A Study on Wild rat Behaviour and Control on a Pig farm

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The Present Thesis is a partial fulfilment of the requirements for Master of Science (Msc) degree in Veterinary Medicine for International Students at the Swedish University of Agricultural Sciences (SLU), in the field of Pig diseases.

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Dedicated to my dear family.

Quotes

As a man thinketh in his heart so is he.

In Him was life and the life was the light of man, the light shineth through darkness and darkness cannot overcome it.

There is a spirit in man, the inspiration of the Almighty that giveth understanding.

Abstract of Thesis

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Wild rodents are known to be carriers of pathogenic organisms that affect both humans and domestic animals. In this study, two rats were followed by radio tracking for an aggregate period of 24 hours each to determine their territories, path preferences and activity levels. In addition, a video recording equipment with two cameras positioned at different locations along a pathway was used. Recordings of rat activities for 5 days were made and used to evaluate the general behaviour of wild rats around live traps and around an accessible pig pen. A bait preference study was carried out in 8 successive days of 24 hours each and pig feed was used as a control feed because of its abundance in the pig house. This was compared with four different test baits i.e. peanut butter, caviar, wax block plus walnut oil and pig feed plus walnut oil. The activity pattern in 24 hours was estimated from the bait preference study.

A territory of approximately 500 m^2 was recorded, as well as a path preference from the home site through the accessible burrows into the pig house. Rats also moved from the drainage system into pig pens. Furthermore, the frequent movement of rats to and from a pig pen via a low fence situated directly opposite an exit burrow was recorded. There was an evidence of pig feed plus walnut oil having the highest test bait acceptance value, followed by peanut butter, wax blocks plus walnut oil and caviar, respectively. The pattern of feeding activity estimated, showed an onset of activity after dusk which increased until about 9 pm. This was followed by a rise in activity level until it reached a peak between 3 and 4 am. Thereafter the activity level dropped steadily.

In conclusion, this study agrees with previous studies on the behaviour of the wild brown rat. The results suggest that the path preferences should be a vital part of bait positioning during rodent control programmes. Wild rats should be considered to be disease risk factors to pigs whose pens they visit. Construction and maintenance of functional barriers will enhance rodent control and limit poisoning in domestic animals living on the farm. Ideally, pig feed should be adopted as the choice of base for poisoned bait on a pig farm.

Key words: Wild brown rats, activity, pig pens, bait, radio tracking, control.

Contents

INTRODUCTION

Brown rats have their natural habitat within and around buildings, farms, sewers, and on garbage dumps. Generally, wild rodents have been known from previous studies to be carriers of a variety of organisms that may cause disease in humans and domestic animal populations (Gratz, 1994; Webster and MacDonald, 1995). They can cause serious damage to structures, equipment or furniture.

Wild rodents have been reported to be carriers of parasitic organisms like *Toxocara cati,* which causes toxocariasis in humans, *Nippostrongylus brasiliensis, Heterakis* spp (Webster and MacDonald, 1995; Stojcevic et al., 2004), *Taenia taeniformis, Hymenolepsis diminuta, Capillaria hepatica* (*Seong* et al., 1995; Webster and MacDonald, 1995; Stojcevic et al., 2004) and *Trichinella* spp which cause trichinosis both in humans and swine (Leiby et al., 1990; Marinculic et al., 2001; Mikkonen et al., 2005; Hurnikova et al., 2005). There have also been reports of some protozoans being haboured by wild rodents. Webster and MacDonald (1995) found *Cryptosporidium parvum,* causing cryptosporidiosis in 63% of the rats studied although in another study by Quy et al (1999), 24% of the rats studied on a livestock farm carried this organism. It was noted that seasonal changes, age and sex were factors that affected the varying percentage of infected rats. Quy et al (1999) again reported *Toxoplasma gondii*, an organism that causes toxoplasmosis, in 35% of the rats, *Trypanosoma lewisii* and *Eimeria separata* in 29% and 8% of the rats respectively. Also reported bacterial organisms found in wild rodents are, *Salmonella* spp (Davis 1948, Nakashima et al., 1978; and Hilton et al., 2002), *Leptospira ictero-haemorrhagiae,* the causal agent of Weils disease (Sunbul et al., 2001; Tokarevich et al., 2002 and Pezella et al., 2004), *Brachyspira hyodysenteriae*, the etiologic agent of swine dysentery (Joens and Kinyon, 1982; Fellström et al., 2004). Webster and Macdonald (1995) again showed that *Listeria monocytogenes* causing listeriosis, *Pasteurella* spp causing pasteurellosis, *Pseudomonas* spp causing meiliodosis and *Yersinia enterocolitica* causing yersiniosis, are all infectious organisms carried by wild rodents.

Humans and farm animals have been infected, and continue to be infected with loads of rodent-carrying infectious organisms. This poses a continuous risk of disease outbreak on livestock farms and in humans likewise. Therefore a need for effective rodent control cannot be over-emphasized. Rodent control strategies that are carried out are usually geared towards reducing the rodent population of a densely populated area drastically. Usually these strategies involve the use of rodenticides, simply because the use of other control measures such as traps and ensuring good structural barriers are not sufficient to effectively reduce the rat population (Cowan et al., 2003). Thus, the use of rodenticides seems to be the best rodent control measure. However, rodenticides use has its own draw backs since the success of such a strategy greatly depends on repeated application. These drawbacks include; wild and domestic animal poisoning, environmental hazards, and development of resistance in target species. For instance, pigs are very sensitive to anticoagulants and e.g. coumatetralyl poisoning in pigs was reported by Dobson (1973). Occurrence of reinvasion after complete elimination probably due to the metapopulation structure of rat population where reinvasion of rats is mainly represented by edge populations, is also a common situation. Invariably, an optimal control strategy that depends on the phenomenon of understanding rodent behaviour and population dynamics, and the determination of rodenticides resistance genes as well as blood clotting response tests will be necessary for tackling these drawbacks.

In this specific study, a pig herd was chosen as a representative of a rat invaded farm because of a known history of repeated massive rodent invasions and frequent use of rat poison positioned within and around the farm buildings and the feed mill likewise. Furthermore, rats caught on the farm were examined for a mutation in a warfarin resistance gene (VKORC1) due to the extensive use of rat poison in the herd. This mutation has previously been found in Denmark and Germany

The main objectives of this study were to improve rat control and provide risk assessment, using this selected pig farm with known history of rat infestation as a case study. This was performed by carrying out a behaviour study on rats using telemetry and digital video recording to determine their activity pattern and path preferences. A bait preference study was done in order to determine the preferred bait in a pig house.

LITERATURE REVIEW

Wild rats

History and Geography

The brown rat (*Rattus norvegicus*) is a species of the family Muridae; the largest mammalian family (Nowak, 1991), order Rodentia and class Mammalia. It is generally known to have originated from Asia. Following a series of accidental introductions, the species had found its way to Eastern Europe by the early eighteenth century. By the year 1800, it occurred in every European country (Meyers and Armitage, 2004). The brown rat can be found on every continent of the world except Antarctica (Silver, 1927; Nowak and Paradiso, 1983). In Europe and America, it has been reported to have displaced the black rat (*Rattus rattus*) which had been present since Roman times (Cowan et al., 2003). Nowak, (1991), however states that black rats are more common than brown rats in the tropical zones.

The brown rat in rural areas is seen predominantly as a storage pest living on the supplies of harvested cereals, root crops and also on livestock feeds that can be found in farm buildings (Cowan et al., 2003).

Physical Description

On the average, brown rats are up to 440 mm long, nose to tail and weigh about 200 to 500 g (Nowak, 1991). Males are usually larger than females. The length of the tail is shorter than the length of the body. The ears are relatively shorter than those of other species and do not cover up to the ears when pulled down. Naturally, brown rats are covered with brownish fur on their back which usually lightens to a gray color near the underside but can also take the colours of a typical black rat, which equally may take the colour of a typical brown rat. The brown rat can easily be mistaken for black rats, but while the temporal ridges of brown rats are straight; those of the black rats are otherwise curved (Nowak and Paradiso, 1983). Furthermore, the black rat is smaller and more slender built, has a longer, thinner tail (longer than the body), tail is uniformly coloured, and has a more pointed head and larger ears.

Habitat

Brown rats prefer to live alongside the rapid expansion of human population. Commensalism, which is a human dependent association, is the chosen lifestyle of brown rats and also black rats. The rat has chosen to be wherever we humans choose to live especially where there is constant supply of food (Myers and Armitage, 2004). These rodents occupy a variety of habitats including garbage dumps, sewers, open fields, woodlands, feed mills, farm houses and nearly anywhere else that food and shelter can be found (Nowak and Paradiso, 1983). The normal home range of *R. norvegicus* is about 25-150 m in diameter (Grzimek, 1975, Taylor and Quy, 1978); however individuals have been known to move as far as 3 km from their nests in a single night (Nowak, 1991). The home range and territories are dependent on factors as e.g. population density, food supply, vegetation.

Wild rats are known to dig burrows which can be a simple tunnel leading to a chamber or a complex interconnecting tunnels passages and cavities (Calhoun, 1962). The burrow usually consists of an entrance, a tunnel, and a cavity which could be used as nest cavity or food storage (Calhoun, 1962). It has been reported that there are no significant differences in the burrowing behaviour of the domestic and wild rats (Nieder et al., 1982).

Reproduction

The Brown rat is a prolific breeder and breeds all year round, but breeding is less pronounced during colder months of the year. The gestation period is 21 to 24 days and the average number of offspring is 8 but ranges from 2 to 14 and it takes 3 to 4 weeks to wean the young ones (Grzimek, 1975). The age at sexual maturity for both male and female is about 3 to 4 months. Generally, brown rats are known to have a polygynandrous (promiscuous) mating system i.e. they tend to breed in large groups. They are also known as social animals (Calhoun, 1962). Once a female enters her estrus period, she mates several hundred times with competing males (Nowak, 1991). The maximum lifespan of *Rattus norvegicus* is 3 years in captivity and up to 2 years in the wild with an average age of 8-10 months.

Animal behaviour

Behaviour is generally defined as the action and reaction of an organism relative to internal and external conditions in the environment. Behaviour can be conscious or unconscious**.**

Ethology is the scientific study of behaviour of animals. Charles Darwin, in his book, *The expression of the emotions in man and animals* (Darwin C, 1872) made an early attempt to explain the complexity and variation of human and animal behaviour. He looked at behaviour from the background of evolutionary thought (Archer J, 1992). Oskar Heinroth in 1911 did a comparative study on the social behaviour of wild fowl with much interest in imprinting; this work was taken up by Konrad Lorenz (Archer J, 1992). Niko Tinbergen worked on observing animals in their natural habitat using experimentation, photography, filming and analysis, while Lorenz surrounded himself with his animals studying the displays of similar species of birds (Archer J, 1992). An observed behaviour can be called instinctive, or natural, in that they occur in all members of a species under specified circumstances.

Rat behaviour

Social system

The male social system of brown rats is usually dependent on the population density. When the population density is low, the male rats become territorial and in this instance each male will have his own territory. Furthermore, each male will defend the territories around the burrow of one or more females and mate exclusively with them (Barnett, 1958). A territory can be defined as an area that is known to the rat and visited on a daily basis. On the contrary in a high population density situation, the males have overlapping home ranges and their interactions with each other are not based on location or territory but rather on activity. In such conditions one rat usually becomes more socially dominant than other rats (Barnett, 1958; Lott, 1984). Home range refers to the total space occupied by the individual rat as it engages in its various activities from day to day (Calhoun, 1962).

Wild female rats may rear their young singly or collectively (Schultz and Lore, 1993). There is usually a burrow of several females each with a separate chamber. Generally, a group of several females, a few adult males and many sub adult offspring are called breeding demes.

Mating system

The mating system of the rat is influenced by the social system and population density. The mating system is polygynous at low population density where one male mates with more than one female. On the other hand, it is polygynandrous at high population density. In this case, multiple males mate with multiple females within the group. Group mating rarely leads to conception because it is stressful for the females and the mating intervals are short (Matthews and Alder, 1977; Moore, 1999). Moreover, the low possibility of conception in group mating may be a cause for a limited overall population size (Nowak, 1991).

Food habits

Brown rats are excellent foragers and are able to survive quite easily as long as there is a steady supply of any type of food and water. They particularly make use of their sense of smell and touch to locate food. In urban areas, they survive mainly on discarded human food, and anything else that can be eaten without any negative implications. Examination of a wild brown rat's stomach in Germany revealed 4000 items, mostly plants although studies have shown that brown rats prefer meat when given the option (Nowak and Paradiso, 1983). It has been reported that brown rats readily adapt their feeding habits to different structural conditions in the environment (Klemann and Pelz, 2006).

Rats' sense organs

The range of the rat's hearing is between 20Hz and 76,000Hz; therefore, rats can hear ultrasound (Fay, 1988). Rats make long vocalisation when they are happy or distressed. These sounds are made when they see a predator (Blanchard et al., 1991) or experience pain (Cuomo, 1988). Very high pitched sounds can also be made by young rats to elicit maternal care and also to avoid being stepped on roughly by their mothers (Allin and Banks, 1971; Carden and Hofer, 1992). Short high pitched calls can also be made in positive situations such as when feeding is anticipated or play is ongoing (Burgdof and Panksepp, 2001).

There is an interaction between the social system and feeding behaviour of the rat, called social learning. For instance, young rats will eat only food that adults in the colony have learned to eat and eventually prefer this diet (Galef, 2001). It is also learned that a food that makes a rat ill may be poisonous and dangerous in the future and therefore avoided (Garcia et al., 1974).

Although rats are generally believed to be colour blind, they have two classes of cones, a short blue ultra violet sensitive photopigment and the middle green cones, which contain a pigment that is maximally sensitive in the middle wavelength of the visible spectrum (Jacobs et al., 2001). Rats do not have long wavelength red cones and therefore cannot visualise red colour but they are able to see ultraviolet colours (Jacobs et al., 2001).

Rats can detect odour with the nose and also with the vomeronasal organ (Agosta, 1992). The selection of food is also made possible by the use of the olfactory organs. The vomeronasal organ is reported to be suitable for detecting pheromones and other urine secretions (Brennan, 2001). It has been established that the vomeronasal organ is very useful for communication in animals (Bradbury and Vehrencamp, 1998). For instance, male rats have been known to display penile erections and associated behaviour indicative of sexual arousal, an experiment was conducted to determine the effective stimuli for these non contact erections and results show that receptive female rats broadcast a volatile pheromone that evoke erection (Sachs, 1997). Furthermore, rats always respond to human odour and it seems probable that in many situations wild rats may avoid objects that have recently been handled by man (Taylor et al., 1974). A study has been made by Howard and Marsh (1970) on the use of olfaction in rodent control, indicating that an attractive odour will increase the chances that most wild rodents will locate a bait carrying the odour, but the authors could not ascertain whether wild rats can be conditioned to associate an exotic odour with a palatable bait.

Rats and diseases

The Norway rat is a pest to the domestic animal and human population. Wild rats trapped from 11 farms in the United Kingdom were found to carry numerous zoonotic pathogens often at high prevalence (Webster and Macdonald, 1995). The result of a series of studies on leptospirosis and other zoonoses, investigated using a variety of serological and parasitological techniques on trapped wild brown rats from different farms, reveals that parasites that can cause diseases in humans and livestock like cryptosporidiosis, Q fever, salmonelosis, babesiosis, listeriosis, yersiniosis, toxoplasmosis, helminthosis, pasteurellosis and viral infections like hantan-fever, were all detected (Webster and Macdonald, 1995). A study was also carried out to detect helminths in wild rats in Korea (Seong et al., 1995). More recently, the parasitological survey of wild rats in Croatia was also investigated (Stojcevic et al., 2004). Wild rat is a significant vector of Cryptosporidium parvum (Quy et al., 1999) and the zoonotic potential of gastrointestinal helminths infected rats in Jamaica, has been recently evaluated and nine species of gastrointestinal helminths were recovered (Waugh et al., 2006)

Wild rats are obvious reservoirs of various infectious diseases in livestock including pigs. Dubey (1995) examined the sources and reservoir of toxoplasma gondii infection on 47 swine farms in Illinois and concluded that all farms had the evidence of toxoplasma gondii infection either by antibody detection in swine or by oocyst detection or by recovery from rodents through bioassay. Nonetheless, it has been shown that the wild brown rat in Croatia is not a reservoir of *Trichinela spiralis* in pigs (Hanbury et al., 1986) but rather trichinellosis infected rats are victims of improper pig slaughtering (Stojcevic et al., 2004). The evidence of *Brachyspira hyodysenteriae* which causes swine dysentery, in wild rodents was detected after investigating 41 rats (Joens and Kinyon,1982) from pig farms, and finding identical strains of *B. hyodysenteriae* in mice and pigs on another pig farm suggests that wild rodents may be carriers of the organism affecting pigs (Fellström et al., 2004)

Radio telemetry

Telemetry generally refers to a variety of techniques associated with obtaining biologically related remote measurements at a distance from the subjects of measurements (Cochran, 1980). These techniques have developed over 2 decades from the use of radio tracking to passive integrated transponders (PIT tagging) which has been used on rats by Klemann and Pelz (2005), and quite recently, the satellite based global positioning system (GPS) has been developed. Records show that the first successful and meaningful long term animal tracking via satellite occurred in 1977-78 when three polar bears were tracked (Cochran, 1980). The smallest GPS collar built so far is about 40g (Blue sky telemetry™, Scotland) which makes it too heavy for use on wild rats.

Radio tracking

This tracking method presents as a technique suited for radio transmission and reception. It is also known as radio location telemetry. The radio tracking system usually comprises of a radio tag, transmitting antennae, a receiving antennae and a receiving equipment. This technique is very useful in wild life telemetry and can been classified into wide band and narrow band systems (Cochran, 1980). It has been used for tracking rats to determine long distance movements (Taylor and Quy, 1978) and also in a study on the biology of brown rats (Recht, 1988) and also used for bait avoidance studies on black rats (Leung and Clark, 2005).

Practically, narrow band is said to allow for the use of radio tags which have size, longevity and range characteristics suitable for the study of free-ranging animals, whereas wide band system does not. The wide band technique is most commonly used in obtaining physiological measurements. Kjos and Cochran (1970) used recorders to obtain indices of activity based on signal changes (Cochran, 1980). It is known that slight movements of the transmitter mounted animal usually cause a change in the amplitude or frequency of the received signal so by listening to the signal, it is possible to know when the animal is moving. However, movement induced signal changes are often complex because, to find a simple direction, the interpretation of the signal changes is a function of the rotation of a directional receiving antenna which may be difficult for an inexperienced operator (Cochran and Lord, 1963; Cochran, 1980).

The radio racking system has been used in studies on long distance movement of rats (Taylor and Quy, 1978), biology of domestic rats (Recht, 1988) and the ecological perspectives on the management of rodents (Cowan et al., 2003).

Wild rat control

Rodent control is the reduction or regulation of the population of destructive or dangerous rodents through chemical, biological or other means. The three widely used methods for rodent control are the use of snap traps, ensuring a structurally sound barrier and application of chemical substances. Deratisation activities are usually geared towards reducing the population of rats or achieving total elimination. Control programmes have been effective against the hazards of epidemic plague in the United States and other developed countries. Moreover these programmes have evolved over a long period of time and are now accompanied by improved control technology and sanitation standards (Barns, 1978). These tasks involve the research and development of several eradication techniques and have become inevitable because of the need to sustain the health of livestock and humans (Quy et al., 1992; Endepols et al., 2003; Leung and Clark, 2005; Klemann and Pelz, 2005).

Rodenticides

Rodenticides are chemical substances that can be used to kill rodents. These substances can be presented in three forms; as baits, as tracking powders and as fumigants. Anticoagulant compounds which are derivatives of either 4-hydroxycoumarin (e.g., warfarin, bromadiolone, brodifacoum) or indane-1, 3-dione (e.g., diphacinone, chlorophacinone) were introduced over 50 years ago (Pelz et al., 2005). However, the resistance to warfarin and diphacinone anticoagulants in brown rats was first reported in 1958 (Boyle, 1960). The initial reports were from Europe but resistance in wild rodents have now become a worldwide phenomenon (Kerins et al. 2001; Lodal, 2001; Pelz 2001, Pelz et al., 2005). Mutations in the VKORC1 gene coding for the vitamin k oxide reductase is today believed to be the basic mechanism of anticoagulant resistance in laboratory and wild rodents (Pelz et al., 2005)

Figure 1: Anaesthetic recovered rat with transmitter (brass collar) around the neck.

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INTRODUCTION TO RESEARCH REPORT

Several studies have shown that Brown rats (*Rattus norvegicus*) are carriers of infectious organisms that cause diseases in both humans and domestic animals (Webster and Macdonald, 1995; Hilton et al., 2002; Mikkonen et al., 2005). The brown rat lives wherever humans live and also where there is constant supply of food (Meyers and Armitage, 2004). Therefore, apart from human habitations farm buildings are not left out regarding the activity of the brown rat. A recent study by Leung and Clark (2005) showed that the presence of rat activity on a pig farm was due to availability of food and possible hide outs on the farm. Pigs are therefore not an exception to the possibility of infection by diseases carried by wild rats. Archer (1992) stated that experimentation, photography and filming can be of good use in observing animal behaviour at the species level. Thus, video recording equipment has been used in recent past for the study of rat feeding behaviour (Brunton, 1995; Klemann and Pelz, 2005). There has also been an extensive use of radio tracking to determine various aspects of the behaviour of wild rodents (Taylor and Quy, 1978; Recht, 1988; Cox et al., 2000; Leung and Clark, 2005). Warfarin anticoagulants have been used for rodent control for over 50 years (Pelz et al., 2005). Pigs are known to be very sensitive to anticoagulants. For instance, coumatetralyl poisoning in pigs was reported by Dobson (1973). In view of the known history of massive invasion of brown rats in a particular pig herd, and the possibility of observing rat behaviour using telemetry and video recordings, we therefore hypothesise that an increased knowledge on the behaviour of wild rats within this pig herd will improve risk assessment regarding transmission of infectious agents to pigs. It will also provide valuable information for obtaining efficient rodent control on a pig farm.

The aims of the present study were as follows:

- To increase the knowledge of wild rat behaviour on a particular pig farm with history of repeated heavy infestation of rats, by studying their path preference, movement pattern and activity pattern.
- To understand the choice of bait preferred by wild rats.

RESEARCH REPORT

A study on wild rat behaviour and control on a pig farm.

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ABSTRACT

Wild rodents are known to be carriers of pathogenic organisms that affect both humans and domestic animals. In this study, two rats were followed by radio tracking method for an aggregate period of 24 hours each to determine their territories, path preferences and activity levels. In addition, a video recording equipment with two cameras positioned at different locations along a pathway was used. Recordings of rat activities for 5 days were made and used to evaluate the general behaviour of wild rats around live traps and around an accessible pig pen. A bait preference study was carried out in 8 successive days of 24 hours each and pig feed was used as a control feed because of its abundance in the pig house. This was compared with four different test baits i.e. peanut butter, caviar, wax block plus walnut oil and pig feed plus walnut oil. The activity pattern in 24 hours was estimated from the bait preference study.

A territory of approximately 500 m^2 was recorded, as well as a path preference from the home site through the accessible burrows into the pig house. Rats also moved from the drainage system into pig pens. Furthermore, the frequent movement of rats to and from a pig pen via a low fence situated directly opposite an exit burrow was recorded. There was an evidence of pig feed plus walnut oil having the highest test bait acceptance value, followed by peanut butter, wax blocks plus walnut oil and caviar, respectively. The pattern of feeding activity estimated, showed an onset of activity after dusk which increased until about 9 pm. This was followed by a rise in activity level until it reached a peak between 3 and 4 am. Thereafter the activity level dropped steadily.

In conclusion, this study agrees with previous studies on the behaviour of the wild brown rat. The results suggest that the path preferences should be a vital part of bait positioning during rodent control programmes. Wild rats should be considered to be disease risk factors to pigs whose pens they visit. Construction and maintenance of functional barriers will enhance rodent control and limit poisoning in domestic animals living on the farm. Ideally, pig feed should be adopted as the choice of base for poisoned bait on a pig farm.

Key words: Wild brown rats, activity, pig pens, bait, radio tracking, control.

INTRODUCTION

One important vector of human and livestock diseases is the wild brown rat. The brown rat (*Rattus norvegicus*) is a species of the muridae family in the class, mammalia (Nowak, 1991). The destructive behaviour of rats has always proven to be sources of continued menace to the public. Furthermore, their role as carriers of parasites and other infectious organisms that affect humans and animals makes them unwanted (Joens and Kinyon, 1982; Webster and Macdonald, 1995; Stojcevic et al., 2004).

As with all types of farm buildings and other human habitations, a pig farm is not an exception regarding activity of wild rats because of the availability of food and possible hide outs (Leung and Clark, 2005). Henceforth, pigs are not an exception to the possibility of infection by diseases carried by wild rats. There is an ongoing extensive study at the Swedish University of Agricultural Science, Uppsala, Sweden, on the effects of wild rats as reservoirs of pathogenic organisms in pigs.

The behaviour of an animal is the action and reaction of an organism, relative to the internal and external conditions of the environment where the animal exists. Instinctive or natural behaviour occur in all members of the same species in a specified environment, therefore experimentation, photography and filming can be of good use in observing animal behaviour at the species level (Archer, 1992). Thus, video recording equipment has been used in recent past for the study of rat feeding behaviour (Brunton, 1995; Klemann and Pelz, 2005). There has been an extensive use of radio tracking to determine various aspects of the behaviour of wild rodents (Sanderson and Sanderson, 1964; Taylor and Quy, 1978; Recht, 1988; Cox et al., 2000; Leung and Clark, 2005). Food supply and other habitat factors can cause changes in rat behaviour (Berdoy and Macdonald, 1991), relative to the food choice (Klemann and Pelz, 2005). Thus, the success of control operations can be affected by bait uptake (Quy et al., 1992b).

Warfarin anticoagulants have been used for rodent control for over 50 years (Pelz et al., 2005). Nonetheless the status of warfarin resistance in wild rodents worldwide is alarming. There is a recent identification of a protein of the vitamin k oxide reductase (VKOR) complex, a complex repressed by warfarin compounds leading to inhibition of the blood coagulation (Pelz et al., 2005). This protein is named VKORC1 (Rost et al., 2004) and the eight mutations in this gene observed by Pelz et al. (2005) in both resistant laboratory strains and wild brown rat from various parts of Europe, indicate that such mutations could be the genetic bases for anticoagulant resistance.

In view of the known effect of wild rats as reservoirs of disease causing agents in pigs, and the possibility of observing animal behaviour, we therefore hypothesise that an increased knowledge on the behaviour of wild rats within a pig herd will improve risk assessment regarding transmission of infectious agents to pigs. Furthermore, increasing our knowledge of rat behaviour in various environments is valuable for obtaining an efficient rodent control. Since pigs are very sensitive to anticoagulants and since the use of anticoagulants on a long term basis may result in anticoagulant resistance, other alternatives for rodent control in pig farms may be needed.

Therefore, the objectives of this study were to obtain information on the territory, home site, path preferences, movement pattern and the activity pattern of wild rats on a pig farm with a known history of repeated massive rodent invasions. A particular objective was to see if rats actually entered pig pens occupied by pigs. This knowledge would further assist rodent control institutions to optimise rodent control strategies. Furthermore, we sought to determine the choice of bait preferred by the wild rat on a pig farm in order to maximise poisoned bait acceptance.

MATERIALS AND METHODS

A commercial pig farm in Sweden was chosen and used for this study. This farm was selected because of the history of massive rodent infestation and reinfestation despite applied control measures. The pig farm consisted of three pig houses, a feed mill and feed store, a machine room and a workshop. A detailed map of the pig farm and that of the selected pig house can be seen in Figures 1 and 2. Only one of the pig houses was used in this study. This was because of obvious signs of very old and recent rodent activities in this pig house in form of rat tracks, and presence of rat feaces. The 2-year eradication programme history was retrieved from the farm records (table 1) and analysed.

The trials on laboratory and wild rats were approved by the Ethical Committee for Animal Experiments, Uppsala, Sweden.

Table 1: A record of rodenticide administration on the studied pig farm during 3 years

Date	**Types of rodenticides used**	**Location**
12th April 2005	Difenacoum, Bromadiolon wax block	Entire farm
	Racumin Powder	Pig house
12th May 2005	Difenacoum, Bromadiolon wax block	Entire farm
	Racumin powder	Pig house
14th June 2005	Bromadiolon	Pig house
7th Oct 2005	Difenacoum	Entire farm
	Bromadiolon wax block	Outside
9th Oct 2006	Difenacoum, Bromadiolone	Entire farm
	Racumin powder	Pig house
31st Jan 2007	Racumin powder	Feedmill and outside
	Racumin powder, Difenacoum	Machine room
22ndMar 2007	Difenacoum	Entire farm

Radio tracking

A complete radio tracking equipment which consisted of a radio signal receiver (A11-0200 SE) and a directional, hand-held antenna (Y-4FL 151-153MHZ), was used for the radio tracking studies. Three radio transmitters (brass collars) each weighing 8.5 g, (Biotrack Ltd UK) were used. The transmitting frequencies for each of the three collars were 151:104, 151:126 and 151:116, respectively. By specification, they were expected to give signals at a range of up to 80-300m. The collars included the TW-4 transmitter with activity sensors. They were made of separate oscillator and amplifier/antenna matching circuit. They also had an independent pulse-forming circuit and built from some of the smallest surface mount components available (Bio track Ltd UK). The radio tags provided signals at a range of 20 m maximum when tested with receiving equipment within an enclosed environment, in this case, the pig house and up to 30 m in the open field.

At the onset of this trial, it was indicated that the rat population was zero or close to zero as there were no rat tracks within and around the pig houses and feed mill. Five opened live traps containing peanut butter and flour were used to establish the presence of rats on the farm. Four were placed in the farm house (Fig. 2) and one in the feed mill. The flour was spread on the floor around the live traps to observe rat tracks. In addition, the pig house and feed mill were naturally covered with dust originating from the pigs which made it possible to observe all rat tracks on all surfaces. The process of establishing presence of rats was carried out for a period of 5 months (February to June 2007) with regular checks, made at least once a week before the rats appeared to be continuously present. The onset of rat trapping was determined by the evidence of rat tracks within or close to the pig house. There were no indications of rat activity anywhere else on the farm throughout the studies. Approximately, five rats were present at the onset of the studies in June 2007 and the number of rats increased to approximately twenty five at the end of all the trials in October 2007. Rat trap cage model L16 (Allan Ahlgren AB) was used for these experiments. Trapping was carried out by setting live traps at strategic locations within the pig house. In addition, fifteen rats were snap-trapped at the end of the studies.

In total, three rats were caught and used for the tracking experiments. The first rat weighing 200 g was caught in the pig house 7 days after their presence was established, which was 3 days after the live trap was set. The sex of the caught rat was not recorded due to unexpected technical problems. The caught rat was then transported and anaesthetised in an anaesthetic chamber. 2 ml of Isoflurane (Schering-Plough Animal Health) in a 5 litre capacity chamber which is approximately 4% of Isoflurane was used. The rat lost its reflexes about 4 minutes after administering Isoflurane and immediately a radio transmitting collar of 151:104 frequency was fit around the neck of the rat. The rat was thereafter quickly transferred back into the live trap with adequate insulation for anaesthetic recovery and eventually released at the trapping spot. It took about 30 min to attain complete recovery and to check that the collar was well fitted and that the rat coped well with it. This technique was initially tested on laboratory rats to optimise the use of the equipments and animal handling for anaesthetic and collar application.

Tracking commenced 24 hours later and was done over a period of five days. The rat could not be followed afterwards due to loss of signal. An accumulated period of 24 hours tracking was achieved during these days and location fixes on the pig farm were determined (fig 2). For the second and third trials, the same procedures of trapping, collar application and tracking were carried out 4 and 6 weeks respectively after the first trial. The second rat was a male weighing 400 g while the third rat was a female weighing 250 g. The signal from the second rat was never recovered and therefore, in the third trial, the rat was followed immediately after its release in order to avoid the loss of signal.

Video equipment

Video recording equipment that consisted of two infra red cameras, additional red bulbs connected to a power source, connecting cables and a computer was used for the video recording trials. The recording was done on Real Time with the use of a digital video recording software (iGuard version 2.57 GmbH).

General behaviour study

Two separate studies were performed using the video equipment to record rat activity in a natural environment. The first study which involved recording of the general behaviour of the wild rat was done by fitting the two cameras on the wall of the pig house at selected locations tagged location 01 and 02, respectively. This was done in order to view and record night and day activities of the rats for 5 days around a pig pen and around live traps. The recordings were carried out for 24 hours each day, along a dark, dusty and sandy pathway, located beside and along the entire distance of a row of pig pens in the pig house (fig 2).

This favoured path for the rat activity was selected for these recordings based on results from the radio tracking study and since there had been earlier observation of the presence of fresh rat feaces at different positions, active rat burrows and rat tracks in the live traps that were placed along this path. Camera 01 was mounted in order to obtain a view of rat activity around a pig pen and around the possible exit burrows. Notes were made on the activity level, the movement pattern and the path preferences. During this experiment the back door of the trap was opened. The rat activity was defined solely as the presence of rat within a camera view.

Bait preference and activity pattern

Four different food types that could be used as baits were used in this study. Dry pig feed was used as the control bait while peanut butter, caviar and wax blocks plus walnut oil (vanilla scent) were used as the test baits (fig 3). The rats were already familiar with peanut butter because it had been presented as feed in the live traps for about 6 months before the trial started. The baits were presented to the rats by filling up small bowls with the baits. The bowls were firmly attached to the inside of the live traps to avoid being overturned. The traps were labelled numbers 1-4, respectively. An infra red camera, already mounted at location 02 (fig 2) was employed for viewing. Recordings were made in real time, with the *i*guard software.

Two live traps, one containing pig feed and a second with the test bait, were placed side by side and in opposite directions, at the viewing site (fig 4) and recorded for 24 hours. The direction and position of the traps were interchanged, and the food containers refilled, after the first 24 hours. Thus, sufficient food was provided to the rats. The feeding activity was then recorded for another 24 hours. This procedure was carried out on the three test baits for 6 consecutive days, 2 days per trial. An additional trial was done by presenting pig feed as the control feed and pig feed plus walnut oil (vanilla scent) as the test baits. The same pattern of arrangement as with the other test baits were followed on days 7 and 8. New pair of gloves was used on each day when touching the traps or the food in the traps in order to eliminate neophobia.

The preferred bait was determined from this study, by estimating the average time of feeding in seconds per trial. The time of feeding was considered to be the time the rats were viewed to have been performing the actual act of eating excluding the time spent moving or playing around the feed bowls. The presented feeds were not completely eaten by the rats during the experiments except on one occasion. The test bait acceptance was calculated by using a modification of the EPPO (1982) guideline, Eq (1). Test bait acceptance value of 0.5 indicated equal acceptance to the standard bait (Klemann and Pelz, 2005).

$$\text{Test bait acceptance} = \frac{\text{Total time on test bait (sec)}}{\text{Total time on standard bait (sec)} + \text{Total time on test bait (sec)}}$$

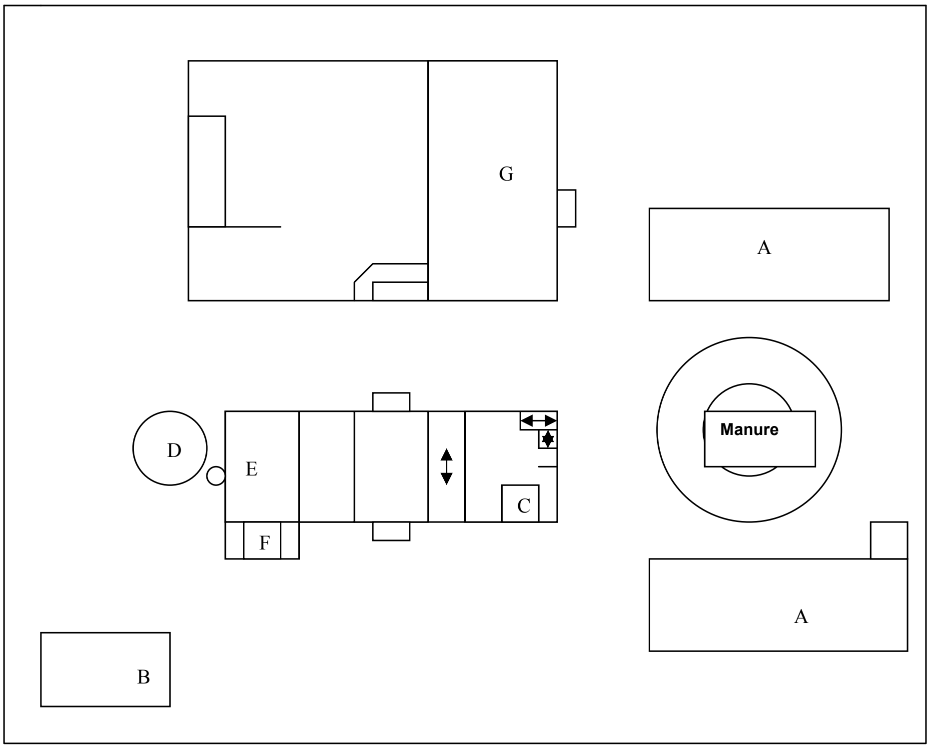

Figure 1. Map showing the buildings on the pig farm. A- Pig houses, B- Machine room, C- Feed mill, D- Feed store, E- Grains, F-Office and G- Pig house studied.

Activity pattern

The 24 hour activity pattern of the rats over the 8 day trial period was also estimated from the preference studies. The aggregate time of feeding activity was estimated for every hour of the day.

Statistics

The Mixed Procedure Model with the SAS system was used to analyse the effect of Time of day on the time of activity. $P<0.05$ was considered to be statistically significant. The differences of Least square means of the different times of the day were also analysed with The Mixed Procedure Model. $P<0.05$ values were considered to be statistically significant.

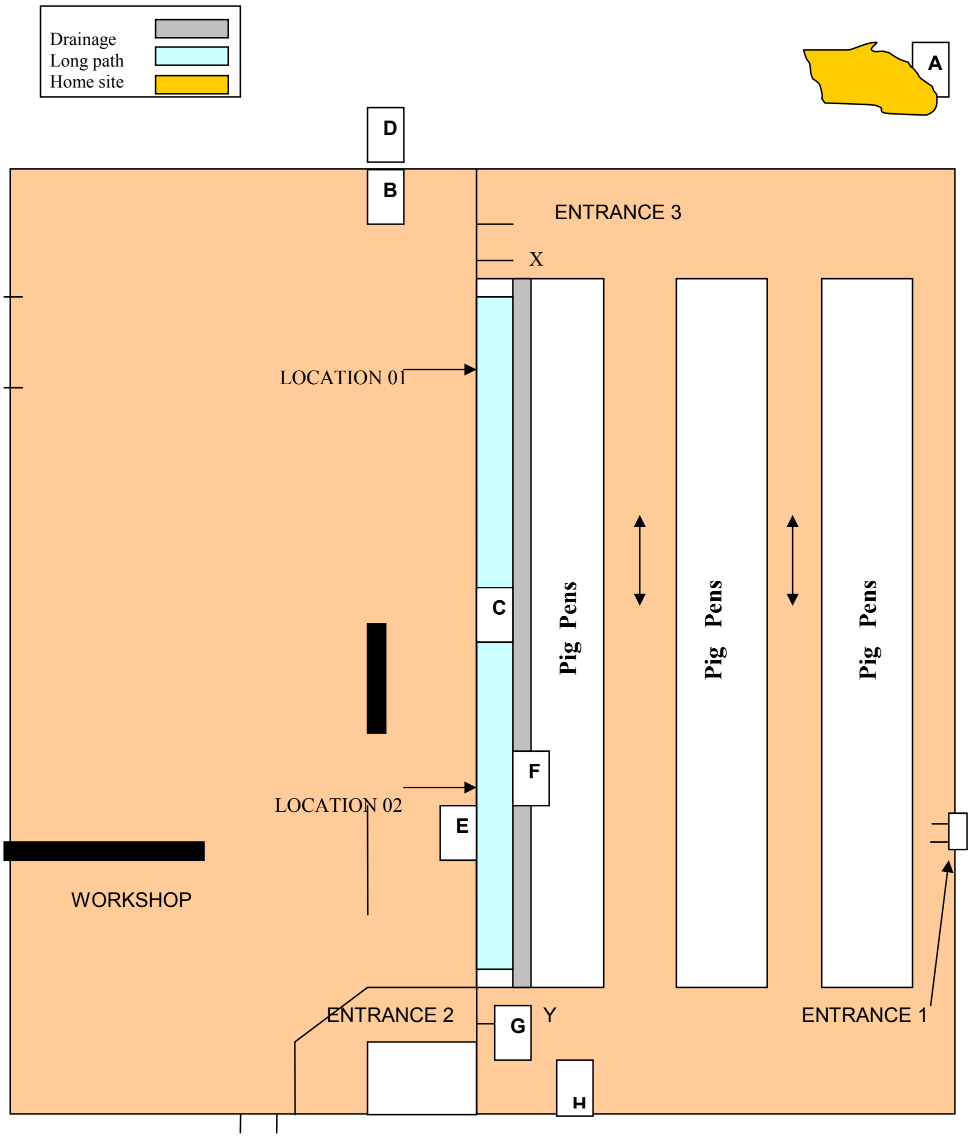

Figure 2. Map of pig house showing the locations A-D of the first tagged rat and E-H of the second rat during tracking. Points X and Y are drainage openings and locations 01 and 02 are camera locations for recording of general behaviour.

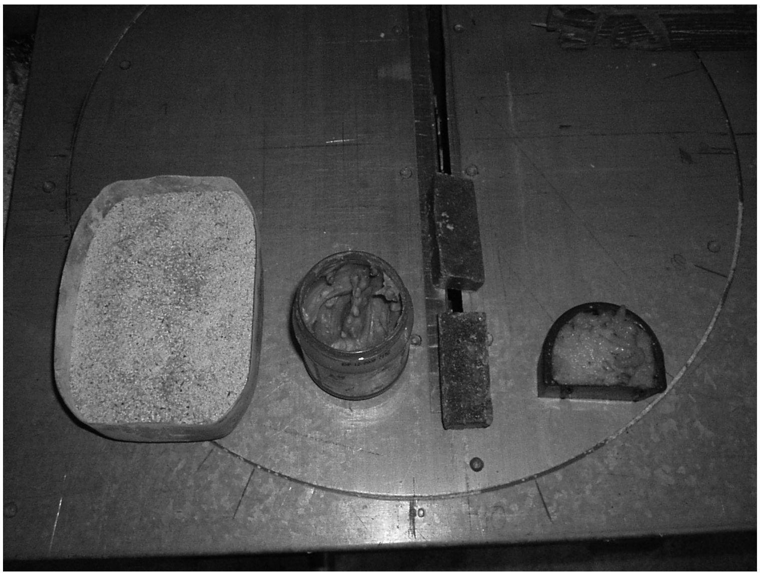

Figure 3: Bait types (From left to right; pig feed, peanut butter, wax blocks, caviar)

Figure 4: The positioning of the live traps

RESULTS

Radio tracking

The first day of tracking which took place in the afternoon, yielded no signals within the pig house, the workshop and around the entire farm. Radio signal was received from the first tagged rat in the morning, before noon, on the second day of tracking. The rat was located at the back of the pig house called point A (fig 2), within a large pile of rocks and was surrounded by several old and active burrows. The rat was positioned at this location throughout the tracking session. The distance from the rat to the tracking point was about 15-20 m and tracking points were located by triangulation. The position of the rat after midnight, on the third tracking day, was at a location close to one of the entrances into the pig house (point B). Signal was received from this area for about 30 minutes. The next location of signal was at an area along the long path (fig 2) between the wall of the pig house and a row of pens (point C). About 40 minutes of signal was continuously received from this area. Thereafter, the signal was lost but later found coming from point B for a few minutes. The rat was back at point A and stayed there until the end of the tracking session, before dawn. Tracking sessions were carried out during 3 to 6 hours at each radio tracking occasion.

A fourth tracking session was carried out on the evening of the third tracking day but this was disrupted by heavy rainfall. During this session, the rat was located within the pile of rocks behind the pig house throughout the tracking time. After dusk, at the onset of the fifth tracking session, on the fourth tracking day, the rat was located at site A up until about 2 hours before midnight. Thereafter, the rat was located at an area D close to location B, but still outside the pig house. The rat remained at this location until the end of the tracking period, about midnight. The tracking session, on the fifth tracking day which was carried out after dawn until mid morning, indicated the location of the rat to be at location A and this location was unchanged throughout the tracking period. Subsequent attempts to continue tracking of the first rat after four weeks were not successful as no signal was received. The second tagged rat could not be tracked at any time also because there was no signal from the radio tagged rat despite a search for signals for 2 weeks.

The third tagged rat was successfully followed, immediately after release. Signals received during the afternoon showed that the rat was located in the workshop area, point E, behind the wall that separates the pig house and the workshop. On observation, active burrows were found in this area and holes made in the straws kept in this area. After midnight, the rat was located at an area, point F along the drainage and about 2 hours later at another area, point G close to entrance 2. The movements of rats were observed with a torch during this tracking time. Rats were seen moving in and out of the feeding troughs along the pens and also across open floor. They were also seen moving in and out of the drainage from the opening at both ends of the drainage, labelled openings X & Y (fig 2). Early in the morning, after dawn, signal was received from the area, point F and later at points G and H. After about 3 hours, signal was lost completely and was not found thereafter. Attempt to locate the rat around the pig farm for another 3 weeks proved abortive.

General behaviour

The observed behaviour from location 01 (fig 2), revealed a high level of activity around the pig pen during the 5 days of recording. The rats moved in and out of the exit burrows at random intervals. They moved both to and from the dusty path and also climbed onto the fence of the pen. They either made their way down into the drainage X, on the floor of the pen or back towards the exit burrows. On some occasions they went in or from the direction of the pen and they sometimes made cautious movements within the pen as seen in fig 5.

The rats moved in and out of the burrows which were situated close to the live traps. The rats usually moved slowly out of the holes and sometimes made a quick dash especially when they were chased by another rat. Movements were usually made freely on open surfaces although thigmotaxis was exhibited in some instances. The rats' activities when there was food supply mostly comprised of feeding and movement around the traps but when the rats had little or no food supply, the activities mostly displayed included running across the viewing area while they ignored the live traps except for very few and short visits made at long intervals.

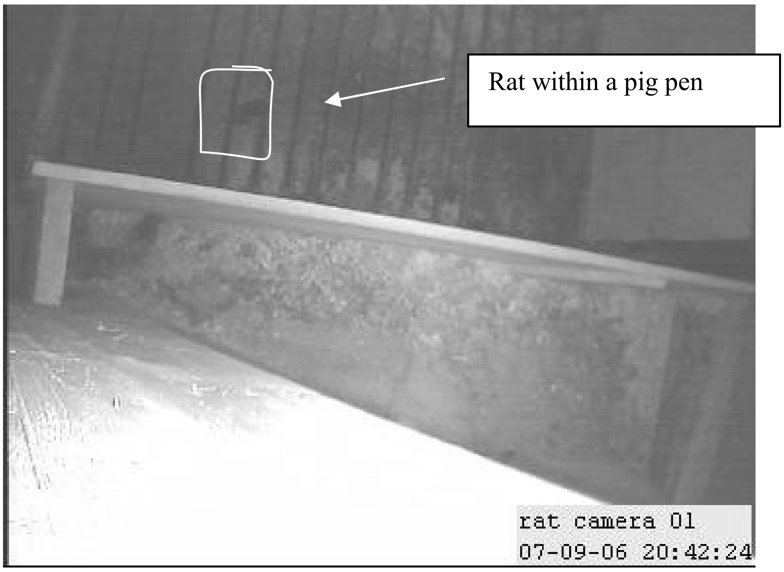

Figure 5: A rat found within a pig pen

Bait preference and activity pattern

The outcome of the bait preference trial is shown in fig 6. PFW (dry pig feed plus walnut oil) was best accepted against the control feed PF (dry pig feed), compared to the other feed types PN (peanut butter), CA (caviar) and BW (wax block plus walnut oil). The test bait acceptance measurements (Table 2) show that test bait PFW has the highest value of 0.4, followed by test baits PN, BW and CA respectively. The number of rats during this trial was estimated to be approximately 25.

Table 2: No. of visits, total and average time spent over 24 hours and the calculated test bait acceptance.

No of visits	Total time(sec)	Average time per visit(sec)	Test bait acceptance
PF 30 PN 16	3199 810	106.6 50.6	0.2
PF 76 CA 14	13484 672	177.4 48	0.05
PF 110 BW 82	24648 2423	224 29.5	0.09
PF 108 PFW 84	21653 12368	289.3 147.2	0.4

PF- Dry pig feed BW- Wax bait plus walnut oil CA- Caviar
PN- Peanut butter PFW- Pig feed plus walnut oil (vanilla scent)

The results of the 24 hour activity pattern estimated over eight days are shown in fig 7. The effect of the time of the day on the activity time was significant ($P<0.05$). The time of rat activity increased gradually after dusk, dropped considerably between 9 and 10 pm but continued to increase again until it reached the highest peak 3 to 4 hours after midnight. Thereafter there was a sharp decline in activity within 3 hours at dawn. The differences of least square means of time of the day showed that the increase in activity after dusk, between 5 pm and 8 pm was significant ($P<0.05$) but the reduction in the time of activity after 9 pm was not significant ($P>0.05$). Furthermore, both the increase in activity after midnight and eventual decrease from 4 am until 6 am were significant ($P<0.05$).

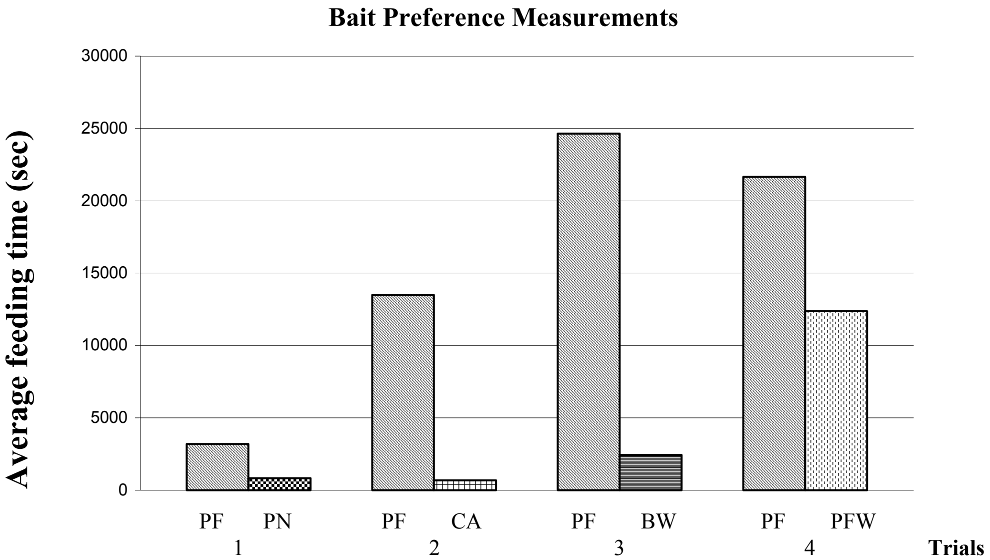

Figure 6: Bait preference results estimated as total time (sec) spent by rats at each bait station. PF-Pig feed; PN- Peanut butter; CA- Caviar, BW- wax bait + walnut oil; PFW- Pig feed + walnut oil.

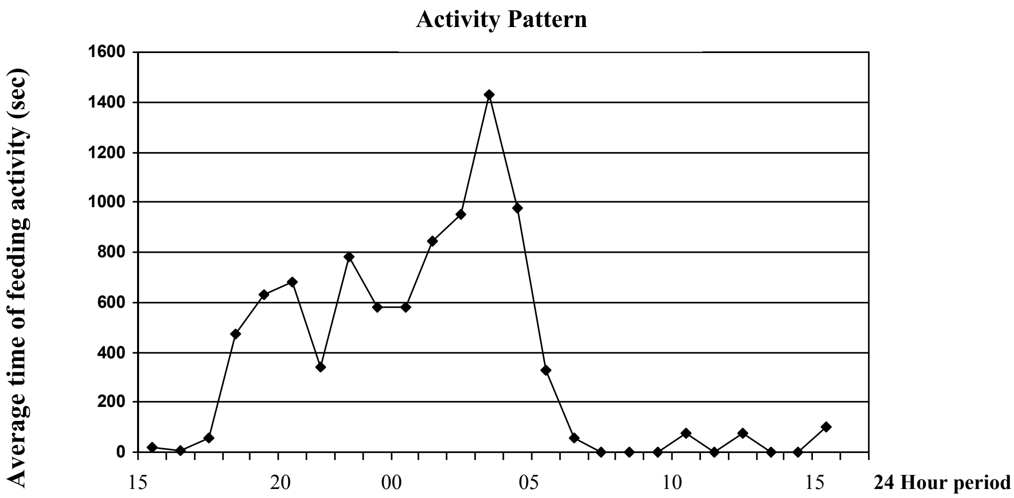

Figure 7: Chart showing the 24 hour feeding activity pattern of rats estimated over 8 days.

DISCUSSION

All results from the radio tracking studies should be interpreted with great caution due to the limited number of observations and the lack of knowledge of the sex of the rats. Nevertheless, the recorded signal of the first radio tagged rat reveal that site A, probably was the home site of this rat. This is evidenced by the length of time the rat occupied this site during the daytime tracking period. The home site was surrounded at the edges by both dead and live burrows as previously described (Recht, 1988). These burrows act as exit burrows for the rats and several burrows were also found at site B and at the edges of the sandy pathway. These provided easy access for the rats into the specific pathway within the pig house. The easy access was a possible factor that determined the choice of movement area. Furthermore, the use of an extensive and specific movement pathway was also recorded in the work of Recht (1988) as a social behaviour where rats have made individual movement of up to 100-300 m in a single pathway.

Continued tracking of the first rat and tracking of the second rat were not possible due to loss of signal. The reasons for the loss of signal are uncertain but might be due to loss of the transmitting collar, a failing battery (Cowan et al., 2003), long distance movement of the rats (Taylor and Quy, 1978; Hardy and Taylor, 1980) or death. The third radio tagged rat did not reveal a specific home site probably because of the short time of tracking but the location (E) of the rat after its release from the site of capture, was surrounded by burrows which served as exit channels out of the pig house. Furthermore, it was observed that the openings of the drainage upon which a row of pens were situated, served as exit and entry points for the rats' movement directly into the pen. Movement of rats in and out of feeding troughs along the first and second row of pens closest to the pathway were observed during a tracking night but these movements were not noticed along other pens.

The outcome of the radio tracking indicated a territory with a size of about 500 m^2 for one of the rats. This was an estimate of the area covered by the location points recorded. The mean observed home range, which is typically larger than territories, of 11 rats tracked within and around farm buildings for a period of 3 months was reported to be about 2000 m^2 by Cowan et al., 2003. Due to technical difficulties encountered and signal loss, we decided not to proceed with the tracking experiments. Nonetheless, the territory observed in this study and the movement pattern with respect to accessory burrows and path preferences within the pig house could be of great help in enhancing rodent control at least in this particular pig herd. Knowledge of individual rat's movement pattern, and distance covered may be essential (Taylor and Quy, 1978). For instance rats with home ranges larger than the size of the treated area may not have enough access to bait thereby reducing bait efficiency (Cowan et al., 2003).

Movements of rats to and from a pig pen as recorded by the video camera and observed movements during tracking nights are indications of the rats' path preferences. The observations made in this study clearly showed that rats do enter pig pens occupied by pigs. They would go into the pen in search of food as long as they have unhindered access. General observations indicated that pigs were asleep while the rats were in the pen. In these instances the rats seemed to be quite cautious with their activity within the pen, being careful not to call the attention of the pigs. Thus, the pigs within the pens visited by the rats could be at a risk of being infected by pathogens transmitted by rats. With the observations made during tracking and the video recordings, we can describe the activities of rats within the pig house to be centred on the constant availability of food source in accordance with Fenn et al, (1987). The removal of food source should improve rodent control; this is evidenced by a reduction in rat activities around live traps containing no food which was observed in this study. However, it will be quite an impossible task to eliminate accessible food sources such as feeding troughs within a pig house.

The maintenance of effective barriers around the pig house and pig pens should be considered as an important factor for efficient rodent control strategies. Effective barriers will reduce the need of chemical poisoning for rodent control thereby reducing the risk of domestic animal poisoning within a pig farm. In this study, the radio tracking which was carried out in June, showed the onset of rat activity around the home site and at the back of the pig house at about midnight, 1 hour before the presence of rat activity was registered in the pig house. In contrast, the 24 hour activity pattern obtained from video recording during the bait preference trials which was carried out in October, showed the onset of rat activity within the pig house as early as 6 pm with the highest peak of activity at about 4 am in the morning. The decline in activity about 9 pm is a probable indication of a resting period for the rats after an initial increase in feeding activity. Because of the variation in the time of decline during each of the 8 days, this decline could not be shown to be statistically significant.

Bait uptake has been demonstrated to play an important role in the success of rodent control (Quy et al., 1992). In a previous study on bait avoidance by black rats, Leung and Clark (2005) used cracked wheat, wax block, Racumin paste® and pig feed and the results showed poor bait acceptance which was caused by abundant feed supply in the piggery. In this study, pig feed was selected as a control feed for the bait preference studies because it was the most abundant, naturally available feed within the pig house. Neophobia was observed in the first trial and it reduced drastically on the second day of the first trial as evidence by the increase in feed intake. This suggests that the new objects used to present the feed in the live traps were the probable cause of neophobia but not the content of the containers since the rats were already familiar to pig feed and peanut butter.

The preference of pig feed over the other baits is an indication that feeding in wild rats is a learned behaviour. Rats seem to be consistent in their choice of feed once learned. Peanut butter, which was next preferred, had been used continuously as feed source in the live traps before the preference studies. This is a further proof that social learning is a strong factor in determining rat feeding behaviour (Galef, 2001) rather than feed attractiveness. Furthermore, since Quy et al (1996) showed that acceptance of palatable baits as tested in the laboratory did not provide effective rat control in farm treatments, it can be suggested that the preference of pig feed on this farm study was due to a learned behaviour and bait location rather than palatability.

The records of rodenticide administration and the observation that no rat activity was recorded for a period of almost 5 months (February to June) after a massive rodenticide treatment (table 1) indicated that rats colonizing this particular pig herd were sensitive to the rat poisons used. This observation was further supported by the fact that a mutation in the VKORC1 gene (Tyr139Cys), indicating warfarin resistance and commonly found in Denmark and Germany, was not observed in any of 20 rats caught at the farm before the start and at the end of the trials (data not shown). Nonetheless, repopulation of rats on this farm could be as a result of the metapopulation structures involving edge populations that may be found living in the surrounding vegetation or nearby farm buildings.

In conclusion, the results obtained from this study suggest that the territory and path preferences of rats in a pig herd should be used as an indication for positioning baits. The presence of rats within the pig pens and the frequency of visits suggest that wild rats could act as risk factors for transmission of pathogens to pigs within a pig house. The need for construction of effective barriers around a pig house and pig pens, good sanitation measures and avoiding structures and secure hiding places in the pig house that can serve as passage ways are highly recommended for effective rodent control. Lastly this study revealed that pig feed which is the most abundant feed in a pig herd should be preferred as a base for poisoned baits in order to improve rodent control.

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