A Study of Tuberculosis in Hedgehogs so as to Predict the Location of Tuberculous Possums.

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Abstract

Hedgehogs are spillover hosts for *Mycobacterium bovis*, which means the prevalence of disease in the hedgehog is directly related to the prevalence of disease in a local reservoir population such as the possum.

Possums have home ranges similar to that of hedgehogs and on large farms, locating a tuberculous hedgehog coud substantially reduce the area where extensive control is required to eliminate tuberculosis from the wild animal population. Male animals usually have a larger home range than females and this is true of the hedgehog. In utilising the knowledge of a hedgehog's home range, female hedgehogs could provide a specific local indicator of the presence of tuberculous possums and male hedgehogs could locate the general region on the farm with tuberculous possums.

The hedgehog could also be considered a temporal indicator of tuberculosis in the wild animal population especially where there has been a history of tuberculosis. The longevity of the hedgehog is reasonably short (2-3 years in the wild) and should sufficient control of other tuberculous animals occur then the disease will also disappear from the hedgehog population.

Hedgehogs from this study were noted to be carriers of *Salmonella enteriditis*, *Sarcoptes scabiei*. This is believed to be the first report of these pathogens associated with hedgehogs in New Zealand.

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Chapter 1

Introduction

Introduction

Mycobacterium bovis infection is considered endemic in some areas of New Zealand. In most of these areas the Australian brushtailed possum (*Trichosurus vulpecula*) appears to be the most important reservoir of infection. There is some evidence, which suggests that infection occurs in small clusters or hot spots, which may persist for years at the same location, possibly through possums infecting their progeny and other animals which den in the same vicinity. It is however, difficult to locate these hot spots, especially when clinically diseased animals have died and the subclinical cases have not yet developed clinical disease. Various approaches are being investigated to develop "hot spot predictors" to assist control efforts.

The hedgehog, although a common mammalian inhabitant of much of the New Zealand countryside and urban areas, has only recently been confirmed to be a host for *Mycobacterium bovis*,(3) due to apparently eating infected carcasses. *M. bovis* organisms have been noted to survive in carcasses for a short period of time.(4) Hedgehogs will eat almost any animal substance, including meat, bones, maggots as well as vegetation and arthropods. It seems likely that many hedgehogs in endemic areas will be exposed to *M. bovis* infection from the investigation of decomposing carcasses, especially of possums.

Hedgehogs have a home range similar to possums,(5) and the presence of tuberculous hedgehogs may be an indication of infected possums denning within the hedgehog's home range.

The complete spectrum of the pathology of tuberculosis in hedgehogs is unknown, however necrotic tissue associated with TB is often found in mesenteric lymph nodes and lungs.(3) Infection seems to occur mainly via the oral route as discussed above and excretion is not well understood. It is possible that organisms are excreted via urine, subsequent to kidney infection. Hedgehogs are known to leave urine trails as they wander across pasture.(1) Another behaviour shown by hedgehogs is self-anointing. This involves covering their spines with saliva in a frenzied motion. It has been reported that hedgehogs show this behaviour as a result of strong olfactory stimulation.(2, 5) It is not known if hedgehogs excrete *M. bovis* in saliva. In any case it is unlikely that hedgehogs would commonly excrete sufficient organisms to be infectious for other animals by either of these routes.

Current understanding of the ecology of hedgehogs suggests that they are a spillover host for tuberculosis in endemic areas of New Zealand. Lugton et al [3] suggest that in the absence of infectious food sources infection within a hedgehog population is unlikely to be self-maintaining. Thus if tuberculosis is detected in hedgehogs, it is likely that it demonstrates that infected carrion has been present within their home range.

This research described here involves a longitudinal field study in the Wairarapa district of New Zealand and a prevalence survey based on necropsy examination of hedgehogs from selected areas of New Zealand in relation to tuberculosis. *Salmonella enteriditis* infection and *Sarcoptes scabiei* infestation, which affect the hedgehog are also described.

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Chapter 2

A Review of the Literature

Introduction of the Hedgehog into New Zealand

The hedgehog (*Erinaceus europaeus*) is the only insectivore that has become naturalised in New Zealand. It was first introduced unsuccessfully in Canterbury in the 1870s. Several other attempts were made to import them from Britain but it was not until the 1890s that wild hedgehogs were discovered in Sawyers Bay, Dunedin.[(8)] The North Island became colonised around 1910.

Initially hedgehogs were introduced to remind expatriate British people of their home country, however later they were regarded as natural predators of garden slugs and snails and more importations were encouraged. Towards the end of the thirties a bounty was placed upon the hedgehog by the Acclimatisation Societies and Sporting organisations because it was believed that hedgehogs ate ground-nesting birds thus destroying the sport. A price of 3 pence was paid for each snout brought in and in 1940 this was raised to 6 pence. During 1939-1948; 53,647 snouts had been submitted for the bounty in the North Island alone.[(45)] Regardless of this bounty hedgehogs continued to expand into new areas of New Zealand and in the 1950s hedgehogs had colonised much of the North and South Islands, and had been introduced to Stuart, Chatham and Waiheke Islands.[(4)] Hedgehogs are abundant in lowland areas and farming country of New Zealand. They are less common in highland areas, dense bush, wetlands and mountainous terrain.

Nocturnal Activities and Territoriality

Hedgehogs are nocturnal animals and sightings during the day are most often animals in ill health. While it seems that hedgehogs ‘prefer’ to be nocturnal, certain pressures like food supply, lactation and disease may increase the level of activity. Reeve (1994)[(35)] noted a study in Russia where one lactating female hedgehog was active during most of the day and night.

Nightly activities include locomotion, foraging, pauses, courtship, interactions with other hedgehogs, grooming and nest construction. Studies on the activities of hedgehogs show a majority of the time is spent foraging, during which the animal meanders over pasture at a steady pace, punctuated by pauses and short intervals of swift movement. Bouts of courtship accounted for about 4% of the time.[(35)]

Solitary lifestyles are fundamental in the hedgehog. Males play no part in parental care and the young disperse after weaning (6 weeks). Whether or not an animal is territorial could depend on factors such as distribution and abundance of resources like food, nest sites and potential mates as well as the relative energy cost required to defend a patch against conspecifics.

Field observations of territoriality are rare and while home ranges overlap, sometimes completely,[8, 29] no studies have provided evidence of scent marking of locations. Morris[26] was the first to suggest that rather than defending territory hedgehogs may mutually avoid one another. Others have suggested hedgehogs may create a ‘personal space’ by body odour cues.[8] Reeve (1994)[35] volunteered an association of avoidance with the extravagant behaviour of self-anointing.

Hedgehogs olfactory sensing is highly evolved with the lobe of the brain well developed and they also possess a vomeronasal organ. Very little is known about how hedgehogs use odours in their daily activities, however it follows logical thinking that olfaction plays an important role in finding food, detecting potential predators, orientation and place recognition, sexual behaviour, maternal behaviour and other activities[35].

Morris (1985)[25] studied the effects of supplementary feeding on the home range of hedgehogs. The experiment entailed placing out food in urban gardens and then removing the source for a period of one week. Beyond the 6th day after food removal, none of the six radio tagged hedgehogs turned up in the garden to feed. However on the first day of returning the food, all six hedgehogs turned up to feed. The olfactory sense in hedgehogs has been likened to that of a dog.[18]

Similar ‘social’ systems have been reported for free ranging cats (*Felis catus*) and several carnivore species including the raccoon (*Procyon lotor*), brown and black bears (*Ursus arctos* and *Ursus americanus*) (cited by Reeve N.J. 1994[35]). Australian brushtailed possums, *Trichosurus vulpecula* mark their trails and read each other’s signs.[15] Kean suggests that the animals avoid each other’s presence, the net result being that they maintain their distance from each other and share their common food on the basis of a temporal strategy rather than a spatial one. Social interactions are not totally uncommon, hedgehogs have been known to tolerate each other’s company. Schoenfeld and Yom-Tov (1985)[37] recorded 10 adult *Erinaceus europaeus concolor* under a dense hedgerow ranging 11m by 2m. Similarly it is not uncommon at the site of a food source to find several hedgehogs close together or feeding from the same bowl. In Wellington, New Zealand, about a dozen hedgehogs were sighted together on a lawn. The reason for this high concentration of animals was not clear, however a food source may have been the attractant (pers. comm. A.J. Harris, Ministry of Agriculture and Fisheries, Hastings.). Reeve (1994)[(35)] reported 3460 behavioural records of which 17 were non-sexual encounters with other adults and 4 were fights between males.

Population Density

Estimation of population size of a free-ranging population is a common problem encountered by wildlife biologists. The earliest approaches to this problem developed by Petersen (1896) and later Lincoln (1930), where capture-recapture techniques were applied, were later joined by more rigorous mathematical treatments of the stochastic CMR models of population estimation employed by the Jolly-Seber method [(24)]. These methods have been used sporadically to estimate hedgehog populations. British estimates of hedgehog density range from 0.23-0.33 ha^{-1} in rural areas to 0.83 ha^{-1} on a suburban golf course in London[(35)]. In New Zealand Parkes[(29)] records a higher density over the summer in pasture and pine plantations as 2.5 ha^{-1}.

Home Range and Influencing Factors

Home range is a concept commonly employed to indicate the area used by an animal during its routine activities. It is misleading to report home ranges without reference to the length of the observation period. There are three different methods of calculation, which could be used to provide an estimate of the "home range" of an animal like the hedgehog:

- The range area used during a single night, a normal activity period, termed here "activity area".
- The asymptote of cumulative range area per night, representing the 'normally used area.'
- The area encompassing all the places in which an individual is recorded during an entire year, reflecting the total area familiar to an animal.[(26)]

Radio tracking can be used to supply information about a hedgehog's home range. It provides a valuable indication of the area used by the animal to fulfil its needs and can be used to analyse spatial relationships indicating territoriality or population density. Maps showing the spatial organisation of individual home range areas can also provide useful insights into territoriality or social relationships within a study population. Most studies of hedgehog ranges have used simplistic determinations of home range area, drawing minimum area concave or convex polygons around the plots of all the known locations of an animal during specific periods.

Home ranges of the European hedgehog have been well studied. Fig 2-1 summarises the average range in hectares stratified by sex where the distance travelled per night by hedgehogs is 1-3 km for males while females and juveniles travel about 0.5-1 km.

Many researchers have identified a significant difference between the home ranges of males and females. Morris (1969) (cited in Reeve 1994[35]) showed males still move larger distances even in the presence of supplementary food. It has been suggested that males cover a larger area, seeking females during the breeding season.

Seasonal variation of home ranges has been observed to occur. One Swedish study found pre- and post- breeding season males had a home range similar to the females.[35] Others in the United Kingdom and New Zealand have not found this distinction, and it has been suggested that the active period of the year for hedgehogs (ie. non-hibernation) equates to the breeding season. Reeve (1981)[33] and others mentioned earlier, found that home ranges overlapped, sometimes completely, irrespective of sex and that any one animal had a tendency to stay in the general area over a period of years. While each researcher has revealed a little more about the movements and activities of wild hedgehogs, a number of studies have suffered from specific drawbacks. Brockie's[3] and Morris'[26] studies had insufficient recaptures over time. Parkes'[29] and Campbell's[8] work, though based on a large number of recaptures were conducted in areas of an imposed artificial limit, such as the boundaries of an orchard, paddock or golf course, thus restricting the interpretation of the extent of the animals true movements. Brockie (1974)[3] suggests further progress in studying hedgehogs should involve long term commitment in order to monitor large numbers of animals over a wide area, sufficient to include both summer and winter activity and any signs of migration.

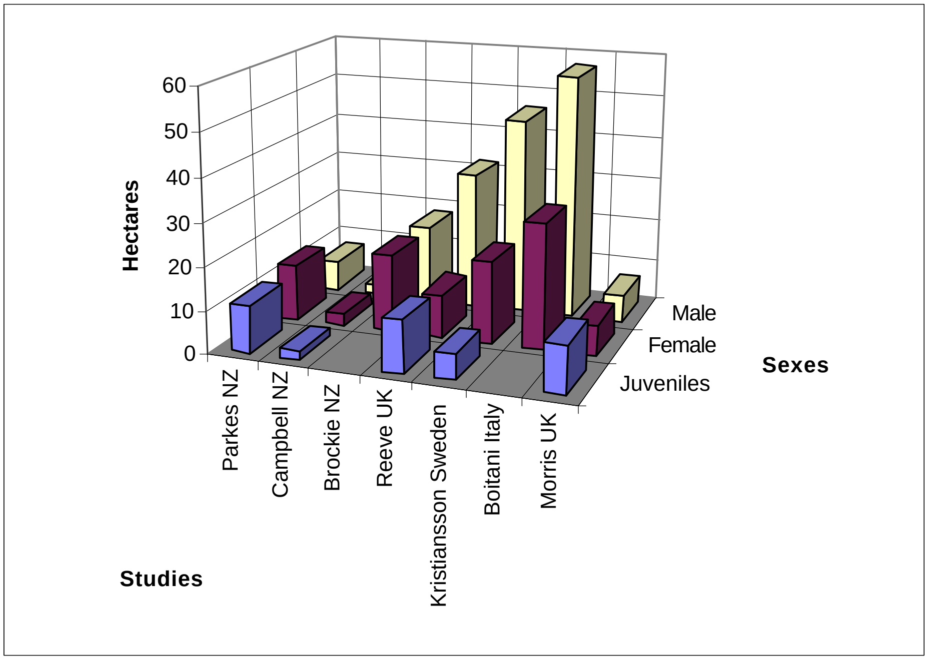

Figure 2-1 Comparison of home range estimates of hedgehogs from various studies. (References: 3, 8, 26, 29, 35,)

The major factor influencing the size and shape of the home range is reproduction. It has already been established males travel further than females and the reason suggested is to encompass more females' home ranges.[26]

Hedgehogs also exhibit seasonal weight variations. Fig 2-2 shows the findings from two investigations.[3, 33] Males come out of hibernation up to six weeks before females. During this time their weight increases. Once they begin breeding their weight drops, most likely because activities are focused more on mating and courtship and less on foraging. Toward the end of summer as mating decreases, on average the males display weight gain, presumably in preparation for hibernation. Similarly females show a weight increase after hibernating, then later in the active season display a weight loss, presumably due to gestation and lactation. Overall the females then gain weight, some may lose it again if they gestate a second litter. Thus reproduction seems the major factor influencing weight. While feeding is also important, hedgehogs do not store up food in any way, except of course as fat reserves, rather they eat what they find. Their home range will also have a variety of areas where food can be found.

Figure 2-2 Seasonal fluctuations of weight in the European hedgehog.

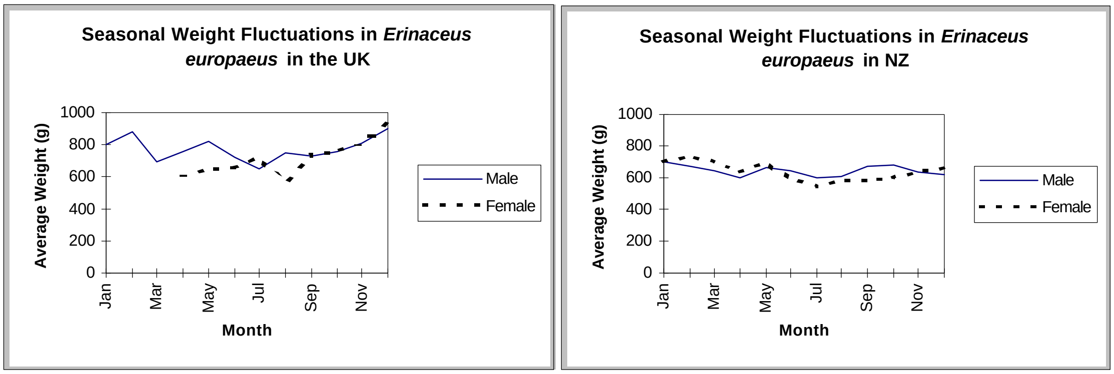

Figure 1-2. Adapted from Reeve[33] and Brockie.[3]

Hedgehogs are mainly scavengers and their diet is quite varied. It can contain any of the items listed in Table 2-1.[2, 8, 35] This can lead to infection with many diseases.

Table 2-1 Diet composition of *Erinaceus europaeus*

Order	Species	Average % in Diet*
Insects		
Beetles	Carabidae	47
	Scarabaeidae	18
	Other Beetles	29
	Beetle Larvae	15
Orthoptera		12
Earwigs		54
Hemiptera		8
Hymenoptera		18
Lepidoptera		53
Diptera		17
Other Insects		33
Other Invertebrates		
Arachnida	Spiders	18
	Harvestmen	24
Crustaceans	Woodlice	24
	Sandhoppers	18
Myriapods	Centipedes	2
	Millipedes	50
Earthworms		48
Molluscs	Slugs	34
	Snails	19
Vertebrates		
Amphibians		15
Birds	Adults/Hatchlings/Eggs	13
Mammals		13
Plant Material		71

*Revised from Reeve.[35]

Diseases of Hedgehogs

Hedgehogs like other mammals suffer from a wide range of parasitic infestations, fungal, bacterial and viral diseases. The list in Tables 2-2 and 2-3 has been drawn up largely by veterinarians interested in hedgehogs as vectors of stock diseases, or by hospital pathologists tracing the origin of certain human infections or parasites. The effect of these infections on hedgehogs has not received much attention and thus the epidemiology of diseases is mere speculation. The general view is that if the hedgehog is infected it is potentially infectious.

Table 2-2 External parasites and fungal infections of the European hedgehog (*Erinaceus europaeus*)

Affliction	Agent	Country	Prevalence	References
Fleas	*Archaeopsylla erinacei*	UK, Europe	99.98%	2,6
	A. erinacei maura	Spain		2
	Nosopsyllus fasciatus	Europe, NZ		1,2,3
	Ctenocephalides felis	Europe, NZ		1,2,3
Ticks	*Ixodes hexagonus*	Europe		2
	Haemaphysalis spp.	Europe, NZ		1
Mites	*Caparinia tripilis*	Europe, NZ	50%	1,2,3
	Notoedres muris	NZ		1,2,3
	Demodex erinacei	Europe, NZ		1,2
	Hirstionyssus spp.	NZ		1
	Sarcoptyes scabiei	Europe	4%	2
Myiasis	*Hemipyrellia fernandica*	UK		2
	Lucilia spp.	Europe, NZ		2,3
Fungi	*Trichophyton spp. (4)*	UK, Europe, NZ	10-47%	1,2,3
	T. mentagrophytes erinacei	UK, Europe, NZ	20-25%	1,2,4

Table 2-3 Internal Parasites and fungal infections of the European Hedgehog (*Erinaceus europaeus*).

Affliction	Agent	Country	Prevalence	References
Helminths				
Trematodes	*Brachylaemus erinacei*	UK, Europe	2.7-80% (Berlin)	2
	Agadistomum pusillum	NZ		1
	Eupryphium melis	NZ		1
	Harmostomum spp. (3)	NZ		1
Cestodes	*Hymenolepis spp. (3)*	UK, Europe, NZ		1,2
Nematodes	*Crenosoma striatum*	UK, Europe, NZ	30-50%	1,2,3,5
	Capillaria spp.	UK, Europe, NZ	10-80%	1,2,3,5
Protozoa				
Coccidia	*Isospora rastegaivae*	UK, Europe	13-15%	2,5
	Toxoplasma gondii	Europe	29%	2
	Giardia	NZ		3

Affliction	Agent	Country	Prevalence	References
Fungi	*Candida albicans*	NZ	87%	1
Bacteria	*Bordetella bronchiseptica*	Europe	1%	2,5
	Clostridium perfringens	NZ	100% (10)	1
	Escherichia coli	UK, Europe, NZ	21-92%	1,2
	Leptospira spp. (17+)	UK, Europe, NZ		1,2,3,4,5
	Listeria monocytogenes	NZ		3
	Mycobacterium avium	UK		8
	M. bovis	NZ	4%	3,7
	M. intracellulare	USA		2
	M. leprae	UK Experiment		2
	M. marinum	USA		2
	Proteus spp.	NZ	3-79%	1,2
	Pseudomonas spp.	Europe, NZ		1,2
	Salmonella enteritidis	Europe, NZ	17-21%	2, 5
	S. typhimurium	UK, Europe, NZ	40-64%	1,2
	Staphylococcus aureus	NZ	85%	1
	Streptococcus spp.	UK, Europe, NZ	47%	2
	Yersinia pseudotuberculosis	UK	10%	5
Rickettsiae	*Coxiella burnetti*	Europe		1
Viruses	Foot and Mouth disease	UK, Europe		1,2
	Rabies (Lyssa virus)	Experimental		2
	Yellow Fever (Flavi virus)			2
	Tick Borne Encephalitis	Europe		2
	Cytomegalo virus (Herpes)			2
	Paramyxo viruses (Morbilli)			2

References: 1: Smith,[38] 2: Reeve,[35] 3: Brockie,[3] 4: Twigg,[40] 5: Keymer et al,[16] 6: Baker et al,[1] 7: Lugton et al,[19] 8: Matthews et al.[21]

Zoonotic Diseases

While many papers have been written on diseases found in hedgehogs, there have been few occurrences where reported cases of disease can be directly attributed to hedgehogs with certainty. In one case in Italy in 1984, a hedgehog was directly responsible for causing a leptospirosis outbreak in people by drowning in the local water reservoir.[6] There has been one case of infestation of a human with hedgehog fleas (*Archaeopsylla* *erinacei*), as well as several cases of hedgehog ringworm in man.[32] Scabies is another infectious zoonoses, which can be contracted from hedgehogs.[35]

There are certainly other diseases that need thorough investigation. It has been long recognised that hedgehogs carry *Salmonella*. Most studies focus on the mere prevalence of *Salmonella spp.* present in hedgehog faeces, and occasionally lymph nodes. Speculation on the potential epidemiology of this disease is continually made as to the possible implications of being a vector, yet research so far has not extended beyond prevalence studies. One researcher in Germany looked at the prevalence of *Salmonella* in snails and slugs.[41] He followed up with faecal surveillance in hedgehogs where they identified *Salmonella spp.* of the same serovars. Again, the hedgehog was a suggested reservoir for this disease as diets often consist of slugs and snails. Most studies have followed a similar route in the diagnosis of disease in hedgehogs. Studies tend to be carried out from a veterinary zoonotic potential point of view and the presence of organisms does not indicate a commensal or parasitic relationship with the hedgehog.

Tuberculosis caused by *Mycobacterium bovis* is a serious zoonotic disease, which occurs in many countries around the world. Recently in New Zealand *Mycobacterium bovis* infection was reported in hedgehogs.[19] Infection seems to occur through the oral route, yet primary lesions are found in the lungs. Lugton et al suggested that as hedgehogs are omnivorous in their eating habits it seems quite likely that in endemic areas where tuberculous possums are found they will be exposed to infection due to investigation and consumption of carcasses.

Tuberculosis in New Zealand

Prior to the arrival of the first people in New Zealand, the mammalian fauna was limited to only two species of bat. By the 19th century, large areas of forest had been cleared, replaced by pasture, and cattle and sheep introduced. Recreational purposes and a domestic fur industry saw the introduction of deer and the Australian brushtail possum.[28] *Mycobacterium bovis* was presumably introduced with cattle early last century and by the middle of the 20th century tuberculosis had become so common, that it was considered a serious public health problem.

In New Zealand, at least 12 wild animal species can be infected in the wild, but as few as 1 or 2 appear to be reservoir hosts for tuberculosis. The remainder are spillover hosts and most are considered terminal hosts. It is now widely accepted that the possum is a reservoir host.[31] The role of the ferret is under active discussion.

Involvement of a wide range of small wild animal species seems to be a feature of bovine tuberculosis only in New Zealand, where predators and scavengers, including ferrets, stoats, weasels, feral cats, hedgehogs and feral pigs are infected. Lesions in naturally infected animals indicate infection occurs primarily via the digestive tract. A likely explanation for occurrence of tuberculosis in predators/scavengers is that New Zealand has abundant, suitably sized tuberculous prey (e.g. possums) and carrion as a potential source of infection. Ferrets, stoats, cats and hedgehogs have not become similarly involved in the disease in England or Ireland, probably because badgers are unlikely prey for small carnivores and the amount of carrion is small. The lack of large carnivores and scavengers in New Zealand may also be important. Small predators occur at high density and have limited competition for relatively abundant small carrion, such as possum carcasses, and have access to large carrion also. This ecology is vastly different in countries where canid carnivores are present.[44]

With the advent of farming, population sizes of introduced and native wildlife have declined. Usually on each farm there are some areas which cannot be cultivated for various reasons and are left in native bush. These areas and shelterbelts create islands of habitat in the matrix of cultivated land. Shelterbelts are crucial for preventing wind and water erosion as well as providing cover for farmed animals. While maintaining shelterbelts and islands of bush can be important for the conservation of a species, these islands can also be reservoirs of pests and disease.

Longitudinal studies of possum populations infected with Tb have provided strong evidence that a high proportion of possums with clinical tuberculosis is clustered both in space and time.[7, 13] This clustering with regard to cultivated land also occurs within bush areas and does not necessarily occur over the entire habitat. The colloquial term ‘hot spot’ is used to describe these clusters and refers to Tb endemic areas where possums are infected with tuberculosis.

Control of tuberculosis in New Zealand

The objective of control is to reduce the level of disease due to *M. bovis* in man, in domestic stock, and in wildlife. In principle, tuberculosis is one of the easier diseases to control. However it has changed its character under the influence of past control measures (Fig 2-3). It is no longer an infectious disease determined largely by contact rate – rather, it is a behavioural disease determined by the behaviour patterns of farmers, stock traders, wildlife and domestic stock.[27]

In designing control programs, it is necessary to consider the nature of each of the transmission pathways, the size of the flow if infection through each pathway with and without a control program in operation and our capacity to influence each pathway. Further gains in control are likely to be made most effectively by intensifying control on farms with persistent problems. Farmers are wanting the ability to predict the hot spots on their farms so they can target their resources in possum control and develop grazing management strategies that may reduce the risk of cattle or deer becoming infected with tuberculosis.[22] Currently the only mechanism available to locate hot spots is the post mortem examination of possums in an area to identify if they have gross visible Tb lesions. There is evidence that predator/scavenger species are infected with tuberculosis by eating carcasses of infected dead animals.[19] The disease becomes concentrated in the species that are higher in the food chain, and significantly higher prevalences of Tb are found in some predator species compared with possums. Because hedgehogs have home ranges that are similar in size to possum home ranges, they could potentially be useful as indicators of the geographic location of hot spots.

Wildlife ecology

Possums were introduced into New Zealand in the 1850s and are abundant right throughout New Zealand except for Northland and South West Fiordland. Cover and a suitable and varied food supply are apparently the possums' only requirements. Hence they are found in a diverse range of habitats. They live in all types of forest from sea level to tree line, in scrubland and tussock grasslands, shelter belts, orchards and cropping areas. Forests are the major habitat especially mixed hardwood forests, where possum densities are higher than in beech or exotic pine forests. Forest /pasture margins often support very dense populations.

New Zealand has the largest known population of wild ferrets in the world. Released in the mid 1870s as a form of biological control for rabbits, they now inhabit most parts of New Zealand except for Northland, Taranaki and the west coast of the South Island. No distribution studies have been undertaken since the early 1960s. Ferrets are limited to pastoral habitats, especially pasture, rough grassland and scrubland, and the fringes of nearby forest.

Hedgehogs are distributed throughout New Zealand especially near the coasts but are less numerous in hilly or mountainous areas. They are scarce or absent from areas with more than 250 frosty days a year such as the upland of the Southern Alps and parts of the Central Northern Plateau. Hedgehogs are less common on dry open land and upland areas where invertebrates are less abundant. And because dry nest sites are hard to find, few hedgehogs have penetrated into New Zealand rainforests.

No single measure is going to achieve the desired result in controlling wildlife tuberculosis, and the key to progressive success will be better integration of different control measures to reduce the problem to a point where it is no longer a major concern. There are promising signs that this is now an achievable goal, based on research evidence, which is coming forward from a range of sources.[27]

Study Design

Many diseases are still difficult to detect, even in humans and domestic animals. However, the covert nature of disease, and particularly its quantitative aspects, is inherently more important in wild animals than in either livestock or humans. The wildlife worker/veterinarian has much greater difficulty finding diseased individuals than does the physician and is seldom able to count wild populations in the way that cattle in a pen or children in a school can be counted.[43]

In a wild species one is seldom able to follow the clinical progression of naturally occurring disease in an individual, and most diseased individuals are not detected as being sick until they are *in extremis* or dead.

Field prevalence surveys are a deceptive guide. Prevalence as measured by such studies is determined by the relationship between incidence and the duration of the disease, and is even less reliable if the disease is patchy in its distribution. A longitudinal study of the disease, taking into account the temporal and spatial aspects of disease occurrence is usually required to gather information needed to describe the epidemiology more accurately.

Figure 2-3 Time line showing the events leading up to current control measures for tuberculosis in New Zealand.

19th C	*Mycobacterium bovis* introduced into New Zealand through the importation of infected cattle
1945	Voluntary TB testing of dairy cows
1956	Compulsory testing of town-supply dairy herds
1961	Compulsory testing of all dairy herds
1967	Possum identified as having tuberculosis
1968	Voluntary testing of beef herds
1970	Compulsory testing of beef herds
	The introduction of three monthly whole herd testing
	The possum is implicated as a TB vector
	1080 poison used to eradicate possums
1976	79% of the nations' cattle are accredited free from tuberculosis
1977	The movement control scheme is introduced
1979	Approximately 700 herds on movement control
1980	Funding for possum control cut
1982	Ferret identified as having tuberculosis
1985	Voluntary eradication of tuberculosis in farmed deer implemented
1989	Funding of possum control returns to pre-1978 level
1990	1100 herds are now on movement control
1991	Compulsory eradication of farmed tuberculous deer
	Four levels of TB control areas defined. Surveillance, Endemic, Fringe and STI (special tuberculosis investigation) areas
	Questions raised about the role of predators, especially the ferret, in Tb epidemiology
1995	TB control funding levels reach $31.3 Million. Fifty percent is spent on vector control
	Hedgehogs identified as having tuberculosis
	1388 cattle herds and 207 deer herds are on movement control
1996	Movement control scheme revised

Constructed from O'Neil & Pharo.[28]

There are a variety of epidemiological studies, which can be used to elucidate information from health situations. In general there are two main types, experimental and observation studies. Experimental studies include intervention studies or clinical trails. Individuals are allocated into groups where one group will have a procedure applied. It is then possible to evaluate the efficacy of the procedure by comparing groups [39].

In contrast to experimental studies, observational studies do not allow the investigator to control any of the factors in the system under study. Types of observational studies include; cross-sectional, case-control and cohort studies. A cross-sectional study investigates relationships between disease and hypothesized causal factors in a specified population at a single point in time. Advantages of this approach are that it is relatively inexpensive and quick to conduct, random samples can be selected and there is little risk to the subjects. However, this type of study is not suited for rare diseases or ones of short duration. Incidence cannot be calculated and the temporal sequence of cause and effect cannot necessarily be determined [39].

Case-control studies compare a group of diseased individuals with a group of healthy individuals with respect to hypothesized causal factors. The advantages here include that rare disease or those with long incubation periods can be studied, they are also relatively quick and inexpensive to conduct with little risk to the subjects. However, incidence and prevalence cannot be calculated and the proportion of exposed and unexposed individuals in a target population cannot be estimated. Sometimes data collection relies on recall or past records and validation of information is difficult. Cohort studies look at a group of individuals exposed to a factor and compares them with a group of individuals not exposed to the hypothesized causal factors of a disease. Cohort studies allow calculation of incidence and also permit flexibility on choosing variables. Often though, large numbers of subjects are required to study rare diseases and they can be relatively expensive to conduct. Follow up in these studies can be of a long duration and sometimes maintaining follow up becomes difficult. This type of study can sometimes be referred to as a longitudinal study because it is based on observations conducted over a period of time, which separates the exposure from hypothesized causal factors, and the onset of disease [39]. In contrast, Martin and Meek (1987) describe a longitudinal study as an observational study involving repeated observations of individuals in a population over a period of time. The study is comprised of a series of cross sectional surveys taken at regular intervals, individuals in the population do not have to be permanently identified [20]. This approach combines the benefits of cohort study methods with the benefits of cross-sectional sampling.

In many situations involving free populations of wild animals, periodic estimates of population parameters are analogous to a series of still photographs of a revolving door of a building, taken from above,. The number of individuals in each photo can be counted but it is unclear whether the faceless individuals are going round and round (a sedentary population) or if new persons are continually passing through, in one or both directions. The ability to distinguish between residents and transients is usually critical in disease investigation.[43]

Methodology of a Field Study

Trapping

Essentially there are two approaches to trapping; in one, comprising of snares, pitfalls, nets and some uses of break back traps, the device is hidden and the animal runs into it or inadvertently steps on the release mechanism. The other approach uses traps in the stricter sense and usually relies on exploiting the animals' exploratory drive towards a new object or its attraction to bait. This immediately presents a problem if a representative sample is required because members of a population vary in their responses and therefore, in their reaction to traps. Some individuals are trap-shy and others trap-prone. The reaction to traps may not be the only cause of trap-shyness. Some sections of the population will not be trapped because they are weanlings, some animals may not encounter a trap as often as other sections of the population, and individuals may be inhibited from entering a trap because the previous animal has left scent there. Conversely, scent from a member of the opposite sex, or from the same sex, may attract animals to traps. The bias caused by any variation in the animals' reaction to the traps may undermine the assumptions used in analysing the trapping data.

Kikkawa[17] reviews various factors affecting trapping success:

- Choice of bait may be important in obtaining a catch or improving trapping results.

- Selection of a site for the trap. Placed in runways or near obvious signs of the animals you wish to trap.
- Physical factors such as weather or barometric pressure affect trapping success.
- The structure or the composition of the habitat and the availability of food will often affect population density and distribution and thus alter trap success between areas or seasons.
- The type of trap employed may have an effect on trapping success. Most comparisons show that live traps are more efficient than snap traps. It is also important to set traps with care, for those which have an adjustable tripping weight; incorrect setting can bias results.

Choice of traps

The type of study and the results required will affect the choice of traps. If live trapping with mark and release is carried out, data on reproductive condition and age will often be crude. Live traps may also be used for capture prior to killing and subsequent dissection. This would allow a detailed study of reproductive conditions, perhaps age, and many other physiological or anatomical parameters.

If snap traps are used repeatedly in one area then enough time must be allowed to elapse between trappings to allow the population to re-establish itself in that area. The removal of animals by live or snap trapping may cause others immediately adjacent to the study area to move into it. This ‘vacuum effect’ can be more marked in removal trapping but may also occur in mark-release trapping.

It should also be noted that live trapping may cause an increase in locomotory activity after release and so affect subsequent movements.[10]

Number of traps

Ideally the number of traps placed at each trapping point should be large enough, so that no animal is prevented from being caught. In practice, as a compromise with respect to trapping effectiveness and effort, it is convenient to have 20% of the traps empty. The trap spacing in a line or grid will determine whether or not all the population resident on the study site will have an opportunity to approach a trap and then, if enough traps are present, be captured. If spacing is too wide then some animals may be missed in between the trap points and thus never encounter a trap. Random spacing is carried out for statistical reasons and irregular spacing for practical reasons. Female animals often have a smaller home range than males and thus wide spacing will bias the sex ratio if some females are missed and all males are caught.(31, 35)

Radio tracking

Attaching a radio transmitter package to a hedgehog poses several problems. Hedgehogs have a poorly defined neck, lack a 'waist' and have a small tapering tail so collars and bands are generally impractical. Choosing an adequate transmitter is ultimately a trade off between transmission range and possible adverse effects on the animal. Adaptations have been used in New Zealand where a harness of silicone rubber tubing is applied around the hedgehog's neck.(24) Such elastic harnesses allow the hedgehog to roll up adequately for defence, but they are likely to constrain natural movement to some extent. The spiny skin is very muscular and mobile and it has been noted that hedgehogs frequently escape their harness.

In contrast, gluing transmitters to the dorsal spines has been successfully used by almost all of the more recent studies.(35) Attaching transmitters to the spines has shown to be reliable and does not seem to inhibit free movement.

The transmitter needs to be robust, encased in waterproof resin and have a battery with good power delivery and long life. The cumulative weight of these transmitters can be cumbersome, yet Reeve(35) suggests the use of transmitters which weigh between 12 and 28g as being optimal.

Radio tracking can be used to supply information about a hedgehog's home range. It provides a valuable indication of the area of habitat(s) used by the animal to fulfil its needs and can be used to analyse spatial relationships indicating territoriality or population density. Maps showing the spatial organisation of individual home range areas can also provide useful insights into territoriality or social relationships within a study population.

Although radio-tracking data may be described as continuous data, in practice each period of activity is recorded as an independent series of consecutive fixes. A minimum of two fixes per hour per animal is recommended.(34) It is obvious that longer intervals between fixes reduce the accuracy of the revealed route but the significance of error also depends on the level of the animal's activity. Correctly mapping the precise location of the animal at each fix can also be a problem, especially when following animals through dense woodlands or across featureless open grasslands.[35]

Justification of home range analysis techniques

Home range is often described as "the area transversed by the individual in its normal activities of food gathering, mating and caring for young.[5] Similarly Jewell in 1966 restated it as "the area over which an animal normally travels in pursuit of its routine activities.[14] These are generally useful concepts however the key word 'normal' can lead to some confusion. White and Garrott (1990)[42] argue that home range is not *all* the area the animal tranverses during its lifetime but rather an area where the animal routinely moves. An animal may explore and become familiar with areas surrounding its normal home range, it may also shift its home range in response to changing conditions or even be migratory. Reeve (1994)[35] stipulates that it is important to note a time scale over which the range is measured. I propose a definition of home range as the area over which an animal is regularly located within a period of time. The numerical estimate representing an area over which the animal pursues its activities of food gathering, mating and caring for young.

The oldest and most common method of estimating home range is the minimum convex polygon. The polygon is constructed by connecting the outer locations to form a convex polygon, then the area of the polygon is calculated. While simplicity, flexibility of shape and ease of calculation are the advantages of the minimum convex polygon, its major drawbacks are the fact that the minimum convex polygon is influenced by peripheral locations and the range area can include large areas never visited. To avoid incorporating such outliers, Burt (1943)[5] recommends excursions outside its normal area should not be included in the analysis, alternatively percentage polygons can be constructed.

Home range is not typically a piece of land with resources distributed evenly within a boundary. More often it is a heterogeneous environment with certain areas rich in resources scattered throughout areas poor in resources. Studies have shown various animals use certain areas within their home range more frequently and for different reasons.[2, 11, 25, 29, 30, 33] Therefore objective criteria with a biological basis are needed to select movements that are 'normal'. One method is to use a probability level, for example a 95% estimation of an animal's home range. That is the area within which an animal will most likely be located for 95% of the recorded observations. Thus the term utilisation distribution can be defined as the two dimensional relative frequency of the points where an animal was located over a period of time. The utilisation distribution therefore is a probabilistic model of home range that describes the relative amount of time that an animal spends in any place. The home range can be specified within a 95% probability contour. White and Garrott (1990)[(42)] suggest that the use of a 5% error or any other estimate should not be considered normal. However different methods of home range estimation are erroneous for different reasons and choosing a percentage contour may reduce the amount of error influencing the estimation.

Dixon and Chapman (1980)[(9)] developed a technique by which one or more centres of activity, home range size and home range configuration could be determined. This method calculates the harmonic mean centre of activity based on areal movements and is calculated from a grid superimposed upon the distribution of fixes. Although the technique is less sensitive to departures from a normal distribution of fixes, highly skewed or leptokurtic distributions will result in inaccurate home range representations.[(12)]

The Kernel method is a non-parametric technique, which free the utilization distribution from parametric assumptions and provides a means of smoothing location data to allow more efficient use of it. Worton (1989) describes the kernel estimator as a method that, places a "scaled down" probability density function, namely a kernel, over each data point and the estimator is constructed by adding the kernel components. Thus, where there is a concentration of points the kernel estimate has a higher density than where there are few points. Because each kernel is a density the resulting estimate is a true probability density function itself [(46)]. Kernel estimators have been shown to overestimate home range with small sample sizes.[(36)] Seaman and Powell showed that samples of less than 30 fixes would grossly overestimate the range size using kernel estimation.

Most studies of hedgehog ranges have used simplistic determinations of home range area, drawing concave or convex polygons around the plots of all the known locations of an animal during specific periods.

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Chapter 3

A Longitudinal Study of Tuberculosis in Hedgehogs.

R. J. Gorton, D.U. Pfeiffer and R.S. Morris.

Introduction

The hedgehog, although a common mammalian inhabitant of much of the New Zealand countryside and urban areas, has only recently been confirmed to be a host for *Mycobacterium bovis*,[8] due to apparently eating infected carcasses. *M. bovis* organisms have been noted to survive in carcasses for a short period of time.[6] Hedgehogs will eat almost any animal substance, including meat, bones, maggots as well as vegetation and arthropods. It seems likely that many hedgehogs in endemic areas will be exposed to *M. bovis* infection from the investigation of decomposing carcasses, especially of possums. Hedgehogs have a home range smaller than possums.[13] Therefore the presence of tuberculous hedgehogs may be an indication of infected possums living within the hedgehog's home range.

The following study investigated the biology of the hedgehog using a series of capture-mark-recapture surveys.

Material and Methods

Study Site and Study Design

The study site was located on a farm (323.8 hectares) situated at the southern end of Lake Wairarapa, North Island of New Zealand. The farm has been on movement control for tuberculosis since February 1993. Studies were conducted on this site concerning tuberculosis in possums and ferrets in 1994-95.

The habitat is mainly open pasture, which supports the stud farm of sheep and cattle. There are areas of native bush, which represent a preferred habitat for hedgehogs. Most bush areas consist of manuka (*Leptospermum scoparium*) and karaka (*Corynocarpus laevigatus*) trees, with pampas grass (*Cortaderia selloana*) and ponga (*Cyathea dealbata*). The area at the bottom of the hill to the west of the farmhouse mainly has weeping willows (*Salix chrysocoma*), cabbage trees (*Cordyline australis*), ferns of various species, blackberry (*Rubus procerus*) and tussock (*Festuca novaezelandiae*).

The study site was divided into distinct areas according to habitat and clusters of traps: The Swamp, Jurassic Park, The Triangle, House, Club Med, Pampas Alley, Queen

Street and The Bottom Hayshed (See Appendix[1]). The study was based on capture-mark-recapture of hedgehogs living on the study site and followed by a period of cull trapping.

Over the study period, radio transmitters were attached to a total of nine hedgehogs. These animals were tracked to establish their home ranges. From all the hedgehogs captured, blood samples were collected and the serum stored at -84^{o}C. At the end of the study all hedgehogs were euthanased and necropsied for the presence of tuberculous lesions.

Field work spanned from October 1995 to May 1996 with visitation beginning at monthly intervals, then changing to fortnightly intervals in February and again to weekly intervals during the cull period. A return to the site occurred in October 1996 for two further visits to capture and cull tagged animals not retrieved last season. Each visit was for a minimum duration of four days.

Trapping

One hundred and fourteen cage traps were constructed manually using 50mm X 25mm 12 gauge mesh. Each cage was 112mm X 138mm square, and ranged from 400 - 450mm in length. The entrance to each cage consisted of a flap door 125mm long with the last 25 mm folded at a 30^{o} angle.(16) Animals entered the cage by pushing up the flap door and once the animals had penetrated the cage sufficiently the door fell down, trapping the animal inside. Each trap was baited with approximately 50g of tinned pet food.

Traps were set ~20-50 metres apart along the edges of hedgehog habitat and in obvious animal trails (pers comm I. Lugton). Each morning trap lines were checked, emptied and reset over a 3-4 day trapping period each visit. Between trapping periods traps were left on site, but in such a manner so as to avoid capturing animals.

Active hedgehogs (other than the hedgehog being tracked) spotlighted during night tracking were also captured and examined. This method has been successfully used before.(12) The investigators walked quietly around the study site listening and scanning the area with an adapted lamp. A torch with a dark red filter was used, as hedgehogs are not disturbed by red light.

General Procedure for Animal Examination

Hedgehogs were anaesthetised with 0.1-0.3 ml (10-30mg/ml) ketamine hydrochloride intramuscularly. The muscle chosen was one of the unique dermal muscles called the orbicularis, used by hedgehogs to curl up. Physical weight and size was used to determine the required dose of ketamine. Juveniles received 0.1ml, adolescents (400-600g) received 0.2 ml and adults 0.3 ml. After allowing a period of 5-10 minutes for the ketamine to take effect, the animals were encouraged to unroll using a method described by Gregory.[(5)]

Each hedgehog was weighed and trap number, date, observer, ID, colour, sex, age, length, condition, pregnancy and lactation status, ketamine dosage and the amount of blood taken were noted (See Appendix[2]). Kitchen scales were used to estimate the body weight in grams at 25g intervals. An ear tag crimped into the left ear permanently identified the animals. The ear tags are size 1 monel tags (supplied by The Banding Office, Dept. of Conservation, Wellington, New Zealand). Colour was a relative measure defined as five groups (Dk brown, Med Brown, Lt Brown, Blonde, and Albino). It was based on assessing the colour of the band on the spines and the hair around the base of the spine area. In the case of blonde hedgehogs the presence of non-banded yellow spines, pink feet and nose but black eyes was definitive for this class. Sex was easily defined as in Reeve[(13)] page 42. Age class was based on a dichotomous classification of <1yr and >1yr. The distinction focused on physical size, weight and time of the year and occasionally condition score. Length was measured in millimetres from the tip of the nose to the tip of the tail. Condition score was based on an ordinal scale of 1-5:

1 = emaciated.

2 = no fat, reasonable muscle tone.

3 = average fat (1-2 mm).

4 = good fat (2-4 mm).

5 = very fat (>4 mm).

Condition was ascertained by palpating the sternum and ribcage. The degree of ease to feel these bones determined fat deposit and muscle tone. This has an inverse relationship with condition. Very easy in this context represented a condition score of 1. A skin flap was pinched between finger and thumb, and thickness was converted into a condition score. Age and weight also contributed to the final condition score.

Female hedgehogs had their abdomen palpated to establish pregnancy status. Nipples were massaged to determine the presence of breast tissue and to draw milk to determine lactation.

Finally, up to 5 mls of blood was drawn by cardiac puncture. The heartbeat was detected, then a 1½ inch 20 gauge vaccutainer needle was inserted between the ribs below the left forearm. Blood was collected into a non-additive vaccutainer. The tubes were stored temporarily in a warm room (20-25^{o}C) to allow the blood clot to shrink. After centrifuging the vaccutainers at 3000 rpm for 5 minutes the available serum was drawn off and frozen at -85^{o}C.

Hedgehogs were placed under a bush or in long grass to recover. Recovery occurred one hour after the initial injection giving 20-30 minutes to perform all measurements especially the cardiac puncture. The dose of ketamine was sufficient to produce peripheral analgesia during this time.

Radio Tracking

Five adult male, 3 adult female and 1 female juvenile hedgehog had radio tracking devices attached (supplied by Sirtrack, Havelock North, New Zealand). Each transmitter weighed 15g with a battery life of about 6.5 months. They transmitted 60 pulses per minute at 140-160 MHz.

A 40mm X 40mm square area of spines was clipped away from between the shoulder blades on the back of the animals, using standard toenail clippers. A fast setting epoxy resin glue was used to secure the transmitter to the stubble of the clipped spines. This was held in place until the glue began to harden, and the hedgehog was placed back into the cage and left for one hour until the glue had hardened sufficiently to prevent immediate sloughing off at release.

Radio tracking began soon after sunset (~20:00-21:00 hours). A minimum of 3 fixes per hour and 20 fixes per night was obtained per hedgehog. Fixes were obtained by zeroing in on the subject and spotting the hedgehog using a red light. This allowed minimising the disturbance to the hedgehog’s normal activity. The 3 fixes per hour were staggered 10-30 minutes apart in order to allow for minimum disturbance and prevent conditioning the hedgehog to a routine. At each fix, the time, place, weather and hedgehog activity was noted. If the author found herself in the middle of a featureless paddock, the place was marked with a numbered tent peg and found again the next morning. The exact geographic location of most places was determined by taking metre long strides back to the nearest landmark and distance and compass angle were noted. In addition locations were marked on an aerial photograph of the farm.

The Cull

Capture techniques involved the routine trapping as well as the use of a Jack Russell terrier for finding the animals. Each hedgehog captured was anaesthetised with ketamine. A vaccutainer of blood was taken using cardiac puncture. With the vaccutainer needle left in the heart, a needle sleeve was inserted over the needle to allow 1 ml of 60 mg/ml sodium pentobarbitone to be injected into the heart to euthanase the animal. Clinical death was confirmed by the absence of a heartbeat and corneal responses, then the animal was put aside for autopsy. Other statistics such as weight etc were measured at necropsy.

The necropsy procedure involved removing the spineless skin of the ventral body whilst noting the appearance of the numerous subcutaneous lymph nodes. Mandibular lymph nodes were examined before disarticulating the clavicle, cutting through the axillary regions to expose the retropharyngeal lymph nodes. The ventral surface of the thorax and abdominal musculature was then removed. Lungs and heart were separated from the diaphragm by severing the vena cava, oesophagus and aorta, and lifting the organs back towards the clavicles. Lungs were inspected and palpated dissected out and sectioned. Abdominal organs were examined paying particular attention to the main branch of mesenteric lymph nodes. The liver and kidneys were also removed and sectioned. The stomach was opened last and the contents removed to estimate volume and characterisation of the contents.

A pooled tissue sample was taken from each animal consisting of mandibular, retropharyngeal, bronchial and mesenteric lymphatic tissue. Samples of suspicious lesions for mycobacterial culture were also taken if appropriate. Tissues removed for bacteriology were stored in sterile plastic containers at -85^{o}C and later submitted to the Wallaceville

Animal Health Laboratory for culture using techniques described by Buddle.[(3)] Tissues were also fixed in 10% buffered formalin for histological examination by the author. Paraffin blocked tissue prepared from this material by routine histological processing was sectioned and stained using the haematoxylin and eosin and Ziehl-Neelsen methods.

The information was recorded on a standard necropsy data recording sheet (designed by MAF. See Appendix[2-4]). A tentative tuberculosis diagnosis was made at the end of the examination.

Analysis

Data was stored using the database management software Microsoft Access 7. Most of the analysis involved descriptive statistics that were generated and graphed in the spreadsheet software Microsoft Excel 7. The statistical software packages NCSS and Statistica were used for specific graphical analyses.

Population density estimates were calculated using a specifically designed software package called NOREMARK (Dept Fishery and Wildlife, Colorado State University, Fort Collins, Colorado, USA). Information about the total number of animals marked, number of new individuals, the number available for recapture and the number of visits to the site was used as input for calculation of 95% confidence intervals of an estimated size of the population.

Survival analysis was performed using the statistical software package Statistica Version 5 (Stat Soft Inc., Tulsa, Oklahoma, USA). The first and last capture of an animal was used to define the time to event (i.e. time to disappear from the population) survival analysis variable. Time between the initial capture and final capture was calculated and rounded to the nearest month. Because the event variable was disappearance, tagged animals that were culled at the end of the study period (i.e. whose location is known) were categorised as censored data. The Log-rank test was used to test for differences between survival distributions for the different sex and age groups.

Home range estimates were calculated using the home range analysis software, Calhome 1.0 (U.S. Forest Service, Pacific Southwest Research Station, 2081 East Sierra Ave, Fresno, California 93710). X, Y coordinates entered sequentially in ASCII text file format were used as input for the software. Home range estimates based on kernel estimation and minimum convex polygons (MCP) were calculated. The results were presented using the graphical software Sigma Plot 2.01 (Jandel Scientific Software).

For the purpose of this analysis, minimum convex polygons and percentage contours of the kernel estimation have been used and compared. Harmonic mean estimators were not used due to the strong skewness of the spatial data.

Results

Trapping success

One hundred and six traps were set along the edges of bush clusters and in animal trails. The remaining traps were used as replacements when livestock or farm machinery damaged traps.

From a total of 59 trap nights, each trap night's catch achieved a catch success of 4.3% (Range 0 - 10%). A further 2-5% of traps had bait taken or disturbed.

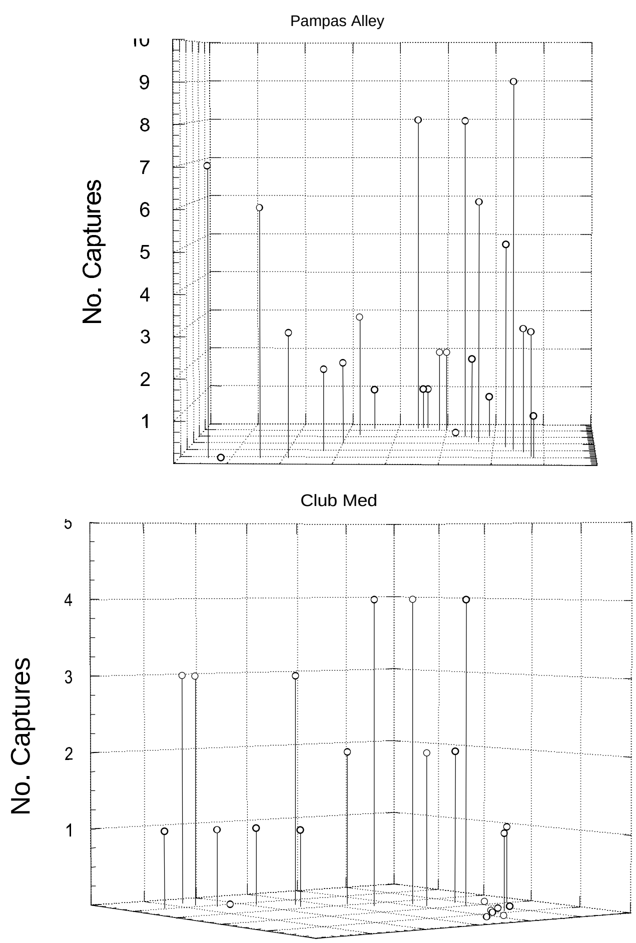
Habitat containing pampas grass (*Cortaderia selloana*) was consistent with high catch probabilities. Capture in pampas grass was 3-4 times more likely than in areas with sparse ground cover or native bush (Chi^2 statistic = 57.58, p = <0.005 (See Table 3-1)). Areas of the farm labelled Pampas Alley, Club Med, Queen Street and the Bottom Hayshed were areas of the highest catches as they all contained pampas grass and/or long grass as a predominant habitat type (See Appendix[1]). Where native bush dominated with extensive ground cover ('Jurassic Park' and 'The House') moderate numbers of hedgehogs were captured. Captures from around the house were only possible by dogs sniffing the hedgehogs out, as traps tended to have bait taken by cats. 'The Swamp' was an area that was prone to flooding and only one hedgehog was caught there during the study.

While the area 'Pampas Alley' consisted mainly of pampas grass, trap success was variable (Fig 3-1a.). However the area 'Club Med' consisted of a wide range of habitat types from pampas grass to native bush. Overall the highest trap success probabilities were in areas with predominantly pampas grass (Fig 3-1b.).

Table 3-1 Trap catch success and odds ratio of capture success stratified by habitat type (95% confidence limit).

Habitat	*Number of Traps/Area*	*Capture success*	*No Capture (trap nights)*	*Odds Ratio*
Pampas Grass	24	69	1347	3.73
Long Grass	32	67	1821	2.68
Native bush with ground cover	18	30	1032	2.11
Trees with no ground cover	5	4	291	1
Swamp	20	1	1179	0.06

Figure 3-1 Trap catch frequency for two selected areas: Pampas Alley and Club Med (X and Y co-ordinates (not shown) represent arbitrary map co-ordinates from the site).



Ninety-five hedgehogs were trapped and tagged with a total of 175 captures over the study period (Table 3-2). Most hedgehogs were individually trapped except for three occasions when traps contained two hedgehogs. One occasion involved two juvenile males while on the other two occasions, an adult male and adult female were found together in the trap.

Individual hedgehog recaptures occurred on average 2.95 times (range 2-9) The ratio between males and females trapped was close to 1:1, however males were more likely to be recaptured during a majority of the active season than females (Fig 3-2). The overall odds ratio of male recaptures to female recaptures was 1.5, p = 0.3. Forty one percent of animals in the tagged population were recaptured at least once, with fifty-three percent of the recaptures being single recaptures.

Table 3-2 Descriptive capture statistics of the observed hedgehog population.

	Male			*Female*			*Population Total*
	Age			*Age*			
	<1	*>1*	*Total*	*<1*	*>1*	*Total*	
Total Tagged:	16	34	50	17	28	45	95
Captured Once	12	17	29	13	14	27	56
Captured 2+	4	17	21	4	14	18	39
Total Recaptures	6	42	48	5	27	32	80
Mortality	1	5	6	0	1	1	7
Total Culled:	8	46	54	11	33	44	98
Tagged	1	10	11	3	13	16	27
New	7	36	43	8	20	28	71

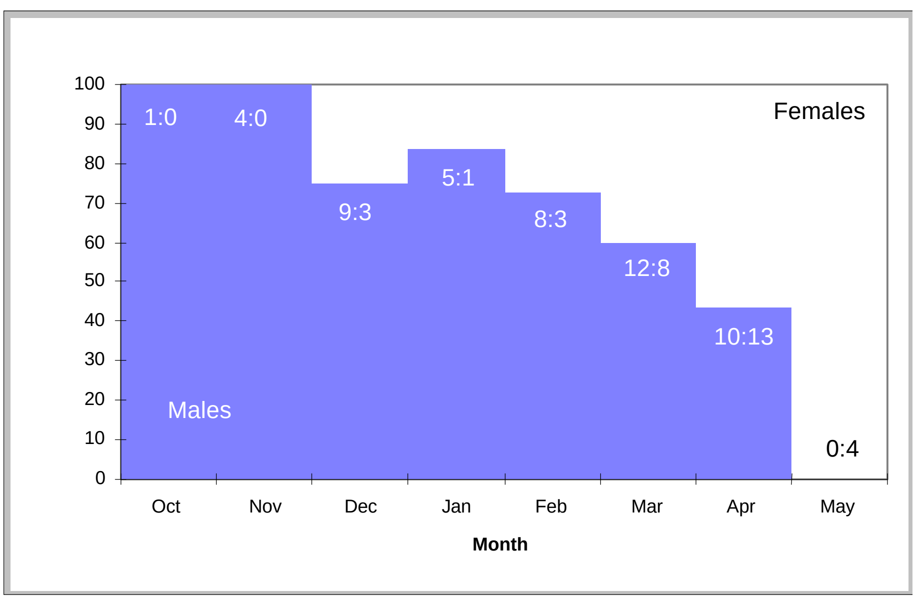


Figure 3-2 Percentage of males in total recaptures for each month during the longitudinal study (column labels represent male-female ratios).

Population density

The minimum number known alive was calculated as 193 hedgehogs with the total population estimate as 288 (95% CI: 248.2-342.9). The daily population estimate was calculated 241.9 (95% CI: 209.0 – 286.7). The estimated density per hectare was 0.88 hedgehogs.

Dispersal

Time between recaptures varied greatly (Table 3-3). Only 35% of the population have known outcomes, that is were culled or found dead, while the rest of the population disappeared. Fifty percent of the population disappeared within the first month following their initial capture. Seventy-five to eighty percent of the population had disappeared by the third month after first capture. There was no difference in time to disappearance between males and females (Log Rank = -0.0676, p= 0.95). Juveniles disappeared more quickly than the adults did (Log Rank = 2.09, p = 0.036) (Fig 3-3). Seventy-five percent of the juvenile population disappeared during the first month after initial capture.

Table 3-3 Random selection of hedgehog captures and subsequent recaptures throughout the study period.

	OCT95	NOV	DEC	JAN96	FEB1	FEB2	MAR1	MAR2	APR1	APR2	APR3	MAY1	OCT96
Observations	18	13	28	20	20	7	22	25	16	15	28	12	33
A001*	○	■											
A002*	◆	◆											
A004	○			○									
A006	○		○										
A007	○		○										
A009	○		○									✖	
A010	○	○	○		○			○					
A013*		○	○						○			✖	
A014*		○	○				○	○					✖
A015*		○	○	○									
A016		◆	◆			○	○	○			○		✖
A017*		○	◆	○	■								
A018		○			■								
A019		○	○						○	○		✖	
A020		○		○					○				✖
A021		○		○	○		■						
A024			○										✖
A026			○					○		✖			
A030			○				○				✖		
A031			○						○		✖		
A036			○					○					
A037			○				○	○	○	✖			
A038*			○	○		○						✖	
A039				○						✖			
A042				○				○			✖		
A055					○	○							
A059					○		■						
A062						○				✖			
A065							○						✖
A068							○	○	○				
A069							○			✖			
A070*							○					✖	
A077							○	○	○				
A078							○						✖
A086								○		✖			
A089								○	○				✖
A090								○		✖			

Key to Table 3-3

O:	Captured
◆:	Captured more than once that visit
■:	Found dead
✖:	Culled
***:**	Radiotagged animals

Observations include captures of new animals, recaptures in the same time period, recaptures from previous periods and dead animals found around the study site, which were autopsied.

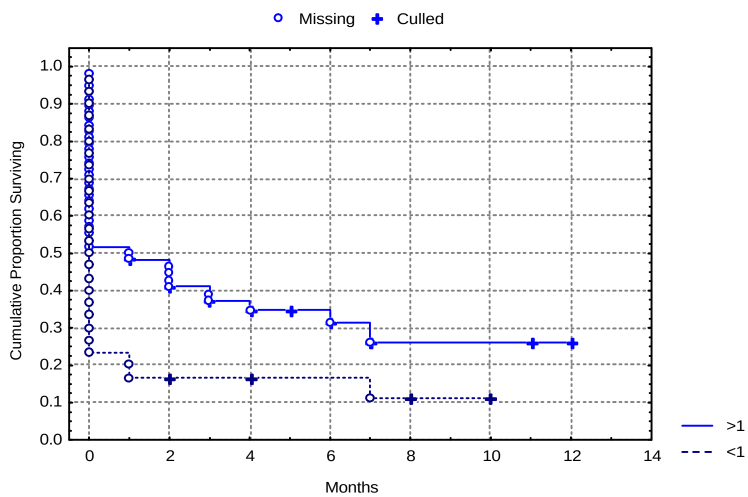


Figure 3-3 Survival curve for time to disappearance stratified by age group.

Demographics

The percentage of adults in total animals newly captured for different months of the study is shown in Fig 3-4. Juveniles began appearing in the population in December approximately 6-8 weeks after the adults emerged from hibernation and their proportion increased until the end of the study. Thirty-seven percent of the population were juveniles.

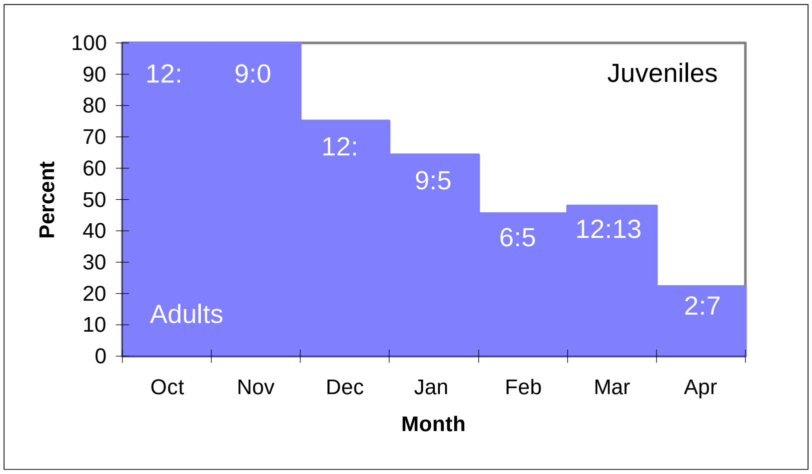


Figure 3-4 Percentage of adults in total new captures in each month of the study (Column labels represent adult-juvenile ratios).

Males were more likely to be trapped in the early months of the active season. As the season progressed the catch ratio between males and females was 1:1. Late in the season females were more likely to be captured than males (Fig 3-5).

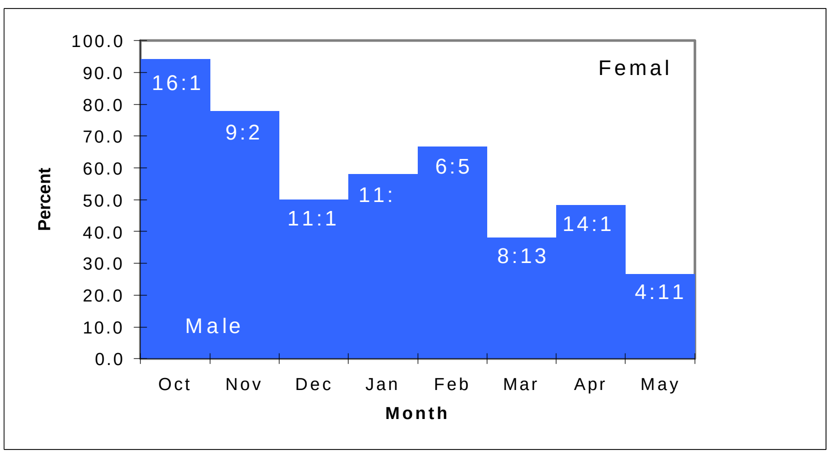


Figure 3-5 Percentage of males in total captured adult hedgehogs for each month of the study (Column labels represent male-female ratios).

The body weights of the adult hedgehog population were normally distributed whereas the juvenile population had a distribution skewed to the left. Mean body weights in each age group category were 688.7g (SE = 10.8) and 286.5g (SE = 16.2) respectively. Most hedgehogs above 500g were classified as adults, however when the body weight was between 400-600g the distinction between adult and juvenile was difficult and needed to be assessed on other factors. Most juveniles weighed 150-200g and were six to eight weeks old at the initial capture. Towards the end of the active season recaptured juveniles displayed significant increases in weight over a short period of time. A026, a juvenile male, gained 200g over a period of 7 weeks and a further 24g during the following three weeks.

Seasonal fluctuations of body weight were evident in the adult hedgehog population (Fig 3-6). Males began the active season with high average weights and proceeded to drop in weight until about February when they began gaining weight again. Females also displayed a weight fluctuation curve with a parabolic shape. After the initial weight increase early in the active season, average weight dropped, but increased again later in the season.

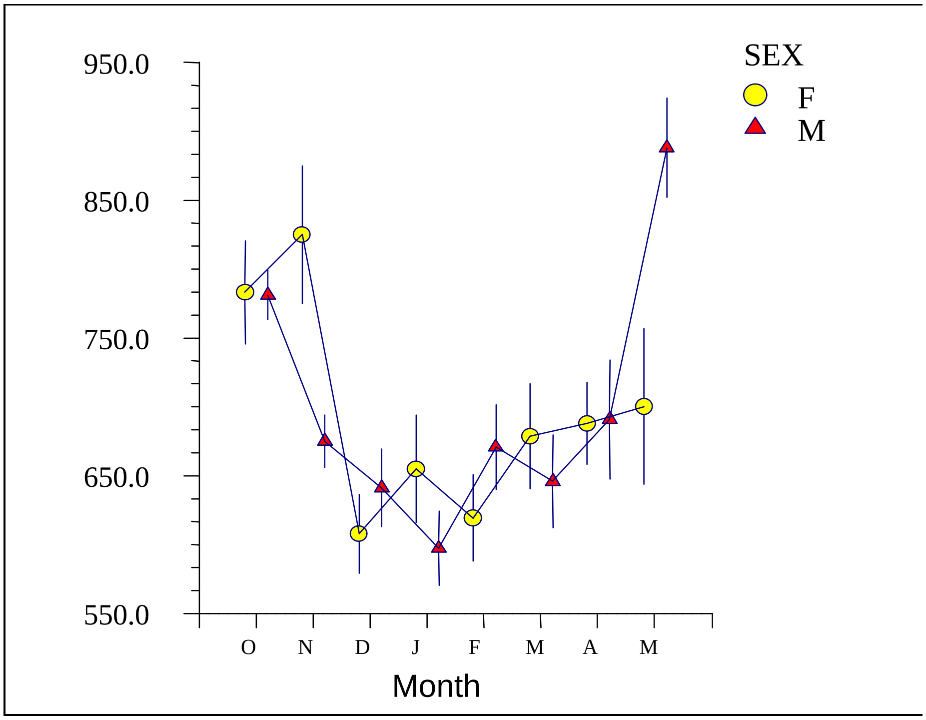


Figure 3-6 Seasonal fluctuations of the average body weight in hedgehogs between October95 and May96 for the study population.

As weight increased corresponding condition scores in the hedgehog population increased (Fig 3-7). Classification of condition score depended on a subjective assessment by the examiner. Adults were usually in good condition, ie. Score 3 and above, those who scored below three were usually in poor health and some kind of disease was usually evident. Juveniles were never classed as score 5 and the body weight range for adults with a condition score of 1 is skewed.

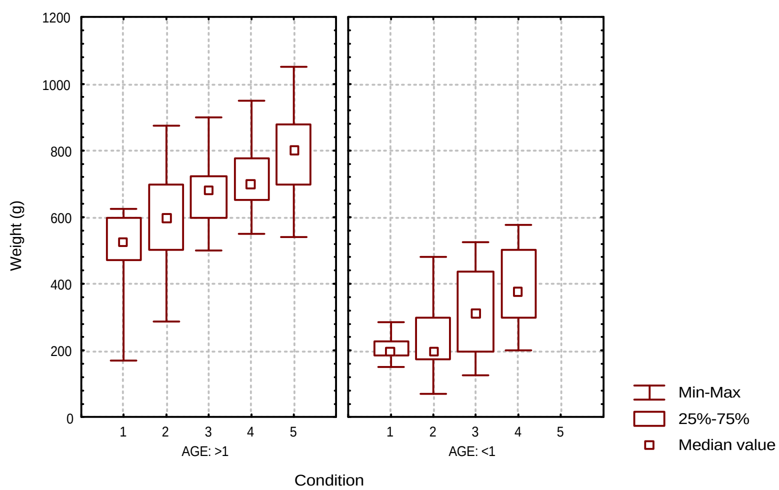


Figure 3-7 Box-and-Whisker plots for body weight by condition scores and age class in hedgehogs.

An assessment of the relationship between body weight and length of the hedgehog showed that in juveniles as weight increased, length also increased. Adults reached an upper limit of 29 centimetres in length while continuing to gain body weight.

Mortality

Mortality in the population was rarely observed. The outcome of those that disappeared is unknown. It is considered likely that most have died. There was an observed 8% mortality in the population caused by methods used in the study. Two male hedgehogs died after having their transmitters entangled in long grass. Infection from the wound inflicted overcame the animals. Other incidents involved hedgehogs dying in traps. On two occasions predatory animal such as a ferret or a hawk must have attacked them in the trap.

Some accidental deaths were observed with hedgehogs trapped under electric fences. One such episode involved five male hedgehogs all within 10 metres of each other along a live wire used for holding cattle.

Population cull

A cull of the population began in the middle of April 1996. Ninety-eight hedgehogs were captured over a total period of seven weeks during the months of April, May and October 1996 (Table 3-2). During the cull period 69 new individuals not previously tagged were captured. Two other hedgehogs had distinct markings on their ears indicating that they had previously been tagged and only 28% of previously tagged animals were captured and culled.

Eighty-five percent of the captures during the cull period were adults with approximately equal proportion of males and females. The odds of recapture during the cull period for animals tagged during the previous capture-mark-recapture study period were 5.09 times as high for hedgehogs which had been captured at least twice before than for those individuals who had been captured only once.

Disease status

No tuberculosis was found or cultured from animals with at least one suspect lesion nor from a sample of hedgehogs without visible lesions. There was a fungal disease present in seven hedgehogs from two distinct areas of the farm. The hedgehogs came from either 'The Bottom Hayshed' area or a cluster of bush situated between 'The Swamp' and 'Club Med' areas (Appendix[1]). These hedgehogs displayed several 1-2mm round grey translucent foci protruding from the pleura of the lung. This was often associated with enlarged mesenteric lymph nodes. The hedgehogs were juvenile animals, except for one.

Histological examination of the lesions revealed granulomas formed in the parenchyma of the lung. Bacterial and fungal stains revealed *Aspergillus* fungi associated with the granuloma tissue. Two of these hedgehogs later cultured positive for *Salmonella enteriditis* phage type 9a.

Four out of a sample of nineteen hedgehogs sent for culture returned positive for *Salmonella enteriditis* phage type 9a. Enlarged and/or necrotic lesions present in the main mesenteric lymph node was consistent with this disease. Further discussion is presented in Chapter 5.1

Twelve hedgehogs had skbin lesions consistent with mange. Seven had either *Caparinia tripilis* and/or *Notoedres muris* mites present. No mites were identified from three hedgehogs and two did not have skin scrapings taken. Further discussion is presented in Chapter 5.2.

Home Range Analysis

Radio transmitters were attached to nine hedgehogs, four females and five males. The known outcome of each of these hedgehogs is listed in Table 3-4. Five hedgehogs were tracked and captured at regular intervals for an average of 5.4 months (range 1-12). Capture data for another hedgehog (A016) was included in the analysis, because of the large number of locations available.

Table 3-4 The known outcome of each of the radio tagged hedgehogs.

Animal ID	*Sex*	*Epilogue*
A001	M	Found dead 2 months after the attachment of the radio tag.
A002	M	Radio tag ripped off its back because it was tangled in grass. Found hedgehog dead 2 weeks after the recovery of the radio tag.
A003	M	Lost animal possibly because it had moved beyond tracking range. Found radio transmitter in burrow 4 months after attachment, but no hedgehog.
A013	F	Culled
A014	M	Found transmitter in grass. Later trapped hedgehog and found all spines had grown back in three months.
A015	F	Transmitter failed. Hedgehog never found.
A017	M	Found dead in trap. Cause of Death unknown.
A038	F	Culled
A070	F	Culled

The detailed movements for each hedgehog are described in the following paragraphs.

A013 A013 was first captured on 8th November 1995 (Fig. 3-8) and was later recaptured and radio tagged on the 13th November 1995. The adult female denned consistently along 'Pampas Alley.' On the 12th January 1996 she was located with 5 one week old nestlings.

At night during radio tracking the animal moved across open pasture returning to the pampas grass for denning at daybreak. On 2nd April 1996 her radio transmitter was removed and replaced with another as the battery of the first had almost expired. This hedgehog was culled on the 8th May 1996. She was found with 3 six week old nestlings which were her second litter. Two of the hoglets had been previously eartagged (A094 and A097).

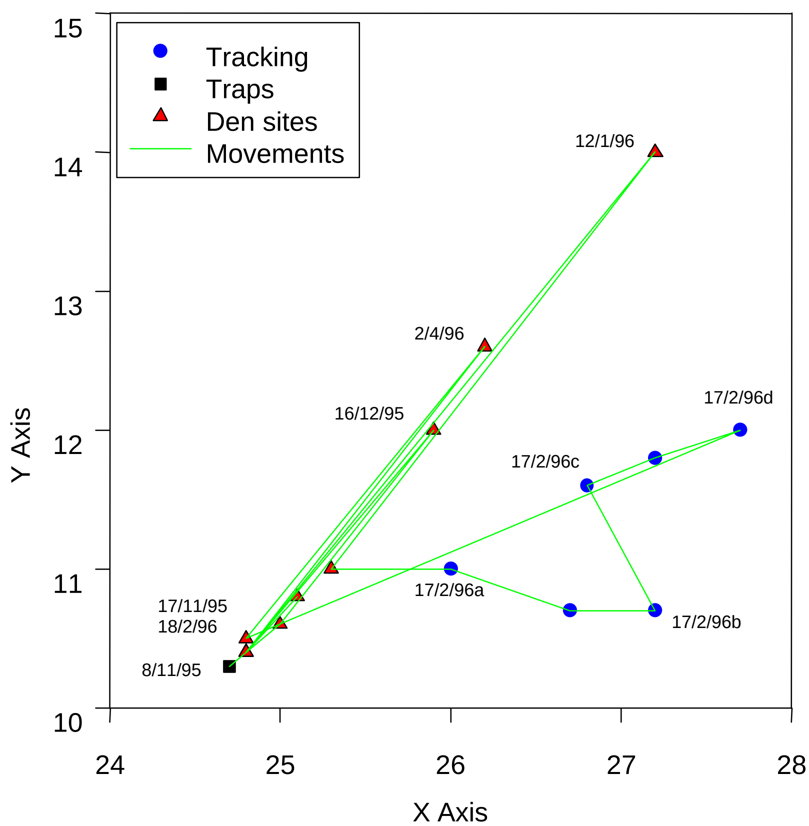


Figure 3-8 Recorded locations for hedgehog A013 during the period between 8/11/95 and 8/5/96.

A014 This adult male was initially trapped on the 8th November 1995 at ‘Club Med’ (Fig. 3-9). A radio transmitter was adhered to his back on 14th December 1995. Initially the animal was located at den sites (17/12/96) which were followed up by two nights of radio tracking one month later. The first night (15/1/96) was spent with A015 in courtship and mating on open pasture. The following night started at a den site (16/1/96a) where he proceeded up a fence line to the ‘Triangle’ where A015 denned. After 1 hour of movement in this area he covered approximately 800 metres in 10 minutes into a hay paddock situated beside ‘Club Med.’ Here he was found courting another female (A039). The following morning of 17th January 1996 located him back at a den site in the same pampas bush used the night before. Not long after this he dislodged his transmitter, which was then found in grass not far from the den site located on 17/1/96. This animal continued to be trapped throughout March 1996 three times around ‘Club Med.’ In October 1996 he was captured outside his known range of the previous season and was culled.

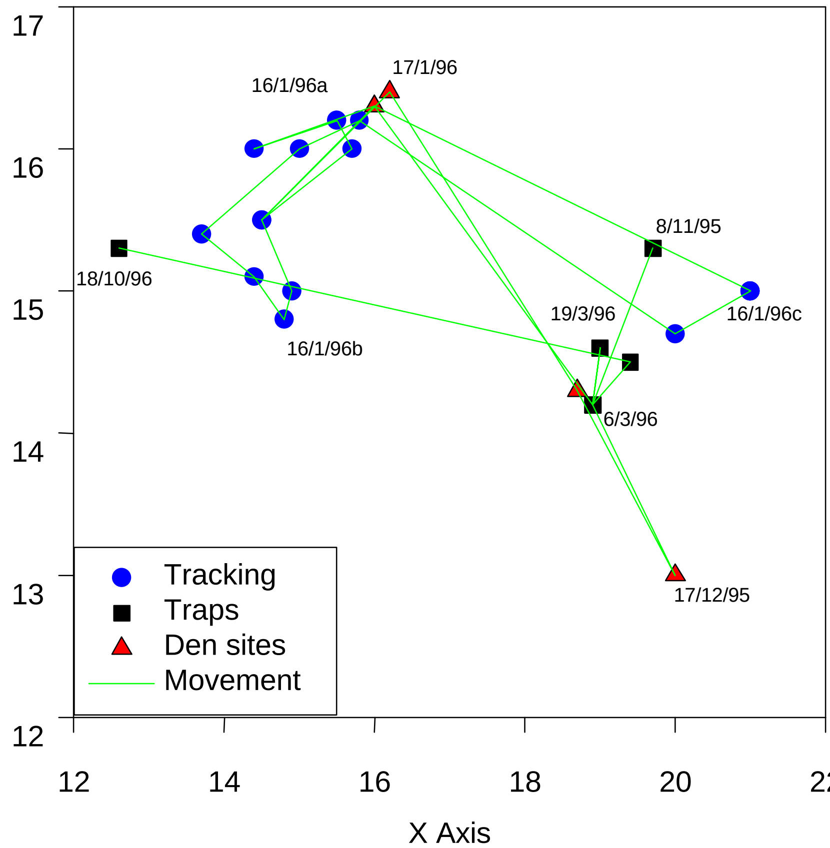


Figure 3-9 Recorded locations for hedgehog A014 during the period between 8/11/95 and 18/10/96.

A015 This adult female was first captured on the 8th November 1995 and was radio tagged when recaptured on the 14th December 1995 (Fig. 3-10). Her only den site was located in a blackberry thicket called the 'Triangle,' from which she exited each night by way of an old drain. Initial tracking involved following her around the cattle yards and wool shed of the farm. On the 15th January 1996 she was found on open pasture involved in courtship with A014. Recapture on the 17th January 1996 was the last known location for this hedgehog as subsequent visits to the study site failed to locate the animal. Evidence suggests the transmitter failed.

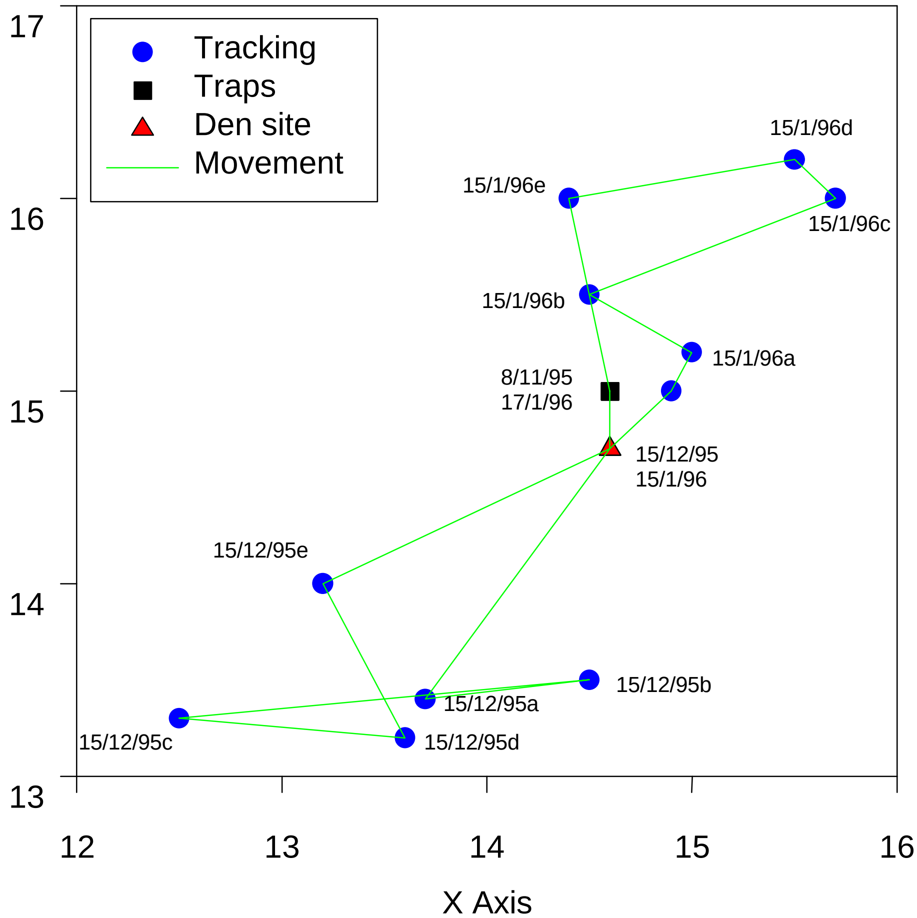


Figure 3-10 Recorded locations for hedgehog A015 during the period between 8/11/95 and 17/1/96.

A016 This adult male hedgehog was captured repeatedly over seven months giving a total of 9 locations. Initially captured close to the farmhouse on the 8th November 1995, he was again captured in the next trap down the trapline on the following day (Fig. 3-11). In Dec 1995 the animal was trapped on the same trapline. However on the next day he was recaptured approximately one kilometre away in a pampas plantation. For the next six months he was either captured in the pampas grass plantation or in a cluster of dense bush called 'Jurassic Park.' Both are situated on the periphery of open pasture. In April 1996 he was trapped at the 'Triangle.' Each of these clusters of bush were about 500 metres apart in a straight line.

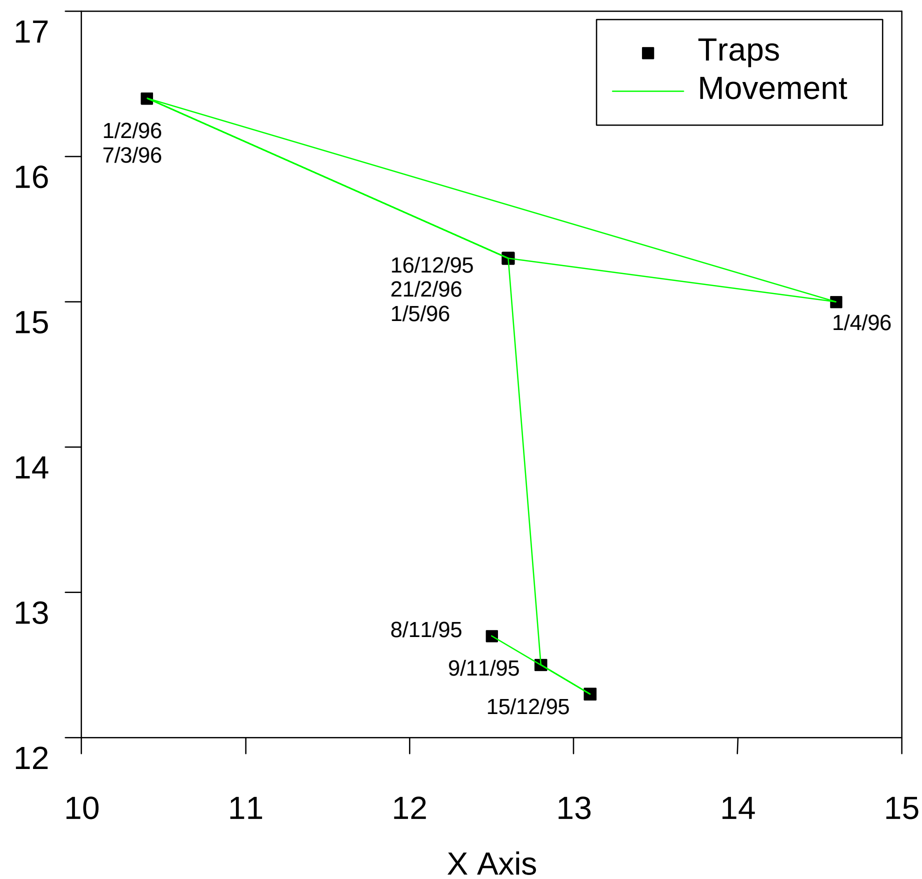


Figure 3-11 Recorded locations for hedgehog A016 during the period between 8/11/95 and 1/5/96.

A017 This animal was followed for only a short period due to untimely death. As an adult male he was captured in November 1995 on 'Queen Street' and was recaptured in the following month in 'Pampas Alley' (Fig. 3-12). Most movements were centered around 'Queen Street' where he denned in long grass along an open drain. He was trapped with a female in trap 9 on the 13th December 1995. It seemed, he was attempting to court her when she entered the trap. On the 17th December 1995 he was found courting A038 (who was not radio tagged at this stage). However a storm developed and the animal dashed into a cluster of bush on the periphery of three paddocks and remained there the following day. He was found dead in Trap 9 on the 20th January 1996. While the transmitter was recovered, the body was not and the cause of death is therefore unknown.

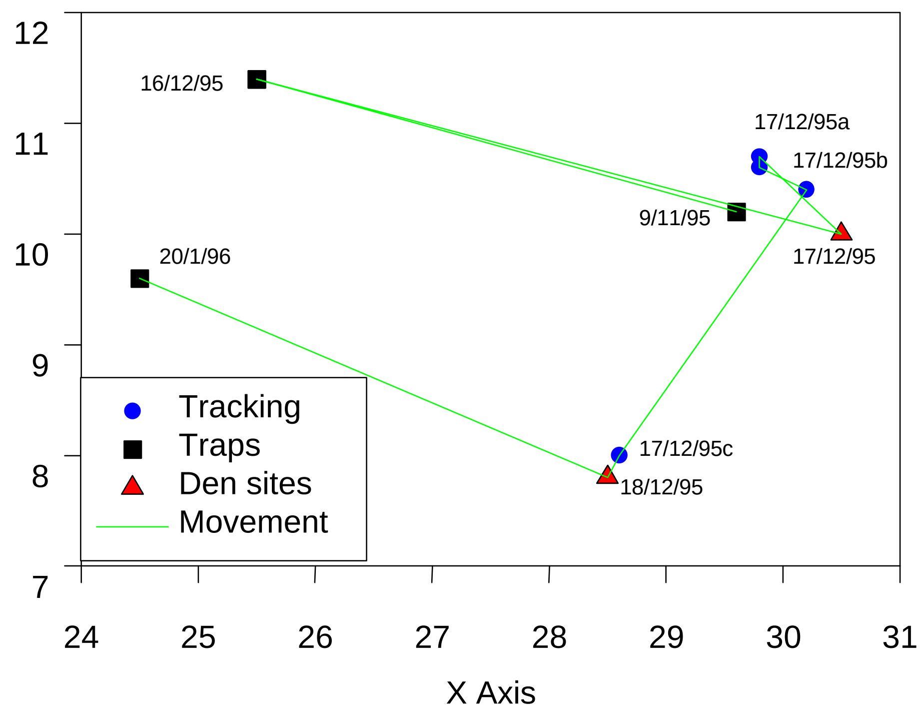


Figure 3-12 Recorded locations for hedgehog A017 during the period between 9/11/95 and 20/1/96.

A038 This hedgehog was an adult female who was tagged on the 17th December 1995 after being found together with A017. She was later trapped in 'Queen Street' for another two months (Fig. 3-13). In Feb 1996 it was decided to radio tag her and she was tracked throughout the month of March 1996. On each occasion when she was tracked, she moved in the same general direction. Starting from

'Queen Street' and moving out into open pasture, stopping for periods of up to 45 minutes to sleep. In mid April 1996 she was found being courted by an unknown male who was not subsequently eartagged. The last two locations were den sites situated in a line of pine trees in the long grass. She was culled on 7th May 1996.

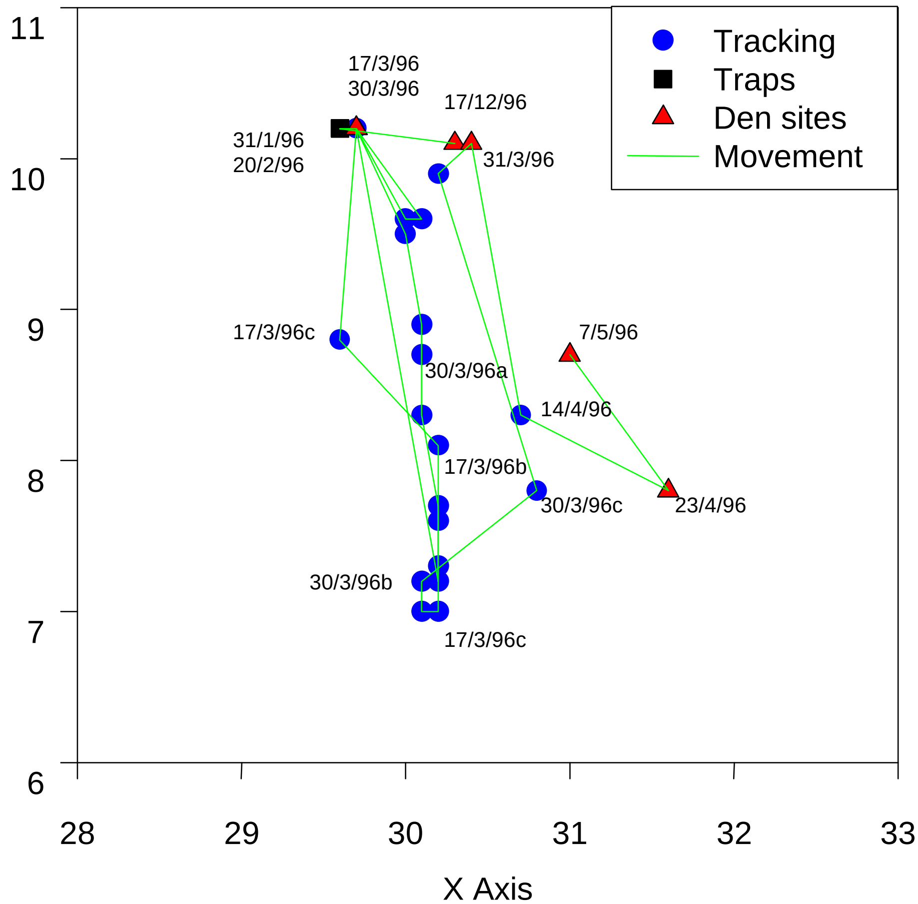


Figure 3-13 Recorded locations for hedgehog A038 during the period between 17/12/95 and 7/5/96.

Home range size

A summary of the size of home range areas is shown in Table 3-5. The average ranges for each of the two sexes for the different home range estimators is listed in Table 3-6. Each hedgehog's estimated range is displayed graphically in Figs. 3-14 through to 3-19.

Table 3-5 A summary of home range estimates in the tracked hedgehogs**.**

Animal Tag No.	*Sex*	*95% MCP [a] (Hectares)*	*80% Kernel (Hectares)*	*90% Kernel (Hectares)*
A013	F	5.08	7.01	8.83
A015	F	4.4	4.5	5.82
A038	F	3.02	3.3	4.59
A014	M	8.79	6.47	16.8
A016	M	7.41	12.09	13.1
A017	M	12.69	12.79	16.97

[a] Minimum convex polygon

Table 3-6 Average home range stratified by sex.

Sex	*95% MCP (Hectares)*	*80% Kernel (Hectares)*	*90% Kernel (Hectares)*
Females	4.16	4.93	6.41
Males	9.63	10.45	15.62

Most hedgehogs had a double ellipse shaped range when estimated using the kernel method, with the exception of A014 (Fig. 3-15) who had two separate ellipse areas. This gives an indication as to whether there is a tendency towards one particular region of the range compared with another. When compared with the minimum convex polygon, the kernel estimation gave an indication as to the area over which the hedgehog is most likely to traverse. Generally male home ranges are twice the size of females.

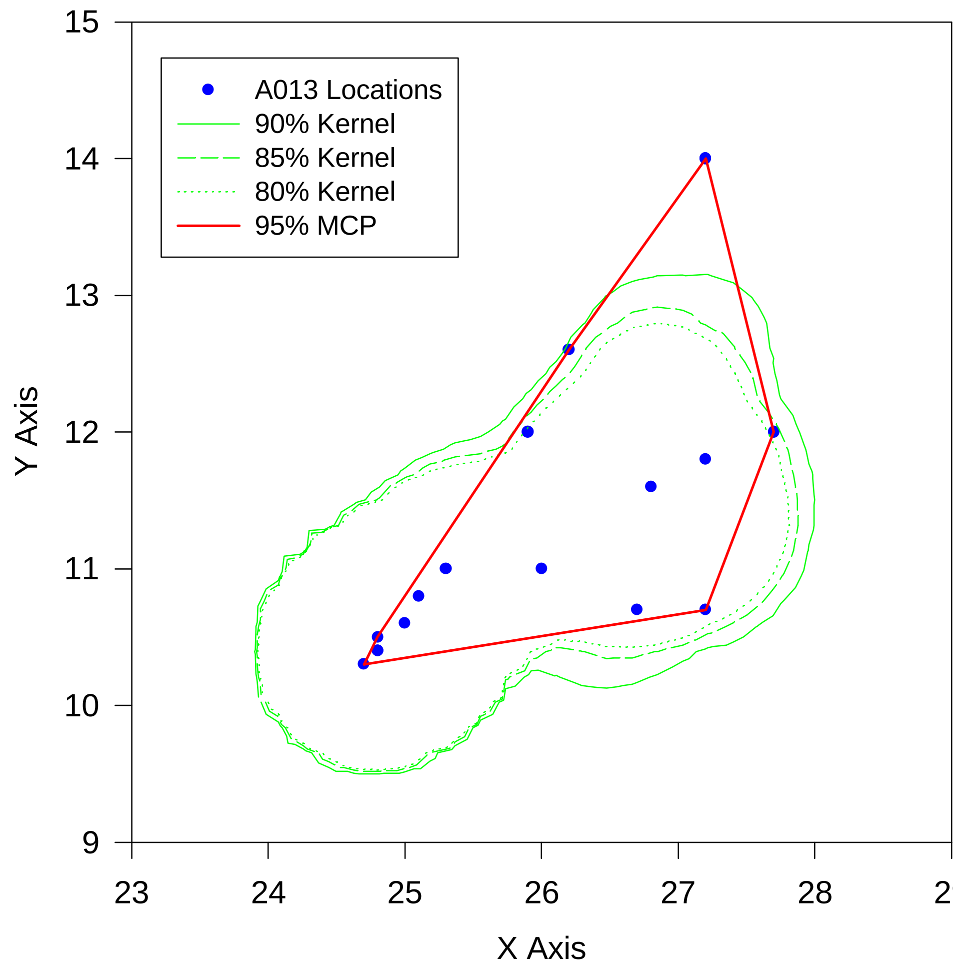


Figure 3-14 Home range estimates for hedgehog A013 based on all recorded locations.

A013 had the largest of the home range estimates among the females (Fig. 3-14). Her range focused around the habitat in which she nested. The longest side of the polygon represents this particular area. Her range also encompassed an area of pasture. There is a location at the extreme of her range (coordinate 27.2, 14) where she gave birth to a litter on 12/1/96. (Refer back to Fig. 3-8.). This point was excluded from the kernel estimation, but not from the minimum convex polygon estimate.

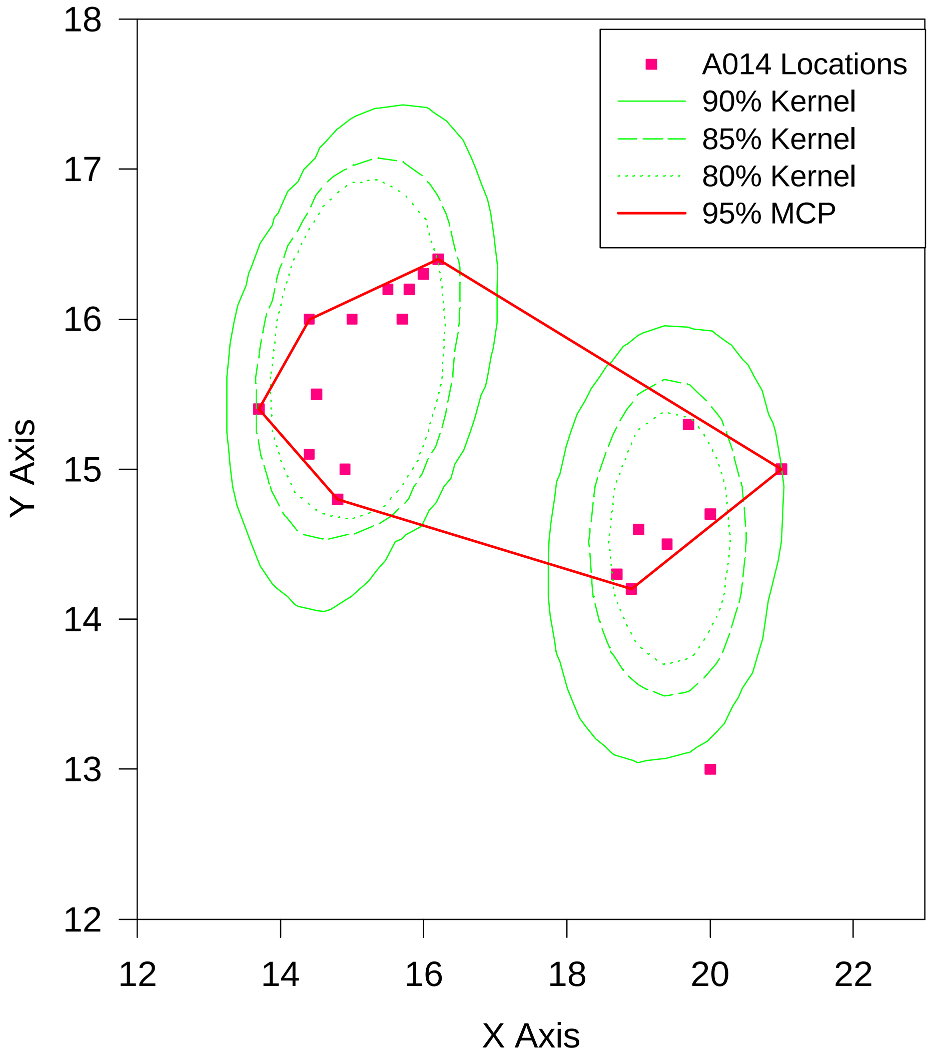


Figure 3-15 Home range estimates for hedgehog A014 based on all recorded locations.

The home range of A014 displayed a bipolar nature (Fig. 3-15). The kernel estimate indicates that he could be found at either extreme of his range. Referring back to Fig. 3-9 highlights that this animal spent a great deal of time travelling between the two areas. While the kernel estimate may reflect to a larger extent the area covered by this hedgehog, the minimum convex polygon estimate encompasses the area between the two extremes and gives a more accurate estimate in this case.

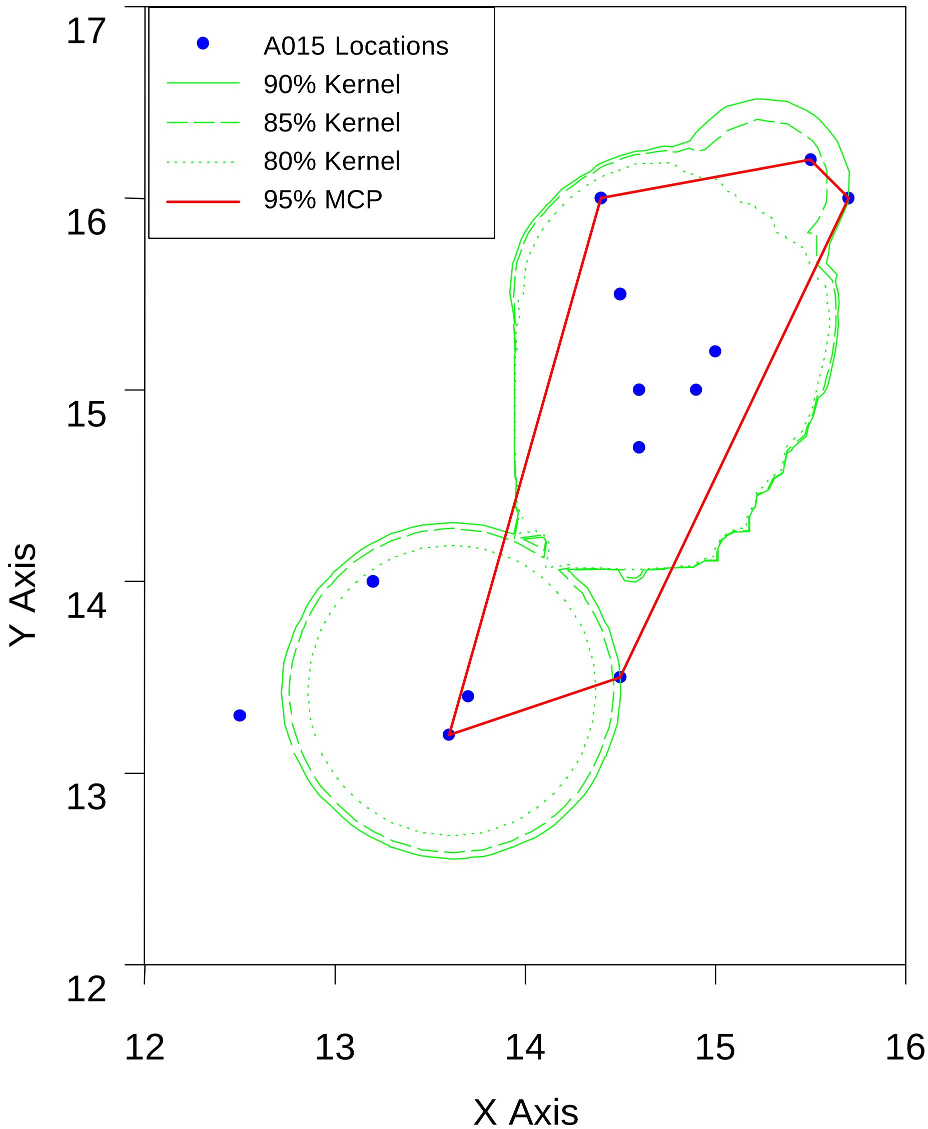


Figure 3-16 Home range estimates for hedgehog A015 based on all recorded locations.

A015's home range estimates focus slightly more around her chosen sleeping habitat while taking in nightly excursions into the surrounding pasture (Fig. 3-16).

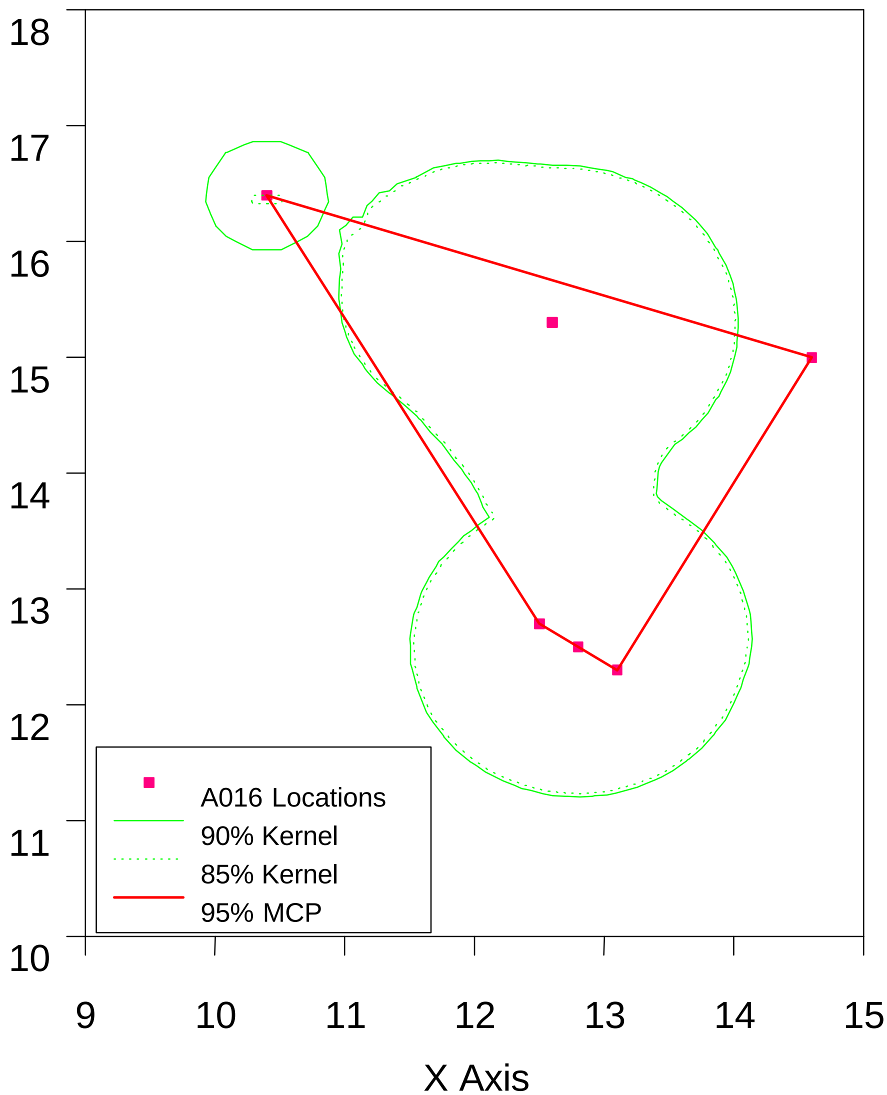


Figure 3-17 Home range estimates for hedgehog A016 based on all recorded locations.

A016 ranged over a variety of sites and from trap data alone (Fig. 3-17). The size of his home range is similar to that of the other two males. A majority of time was spent centered around pasture while being consistently trapped on the edges of bush.

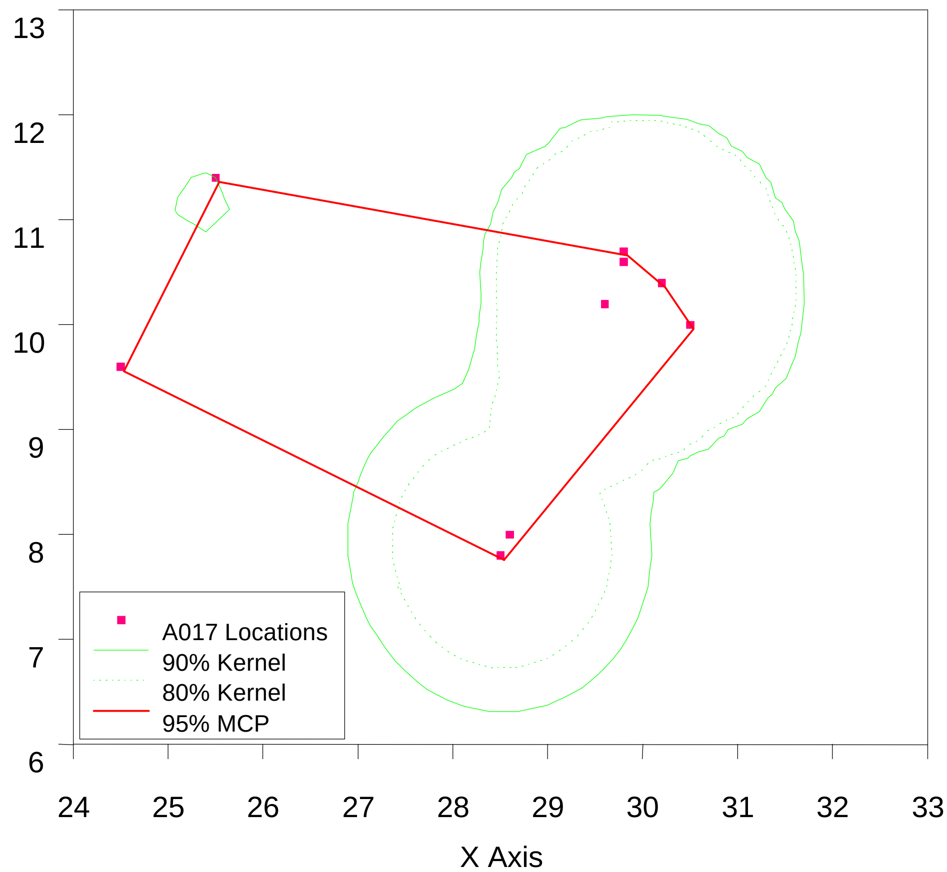


Figure 3-18 Home range estimates for hedgehog A017 based on all recorded locations.

According to the kernel estimate, A017 focused his activities around one end of his range, occasionally making excursions up to 'Pampas Alley' where he was trapped (Fig. 3-18). 'Queen Street' is an area of habitat and long grasses where A017 was predominantly found to nest.

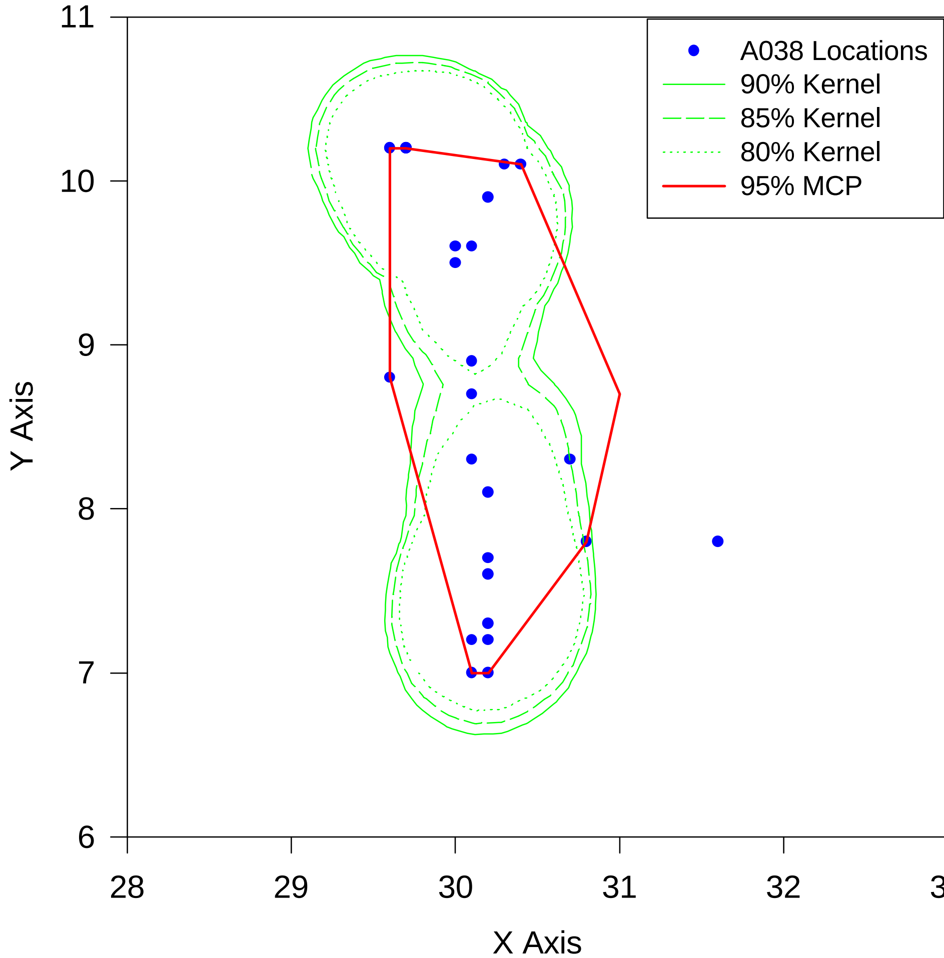


Figure 3-19 Home range estimates for hedgehog A038 based on all recorded locations.

A038 displayed the smallest home range amongst the females (Fig. 3-19). Her range concentrated around 'Queen Street,' a predominant nesting site, and surrounding pasture was minimally used. That is to say - from observations of her movements - she was predictable in where she is mostly likely to be when foraging at night.

The size of the overlapping home range areas were estimated using the 95% MCP estimate. Each hedgehog has some area of overlap with another tracked hedgehog in this study.

Figure 3-20 shows one male and two female hedgehogs whose range estimates overlap. The females' ranges never overlapped during this study, but the male (A017) overlapped both of the females' ranges. A017 shared 1.5 hectares of A013's range estimate, whilst also sharing 0.57 hectares with A038.

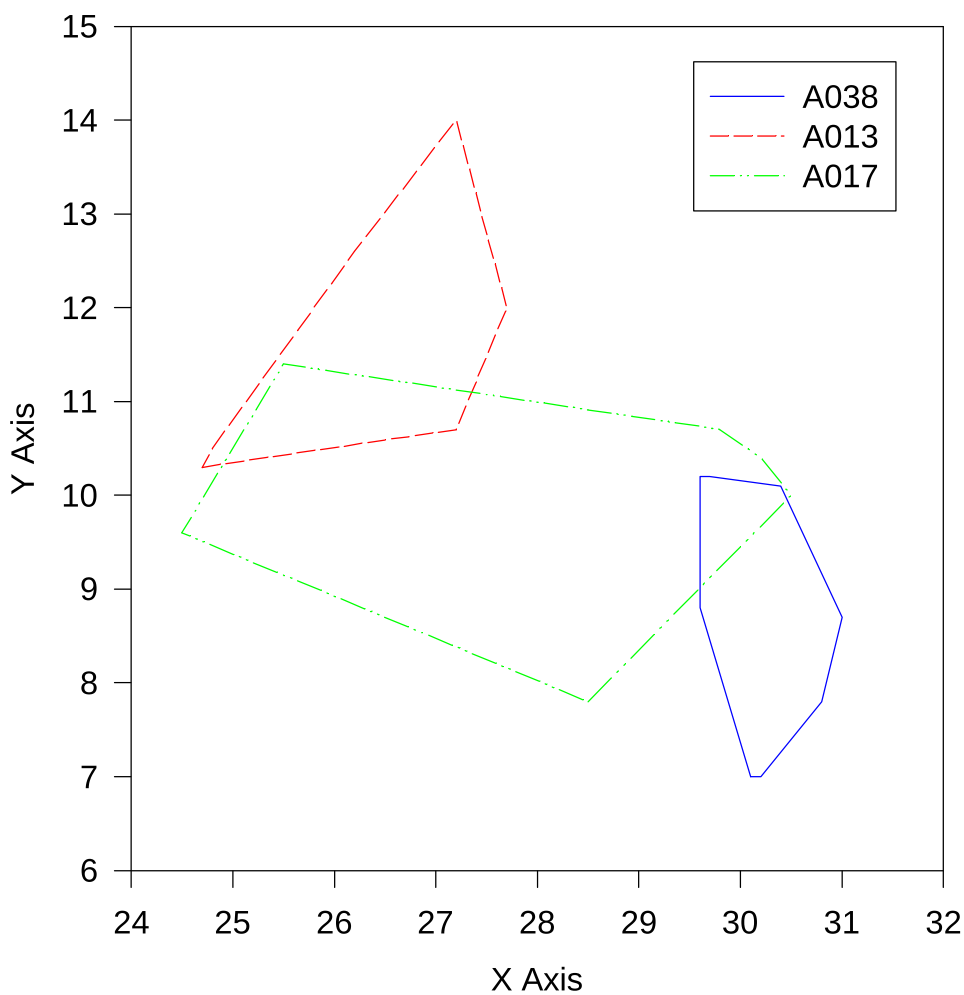


Figure 3-20 Overlapping home ranges of A013, A017 and A038 based on 95% minimum convex polygon estimates.

Fig. 3-21 displays home ranges of one female and two male hedgehogs whose ranges overlap. Each shared a common area of 0.14 hectares. This was also the common area of the two male hedgehogs; A014 and A016. Comparison with their respective kernel estimates suggests this shared area was infrequently used. A015 shared 0.58 hectares with A016 and 1.34 hectares with A014.

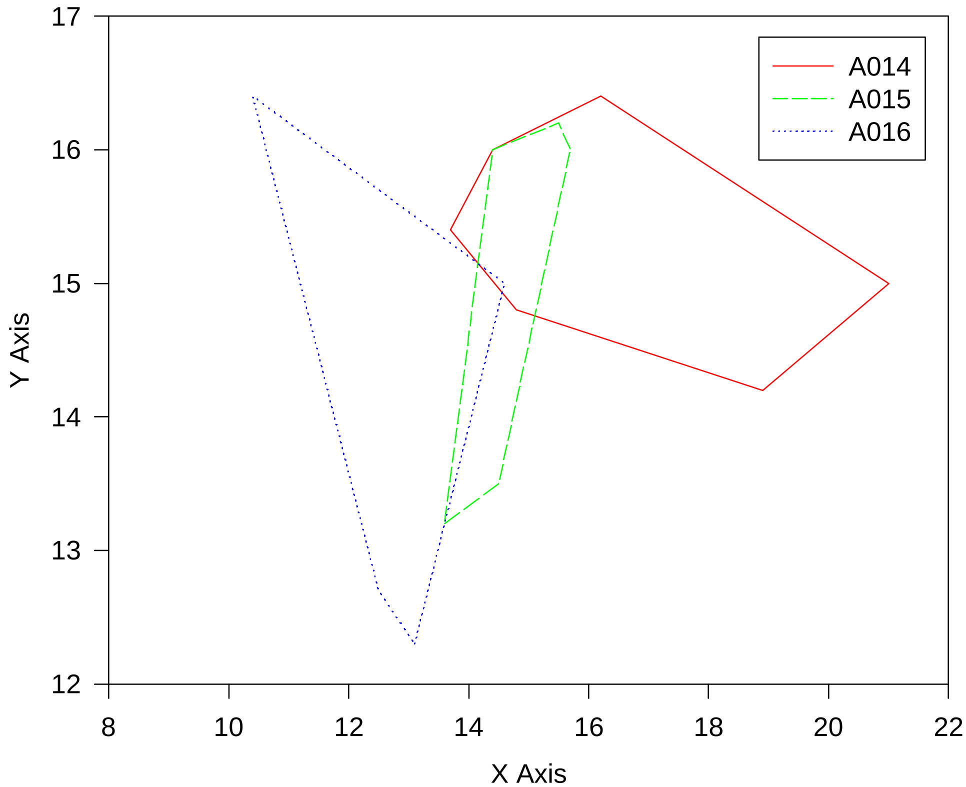


Figure 3-21 Overlapping home ranges of A014, A015 and A016 based on 95% minimum convex polygon estimates.

Discussion

Trapping success in this study seemed to depend on the weather conditions as well as the availability of the traps. Windy and wet weather conditions often resulted in low catch success. One area of the study site was flooded during the majority of the study period and only one hedgehog was ever captured there. Capture success of the traps was influenced by the placement of traps in and around the habitat, the placement direction of the entrance in animal trails, the scent left by previous captures and saturation of traps by captured animals. Captures were more successful when traps were placed around known hedgehog habitat and possible nesting sites. The trap design only allowed the hedgehog to enter one way rather than having access to the trap from all angles like a leg hold trap. Should a trap have been placed incorrectly this would have reduced its availability for trapping animals. Scent left by previous captures is another potential cause of reduced availability. While there is no evidence to support this, it is considered that hedgehogs may be scent orientated in their mutual avoidance of each other.(13) A positive aspect of the trap design is that once a hedgehog was captured, it did not necessarily make the trap unavailable. There were occasions where more that one hedgehog was captured per trap per night. While there have been other capture-mark-recapture studies conducted with hedgehogs there has been little discussion about the trappability of hedgehogs. Other studies only discuss the numbers captured rather than how they were caught.

Given the time span, the total number of hedgehogs captured, 166 over the eight to twelve months study period is comparable to other New Zealand studies. Brockie captured 207 over a two year period while Parkes caught 150 in eighteen months and Campbell located 100 over three years of study. However, it is important to note that the three authors mentioned had limited study site sizes (<30 hectares versus 323.8 hectares) and trapping patterns varied greatly.(2, 4, 10) The use of a Jack Russell Terrier for finding additional hedgehogs in this study greatly enhanced the capture probability.

The estimated population density of 0.88 ha^{-1} is similar to British estimates however is lower than Parkes' (10) 2.5 ha^{-1}estimation recorded during a New Zealand summer in pasture and pine plantations habitats. My study period ranged over spring and summer, and areas where hedgehogs were found were clustered on this site meaning the area actually utilized by the hedgehogs was smaller and would give a larger density if a more accurate area size could be calculated.

Hedgehogs were predominantly captured around habitat containing dense, dry ground cover and bush. This is consistent with Brockie's and Morris' description of their ecological niche in New Zealand.[2, 9] Pampas grass provides an excellent nesting site for hedgehogs as they can burrow very deeply into its leaves, creating a secure and dry nest. Pampas grass is a popular choice for shelterbelts on farms in New Zealand and is frequently found on bush/pasture margins.

Recapturing animals was difficult due to the large numbers of animals which appeared to have dispersed immediately after initial capture. It could also reflect trap shyness and/or trauma caused by handling which might have made hedgehogs avoid traps. It should also be noted live trapping may cause an increase in locomotory activity after release and thereby affect subsequent movements.[7] Of those which were recaptured, they were more likely to be males than females.

The ratio between males and females captured varied over the study period. Initially more males were caught and towards the end of the active season more females were captured. While the overall ratio between males and females was 1:1, other authors have noted this shift in ratios. Males tend to emerge first from hibernation, up to a month before females are noted to appear. Similarly males return to hibernation earlier than females. This is thought to be directly related to their courtship and mating behaviour[13] (see the discussion below about body weight fluctuations).

Juveniles did not appear in the population until 6-8 weeks into the active season. The gestation period of a hedgehog is 6 weeks followed by rearing for 4-6 weeks before the hoglets leave their mother. Appearance of the juveniles in December suggests that there were females active in October even though only one female was trapped during this time. Late into the hedgehog active season juveniles were more likely to be found or trapped as the adults went into hibernation for winter and juveniles were focused on achieving a maximum weight gain before the weather forced them into hibernation. Brockie found those juveniles which weigh below 400g have a reduced chance of surviving winter.[2]

The body weight in adult hedgehogs was normally distributed, while the distribution for juveniles showed skewness. Age at time of capture directly relates to the weight of juveniles as most juveniles were caught at 8-10 weeks of age. Very few juveniles were ever recaptured and it seems plausible that most juveniles may have been captured during their dispersal from the nest. Adult hedgehogs displayed significant weight fluctuations. This has been documented before[1, 13] and relates to the courting behaviour of both males and females. Males seem to emerge from hibernation in an excellent body condition. It is hypothesised that during the time until the females emerge, the males have the opportunity to gain weight. During the rest of the season, males experience a drop in body weight due to courting and mating. It is not until late in the season that male hedgehogs begin gaining weight for the following winter sleep. Females also show significant weight fluctuations. They begin the active season in excellent condition but show an increase in weight. It is logical to presume this is due to the weight of the growing foetuses because the females later lose condition due to the stress of lactation. It is possible for females to have two litters per season and the small increase in mean weight in February may reflect a second gestation period for some as well as other female hedgehogs becoming pregnant. Late return to hibernation probably represents the time taken for females to regain sufficient condition, so that they can survive winter.

Condition scoring in hedgehogs has never been standardised and even with a fairly regimented system the score is still a largely subjective decision made by the examiner. Juveniles were never scored as having a condition score greater than 4. The distribution of adult condition scores was skewed towards the lower end of the scale. The problem arose because of the classification of age, which was based on body weight, length, condition and the time of year. A juvenile in excellent condition weighing say 400 g in February could have been misclassified as a poor condition adult. Most hedgehogs in the adult age group, which were assessed as being in poor condition were diseased, wounded or misclassified.

Mortality in the population seemed low, although it is rare to find carcasses of wild animals. It is difficult to distinguish mortality from dispersal. Because such a large proportion of hedgehogs disappeared, the true extent of mortality cannot be assessed. While digging out radio tagged hedgehogs from under pampas grass, I would come across hedgehog carcasses about eighty percent of the time, but no ear tags could be found with them.

In culling the population at the end of the study, it was interesting to note that 97 hedgehogs had been tagged and ninety-eight hedgehogs were culled. Only twenty-seven of the tagged animals were included in the population captured during the cull, which meant seventy-one individuals were new. To continue finding such large numbers of new individuals in a population, which has been studied for an extended period of time, suggests the total population may not have been adequately sampled during the capture-mark-recapture study period.

Tuberculosis was not found in the population. The study site had been extensively researched in the three years prior to beginning of this study. During these surveys, possums and ferrets were found to be positive for tuberculosis infection. Two hedgehogs were also found with tuberculosis during these investigations. However as a result of the extensive trapping regime which had occurred during these surveys; this study coincided with an ebb in tuberculosis prevalence. Because the hedgehog is considered to be a spillover host for tuberculosis, the removal of the main reservoir species removes the risk of infection for hedgehogs. Hence no tuberculous hedgehogs were found. During the time of the study the farm was taken off movement control because it had had two negative tuberculin tests.

One disease prevalent in the hedgehogs was a particular granuloma present in the lungs of seven hedgehogs, predominantly juveniles. This disease appeared to be clustered in two distinct areas of the farm. Initially the suggestion was that this pathology was caused by a fungal infection. All suggestions for a possible aetiological agent were found to be negative or non-conclusive on further investigation by histological means even though there were some fungal hyphae present in some slides. The only factor specific to these geographically or environmentally distinct areas in terms of hedgehog habitat was that the two areas were prone to spring flooding.

Other diseases found in hedgehogs are discussed in Chapter Four.

Home range analysis showed males have a significantly larger home range compared with females. This supports other findings where male home ranges are approximately twice that of females.[2, 4, 10, 13] In New Zealand hedgehogs, home ranges are considered to be underestimated due to the limited size of the study areas. However these estimates are similar to the findings in this survey. The extent to which males exceed the female ranges is considered to be associated with mating behaviour. Males will roam over greater distances in search of females, while females are more involved in rearing young and do not travel far.

The kernel method for home range sizes seemed to generate results comparable with the minimum convex polygon. However, it was evident for larger percent parameters of the kernel (ie. 90-95%) that ranges were overestimated.(14) In one case, the kernel underestimated the range of A014 because this animal constantly moved between the two extremes of its range, sometimes covering most of the range during a single night. This behaviour was associated with the availability of sleeping habitat. For, at both extremes of this hedgehog's home range were clusters of native bush, and its activities each night were centered initially around these areas.

Error for estimating home range estimates could have been introduced through a number of different sources. The time between each fix, length of recording time and the total number of fixes all significantly affect the estimation of home range.(15) Weather conditions influenced the radio tracking not only because the equipment needed extra protection in the rain but also hedgehogs do not venture far from their previous night's sleeping site. Otherwise the hedgehog heads straight for the nearest cover if the weather sets in for the night and stays there, often not leaving until the next night. So, if the animal has not moved for hours there is very little useful data to collect. While these stationary type fixes may not influence a minimum convex polygon estimation, the kernel estimation will be greatly affected. Thus a true representation of the range is skewed through the effect of a confounding external factor such as bad weather.

Overlapping home ranges were evident in this study. It is known that hedgehogs are not territorial and tend to share habitat. While the sample population for radio tracking was small even in the two areas where hedgehogs were tracked, all hedgehog ranges overlapped with at least one other hedgehog. If trap captures are considered, the density of hedgehogs sharing an area can be high or low depending on the type of habitat available.

The use of each hedgehog's home range can almost be anticipated when tracking an individual animal and showed in the analysis. Hedgehog A038 displayed a somewhat stereotyped activity pattern in the nights she was tracked. Both nights the hedgehog covered virtually the same ground, starting from the same sleeping site and heading in a similar direction she had been tracked taking during the previous two weeks. Other hedgehogs in this study also behaved quite predictably as to their spatial activity. The author has noted when rearing hedgehogs, they also display this stereotyped approach to investigating their environment.

This nature could be exploited if hedgehogs are reliable sentinel animals for tuberculous possums. Possums can have home ranges similar to that of hedgehogs. However possum home ranges are only meaningful if applied to environments similar to those for which they were initially estimated. It has been found that possums living in densely forested areas have smaller ranges than possums from pasture-forest environments.(11) In densely forested areas possums tend to range over 0.3 – 4 hectares while possums with access to pasture can range up to 6.5 hectares. Paterson found in his study of possums in the Castlepoint area of the Lower North Island of New Zealand, that the average range was about 6 hectares if possums had access to pasture. This home range is similar to that of the female hedgehog. In both species males tend to have larger ranges than females, hence female hedgehogs could provide a specific local indicator of the presence of tuberculous possums and male hedgehogs could locate the general region on the farm with tuberculous possums. In areas with large farms, locating tuberculous hedgehogs could substantially reduce the area where extensive control is required to eliminate tuberculosis from the possum population.

This study was unable to conclusively support this hypothesis as no disease was found in either the possum or hedgehog populations. However during previous surveys in the same location, tuberculous possums, ferrets as well as two tuberculous hedgehogs had been removed from the farm. These animals came from a specific area of the farm. Hedgehogs are spillover hosts for *M. bovis,* which means the prevalence of disease in the hedgehog is directly related to the prevalence of disease in a local reservoir population such as the possum. Eighteen months after extensive control efforts on this study site neither hedgehogs nor possums were found tuberculous and the farm was taken off movement control status. This would suggest hedgehogs could provide a temporally as well as spatially specific indicator of tuberculosis in wild animal populations. Chapter four of this thesis describes a prevalence study, which attempts to further clarify the concept.

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Chapter 4

A prevalence study of tuberculosis in New Zealand hedgehogs.

R.J. Gorton, D.U. Pfeiffer and R.S. Morris.

Introduction

Mycobacterium bovis infection is considered endemic in some areas of New Zealand. In most of these regions the Australian brushtailed possum (*Trichosurus vulpecula*) still appears to be the most important reservoir of infection. Various approaches are currently being investigated to develop "hot spot predictors" to assist control efforts.

It seems likely that many hedgehogs in endemic areas will be exposed to *M. bovis* infection through investigation of decomposing carcasses, especially of possums. Hedgehogs have a home range similar to possums [(4)], and the presence of tuberculous hedgehogs may be an indication of a cluster of infected possums denning within a hedgehog's home range.

This study investigated the prevalence of tuberculous hedgehogs in areas considered endemic with *M. bovis* infection and the plausibility of using hedgehogs as an indicator species for tuberculous possums.

Materials and Methods

Three regions in New Zealand were selected mainly due to ongoing projects and the ease of collaboration. Four farms in the Wairarapa district were selected. Each farm had a history of Tb movement control and was part of a PhD project investigating grazing management (pers. comm. Carola Sauter-Louis). Two separate ferret studies conducted in the South Island of New Zealand supplied hedgehogs as non-target captures from North Canterbury and Otago respectively.

The North Canterbury site is part of a four-year survey (Peter Caley of Landcare [(1)]) studying ferrets and consists of three sites. Hedgehogs for this study were collected from only one of these sites.

The Otago survey started in January 1993 and ended in February 1994 (Justine Ragg of Otago University [(3)]). A total of 20 farming properties were sampled throughout the region of Otago and parts of Southland comprising of 15 infected properties and 5 controls. The area ranged from Gore up to Twizel in North Otago and from Milton on the coast to as far inland as Cromwell.

The four farms in the Wairarapa were trapped for a period between one to three weeks using the same type of trap described in Chapter Three. Up to 108 traps were set on each site, baited with tinned cat food and checked daily.

Each hedgehog caught was euthanased using an intraperitoneal injection of 2ml sodium pentobarbitone. Hedgehogs collected from the South Island sites were euthanased by either barbiturate or ether. Each hedgehog was autopsied as described in the previous chapter and examined for tuberculosis.

GPS (Global Positioning system) data was collected from each Wairarapa farm to allow calculation of area trapped. A Pathfinder™ (TDC1) rover system consisting of a hand held datalogger and antenna, supplied by Trimble Navigation, Ltd. California, was used to log into available satellites orbiting overhead and gather two dimensional point fixes in longitude and latitude units. Base station data was obtained from Terralink Inc, Wellington and used to differentially correct the rover files. Trimble Navigation software Pathfinder Professional Post-Processing Utilities Version 2.5X-02 was used to adjust the data recorded in the rover files and calculate the size of areas in hectares.

Calculation of the probability of not detecting disease was based on equation 4.1. The software WinEpiscope 1.0 (K. Frankena, Agricultural University, Wageningen, Netherlands) was used to calculate confidence limits for finding the disease in the given sample size, and confidence intervals were calculated using equation 4.2.

Eq. 4 1: $P = (1\text{-prevalence})^n$

Eq. 4 2: $CI = \text{Prevalence} \pm 1.96 \sqrt{[\text{Prevalence } (1 - \text{Prevalence})/n]}$

Results

Three hundred and seventy five hedgehogs were collected from six sites situated in the Lower North Island and the South Island of New Zealand. The total numbers captured from each site are listed in Table 4-1. The HOH site had the lowest catch success while the sample from the HUO site was the largest. The HUO site consisted of twenty-one cluster samples. The average sample size was 12 with a standard deviation of 10 (the range was 1-36).

Table 4-1 Number of hedgehogs captured on each site.

Location	ID	Number of hedgehogs.
Nth Canterbury	HNC	54
Otago	HUO	253
Wairarapa	HCP	19
	HFB	24
	HOH	4
	HPK	16
	Unknown	5
Grand Total		375

The total area of land trapped on each Wairarapa site varied greatly (Table 4-2). Fig 4-1 shows a slight linear relationship between the size of the farm and numbers of hedgehogs captured on each site. However in considering the proportion of the farm area actually trapped, there is no correlation between hedgehog numbers and area (Fig 4-2).

Table 4-2 Percentage of land included in the trapping grid on each Wairarapa farm.

Farm ID	Farm size (Ha)	Trapping Grid (Ha)	% covered
HCP	2360.4	75.948	3.2
HFB	1391	9.272	0.06
HOH	605.6	11.777	1.9
HPK	1184.9	111.545	9.4

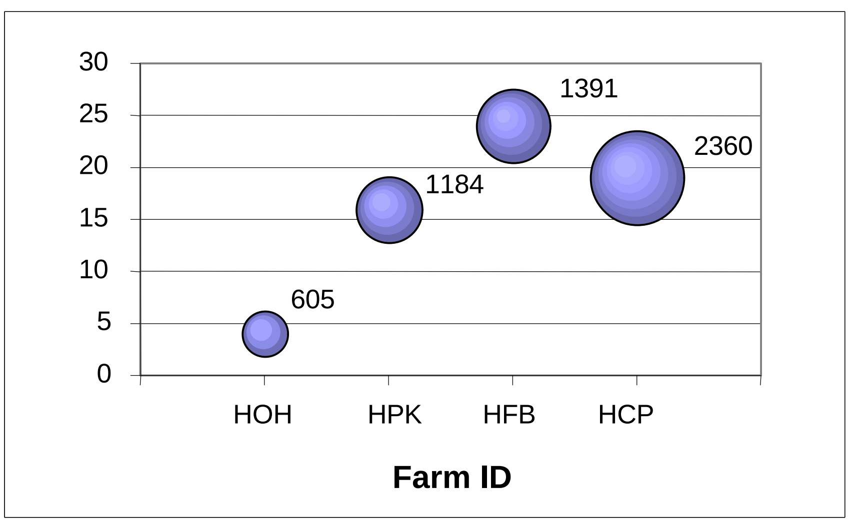


Figure 4-1 Comparison between farm size and the numbers of hedgehogs captured.

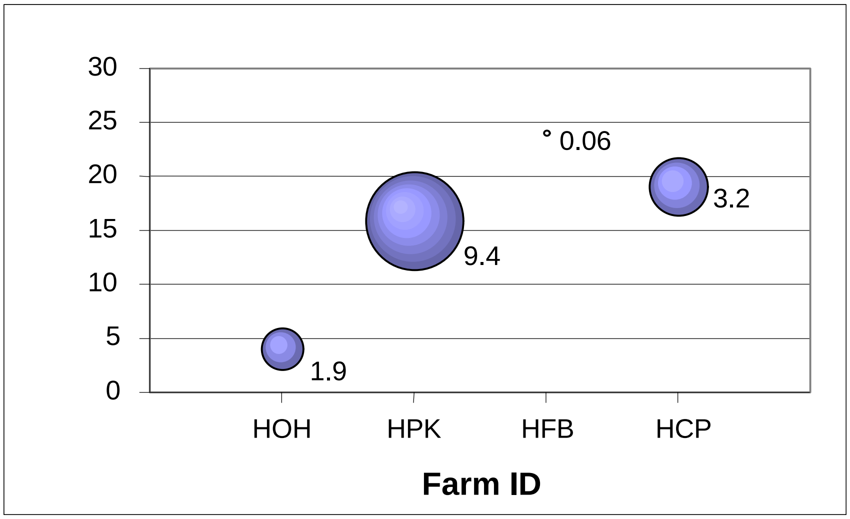


Figure 4-2 Comparison between the proportion of the farm covered by the trapping grid and the total numbers of hedgehogs captured.

Habitat Description

Each site included in the study had unique habitat that supported a variety of wild animals. The following is a description of the habitats with reference to the abundance of hedgehogs.

HCP: This site was a large farm covering more than 2000 hectares. Situated on the East Coast of the North Island, this site consists of steep rolling hills and is quite exposed to the sea and weather (Fig 4-3a.). Apart from a state forest bordering the back of the property, there were very few areas of bush and scrub on the farm except for the occasional line of pampas grass. It was usually very wet underfoot in the valleys, and creeks needed to be forded regularly. Most hedgehogs were captured along the back paddock boundary to the state forest or in pampas grass.

HFB: Situated in Tinui valley this site consists of rolling hills and large sections of native bush (Fig 4-3b.). Areas of bush often bordered on open pasture. Animals were regularly allowed to graze in the larger sections of native bush. Most areas of bush were open and had little ground cover. That is, it was easy to walk through. One area consisted of dense bush with excellent ground cover; it covered a valley with a creek running through the middle. Fifty-eight percent of hedgehogs were captured from this area (14/24).

HOH: This farm was also situated on the East Coast and was extremely exposed to all elements of weather (Fig 4-3c.). There were very few shelterbelts available on the farm except for a long stretch of macrocarpa trees lining the cliff edge. There was also a stand of pines surrounding the house. This site neighboured the HCP site and was jointly managed by HCP staff. Only four hedgehogs were captured at this site.

HPK: This was a neighbouring site to HFB. Situated in Tinui this farm stretched along the river and extended back into the hills. There was a large diversity of habitat. Surrounding the house were clusters of pampas and flax grass. Other areas consisted of crops of Brassica and long grass surrounding the crops. Towards the interior of the farm were large areas of tussock before finally entering an enclosed valley. This valley had ideal habitat for many of New Zealand’s wild animals, yet was enclosed by steep cliffs and a stream, which had to be forded to gain entry to the valley. Entry to this valley could only be gained by horseback or on foot. Fifty percent of the hedgehogs were caught in the tussock area. No evidence of hedgehogs was ever found in the valley.

HNC: This site was situated in North Canterbury and comprised of 3672 hectares of semi-arid habitat. Seventy five percent of the study site consisted of improved pasture, shelterbelts and some small forestry blocks. The remainder of the area, called the Top Block, was hilly and presented a mixture of scrubby gullies, open tussock faces, rocky outcrops, streams and banks of bracken fern. Hedgehogs were captured from all over the site.

A:

B.

C.

Figure 4-3 Different types of landscape and habitat on three of the Wairarapa farms. A: HCP, B: HFB, C: HOH.

HUO: The area ranged from Gore up to Twizel in North Otago and from Milton on the coast to as far inland as Cromwell. The geography of the area was highly varied from dry barren tussock land in Central Otago to dense bush and native forest on the Otago coast. Hedgehogs were captured from a wide range of habitats given the size of the study area.

Tuberculosis History

Both HCP and HOH were being managed together in such a way that grazing management patterns were variable and a lot of shifting of stock occurred between the farms. The owner had six tuberculin reacting cattle in 1996, three of which had tuberculous lesions at slaughter. No area on the farm could be defined as a potential hot spot risk. No tuberculous possums, ferrets or hedgehogs were found on these two farms.

HFB had 51 reactors in the first half of 1996 of which 26 had tuberculous lesions at slaughter. These animals had been grazing around a section of native bush known as the middle block (Fig 4-4). In 1997 there were 13 reactors of which ten had lesions. These animals had also been grazing around this area. Tuberculous possums, ferrets and hedgehogs had been found previously in the past on this property.

Six cattle reacted to tuberculosis testing in 1996 from HPK. Three had tuberculous lesions at slaughter. These animals had been grazing in and around the enclosed valley. One tuberculous possum was also found in this valley.

Five contiguous properties in the North Canterbury area were selected because of Tb breakdown in their cattle stock during 1992-94. Extensive trapping for ferrets began in November 1994 as well as intense possum control in 1993. Hedgehogs were captured during the ferret study.

The HUO site included properties that had not received any recent possum control (i.e. none over the last 5 years). While some farmers had done some low-level control this would have had very little impact. Each of the properties in the endemic area of Otago had an ongoing tuberculosis problem. Tuberculous possums had been found on some properties while others have yet to detect possum infection. Approximately 120 possums and 253 hedgehogs were captured during the study and none revealed tuberculous lesions. Eleven out of the 17 infected properties sampled had tuberculous ferrets. No tuberculous wild animals were detected on the control farms.

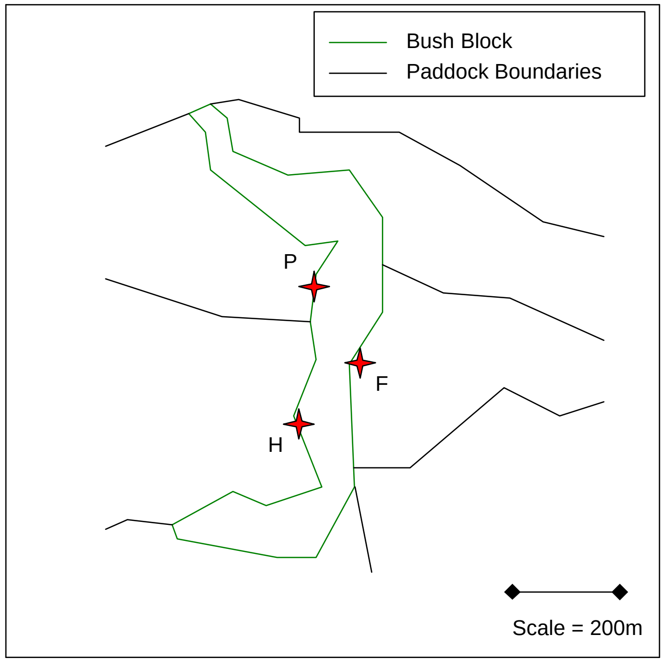
Tuberculosis Prevalence in Hedgehogs

Only one hedgehog in the total Wairarapa sample of sixty-nine, cultured positive for *M. bovis*, giving a prevalence of 1.5% (95% CI: 0-4.3%). The tuberculous hedgehog came from the middle block on the HFB site. Trapping around this middle block in March 1997 initially resulted in the discovery of a tuberculous hedgehog, followed by a tuberculous ferret and possum. Twenty-four hedgehogs were removed from this site giving a specific local prevalence of 4.2% (95% CI: 0-12%).

Each of the tuberculous animals (i.e. the hedgehog, ferret and possum) were captured within an area of 1.124 hectares. The distances between the locations where the animals were caught is listed in Table 4-3. The measured distance is represented as a linear measurement and does not take the surrounding habitat into account. The ferret was captured on the opposite side of the block at the top of a cliff, while the possum was captured on the other side of a creek, which ran though the middle of the block (Fig 4-4). However despite the seemingly variable geography of the area, consideration of average home ranges of each species shows considerable overlap in the range of each animal.

Table 4-3 Distance between capture sites of the tuberculous animals**.**

Tuberculous animals	Distance (metres)
Hedgehog and ferret	143.952
Hedgehog and possum	310.726
Ferret and possum	222.068



H = Hedgehog, P= Possum, and F = Ferret.

Figure 4-4 Positions where each tuberculous animal was captured around the middle block on the HFB site.

The Ability to Detect Disease

Assuming that the expected prevalence of tuberculosis in hedgehogs is about four percent [(2)], the probability of not detecting disease is listed in Table 4-4 for the five sites negative for tuberculosis in the hedgehog population.

Table 4-4 Probability of failing to detect disease in the population.

Site	Sample size	Probability of failure
HCP	19	0.46
HOH	4	0.85
HPK	16	0.52
HNC	54	0.12
HUO	12 (average)	0.61

Estimation of the prevalence of disease at the HFB site is 4.2%. The probability of diagnosing at least one diseased animal out of a sample of 24, given a population of 100 and an estimated prevalence of 4% is 67.27%. The 95% confidence interval suggests that the true prevalence lies between 0-12%.

Discussion

Trapping techniques employed in this study experienced the same problems as the longitudinal study presented in Chapter 3. Both weather and suitable habitat were the limiting factors. Areas that were exposed to high winds and rain or had sparse ground cover yielded low numbers of hedgehogs.

Neither the size of the farm nor the area trapped had a meaningful correlation with the numbers captured in the Wairarapa samples. However as only four farms were sampled from this district, the sample size is too small to deduce any firm conclusions. Given the habitat descriptions of most areas it seems plausible that the trap success is strongly influenced by the surrounding habitat and its suitability for hedgehogs. HOH was an extremely barren place with very few shelterbelts, and had the lowest captures whereas HFB, with pockets of scrub with dense, dry ground cover, was synonymous with high numbers of hedgehogs captured.

In most places pampas grass or native bush with dry, dense ground cover was associated with high catches of hedgehogs. In contrast areas that were damp, unsheltered or barren were associated with low numbers of hedgehogs captured.

Possums use a wide range of habitat types of which the hedgehog would co-inhabit about one-third. Some areas suitable for both species may also have geographical features such as rivers or cliffs that isolate an area from either species. This was true for the HPK site where a stream, which crossed over the entrance to the valley, effectively isolating the area for movements of animals. This valley had been identified as a potential hotspot and could successfully support hedgehogs, however no evidence of hedgehogs was ever found within the valley.

Clinical histories of the area showed that *Mycobacterium bovis* infection was still prevalent in both stock and wild animals.

The prevalence of tuberculosis in hedgehogs has been estimated to be about 4% in the Wairarapa district [2]. Coincidentally, the tuberculous hedgehog diagnosed in this study also came from the Wairarapa. However, the sample size of tuberculous hedgehogs in this study was too small to provide strong support for the prevalence estimated by Lugton et al [2]. At this sample size of 24 hedgehogs this study can only state that in the HFB study area the true prevalence is likely to be somewhere between 0 and 12%.

The probability of failing to detect disease was relatively high on most sites excluding the HNC site, because the sample sizes for most sites were too small assuming that the expected prevalence would be about 4%. The HUO sample consisted of 21 sites and the average number of hedgehogs per site was 12. Sixty six percent of the farms captured less than the average number while 4 farms captured between 25-35 hedgehogs each. Because the hedgehogs were collected as a non target animal in the HUO study, the sampling method was not a structured one.

There was no evidence of tuberculosis in hedgehogs that came from ferret studies. However this could be confounded by the fact that both sites had possum control occurring during the study period and the apparent short persistence of disease in hedgehog populations. The vast diversity of habitats that the two studies ranged over may also have contributed to this result, with the hedgehog and the ferret inhabiting different ecological niches.

It is important to note that the viability of the HUO samples was also questionable. These samples had been deep-frozen for at least two years and had also experienced defrosting on a number of occasions when the equipment they were stored in broke down. Hence, although at post mortem there were lesions suggestive of tuberculosis, it was not possible to culture any bacteria. However impression smears of the lesions did not show acid fast microorganisms either.

Although only one tuberculous hedgehog was found in this study, this does not discount the original hypothesis of using hedgehogs as an indicator species for tuberculous possums. While it is difficult to understand the true status of the disease in a population from which only tuberculosis negative hedgehogs were sampled, given an adequate sample size the detection of a tuberculous hedgehog can be a strong indication of other tuberculous wild animals in the immediate vicinity. The level of disease in the hedgehog population directly related to the level of disease in possums and other wild animals because of the scavenging and spatially localised activity areas of hedgehogs. As the disease declines naturally in the possum population it will be hard to detect tuberculosis in hedgehogs given low possum prevalence. The available habitat is the key to whether hedgehogs will co-exist with other potentially tuberculous wildlife.

No single measure is going to achieve the desired result in controlling wildlife tuberculosis. Progressive success lies in integration of a range of measures. The hedgehog alone cannot accurately predict the location of tuberculous hot spots with high sensitivity, although a positive animal is a valuable piece of evidence. However in conjunction with current possum/ferret control procedures, any hedgehogs captured should be examined for tuberculosis. The detection of a tuberculous hedgehog can enable concentration of control measures to a more specific area.

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Chapter 5

A study into two other diseases severely affecting hedgehogs.

5.1
Carriage of Salmonellae and Yersiniae by New Zealand hedgehogs.

5.2
Sarcoptes scabiei infestation on New Zealand hedgehogs.

**R. J. Gorton, D.U. Pfeiffer, R. S. Morris,
D. Belton, J. Ragg and W. Charleston.**

Introduction

Hedgehogs like other mammals suffer from a wide range of parasitic infestations, fungal, bacterial and viral diseases. Many of these can pose a potential threat to public health. *Salmonella enteritidis* and *Sarcoptes scabiei* seriously affect hedgehogs and can often be fatal. This chapter describes the results of two prevalence studies for each of these conditions.

Salmonella enteriditis infection in New Zealand hedgehogs

As hedgehogs feed on carrion and carrion feeding insects such as maggots, the presence of Salmonella in the gut is not surprising. *Salmonella enteriditis* can certainly be pathogenic and occasionally fatal(3) *S. enteritidis* is by far the most common isolate found in British and German hedgehogs, although other salmonellae have been isolated. However in New Zealand Smith(5) noted that *S. typhimurium* was the main isolate.

S. enteritidis was not known to occur in New Zealand livestock prior to 1985. Since the first identification of this serotype in New Zealand, the reported annual number of animal isolates of *S. enteriditis* in New Zealand has gradually increased.

Sarcoptes scabiei infestation on New Zealand hedgehogs

Caparinia, Notoedres and *Sarcoptes* all produce severe mange in hedgehogs and grossly the lesions are indistinguishable. In New Zealand, only *Caparinia tripilis* and *Notoedres muris* have been identified as causative agents of mange in hedgehogs.(1, 2, 6) The hedgehog has not previously been confirmed in New Zealand as a host for *Sarcoptes scabiei*. Scabies is a zoonotic disease and insight into the disease status of the hedgehog is of interest. This section details the findings of such a study.

Chapter 5.1

Carriage of Salmonellae and Yersiniae by New Zealand Hedgehogs.

Introduction

In 1964 a small survey of hedgehogs (*Erinaceus europaeus*) in the Waikato region of New Zealand demonstrated faecal shedding of *Salmonella typhimurium* in 39% of animals sampled.[5] In a subsequent German study of salmonellosis in hedgehogs, *Salmonella enteritidis* was the dominant serotype found.[4] *S. enteritidis* was not known to occur in New Zealand livestock prior to 1985. Since the first identification of this serotype in New Zealand livestock in 1985, the reported annual number of animal isolates of *S. enteritidis* in New Zealand has gradually increased.

Yersiniosis is an important disease of New Zealand livestock and there are several reports of recovery of *Yersinia pseudotuberculosis* from hedgehogs in Europe.[1, 2] There are no published studies of the occurrence of yersiniae in hedgehogs in New Zealand.

Materials and Methods

Current research projects investigating tuberculosis in wild and feral animals in New Zealand provided an opportunity to investigate carriage of salmonellae and yersiniae in hedgehogs trapped in three separate areas of the country. A further two hedgehogs caught in daylight in the Palmerston North garden of one of the authors (RG) were also included in the study. Trapped hedgehogs were necropsied and mesenteric lymph nodes excised and stored at - 85^0C.

Laboratory methods

Salmonellae: Stored deep frozen lymph nodes were thawed, incised and cultured directly on to XLD differential agar, and inoculated into Rappaport enrichment broth. After 24 hours enrichment, broth samples were plated on to XLD differential agar. Colonies displaying the characteristic features of salmonellae were confirmed as salmonellae biochemically, and referred to the Enteric Reference Laboratory of the Communicable Disease Centre for serotying and phage typing.

Yersiniae: The incised lymph nodes were cultured directly on to yersinia selective agar, and inoculated into phosphate buffered saline (PBS). The PBS broths were held at $4^{o}C$ for 7 days, and then subcultured on to yersinia selective agar. All yersinia selective agar plates were incubated for 48 hours at $30^{o}C$, and any colonies exhibiting the characteristic features of *Yersiniae* were speciated by biochemical tests.[(6)]

Results

Salmonella enteritidis phage type 9a was recovered from eight of the 202 lymph nodes cultured. Of the ten lymph nodes that yielded *S. enteritidis,* seven were noted to be enlarged at necropsy, two samples were discoloured to a pale yellow and a further two also displayed either calcified or liquefactive necrotic lesions. Of the other 182 lymph nodes submitted for culture twenty-two showed enlarged mesenteric lymph nodes, nine of which had pale yellow discolouration and caseous necrotic foci. Isolation of *S. enteritidis* by broad geographic region is displayed in Table 5.1-1. The difference in prevalence of *S. enteritidis* between the regions is statistically significant ($X^2 = 21.46$, 2 d.f., $P< 0.005$).

Salmonella typhimurium was recovered from the lymph nodes of the two hedgehogs found in Palmerston North. One of these hedgehogs had suffered from diarrhoea. A faecal swab taken for culture was negative for *Salmonella* but the animal later was culture positive based on a lymph node sample.

No *Yersiniae* were recovered from any of the nodes cultured.

Table 5.1-1 Recovery of *S. enteritidis* by location.

Location	No. sampled	No. of isolates	Salmonella species	Prevalence of Salmonella (*)
Wairarapa	19	4	*S. enteritidis* 9a	21% (2.6-39)
North Canterbury	53	4	*S. enteritidis* 9a	7.6% (0.5-14.6)
Otago	128	0		0% (N/A)
Palmerston North	2	2	*S. typhimurium*	100% (N/A)
Total	202	10		5% (2-8)

*95% confidence interval

Discussion

Of the *S. enteritidis* isolates received by the Enteric Reference Laboratory of the Communicable Disease Centre for phage typing, phage type 9a is by far the most common phage type recovered from non-human source.[1, 2] The results reported here confirm that hedgehogs in at least some parts of New Zealand carry *S. enteritidis* phage type 9a, and that they may possibly be reservoir hosts of this phage type**.**

The striking regional difference in recovery of *S. enteritidis* demonstrated here warrants further investigation. Although care must be taken in interpretation of these results as sample sizes were small from some regions. The fact that no isolates were cultured from the Otago region may be more a reflection of the quality of the samples rather than the culture techniques, as animals from this area had been deep frozen for up to three years.

This study confirms the carriage of *S. typhimurium* by New Zealand hedgehogs. Smith et al[5] reported a prevalence of 39% from faecal samples from 33 hedgehogs. Only nine of these hedgehogs had lymph nodes submitted for culture. Three hedgehogs were positive for *S. typhimurium*. Two hedgehogs in this study also had *S. typhimurium*. It is interesting to note that all the hedgehogs which cultured positive for *S. typhimurium* in both this study and Smith et al's[5] came from suburban areas. However regardless of the culture technique used to isolate *S. typhimurium* (lymph node versus faecal culture) there is still insufficient information to define the role of the hedgehog in the epidemiology of salmonellosis.

There is no evidence from this study that New Zealand hedgehogs carry *Yersiniae*.

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Chp 5.2.

Sarcoptes scabiei *infestation of New Zealand hedgehogs*.

Introduction

In New Zealand, *Caparinia tripilis* and *Notoedres muris* have been identified as causative agents of mange in hedgehogs.[1, 2, 6]

Sarcoptes scabiei has also been previously reported as causing mange with severe disease in hedgehogs in Europe and the United Kingdom.[3, 4, 5] However the hedgehog has not previously been confirmed as a host for *Sarcoptes scabiei* in New Zealand. Scabies is a zoonotic disease and insight into the disease status of the hedgehog is therefore of interest. This paper details the findings of such a study.

Materials and Methods

The hedgehogs collected during research projects conducted in Otago, North Canterbury and the Wairarapa were examined for mange and skin scrapings were taken. Additional hedgehogs were presented as incidental clinical cases from Palmerston North, Auckland and Whangaparoa. Most animals were presented dead or were euthanased soon after collection.

Skin scrapings were digested using 10% KOH and the residue washed and centrifuged to recover mites. Mites were mounted on slides in Hoyer's medium and examined to identify mites.

Biological details were recorded for each animal. Condition score was based on a scale of 1-5:

1 = emaciated.

2 = no subcutaneous fat, reasonable muscle tone.

3 = average subcutaneous fat (1-2 mm).

4 = good subcutaneous fat (2-4 mm).

5 = very fat (>4 mm).

Hedgehogs were categorised as rural or urban based on their capture location: Rural included farmland in Otago, North Canterbury and the Wairarapa Urban areas encompassed Auckland, Whangaparoa and Palmerston North.

Results

Five hundred and forty nine hedgehogs were collected during various studies. Of these 29 were observed to have dry, grey crustiness on the skin consistent with mange (5.3% (3.4-7.1% at 95% CI)). Twenty hedgehogs were sampled and examined for mites. The results are summarised in Table 5.2-1. No mites were identified on three hedgehogs while *Sarcoptes scabiei* was isolated from six (30%). All six hedgehogs from urban areas were positive for *Sarcoptes scabiei.* Hedgehogs from rural areas were infested with *Caparinia tripilis, Notoedres muris* or a mixed infection of both species. One hedgehog was sampled twice. The first sampling showed a mixed infection of *Caparinia tripilis* and *Notoedres muris*, yet when sampled 5 months later only *Notoedres muris* was found. Weight and condition had also improved over this period.

Table 5.2-1. Mite species identified in hedgehogs with mange stratified by capture location and sex.

		Sex		
Region	Mange mite species	Female	Male	Grand Total
Rural areas	*Caparinia tripilis*	2	2	4
	C. tripilis and *N. muris*	1	5	6
	No mites identified	1	2	3
	Notoedres muris	1	0	1
Rural areas Total		5	9	14
Urban areas	*Sarcoptes scabiei*	3	1	5*
	S. scabiei and *C. tripilis*.	0	1	1
Urban areas Total		3	2	6
Grand Total		8	11	20

*Includes one animal of which sex was not recorded

Males and females were equally likely to be affected with mange, and mean weight did not differ significantly from unaffected hedgehogs. However, the general condition of affected hedgehogs was poor. Sixty-two percent of the affected animals had a condition score of 2 or below (18/29).

Cases were found during all months of the year except for October with May, June and July having the highest proportion of cases (Fig 5.2-1.).

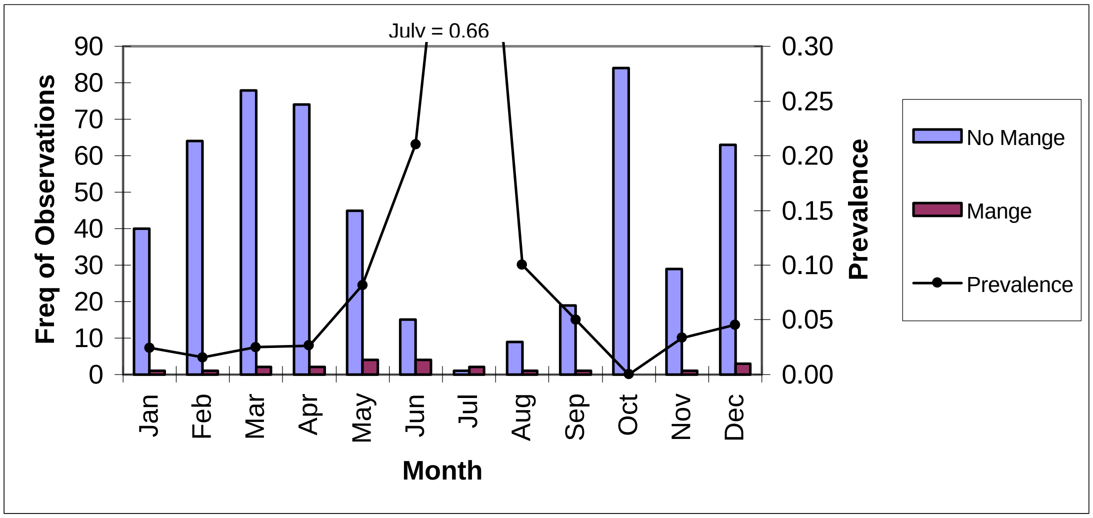

Figure 5.2-1. Temporal occurrence of mange on Hedgehogs.

Discussion

In New Zealand two mites have been identified which cause mange in hedgehogs. Brockie[1] examined 650 hedgehogs in five localities in North Island, and found 37% were affected. *Caparinia tripilis* was the only mite found, except for one animal from which *Notoedres muris* was isolated. Smith[6] recorded dual infection with *Caparinia tripilis* and the dermatophyte *Trichophyton erinacei.* Heath[2] noted a small colony of captive hedgehogs infected with *Notoedres muris.* The current paper describes the first isolations of *Sarcoptes scabiei* in wild hedgehogs in New Zealand.

Brockie[1] reported that mange caused by *Caparinia tripilis* was more prevalent in adults than in juveniles as well as on males compared with females. In this study, sample size was too small to be able to confirm Brockie's findings. Condition scores of hedgehogs infected with mange are frequently below average.

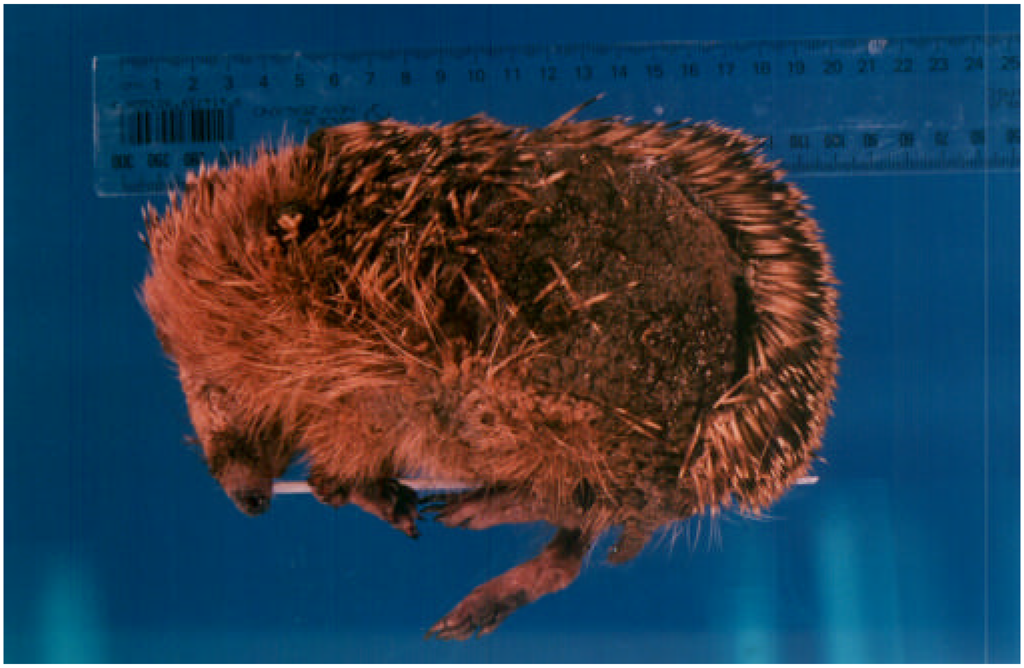

Figure 5.2-2 Mange caused by *Sarcoptes scabiei.*

Figure 5.2-3 *Sarcoptes scabiei* mite.

Poor condition may reflect the effect of the infestation. Hedgehogs in this study were often found during the daytime in a distressed state. Brockie also found that cases of mange were more prevalent during autumn and winter as in this study. The isolates of individual mite species in this study are only indicative of their true prevalence, as no standardised amount of material was processed. Some samples produced numerous mites while others had very few to no mites recovered. In all *Sarcoptes* infections large numbers of mites were present in the samples.

Caparinia, *Notoedres* and *Sarcoptes* all produce severe mange, sometimes fatal in hedgehogs and grossly the lesions are indistinguishable. Thick, dry grey crusty exudate forms on the surface of the skin particularly the hair-covered areas of the face, legs and flanks. The infection can spread into the region covered with spines. The hedgehog is frequently incapacitated and is unable to curl up. Both, Brockie[(1)] and Heath[(2)] reported spine loss with *Caparinia tripilis* and *Notoedres muris*. *Sarcoptes* has also been documented in Europe as having a similar effect.[(4)] This study did not record severity of disease with mite infestations, but spine loss was noted with *Sarcoptes scabiei* infestations and was occasionally complicated by myiasis (Fig 5.2-2.).

Histopathological findings for *Notoedres* and *Sarcoptes* include large amounts of accumulated keratin, purulent material and necrotic debris on the skin surface. The epidermis is thickened with numerous mite tunnels and large pustules. However while there may also be dermal oedema there is relatively little or no cellular inflammation in the dermis. *Caparinia* is not a burrowing mite yet also produces the gross lesions described above.

Sarcoptes scabiei causes ‘scabies’ in humans and *S. scabiei* var *canis,* sarcoptic mange in dogs (Fig 5.2-3). The infection in hedgehogs is a potential zoonotic risk. During this study one author had to be treated for scabies resulting from handling a ‘mangy’ hedgehog. The infection spread from the initial site of the wrists up the arms, down the torso and legs before total resolution. Treatment lasted 20 days.

A hedgehog infested with *S. scabiei* was found on a property where a Staffordshire Bull Terrier had recently been treated for sarcoptic mange. One of the two dogs resident on this property was known for killing hedgehogs. The strength of a causal link here is only speculative and may be coincidental.

It interesting that *Sarcoptes* infection of hedgehogs in New Zealand seems restricted to urban areas. While hedgehogs appear to be a large reservoir of mites, it is not clear how they initially become infected. It may be that in urban areas *Sarcoptes* is far more prevalent than in rural areas. Mites do not survive for long off the host and while interspecies transfer might sporadically occur, it seems that intraspecies transfer of mites is probable once the infection is present in the hedgehog population.

Sarcoptes scabiei is another disease in hedgehogs that can be added to leptospirosis, ringworm, salmonellosis and tuberculosis as potential zoonotic risks to humans. Hedgehogs should be treated carefully with respect and consideration of their potential associates.

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Chapter 6

General Discussion.

Demographics

The population of hedgehogs observed in the longitudinal study showed seasonal fluctuations in body weight and condition score. A fluctuation in the ratio of males and females, adults and juveniles was also evident. This supports the information other researchers have previously reported.[2, 3, 5, 6] Reeve[6] collates a number of studies that also report similar findings. It is thought that this fluctuation in relative numbers, as well as body weight changes, is directly related to courtship and mating behaviour. Males, having emerged first from hibernation, spend a great deal of time foraging thus resulting in a significant weight gain. Once females emerge from hibernation, the males spend much of their time in courtship and mating. Males then exhibit a weight loss while females gain weight due to pregnancy.

The ratio of females to males in the latter stages of the active season is approximately 3:1. This is because males have returned to a hibernating state and females continue to forage in order to accumulate sufficient body weight and fat to survive the following winter.

Juveniles appear in the population about two months after the adults and spend their entire active time foraging in order to gain weight for the following winter hibernation. The ratio of juveniles and adults is about 3:1 (Fig 3-4) in the later months of the active season.

Habitat preference and Home Range

Hedgehogs are creatures of habit and they showed in this study a high preference for areas which provided dense dry ground cover and bush. This is consistent with Brockie's description of their ecological niche in New Zealand.[2] Pampas grass provides an excellent nesting site for hedgehogs as they can burrow very deeply into its leaves, creating a secure and dry nest. Pampas grass is a popular choice for shelterbelts on farms in New Zealand and is frequently found on bush/pasture margins.

Home range analysis showed males have a significantly larger home range compared with females. This supports other findings where male home ranges are approximately twice the size of females.[1, 3, 5, 6] In New Zealand hedgehogs, home ranges were considered to be underestimated due to the limited size of the study areas. However these estimates were similar to the findings in this survey. The extent to which males exceed female ranges is considered to be associated with mating behaviour. Males will roam over greater distances in search of females, while females are more involved in rearing young and do not travel far.

The use of each hedgehog's home range can almost be anticipated when tracking an animal and this was evident in the analysis. Hedgehog A038 displayed a stereotyped behaviour in the nights she was tracked. Both nights the hedgehog covered virtually the same ground, starting from the same sleeping site and heading in a similar direction she had been tracked taking during the previous two weeks. Other hedgehogs in this study also behaved quite predictably as to their spatial activity. The author noted when rearing hedgehogs, they also display this stereotyped approach to investigating their environment.

Diseases

Hedgehogs, like other mammals, suffer from a wide range of parasitic infestations, fungal, bacterial and viral diseases. The lists in Tables 2-2 and 2-3 have been drawn up largely by veterinarians interested in hedgehogs as vectors of stock diseases, or by hospital pathologists tracing the origin of certain human infections or parasites. The effect of these infections on hedgehogs has not received much attention and thus the epidemiology of diseases is mere speculation. The general view is that if the hedgehog is infected it is potentially infectious. This study highlights three diseases notable as zoonotic risks. Hedgehogs from this study were noted to be carriers of *Salmonella enteritidis*, *Salmonella typhimurium*, *Sarcoptes scabiei* and *Mycobacterium bovis*. While this confirms other findings both here in New Zealand and overseas,[4, 6, 7, 8, 9] there is insufficient information to define the role of the hedgehog in the epidemiology of both salmonellosis and scabies. However evidence strongly supports the hypothesis of hedgehogs being spillover hosts of *M. bovis* and utilisation of this knowledge in control methods for bovine tuberculosis in New Zealand is plausible.

A Sentinel Animal for Tuberculous Possums

Involvement of a wide range of small wild animal species seems to be a feature of bovine tuberculosis only in New Zealand, where predators and scavengers, including ferrets, stoats, weasels, feral cats, hedgehogs and feral pigs are infected. In the absence of large animal predators, large and small carrion is available to smaller predators/ scavengers such as the hedgehog.

Hedgehogs are spillover hosts for *M. bovis,* which means the prevalence of disease in the hedgehog is directly related to the prevalence of disease in a local reservoir population such as the possum. The nature of hedgehogs' home range usage can be exploited if hedgehogs are reliable sentinel animals for tuberculous possums. Possums have home ranges similar to that of hedgehogs and on large farms, locating a tuberculous hedgehog could substantially reduce the area where extensive control is required to eliminate tuberculosis from the wild animal population. Male animals usually have a larger home range than females and this is true of the hedgehog. In utilising the knowledge of a hedgehog's home range, female hedgehogs could provide a specific local indicator of the presence of tuberculous possums and male hedgehogs could locate the general region on the farm with tuberculous possums.

Possums use a wide range of habitat types of which the hedgehog would co-inhabit about one-third. Some areas suitable for both species may also have geographical features such as rivers or cliffs that isolate an area from either the hedgehog or possum. Available habitat, I believe is the key to whether hedgehogs will coexist with other potentially tuberculous wildlife.

Although only one tuberculous hedgehog was found in this study, this does not discount the original hypothesis of using hedgehogs as an indicator species for tuberculous possums. While it is difficult to understand the true status of the disease in tuberculosis negative hedgehogs, given an adequate sample size the detection of a tuberculous hedgehog can be a strong indication of other tuberculous wild animals in the immediate vicinity. As the disease declines naturally in the possum population it will be hard to detect tuberculosis in hedgehogs given low possum prevalence.

Should a tuberculous hedgehog be discovered, there is high confidence of finding other tuberculous wild animals in the immediate vicinity. This was shown on the HFB site where a tuberculous hedgehog was found followed closely by the discovery of a tuberculous ferret and possum.

The hedgehog could be considered a temporal indicator of tuberculosis in the wild animal population especially where there has been a history of tuberculosis. The longevity of the hedgehog is reasonably short (2-3 years in the wild) and should sufficient control of other tuberculous animals occur then the disease will also disappear from the hedgehog population. The longitudinal study site had had a history of tuberculosis infection in cattle, possum, ferret, and hedgehog populations. Eighteen months after extensive control efforts on this study site neither hedgehogs nor possums were found tuberculous and the farm was taken off movement control status after no cattle reactors were evident in the herd. This would suggest hedgehogs can provide a temporally as well as spatially specific indicator of tuberculosis in wild animal populations.

No single measure is going to achieve the desired result in controlling wildlife tuberculosis. Progressive success lies in integration of a range of measures. The hedgehog alone cannot accurately predict the location of tuberculous hot spots. However in conjunction with current possum/ferret control procedures, any hedgehogs captured should be examined for tuberculosis. The detection of a tuberculous hedgehog can enable concentration of control measures to a more specific area.

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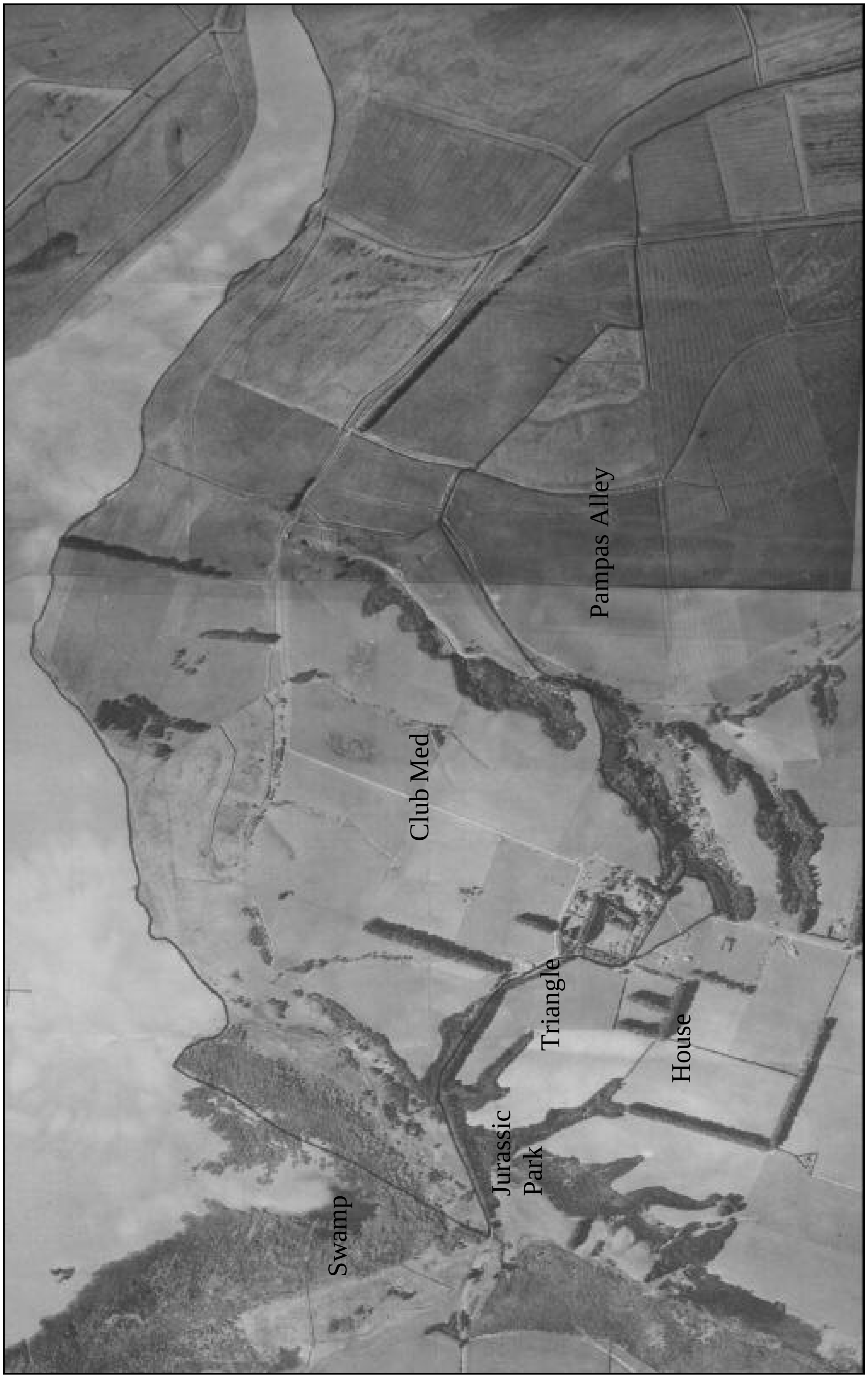
Appendices

Appendix 1 An aerial photograph of the study site described in Chapter three.



Scale: 1cm : 138.8m

Appendix 2-1 Structure of the form used to record biological field data.

Hedgehog Examination Sheet:

Date: ☐ ☐ ☐ Observer: ☐

Trap No. ☐ Eartag No. A

Radio Transmitter Freq: ☐

Colour: Dk Brown ☐ Med Brown ☐ Lt Brown ☐
Blonde ☐ Albino ☐

Sex: M ☐ F ☐ Age: <1 ☐ ≥1 ☐

Weight: ☐ g Length: ☐ mm

Condition: 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Pregnant: Y ☐ N ☐ Lactation: Y ☐ N ☐

Anaesthetic (Ketamine): ☐ mls

Blood: ☐ mls. Ease of Bleed: -1 ☐ 0 ☐ 1 ☐

TB Suspect: 0 ☐ 1 ☐ 2 ☐

Comments:____

____

____

Appendix 2-2 Structure of form used to record radio tracking fixes.

Hedgehog Radio Tracking Sheet:

Frequency: [ ] Observer: [ ]

Date: [/ /]

Time	Paddock No.	Landmarks/ Compass direction from hhog. E.G. NE

Weather Conditions: Dry [ ] Wet [ ] Windy [ ] Calm [ ]

Ease in Tracking Hedgehog: 0 [ ] 1 [ ] 2 [ ]

Hedgehog Activity: [ ]

Comments:____

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____

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Appendix 2-3 Form used to monitor the tagged hedgehog population. Missing numbers mean the hedgehog has died.

Tag No.	DLC	C	W	S	A
A002	9/11/95	4	600	M	M
A003	4/10/95	1	950	M	M
A004	19/1/96	2	900	M	M
A005	5/10/95	1	950	M	M
A006	14/12/95	2	625	M	M
A007	16/12/95	2	725	M	M
A008	5/10/95	1	1050	M	M
A009	13/12/95	2	500	F	M
A010	19/3/96	5	650	M	M
A011	6/10/95	1	800	M	M
A012	6/10/95	1	875	M	M
A013*	2/4/96	3	800	F	M
A014	21/3/96	6	800	M	M
A015*	17/1/96	2	675	F	M
A016	1/4/96	8	700	M	M
A019	2/4/96	4	725	M	M
A020	20/3/96	3	625	M	M
A022	13/12/95	1	550	F	M
A023	14/12/95	1	525	F	M
A024	14/12/95	1	150	F	I
A025	14/12/95	1	325	F	I
A026	20/3/96	2	500	M	I
A029	14/12/95	1	600	F	M
A030	5/3/96	2	775	F	M
A031	3/4/96	2	675	M	M
A032	15/12/95	1	850	M	M
A033	15/12/95	1	625	F	M
A034	16/12/95	1	500	F	I
A035	16/12/95	1	650	M	M
A036	20/3/96	2	700	M	M
A037	2/4/96	5	800	F	M
A038*	20/2/96	3	600	F	M
A039	16/1/96	1	700	F	M
A040	18/1/96	1	200	F	I
A041	31/1/96	2	625	F	M
A042	21/3/96	4	625	F	M
A043	18/1/96	1	675	M	M
A044	18/1/96	1	550	F	M
A045	20/3/96	3	500	M	I
A046	19/1/96	1	500	M	M
A048	19/1/96	1	200	M	I
A050	19/1/96	1	600	M	M
A051	20/1/96	1	150	M	I
A052	20/1/96	1	675	M	M
A053	20/1/96	1	700	M	M
A054	1/2/96	1	175		I
A055	20/2/96	2	250	M	I
A056	31/1/96	1	550	F	M
A057	31/1/96	1	500	F	M
A058	31/1/96	1	150	M	I
A060	1/2/96	1	200	M	I
A061	1/2/96	1	600	M	M
A062	21/2/96	1	760	F	M
A063	6/3/96	2	675	F	M
A064	6/3/96	2	250	M	I
A065	6/3/96	2	275	M	I
A067	31/1/96	1	400	M	I
A069	5/3/96	1	575	F	M
A070*	6/3/96	1	450	F	I
A071	6/3/96	1	300	F	I
A072	30/1/96	1	300	M	I
A073	20/3/96	2	225	M	I
A074	6/3/96	1	800	F	M
A075	1/2/96	1	825	M	M
A076	6/3/96	1	350	M	I
A077	1/4/96	3	350	F	I
A078	7/3/96	1	550	M	I
A079	19/3/96	1	425	F	I
A080	19/1/96	2	300	M	I

Tag No.	DLC	C	W	S	A
A081	19/3/96	1	550	F	M
A082	19/3/96	1	375	M	I
A083	19/3/96	1	225	F	I
A084	20/3/96	1	874	F	M
A086	20/3/96	1	425	F	I
A087	21/3/96	2	400	F	I
A088	20/3/96	1	475	F	I
A089	1/4/96	2	600	F	I
A090	20/3/96	1	625	M	M
A091?	20/3/96	1	725	F	M
A091	1/4/96	1	275	M	I
A092	21/3/96	1	750	M	M
A093	1/4/96	1	750	F	M
A094	1/4/96	1	175	M	I
A095	1/4/96	2	175	F	I
A096	1/4/96	1	150	M	I
A097	2/4/96	1	175	M	I
A099	3/4/96	1	710	F	M
A100	3/4/96	1	375	F	I

Key to Appendix 2-3

Tag No.:	Animals Identification
DLC:	Date Last Caught
C:	No. of times captured
W:	Weight (g)
S:	Sex
A:	Age
*	Radio Tagged animals

Appendix 2-4 Structure of the form used for recording necropsy data collected in Chapters two and three.

Animal ID ________________

Ministry of Agriculture & Fisheries New Zealand

AG.L.47

ANIMAL HEALTH LABORATORY
SPECIMEN SUBMISSION REPORT

ACCESSION No.

SUBMITTERS REFERENCE

1	DATE SENT	DATE RECEIVED	FIRST INTERIM
	SECOND INTERIM	THIRD INTERIM	DATE FINAL

SUBMITTER

NAME Robyn Gorton
ADDRESS Dept Vet Clinical Sciences
Massey University.
PHONE No. OFFICE (06) 356-9099 Ext 7289 HOME

Location:

COUNTY

HERD No. (IF APPLICABLE)

	SUBMITTER CATEGORY	
	SPECIES HEDGEHOG	
1	SEX M F	
2	AGE <1 >1	
3	BREED WILD	
4	MONTH OF GESTATION (FOR CATTLE IN NON-TESTED HERDS)	

HERD OR FLOCK DATA

N.A.	No. at RISK	No. AFFECTED	No. DEAD

ANIMAL INDENT.	PREVIOUS ACCESSION NOS.	V.I.O. Initials

SPECIMENS		EXAMINATIONS
Mandibular LN Retropharyngeal LN Bronchial LN Mesenteric LN	Lung tissue	TB culture/REA Histopathology

HISTORY (INCLUDE CLINICAL FINDINGS, NUTRITIONAL STATUS, NECROPSY)

Tot weight g

Body Length........................cm
Condition 1 2 3 4 5
Preg Status 0 1 2
Lactation Y N
No. fetuses...........Size..........
Stomach Contents:
Vol..............ml
Description:........................

....

Comments:

Tentative Diagnosis:
TB + - ? Salmonella + _ ?

SIGNATURE ________________

DATE ____/____/____

55141E–1,500 pads/10/90 MK

Appendix 3 Photographs showing various aspects of the hedgehog field studies.

Figure A3.1 An unsuccessful trap. Note the trail to the right side of the cage.

Figure A3.2 My indispensable accomplice in finding hedgehogs.

A **B**

Figure A3.3 How to sex a hedgehog; A: Male, B:Female.

Figure A3.4 Positioning of a radio transmitter on a hedgehog.

Figure A3.5 Weighing a hedgehog.

Figure A3.6 The procedure used to bleed a hedgehog.

Figure A3.7 Typical hedgehog trails entering bush areas.

Figure A3.8 A natural barrier to a hedgehogs home range.

Figure A3.9 A view of the habitat involved in a tuberculosis 'hotspot' on the HFB site.

Figure A3.10 A view of 'Pampas Alley' from the longitudinal study site described in Chapter two.