Uncoordinated sites and Figures 4.13 and 4.14 are the graphs of the census data for the Yorkshire Coordinated and Uncoordinated sites. The initial analysis ignores the clear annual cycles and simply draws linear trend lines. These lines show whether population census estimates tended to increase or decrease during the study, in order to allow comparison of the two treatments. Note that successive points in time series are not strictly independent, given the nature of the indirect census method and the intervals between census dates, this was felt to be not too large a problem.

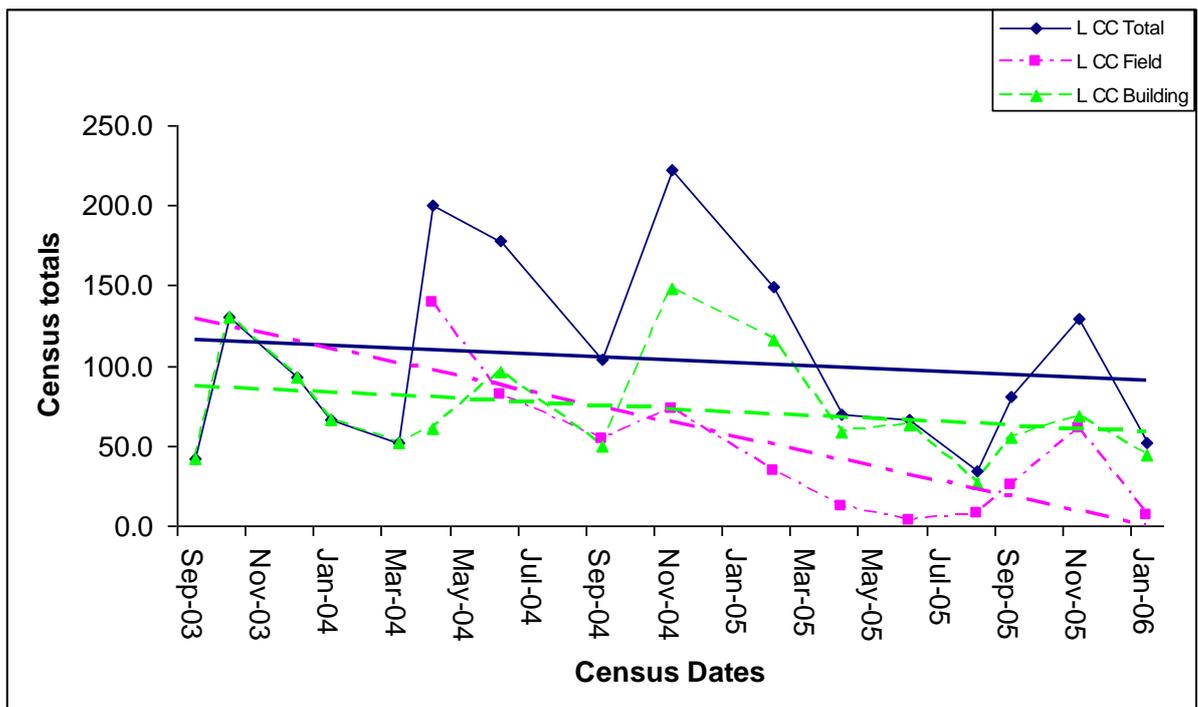


Figure 4.11. The base census data for all the Leicestershire census data at the coordinated site

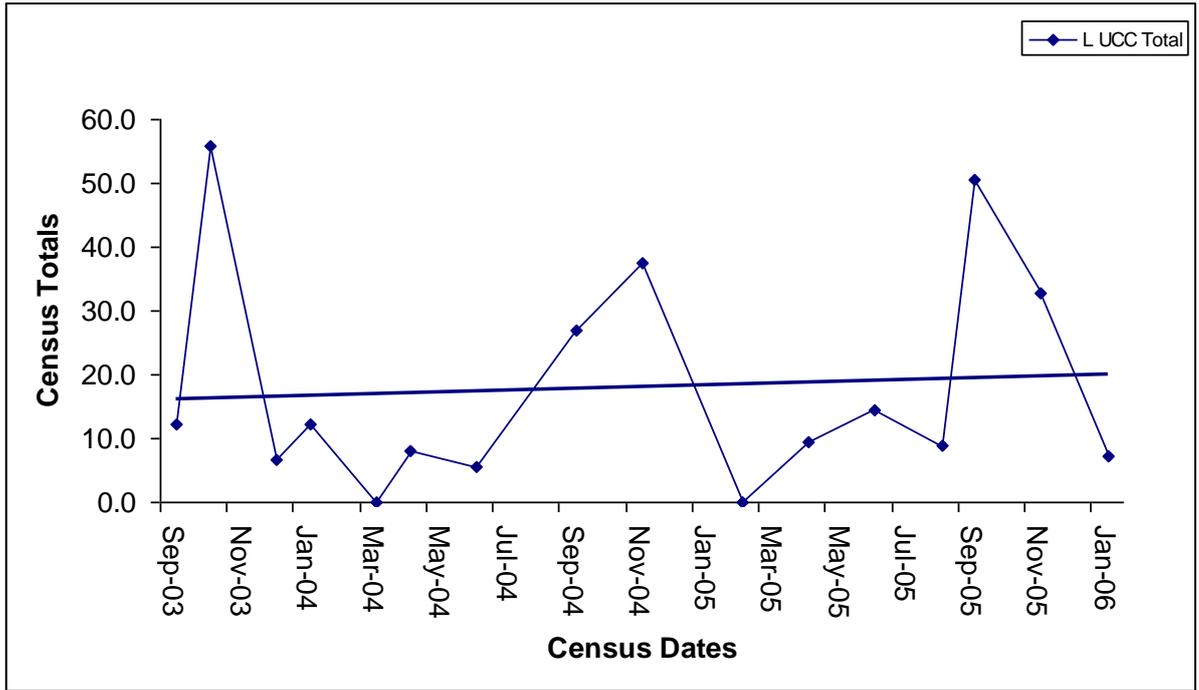


Figure 4.12. The base census data for the Leicestershire census data at the uncoordinated site

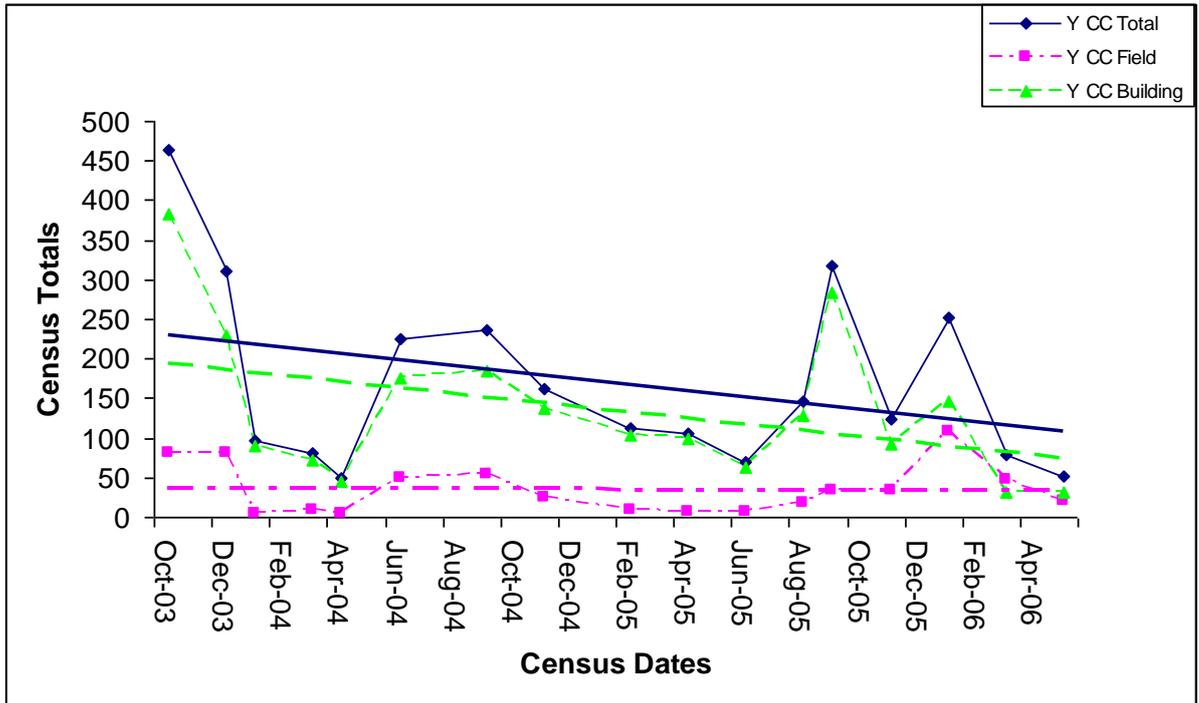


Figure 4.13. The base census data for all the Yorkshire census data at the coordinated site

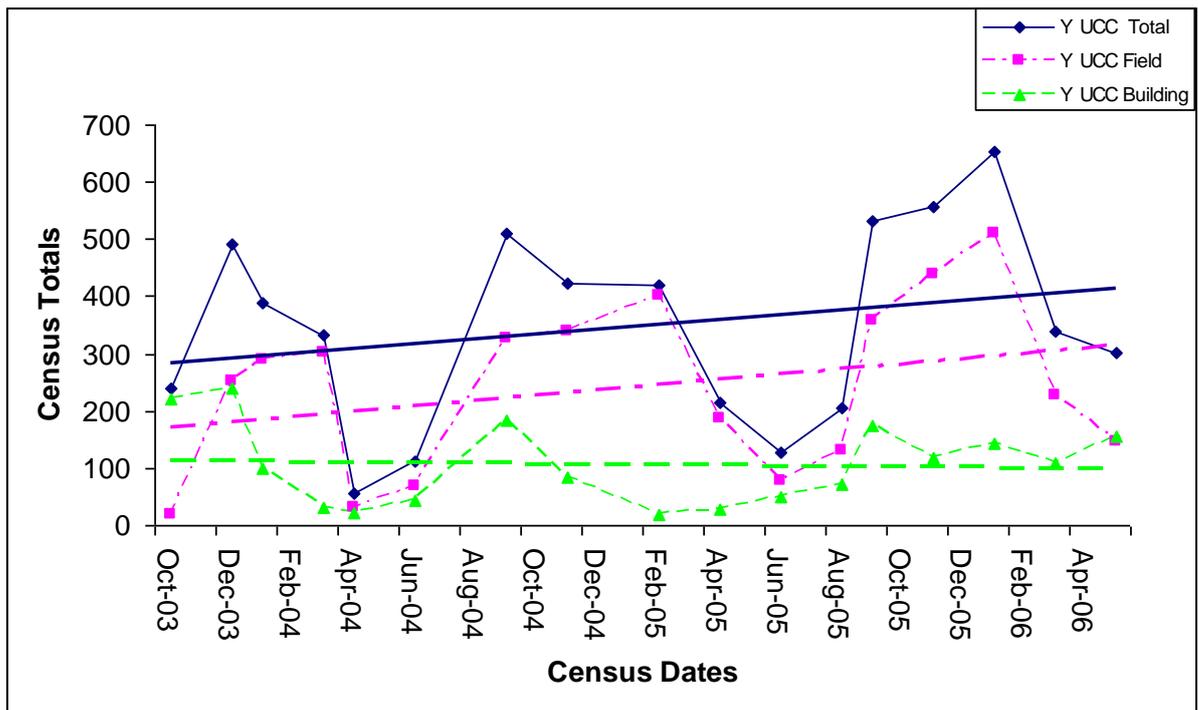


Figure 4.14. The base census data for the Yorkshire census data at the uncoordinated site

Trend lines and their equations were produced for all graphs and the equations are given below in Table 4.1, using all the available census data (as at July 06).

Area and Location of Population	Trend Line Equation
Leicester CC Total population	$y = -0.9084x + 1246.7$
Leicester CC Field population	$y = -4.5977x + 5848.5$
Leicester CC Building population	$y = -1.0199x + 1355.6$
Leicester UCC Total population	$y = 0.1371x - 154.42$
York CC Total population	$y = -8.1103x + 242.64$
York CC Field population	$y = -0.1471x + 36.029$
York CC Building population	$y = -7.9632x + 206.61$
York UCC Total population	$y = 8.1838x + 273.46$
York UCC Field population	$y = 9.1127x + 159.87$
York UCC Building population	$y = -0.9289x + 113.6$

Table 4.1. Equations of the trend lines for population census data.

The trend lines in the graphs above and the equations for the trend lines show that for the Leicestershire and Yorkshire coordinated areas and the Yorkshire uncoordinated area building populations the population trends are downwards. In the Leicester uncoordinated area total and the Yorkshire uncoordinated area total and field populations, the trends were upwards. These trends were in line with expectations for the coordinated areas. The Leicestershire uncoordinated area total is also the building population as there were no field population.

In the comparison of York against Leicester, both coordinated and uncoordinated areas, the census data were ranked in order satisfy the assumptions required for ANOVA. The results of the ANOVA are shown below in Table 4.2

<b>Source</b>	<b>DF</b>	<b>SS</b>	<b>SS</b>	<b>MS</b>	<b>F</b>	<b>P</b>
Location	1	8073.6	8073.6	8073.6	107.08	<0.001
Treatment	1	299.3	299.3	299.3	3.97	0.052
Month	5	2000.2	2000.2	400.0	5.31	0.001
Location*Treatment	1	3776.3	3776.3	3776.3	50.09	<0.001
Error	51	3845.2	385.2	75.4		
Total	59	17994.5				

Table 4.2. ANOVA results for ranked total census population figures

The above table shows that the location, the month and the interaction between location and treatment were all significant ( $p < 0.001$ ). Although the p value for treatment is above the normal value where it is considered to be significant ( $p = 0.05$ ), ranking of data is not the best transformation and under these circumstances the treatment is considered to be borderline significant ( $p = 0.052$ ) and that therefore it could be said that there could be a difference between coordinated and uncoordinated treatments. Yorkshire was the more significant of the two areas (ranked mean

populations: York 42.1, Leicestershire 18.9) and the coordinated treatment more significant than the uncoordinated treatment (ranked mean populations: York 32.7, Leicestershire 28.3). Further analysis, using interaction plots, showed that in Yorkshire the coordinated system was working better than the uncoordinated system. In Leicestershire the reverse was true with the uncoordinated system producing better results than the coordinated system.

The raw census data for the farm buildings were square root transformed and analysed, as shown in Table 4.3 below.

<b>Source</b>	<b>DF</b>	<b>SS</b>	<b>SS</b>	<b>MS</b>	<b>F</b>	<b>P</b>
Location	1	285.32	285.32	285.32	53.88	<0.001
Treatment	1	178.73	178.73	178.73	33.75	<0.001
Month	5	257.98	257.98	257.98	9.74	<0.001
Location*Treatment	1	26.49	26.49	26.49	5.00	0.030
Error	51	270.07	270.07	5.30		
Total	59	1018.60				

Table 4.3. ANOVA results for square root transformed census data for the farm buildings populations

The analysis of the data for the farm buildings shows that location, treatment and month are very significant ( $p < 0.001$ ) and the interaction between location and treatment less so ( $p = 0.030$ ), but still significant. Yorkshire was the more significant of the two areas (mean sq. rt. population: Yorkshire 10.4, Leicestershire 6.1) and the coordinated treatment more significant than the uncoordinated (mean sq. rt. population: Yorkshire 10.0, Leicestershire 6.5). Further analysis, using interaction plots, showed that in both areas the uncoordinated system was working better than the coordinated system.

Analysis was then carried out of comparable treatments. The census data for the total populations for the coordinated area were  $\text{Log}_{10}$  transformed. The results of the analysis are below in Table 4.4.

<b>Source</b>	<b>DF</b>	<b>SS</b>	<b>SS</b>	<b>MS</b>	<b>F</b>	<b>P</b>
Location	1	0.91	.091	0.91	20.33	<0.001
Month	5	0.59	0.59	0.12	2.63	0.051
Error	23	1.03	1.03	0.04		
Total	29	2.54				

Table 4.4. ANOVA results of  $\text{Log}_{10}$  transformed census data for the York and Leicester Coordinated area total populations

For the total populations in the coordinated area it was only the location that was significant ( $p < 0.001$ ) with Yorkshire being more significant than Leicestershire ( $\text{Log}_{10}$  means: Yorkshire 2.2, Leicestershire 1.8). The month (trapping periods) was not significant.

The farm buildings population census data from the coordinated areas was square root transformed and analysed. The results are in Table 4.5.

<b>Source</b>	<b>DF</b>	<b>SS</b>	<b>SS</b>	<b>MS</b>	<b>F</b>	<b>P</b>
Location	1	20.58	20.58	20.58	2.49	0.128
Month	5	88.09	88.09	17.62	2.13	0.098
Error	23	190.30	190.30	8.27		
Total	29	298.98				

Table 4.5. ANOVA results of square root transformed census data for the York and Leicester Coordinated area farm buildings populations

In the analysis of the farmyard population data for the coordinated areas, neither the location nor the month was statistically significant ( $p = 0.098$ ).

The base field population census data from the coordinated areas were  $\text{Log}_{10} + 1$  transformed. The results are in Table 4.6.

<b>Source</b>	<b>DF</b>	<b>SS</b>	<b>SS</b>	<b>MS</b>	<b>F</b>	<b>P</b>
Location	1	709	598	598	0.41	0.532
Month	5	4461	4461	892	0.61	0.697
Error	23	28011	28011	1474		
Total	29	33181				

Table 4.6. ANOVA results of  $\text{Log}_{10} + 1$  transformed census data for the York and Leicester Coordinated area field populations

As with the farmyard populations in the coordinated areas, neither the location nor the month was statistically significant.

The total population census data from the uncoordinated areas were  $\text{Log}_{10}$  transformed and analysed. The results are in Table 4.7

<b>Source</b>	<b>DF</b>	<b>SS</b>	<b>SS</b>	<b>MS</b>	<b>F</b>	<b>P</b>
Location	1	11.37	11.30	11.30	185.79	<0.001
Month	5	1.62	1.62	0.32	5.31	0.003
Error	23	1.28	1.28	0.06		
Total	29	14.27				

Table 4.7. ANOVA results of  $\text{Log}_{10}$  transformed total census data for the York and Leicester uncoordinated area populations

In the uncoordinated areas the analysis of the transformed data showed that both location ( $p < 0.001$ ) and month ( $p = 0.003$ ) were statistically significant. Yorkshire was more significant than Leicestershire ( $\text{Log}_{10}$  means: Yorkshire 2.2, Leicestershire 1.2).

The farm buildings population census data from the uncoordinated areas were square root transformed and analysed. The results are in Table 4.8

<b>Source</b>	<b>DF</b>	<b>SS</b>	<b>SS</b>	<b>MS</b>	<b>F</b>	<b>P</b>
Location	1	243.73	243.73	243.73	53.91	<0.001
Month	5	171.07	171.07	34.21	7.57	<0.001
Error	23	103.98	103.98	4.52		
Total	29	518.78				

Table 4.8. ANOVA results of square root transformed farm building census data for the York and Leicester uncoordinated area populations

The analysis of the farmyard population estimates for the uncoordinated areas showed that both location and month were statistically significant ( $p < 0.001$ ).

Yorkshire was the more significant of the areas (sq. rt. mean populations: Yorkshire 9.4, Leicestershire 3.7).

In all cases the most significant month was the two-month trapping period September / October followed by November / December and then January / February.

The farm building and the field populations from both areas and treatments were  $\text{Log}_{10}+1$  transformed and analysed. The results of the analysis are in Table 4.9.

<b>Source</b>	<b>DF</b>	<b>SS</b>	<b>SS</b>	<b>MS</b>	<b>F</b>	<b>P</b>
Farmyard or Field	1	0.72	0.72	0.72	1.76	0.187
Error	114	46.47	46.47	0.41		
Total	115	47.19				

Table 4.9. ANOVA results of  $\text{Log}_{10}+1$  transformed farm building and field census data for the York and Leicester coordinated and uncoordinated area populations

There is no statistically significant difference between the farmyard and field population estimated ( $p = 0.187$ ). The null hypothesis that there would a difference between farmyard and field populations is rejected.

#### 4.6.2 Time Series Analysis

Figure 4.15 shows the rat populations in all four areas. Yorkshire populations are larger than in Leicestershire (especially Censuses 1 and 2), and the uncoordinated area in Leicestershire has had especially low numbers from the start. It is interesting to note the collapse of both uncoordinated populations at Census 5 (Spring 2004).

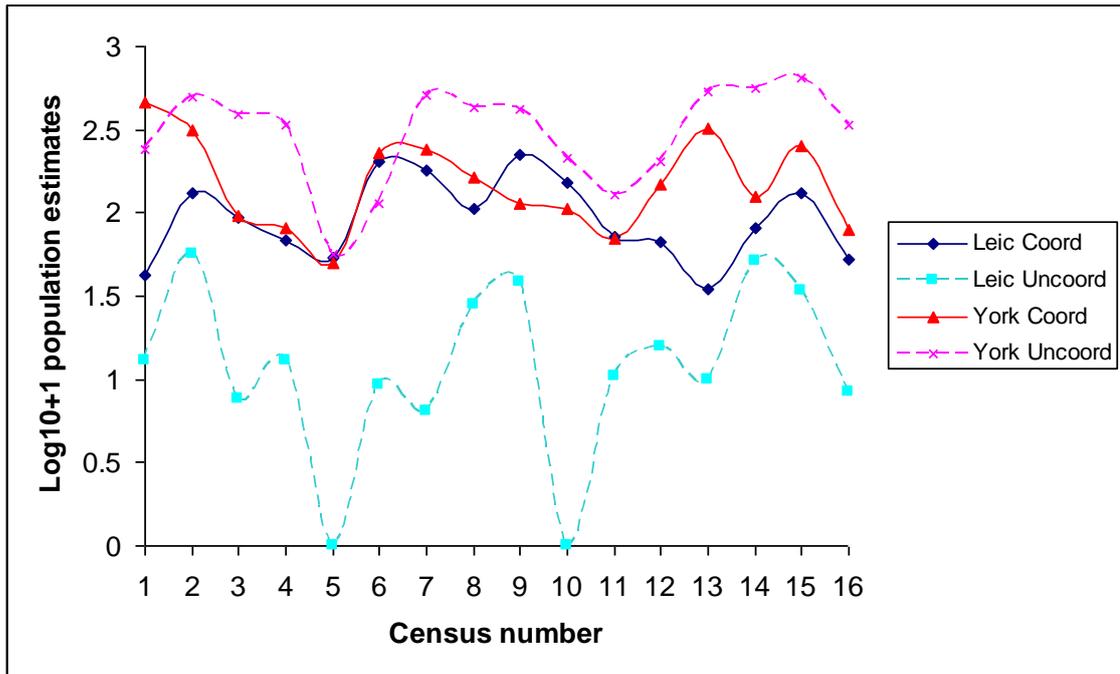


Figure 4.15 Total  $\text{Log}_{10}+1$  population estimates for all areas

Synchrony. *A priori*, it would have been predicted that there would be greater synchrony of population changes within a county than between counties because of local environmental effects. The lowest correlations in line with this prediction were between the Yorkshire building populations in the coordinated and uncoordinated areas (Pearson correlation  $r = 0.554$ ; d.f. = 1;  $p = 0.026$ ). There was also a correlation found between the Yorkshire and Leicestershire uncoordinated populations (Pearson correlation  $r = 0.639$ ; d.f. = 1;  $p = 0.008$ ).

Earlier analysis (Sep 03 – Jun 05) had indicated that there was a very high synchrony between the log population estimates in both coordinated areas from census

3 onwards (Pearson correlation  $r = 0.82$ ; d.f. = 1 (15);  $p < 0.001$ ). This was unexpected and suggested that the parallel coordinated treatments in Leicestershire and Yorkshire were synchronising the two populations and setting the population dynamics into similar patterns of change, even though rat control was not triggered at identical times in the two areas. The log population estimates for the uncoordinated areas were less well synchronised (Pearson correlation  $r = 0.55$ ; d.f. = 1 (15);  $p < 0.01$ ) but still significantly correlated. Over the whole research period the synchrony between the coordinated areas has not been maintained and there is now no correlation between them (Pearson correlation  $r = 0.08$ ; d.f. = 1 (15);  $p = 0.769$ ). Between the uncoordinated areas the synchronisation has increased and they were still significantly correlated (Pearson correlation  $r = 0.639$ ; d.f. = 1 (15);  $p = 0.008$ ).

Delayed Synchrony and cycling. Figure 4.16 shows a most curious feature for the Yorkshire data. Although the linear correlation between coordinated and uncoordinated sites was low, joining the points in temporal sequence provides evidence of *delayed synchrony* between the coordinated and uncoordinated areas. Fig. 4.16 suggests a cycle with a period of about one year and is reminiscent of predator-prey plots. There is one full cycle covering the year September 2003 – September 2004 with a less well defined cycle for the period September 2004 – September 2005. The plot then loops back over itself after September 2005 but broadly seems to repeat the pattern to April 2006.

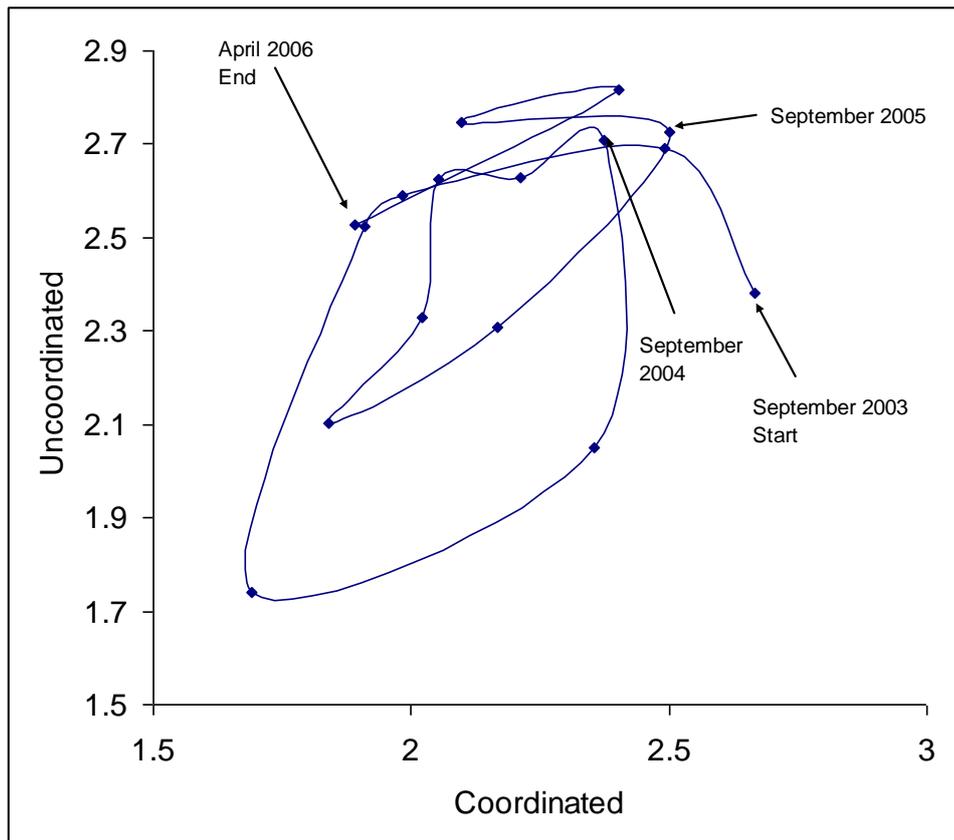


Figure 4.16.  $\text{Log}_{10}$  rat population estimates for Yorkshire Coordinated and Uncoordinated areas showing delayed synchrony

#### 4.6.3 Density Dependence

The population estimates were used to determine if any of the populations were being controlled by internal forces such as density dependence or whether it was the outside influences such as rodent control that was controlling population size. None of the graphs drawn showed a negative trend line (Figures 4.17a & b and 4.18a & b) and therefore it was concluded that density dependence was not the controlling factor in determining the size of the population and that other factors were at work.

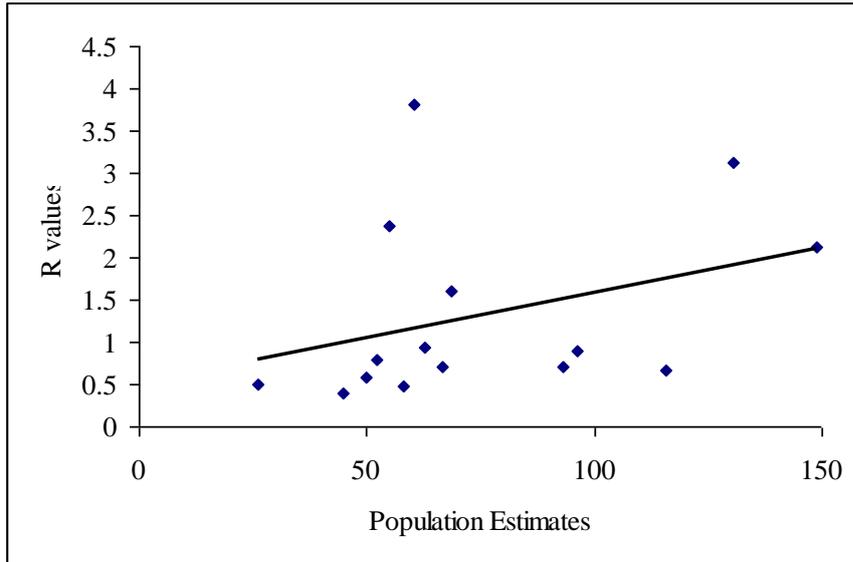


Figure 4.17a. Density dependence determination – Leicestershire coordinated control area

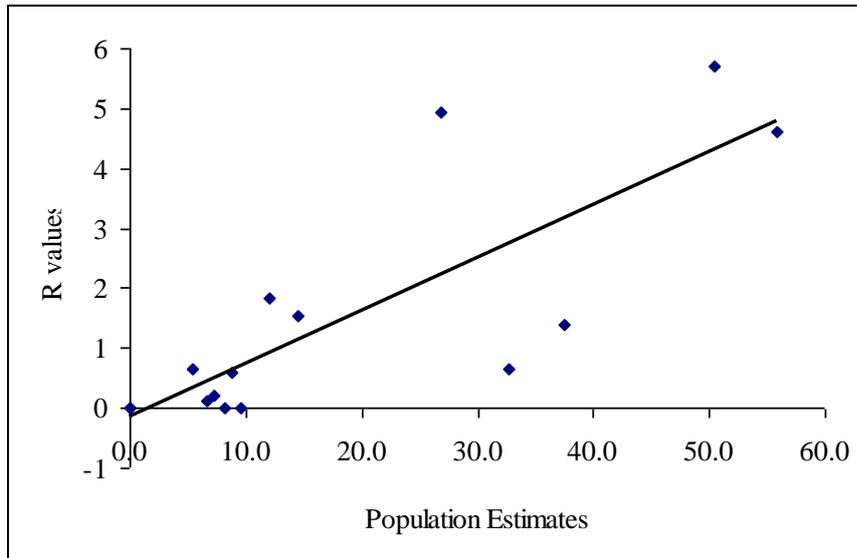


Figure 4.17b. Density dependence determination – Leicestershire uncoordinated control area.

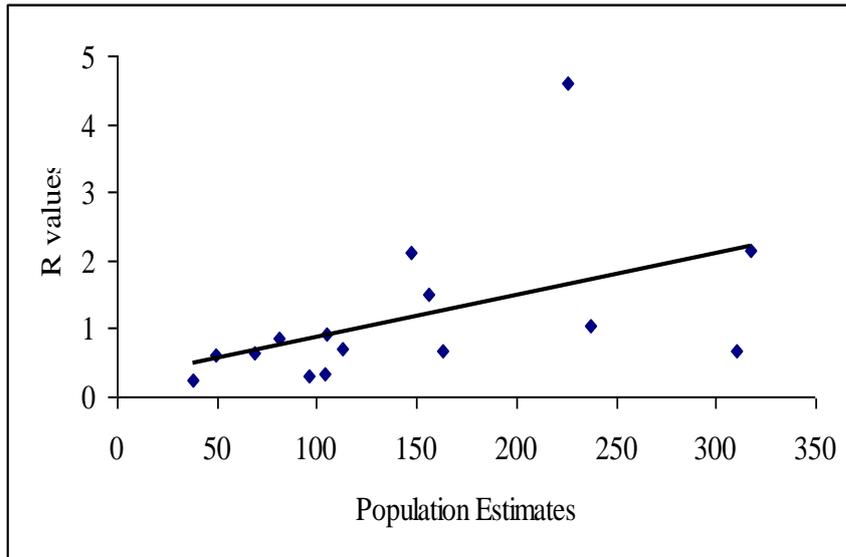


Figure 4.18a. Density dependence determination – Yorkshire coordinated control area

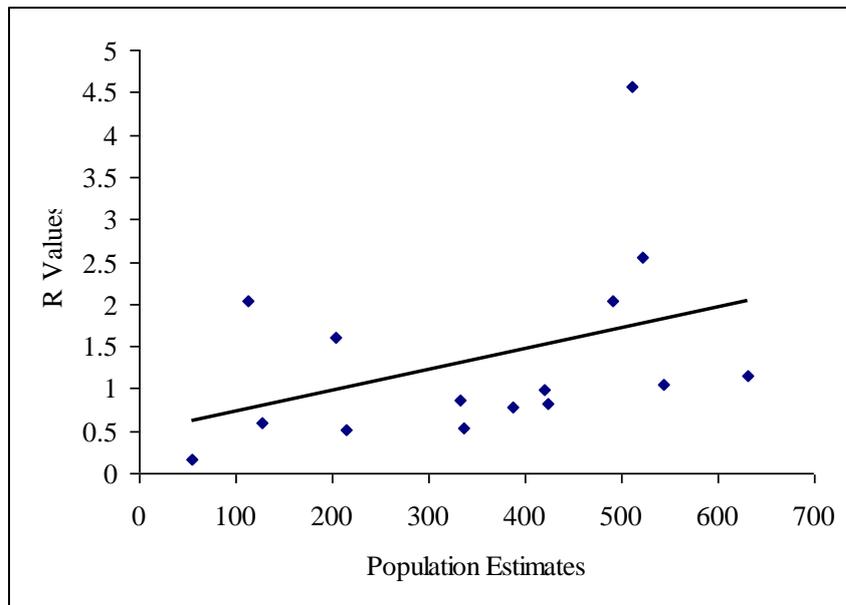


Figure 4.18b. Density dependence determination – Yorkshire uncoordinated control area

#### 4.6.4 Bait Take

One of the objectives of this piece of research was to reduce the amount of rodenticide used. The graph for Leicester, can be approximated by a quadratic trend line ( $R^2 = 0.45$ ,  $p = 0.41$ ), showing that initially the bait take went up (October 2003 – November 2004) and then declined over the second year to the end of the research,

(Figure 4.19). Although the higher  $R^2$  value is quite high (0.45), the fit is not significant because of the small number of data points.

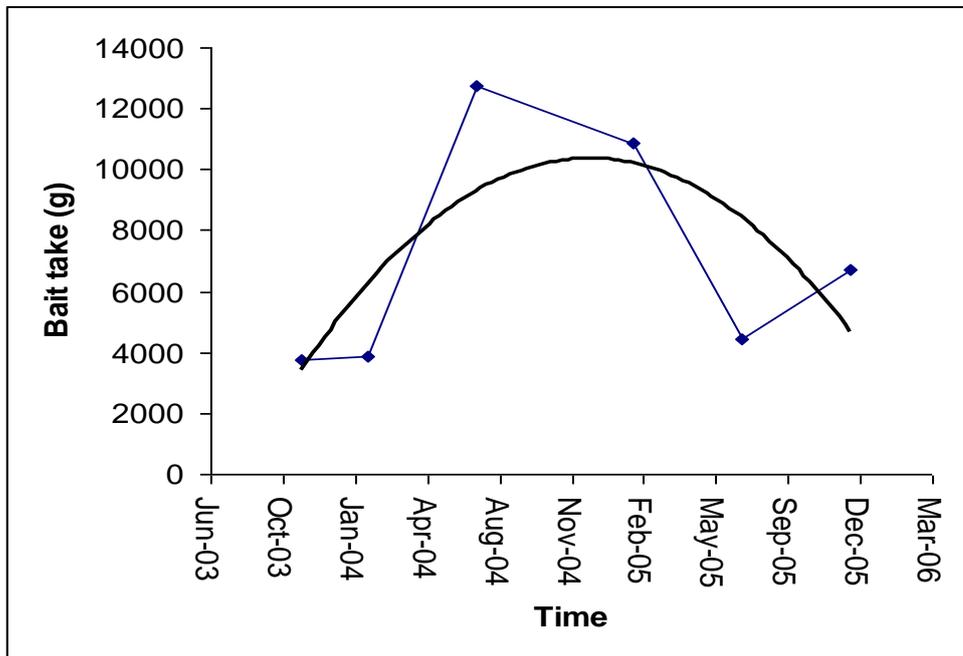


Figure 4.19 The bait takes for Leicestershire coordinated area with quadratic trend line

The null hypothesis that there would be no difference in the bait take over the period can be accepted ( $p = 0.41$ ) for Leicestershire, i.e. there is no statistically significant difference in the bait take over the period even though it appears to drop substantially from autumn 2004 to autumn 2005.

The graph for Yorkshire showed three distinct peaks during the winter periods, which was what we expected to find, but each successive peak is lower than the previous one, (Figure 4.20).

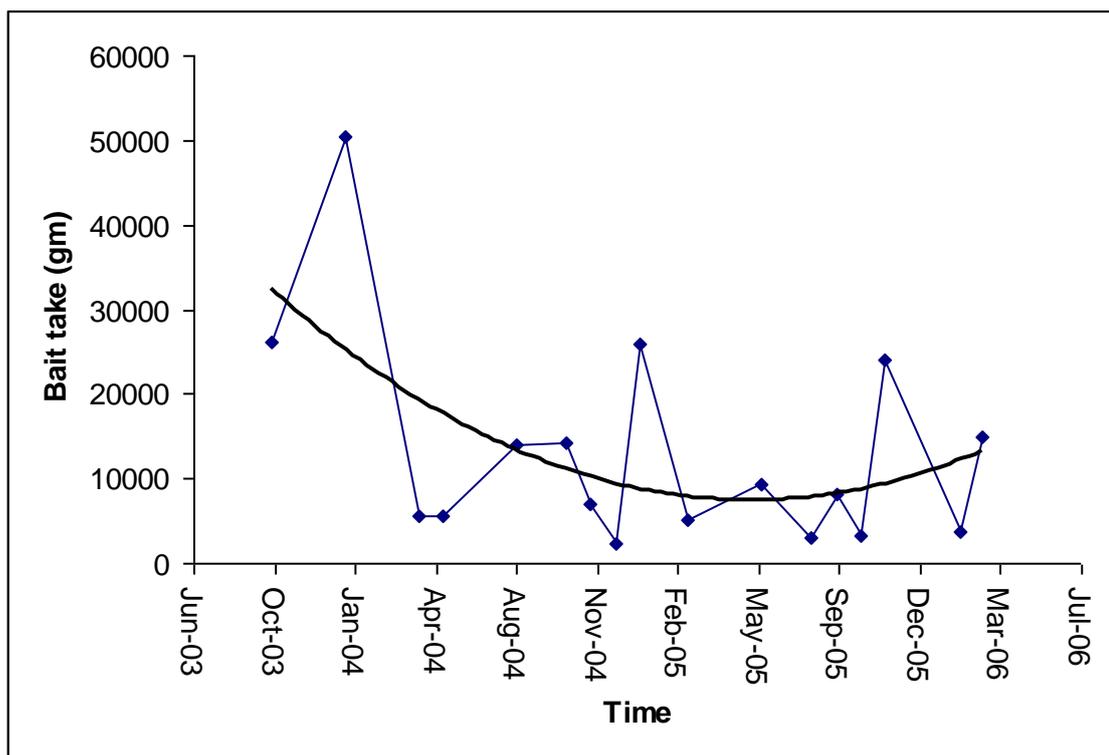


Figure 4.20. The bait takes for Yorkshire coordinated area with a quadratic trend line

What stands out from Figure 4.18 are the three peaks in bait take during the three winters over which this research was conducted. The decreasing size of the peaks around January each year are not necessarily caused totally by a reduced bait take because of falling rat numbers but also by the reducing number of locations, (farms and field sites) that were baited at these times. In January 2004 all six sites were baited but this number decreases by one each year and it is different sites that are excluded in each of the following two years. It is very difficult then to be positive that the amount of bait being taken is reducing. The graph for Yorkshire, using a quadratic trend line ( $R^2 = 0.32$ ,  $p = 0.08$ ), shows that the bait take declined over the first 20 months (October 2003 – May 2005) but then appeared to rise towards the end of the research (March 2006).

The null hypothesis that there would be no difference in the bait take over the period can also be accepted for Yorkshire, because the best fit line (quadratic) was not statistically significant ( $p = 0.08$ ). However, the annual cycle masks the significance of

longer-term trends and it does appear as if 2004 and 2005 bait takes has dropped to a lower level than 2006

On the assumption that rats migrate into farmyards during the winter months the year has been divided into two halves, a winter period (October – February) and a summer period (March to September) for the period of this research and therefore during the winter periods the bait consumption within the farmyards should be at its highest. Because of this difference in numbers of sites baited in Yorkshire a base line was taken of the first baiting session but discounting farms four and five and only these farms and field sites were counted subsequently. Field sites that were not included in the initial baiting or where baiting was started subsequently, were also excluded from the calculations. These figures are then taken as the base line of 100% and all changes in subsequent bait take are relative to them. The data were broken down into farm buildings and field sites.

Using these base line figures the following totals were arrived (Table 4.10):

	October – February (Winter)				March – September (Summer)			
	Farm Buildings (g)	%	Field Margins (g)	%	Farm Buildings (g)	%	Field Margins (g)	%
Winter 03/04	69134.5	100	7305	100				
2004					24060	100	1355	100
Winter 04/05	46810	68	2540	35				
2005					22420	93	3300	244
Winter 05/06	27685	40	3320	45				

Table 4.10. Yorkshire Coordinated site bait take data

The figures of winter and summer farm building and winter field margins in Table 4.9, show a declining trend in bait take, which is was one of the objects of this research. A 60% reduction in bait taken over three winters in the farm buildings is a

good result and was what was expected, if the numbers of rats could be reduced and kept at low levels. In Leicestershire the field margin populations were not found initially. The information from the land owners and gamekeepers was that there were no large field populations. Initial walking of the area indicated that there were scattered small populations based around the many pheasant feeders (150 on one farm alone) and tracking plates around a selected few, where the signs indicated that the population in the locality may be sizeable, showed that there were no large field populations. On a subsequent walk across the area it was found that populations had become established at several sites, but not based around pheasant feeders and the data from these have been included in the data set below in Table 4.11.

	October – February (Winter)				March – September (Summer)			
	Farm Buildings (g)	%	Field Margins (g)	%	Farm Buildings (g)	%	Field Margins (g)	%
Winter 03/04	7610	100						
2004					5230	100	7320	100
Winter 04/05	4890	64	5970	100				
2005					4430	85	0	0
Winter 05/06	3320	44	3380	57				

Table 4.11. Leicestershire Coordinated site bait take data

Both areas in both seasons show a decline in bait take over the period of the research. As with the Yorkshire data, there was a decline of 56% in the bait take from the Leicestershire farm buildings over the three winters. The drop from 100% to nil in bait take in the field sites in the second summer is the result of the decision not to bait because of the very small numbers of rats found during the censuses at this time (farm A – five rats over four sites, farm B three rats over two sites), and it was felt that baiting would kill more non-target species than rats (Brakes & Smith, 2005).

## 4.7 DISCUSSION

### 4.7.1 General Discussion

Controlling the rats over the wider area in the coordinated area has been shown to be effective with total rat numbers reducing year on year. This was what was expected and therefore as a strategy it is worth considering its use if an area has a large population that needs to be reduced. On the other hand, when considering the baiting and secondary poisoning, this may have other implications. Farmers or rodent control staffs do not generally bait outside the farmyard and so the provision of bait out in the countryside, where a wider range of species will have access to it, must increase the risk of both primary poisoning of non-target species and secondary poisoning of predators and scavengers of both the target and the non-target animals. As a result a value judgement has to be made – should baiting be carried out over this wider area and more rats killed, thus reducing the potential for damage in the farmyard and across the area or should baiting be confined to the farmyard and thus be able to be targeted more precisely at the rats and thereby reducing the risk of primary poisoning of non-target species? This would also reduce the risk of secondary poisoning from the consumption of poisoned non-target species.

In both the Leicester and Yorkshire areas very few dead or debilitated animals were found above ground as the result of poisoning. This indicates that although we have spread the risk of secondary poisoning over a larger area, still very few of those poisoned animals died above ground and that when they began to feel the effects of the rodenticide they retreated to their burrows and the majority died below ground away from the risk of being taken by predators that hunt solely above ground. There is nothing that can be done to prevent those predators that enter the burrows to hunt, such as weasels and stoats, from being subject to secondary poisoning. Unless there is some

instinct in them that tells them that some rats have been poisoned and should not be eaten, they are very likely to take poisoned rats because they are an easy meal.

Farms nowadays are restricted in the numbers of staff that are employed and it is only on the larger estates where there are game shooting interests that one is liable to find a full-time gamekeeper. Even then one gamekeeper may be employed to manage the game across several estates. Working to control the rats over a much wider area than is normal, as has been carried out in this piece of research, is a great deal of additional work, and would be a particularly large burden on a farm where there is a limited number of staff. It would still be a great deal of work for a dedicated member of staff, such as a gamekeeper, if there are large numbers of field sites that need regular attention. It is therefore down to the landowner where his or her priorities lie, are they prepared just to control the rats in and around the vicinity of the farmyard and accept the damage that can be caused by the seasonal fluctuations in numbers, particularly in the autumn and winter, when there is liable to be an increase in the volume of stored food or grain? If they are not prepared to accept this level of damage, are they prepared to have their staff put in the effort to control the rats over the wider area? This very much depends on the value of the damage that is done, which has not been quantified as part of this research, and has then to be set against the increase in costs involved with this level of control.

#### 4.7.2 Population Trends

In Leicester and Yorkshire the trends in the rat population for the coordinated area, (total, buildings and field populations), were all downward during the course of the study. The trends for the uncoordinated areas show differing results with the Leicester total/building showing a rising population whereas the Yorkshire building

population is declining. One might have hoped that the rat populations in the farm buildings would have shown a decline in both areas because this was where farmers did their rodent control. The farmers in Yorkshire were obviously doing a better job in this respect than those in Leicestershire. In mitigation, the Leicestershire farmers have much smaller numbers of rats to deal with and it may be that they do not see this number of rats as causing them a major problem, such that they need to take stringent measures to control them.

These results are generally as expected, with the total populations in both the coordinated areas decreasing over the period of the research. The decline in the population in Yorkshire was far more marked than it was in Leicestershire mainly because there were many more rats there than there were in the Leicestershire area. However, with rodenticide resistance being present in Yorkshire but not known to be present in Leicestershire logic would indicate that it would have been easier to control the rats in Leicestershire and bring their numbers down to a much lower level than was achieved. To be set against this argument though, was the fact that on Farms A and B in Leicestershire there was a considerable interest in rearing game birds for shooting. Farm A bought in chicks and these were reared in specially constructed pens in some nearby woodland, which was where rat two was radio tracked to (see Chapter 3). The gamekeeper on this farm put out feed for both the reared and locally bred birds in hedgerows and woodland and this also provided food for the rats. On Farm B there were over 150 pheasant feeding stations and these were kept filled from September to May. They did not rear chicks here but relied on the locally breeding birds to provide sufficient numbers for shooting, but no shooting was done over this land during the period of this research because of insufficient numbers of birds. With this number of feeders spread out over the farm it is very difficult to keep the total rat population down

to reasonable numbers. All feeders were inspected for signs of rat activity of which very little was found. Tracking plates were put down around the feeders with the largest signs of rats to establish the numbers of animals and this showed that there were on average less than five animals around each feeder except for the two feeders on the edge of the farm yard. These two were included in the population censuses for the building population, but were not recorded separately. To try to control this very widespread population was beyond the resources of this research project, so only the largest field populations were controlled on this farm.

It can be seen from the raw census figures at Annex H that there were considerably more rats in the Yorkshire area than there were in Leicestershire. It is also known that in Yorkshire, the rat populations have developed resistance to rodenticides (Lambert, 2003). These two factors, the much larger numbers of rats and the resistance to rodenticides, make controlling the rat population a much more difficult problem. The small increases in the rat populations in both the Leicester and York uncoordinated building areas may be explained because as the censuses were being carried out the land owners were talking to the operators and asking what the population was doing and where they were to be found. They were then applying control measures which they may not have done under normal circumstances but also not to the same intensity as was done in the coordinated areas and therefore possibly not controlling the population as effectively. From the information collected from the farmers in the uncoordinated areas only one was using more than one container of commercial rodenticide in a year so there was really not a great deal of rodent control carried out except in the farmyards. The farmer (Farm seven) that used more than one container of rodenticide was the only one to carry out control of field populations, and he had a major control effort on the those populations that had built up around the large pheasant feeders that he put out

during the breeding and shooting seasons, after the shooting season had come to an end. During the rest of the year he did nothing about the rats in the field colonies on his land. The upward trends for the total and field populations in the uncoordinated areas are in line with expectations. The large rise in the field population in the York uncoordinated area is because land owners were doing what is normal and only concentrating on the problem within the confines of the farmyard and ignoring anything outside that area. The reason for the lack of any field populations within the area of the Leicester uncoordinated site is not known. The conditions would seem to have been suitable, habitat, a source of food and water were all available but with two villages within or bounding the area it may be that the rats preferred to live close to human habitation rather than the more precarious countryside. One farm (Farm E) was within the boundaries of both a village and the uncoordinated area and very few rats were present on this farm at any time, so it may be that there were just no rats other than the few found on the farms in this particular area of Leicestershire, although reports were received from the farmers, of other farms in the vicinity but outside of the research area, that did have large rat populations.

It is accepted that rats are unlikely be eradicated entirely from the countryside or indeed anywhere else, and that if there is rodent control using rodenticides there will always be the risk of primary poisoning to non-target species and some predators being subject to secondary poisoning. If the numbers of rats can be reduced to relatively low levels by this method of control, then the risk of secondary poisoning will also be reduced. There is a down side to reducing the numbers of rats across the countryside, not that the majority of farmers would see low numbers of rats as a bad thing. If rat numbers are reduced then this reduces the amount of food that is available to predators, such as the tawny owl, and consequently pressure is put on them to find alternative

sources of food. This in turn puts pressure on those species that are predated, and their normal predators, and as a result this will have an effect across the whole food chain.

#### 4.7.3 Delayed Synchrony

From Figure 4.16, what seems to happen is that both Yorkshire sites show an annual pattern of increase and decline but the coordinated site is ahead of the uncoordinated site (at least in the first two years) by approximately one month. The two 400 ha sites are separated by approximately 15 km and this therefore seems to be a large-scale spatiotemporal pattern. While more data are needed to confirm this interesting pattern, it is worth considering some possible explanations:

1. The simplest explanation is that some feature of the coordinated control site (perhaps the control itself, perhaps microclimate or crop differences) triggers an earlier increase and then an earlier decrease in numbers. The problem with this explanation is that the factors that trigger an increase are probably not the same as those that trigger a decrease.
2. Coordinated control effectively reduces the rat population and provides a large sink area that draws rats in from other sites, including the uncoordinated control site. After numbers build up again, rats move back to the uncoordinated area, generating a spatio-temporal cycle. This, however, is unlikely because rats tend not to move all that far from their home range (Chapter 3).
3. Generalist predators foraging over areas larger than the study sites respond to local abundance by switching behaviour. Predator-induced mortality then generates spatio-temporal cycles. This sort of effect is known in Fennoscandia, but it is not obvious which generalist predators might be involved in Yorkshire (they would almost certainly need to be predatory birds).

4. There may be some large-scale spatial phenomenon (such as travelling waves) moving across Yorkshire that happens to hit coordinated farms before uncoordinated farms. This is known in other rodent populations, including voles in northern England (Lambin *et al.*, 1998).

#### 4.7.4 Density Dependence

The graphs in Section 4.6.2 all have positive trend lines and this shows that density dependence is not the controlling factor in determining population size. Therefore other factors have to be the cause. In the coordinated areas it is likely to have been the rodent control operations conducted by the researchers and in the uncoordinated areas by the farmers, although in the Leicestershire uncoordinated area none of the farms would appear to have had major problems with rats and none of the farmers indicated that they were spending a lot of time or money on rodent control.

#### 4.7.5 Bait Take

In both Leicestershire and Yorkshire there was a consistent decline in the bait take in the farm buildings during the three winter periods and the two summer periods. This is what one would expect to see if the coordinated control was having an effect and reducing the total numbers of rats within the control area. The reduction in summer bait take may also be the result of the natural decline in rat numbers as the food source in the yards disappears and they disperse back out into the fields. The small reduction in bait take for both areas during the summer indicates that there is a residual rat population remaining in the yards and that the number of rats is approximately the same as the year before. The slowing down of the rate of bait take over the winters in both Yorkshire and Leicestershire may also be the result of bait aversion which would also

affect the bait take figures during the summer periods unless new rats were moving into the area.

One would expect to see a drop in bait take in the field margins in winter as the population has most likely lost its main source of food and the rats have moved to a location closer to a reliable food source. In Yorkshire the bait take declined significantly over the first two winters (100% – 35%) but then rose during the third winter (35% - 45%). The data for the summer field margins in Yorkshire bucks the trends that have been seen of declines in bait take, showing a 2.4 fold increase (100% - 244%), but this might be explained by the absence of readily available natural food in the areas being occupied by the rats and by the rise in the numbers of rats in the field populations. Baiting was only carried out on the Leicester field sites during the summer of 2004 because by the summer of 2005 the numbers of rats found at these sites had declined to single figures and it was felt that baiting was not a worthwhile exercise for such small numbers and may have caused more damage to the non-target species, through primary poisoning, than was justified by the small numbers of rats.

The  $\text{Log}_{10}$  values of both the total population and total bait take are taken and plotted against each other, with adjustments made to take into account the date differences between census and baiting sessions, it shows that in Yorkshire there is a weak positive correlation between the two ( $r = 0.311$ ); but that the correlation between the two factors on Leicestershire is stronger ( $r = 0.808$ ), a rise in population produces a rise in bait take, which is what would be expected.

We were trying to bring about a reduction in the total bait consumed which has been shown to be possible. What is not known is what the total bait consumption would have been in both Leicester and Yorkshire had this research not been carried out. The amount of bait that was used in the farmyards may have been similar to that that

would have been used if this work had not been done, but this is unlikely, judging by the numbers of bait boxes in use on the farms before this research commenced and the numbers used during this research. The numbers of bait boxes that were put out during the research were considerably in excess of those already in use at the start. On this basis, it is very likely that considerably more bait was being used during this research than previously, although this cannot be said for certain. It is good that the numbers of rats were reduced across the coordinated areas but at what cost to non-target species? This was not measured in any way but it is something that needs to be considered when conducting rodent control on this scale (see Ch 6 – Future work).

#### 4.8 CONCLUSIONS

Two conclusions can be drawn from this element of the research:

1. The numbers of rats within a 400 ha area can be reduced and maintained at a low level using the coordinated baiting methods used in this research.
2. The amount of rodenticide bait used can be reduced over time and still maintain the rat population at a low level with the coordinated control technique.

## **CHAPTER 5. LANDSCAPE-SCALE MANAGEMENT OF RAT POPULATIONS: DEVELOPMENT OF THE RAT FUNNEL SYSTEM AND ASSESSMENT OF ITS ROLE IN LANDSCAPE MANAGEMENT**

### **5.1 INTRODUCTION**

The rat funnel system (RFS) was developed from the concept of the trap barrier system (TBS) that was used in the Far East to trap rats prior to and during the growing season of the main rice crop. The TBS was developed in the 1980s by (Lam, 1988) as a development of the system that was then in use, of plastic barriers to deflect rodents away from a growing crop. This just moved the problem from one farmer to another. Lam placed the fence around the growing rice crop and put small holes in the fencing just above the level of the irrigation water with access to the hole being provided by a mound of mud on the outside of the fence. Inside the fence were placed multiple capture traps suspended on poles above the water level. In Malaysia a TBS that extended for 5 km was used to protect reclaimed cropping land that was planted out of synchrony. Over a period of nine weeks 44,101 rats were caught with 6872 being caught in one night. Benefit-cost analysis of this system showed that crop losses would have to be more than 30% for it to be cost effective so alternatives were developed (Singleton *et al.*, 1999b).

Better results were obtained if the TBS was used to protect a late developing crop, such as rice or vegetables, grown after the main rice crop had been harvested. As a result, a trap-barrier system was developed that was built early, about 21 days before the main rice crop or later after the main crop was harvested that had a “trap-crop” planted within the boundary of the fence to entice the rodents inside the barrier where they were trapped and eliminated. The expectation was that this TBS plus trap-crop (TBS + TC) would provide a “halo” of protection to neighbouring crops with a 25 x 25 m TBS + TC reducing the rodent damage significantly over the a surrounding

10 – 20 ha (Singleton *et al.*, 1999b) In Vietnam live trapping of rats also provided additional income as the rats collected could be sold for meat.

Agriculture is very different in the United Kingdom. We do not have a single crop, such as rice, that attracts rats in the same way as in Asia and the landscape is very varied with hedgerows and ditches along field margins. It has been thought amongst farmers for a long time that the number of rats in a farmyard or buildings that are used in winter increases suggesting migration along hedgerows. Two studies, (Clark & Summers, 1980; Drummond & Rowe, 1960), support this belief and this would tend to be supported by the finding of the censuses in this study, particularly in the uncoordinated areas. However the study by Taylor, (1978) did not find that there was this seasonal change.

Part of the coordinated treatment was to remove rats moving into farms. As there was no crop that could be used to trap rats, it was thought that the best alternative was to capture them as they move along the hedgerows into and out of the farm yards during the autumn and spring. A way was needed of bringing the rats into an area where they could be trapped, a funnel system was devised that channelled the animals that were moving along the hedgerow through an enclosed area where they were trapped and killed.

## 5.2 AIMS AND OBJECTIVES

The major aim of this part of the research was to see if it was possible to establish a trapping system similar to that used in the Far East and thus remove rats from the ecosystem. The traps were set up within migratory routes (hedgerows) into and out of farmyards. Knowing how the traps were positioned within any given funnel would allow the direction that the rat was moving in to be determined i.e. was it moving towards or away from the farmyard. In addition to monitoring the rat movements the data collected would allow the examination of the use of such funnels by non-target species and be able to look at the humaneness of trapping with spring traps.

The following null hypotheses were tested:

1. There would be no difference in the movement through the funnels between rats and other small rodents (OSR).
2. There would be no difference in the movement through the different widths of funnel by rats and OSR.
3. There would be no difference in the usage of the funnels between those funnels that had food put in and those that had no food.
4. There would be no difference between the numbers of rats moving into and out of the farms through the funnels.
5. There would be no difference in the numbers of male and female rats caught in the rat funnels.

### 5.3 DESIGN AND CONSTRUCTION OF THE RAT FUNNEL

In Leicestershire rat funnel traps were built in both the coordinated and uncoordinated areas. In total 13 funnels were built on the three farms in the coordinated area, although one had to be removed to allow the farmer to clear fell the railway track cutting and one had to be replaced after the original had been destroyed by sheep. Eight were built on two farms, those that showed the largest rat populations, in the uncoordinated area. In addition, three more were built on a farm outside the uncoordinated area that had been considered when setting up the project as a whole and was known to have been rat infested at that time. In Yorkshire all the funnels were built within the coordinated area. Trapping was carried out using the funnels in Yorkshire and the Leicestershire coordinated area. Traps were also set in the three funnels outside the Leicestershire uncoordinated area. No trapping was carried out in the Leicestershire uncoordinated area.

The areas chosen for the RFS were surveyed for the best locations of the funnels. The majority were built into a gap in a hedgerow, the hedgerow being the corridor down which the rats were expected to move into and out of the farms. Where it was not possible to build into the hedgerow, because there were no gaps in it, the funnel was built alongside and the arms of the funnel extended out through the hedgerow to bring all rats through the funnel trap. Some traps were built alongside a stream or ditch and in this case the arms of the funnel were extended down into the stream or ditch and across to the top of the far bank. In Yorkshire some were built on the edge of woodland at a point where a hedgerow adjoined the wood.

The funnel was constructed of small straw bales, wire netting, half round wooden stakes and some form of waterproof covering for the funnel. In Leicestershire four bales were used as the sides of each trap and in Yorkshire three bales were used,

two as the sides and the third as a cover. At each end of the funnel was a barrier designed to prevent non-target species from entering the funnel, in Leicestershire this was weldmesh cut to allow access of rats and in Yorkshire it was wooden stakes driven into the ground. The gap between stakes or cut in the weldmesh was approximately 50 mm to give rats access but to prevent larger non-target animals entering the funnel. . Short & Reynolds, (2001) indicate that a 60 mm gap is wide enough to allow domestic ferrets (*Mustela furo*) through and that 30 mm gaps allowed stoats to pass through at full speed. In some instances metal sheeting was used as one side of the funnel where it is no possible to use bales as the side of the funnel was hard up against a wire fence. The design can be seen in Figure 5.1 below and a picture of a built one is at Figure 5.2. The traps have been designed with the intention that they used material that was readily available on most farms. In Leicestershire the covering for the funnel was initially made from the large (600 kg) woven plastic bags that fertilizer and seed corn is now delivered in and held down with broken slabs or bricks. This was subsequently replaced with plastic sheeting that had been used to cover a silage clamp and cut to a suitable size. In Yorkshire, the third bale was resting on a piece of hardboard, and then the whole was covered with plastic sheeting (building damp proof sheet). Small bales were obtained for this study but they seem to be no longer produced in any great numbers nowadays so alternatives may need to be found.

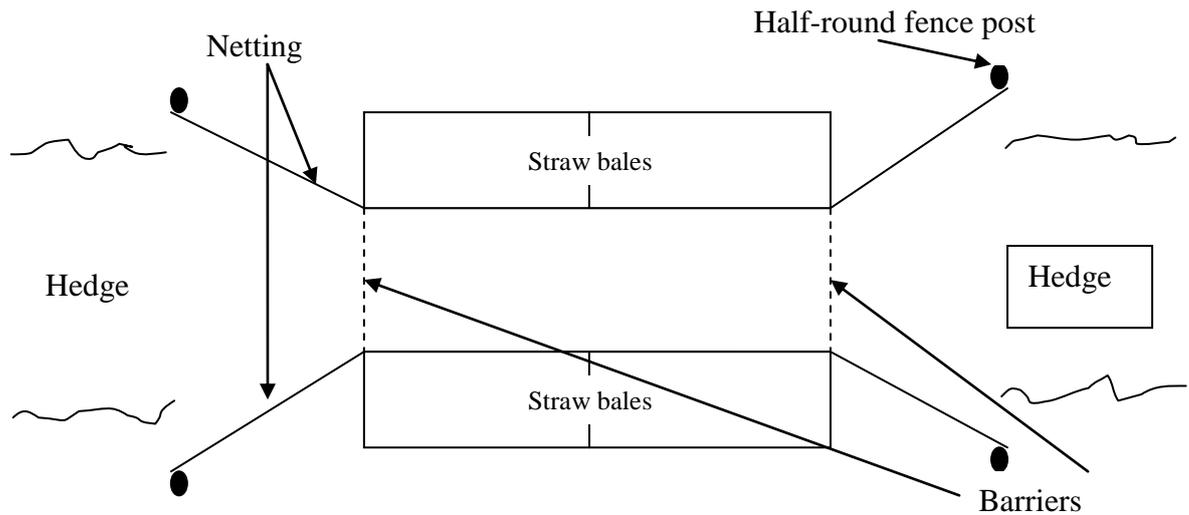


Figure 5.1. Plan of a Leicestershire Rat Trap funnel



Figure 5.2. Example of a Leicestershire rat funnel built into a gap in the hedgerow

Initially in Leicestershire two widths of funnel were constructed, one at 30 cm wide and the other at 50 cm wide, to determine if there was any difference or preference in the usage by rats. Food was also provided in half of the funnels, 5 each of the 30 and 50 cm wide funnels, again to see if this produced any effect. The food used was in the first instance surplus turkey rearing pellets and then whole grain wheat. Selection of

which sized funnel went in which location was done randomly as was the selection of which funnels received food.

In Leicestershire, tracking plates were placed across both the mouths of the funnels for a period of 67 days from 18 February to 25 April 2005 to try to measure usage by rats and OSR, before the traps were placed in the funnels. In the absence of any established method to determine usage, the system used to determine population numbers was used (Quy *et al.*, 1993). Plates were scored using the same system as described in Chapter 3, but were scored for both rats and “other small rodents (OSR)”. Where OSR used the funnels, particularly where there was food provided, it was not possible to identify the species from the tracks. To determine which species were using the funnels, Longworth traps were set for a period of two weeks during this period and the captures recorded. Hay was put in the trap as bedding and food, wheat and casters, were also provided. Traps were checked daily and replenished as necessary. This work was carried out in conjunction with another PhD student, Husni Ibrahim.

The snap traps used within the funnels were, in the main Fenn Mk 3 traps, but in Yorkshire BMI traps were also used in a few of the funnels. In total 14 BMI traps were used in four funnels. The Fenn traps were set into the ground so that when they were in the set position they were at ground level and then covered with grass or straw (see Figure 5.3a below). Bait in the form of whole grain wheat was put on the covering and in the funnel to encourage the rats in. It was not possible to hide the BMI traps as the rat has to physically walk through the trap to be captured (see Figure 5.3b) and again whole grain was placed in the funnel as bait.



Figure 5.3a. Fenn traps in the funnel



Figure 5.3b. BMI traps in a funnel

The Fenn traps were set in a pattern across the entrance of the funnel so that any animal walking through the funnel was captured. The positioning of the trap was such that it was possible to determine which direction through the trap the rat was going from its orientation in the trap when killed. The traps were placed in the funnel such that the safety catch and release mechanism were in the middle of the funnel and so the direction of travel determined.

## 5.4 SITE DESCRIPTIONS

### 5.4.1 Leicestershire sites

#### Coordinated Area

The 24 rat funnels in Leicestershire were built across 6 different farms, 13 on the three farms in the coordinated area, eight on two farms in the uncoordinated area and an additional three on a farm that had a major rat problem at the beginning of the research but that was outside the boundary of the uncoordinated area. These last three were put in because of the low rat numbers in the uncoordinated area and to see if we could establish any movement in the area through the funnels. In the coordinated site it was planned that each of the farms would have four funnels on their land. We actually built 13 funnels in total. One on Farm C was destroyed by sheep and had to be relocated. One of the funnels on Farm B had to be dismantled because it was built across the old railway line in an area of scrub and the farmer wanted to clear the embankments beyond it. We therefore ended up with 11 funnels in the coordinated area. A map showing the funnel locations is at Figure 5.4 below.

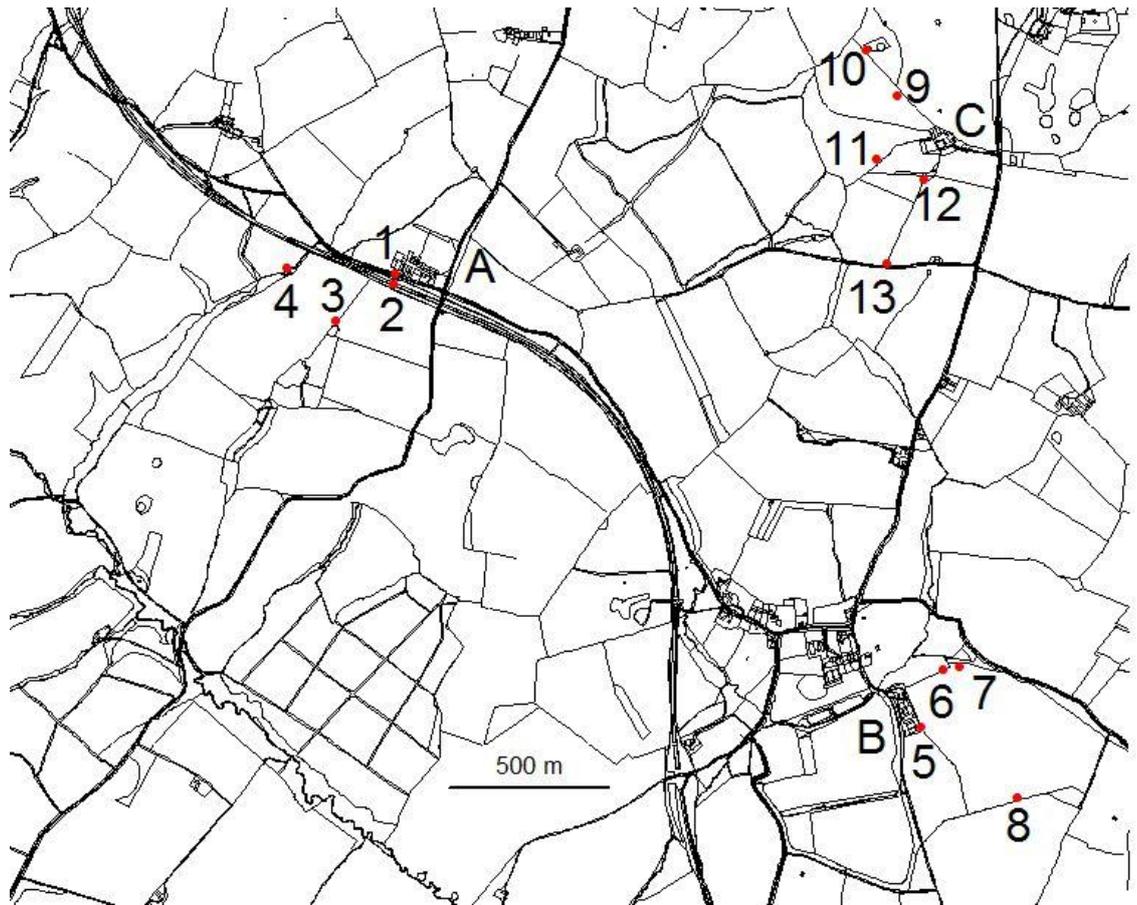


Figure 5.4. Map of the rat funnel locations on the Leicestershire coordinated site.

On Farm A the funnels were built on four very different types of terrain. The first (No. 1) was built alongside the hedgerow that separated the farmyard from the road. It was built between the hedgerow and the cattle-handling crush with the funnel arms running through the hedgerow where there were obvious rat runs. The second (No. 2) was built across the old railway line beyond the burning area in an area of scrub and over a well defined rat run that ran down one bank, across the hardcore base of the line and up the opposite bank towards the farm. This was not replaced after it was removed. The third (No. 3) was located adjacent to a hedgerow just below the edge of an area of woodland and like No. 1 had the arms of the funnel running through the hedge. The final funnel (No. 4) was built on an area of scrub land on one bank of the stream that ran through the farm. In this instance the arms of the funnel went across the stream to catch any animal moving along the far bank and swimming down the stream.

On Farm B the funnels were again located in a variety of places. No. 5 was built at the top end of the farmyard on the top of a bank where there was a lot of rat activity. On one side of the funnel was a hedgerow and on the opposite side was a deep ditch that had a similar flat area on its other side. The funnel was built with its arms through the hedge and through the ditch and up onto the flat area on the other side, again to catch anything that was moving along the ditch. Funnel No. 6 was built against a post and wire fence that ran along the bottom of a field and connected the farmyard to an area of woodland. Funnels Nos. 7 and 8 were built at the opposite ends of a beetle bank (Anon, 1990) that split the field next to the farmyard in two and where there were signs of rat activity, with tracks going to adjacent woodland at one end and the hedgerow at the other. Within the beetle bank there were signs of rat activity. The bank was approximately 400 m long and next to it was a strip of land that ran the whole length of the field where a cover crop of kale and triticale had been planted for the game and song birds. Within the cover crop were a large number of tracks that ran into the beetle bank. Triticale is a plant similar to barley which was produced as the result of the cross between wheat and rye (Oelke *et al.*, 2000) and with the kale provides food for a range of bird species (pheasant *Phasianus colchicus*, blackbird *Turdus merula*, song thrush *Turdus philomelos*, dunnock *Prunella modularis*, greenfinch *Carduelis chloris*, chaffinch *Fringilla coelebs*, tree sparrow *Passer montanus*, yellow hammer *Emberiza citrinella*, reed bunting *Emberiza schoeniclus* and the corn bunting *Miliaria calandra* (Stoate & Leake, 2002). The triticale seed heads also provide a good food source for rodents.

At Farm C all the funnels were built in or adjacent to hedgerows. Nos. 9 and 10 were built within a double fenced area where a new hedgerow had been planted, No. 9 about 30 m from the farmyard and No. 10 at the far end of the fenced area,

approximately 200 m from the farm. Only one side of each of the funnels was made up of straw bales, the other side comprising corrugated iron sheets attached to the fence. The mouths of the funnel at each end were the full width of the fenced area. Within the fenced area were signs of rodent activity along with very obvious signs of badgers (*Meles meles*). Funnel No. 11 was built in a gap in a hedgerow. Despite the presence of wire netting on both sides of the funnel the sheep in the field still destroyed it in less than 48 hours and the remains were removed. I had forgotten that the palatability of straw has improved so much over the years since I was farming that livestock will consume it quite readily without having to put additives to it to make it palatable, as was done nearly 40 years ago. The replacement, No. 12, was built again in a gap in a hedgerow where there was a post and wire fence on one side and a good electric fence on the other to stop the livestock getting at it. This site was adjoining a small wooded area at one end and a good wide hedgerow at the other. The final funnel (No. 13) was built at the far end of the hedgerow from No. 12, and like Nos. 9 and 10 was built on the inside of a wire fence with metal sheeting as one side of the funnel. The arms of the funnel ran along the wire fence on one side, like Nos. 9 and 10 and through the hedgerow on the other.

#### Uncoordinated Area

A map of the locations of the funnels is at Figure 5.5.

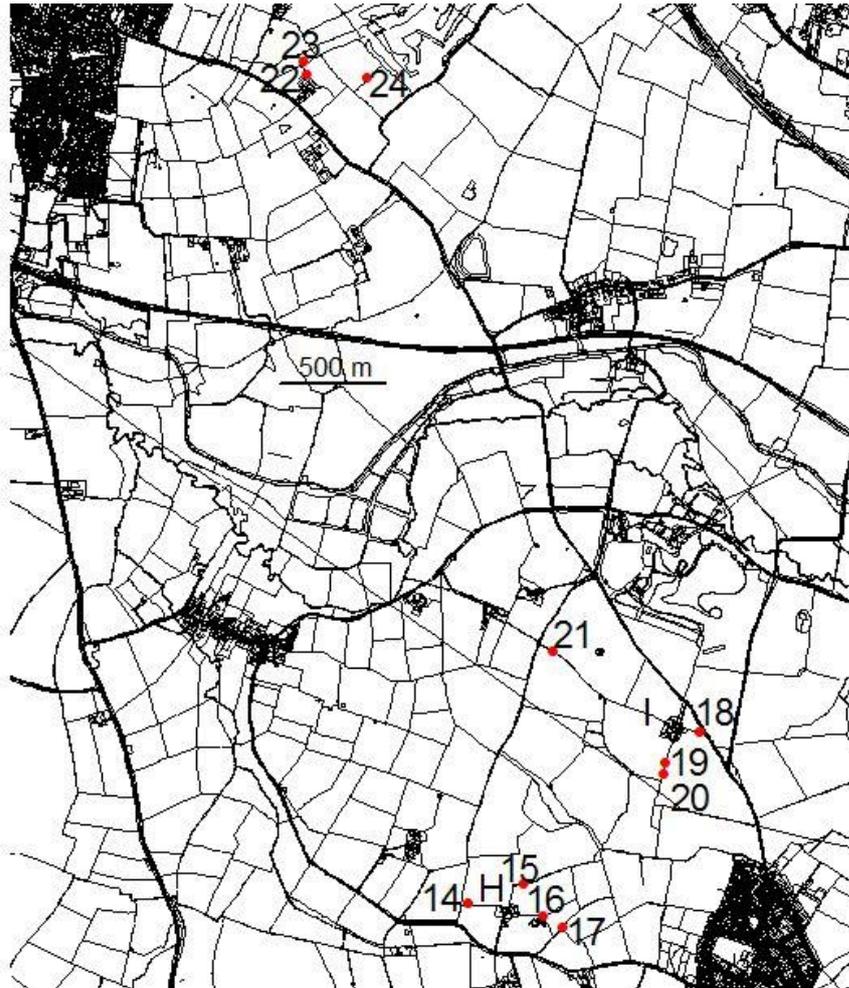


Figure 5.5. Map of the rat funnel locations on the Leicestershire uncoordinated area and other site outside the research area. (North is at the top of the map).

At the uncoordinated site the funnels were built on Farms H and I as these had the largest rat populations. At Farm H three were built into or alongside hedgerows that ran into the farmyard. No. 14 was on the hedgerow between a pasture and an arable field as was No. 15. In both these cases the pasture was used for sheep but the farmer had erected low level electric fences to contain the sheep and both funnels were built behind them. No. 16 was built on an area of ground at the end of a hedgerow between two arable fields, both of which were used for grazing sheep. On one side was a post and wire fence and on the other was a low level electric fence. The arms of the funnel went through the post and wire fence on one side and up to the electric fence on the other. Between the funnel and the farmyard was an area of land used to store silage

bales and also straw. No 17 was built on an area of scrub alongside a hedgerow with the arms on the hedge side going through the hedgerow.

On the final farm in the Leicester uncoordinated area (Farm I) all the funnels were again built into hedgerows. No 18 was at the junction of two fences that formed a T shape, with the cross piece running alongside a road and was built on the down leg of the T between the hedgerow and a cattle trough. The land on the open side was growing winter wheat and on the opposite side of the hedgerow was pasture land. Nos. 19 and 20 were built on the same hedgerow about 75 m apart. Both were built into gaps in the hedgerow, one where a disused jump erected by the local hunt had been and one at the base of an oak tree (*Quercus robur*). On one side of the funnels was a field of winter barley and on the other a sheep proof fence with pasture beyond. Funnel No. 21 was built at the far end of a long hedgerow about 500 m away from the farm alongside a hedgerow that had a deep ditch on the opposite side to the funnel. The arms of the funnel ran through the ditch to the top of the bank on the other side. The land was in cultivation on both sides of this funnel.

The three further funnels that were built were again in or alongside hedgerows. No. 22 had farm buildings on one side and a ditch on the other. On the far side of the ditch was pasture land with sheep grazing and pieces of disused old machinery and other farm paraphernalia stored in it. The adjacent buildings housed cattle and silage clamps. No. 23 was built into a gap in a wide hedge that formed the cross piece of a T at the bottom of the hedgerow that No. 22 was built on. Within 5m was a small pond. On one side of the funnel was set aside land and on the farm side was pasture with sheep. The sheep were prevented from getting at the straw by a pig net fence. The final funnel, No. 24 was built at the top of a pasture field in an old, disused gateway. On the farm side was pasture land on which were run sheep and on the far side was a ditch and

then an arable field. At this funnel, pig netting was erected around it to prevent the sheep from destroying the straw bales as had happened at the coordinated site.

#### 5.4.2 Yorkshire

In Yorkshire all the funnels were built on the coordinated site. A map of the locations of the RFS is at Figure 5.6. All RFS were located in gaps in hedgerows and except where indicated are between two arable fields. The exceptions to this are briefly described below.

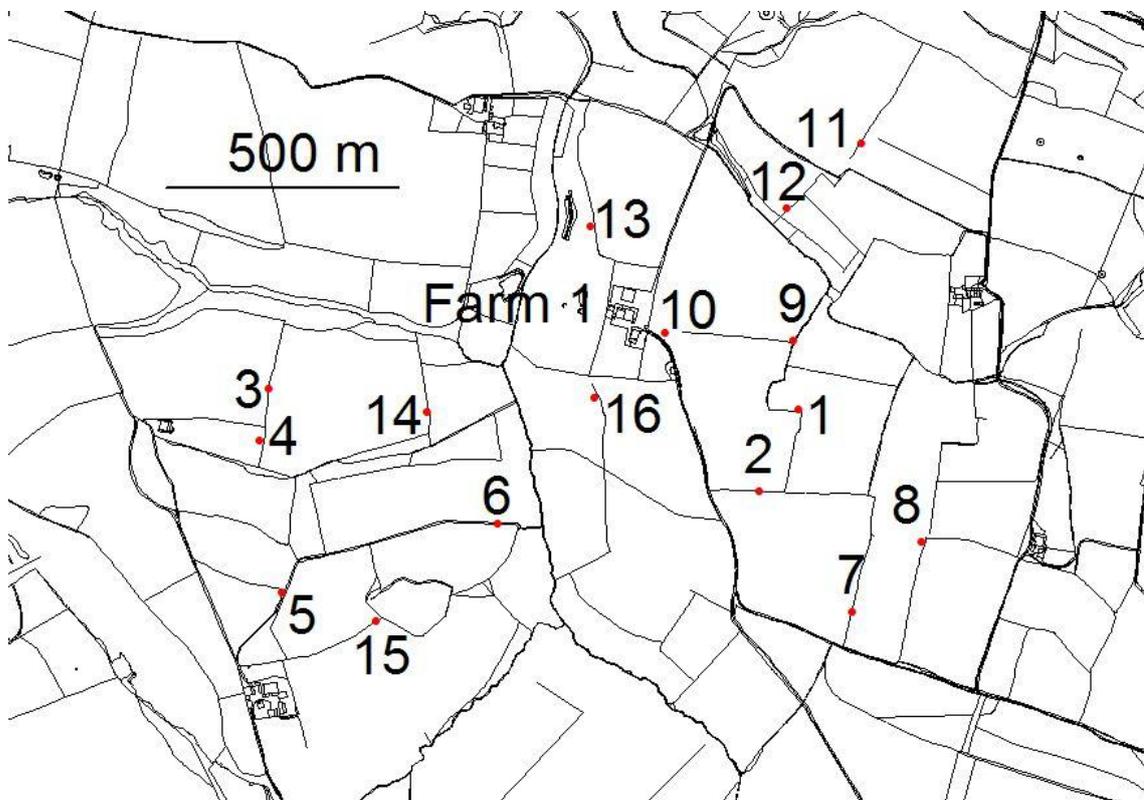


Figure 5.6. Map of the rat funnel locations in the Yorkshire coordinated area. (North is at the top of the map).

No. 4 was located alongside a hedgerow that separated an arable field from a set-aside field. No 5 was on the edge of a small piece of woodland that abuts an arable field. No. 10 was on the end of a hedgerow adjacent to the yard of farm No 1. No. 12 was situated on a hill side and was sandwiched between two stock proof fences that separated two pasture fields. No 13 was located on the rim of a small valley hard up

against a post and barbed wire fence. The land in the valley was permanent pasture that was used to graze sheep, as was the land on the other side of the fence. No. 14 was on a hedgerow that separated an arable field from an area of very wet, boggy ground that was in permanent set-aside. No. 15 was at the end of a hedgerow where it joins a bluebell wood.

## 5.5 DATA ANALYSIS

Funnel Usage. The monthly data for the usage of the rat funnels was analysed for both rats and OSR. Data was tested for normal distribution and equal variance. The data for the OSR were found to be both of normal distribution and of equal variance when square root transformed. The data for the rats were ranked in order to be of normal distribution and equal variance. The data were then analysed using ANOVA. To determine whether rats or OSR were using the funnels more an unpaired t-test was used.

The data collected from the trapping carried out using the funnels were tested for normal distribution and equal variance when necessary and were analysed using  $\chi^2$  or unpaired t-test methods.

Trapped Rat Data. The data were grouped in the first instance by season to analyse the movement into or away from the farmyards. The seasons were winter (December to February), spring, (March to May), summer (June to August) and autumn (September to November). In the Leicester area there were only three seasons, (spring to autumn) and in Yorkshire there were all four seasons. Analysis was also carried out of this same data, but this time to see if the sex of the animal had a bearing on the movement into or away from the farm buildings. In addition a test was done to determine if the fact of trapping the animal and whether it was dead or alive when the trap was checked was significant. Analysis was also carried out comparing the dead or alive data from Leicester and Yorkshire. All the above analysis was carried out using the  $\chi^2$  test.

A t-test was carried out on the data of animals trapped and either killed or not killed to see if the weight of the animal had any bearing on whether the trap killed the animal.

## 5.6 RESULTS

### 5.6.1. Usage and Design of the RFS.

Analysis of the ranked tracking plate sums for rats and OSR showed that there was a statistically significant difference in the usage of the RFS between the two groups (t-test,  $t = 8.82$ , d.f. = 45,  $p < 0.001$ ). From the mean values of the ranks for the different groups it was shown that the OSR were using the RFS far more than the rats (OSR mean 35.46, rats 13.54). The null hypothesis that there would be no significant difference in the movement through the RFS of rats and OSR can therefore be rejected.

The analysis of the data showed that there was a difference in the usage of the funnel by the two groups of animal. For the OSR there was a significant effect of food on the usage of the funnels (ANOVA  $F_{1,23} = 27.75$ ,  $p < 0.001$ ), food increased the usage if the funnel, but there was no effect of funnel width (ANOVA  $F_{1,23} = 0.54$ ,  $p = 0.475$ ) or any interaction between width\*food (ANOVA  $F_{1,23} = 2.55$ ,  $p = 0.126$ ). For the rats the data analysis showed that there was no effect of food (ANOVA  $F_{1,23} < 0.000$ ,  $p = 0.956$ ) or width (ANOVA  $F_{1,23} = 0.370$ ,  $p = 0.549$ ) on the usage of the funnels and there was no interaction between funnel width\*food (ANOVA  $F_{1,23} < 0.001$ ,  $p = 0.956$ ). The null hypothesis that there would be no significant difference in the movement of rats and OSR through the different widths of RFS can be accepted. Looking at the different means of the usage by width indicated that the OSR had a preference for the 30 cm width funnels and the rats had a preference for the 50 cm width funnels. It was therefore decided to build all the funnels at the 50 cm width. As far as the food was concerned this produced two different results. For the OSR food was a significant factor in the use of the funnels and therefore the null hypothesis can be rejected. For the rats the food was not significant and therefore the null hypothesis can be accepted.

### 5.6.2 Numbers of animals trapped.

In Leicestershire there were 123 rats trapped over 3686 trap nights and in Yorkshire 145 rats trapped over 3335 trap nights. Over the same period 63 and 42 non-target animals were trapped in Leicestershire and Yorkshire respectively. The number of rats caught per trap night was 0.033 and 0.043 for Leicester and Yorkshire respectively. The Leicester figure is 30.29% lower than Yorkshire. For the non-target species trapped, the trap night figures are Leicester 0.017 and Yorkshire 0.012, a 26.32% increase in Leicester over Yorkshire. The number of non-target species trapped per rat trapped in Leicester is 43.45% higher than in Yorkshire, 0.51 against 0.29.

Numbers of target and non-target species trapped are shown in Table 5.1

	Yorkshire	Leicestershire
Rats	145	123
OSR	13	19
Other non-target species	29	44

Table 5.1 The numbers of rats, OSR and other non-target species caught

### 5.6.3. Direction of movement in relation to the season.

In both areas the season had no statistically significant effect on the direction of the movement of the animals trapped (Leicester:  $\chi^2 = 1.312$ , d.f. = 3,  $p = 0.519$ ; Yorkshire:  $\chi^2 = 0.659$ , d.f. = 3,  $p = 0.883$ ). The numbers of rats trapped in the RFS showing their direction of movement, towards or away from the farms is shown in Table 5.2 and these numbers are broken down in to sex at Tables 5.3a & b. The null hypothesis that there would be no difference in the numbers of rats moving into or out of farms can therefore be accepted.

	In		Out		Not recorded	
	York	Leics	York	Leics	York	Leics
Winter	4	0	1	0	21	0
Spring	0	6	2	7	23	0
Summer	2	4	8	4	9	0
Autumn	25	61	26	39	24	2

Table 5.2 The numbers of rats trapped in the rat funnels by season and their direction of movement (In – towards the farm; Out – away from the farm)

Yorkshire	Male In	Male Out	Male Not known	Female In	Female Out	Female Not known	Sex not known-direction shown if known
Winter	4	1	10				11
Spring		1	9		1	14	
Summer	1	1	2		1	1	1 In 6 Out 6 Nk
Autumn	8	13	9	8	7	10	9 In 6 Out 5 Nk

Table 5.3a. The numbers of rats trapped in the funnels in Yorkshire by season broken down into sex and direction of movement (In – towards the farm; Out – away from the farm)

	Male In	Male Out	Male Not known	Female In	Female Out	Female Not known	Sex not known-direction shown if known
Leicestershire							
Winter							
Spring	6	5			2		
Summer	1	3		3	1		
Autumn	27	23	2	31	19		

Table 5.3b. The numbers of rats trapped in the funnels in Leicestershire by season broken down into sex and direction of movement (In – towards the farm; Out – away from the farm)

#### 5.6.4. Direction of movement in relation to the sex of the animal.

The sex of the animal had no statistically significant bearing on the direction of movement of the animals trapped (Leicester:  $\chi^2 = 1.352$ , d.f. = 1,  $p = 0.245$ ; Yorkshire:  $\chi^2 = 5.419$ , d.f. = 1,  $p = 0.144$ ). The numbers of rats trapped in the RFS showing their direction of movement, towards or away from the farms, by sex, is shown in Table 5.4. The null hypothesis that there would be no difference in males and females caught in the traps can therefore be accepted.

	In			Out			Not recorded (L – Leic Y – York)
	York	Leic	Total	York	Leic	Total	
Male	13	34	47	16	31	47	L 2 Y30
Female	8	34	42	9	22	31	Y36
Not recorded	10		10	12		12	Y 11

Table 5.4 The numbers of rats, by sex, trapped in the rat funnels and their direction of movement (In – towards the farm; Out – away from the farm)

5.6.5. Relevance of the area to whether or not an animal was killed by the trap.

The results from the analysed data shows that the area is relevant to whether or not the animal was killed, ( $\chi^2 = 9.432$ , d.f. = 1,  $p = 0.002$ ). In Leicestershire fewer rats were caught alive than would be expected and in Yorkshire more rats were caught alive than would be expected, (Table 5.5).

	Yorkshire		Leicestershire	
	Male	Female	Male	Female
Killed	39	61	60	45
Not killed	20	24	6	12
Not recorded		1		

Table 5.5 The numbers of rats that were killed or not killed when caught in a trap in the funnels

5.6.6 Relevance of weight in relation to whether or not the rat was killed.

Some rats were trapped just by one limb or in a few cases by the nose and tail. The two sample t-test showed that in neither area was the weight of the rat significant in whether or not it was killed (Leicestershire:  $t = 1.53$ , d.f. = 24,  $p = 0.139$ ; Yorkshire:  $t = 0.63$ , d.f = 98,  $p = 0.528$ ; Combined:  $t = 0.87$ , d.f = 104,  $p = 0.385$ ). The mean weights of the rats trapped dead or alive in Leicestershire (range 50 – 555g), Yorkshire (range 60 – 640g) are in Figure 5.7.

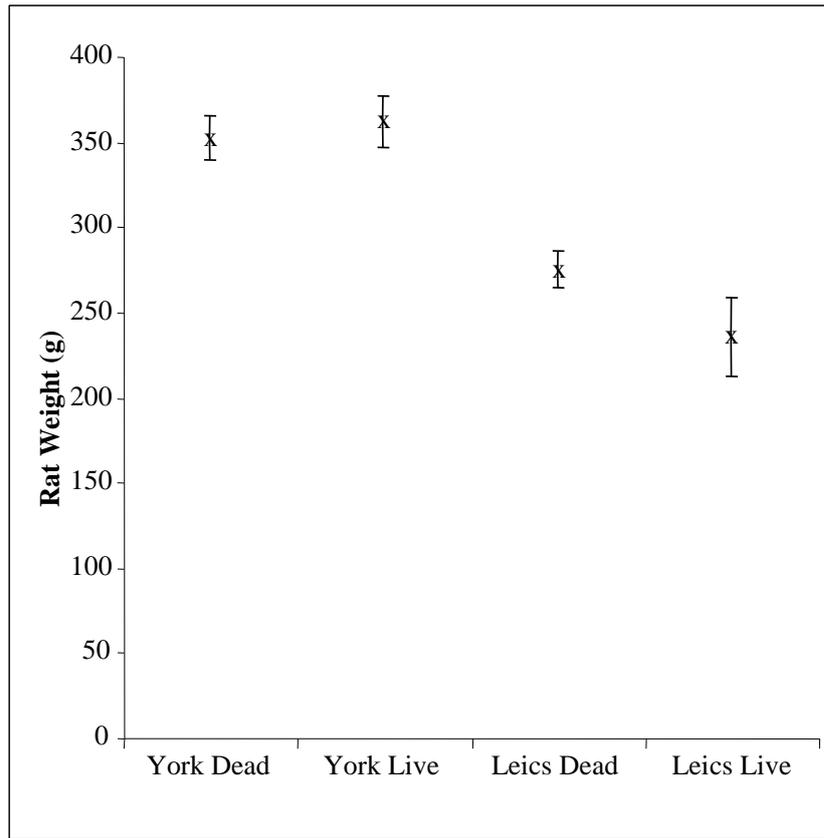


Figure 5.7 The means of the weights ( $\pm$  SEM) of the rats trapped dead and alive in Yorkshire, Leicestershire.

## 5.7 DISCUSSION

### 5.7.1. Usage of the funnels prior to trapping.

One of the objects of this short exercise was to determine if there was a preferred width for the rat funnel. A set Fenn Mk 3 snap trap measures 15 cm and so three traps would span the width of a 50 cm funnel and two would span a 30 cm funnel without there being sufficient space for a rat to enter without crossing a trap. Food was provided in half the funnels build in Leicestershire and halfway through this pre-trapping period those funnels that had had no food provided had food placed in them and those that originally had food in the food was removed. Initially the food used was surplus turkey rearing pellets left over once all the birds had been slaughtered and this was replaced by whole grain once the supply had run out. The analysis showed that the rats and OSR had no distinct preference for the width of funnel and it came as no surprise that those funnels that had food in had greater use than those without. On the basis of the slight preference shown by rats for the 50 cm wide RFS the 30 cm funnels in Leicestershire were adjusted to 50 cm width and when trapping commenced all funnels had whole grain placed in them.

### 5.7.2. Numbers of rats and non-target species trapped

As can be seen from the population estimates in Chapter 4 there is a considerable difference in the numbers of rats found in Leicester and Yorkshire. As a result one would expect to find a difference in the numbers of rats that are moving about the area and therefore a difference in the numbers of rats trapped in the funnels. This was what was found with the numbers of animals trapped in the two areas per trap-

night varying by just over 30% (123 against 145), with Leicester having the lower figure.

As with the numbers of rats trapped, so there is a difference in the numbers of non-target species trapped. In this instance the roles are reversed, with Leicestershire having the larger numbers trapped, the difference between the two areas being just over 33.3%. Why this should be is not clear, except that in the Leicester coordinated area in which the funnels were built, two of the farms have large game rearing interests, one as a commercial enterprise (Farm A) and the other as part of the Game Conservancy research (Farm B). Farm A buys in birds that are then reared in a pen in an area of woodland and as they grow they leave the pen and move into the surrounding woodland. On Farm B there are large strips of land that are planted specifically to feed the game birds. This not only benefits the game birds but also farmland birds and other animals, which are able to take advantage of this additional source of food that exists beyond the period of normal wild foods. In addition both farms provide additional feed for the game birds in the form of grain to encourage the birds to stay within the farm boundaries. On Farm A the feed is scattered on the ground and on Farm B the whole grain is put into feeders where it ends up on the ground, either because it gets spilled when the hoppers are filled or when the game birds feed by knocking the sprung tube that allows them access to the grain. In both cases the feed ends up on the ground and is available to other grain eating animals such as rodents. With this supply of food through the winter and a good burrow it could be possible for the small mammals to breed throughout the year. As a result it may be that there are larger numbers of small mammals and birds around the Leicester area than in Yorkshire. At Table 5.6 below is a list of the species caught with the numbers of each for the two areas.

ORDER & FAMILY	NUMBERS CAUGHT		SPECIES	COMMON NAME
	Leics	York		
Insectivora Erinaceidae <sup>(1)</sup>		1	<i>Erinaceus europaeus</i>	Hedgehog
Carnivora Mustelidae <sup>(1)</sup>	3	6	<i>Mustela erminea</i>	Stoat
	15	4	<i>Mustela nivalis</i>	Weasel
Rodentia Muridae <sup>(1)</sup>	18	12	<i>Apodemus sylvaticus</i>	Wood mouse
	1		<i>Clethrionomys glareolus</i>	Bank vole
		1	<i>Unidentified</i>	Mouse
Rodentia Aplodontidae <sup>(1)</sup>	4	4	<i>Sciurus carolinensis</i>	Grey squirrel
Lagomorpha Leporidae <sup>(1)</sup>	15	10	<i>Oryctolagus cuniculus</i>	Rabbit
Galiformes Phasianidae <sup>(2)</sup>	1	3	<i>Phasianus colchicus</i>	Pheasant
Passeriformes Turdidae <sup>(2)</sup>	1		<i>Erithacus rubecula</i>	Robin (European)
Passeriformes Corvidae <sup>(2)</sup>		1	<i>Corvus monedula</i>	Jackdaw
	1		<i>Pica pica</i>	Magpie
Passeriformes Passeridae <sup>(2)</sup>	2		<i>Passer domesticus</i>	House Sparrow
	2		<i>Unidentified</i>	Birds
	63	42	<b>TOTALS</b>	

Table 5.6. Non-target species trapped in the rat funnels and showing the numbers of each species caught in each area (<sup>(1)</sup> Macdonald & Barrett, (1993); <sup>(2)</sup> Snow & Perrins, (1998)).

One of the aims of building the rat funnels was to try to determine if rats were moving into the farmyards in autumn and winter. From the analysis of the data it would appear that the season has no significant effect on the direction of movement through the funnels and that rats are moving towards and away from the farmyards in almost equal numbers (Total number: towards 99; away 90 and not recorded 79). The largest numbers of rats were trapped during autumn, between September and November (177

out of the total of 268) and as with total numbers similar numbers were moving in both directions (towards 83; away 68 with 26 having no direction recorded). The sex of the animal was also not significant in either area in relation to the direction of travel with an almost equal number of males and females moving in both directions (males: 35 in and 36 out; females: 39 in and 26 out).

### 5.7.3 Humaneness of the trapping

Another element of interest in this research was the humaneness of trapping. The results of the data analysis for both areas showed a statistically significant difference in whether or not the animal trapped was killed or was alive when the traps were checked. A comparison was done between Leicester and Yorkshire and this produced a statistically significant difference between the two areas. In Leicester there were fewer rats caught alive than expected and in Yorkshire there were more caught alive than would have been expected. The vast majority of rats were trapped using Fenn Mk 4 snap traps but in Yorkshire some BMI 110 and 116 traps were used. Of the 71 rats that were found alive when the traps were checked only seven were caught in BMI traps. Of the remaining 64 rats trapped, 18 were trapped in Leicester and 46 were in Yorkshire. The reason why so many more were trapped but not killed in Yorkshire may be the age of their Fenn Mk 4 traps and the use they have had over the years, as a consequence of which the springs may not now be strong enough to close the jaws quickly enough to catch the rat in the correct place to kill it. The majority of rats that were not killed were trapped by one or more feet ( $n = 46$ ). Initially only four funnels had BMI traps in and it was found that they were not catching rats as well as would be expected. Subsequent investigation using a compact digital camera with a movement sensitive firing mechanism showed that instead of walking through the traps and being

caught the rats were moving through the funnel by walking across the top of the traps and therefore not setting them off (see Figure 5.8 below). No one wishes to see animals suffering and animals, whether they be rats or non-target species, do suffer if caught in a trap that does not kill them quickly. Rats that have not been killed will try to release themselves from the trap and in some instances they have chewed off a limb to obtain freedom. There is then a maimed animal that is open to infection and further suffering, and also to predation because it does not have either the necessary agility or speed to escape a predator. Mason and Littin (2003) in their review of humaneness of various methods of rodent control also highlight the fact that rodents can be trapped but not killed by snap traps and indicate that between 7 and 14% of wild rodents trapped may be injured without being killed instantly.



Figure 5.8 A rat moving through a funnel across the top of the BMI traps (Picture courtesy of M Lambert)

Several of the animals trapped were not caught across the neck or chest, which would have killed them, but were trapped by limbs and in one or two cases by the nose and tail. This was thought to be because either the rat was moving too fast and had

gone through the trap by the time the jaws closed, thus trapping it by a limb, or else it was too small to be caught properly in the jaws and was trapped by the nose and or tail. We therefore looked at the size (weight) of the animal in relation to whether or not it was killed by the trap. In both areas, size was not a significant factor as to whether or not a rat was killed when trapped.

## 5.8 CONCLUSIONS

There are several conclusions that can be drawn from this piece of research. The first is that there is a distinct preference in width of funnel shown by rats and OSR, the OSR preferring a narrow funnel (30 cm) and the rats the wider funnel (50 cm). As would be expected, the provision of food in a funnel increased its usage by both the OSR and the rats. This means that the optimal design for catching rats (whilst being less attractive to OSR) would use a 50 cm rather than 30 cm width.

The use of the funnels as a means of removing rats from the environment has been shown to work. A practical question is whether or not farmers would consider using them to bring the rat numbers down bearing in mind the amount of time that needs to be spent checking them each day. They were built with material that is commonly found around farmyards, but whether or not farmers will continue to produce the small bales that were used is open to question, certainly far fewer are now produced and as a result an alternative may have to be found. Building the funnels is not that time consuming, what does take the time is the daily checking of all the traps within the funnels. Farms nowadays have very few staff, it may be just the farmer or the farmer and one or two employees and it is doubtful if one man would be spared for up to half a day, depending on the number of funnels and traps, five days a week just to check the funnels. On game estates however, it would be a different matter because gamekeepers walk around every day and are skilled at trapping.

We have not been able to show that rats move into farmyards in statistically significantly greater numbers during the winter, although the numbers caught in the funnels during the autumn, a time when one would expect to see large numbers of rats leaving the fields for the farmyards, are larger than at any other time of year. What has also been shown is that the rats are not moving predominantly in one direction in the

winter and the reverse direction in the spring, but movement towards and away from the farmyards appears to spread evenly in each direction in each season.

Analysis of the data also shows that the sex and weight of the animal are not significant in determining whether or not a rat is caught.

Non-target species trapped. Rats vary in size and we selected an aperture size (50 mm) in the funnel barriers, based on the past experience of others that would allow a normal rat to move through but prevent larger species from entering and this was the most suitable size aperture to cut into the weldmesh. Unfortunately at this size of aperture other species are also able to pass through, witness the range of species listed at Table 5.6 above. Some of these are much smaller than a rat, a wood mouse for example, some are of approximately the same size such as a squirrel but others, such as the pheasant and rabbit are much larger. It is felt therefore that it is almost, if not completely impossible to exclude non-target species from the funnels. A gamekeeper may feel that this is not a problem, he may lose one or two birds to the traps but he also gains by trapping weasels and stoats (as well as rats) that may eat the gamebird eggs or predate the young chicks, thus increasing the number of birds available to his “guns”. Bearing in mind the price that people are prepared to pay for a days shooting this is a cost effective exercise. For the farmer, who also has conservation in mind, trapping non-target species may not be a price he is prepared to pay. But what are the alternatives? Rodenticides placed out in the field to poison the rats will without doubt be available to non-target species, such as small rodents (Brakes & Smith, 2005), and once poisoned these then become more liable to predation to a wider range of species such as the raptors, because of the changes in behaviour that rodenticides induce. This then has to be a judgement call by the land owner, will he risk trapping a few non-target species or put out rodenticides and risk poisoning a wider range of non-target species or

does he do nothing about the rat population in his fields and just concentrate on controlling those in the farmyard? There is no easy way around this problem of trapping or poisoning non-target species if one is going to control the rat population and it has to be a trade-off between controlling the rats and the risk of killing a few non-target species.

From the total number of rats trapped (268), 26.8% (71) were not killed when captured. This is an extraordinarily large proportion and in terms of humaneness is a major problem that tends to contradict Mason and Littin (2003). The traps, whether they be Fenns or BMIs are designed to kill a rat when they are released from sprung and clearly in a lot of instances they failed to do so. This causes pain and suffering and whatever one feels about rats, we should not be causing this level of distress. As with everything that is operated by a spring, over time the spring may become weakened and might not operated at maximum efficiency. There is therefore a need to ensure that whatever type of trap is used, if it is designed to kill, that it does so and once it is found not to do so it should be thrown away or have a new spring fitted. This, however, is unlikely to be the case on a lot of farms as rats are seen as pests and very little consideration is likely to be given to their welfare. Indeed, I have seen sprung traps that have not been checked for several weeks, if not months, never mind every day, as the contents were in some instances partly eaten and some were partially or completely desiccated, indicating that, even where there were gamekeepers, they were not complying with the law and checking the set traps daily for captures.

Overall we were able to show that funnels are a means of trapping rats that are moving along hedgerows and that more can be caught in the autumn than at other times of year. It has not been shown that more rats were trapped moving in towards the farmyard than away from them and that sex and the size of the animal was not relevant

to being captured. What has also been shown is that not all the traps that were used were as effective as they might have been in killing the rat within a short space of time. Whether or not this is down to the age of the particular traps used and the strength of their spring is open to question. This does, however, raise a question over the humaneness of snap traps.

It is not possible, from this study, to determine whether it was the coordination of poisoning across the landscape (see Chapter 4) or the use of the RFS to trap rats that reduced the rat numbers. These two factors could in principle be separated in a 2 x 2 design that varied both, but the scale of such a study was beyond what was feasible here.

## CHAPTER 6 – GENERAL DISCUSSION AND FUTURE WORK

### 6.1 GENERAL DISCUSSION

In 1950 the introduction of Warfarin brought about a revolution in rodent control, and since then anticoagulant rodenticides have been used almost exclusively to control rodents, and in particular, rats. Early development of resistance to warfarin in 1958 led to the development of the second generation rodenticides, which are many times more toxic than warfarin and relatively more toxic to birds. The continual use of warfarin and the more recently developed second generation rodenticides has, like the over use of antibiotics and the recent rise of MRSA, seen the development and spread of resistance to the anticoagulant rodenticides. As a result, in some areas there are no effective control measures that can be taken. Newbury District Council, for example, stopped carrying out any rat control in West Berkshire several years ago. Even where the anticoagulant rodenticides are effective in reducing the numbers of rats, it is only ever a short term measure (Smith, 1994, 1995), because rats have a very high reproductive rate and those that survive the treatment can bring the population back to original levels very quickly. High mobility also aids in the recolonisation of an area following an eradication programme. As a result, the rodenticide treatment needs to be repeated on a routine basis. With this continual use of rodenticides the risk of primary and secondary poisoning of non-target species increases. Alternative measures which reduce the reliance on anticoagulant rodenticides therefore need to be found to control the rat population.

It was shown in Chapter 2 that the analysis of the rodenticide loads carried by rats from areas of known rodenticide resistance, and from those where there is no known resistance, that those rats carry rodenticide resistance also carry a higher rodenticide load. It has been shown in Chapter 4 that conducting rodent control over a

wider area than just a single farmyard in a coordinated fashion can reduce the numbers of rats and that they can be kept at a lower level. What also came out of this aspect of the study was that the amount of rodenticide used decreased over the period of the research. Chapter 5 showed that the use of the rat funnels, although in concept a good idea, were very labour intensive and, therefore for the majority of farmers not cost effective. The higher rodenticide loads in rats from areas of known rodenticide resistance means that there is a greater risk to predators and scavengers of secondary poisoning in these areas. The reduced numbers of rats resulting through coordinated poisoning also has a possible effect on predators and scavengers by reducing the amount of food that is available to them.

This outcome presents a dilemma, on the one hand it yields a reduced rat population, a good thing for farmers, and on the other is the reduced amount of food for predators and scavengers, some of which may contain a high rodenticide load sufficient to kill the predator. Therefore alternative measures need to be found which reduce the reliance on anticoagulant rodenticides and that on the one hand reduce the rat population so that it does not cause financial damage to the agricultural community, and which are cost effective, but on the other maintains a rat population that is sufficient to provide food for rat predators and scavengers.

## 6.2 ALTERNATIVE MEASURES

Some alternative strategies have already been investigated and are discussed briefly below.

### 6.2.1 Habitat manipulation

Some measures have already been examined, such as the cutting down and removal of vegetation around a farmyard and the disposal of all the rubbish (old tyres, unused machinery, old stacks of bales) that can be found in a large number of farms. These measures have been found to be as cost-effective as control using anticoagulants (Lambert 2003). This works by exposing rats to greater predation as there is less cover and reduces the number of available nesting sites thus restricting breeding.

### 6.2.2 Immunocontraception

Fertility control is another alternative that has been proposed for species that have high fecundity, rapid population turnover or for whom a more humane method of population control is wanted. Several methods have been proposed as how to achieve infertility, such as using steroids and synthetic hormones but these require to be repeatedly administered, have adverse side effects and are not specific to the target species (Chambers *et al.*, 1997; Kendle *et al.*, 1973). Chambers *et al* (1997) proposed immunocontraception as a method of rodent control. Immunocontraception could be applied using a species specific viral vector that induces an immune response(s) against reproductive cells, fertilisation or implantation, all of which lead to infertility. Delivery of the vector could be a major problem; is it to be a vaccine or delivered in some form of bait? With either system, will the vector be self perpetuating enough for a significant reduction in the population to be achieved? Immunocontraception has been shown to work on a small population of white-tailed deer (*Odocoileus virginianus*) on Fire

Island, New York, USA and reduced the fawns to 13 – 14% of the population in the treated area as opposed to 16 – 33% in the untreated area (Naugle *et al.*, 2005). Naugle *et al.*, state that immunocontraception can be delivered effectively but that “technical and logistical improvements are needed”. Applying this technique to a confined population and one that can be readily seen is one thing, applying it to a rat population is something else. Using a viral vector could also be classed as biological control.

### 6.2.3 Ultrasound devices

Ultrasound is taken to be sound that is above the hearing of human beings, anything above about 20 kHz. Ultrasound has been shown to affect the behaviour of rats and mice. Repeated exposure to two second bursts at a frequency of 20 kHz at 98 – 100 decibels causes diuresis in rats and cardiac hypertrophy can be caused by other sound stresses (Meehan, 1984). There are two major drawbacks to ultrasound. Firstly it is highly directional and cannot penetrate objects or go round corners. Secondly, the initial impact lessens as exposed individuals rapidly habituate. Reviews of the evidence of the efficacy of ultrasound devices has been carried out and, despite the manufacturers claims that their devices would disrupt the behaviour or kill rats and mice, no scientific evidence has been forthcoming to support these claims (Lund, 1988b; Meehan, 1984).

### 6.2.4 Biological Control

There are a number of animals in the UK that prey on rats, for example owls, foxes, weasels, and stoats. With the exception of owls, the others are sometimes considered to be pest species in their own right, taking game birds that are being or have been reared specifically for shooting. It is questionable as to how many rats are taken by these predators and whether or not they could realistically control the rat

population. Smith, (1994) quotes Greathead & Waage, (1983) as saying that “conventional wisdom is that vertebrates are normally poor prospects as biological control agents”. We know from experience that introduced predatory mammals can become pest species in their own right and some have done considerable damage to and even eradicated some of the native species, (Taylor *et al.*, 2000; Taylor & Thomas, 1993; Thorsen *et al.*, 2000), although this tends to be on islands or in parts of the world with no predatory mammals. There have been successes using vertebrates to control vertebrates. When the oil palm was introduced to Malaysia from West Africa it was exploited by several rodent species, of which the most important is the Malaysian wood rat (*Rattus tiomanicus*). The barn owl spread across Malaysia from Indonesia as the oil palm spread and was found to be eating almost exclusively the wood rat (Lenton, (1980) quoted in Smith, (1994)). The success of the barn owl was severely limited by the lack of nest sites, but when nest boxes were provided, with an occupancy reaching 68%, the number of owlets ringed per month rose from 0.15 in the first six months to a maximum of 0.74 in months 13 – 18 and an average of 0.55 for the full 29 months of the monitoring period. The decrease in the damage to the oil palm fell from 6% to 1.5 – 3.9% (Duckett, (1991) quoted in Smith, (1994)).

### 6.3 AN ECOLOGICAL APPROACH TO RODENT CONTROL

Rats are able to establish a colony anywhere the basic requirements of food, water and harbourage are available and the size of the colony is dependent on the extent of any one of these resources. Once the colony has reached a size at which it can no longer grow because one or more of the resources do not allow it, then some of the animals within the colony will emigrate to new areas to set up a colony (*r*-strategists) (Macdonald & Fenn, 1994). Wolff, (2003) indicates that it is related females, in the majority of rodent species, that defend territory against unrelated females and that it is the juvenile males that leave the natal site. The female offspring tend to stay and try to establish breeding sites on or near the natal site. In the radio tracking carried out here (Chapter 3) it was two females that left during the early summer and set up new home ranges several hundred metres from the capture site. This in part contradicts the findings of Wolff (2003) and does show that it is not just the males that leave the natal site.

To be effective, anyone attempting to control rats needs to understand their biology and therefore use a numbers of different strategies to counter the natural abilities that they have. Tobin *et al.*, (1997) looked at the control of the black rat in macadamia orchards in Hawaii where the rodenticide was put on the ground. They found that the animals did not come down onto the ground but remained in the trees when foraging. The bait was then placed in the trees and as a result a more efficient use was made of the rodenticide. A very simple solution to a major problem for the farmers, but one that was only found as the result of studying the biology of the animal. When moving from one area to another, rats will move along existing corridors, such as hedgerows or against vertical surfaces thereby reducing the risk of predation. If there is no such corridor then they will move across open areas using the cover of the

vegetation or any other material that is available, such as old machinery, and other material that is found dumped around a lot of farmyards. Habitat manipulation is therefore a good starting point, not to mention the benefits of good hygiene in keeping a farmyard clean (see Section 6.4.1). Making buildings where grain or animal feed is stored rat proof is a sensible precaution as is clearing up any spilt grain or animal feed, but the construction of the doors that allow access to the large tractors and trailers in use nowadays does not make rat-proofing easy. One successful application of alternative strategies, where the animal's biology and behaviour were used along with an organised control operation and incentive scheme for trappers, was the eradication of the coypu (*Myocastor coypus*) from Britain (Gosling & Baker, 1989).

Rats are neophobic and therefore avoid anything new within their home range. If using bait or live traps then they should be left out in the location in which they are to be used to allow the rats to become acclimatised to them before they are put into use. Baiting then needs to be monitored to establish whether or not bait is being taken. If it is not, then the rats may be exhibiting "bait shyness" because they have come across it before and it made them ill, and an alternative bait then needs to be found. (Cox & Smith, 1990) found evidence in the field that larger, dominant rats exclude smaller subordinate rats, based on the declining weights of carcasses collected during treatment. Some rats are likely to survive a short baiting session as the dominant rats will exclude the subordinate ones from the bait (Nott & Sibly, 1993), if it is seen as a good food source, certainly for a period of time until the rodenticide debilitates or kills the dominant animals. The subordinate rats may then have access to the bait but not sufficient time to ingest a lethal dose, which may result in them being ill but recovering and developing bait shyness.

Ecologically-based rodent management (EBRM) was proposed by Singleton *et al.*, (1999a) following the similar approach taken with insect and weed pest management, (integrated pest management and ecologically-based pest management). Rodent control is not a new problem, Singleton *et al.*, (1999a) quotes Aristotle (384 – 322 BC) “*The rate of propagation of field mice in country places, and the destruction that they cause, are beyond telling*”. We only have to witness the mouse plagues that occur in Australia on a regular basis to see that they are still occurring. Singleton *et al.*, (1999a) estimated from data on the rice lost to rats, pre-harvest in Laos and post-harvest in Cambodia, that the amount of rice lost in Indonesia was enough to feed 25 million Indonesians for a year. This is a staggering figure and for this part of the world probably means that many people go hungry. EBRM was initially developed in the Third World to reduce this enormous loss of food stuffs where the population does not have the finance to be able to afford rodenticides, but the principles could equally well be applied to the developed world. This is the basis of coordinated control used together with trapping migrating rats (Chapters 4 and 5).

A range of measures need to be taken to be able to control a rat population effectively and ensure that it is kept down to a level where the damage that it causes is reduced to a position that is economically sustainable, and chemical rodenticides should be just part of the range of measures. Burn *et al.*, (2002) say that rat populations are unlikely to be eradicated over the long term and therefore the population should be managed by the use of measures that are less damaging to wildlife. The current system of almost total chemical control is probably unsustainable economically and does not clear a site of rats in the long term because of their high rate of reproduction and mobility.

If alternative practical and cost effective measures to rodenticides can be found to control the rat population in the western world this will have a beneficial effect on the non-target species that predate them by reducing the risk of secondary poisoning. In addition, the problem of resistance is mitigated and concerns about the humaneness of anticoagulants may be reduced.

## 6.4 FUTURE WORK

### 6.4.1. Continuation of population monitoring.

The work that has been reported here is the first long-term recording of rat populations over an extended area, but even so 2.5 – 3.5 years is not really very long. This type of measuring of rat populations along with the control measures needs to be continued into the foreseeable future so that a good picture can be built up of the effects of coordinated control on the rat population in the agricultural environment. Farmers, I am sure, would be only too willing to let someone else conduct their rodent control, particularly if it was costing them nothing, as in this case. However, as was found at the start of this research, finding farmers whose land adjoins who will admit to having a rat problem and then allow researchers free access to their land and premises is something else.

### 6.4.2. Reverse Experiment.

One of the problems with ecological studies on a realistic scale is that there is insufficient replication for conventional statistical analysis. This problem was addressed by Stewart-Oaten *et al.*, (1992) who discussed before and after time series studies as a practical solution. The before and after comparison could not be used here because there was insufficient time to study the untreated sites. Now that the rat population trends on the four sites used in this research are known, however the reverse experiment could be conducted with the two sites in each area having the treatments reversed. This could be a major problem, because the farmers that have had the control done for them are of the opinion that rats numbers have reduced and would wish to keep it that way and so might well maintain the baiting regime that has been used during the research. Those who have not had control done for them would, I am sure,

be delighted to have it taken out of their hands. Conducting the reverse experiment should show whether or not the rat population will rise back to the pre-research levels on the current coordinated sites, and if so over what time period, and whether or not coordinated baiting can reduce the rat population in the present uncoordinated sites and is therefore a better system than the farmers just baiting in and around their farmyards. In addition, it would shed light on the causes of the delayed synchrony seen in Yorkshire (see Figure 4.16). In practice the reverse experiment could only be conducted in Yorkshire because of the very small numbers of rats found Leicestershire uncoordinated area and because of the lack of any field populations there.

#### 6.4.3. LD<sub>50</sub> research on predators and scavengers

We are all concerned about the numbers of predators and scavengers being killed as the result of secondary poisoning and part of this research was to try and reduce the amount of rodenticide used in the countryside. LD<sub>50</sub> testing is unpopular with the majority of the population and would not be accepted by those who support animal rights but there is a scientific case for estimating the LD<sub>50</sub>s for those animals that are most at risk, such as Red kites, other avian predators and scavengers, stoats and weasels, in order to carry out a more precise risk assessment. At present all that can be said from the results of the analysis of carcasses conducted under WIIS is that  $X \text{ mg kg}^{-1}$  is a level that is expected to cause death in any particular animal.

#### 6.4.4. Quantify the value of the damage done.

To be able to make a valid assessment of the value of doing rodent control over the wider area, the costs involved in terms of materials and time need to be evaluated. The damage that rats cause, spoiled grain, feed, chewed pipes and so on, needs to be

costed and this set against the costs of doing the rodent control in a cost-benefit analysis. It is only once one has these figures that the true value of doing this type of control can be properly assessed. The assessment of the damage caused by rats could be done by a survey of a number of farmers and include the loss of income from the sale of grain because it needed cleaning or the cost of cleaning before sale, the cost of the loss of feed, damage caused by chewed water pipes and electric cables.

6.4.5. Establishing the numbers of small rodents and other non-target species affected by rodent control over the wider area.

A useful addition to the work described here would be to estimate the numbers of small rodents (wood mice, voles, shrews etc.) and other non-target species (stoats, weasels, hedgehogs, grey squirrels etc. as well as avian predators and scavengers) in an area before and after carrying out coordinated or uncoordinated control. Once a base line had been set, the work on the rodent control could be started. Once rodent control has started, the numbers of these non-target species should ideally to be monitored as well as the rat numbers (Brakes & Smith, 2005). This should then establish what the effect on the non-target species is of rodent control over this wider area. Once completed, a better judgement could be made of the effectiveness of the rodent control in relation to non-target species and its effect.

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## ANNEX A CALCULATIONS FOR THE RISK ANALYSIS

### Yorkshire rats : bromadiolone and weasel

<u>Rat Weights</u>		<u>Bromadiolone concentration</u>
Mean gross weight	433 g	
Mean net weight (WB)	353 g	$0.0665 \times 1.25 = 0.083 \text{ mg kg}^{-1}$
Mean liver weight	20.5 g	$6.68 \times 1.25 = 8.35 \text{ mg kg}^{-1}$
Liver contains	$20.5 / 1000 \times 8.35 = 0.1712 \text{ mg}$	
Whole body contains	$353 / 1000 \times 0.083 = \underline{0.0293} \text{ mg}$	
Whole rat contains	0.2005 mg	
Weasel lethal concentration:	0.48 mg kg <sup>-1</sup> bromadiolone measures in carcass	
Assume weasel will absorb 12% of poison consumed (MacVicker, 1998)		
Weasel lethal dose:	$0.48/0.12 = 4 \text{ mg kg}^{-1}$ (c.f. 1-1.5 mg kg <sup>-1</sup> for rat)	
Weight of weasel <sup>(1)</sup>	Female 63 g	Male 118 g
Female weasel must consume	$63 / 1000 \times 4 \text{ mg of poison}$	
	= 0.252 mg for lethality	
	≡ 1.26 rats	
Male weasel must consume	$118 / 1000 \times 4 \text{ mg of poison}$	
	= 0.472 mg for lethality	
	≡ 2.35 rats	

Using the above calculations the following table can be compiled of the number of rats needed to be consumed to kill an animal:

	Liver only	Body tissue only	Body and liver
Female weasel	1.5	8.6	1.3
Male weasel	2.8	16.1	2.4

Leicestershire rats : difenacoum and red kite

<u>Rat Weights</u>		<u>Difenacoum concentration</u>
Mean gross weight	293 g	
Mean net weight (WB)	227 g	$0.037 \times 1.25 = 0.046 \text{ mg kg}^{-1}$
Mean liver weight	11.5 g	$0.047 \times 1.25 = 0.059 \text{ mg kg}^{-1}$
Liver contains	$11.5 / 1000 \times 0.059 = 6.78 \times 10^{-4} \text{ mg}$	
Whole body contains	$227 / 1000 \times 0.046 = \underline{1.04 \times 10^{-2}} \text{ mg}$	
Whole rat contains	$1.11 \times 10^{-2} \text{ mg}$	

Red kite lethal concentration:  $0.292 \text{ mg kg}^{-1}$  difenacoum measured in carcass

Assume red kite will absorb 12% of poison consumed (MacVicker, 1998)

Red kite lethal dose:  $0.292 / 0.12 = 2.4 \text{ mg kg}^{-1}$  (c.f. 1-1.5  $\text{mg kg}^{-1}$  for rat)

Weight of red kite<sup>(2)</sup> : Female 800 - 1200 g (mean 1000 g)  
 Male 1000 - 1300 g (mean 1150 g)

Female red kite must consume  $1000 / 1000 \times 2.4 \text{ mg}$  of poison  
 = 2.4 mg for lethality  
 $\equiv 216.2$  rats

Male red kite must consume  $1150 / 1000 \times 2.4 \text{ mg}$  of poison  
 = 2.76 mg for lethality  
 $\equiv 250.9$  rats

Using the above calculations the following table can be compiled of the number of rats needed to be consumed to kill an animal:

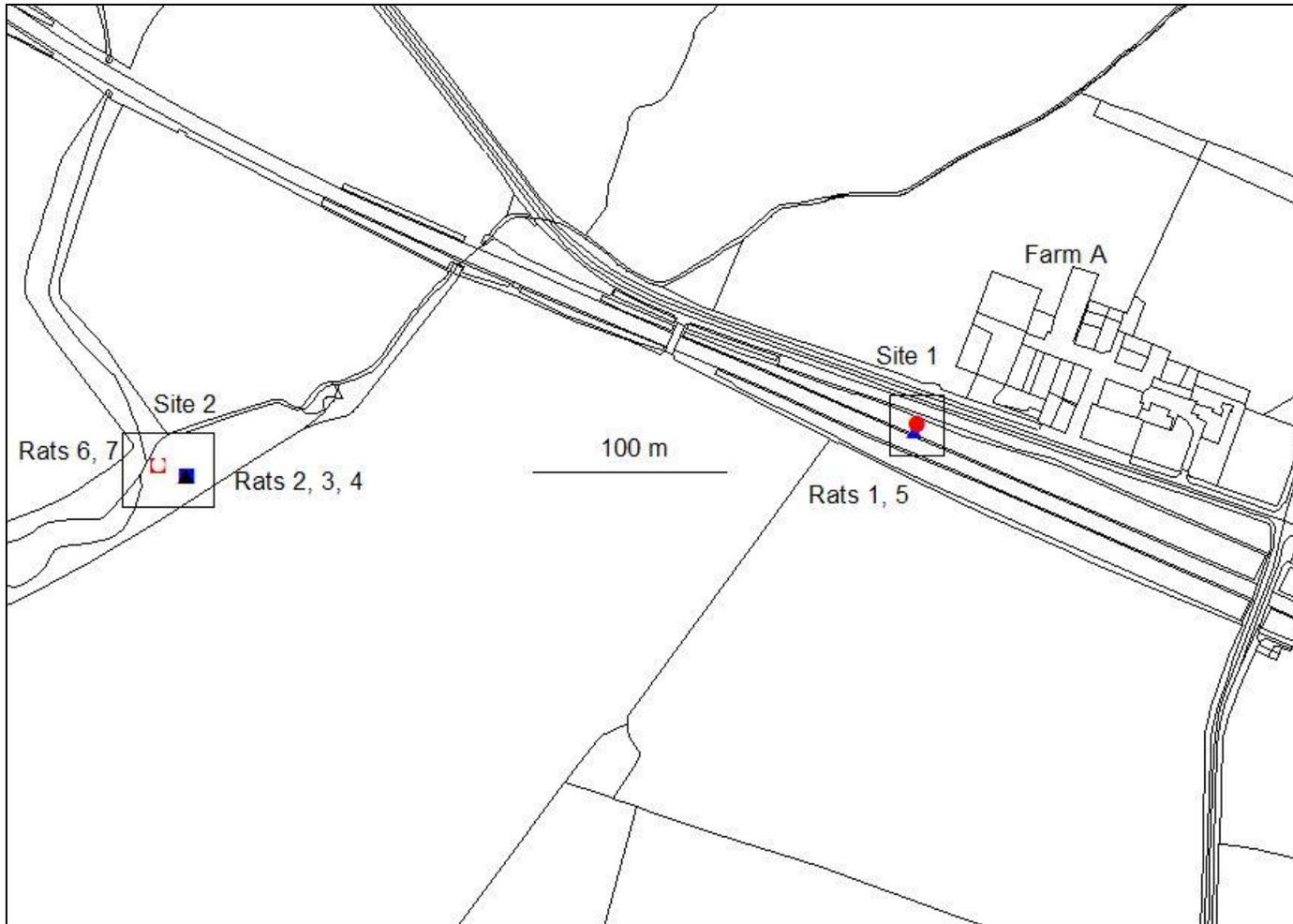
	Liver only	Body tissue only	Body and liver
Female red kite	3539.8	230.8	216.2
Male red kite	4070.8	265.4	248.6

<sup>(1)</sup> (Crocker *et al.*, 2002)

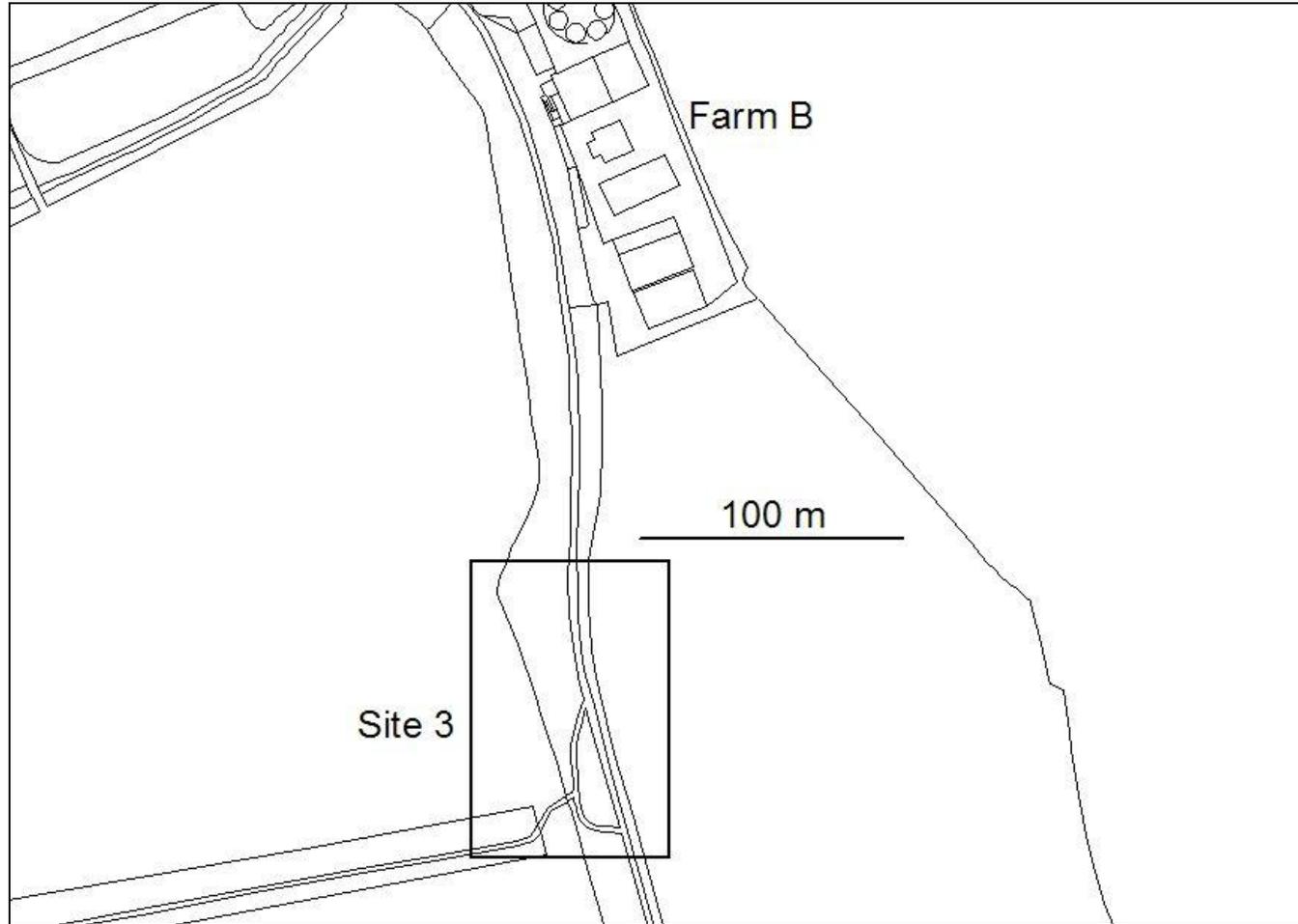
<sup>(2)</sup> (Snow & Perrins, 1998)

**ANNEX B. MAPS OF THE TRAPPING SITES AND INITIAL TRAPPING LOCATIONS**

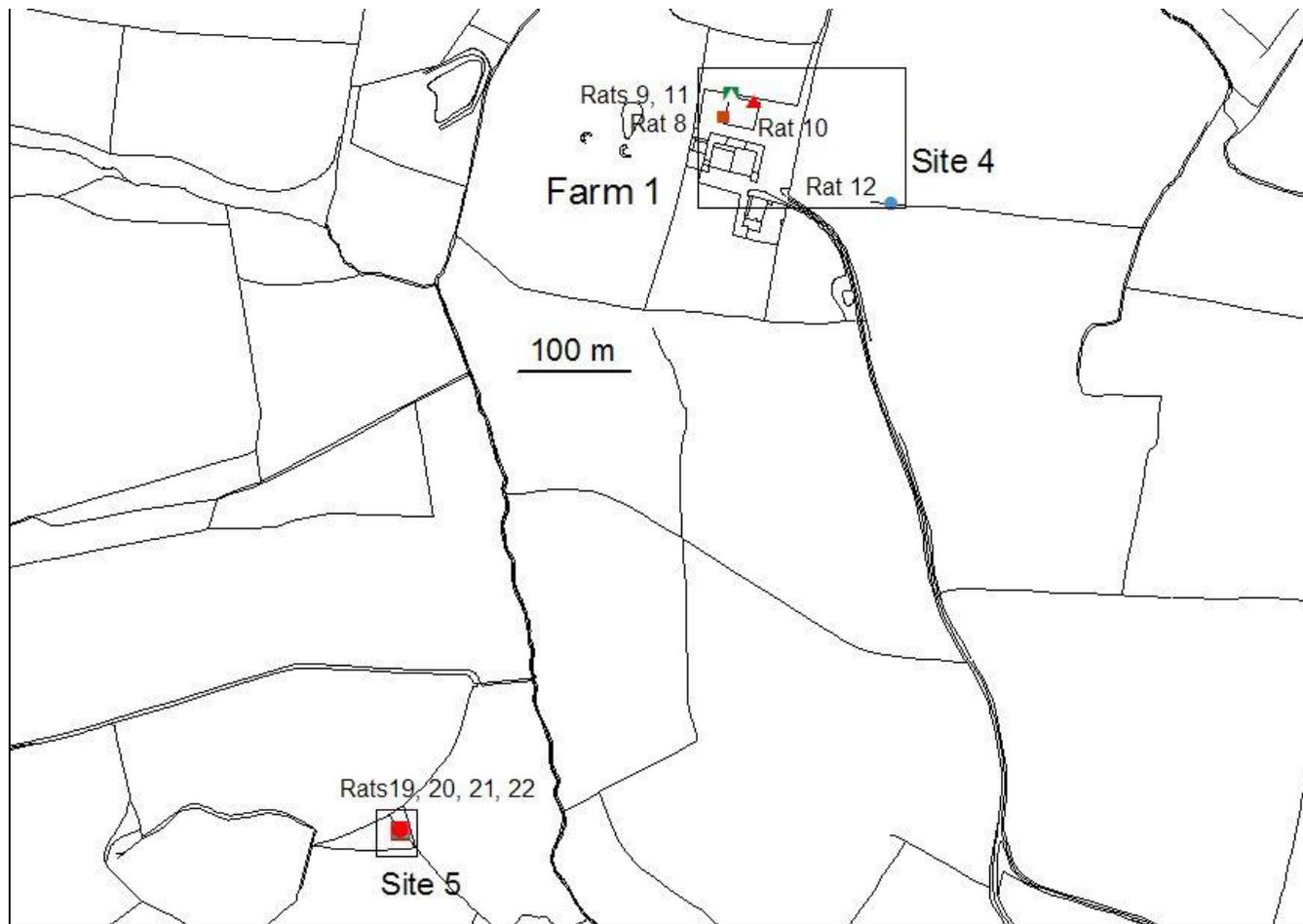
(Note: North is at the top, this edge, of the maps)



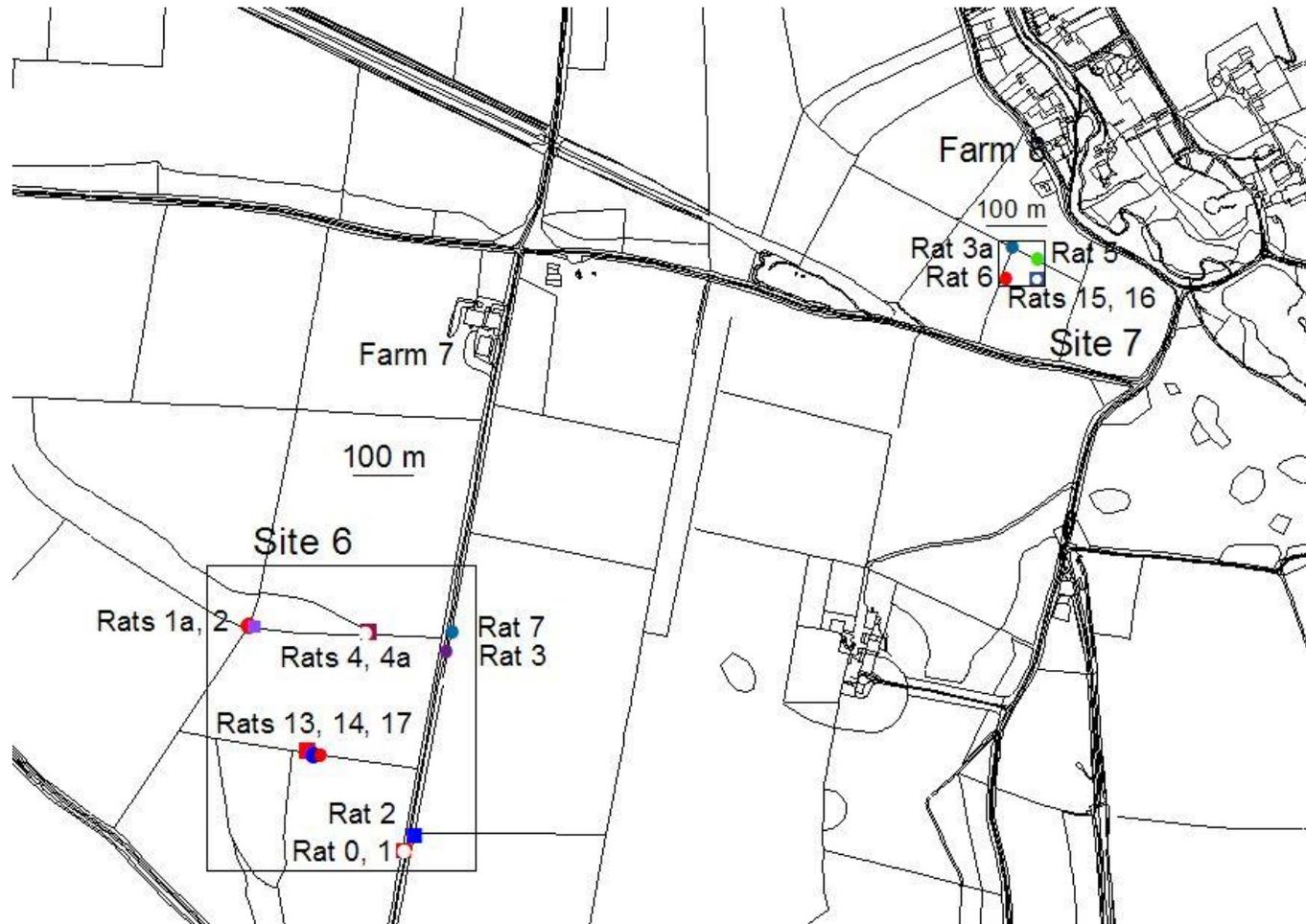
Leicestershire Coordinated area trapping sites 1 and 2 showing initial trapping location of rats trapped



Leicestershire Coordinated area trapping site 3



Yorkshire Coordinated area trapping sites 4 and 5 showing initial trapping location of rats trapped



Yorkshire Uncoordinated area trapping sites 6 and 7 showing initial trapping location of rats trapped

ANNEX C. DETAILS OF RATS FITTED WITH RADIO COLLARS AND THEIR FATE

YORKSHIRE

Capture date	Rat No	Freq	Sex	Weight (g)	Capture location	Fate
05/03/2004	0	173.539	Male	525	Farm 7 Site 5	Disappeared between 23/03/2004 and 25/03/2004.
05/03/2004	1	174.353	Female	425	Farm 7 Site 5	Died between 26/03/2004 and 29/03/2004. Dug out of burrow 29/03/2004, looked poisoned, other dead rats nearby.
05/03/2004	2	174.56	Male	500	Farm 7 Site 5	Died between 16/03/2004 and 23/03/2004. Dug out of burrow 24/03/2004, looked poisoned, other dead rats nearby.
05/03/2004	3	174.671	Male	570	Farm 7 Site 5	Died between 26/03/2004 and 29/03/2004. Dug out of burrow 31/03/2004, looked poisoned, other dead rats nearby.
05/03/2004	4	174.86	Female	385	Farm 7 Site 5	Died between 24/03/2004 and 25/03/2004. F/D under remains of old hen hut in copse 25/03/2004. Poison point nearby.
24/03/2004	5		Male	475	Farm 8 Site 6	Signal disappeared between 08/11/2004 and 18/11/2004. Battery probably flat.
24/03/2004	6		Male	370	Farm 8 Site 6	Disappeared between 15/04/2004 and 21/04/2004.
31/03/2004	7	173.967	Female	440	Farm 7 Site 5	Died between 10/05/2004 and 28/05/2004. F/D on surface, probable predator attack.

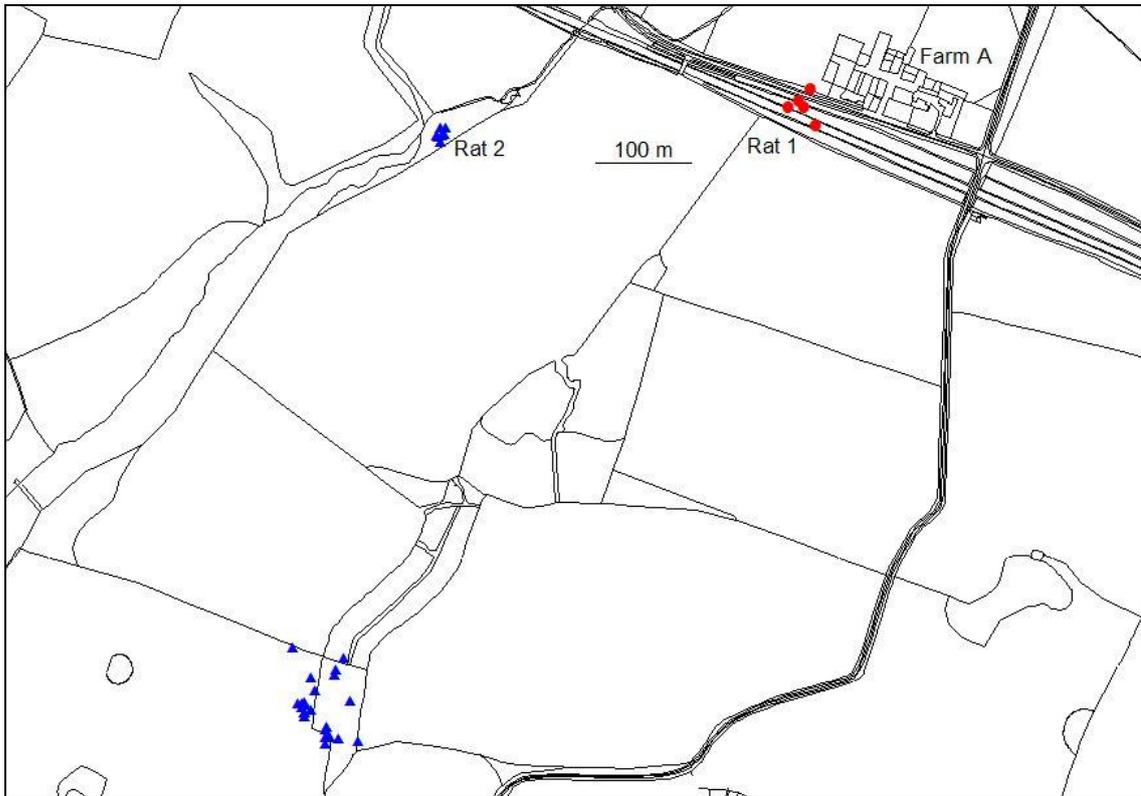
<b>Capture date</b>	<b>Rat No</b>	<b>Freq</b>	<b>Sex</b>	<b>Weight (g)</b>	<b>Capture location</b>	<b>Fate</b>
31/03/2004	1a	174.353	Male	415	Farm 7 Site 5	Died between 09/04/2004 and 16/04/2004. In old rabbit warren.
31/03/2004	2a	174.56	Female	495	Farm 7 Site 5	Died between 09/04/2004 and 16/04/2004. Under felled tree trunk.
31/03/2004	3a	174.671	Male	420	Farm 8 Site 6	Died between 15/04/2004 and 21/04/2004. Signs of predator attack/cannibalism. Old scruffy looking rat.
31/03/2004	4a	174.86	Female	350	Farm 7 Site 5	Died between 01/04/2004 and 05/04/2004. Could not recover corpse as died under tree roots. Probably poisoned, other dead rats nearby.
07/07/2004	11	173.634	Female	350	Farm 1 Site 4	Intact collar found in wheat field 10/08/04
07/07/2004	9	173.815	Female	350	Farm 1 Site 4	Picked up half dead at back of Dutch barn 01/09/04. No internal signs of a/c poisoning
07/07/2004	8	173.916	Male	480	Farm 1 Site 4	Probably dead in soil and rubble pile to W of NW corner of N pig shed 17/08/04. Intact collar retrieved 02/09/2004 but no sign of rat apart from matted fur. Probably decomposed.
07/07/2004	12	174.392	Male	495	Farm 1 Site 4	Died between 05/01/2005 and 10/01/2005. F/D in shallow burrow at NE corner of new shed. Prob poisoned as farmer has been using Slaymore inside new barn.
07/07/2004	10	174.444	Male	300	Farm 1 Site 4	Died between 03/09/04 and 15/09/2004. F/D under base of S pig shed, probably poisoned, although body well rotted.

<b>Capture date</b>	<b>Rat No</b>	<b>Freq</b>	<b>Sex</b>	<b>Weight (g)</b>	<b>Capture location</b>	<b>Fate</b>
14/09/2004	15	173.916	Female	255	Farm 8 Site 6	Disappeared between 07/10/2004 and 15/10/2004.
17/09/2004	16	173.634	Female	300	Farm 8 Site 6	Died or shed collar between 20/09/2004 and 07/10/2004. Body not recovered.
17/09/2004	13	173.703	Male	450	Farm 7 Site 5	Lost signal after 02/02/05
14/10/2004	14	173.474	Female	400	Farm 7 Site 5	Lost signal between 08/11/04 and 10/12/04
14/10/2004	17	174.445	Female	300	Farm 7 Site 5	Lost signal between 10/12/04 and 01/02/05. Poss flat battery as collar previously on Rat No 10, started 07/07/04
09/03/2005	19	173.221	Male	390	Hag Wood	Collar had come undone. Picked up in valley between Howthorpe and Airyholme 08/04/05. Live rat seen nearby!
09/03/2005	20	173.263	Female	380	Hag Wood	Recaptured 29/04/2005. The collar had rubbed neck making an open wound. Present batch of collars have thinner cable ties which is the probable cause of the injury. Rat was killed with isoflurane and the collar removed.
23/03/2005	21	173.332	Male	475	Hag Wood	Collar came off or rat died between 15/04/2005 and 22/04/2005. Could not retrieve collar - impenetrable blackthorn thicket in the way.
23/03/2005	22	173.244	Female	425	Hag Wood	Collar came off between 15/04/2005 and 22/04/2005. Collar retrieved from next to pheasant feeder.

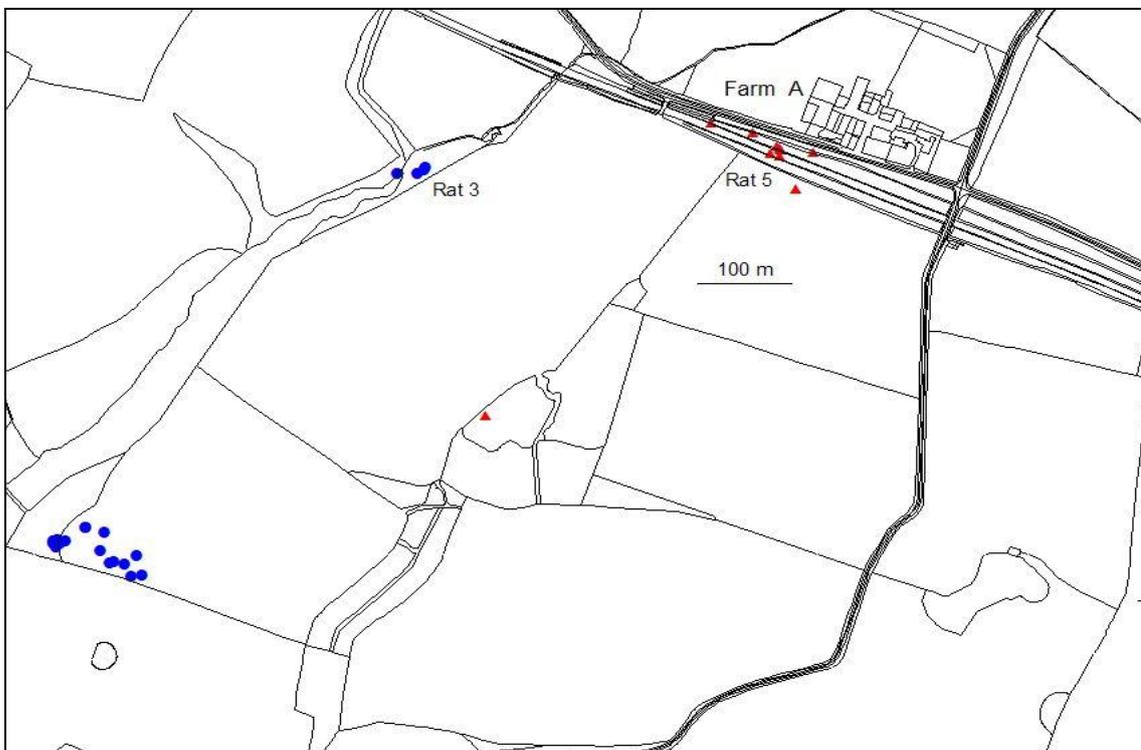
**Leicestershire**

<b>Capture date</b>	<b>Rat No</b>	<b>Freq</b>	<b>Sex</b>	<b>Weight (g)</b>	<b>Capture location</b>	<b>Fate</b>
12/05/2004	1	174.447	Male	415	Farm A - Site 1	Signal within same area from 19/05/2004. Intact collar found under tin sheeting 06/06/2004.
12/05/2004	2	174.781	Female	300	Farm A - Site 2	Signal lost after 18/10/2004. Battery probably flat.
12/05/2004	3	174.511	Female	280	Farm A - Site 2	Signal lost after 22/09/2004. Battery probably flat.
07/06/2004	4	174.671	Female	290	Farm A - Site 2	Increased pulse signal within same area from 24/05/2004. Animal dead or collar came off. Unable to recover - collar 4 <sup>+</sup> ft down below concrete slab.
07/06/2004	5	173.868	Male	335	Farm A - Site 1	Signal lost after 01/07/2004. May have been taken by Tawny owl seen hunting and taking rats in area.
07/06/2004	6	174.616	Female	380	Farm A - Site 2	Variable signal (alive/dead) from 29/06/2004. Collar found intact in oilseed rape field after harvest.
07/06/2004	7	173.366	Female	320	Farm A - Site 2	Animal killed by farm dogs on 09/11/2004. Collar recovered.

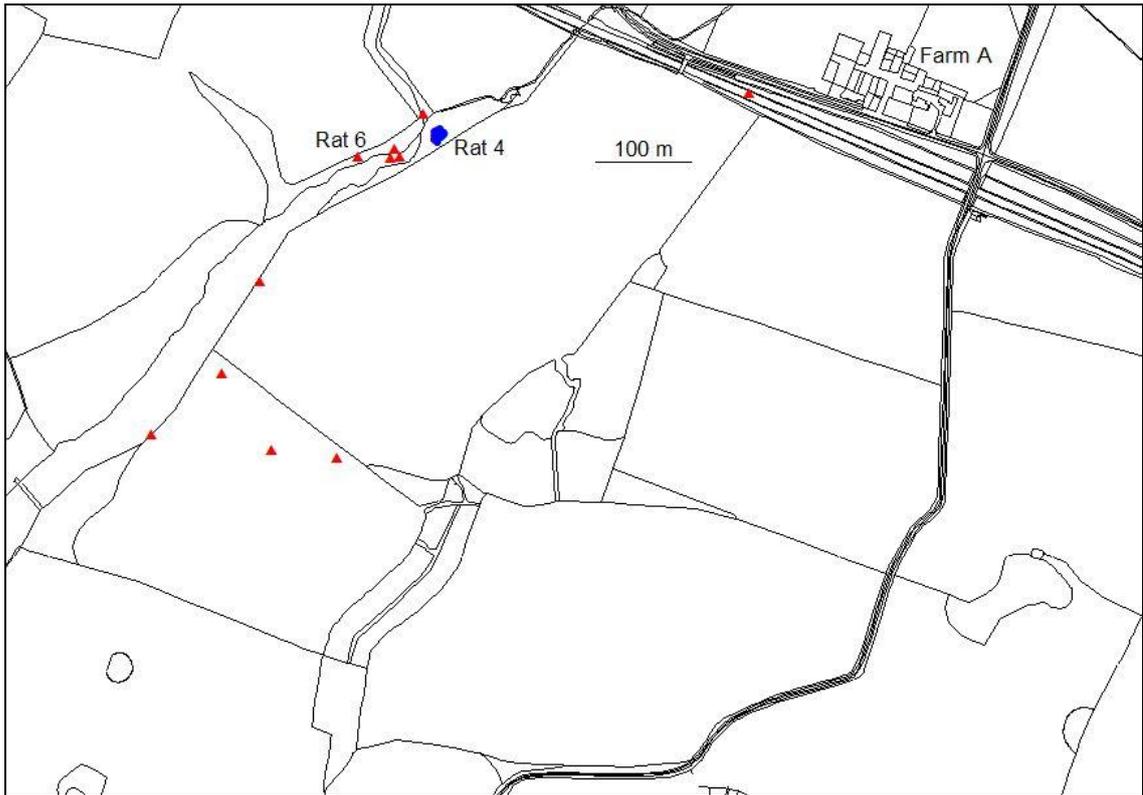
ANNEX D. MAPS OF THE MOVEMENTS OF RADIO COLLARED RAT  
(Note: North is at the top, this edge, of the maps).



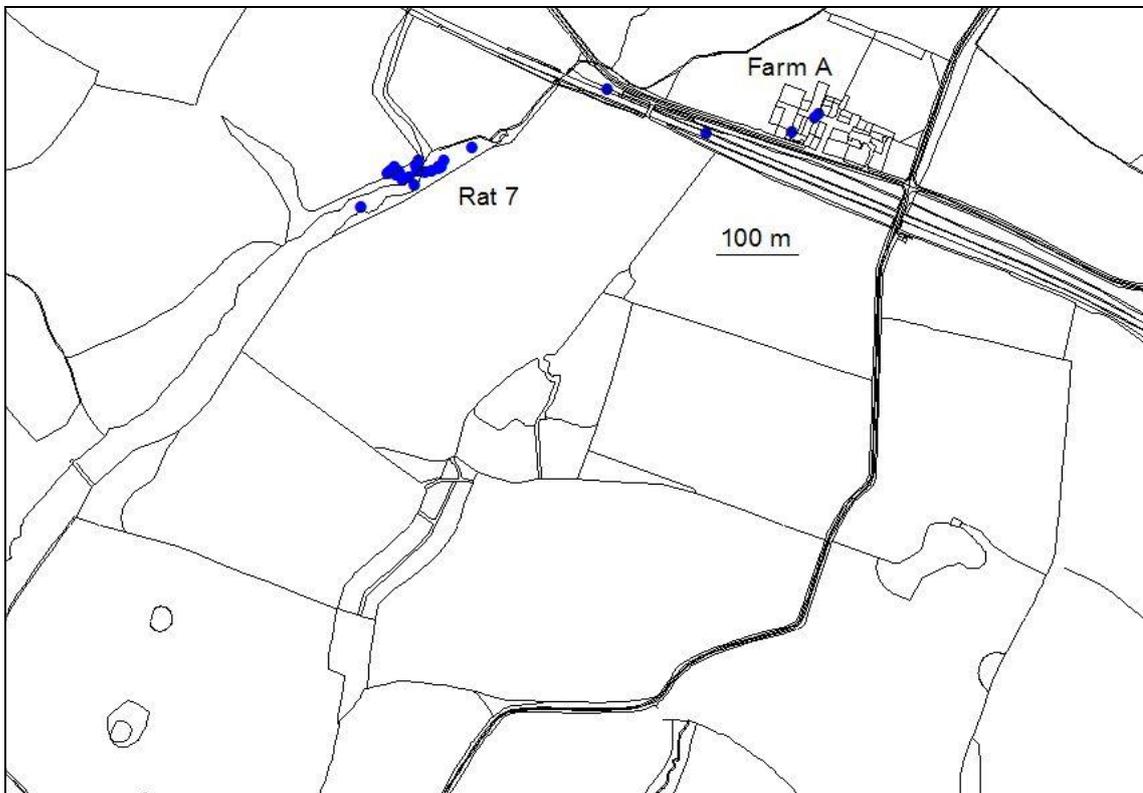
1. Plot of the movement of Leicester rats 1 and 2 (CC Area – Farm A)



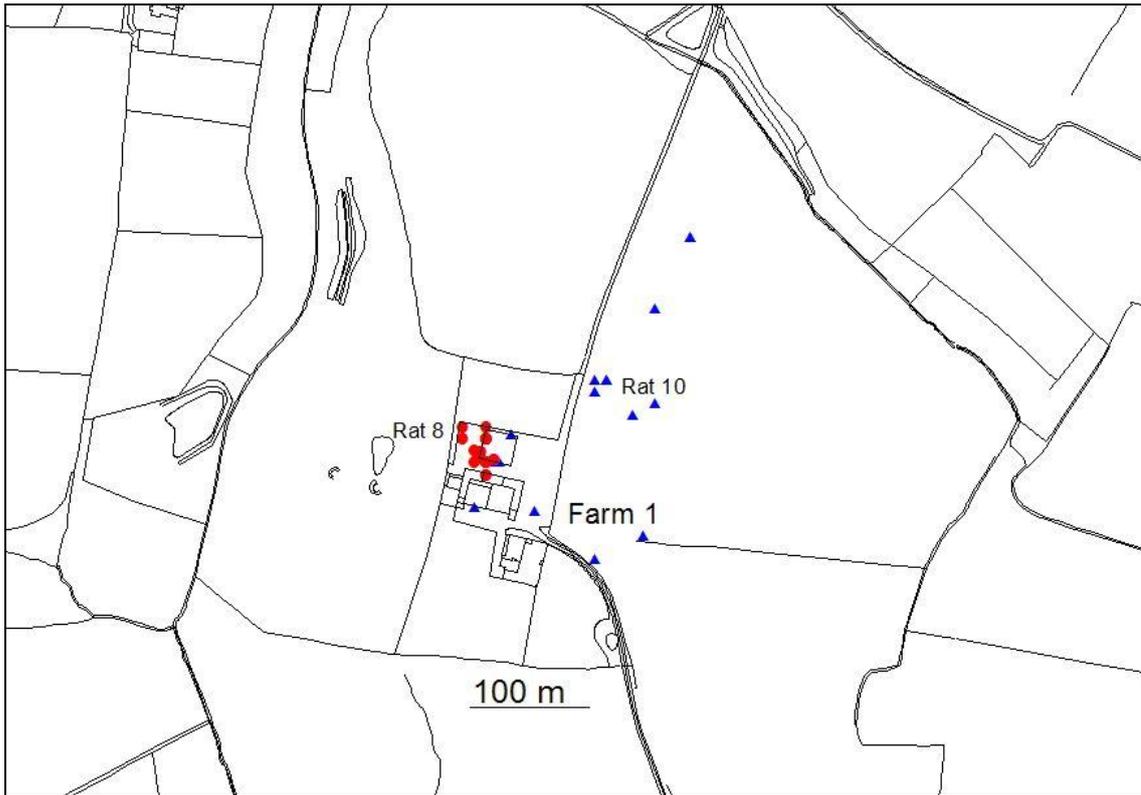
2. Plot of the movement of Leicester rats 3 and 5 (CC Area – Farm A)



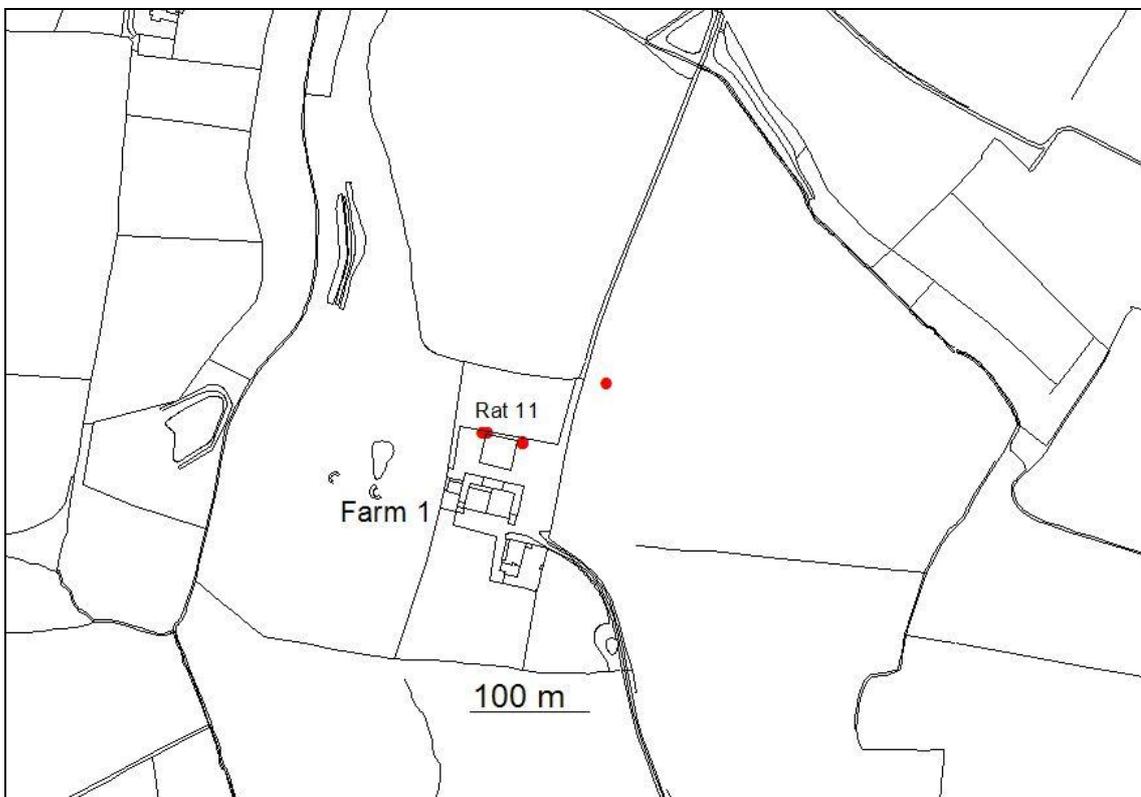
3. Plot of the movement of Leicester rats 4 and 6 (CC Area – Farm A)



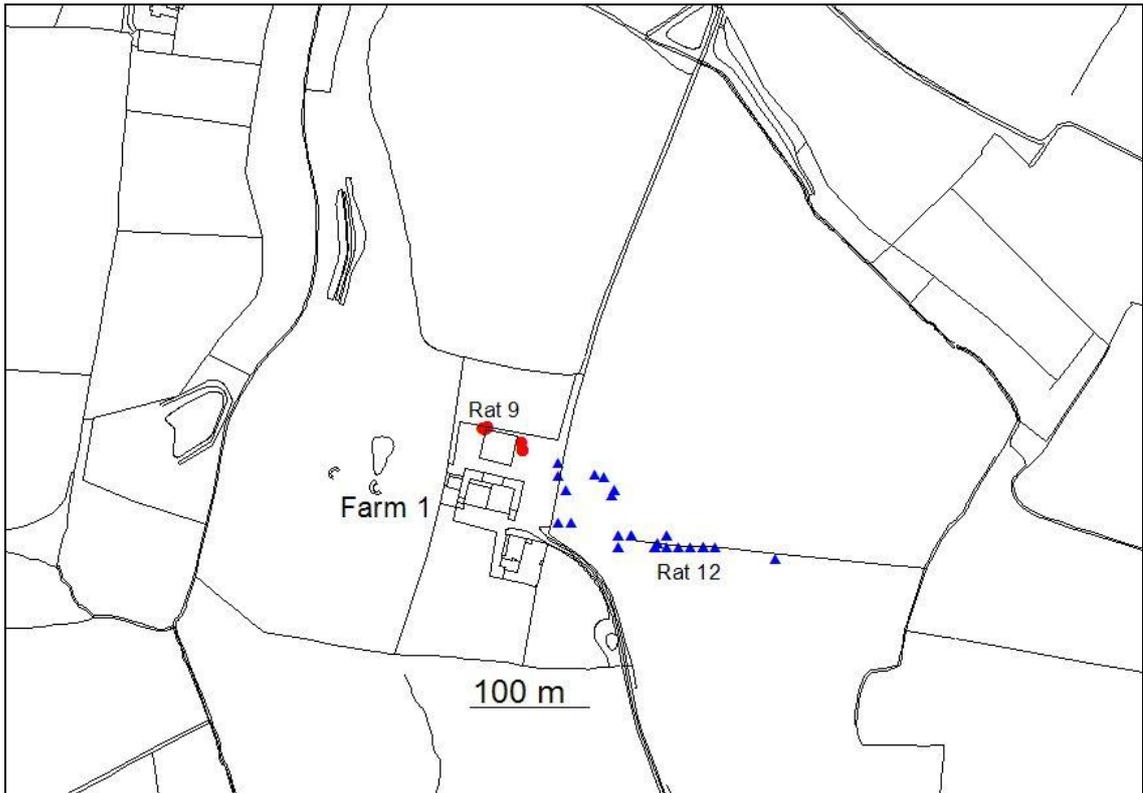
4. Plot of the movement of Leicester rat 7 (CC Area – Farm A)



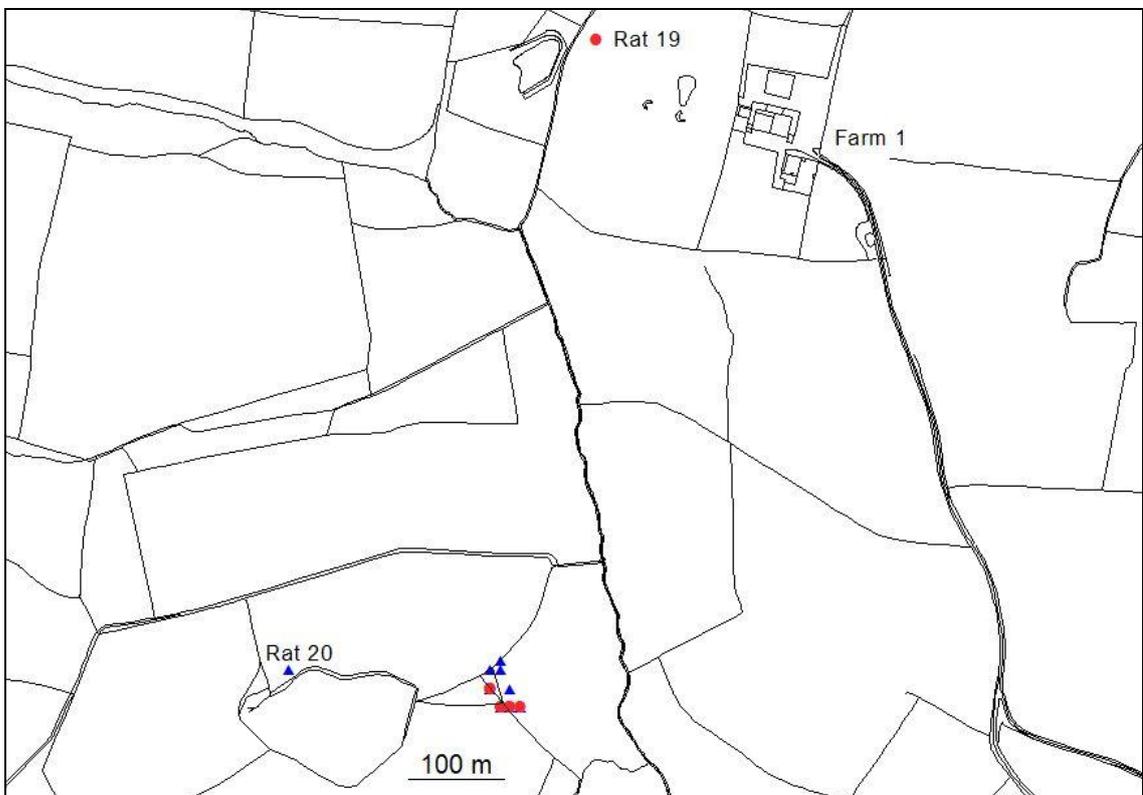
5. Plot of the movement of York rats 8 and 10 (CC Area – Farm 1)



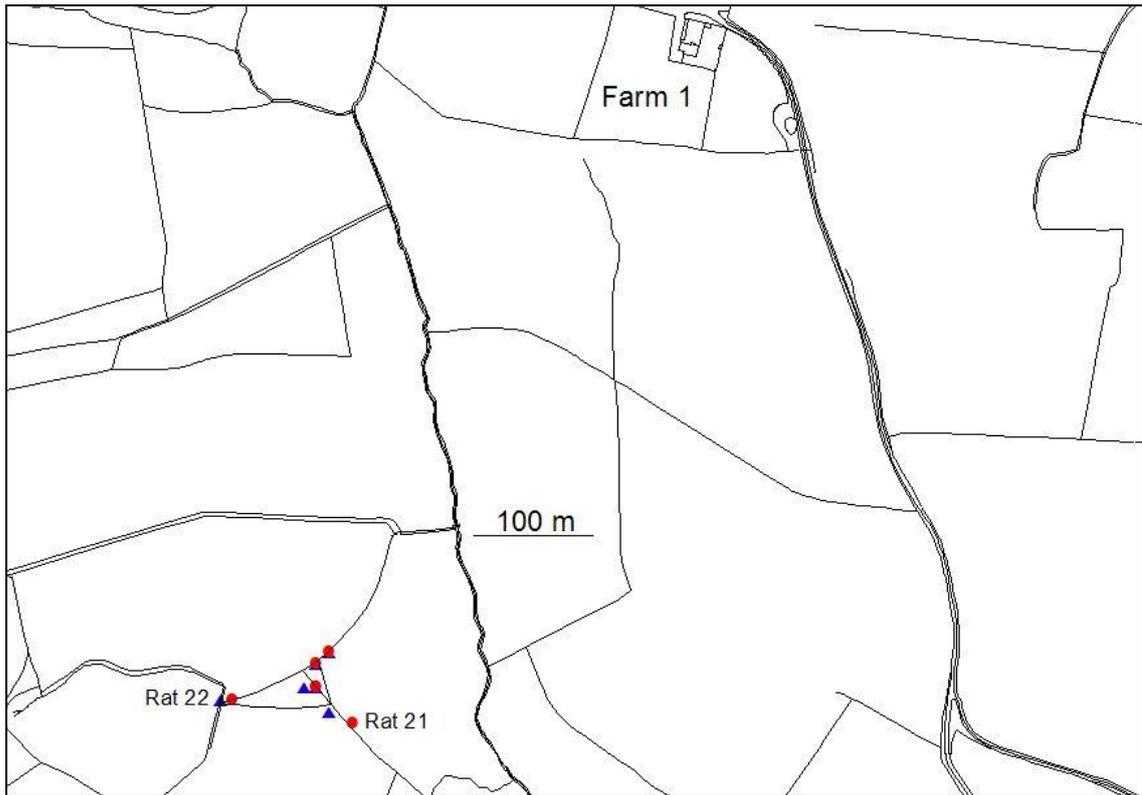
6. Plot of the movement of York rat 11 (CC Area – Farm 1)



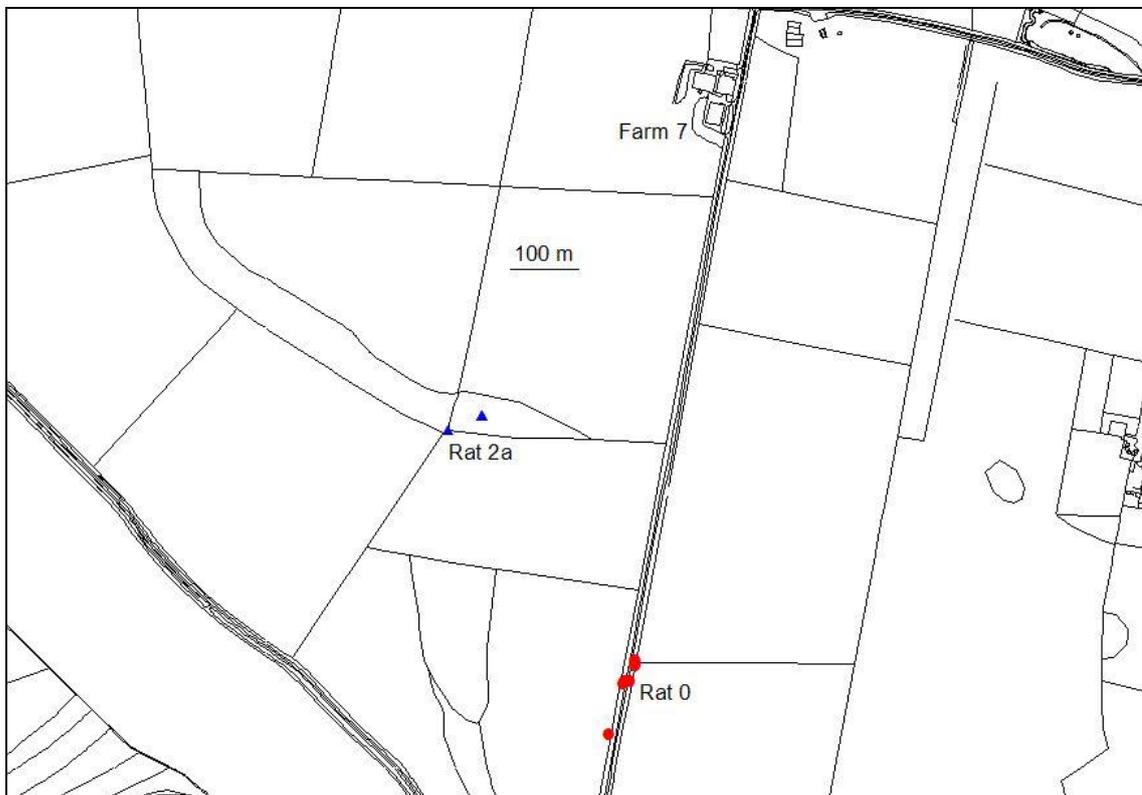
7. Plot of the movement of York rats 9 and 12 (CC Area – Farm 1)



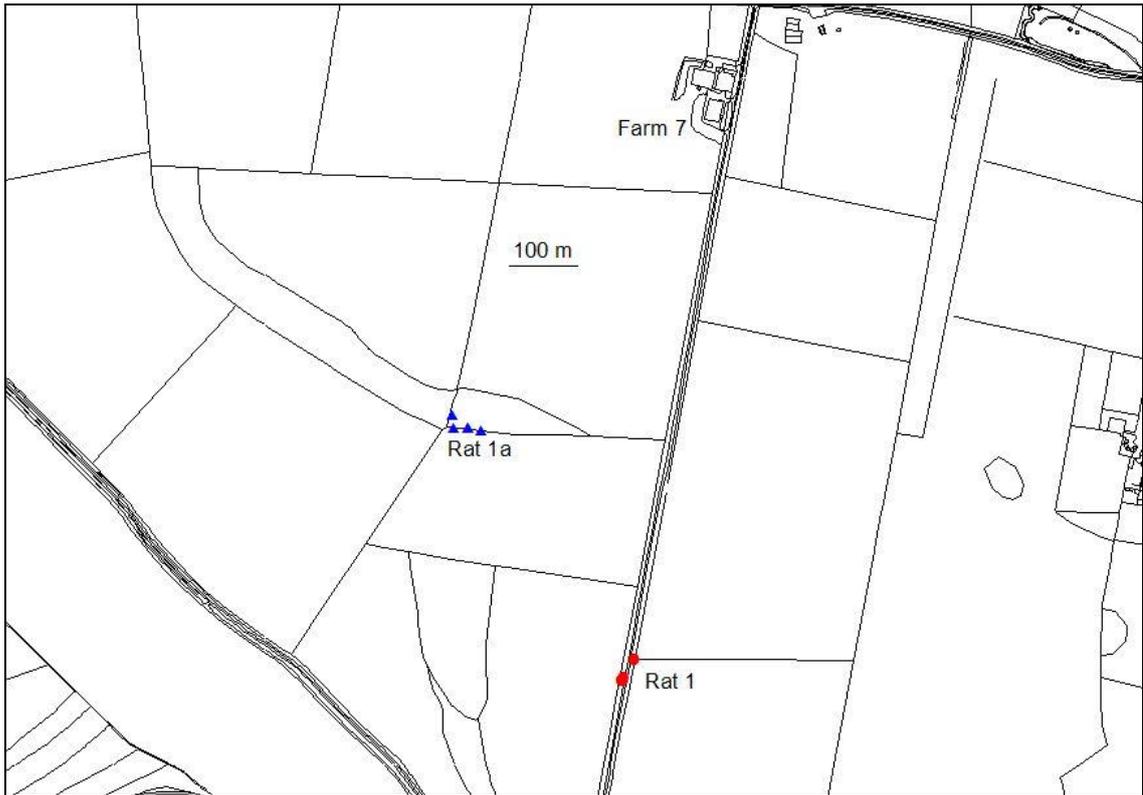
8. Plot of the movement of York rats 19 and 20 (CC Area – Farm 1)



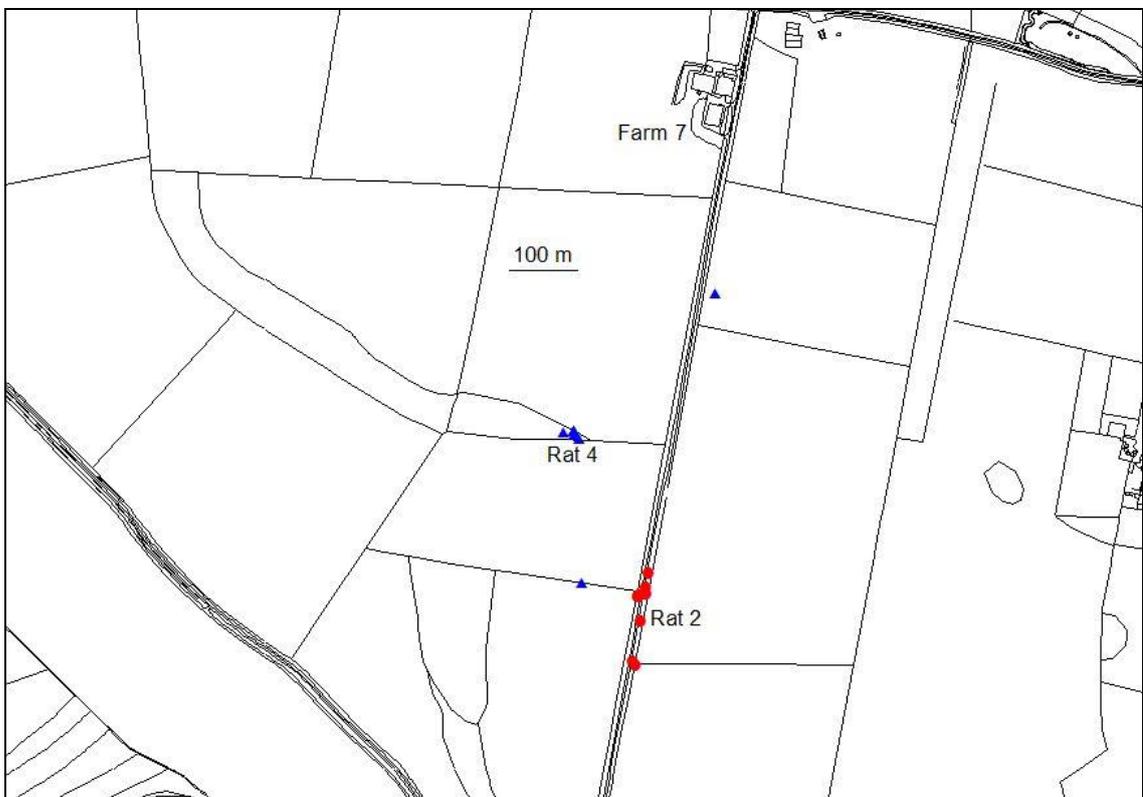
9. Plot of the movement of York rats 21 and 22 (CC Area – Farm 1)



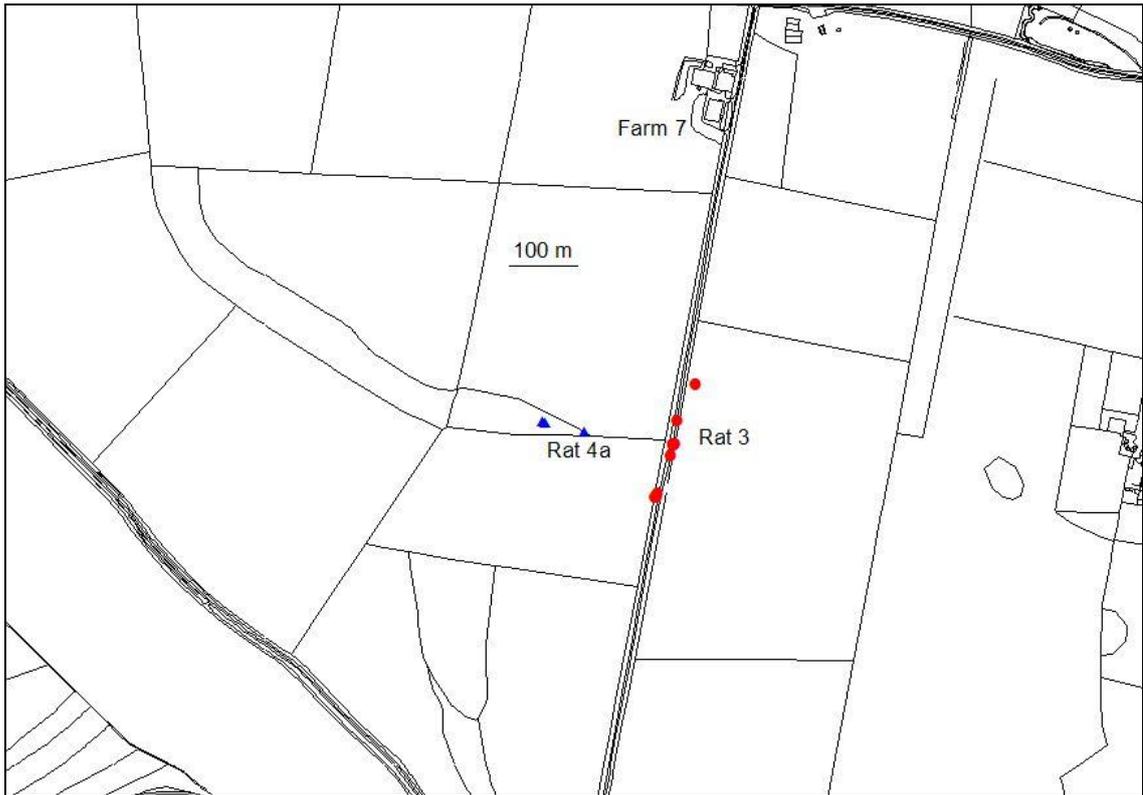
10. Plot of the movement of York rats 0 and 2a (UCC Area – Farm 7)



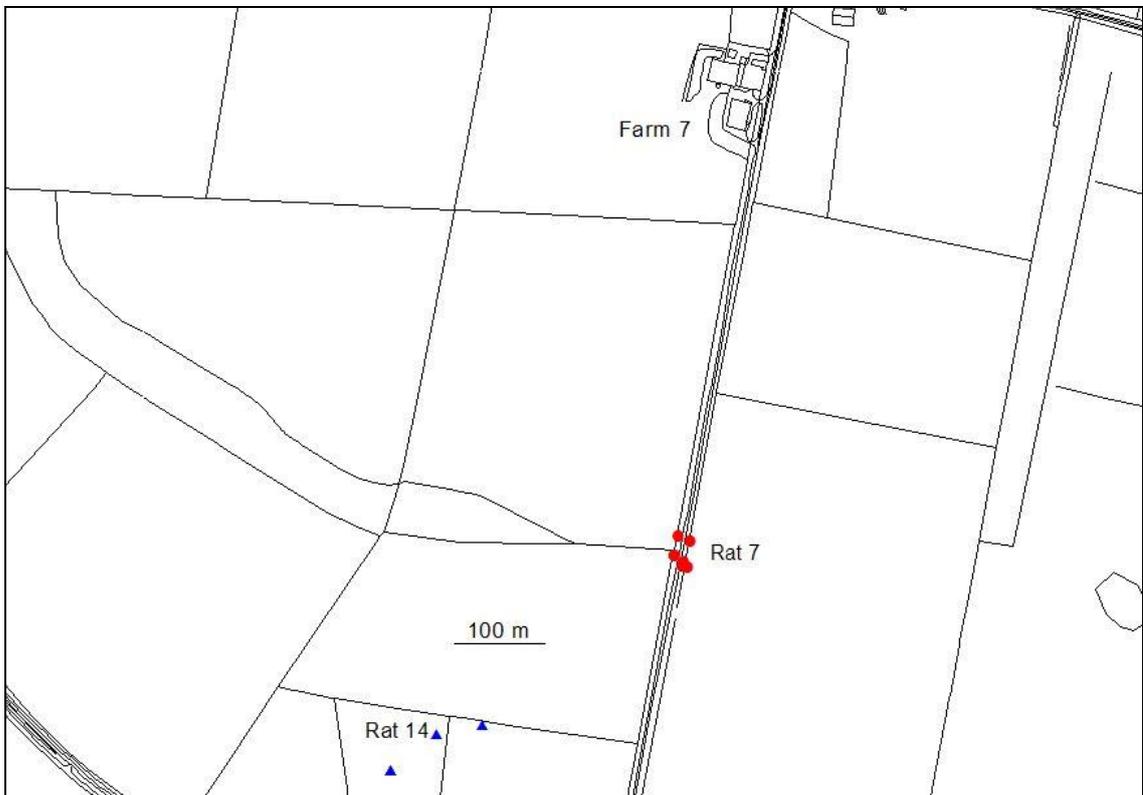
11. Plot of the movement of York rats 1 and 1a (UCC Area – Farm 7)



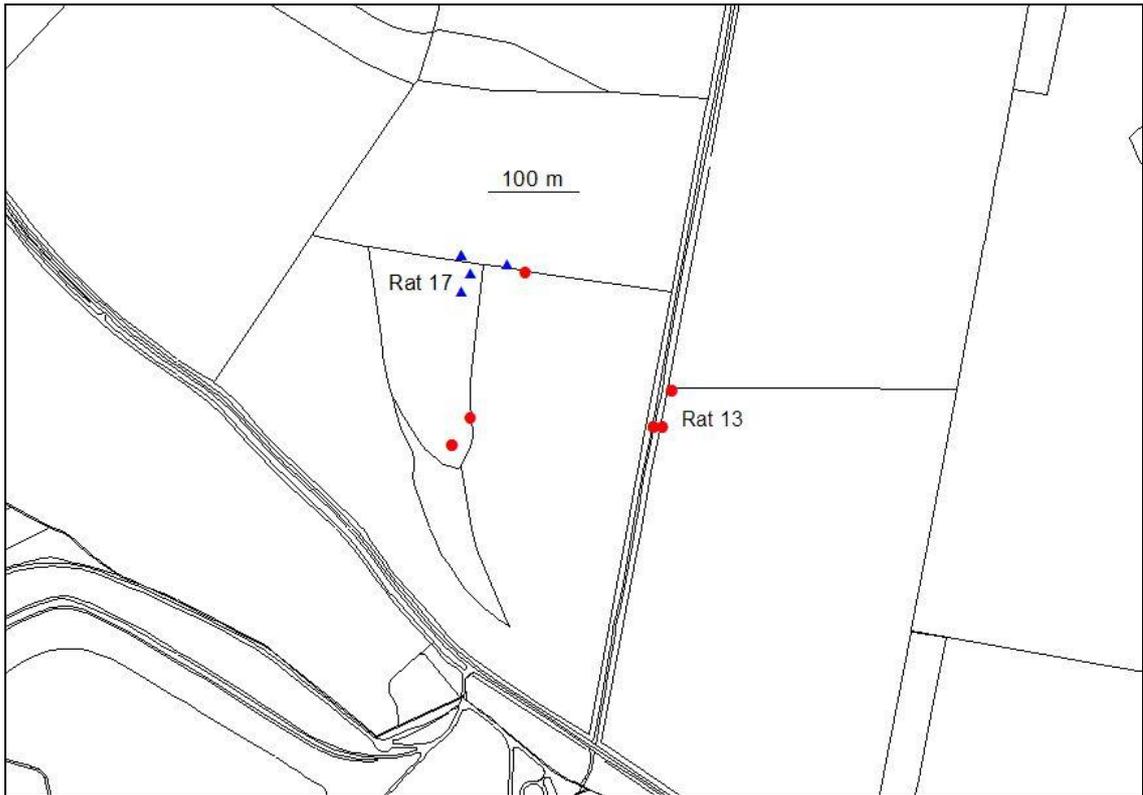
12. Plot of the movement of York rats 2 and 4 (UCC Area – Farm 7)



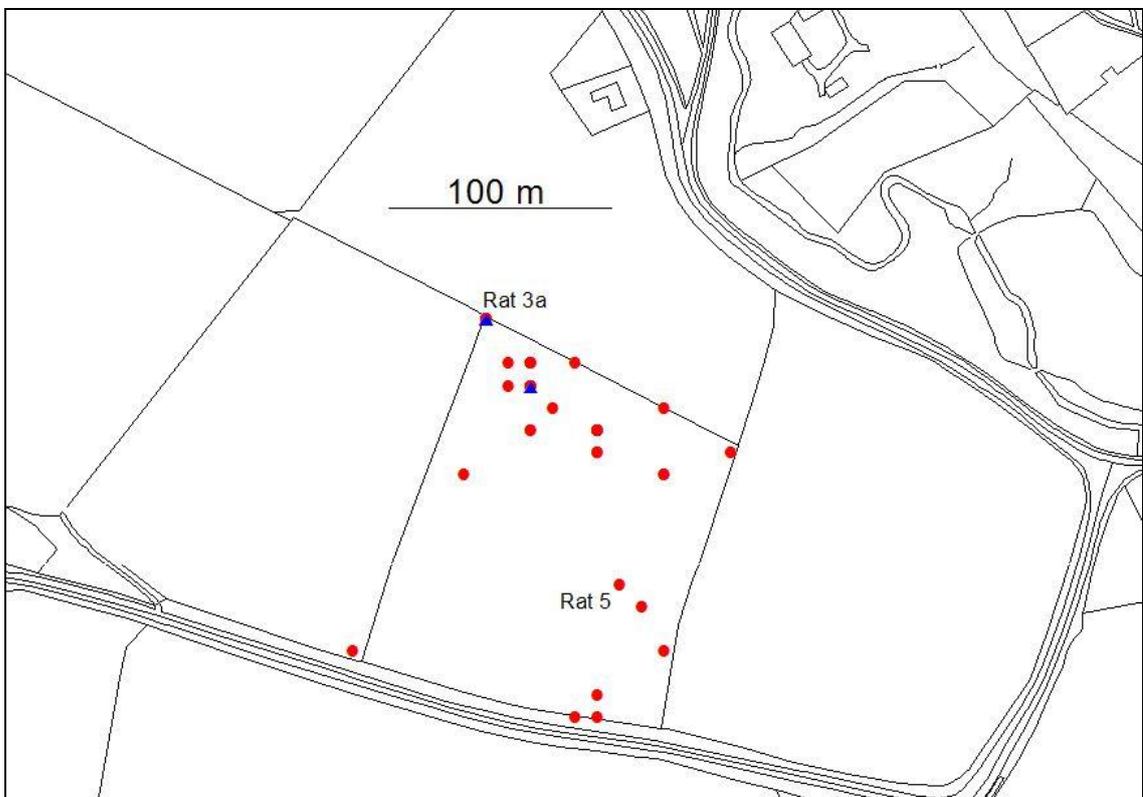
13. Plot of the movement of York rats 3 and 4a (UCC Area – Farm 7)



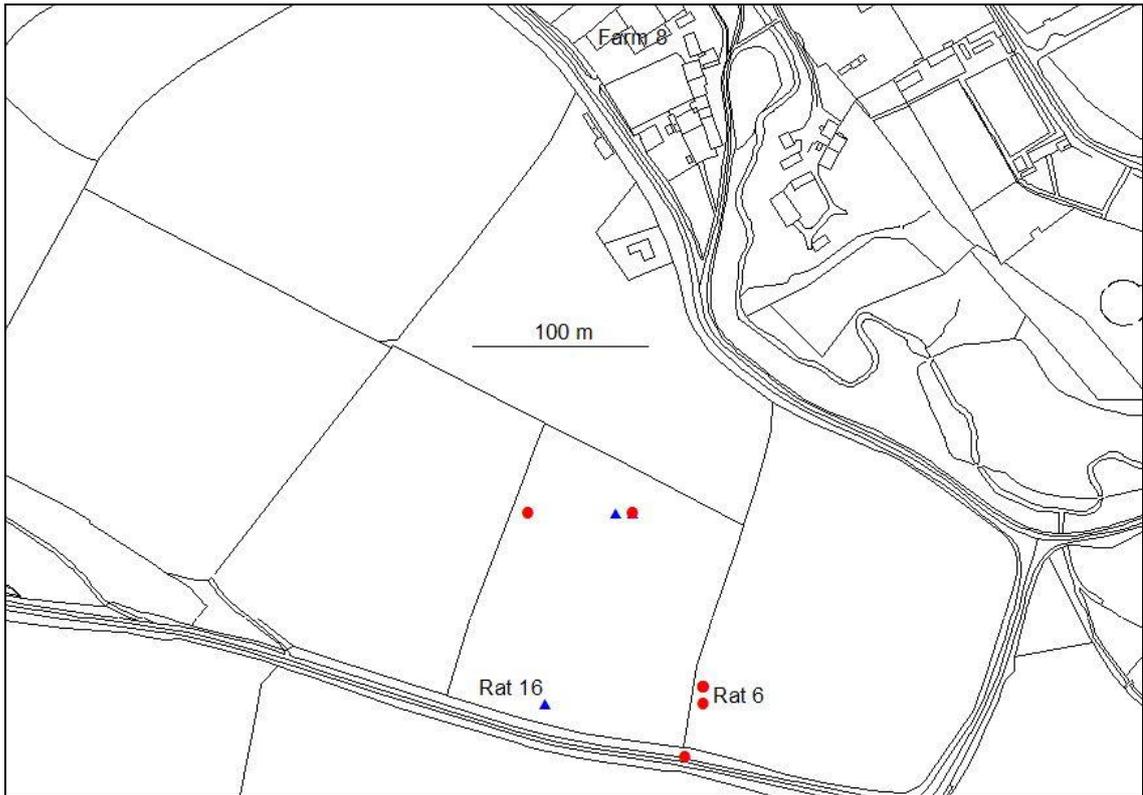
14. Plot of the movement of York rats 7 and 14 (UCC Area – Farm 7)



15. Plot of the movement of York rats 13 and 17 (UCC Area – Farm 7)



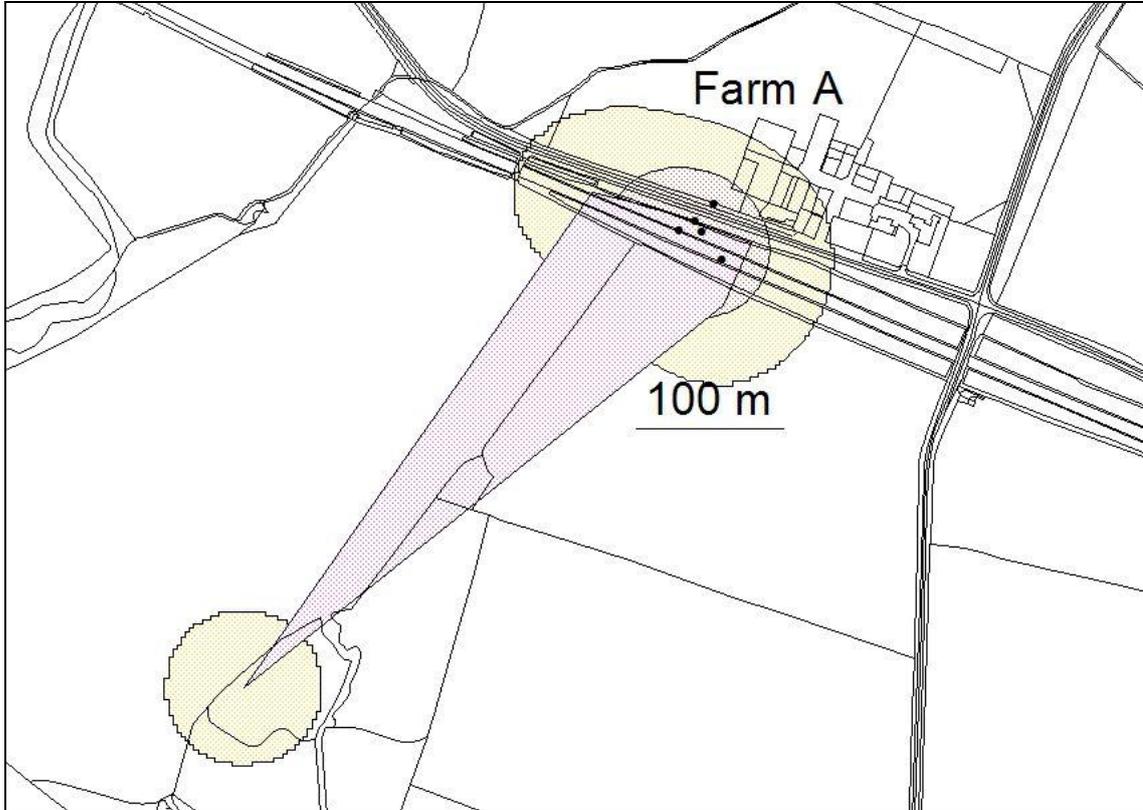
16. Plot of the movement of York rats 3a and 5 (UCC Area – Farm 8)



17. Plot of the movement of York rats 6 and 16 (UCC Area – Farm 8)

ANNEX E. MAPS SHOWING THE MOVEMENT, MINIMUM CONVEX POLYGON AND KERNEL AREAS FOR RADIO TRACKED RATS

(Note: North is at the top, this edge, of the maps)



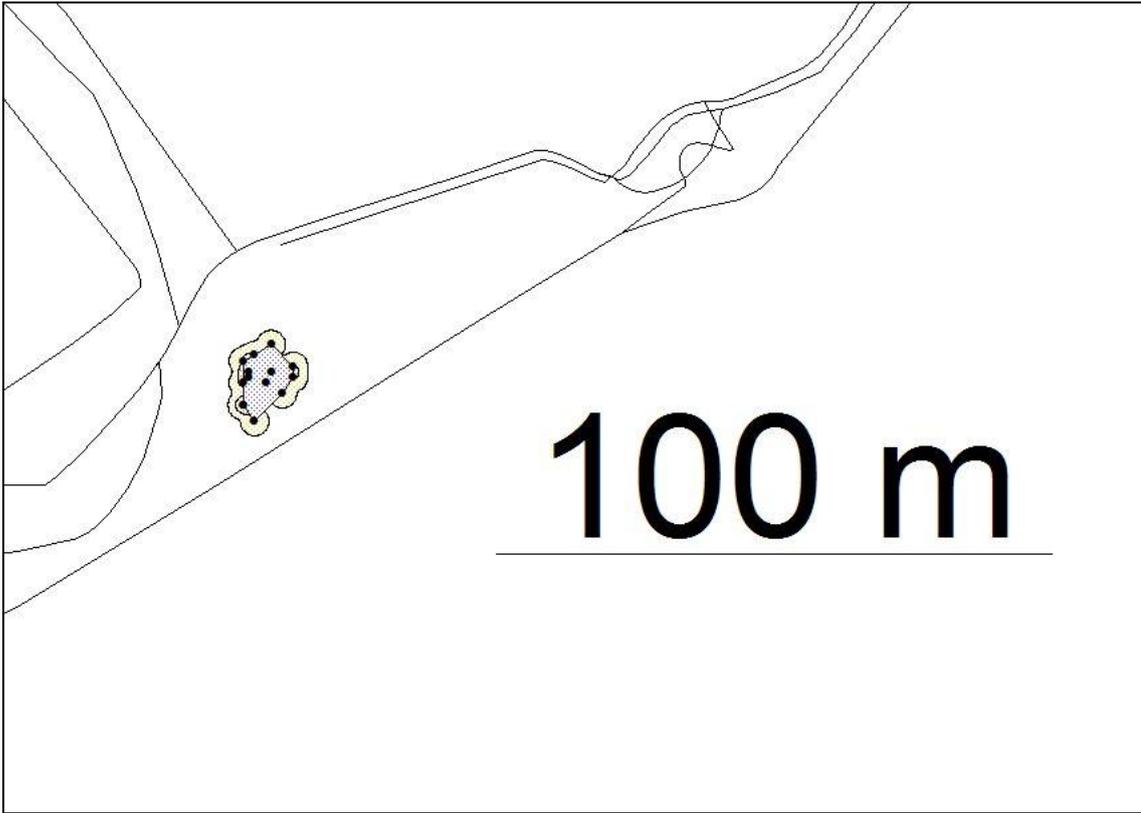
Rat 1



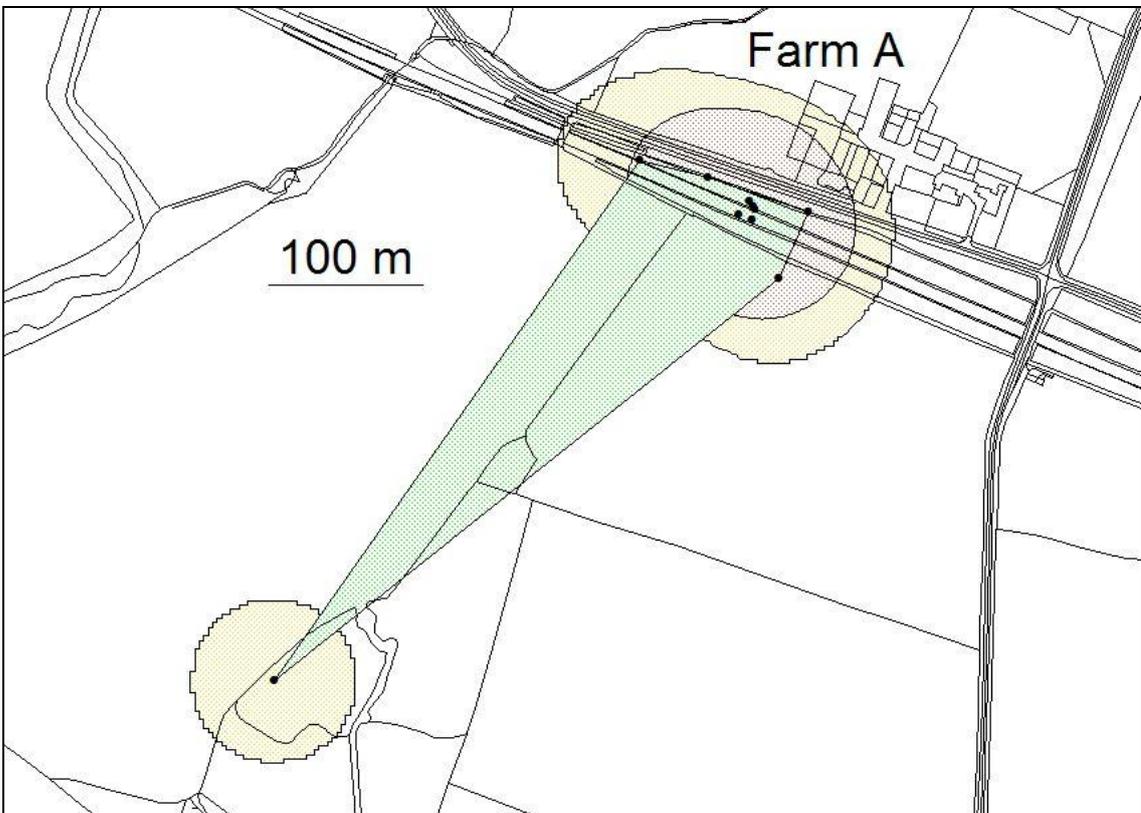
Rat 2



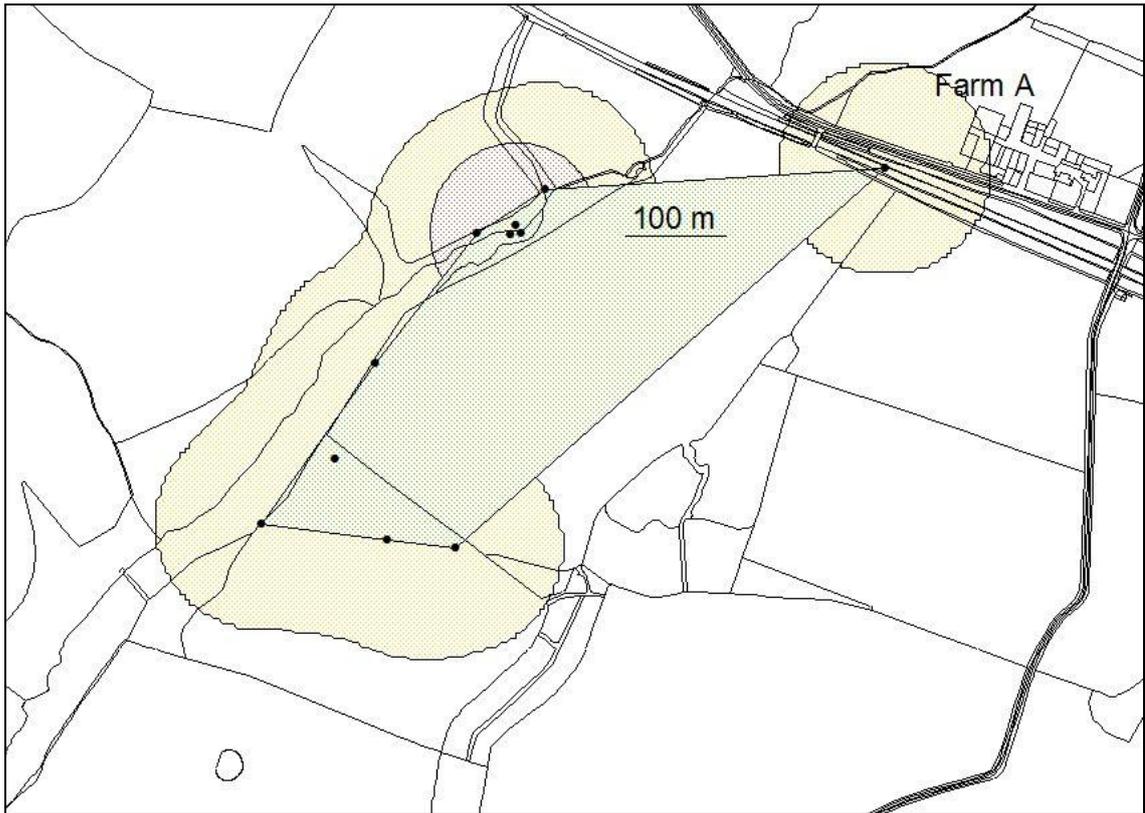
Rat 3



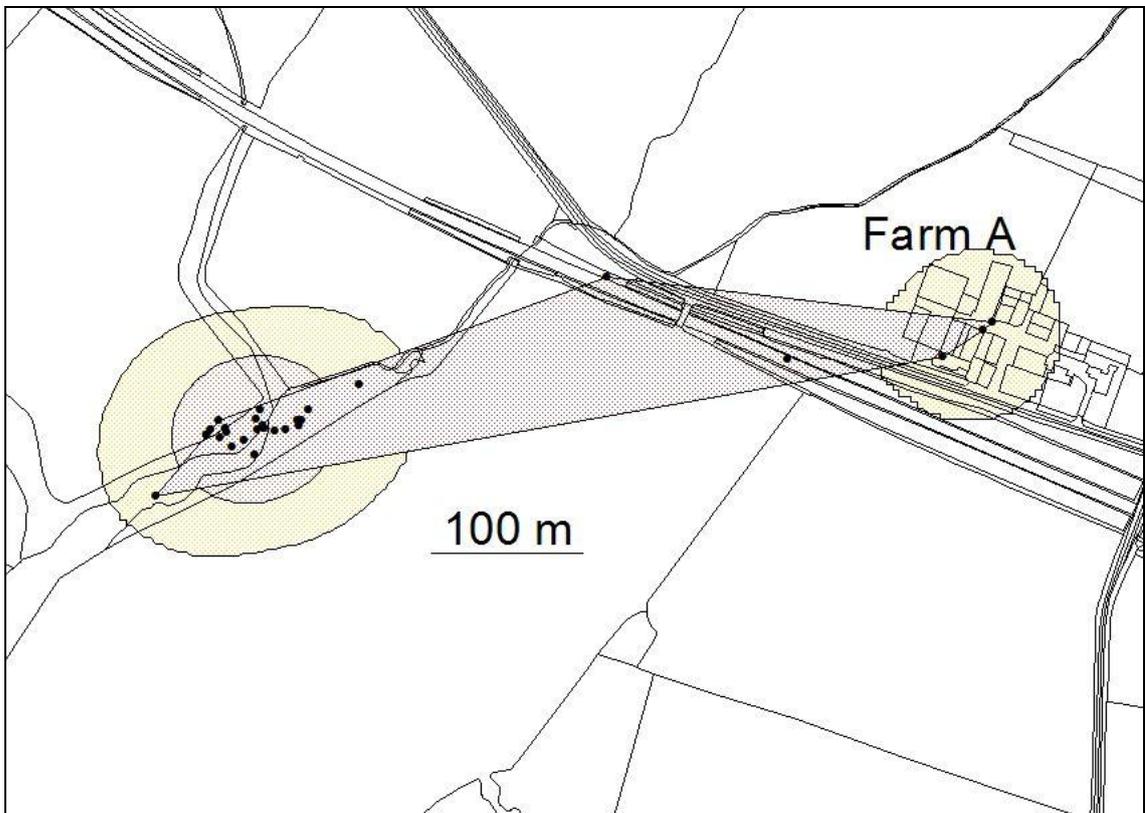
Rat 4



Rat 5

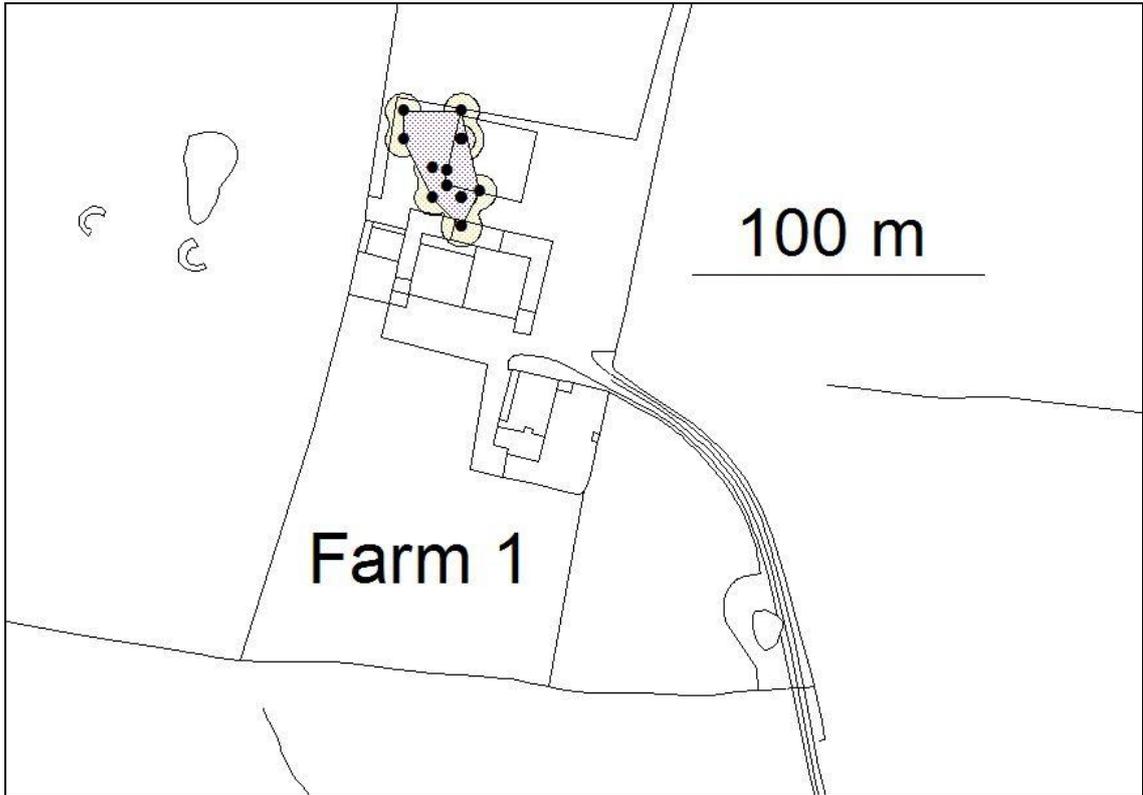


Rat 6

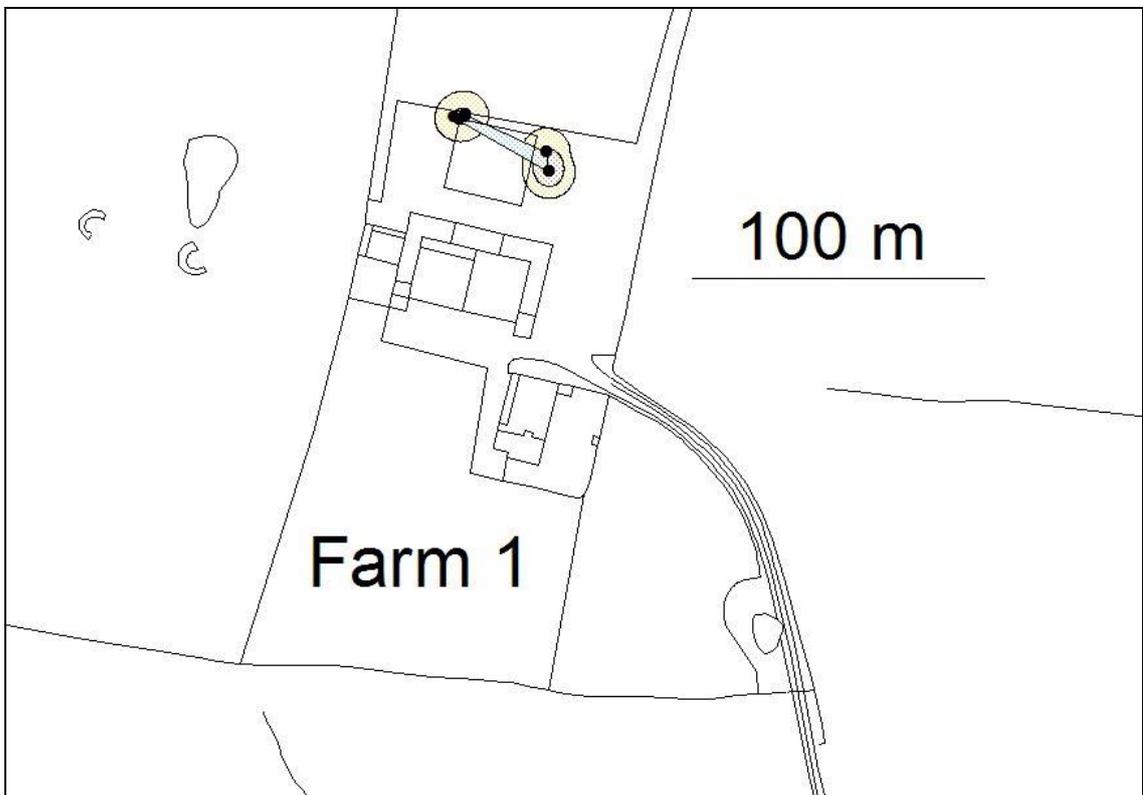


Rat 7.

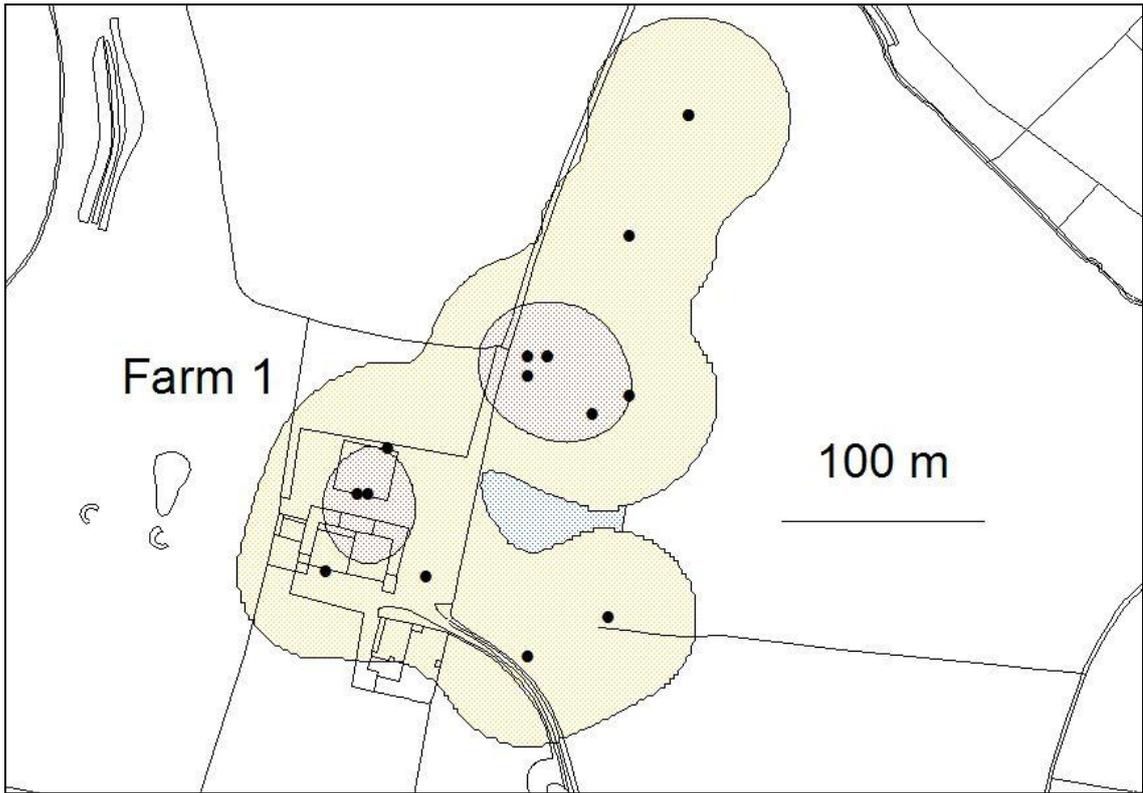
Yorkshire Coordinated Area



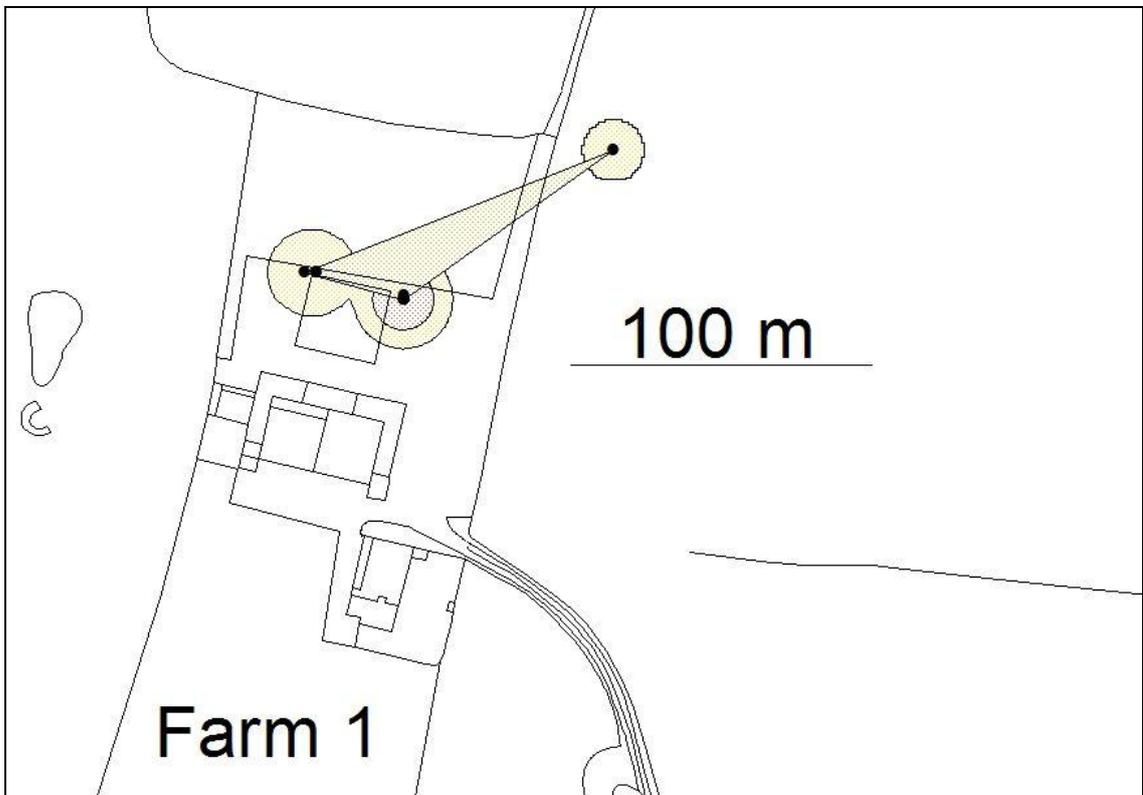
Rat 8



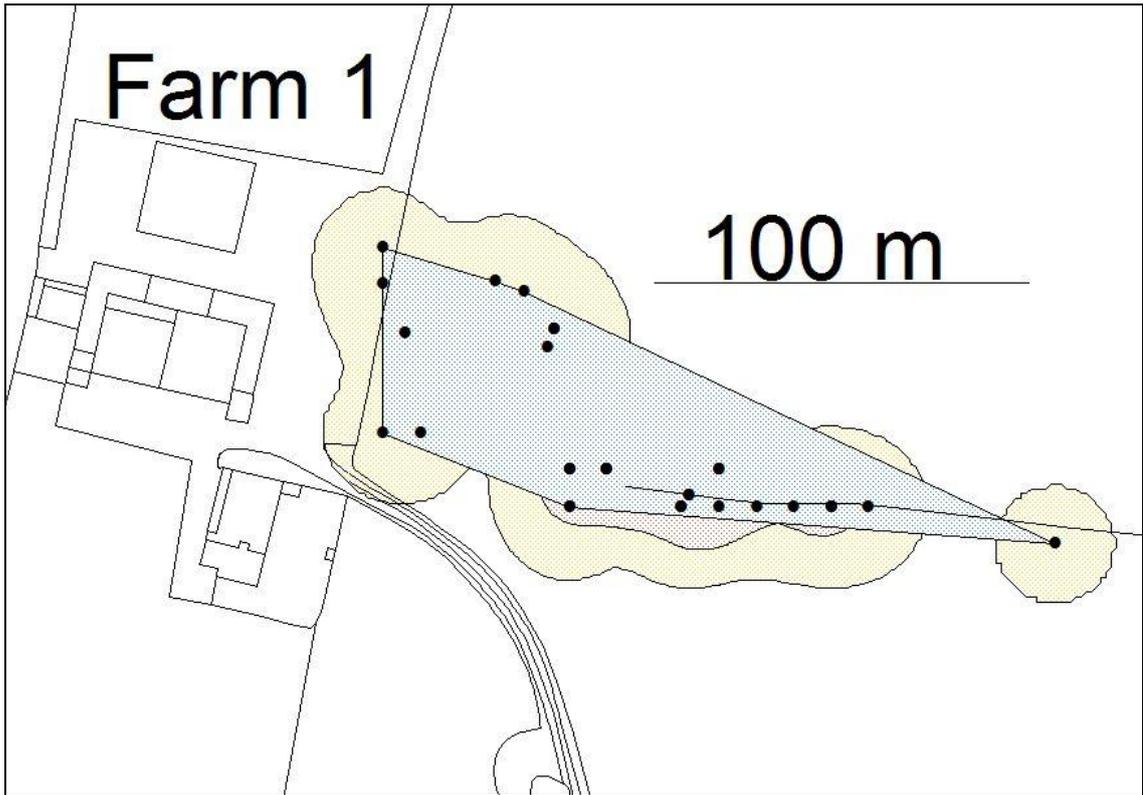
Rat 9



Rat 10



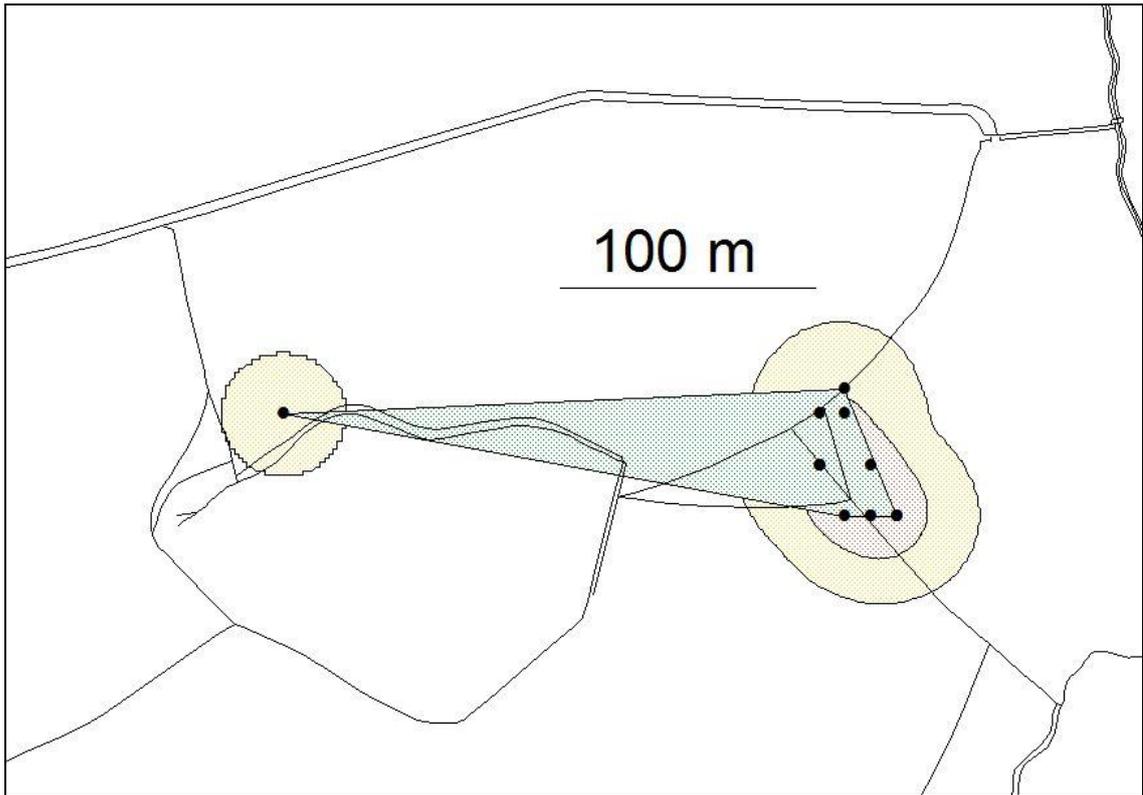
Rat 11



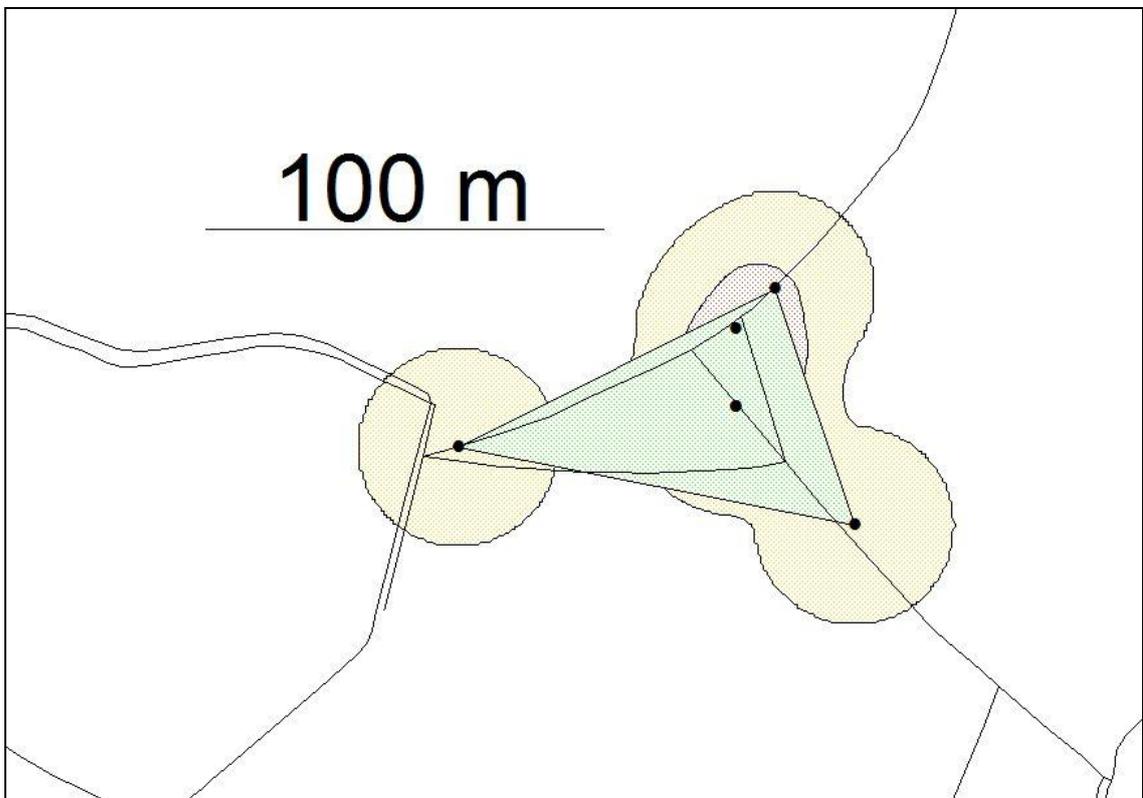
Rat 12



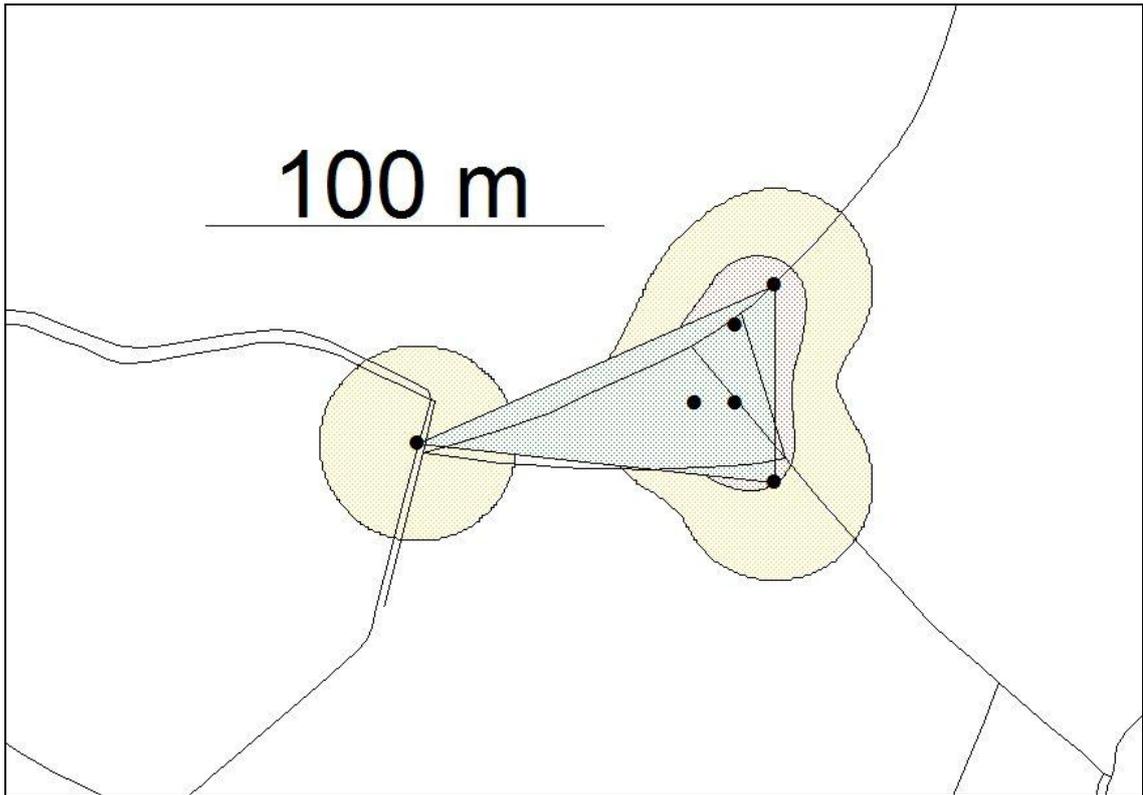
Rat 19



Rat 20

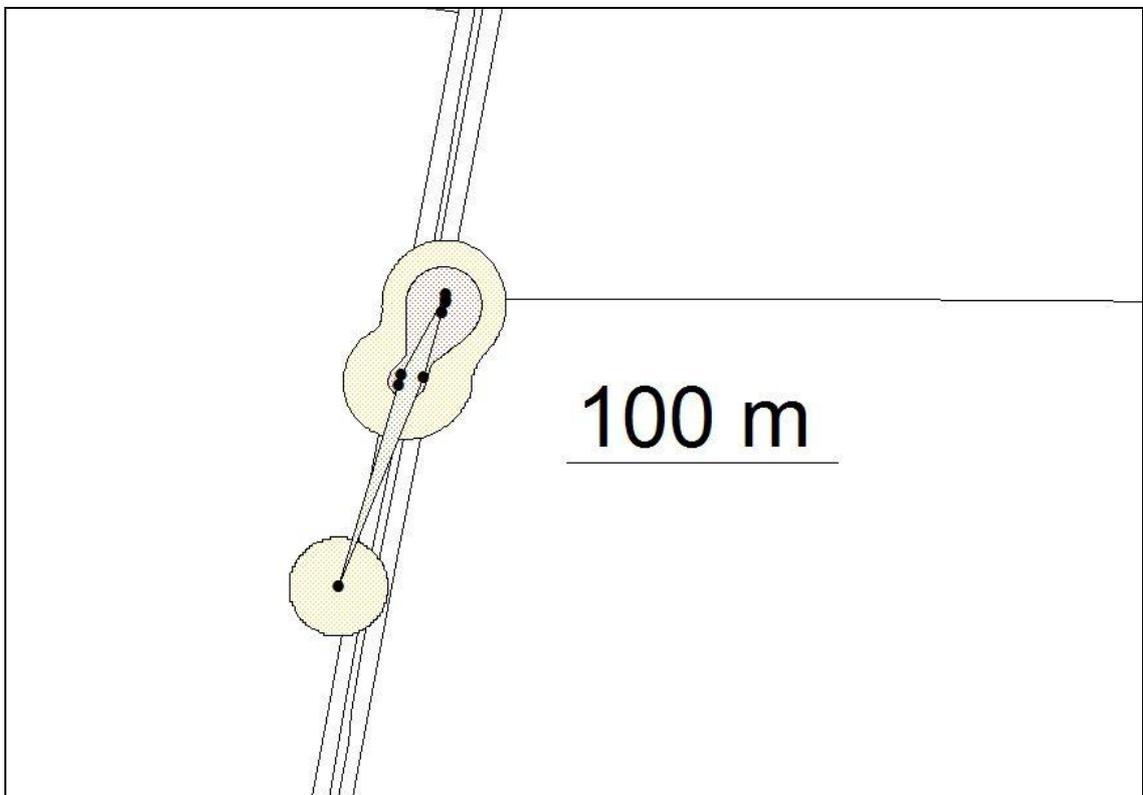


Rat 21

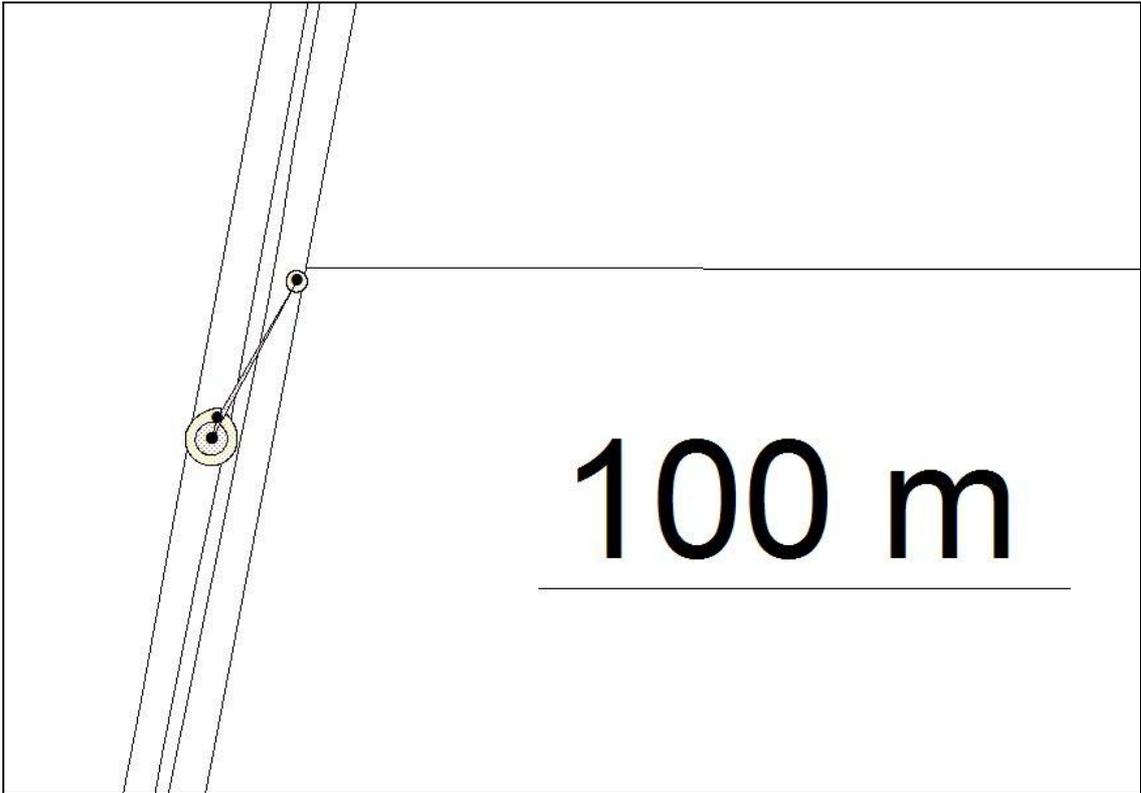


Rat 22

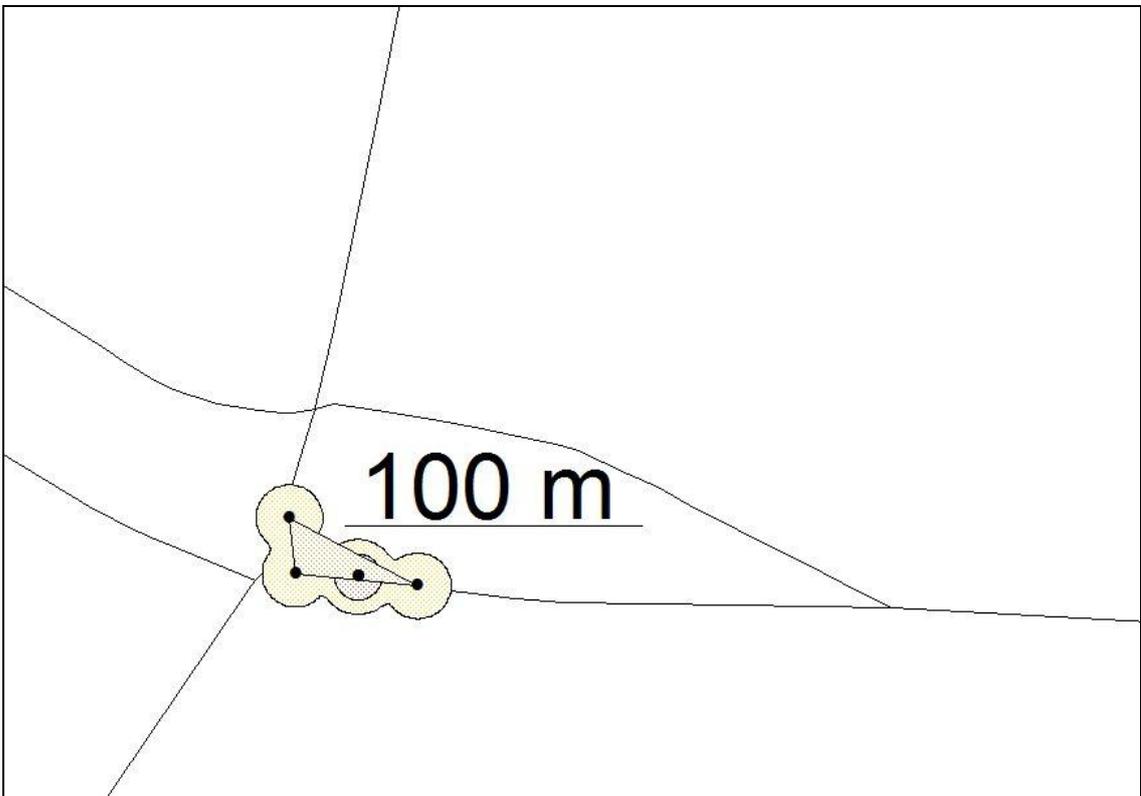
Yorkshire Uncoordinated Area



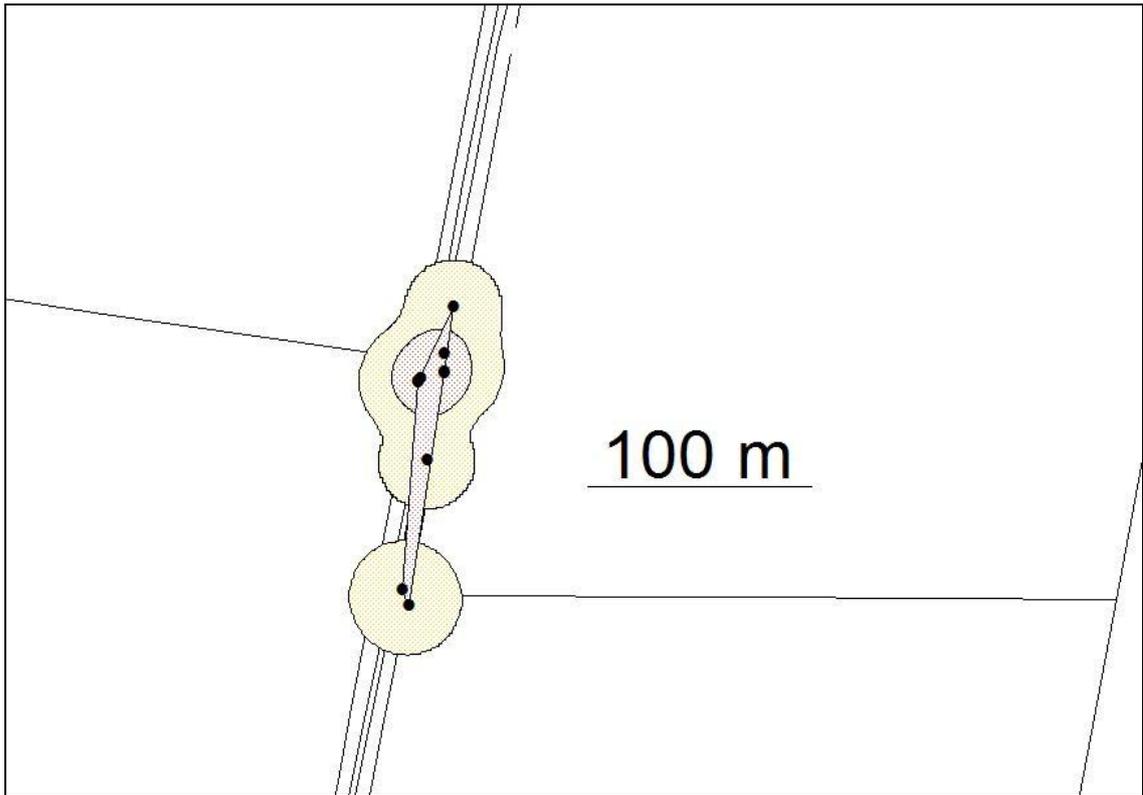
Rat 0



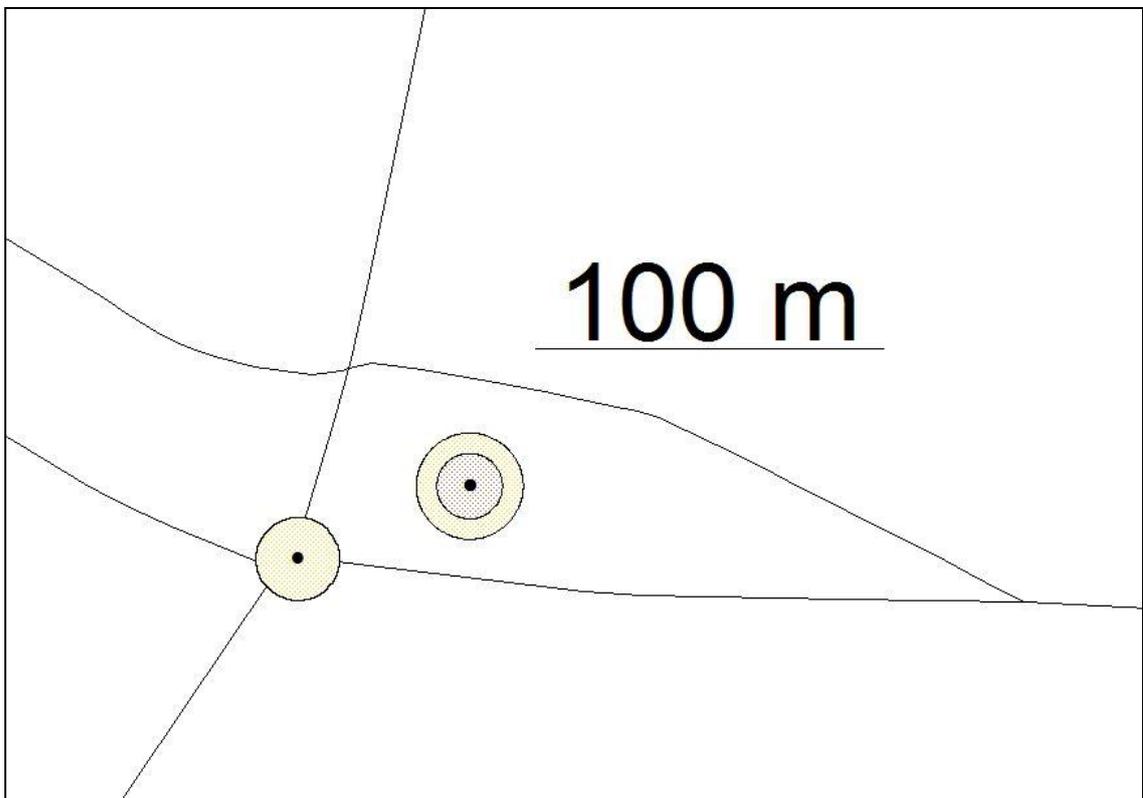
Rat 1



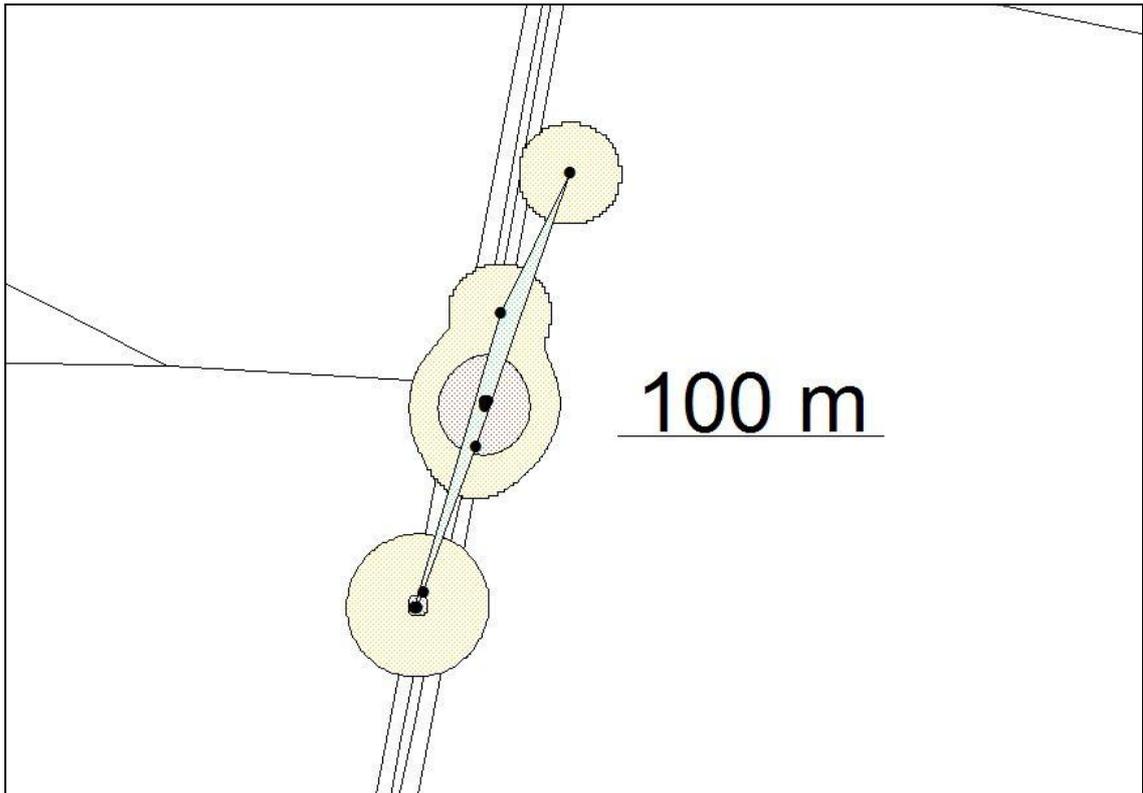
Rat 1a



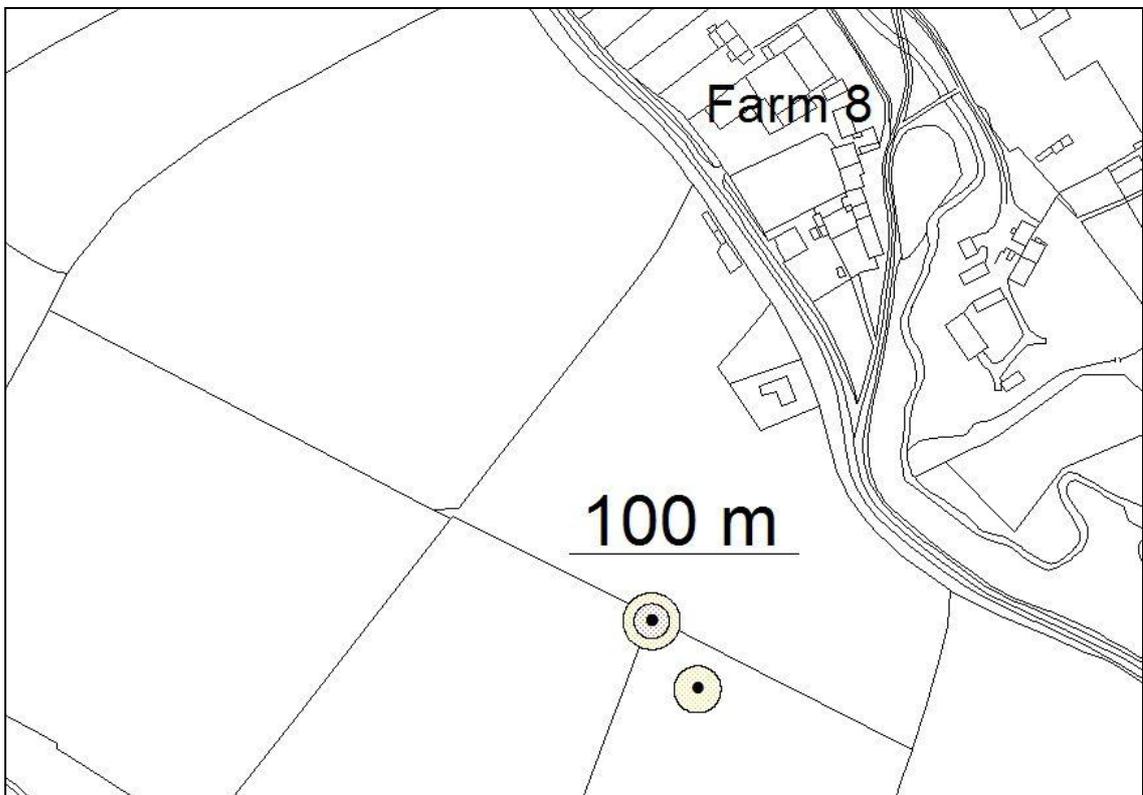
Rat 2



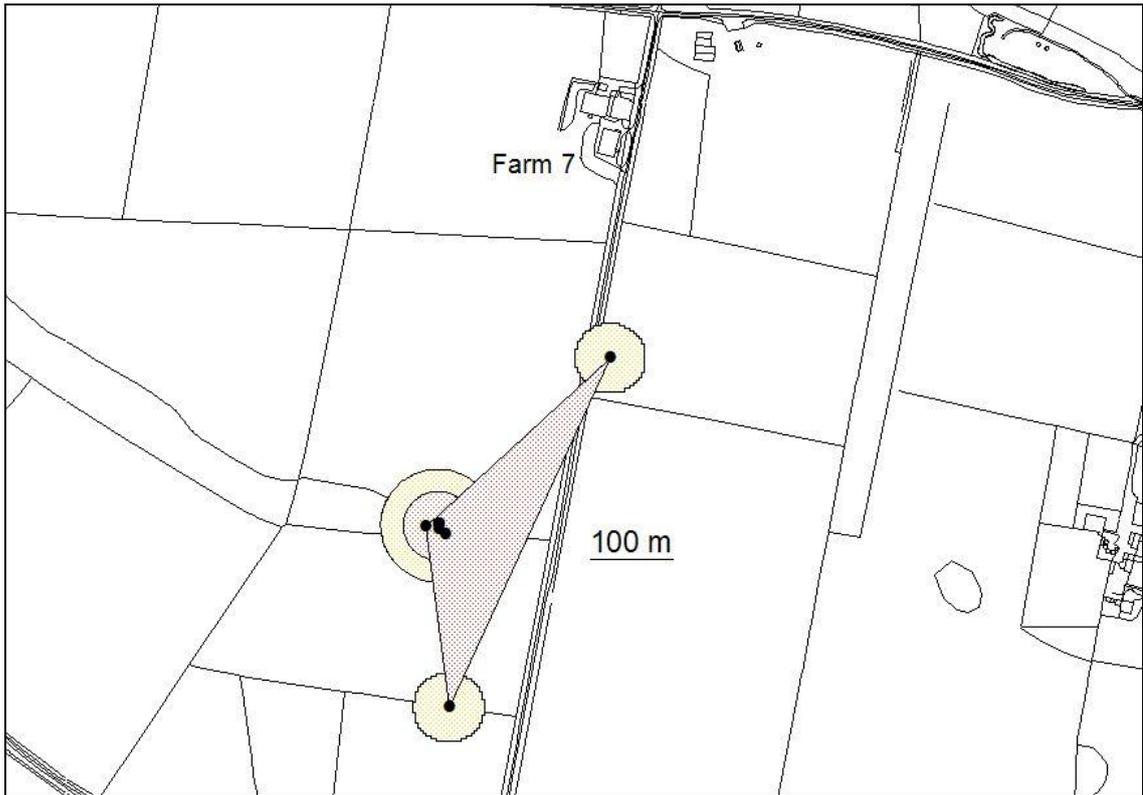
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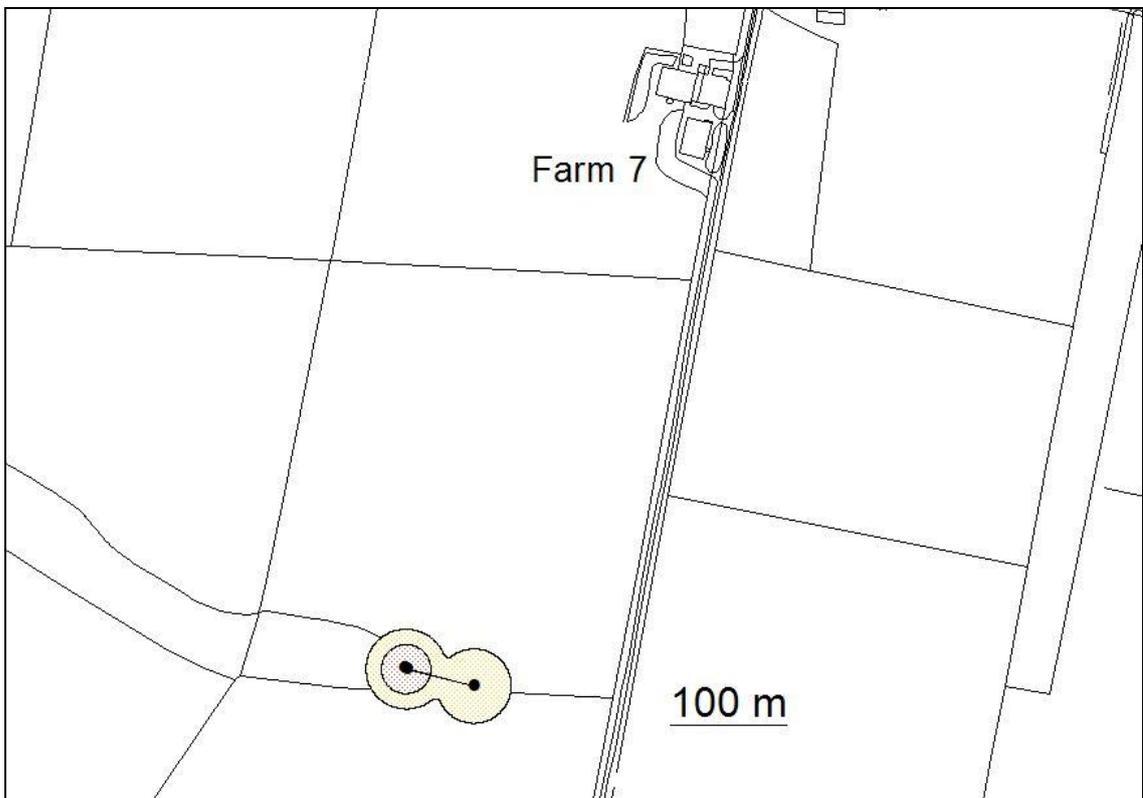
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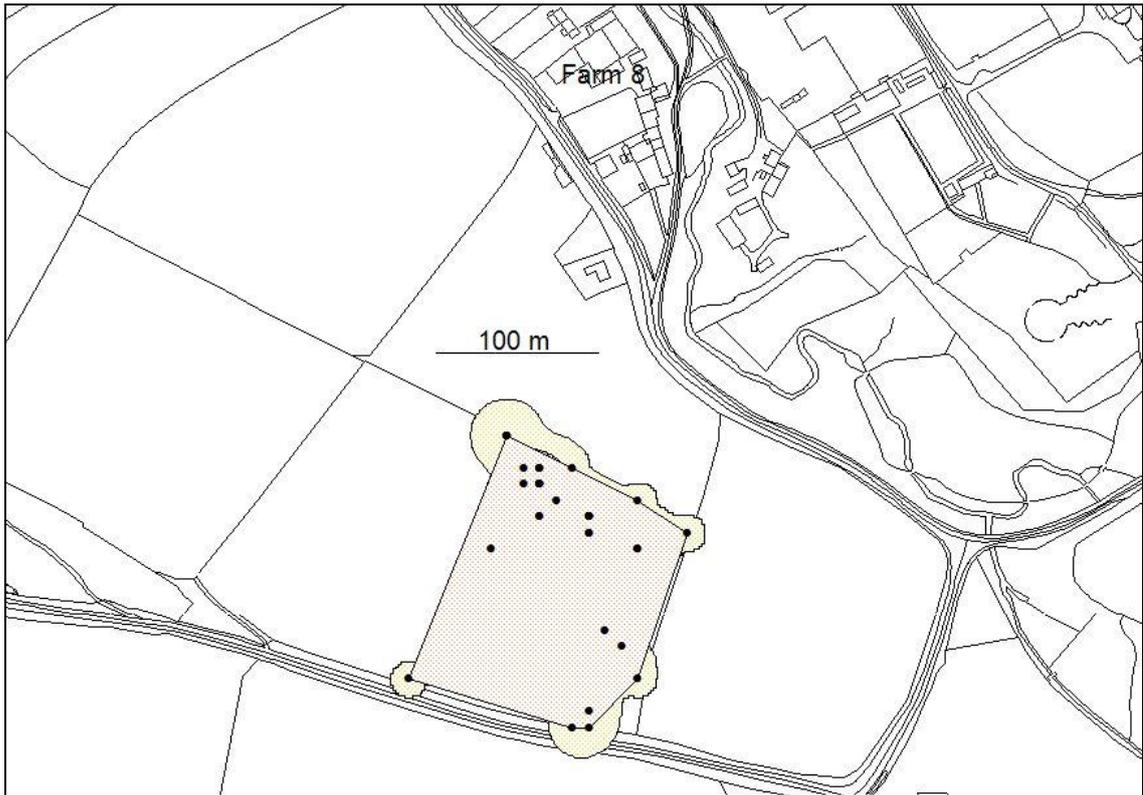
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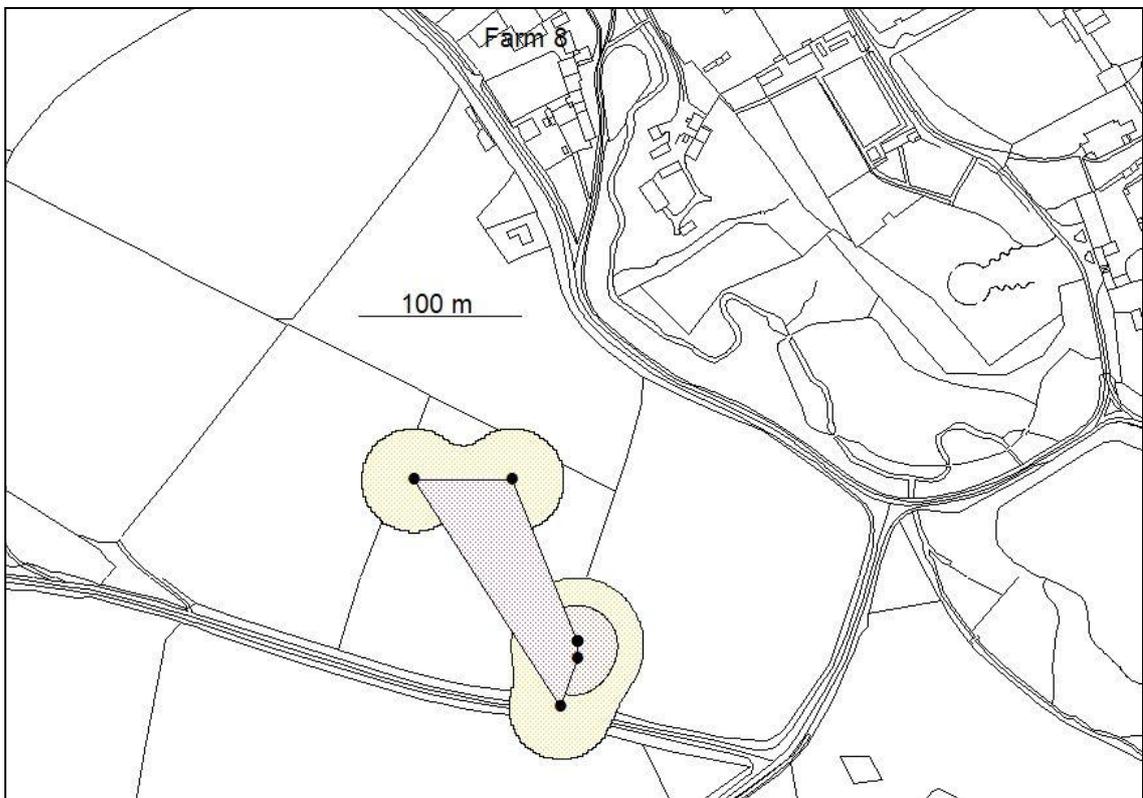
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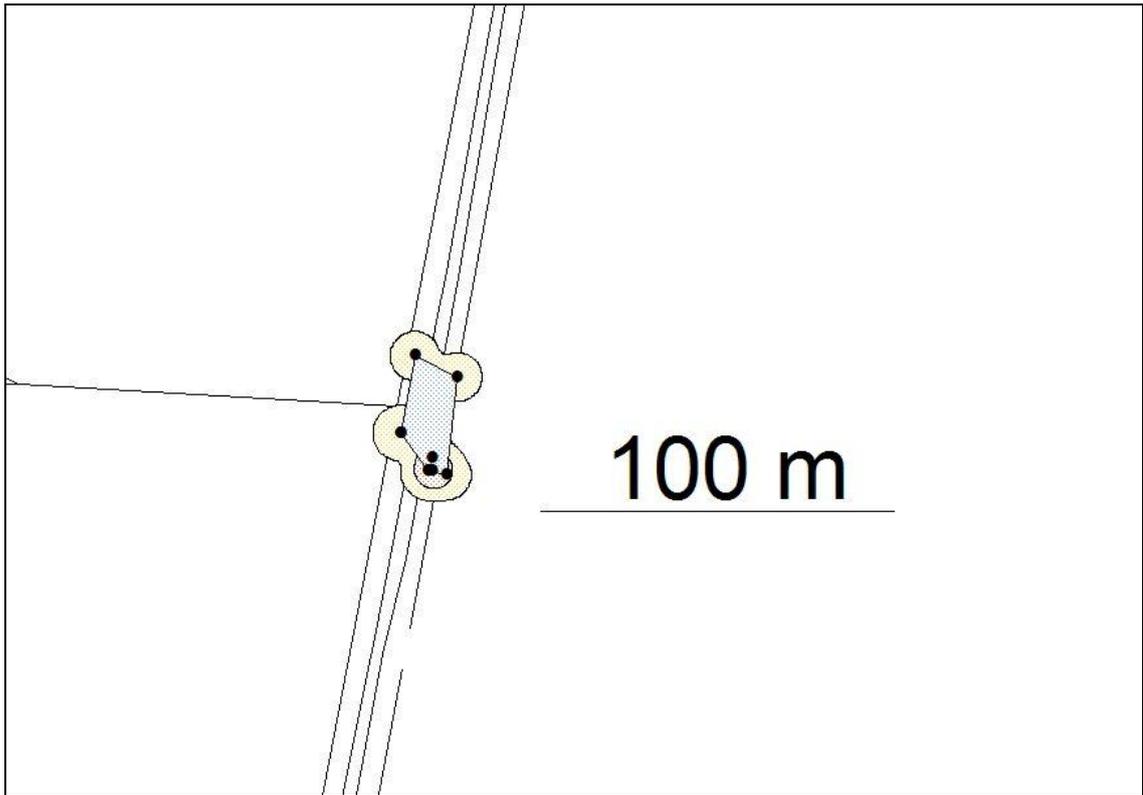
Rat 4a



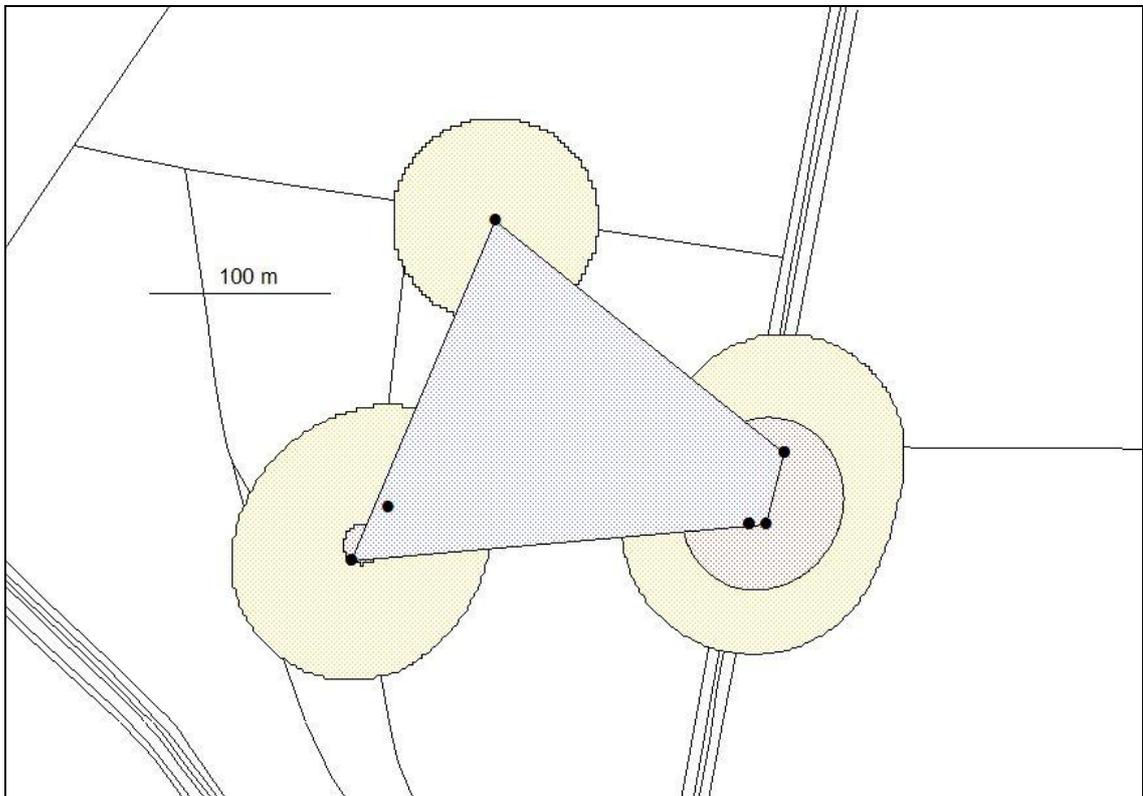
Rat 5



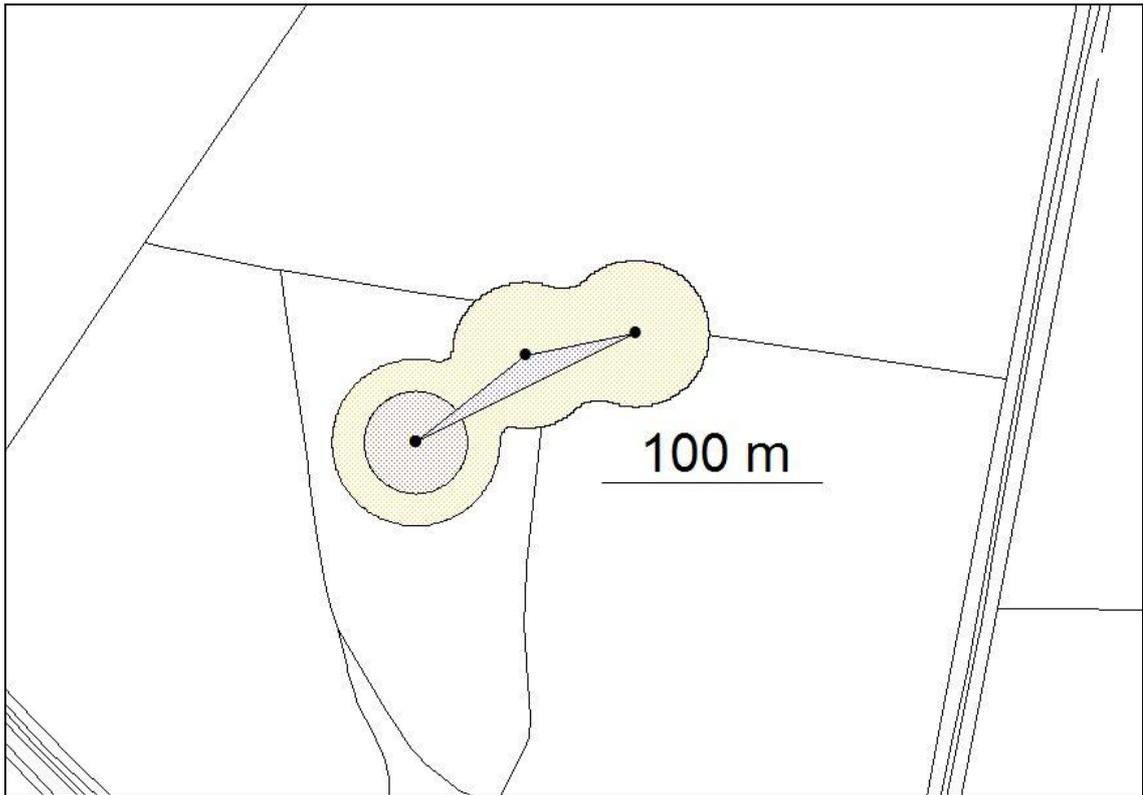
Rat 6



Rat 7



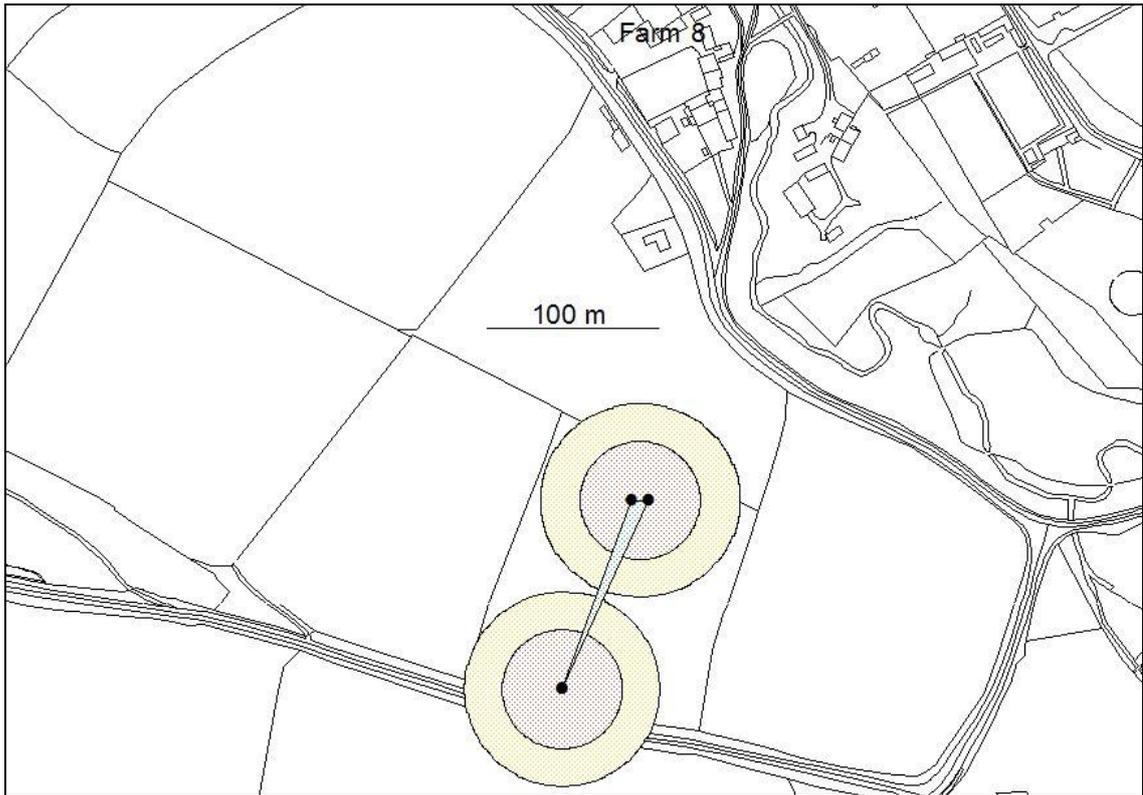
Rat 13



Rat 14



Rat 15



Rat 16

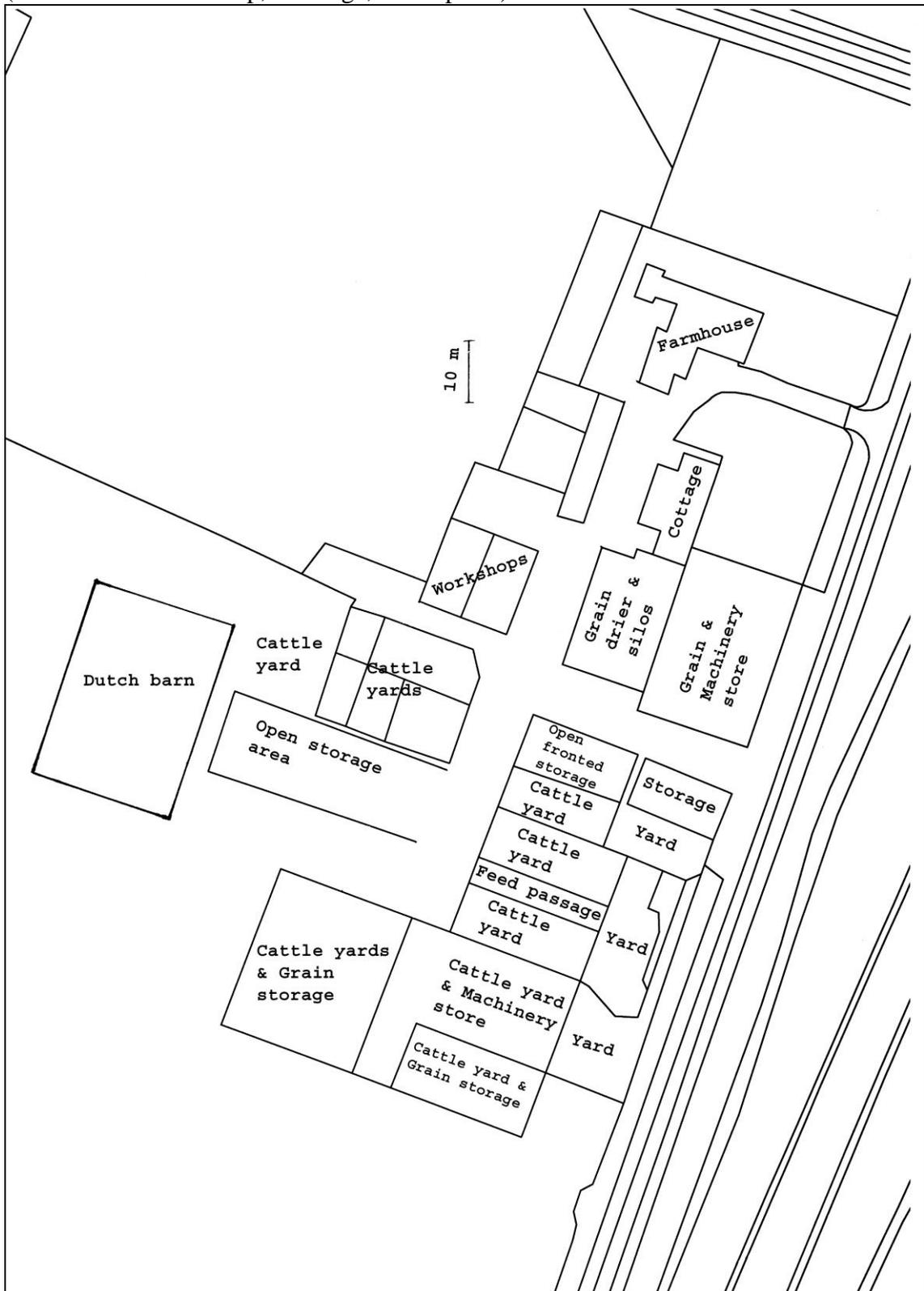


Rat 17

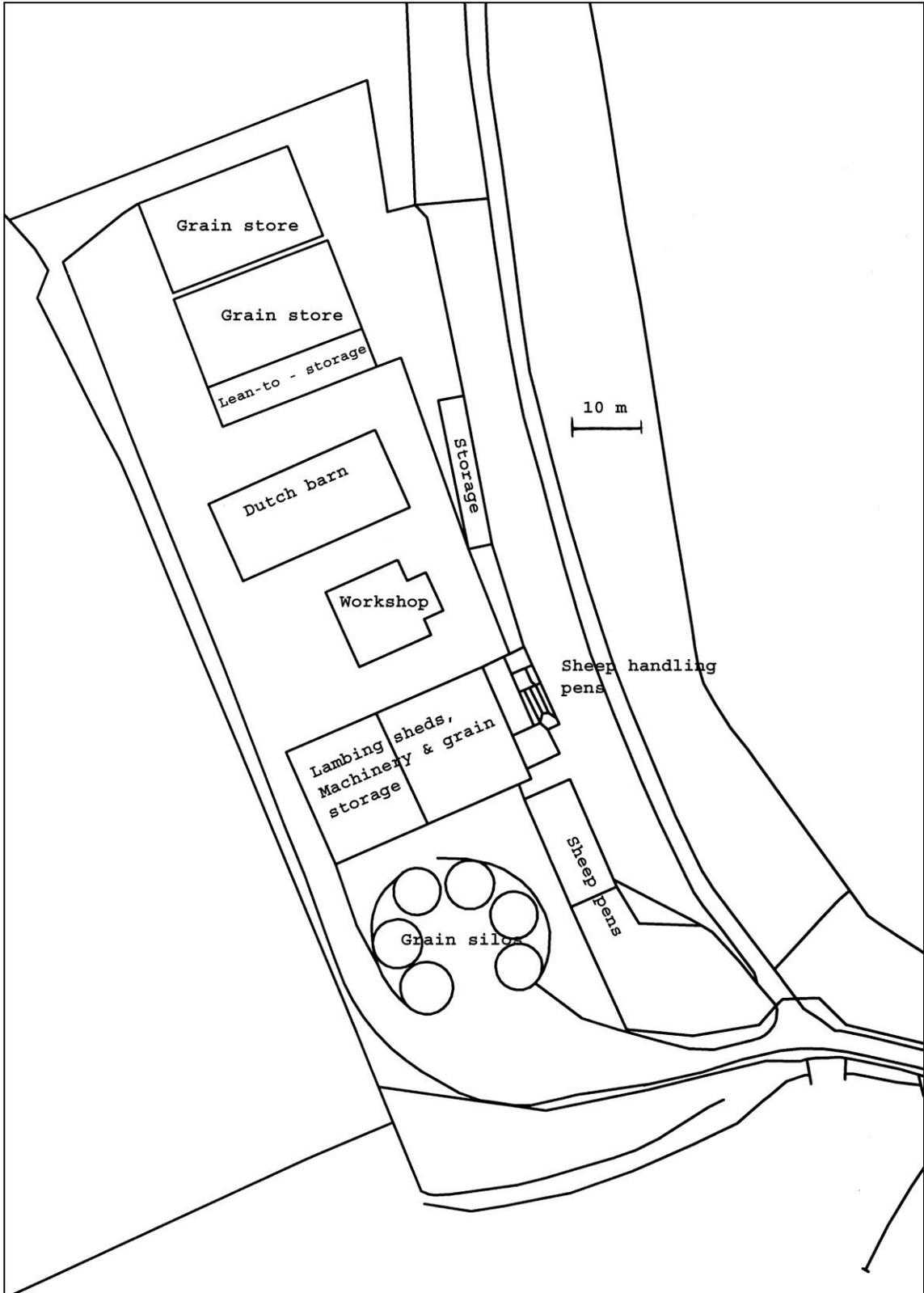
ANNEX F LEICESTERSHIRE FARMYARD PLANS

COORDINATED SITE

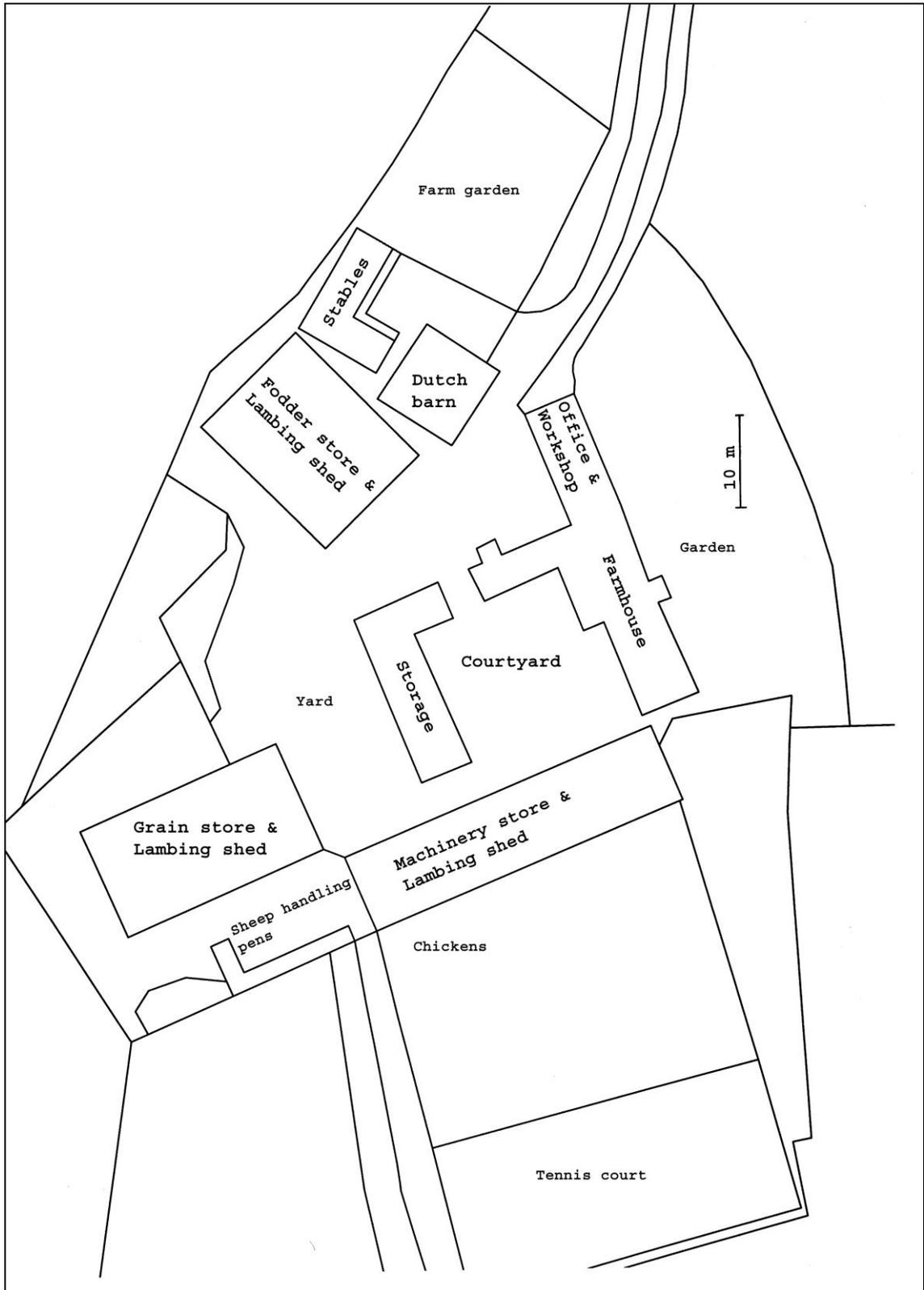
(Note: north is at the top, this edge, of the plans).



Site Plan Farm A

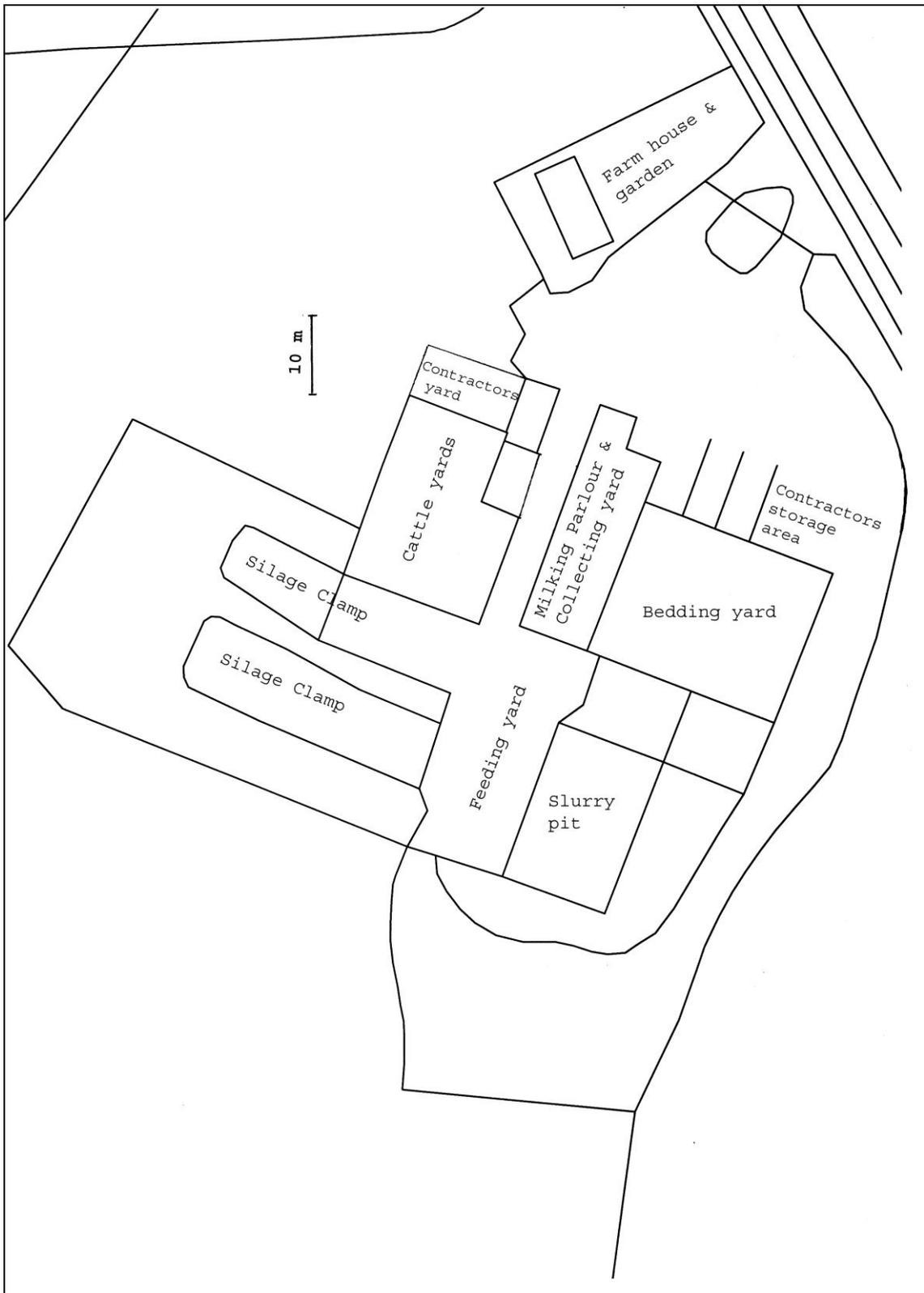


Site Plan Farm B

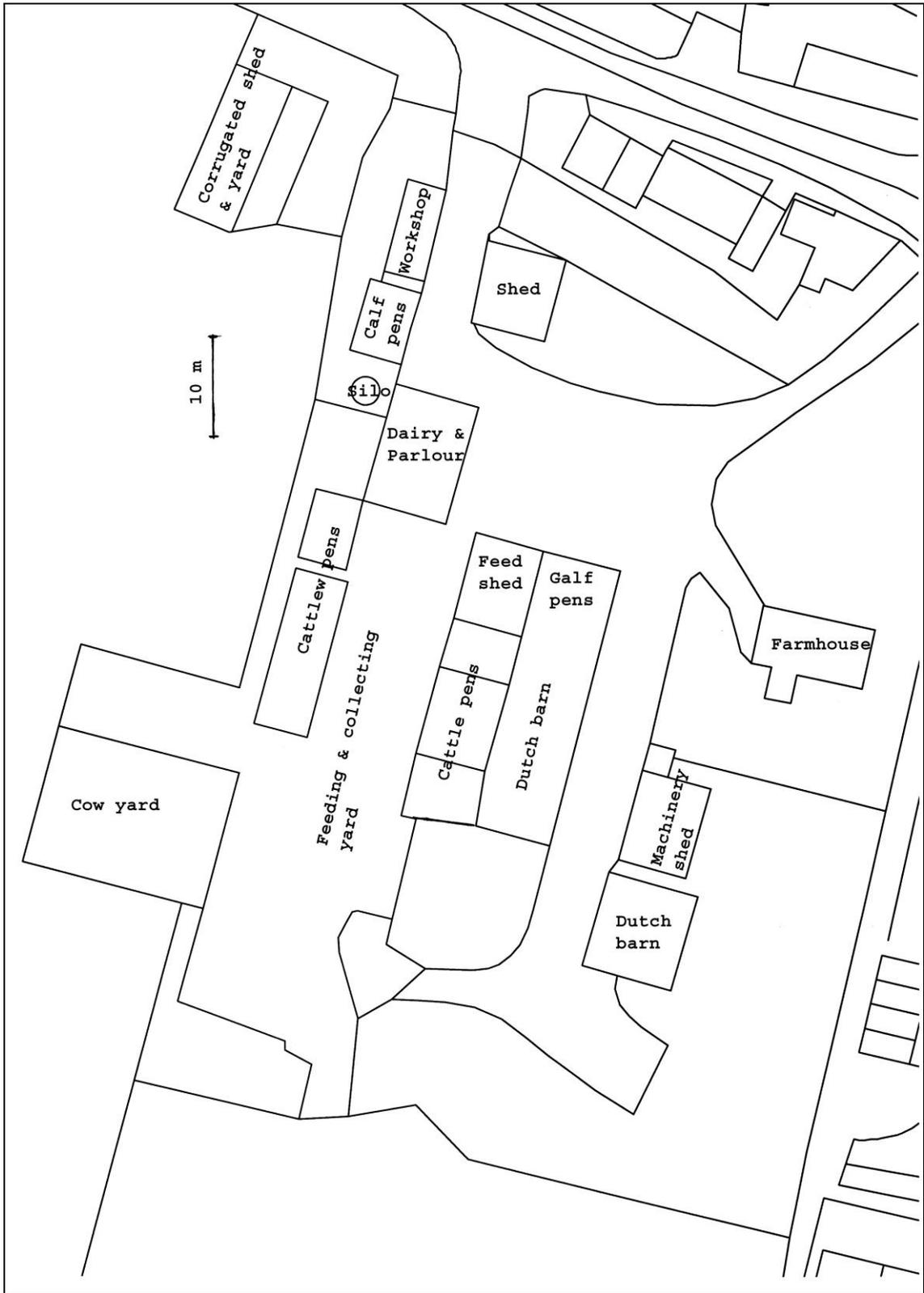


Site Plan Farm C

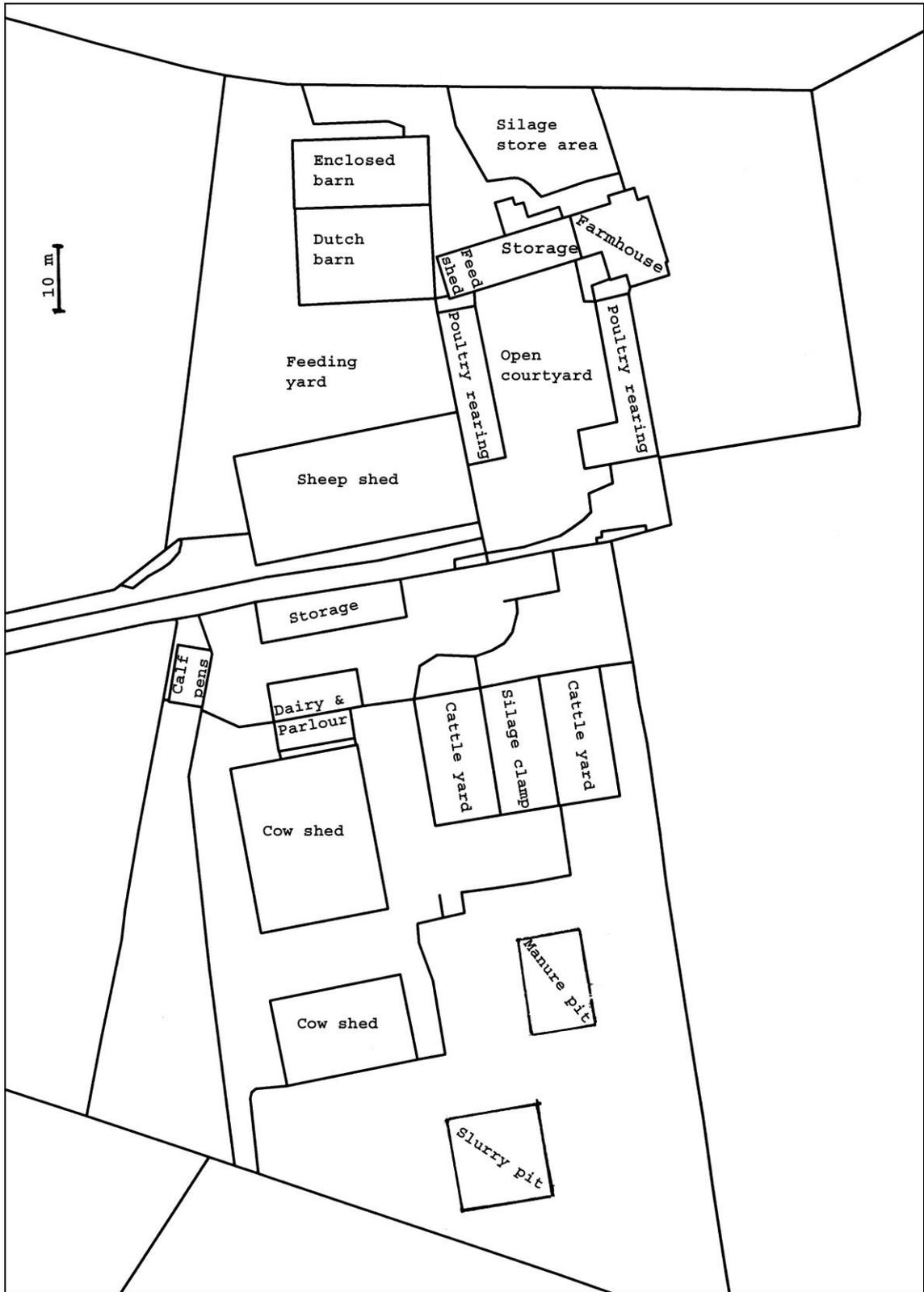
LEICESTERSHIRE UNCOORDINATED SITE



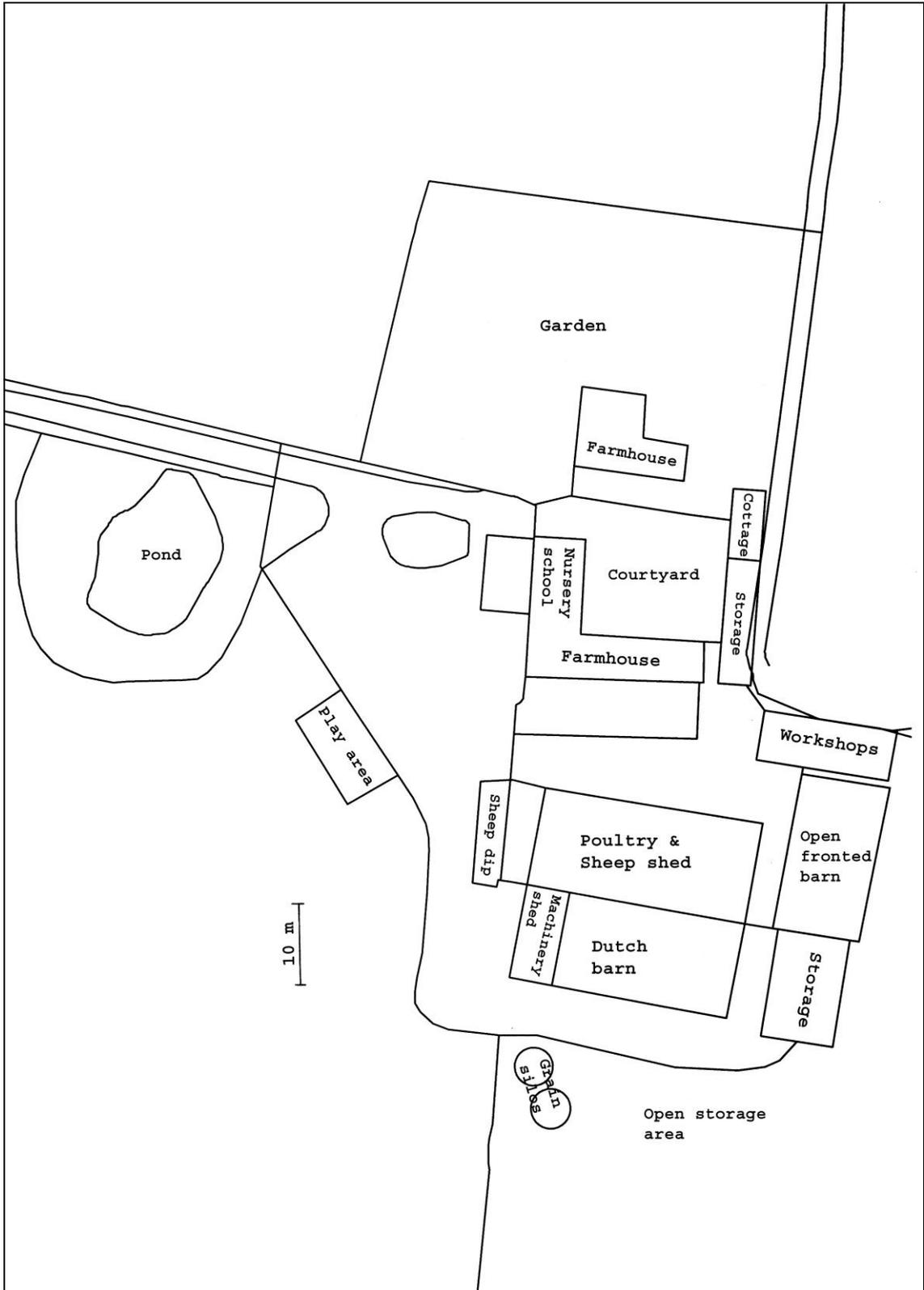
Site Plan Farm D



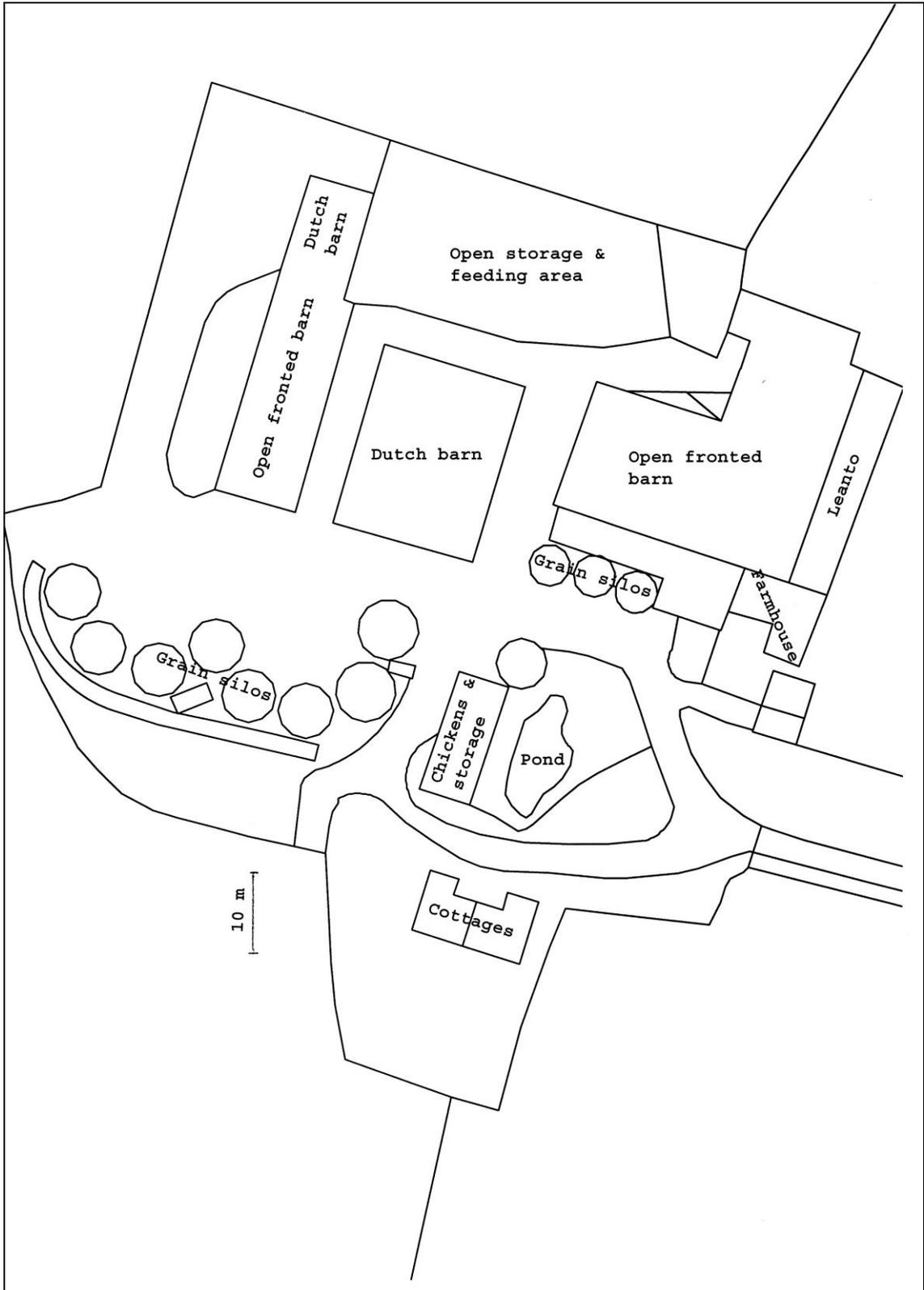
Site Plan Farm E



Site Plan Farms F and G



Site Plan Farm H

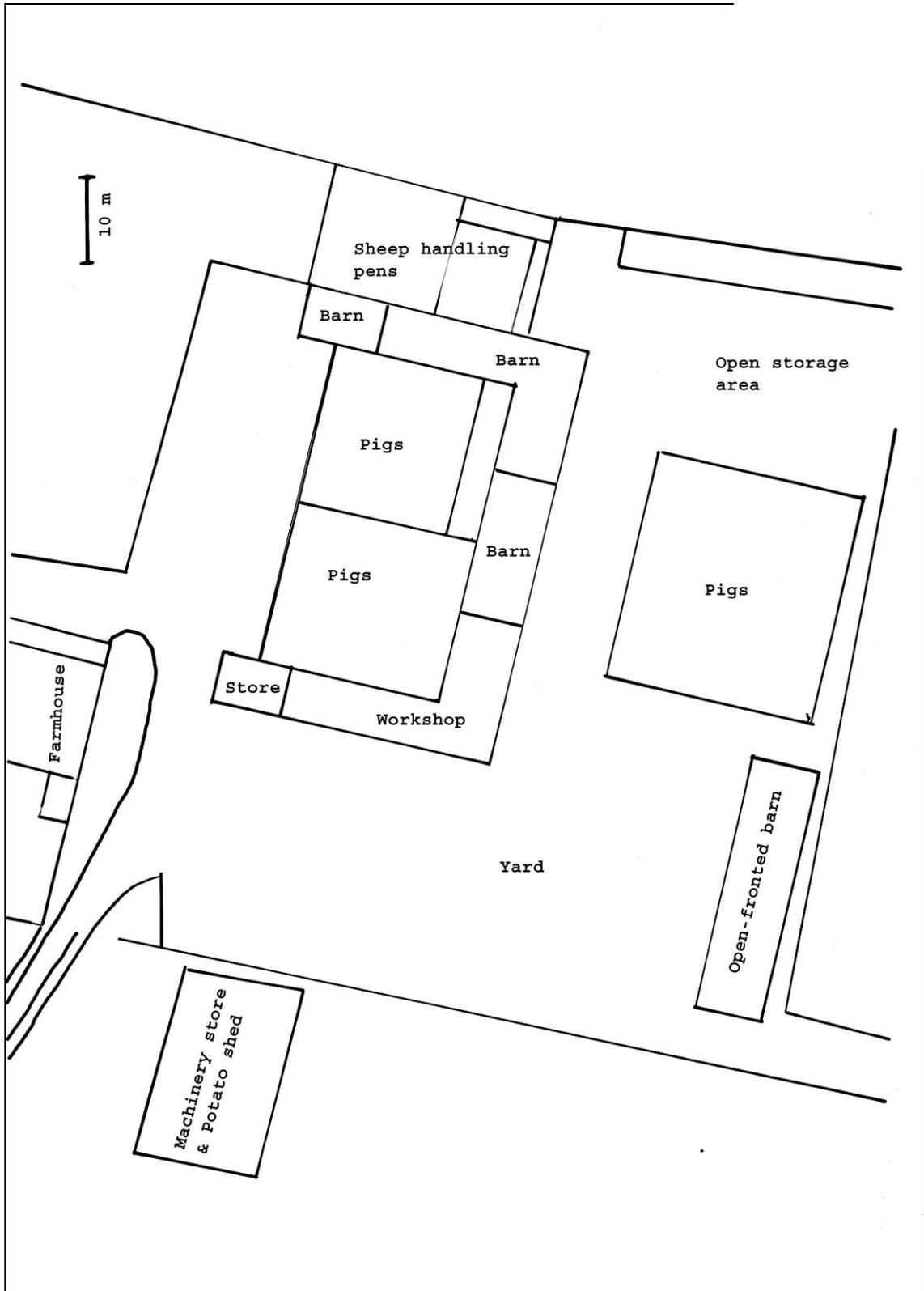


Site plan Farm I

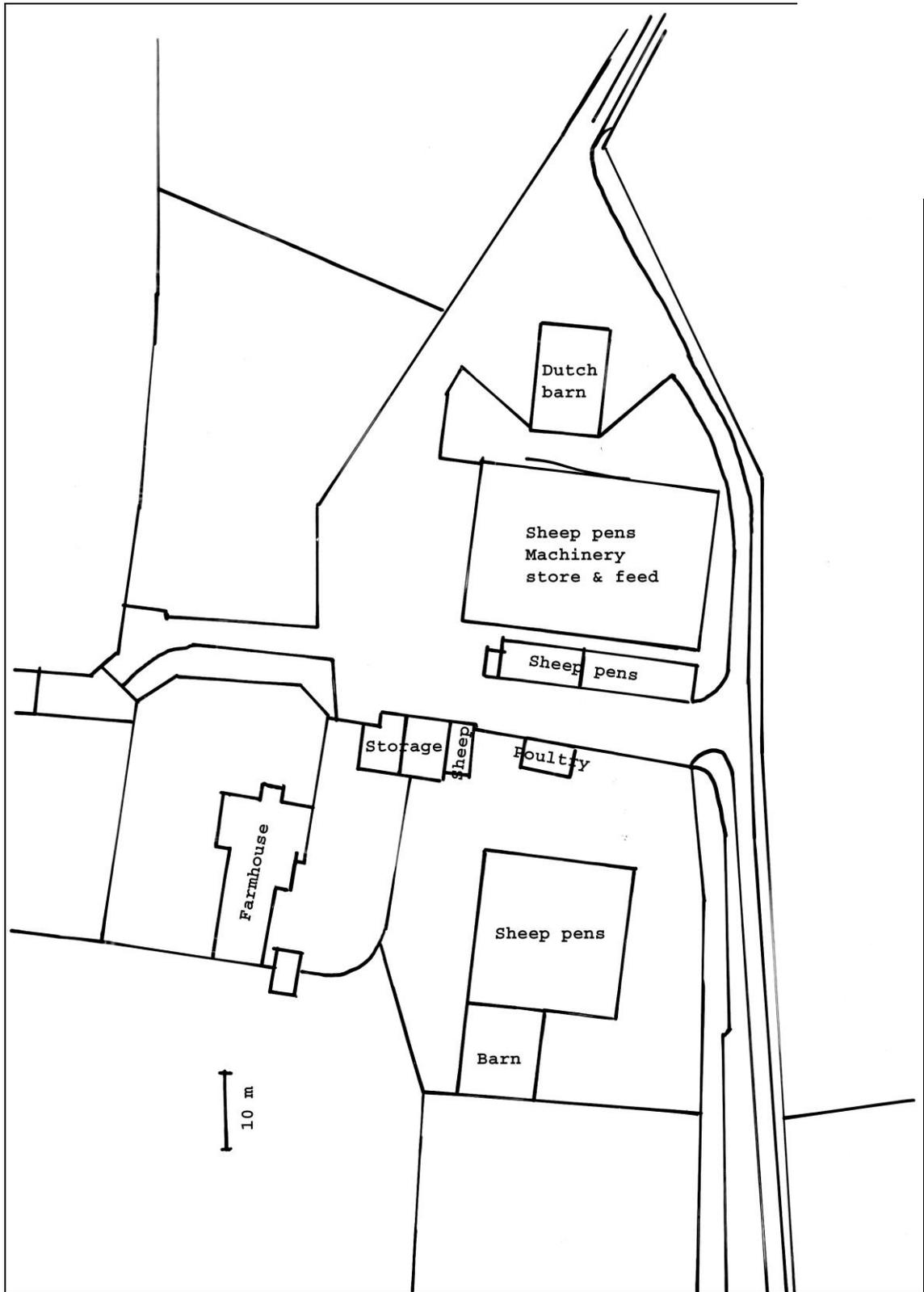
ANNEX G – YORKSHIRE FARMYARD PLANS

COORDINATED SITE

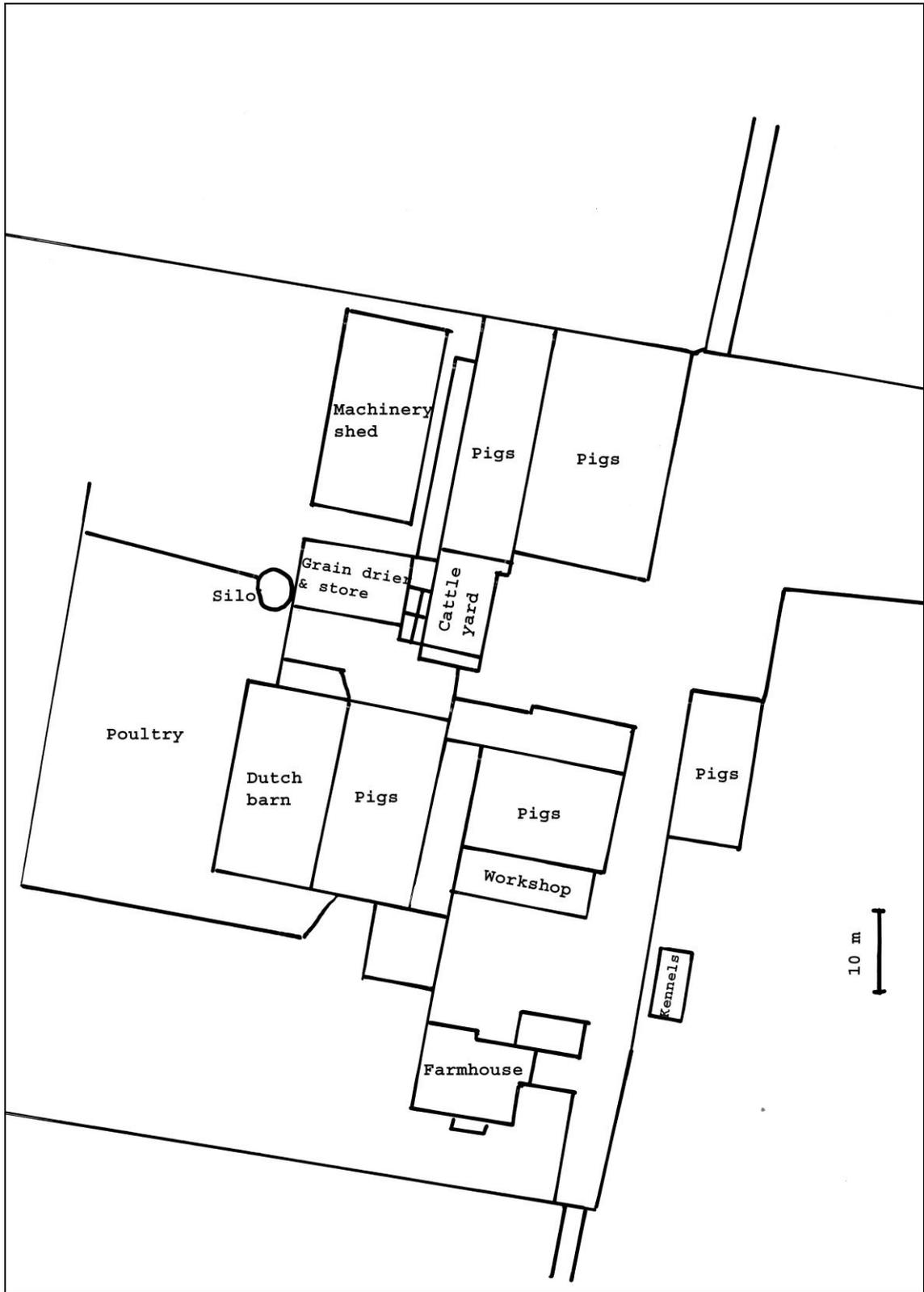
(Note: North is at the top, this edge, of the plans)



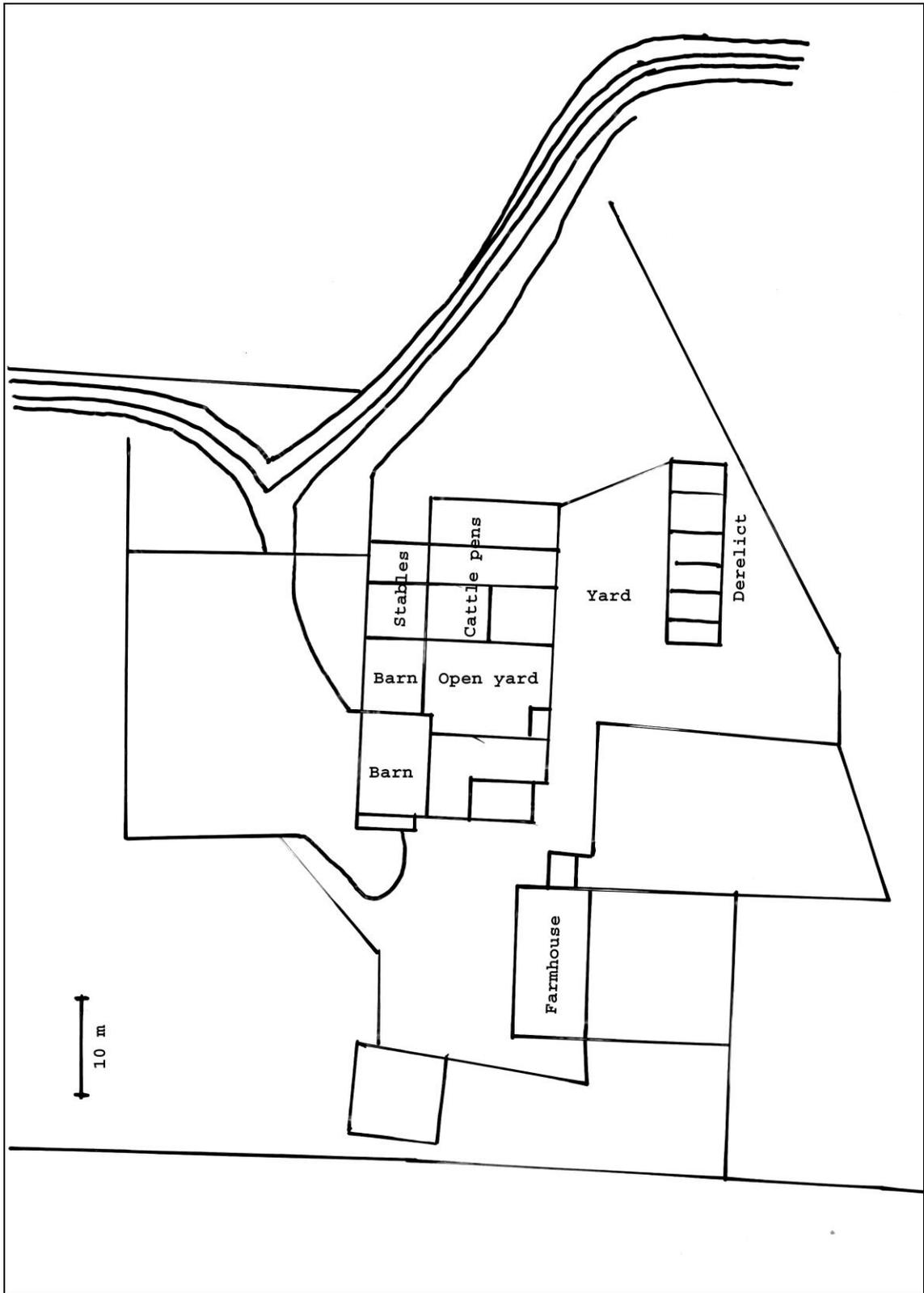
Site plan Farm 1



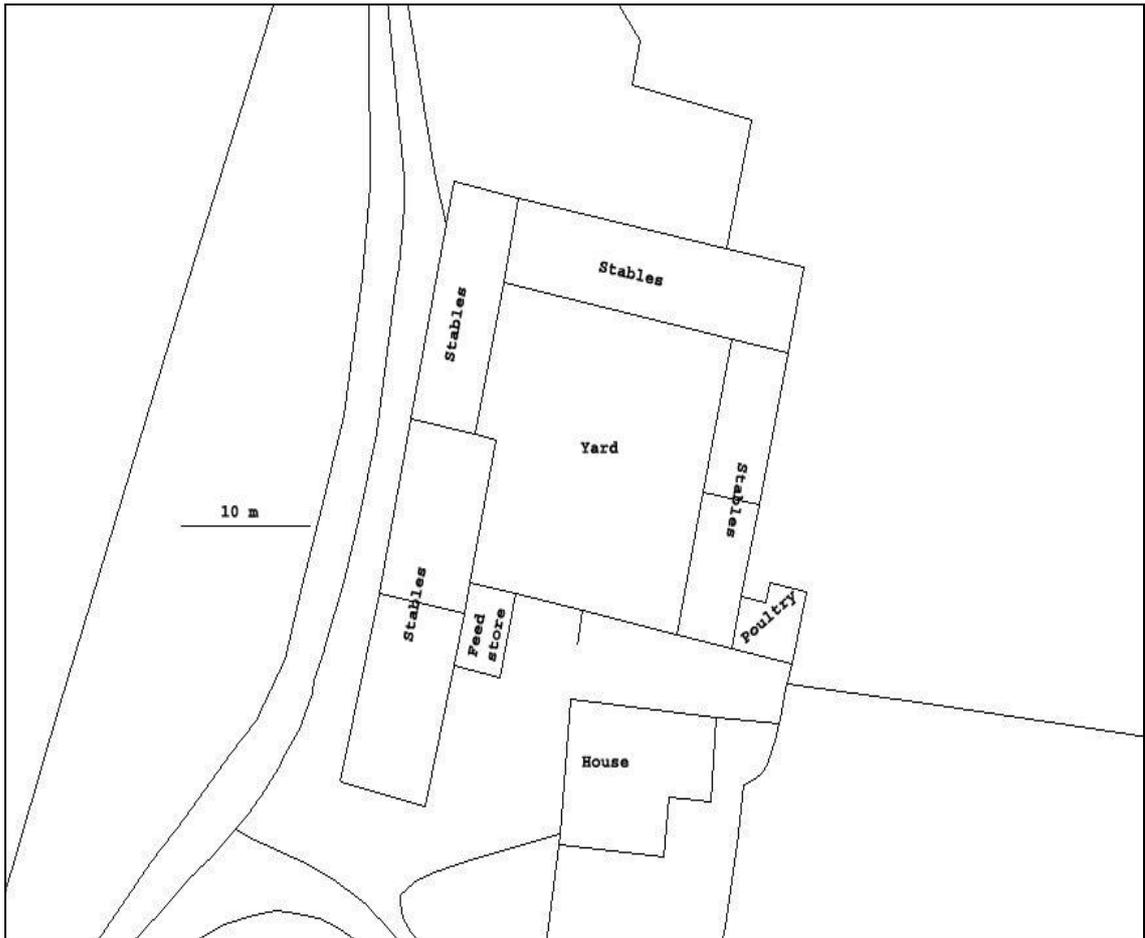
Site Plan Farm 2



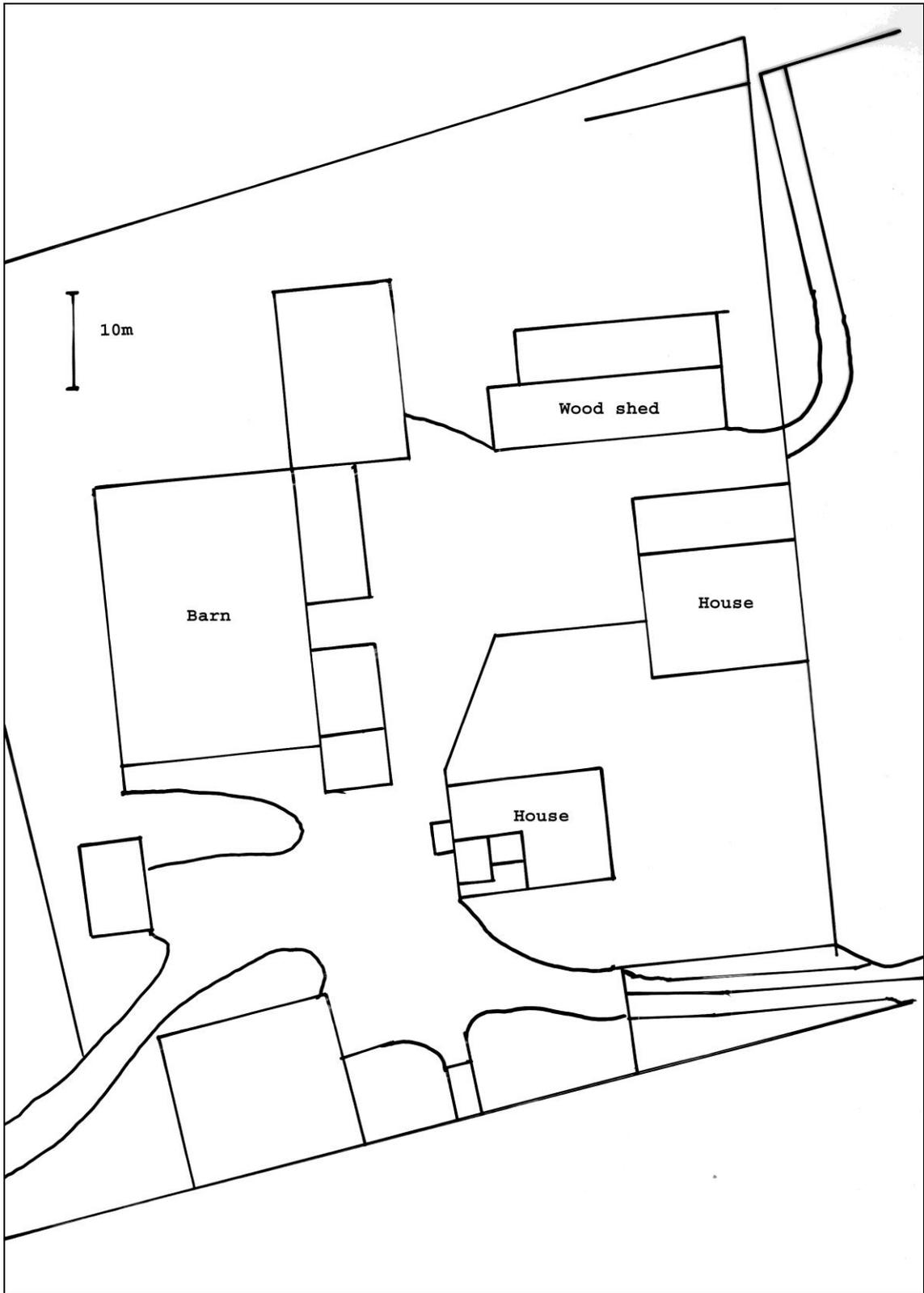
Site Plan Farm 3



Site Plan Farm 4

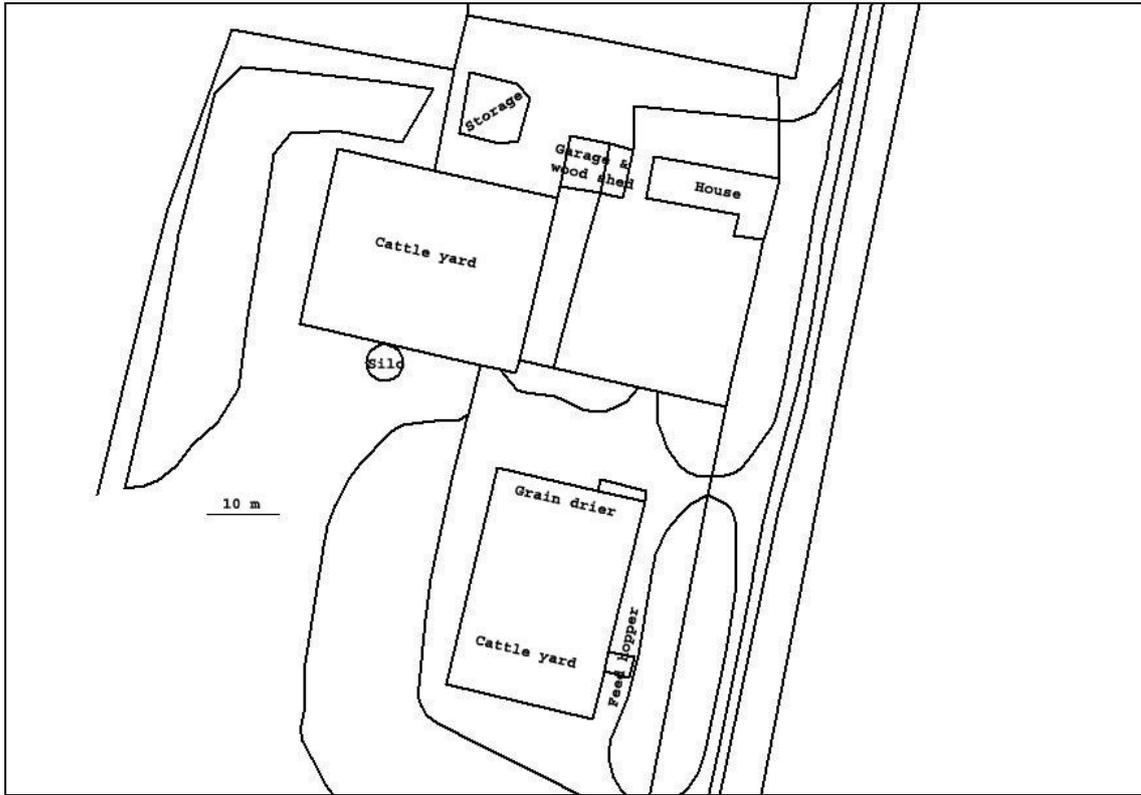


Site Plan Farm 5

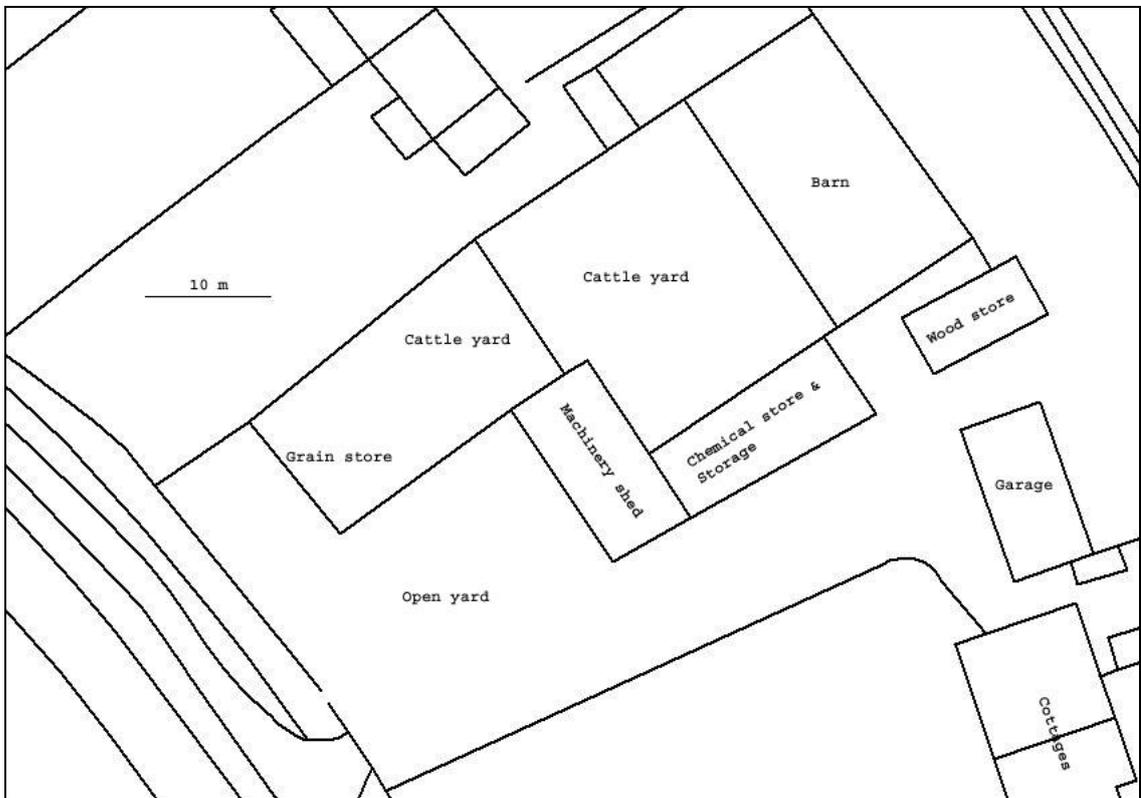


Site Plan Farm 6

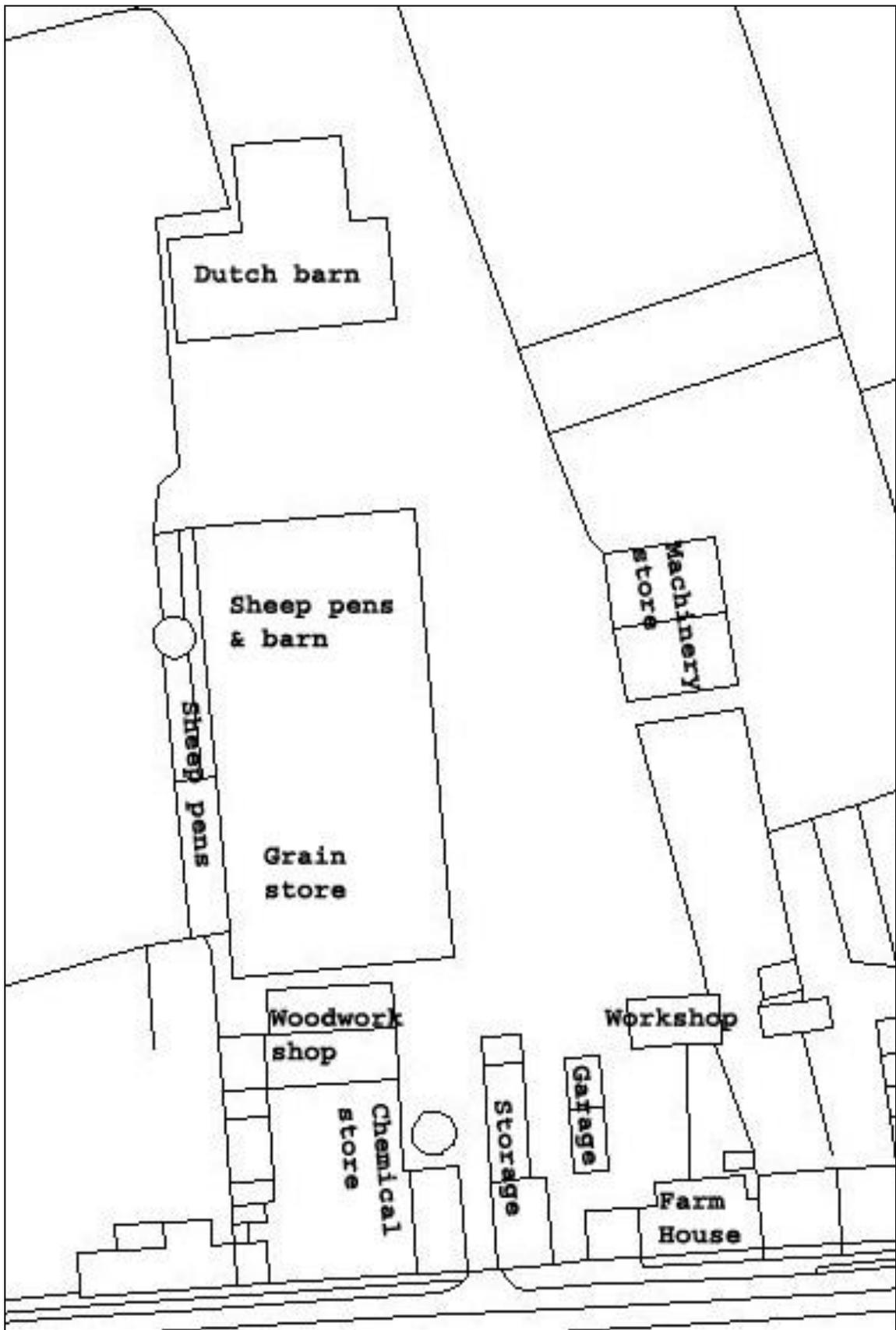
YORKSHIRE UNCOORDINATED SITE



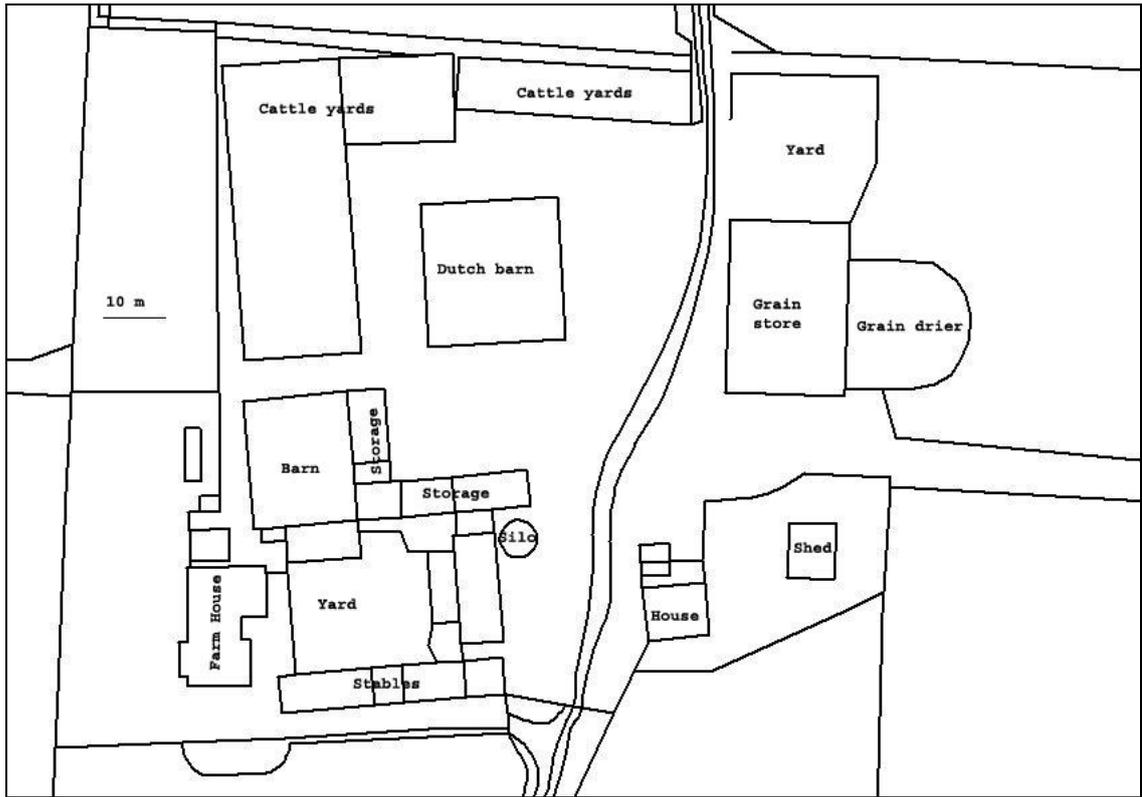
Site Plan Farm 7



Site Plan Farm 8

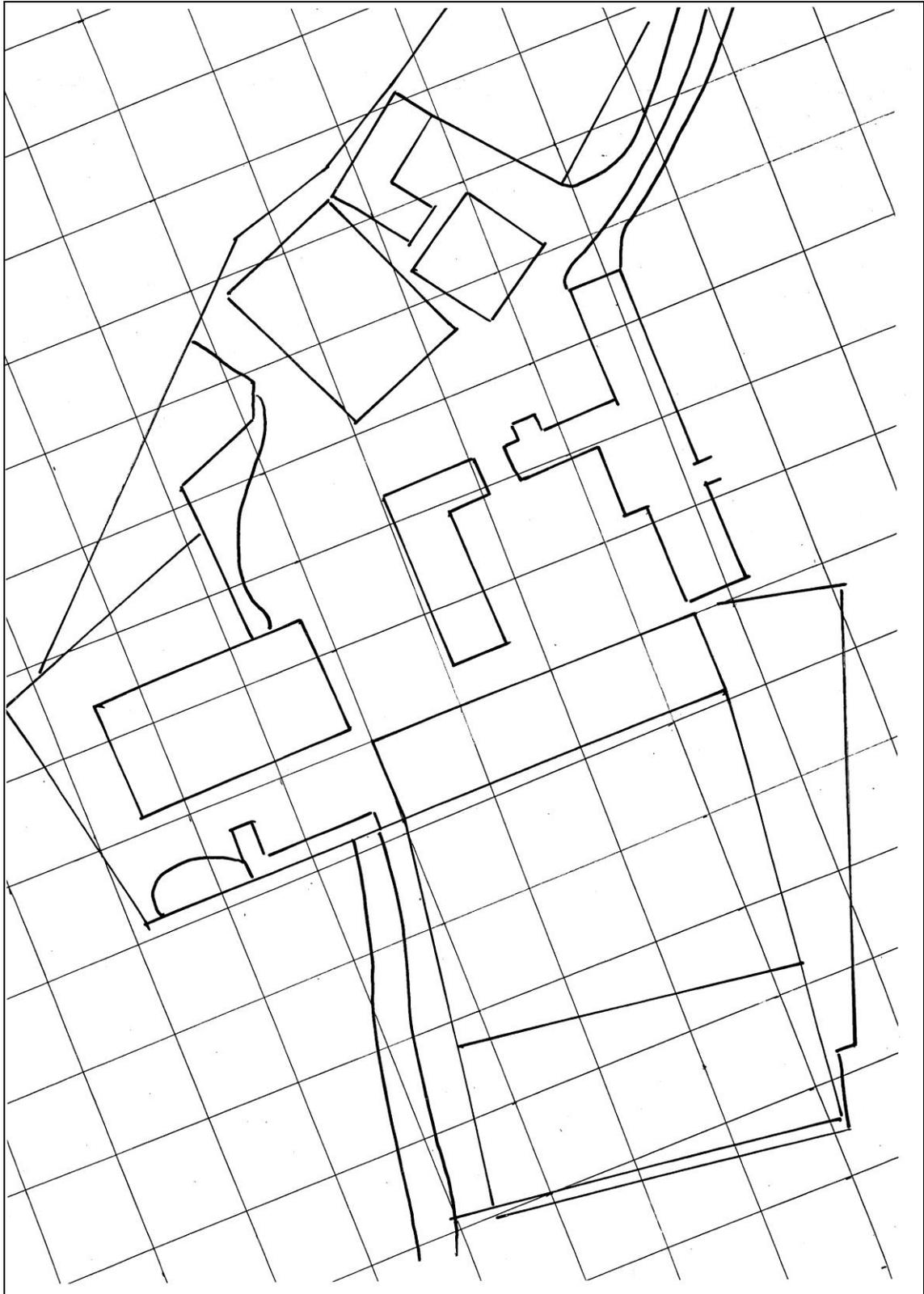


Site Plan Farm 9



Site Plan Farm 10

ANNEX H EXAMPLE OF A GRIDDED FARM PLAN  
(Note: North is at the top, this edge of the plan).



Farm Plan of Farm C with 10 x 10 m grid overlaid

ANNEX I RAW CENSUS DATA FOR BOTH RESEARCH AREAS  
LEICESTERSHIRE

Period	Coordinated Area			Uncoordinated Area
	Buildings	Field	Total	Total
Sep-03	42	0	42	12
Oct-03	131	0	131	56
Dec-03	93	0	93	7
Jan-04	67	0	67	12
Mar-04	52	0	52	0
Apr-04	60	139	200	8
Jun-04	96	82	179	5
Sep-04	50	54	104	27
Nov-04	149	73	222	37
Feb-05	116	34	150	0
Apr-05	58	12	70	9
Jun-05	63	4	66	15
Aug-05	26	8	34	9
Sep-05	55	25	81	50
Nov-05	69	60	129	33
Jan-06	45	7	51	7

YORKSHIRE

Period	Coordinated Area			Uncoordinated Area		
	Buildings	Field	Total	Buildings	Field	Total
Sep/Oct 03	383	80	463	221	19	240
Nov/Dec 03	230	80	310	240	251	491
Jan/Feb 04	91	5	96	100	288	388
Mar/Apr 04	72	9	81	30	303	333
May/Jun 04	44	5	49	23	32	55
Jul/Aug 04	176	50	226	42	70	112
Sep/Oct 04	184	53	237	184	327	511
Nov/Dec 04	138	25	163	84	340	424
Jan/Feb 05	104	9	113	18	402	420
Mar/Apr 05	98	7	105	27	187	214
May/Jun 05	63	6	69	49	78	127
Jul/Aug 05	128	19	147	72	132	204
Sep/Oct 05	283	34	317	173	359	532
Nov/Dec 05	92	33	125	118	439	557
Jan/Feb 06	146	107	253	144	510	654
Mar/Apr 06	31	47	78	110	228	338