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BEHAVIOURAL PATTERNS OF POSSUMS AND CATTLE WHICH MAY FACILITATE THE TRANSMISSION OF TUBERCULOSIS

**A thesis presented in partial fulfilment of the requirements for the degree
of Master in Veterinary Science at Massey University**

Brent Maynard Paterson

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ABSTRACT

Behavioural patterns of a population of Australian brushtail possums with endemic tuberculosis were studied using radio telemetry, and by direct observational techniques, from November 1990 to April 1992. The study area, on the east coast of the Wairarapa, New Zealand, allowed observations of interaction between the major wildlife vector of tuberculosis in New Zealand, and cattle run as part of a commercial farming venture. The rugged 40 ha study area is mainly covered in 2-10 m high scrub, with patches of native bush and some large trees. Part of the area has been cleared of scrub and grassed. Poorer quality pasture is also available in small pockets in many other areas of the paddock.

Possums had distinct ranges that remained constant over the duration of the study period, and ranges of many possums overlapped. Males had significantly larger ranges during the breeding season, and had the largest ranges overall. The area covered by a possum in a night's activities varied considerably between possums, and often for an individual over consecutive nights. There were no significant differences between home ranges of tuberculous and non-tuberculous possums, although there were indications that the size of nightly activity areas of the former decreased as the disease progressed. Twenty-five juvenile possums were followed over 8-10 months, 2 dispersed from the area, and 7 died within their natal home range. Most of the juveniles died from starvation and exposure.

Interactions between possums and cattle were observed in a natural setting, and also by introducing sedated possums to the same area to simulate terminally-ill tuberculous animals. Possums spent a variable amount of time feeding on pasture in the 40 sq.m observation area, ranging from a few minutes, to several hours. Normally possums appeared to avoid cattle whenever possible, and if necessary climbed trees to get away. The activities of several debilitated possums are described and their apparent indifference to external influences - in particular time of day - noted. The intense interest shown by cattle in sedated possums is described, and the possibilities for transmission of tuberculosis from possums to cattle discussed. It is concluded that transmission of tuberculosis is unlikely to occur on open pasture under normal circumstances, but that sick tuberculous possums, and later their carcasses, are a source of infection.

Tuberculosis in English badgers is compared, and contrasted, with the situation in New Zealand. Possible explanations for the absence of the disease in Australian wildlife are discussed. The differences in habitat and population density are suggested as the main reasons for the variations between, and within, countries. The importance of controlling tuberculosis in New Zealand, deficiencies in present control systems and possible areas for future research are outlined.

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Department of Veterinary Clinical Sciences
Massey University
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Chapter 1

Introduction and Project Outline

1.1. INTRODUCTION

1.1.1. PROJECT BACKGROUND

This work is part of a 5-year longitudinal study of the epidemiology of bovine tuberculosis in a feral possum population in contact with cattle. The study is a cooperative project between the New Zealand Ministry of Agriculture, Animal Health Board, and Massey University.

The objectives of the longitudinal study are:

- (i) to describe the epidemiology and effects of bovine tuberculosis in a mixed possum and cattle population
- (ii) determine the significance of each of the mechanisms of transmission of tuberculosis within possum populations, and between possums and cattle
- (iii) to study the behavioural ecology of possums and cattle on the study site to determine behavioural factors in both species which facilitate transmission of infection within, and between, the two species

The studies reported in this thesis address the third objective, principally using radio triangulation techniques and direct behavioural observations.

The longitudinal project began in 1989, after confirmation that possums in the area were infected with tuberculosis (TB). A sequential capture-recapture study was developed, and for 3 nights each month possums are caught, and measurements are taken on qualifying animals in accordance with the study protocol. Each animal is uniquely identified with metal ear tags and then released. There is an estimated population of 145 possums in the study area (D. Pfeiffer, pers.comm.), almost all of which den on the northern side of the paddock. Approximately 15-20 beef cattle have been grazed in the paddock throughout the project, although were restricted to the southern half of the paddock during most of this study. Every 3 months the steers are tested for tuberculosis, using a single intradermal skin test. Additional studies are run by other members of the research group in conjunction with the routine trapping and aim to examine other aspects of tuberculosis in the area.

1.1.2. Tuberculosis, and Tuberculous Possums in New Zealand

The Australian Common Brushtail possum (*Trichosurus vulpecula* Kerr 1792)¹, was first introduced into New Zealand about 1840 (Pracy, 1962), and has since become both abundant, and a pest. Originally introduced for its potential as a fur producer, the possum has since spread virtually the length and breadth of the country. The possum adapted extremely well to New Zealand conditions, and can be found from sea-level through to high altitude forest. The highest concentrations of possums are found along the bush-pasture margins, where pasture species are a significant proportion of their diets (Coleman *et al.*, 1980; Clout and Gaze, 1984; Harvie, 1973). The possum

¹All future occurrences of 'possum' in the text refer to this species.

utilises a wide variety of food types, but particular species are often preferentially eaten. In many areas this has led to the death of native species due to defoliation, and possums compete with native birds for foods from some plant species (Fitzgerald, 1981 and 1984b).

The realisation of the damage possums cause to native bush and wildlife has led to an increased effort towards their control, and ongoing studies to quantify both the significance of the problem and effectiveness of control methods. However, the discovery in 1967 of a tuberculous possum, and subsequent evidence of links between tuberculosis in possum populations and in co-existing cattle herds, has turned the problem into one of national significance.

Tuberculosis (formerly called consumption or phthisis) has been recognised for many centuries, and probably existed in classical times. It was possibly introduced into Britain by Roman invaders, but was unlikely to have been a serious disease where few animals were kept, or they are grazed in an extensive system. As small villages began to coalesce into ever larger towns, and cattle began to be kept together in larger numbers - particularly when they were housed through much of the year - communicable diseases were likely to become a cause of significant wastage. Diseased cattle were common in dairies supplying milk to towns in 19th century Europe including Britain - in 1847 Hunting found 20% of 4,000 cattle in Durham affected with tuberculosis (Francis, 1958). It was not until the 1870s that the importance of tuberculosis in cattle was recognised, and by this time the disease was widespread.

Cattle were first introduced into New Zealand in about 1840 from England, and bovine tuberculosis arrived with one or more of the early importations. It was not formally subjected to a control program in New Zealand until 100 years later, when a voluntary 'test and slaughter' program for dairy herds supplying town milk was initiated. Factory supply herds were included in 1958, and the scheme became mandatory for both in 1961. Beef cattle were compulsorily tested from 1971, but not until 1977 were all cattle in New Zealand under test or surveillance (Animal Health Division of M.A.F., 1986). There were significant reductions in the incidence of infected animals as the scheme progressed, but though the number of infected herds dropped initially, it then stabilised. In several areas of the country, notably the west coast of the South Island, and in the southeast of the North Island, a significant number of herds remained infected, or were reinfected. Stricter testing and control measures in such areas failed to resolve the problem. Epidemiological studies indicated that in these areas the disease was endemic in a species other than cattle. After the initial finding of an infected possum on the west coast of the South Island in 1967, surveys of possums on farms with TB problems found local prevalences of tuberculosis greater than 10%, and these findings were repeated in other areas (Livingstone, 1988). Possum control programs began in Buller South county in 1972, and there was a rapid drop in the number of infected herds (from 95% of herds to 37%) over the next 2-3 years. Control operations, including trapping, poisoning by air and ground, and shooting, have since been the main methods used to reduce possum numbers in endemic TB areas. In conjunction with these programs, a policy of farm quarantine and movement control was introduced in 1977,

when it was realised that herds in previously non-endemic areas were becoming infected. It was thought the movement of cattle and deer from areas of endemic tuberculosis into other farming districts, was spreading the disease. In many of these new areas the possum populations, previously free of tuberculosis, were found to be infected.

There was a reduction in the number of herds on movement control through 1977 to 1981, but then began a slow, and continuing, upward trend, although the number of animals reacting to the tuberculin test has declined. It is now recognised that, in many areas, tuberculosis is maintained in the feral possum population. Furthermore, eradication of either the possums or the disease is unlikely in most of them (Animal Health Division of M.A.F., 1986). Present policy is to contain tuberculosis in endemic areas - those with a persistent TB problem - and eradicate it from others. Control in endemic areas attempts to restrict the spread of possums from foci of infection, often by the use of low possum density 'buffer zones' which are regularly poisoned, and surveillance testing of cattle in the area as an indicator of infection. Each endemic area has strategies developed for its particular circumstances, but these control measures have had variable success. The number of endemic areas in New Zealand has steadily increased over the past 12 years, several of them as a result of possum populations being infected by tuberculous cattle or deer brought into the area. Buffer zones have not always proved effective, and infected possum populations have been found moving down catchments at a rate of 4-8 km/year (Livingstone, 1988). In many areas possum control operations have proven successful - in the short term. Populations are reduced to relatively low numbers and cattle reactor rates decline, but, without continued pressure on the area, repopulation occurs over the next 2-3 years, and cattle reactor rates subsequently increase. Many of the techniques used in the past for controlling the spread of tuberculosis through wildlife populations are neither practical, effective, or economic, in present situations. There is also a need to consider welfare implications of the methods. The increasing national recognition of the problem has led to an increasing research effort aimed towards an understanding of the disease.

The biology, ecology and behaviour of possums has been well researched in New Zealand and Australia. The interactions between possums, cattle, deer, *Mycobacterium bovis*, and other factors associated with the spread, and maintenance, of tuberculosis in New Zealand have only recently begun to be addressed.

1.1.3. Study Aims

The main aim of this work is to investigate behavioural factors in possums and cattle that may facilitate transmission of tuberculosis between and within these species. The study site is part of a commercial sheep and beef cattle farm in the Wairarapa, with a long term problem of TB in the cattle. Investigations include:

- observational studies of possum and cattle behaviour - specifically interactions between animals, particularly on the bush-pasture margin.
- investigations using radio-telemetry to determine
 - (i) activity areas and use of the site, by both possums and cattle and
 - (ii) the extent and direction of movement of any possums dispersing from the site.

The following chapters describe results from radio-triangulation studies, behavioural observations of natural activity in the study area, and an experimental study of interactions between sedated possums and cattle in a confined area. Final summaries and conclusions follow.

Figure 1.1 The Australian common brush-tailed possum



Figure 1.2 Possum in a live-catch trap

Note metal identification tags in each ear



1.2. STUDY AREA

1.2.1. Geography and Location

The study was carried out on Waio Station near Castlepoint (40°51'S, 176°14'E), on the Wairarapa coastline 63 km east of Masterton (Figure 1.3). The study site covers approximately 75% of the 40 ha 'Backdrop' paddock, over half of which is grazed by cattle. In early 1991 a fence was constructed down the length of the paddock, restricting cattle to the southern, more developed, side. Possums den predominantly on the northern slopes, although they feed on both sides of the fence. The bowl shaped paddock varies from 60 to 270 metres above sea level (a.s.l), with an opening to the west (Figures 1.5 and 1.6). Several water courses combine to form a main creek draining the valley. The northern ridgeline drops steeply down to the valley floor, and there are several spurs off this ridge. The southern side of the paddock, which slopes more gently, consists mainly of stands of manuka, although 30-40% of the area has been cleared and there are also large amounts of pasture under the manuka trees. The northern part of the paddock is predominantly covered with mingimingi (*Leucopogon fasciculatus*), manuka (*Leptospermum scoparium*) and gorse (*Ulex europaeus*), with small remnants of broadleaf forest. A line of pine trees (*Pinus radiata*) extends part-way along the northern ridgeline, and there are 5-8 large, individual pine trees scattered through the study area. A steep sided gully (punga gully) drops from the north ridge down to the mouth of the valley and contains the richest variety of native bush in the area. Punga gully lies on the periphery of the trapping areas, and is fenced off. There are signs indicating that a large number of possums are active in the gully, and possums denning in this area are often caught in nearby traps.

1.2.2. Climate

Coastal Wairarapa is subject to a wide variety of weather conditions, from drought to heavy rain and snow, with considerable variation along the coast. Rainfall can vary from less than 500 mm to more than 2500 mm per year, mainly falling from June to October. The region around the study area is subject to more rain, and considerably more wind, than the average along the coast. Rainfall varies between 0 and 300 mm per month in summer, to 1800 mm or more in winter months. Cold southerly storms are common in autumn and winter, though may occur at any time of the year. Strong, and persistent, north-westerly winds are the most significant climatic feature in the area. These winds are strongest between September and January and may continue for 2-3 days, with an average speed of 50-65 km/hr. Gusts of more than 100 km/hr are frequently recorded. Minimum and maximum air temperatures range between 1-15°C in winter, and 9-28°C in Summer (Meteorological data from Castlepoint lighthouse). There are occasional frosts on the valley floor and in sheltered areas.

Figure 1.3 Location of study site in the lower part of the North Island

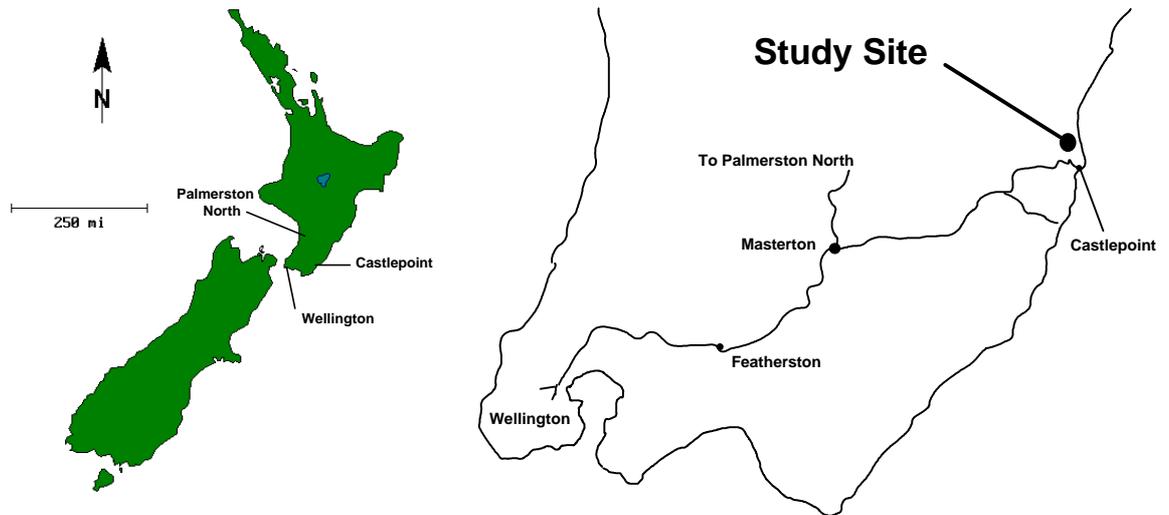


Figure 1.4 Digital terrain model of the Castlepoint study area

Several of the figures in following chapters are based on this model. A 3-dimensional surface is obtained by laying a 'fishnet' surface over the terrain model and overlaying data, such as home ranges, on the surface.

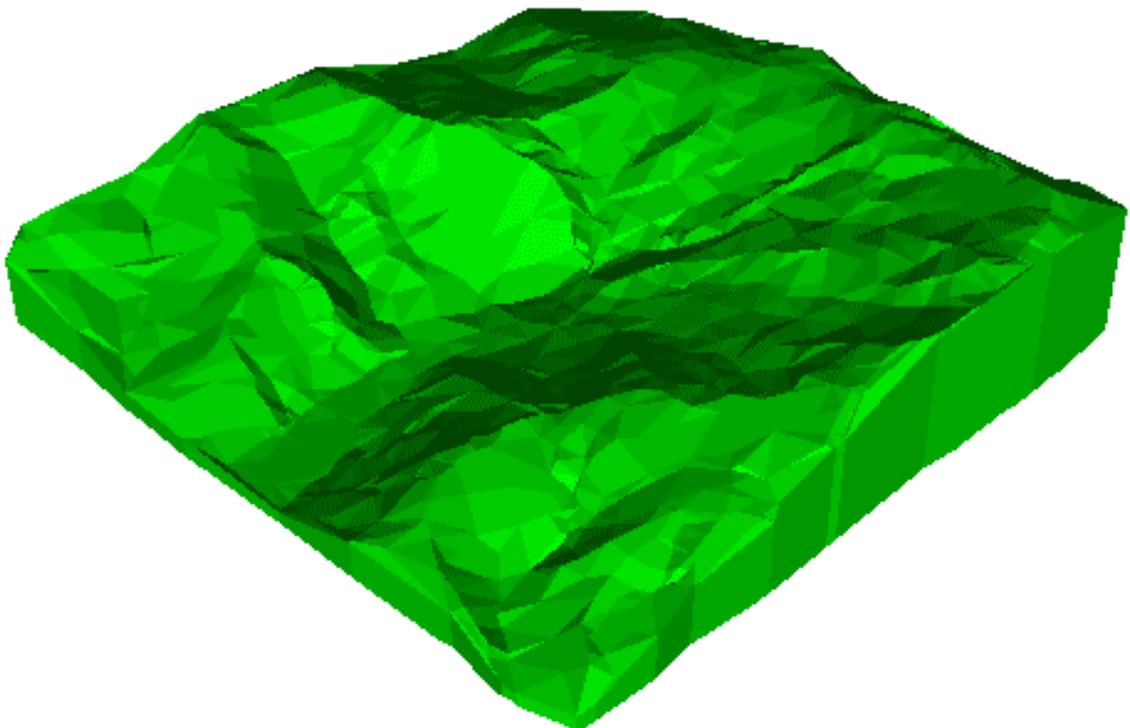


Figure 1.5 Northern part of the Castlepoint study area

The study area begins at the top end of the flat grassed area (lower centre of photo)

**Figure 1.6 Southern part of the Castlepoint study area**

The dividing fence follows the path of the cleared, zig-zag, line down the centre of the photo.



1.3. SOCIAL ORGANISATION AND BEHAVIOUR OF THE POSSUM

1.3.1. Introduction

Possoms are small, nocturnal, predominantly arboreal, herbivorous marsupials native to Australia, and introduced by Europeans to New Zealand. There are various genera within the superfamily Phalangeroidea; but of the species within the superfamily, the common brush-tail possum (*Trichosurus vulpecula* Kerr 1792) is the most widely spread and successful. This species has adapted to a wide variety of habitats over a substantial proportion of Australia and almost all of New Zealand. South-east Australia, Tasmania, and New Zealand have the highest population densities and presumably represent the most favourable environments (Kerle, 1984). Possoms may be found from sea-level to sub-alpine woodlands. Habitats range from dense podocarp and hardwood forest, through open eucalypt forests, to scrublands, tree-lined watercourses and other protected sites in the midst of open pasturelands and semi-arid areas, and buildings in both town and country. The major proportion of their diet consists of 4-6 leaf types (mainly eucalyptus in Australia), although they eat a variety of other foods including fruits of many trees, pollen, buds and flowers from a variety of species, grasses and clovers and possibly fly larvae and moths in small amounts (Fitzgerald, 1982).

The possum has been extensively studied. Morgan and Sinclair (1983) list 808 references, from 1835 to 1982, covering all aspects of the species life history - 39 of these having 'behaviour' as a key word. Many more reports and papers, particularly from New Zealand, have been published since this bibliography was compiled. Many of these papers describe capture-recapture projects and radio-telemetry results from various parts of the country, and relate these findings to the prevention and control of tuberculosis in New Zealand's possum population. However, few of the studies were of tuberculous possum populations or included direct observation of the animals. The often dense vegetation which provides much of the natural habitat of the possum in New Zealand, and its nocturnal nature, make it a difficult animal to observe in the wild. Limited numbers of captive studies have been undertaken, but these often lack relevance to the field situation (Biggins and Overstreet, 1978; Kean, 1967; Winter, 1976).

1.3.2. Activity Patterns

Possoms are nocturnal creatures although sick and/or starving animals have been seen abroad in daylight (Cowan, 1990b, pg 83; Ward, 1978; T.Harris, pers.comm.). They become active in their dens 1-2 hours before dusk and generally emerge within an hour after sunset (Winter, 1976; Ward, 1978; MacLennan, 1984). Both sexes become active about the same time at dusk, although females return to their dens earlier than males, and there is more variability in the time possums return to dens at dawn (Winter, 1976). Most possums are in their daytime dens approximately an hour before dawn (Jolly, 1976b; Green and Coleman, 1986; Ward, 1978; Brockie *et al.*, 1987). Variation in habitat type does not affect these basic patterns, which are similar for eucalyptus forests through to dense New Zealand hardwood forest. Possoms spend the first 1-2 hours after emergence in the area of the dens, sitting and grooming (Ward, 1978; MacLennan, 1984) until moving away to begin

feeding. The greatest distance from the den is reached 4-6 hours after dusk. Winter's (1976) study indicated a bimodal feeding peak, either side of a 12-1 am rest period, as did Ward (1978), while MacLennan saw no clear peak. All 3 authors noted feeding preferences, some animals returning to the same tree to feed over several nights. The majority of possums begin returning to their dens 2-3 hours before dawn.

The proportion of time possums spend on various activities through the night have been studied by MacLennan (1984) and Winter (1976), although other researchers have commented on an individual possum's particular activity at certain times of the night (Jolly, 1976b). Winter and MacLennan found possums spend more than 40% of the night immobile, generally in trees, with females stationary more often than males, and for longer periods². Periods of immobility varied from minutes to more than 1½ hours. Possums spent 30% of their time travelling in both studies, and 16-25% of their time feeding. The remainder of the time is taken up with grooming and social interactions.

There are differences in time allocations which possums spend on activities when on the ground, compared with when they are in trees. Males and females both spent a similar amount of time (8.9%) on the ground in MacLennan's study, however the females spent significantly less time feeding but more time sitting than males. In comparison, Winter's study found males spent 18% of their time on the ground and females 9%, with both sexes feeding for about half of that time. In both studies possums spent proportionately less time sitting when on the ground than in trees. Ward (personal communication with MacLennan, 1984) found possums in a native podocarp forest in New Zealand spent 46.1% of their time inactive, 11% feeding, 22.3% grooming and 20.6% otherwise active. The latter possums spent considerably more time grooming than either of the Australian studies.

There are no reports of activity patterns of possums from a pastoral habitat in New Zealand. Pasture species are an important part of the diet in such habitat (Gilmore, 1967; Harvie, 1973). Possums are selective browsers rather than grazers and it is likely that behavioural patterns described for an arboreal environment are modified when feeding extensively on pasture - particularly the amount of time spent in the trees. A small group of trees could provide sufficient food for a possum, but if grazing the animal may need to move over a large area of pasture to obtain a similar food intake. Pasture species are also more easily digested than leaves, and the amount of time spent immobile may decrease.

Possums spent less than 2% of their time out of the den interacting in Winter's study and less than 1% in MacLennan's. Some individuals spent considerably more time than this on certain nights, particularly when courting a female. However, few interactions were observed overall. Winter indicates the shortcomings of behavioural observations from a distance at night, and MacLennan doesn't comment on his subjects' interactions. The majority of interactions were sexually related,

² Winter: Males 36%, Females 44%; MacLennan: Males 50%, Females 51% of the time.

usually as a result of aggression by the female in response to a male's advances (Winter, 1976). Jolly (1976b) reported a wider variety of aggressive encounters, but could not provide as much contextual data as Winter.

The effect of weather conditions on activity patterns has been poorly documented. Jolly (1976b), Ward (1978) and Winter (1976) found that heavy rain caused the possums to seek shelter, and delayed the emergence of possums from their dens at dusk. Strong winds did not appear to affect their activity, although heavy frosts caused them to den early (Brockie *et al.*, 1987). In contrast, during observations carried out by the writer, it was found that few possums were out on open pasture during high winds. Jolly (1976b) cites Bamford in suggesting that maximum temperature over the previous 12 hours, and relative humidity at the time affected the number of possums seen.

1.3.3. Home Range Size and Population Density

Population densities vary widely over different habitat types. Winter (1976) determined a population density of 2.14-2.19 per ha over 3 years on a 17 ha site near Brisbane, whilst Dunnet (1956), on a 60 ha pastoral site near Canberra, found an average 0.5 possums per ha (range 0.2-2.2). Densities of 0.31/ha in 80 year old Tasmanian forest, and 0.55/ha in regenerating 3 year old bush were described by Hocking (1981). In contrast, possum densities in New Zealand are many times higher and more variable. Batchelor *et al.* (1967) estimated numbers in 6 broadleaf/podocarp forests and these ranged from 9.4-24.2 possums per ha. Crawley (1973) found 6-10 possums per ha using capture-recapture methods in a 14 ha area of lowland forest in the lower North Island, while Coleman *et al.* (1980) trapped a Westland population to extinction and calculated an average of 10.7 per ha. The Westland study was in a podocarp/mixed hardwood forest which bordered on pasture, with an altitudinal gradient of 1000 m. Densities ranged from a high of 25.4 per ha at the forest/pasture margin (250 m a.s.l), down to 1.9 possums per ha at 1200 m a.s.l (alpine grasslands). Densities of possums on developed farmland were shown by Brockie *et al.* (1987) to vary according to habitat. They found 0.12 possums per ha on open pasture, 6.4 per ha along tree-lined streams, and 8.4 per ha in a swamp. Jolly (1976a and b) found similar figures for a bush/pasture habitat on Banks Peninsula with 1.1-10.5 possums per ha.

1.3.3.1. Home range

Home ranges have been calculated in most studies of possum populations. The data collection methods used vary from capture-recapture records and direct observation, to radio telemetry. The areas trapped and patrolled in these studies also vary, as does the habitat type. 'Average' home ranges are only meaningful if applied to similar environments - and are also complicated by varying interpretations of the term. Trends are seen, however, in that possums living in densely forested areas have smaller ranges than those from more open environments (pasture-forest margins) and males have larger ranges than females.

Green (1984) calculates overall male and female home range size for Australian possums as 5.4 ha and 2.4 ha respectively, and range length as 394 m for males and 261 m for females. However, there is a considerable variation in the observations on which the overall figures are based, varying from 3.7-7.4 ha for males, and from 1.0-4.7 ha for females³. In comparison, Green cites average home ranges for New Zealand possums as being 1.9 ha for males, and 1.3 ha for females, with range lengths of 295 m and 243 m respectively.

Studies from which the Australian values are calculated have used similar methods - mark-recapture studies and minimum area methods for calculating home ranges - and were mainly from open eucalypt forests. However, New Zealand data cited by Green has come from a variety of study types and habitats. Mark-recapture and radio-tracking data are equally represented, and environments vary from dense native forest, through to scrub/pasture mixes. Radio-tracking studies give consistently larger home ranges than do trap revealed range, and possums from habitats which have pastoral margins have larger ranges than purely forested areas. Male possums living in forest only areas had home ranges between 0.5 and 3.6 ha, females 0.3-3.8 ha. Possums with access to pasture had ranges between 2.4-65 ha (males) and 0.3-45.8 ha for females, with corresponding increases in range length. A recent study, not included in Green's 1984 paper, found annual home ranges for 11 adult possums on farmland varied between 2 and 105 ha (mean 30 ha) (Brockie, 1991).

Home range size will also be influenced by the period of observation (quoted figures are 6-12 months data), seasonal forays to food supplies or during the mating season, and the distribution of resources within the area (Ward, 1978; Jolly, 1976b; Green and Coleman, 1986). The effect of the latter is seen in Green and Coleman's study where possums moved up to 1.5 km down a mountainside to feed on pasture.

1.3.4. Territorial and Denning Behaviour

Home ranges within a possum population generally overlap between, and within, sexes (Green, 1984; Brockie *et al.*, 1987). Early studies indicated ranges were defended and mutually exclusive, at least those of males (Dunnet, 1956 and 1964), but re-analysis of this data, and further work has determined that territoriality is based on mutual avoidance of co-dominants, and defence, if any, is restricted to den sites (Biggins, 1979; Green, 1984; Winter, 1976; Brockie *et al.*, 1987). Possums in captivity form a male dominant hierarchy, although it is only the highest and lowest ranking individuals that consistently win or lose fights (Kean, 1967; Biggins and Overstreet, 1978). Middle-order possums were in a more flexible position, and the winner of encounters between these animals could not be reliably predicted. Winter (1976) suggests that dominance rights, or privileges, in wild populations are learnt through encounters between individuals rather than defence of an area.

³Individual possum home ranges vary from 0.3-20.6 ha for males, and 0.1-6.5 ha for females

In Australia Winter (1976) observed many interactions between individuals at den sites. Females dominated males over the choice of den sites on 87-100% of occasions. However, males were able to den in other locations in the same tree, whilst other females (apart from joeys) were seldom tolerated. Winter found that where dens were well spread the home ranges of established females did not overlap. Where dens were closer no animal had exclusive use of an area, except for a small region in the vicinity of the den tree. Male ranges were far less exclusive, though some such areas did exist. Extensive forays during the mating season led to both large male home ranges, and the overlaps between individuals of both sexes. None of the New Zealand studies have described territorial behaviour - that is, active defence of an area (Crawley, 1973; Ward, 1978; Brockie *et al.*, 1987; Ward, 1986; Jolly, 1976b). These writers conclude that there is considerable overlap of home ranges of both sexes, and that most animals, once established, remain faithful to an area for most of their lives. Several workers, including Winter, suggest that in the more complex forests of New Zealand individuals cannot defend a 3-dimensional area (Green, 1984).

1.3.4.1. Possum Den Sites

Possums in Australian *Eucalyptus* woodland tend to use 2-5 dens per year (Winter, 1976), while New Zealand animals use 1-15, with an average of 8-10 (Brockie *et al.*, 1987; Cowan, 1989; Green and Coleman, 1987). There is an apparent excess of den sites in New Zealand habitat compared with Australian habitat (Clout, 1977; Triggs, 1982; Green and Coleman, 1987), and populations here are more likely to be limited by food resources rather than the availability of dens (Green, 1984). The number of dens frequented by a possum increases with the period of observation (Ward, 1984). Despite the large number of dens used in a year, many possums have been found to use a few of these locations preferentially (Cowan, 1989). Winter (1976) made similar findings in Australia.

The possum is able to adapt to a variety of den types, but prefers to den high above the ground whenever possible (Cowan, 1989). Denning habits of possums in the Orongorongo forest were similar to Australia, where most animals live in holes in the branches and stems of large trees (Cowan, 1989). Cowan found 92% of his possums denning in trees, which were generally large with significant numbers of epiphytes growing on them. Some possums denned under fallen logs, in clumps of flax, and under gorse bushes. These findings contrast with those of Green and Coleman (1987) who found 73% of their den entrances at or below ground level. In this Westland habitat large trees were uncommon, clumps of epiphytes were rare, and 40% of possum dens were less than 2 m above ground. It is unclear from the paper what proportion of actual den cavities, as distinct from den entrances, were at ground level, but it is considerably higher than at the Orongorongo site. In a bush/pasture habitat possums generally den at ground level. Common den sites include protected locations within or under clumps of flax or grass, under gorse bushes, in haybarns and ceilings, rabbit holes or in the tops of tree ferns (Jolly, 1973; Ward *et al.*, 1986). Cowan (1989) and Ward (1978) found many of the den sites were on the periphery of the area over which the possum ranged, either the previous night, or the following night.

1.3.5. Olfactory Communication

Jones (1921, cited in Winter, 1976, pg 92) concluded that possums have a poorly developed sense of smell, "...as is not unnatural in an arboreal species..." and seems to be of little importance in obtaining food or avoiding enemies. Since this study, several sets of scent glands have been described in the possum, and the significance of olfactory behaviour in possums described. Studies have indicated that each set of glands has a particular significance (Winter, 1976; Biggins, 1979). The most obvious glands are a line down the ventral part of the chest (sternal gland) which stains the fur here a light brown. Other glands include 2 pairs of paracloacals; labial or chin glands; and pouch glands in the female. Deposition of urine on substrate may also be used as a marker. A significant difference between olfactory communication, and visual or auditory forms, is that scent deposits or marks can potentially remain for some time after the initiating animal has left the area (Biggins, 1979). Thus, information such as identity of the marker, sex, sexual status, or territory boundary markers, can be left with relatively little input, and no continuing expenditure. Similarly, other individuals moving through the area can determine the status of resident animals, and in turn, leave their 'mark'. In solitary, nocturnal species, such as the possum, visual and tactile communication is limited and often olfactory and auditory communication is the most common social interaction (Winter, 1976; Biggins, 1979).

1.3.5.1. Pouch Glands

The pouch glands begin secreting when females are sexually active, and continue during lactation (Winter, 1976). The joey becomes stained a reddish-brown, as does the fur around the pouch opening. Biggins (1984) suggests that this may assist in individual recognition between mother and young. As the joey spends less time in the pouch the staining disappears, and auditory and visual cues may become more significant. Kean (1967) found some males followed lactating females, and suggested the pouch may be the source of the attractant. Winter only observed this after the joey had left the pouch. He suggested it corresponded to a second, spring, oestrous cycle and the male was responding to a mixture of scent cues.

1.3.5.2. Paracloacal Glands

Paracloacal glands are of 2 types: (i) a holocrine cell gland which releases entire cells and (ii) an apocrine gland producing a light coloured oily liquid. The cellular secretion is continuously being produced and is voided with the urine, or as a coating on the faeces (Biggins, 1984). There are marked differences in the number of cells produced by immature, adult male, and female possums (Winter, 1976). Kean (1967) suggests the durability of the cells, and sexual differences give the urine a persistent odour, and specific meaning. The second, apocrine, secretion is the strongest (to people) odour released by possums and is released at specific times. It has often been associated with stress or submissive responses (Thompson and Pears, 1962; cited in Winter, 1976). The secretion may also be released when the possum urinates, either dripping from the hairs around the cloaca, or smeared onto substrate (Winter, 1976). The accumulation of oil around the cloaca is probably

transferred in part when a possum sits on a branch, and would make up part of the attraction Winter observed for male possums when they closely investigated locations on branches recently vacated by females, in particular. Kean (1967) observed few instances of its deposition, and had not encountered it in the wild. He did find it on several occasions deposited at the entrance to den boxes occupied by animals known to feel “insecure” and, as with Winter, found it was often released if a possum struggled when being handled.

1.3.5.3. Urine Marking

Urine marking has been noted by Winter (1976), Biggins (1979), and Kean (1967). All writers describe possums moving their anal area along close to the ground with a sinuous motion of their tail. In some cases the urine simply dripped from the vibrissae around the cloaca, in others a distinct trail was left along a branch. Kean found it was regularly induced when transferring possums from spacious cages to restricted areas, and felt it engendered confidence. Winter’s observations were more limited, but he found urine marking associated with 2 distinct situations. The first was generally seen when males were in association with oestrous females, and urine was deposited as they followed the female in the trees. The second was secretions by females placed in front of their trailing joeys. At this stage the female was keeping the joey at a minimum distance of 1 m (except when denning), and Winter assessed the mother-joey bond as breaking down.

1.3.5.4. Chin Glands

The sebaceous chin glands are situated in small areas on the inside of the anterior part of the upper and lower lips. They are often associated with chesting (use of the sternal glands) (Winter, 1976), and this often makes it difficult to determine their use. Chinning can be distinguished from chesting when the sternum of the possum remains off the substrate being marked. When chinning the lower lips of the possum are often drawn back, and saliva may also be deposited in addition to glandular material. Winter described similar objects being marked by chinning as for chesting - tufts of grass, tree bases, ends of broken branches and den rims. However, differences were seen in that these objects tended to be smaller, and the activity less vigorous than chesting *per se*.

1.3.5.5. Sternal Glands

The sternal glands are most commonly used to mark objects. Chesting of the base of trees is seen most often, but branches, the ground, and rims of dens are also marked. When chesting a tree base the possum spreads the forelegs wide around the tree, pulls itself towards the tree, and then rubs the sternum forward along the trunk. The possum then lifts its chest off the tree and returns to the starting position. This action may be repeated several times (Winter, 1976; Jolly, 1976b). The possum may sniff the surface between each stroke, particularly when chesting the ground. Chinning may also be associated with the chesting movement.

In Winter's study chesting was almost always associated with the actual presence nearby, or previous presence of, a possum at that location. It was exhibited 8 times more often by males than females,

and two-thirds of the observations were in the presence of an oestrous female (Winter, 1976). Male possums also frequently mark trees as they move across the ground. There was no apparent pattern, either in number of trees marked, or extent of any marking in Winter's study, but the trees almost invariably had a recent history of possum use. Biggins (1979) noted that dominant possums marked more often. When a possum emerges from its den it may also chest the immediate vicinity, more vigorously if another possum is in the same tree. Marking by females was less vigorous and less frequently seen than that by males. The few observations noted were of chesting den trees and when other possums, usually female, were in the vicinity.

Winter (1976) suggests that the social function of chesting and chinning is to advertise the presence of the marker to a potential rival for a limited resource such as a den, or a mate. Most marking in this context occurs in locations where another male would be exposed to the scent, eg. at the base of a tree or where a female had been sitting. Biggins' 1979 study determined that male possums, exposed to scents of other males, could easily distinguish between individuals. When possums mark their den tree, or trees along the routes they follow to feeding areas, they are both distributing their own scent at focal points in the area, and informing other individuals of their presence. The scent will be freshest and most dense in frequently used locations. Scent marking of male possums may be primarily related to establishing, and maintaining, areas in which the resident male is dominant over intruders (Biggins, 1979). Self-confident resident males would have an increased chance of mating with oestrous females in that area, and also preventing establishment of other males, eg. immatures, in that vicinity.

Joeys may learn from associating scent marks deposited by their mothers during the breakdown of the mother-joeys bond with possible subsequent agonistic interaction if they approach too closely (Winter, 1976; Jolly, 1976b; Biggins, 1979). Thus, scent marking reinforces, and maintains, a system of mutual avoidance between individuals as each animal assesses the freshness, density, and possibly the depositor's identity, of markings in its immediate vicinity.

1.3.6. Vocalisations

The possum has a wide variety of vocalisations, ranging from quiet chatters and clicks, to high velocity screeches. There are a number of discrete calls, and a series of graded vocalisations which are considered to be a continuum from a low to high intensity threat response (Winter, 1976; Biggins, 1984; Kean, 1967). Winter divided the calls into 2 groups: (i) those aimed at causing the withdrawal of another individual, generally involving some degree of threat, and (ii) calls associated with appeasement or encouraging approach from another, eg. males courting females or mother-joeys interactions. Many of the group (ii) calls are quiet and not heard beyond a few metres.

The vocal behaviour of possums, and particularly their contextual associations, has not been extensively researched (Biggins, 1984). Nocturnal species are difficult to study in the wild, and captive specimens are often restricted in their behavioural repertoire - so much so that early

investigators reported an absence of vocalisations from many species (Hediger 1958, cited in Biggins, 1984). Winter observed the change in intensity of 'screeches' with the increase in postural threat exhibited by possums. As a possum moved from a four-legged stance, through three-legged with raised paw, to a full bipedal stance with widespread forepaws and open mouth, the screech developed from a hiss and growl, through to an ear-splitting outburst. A feature of this form of interaction is the closeness of the protagonists, whether or not a true fight ensues, and the open-mouthed hissing and screeching. 'Grunting' was also frequently associated with face-to-face confrontations by Winter (1976, pg 61) and, in part, resembles a short chesty cough. The grunts were given in a variety of circumstances, mostly agonistic, and were often closely associated with screeches. Winter heard grunts from possums in both offensive and defensive situations suggesting the significance of the sound is dependant on the actions of the possums giving the grunt (Winter, 1976).

The distribution of calls through the night was described by Winter for the more vocal of the calls. These were found to peak early in the evening, and late at night (as the possums returned to their dens). This is consistent with a solitary species in which very loud calls are used in the maintenance of a minimum distance between individuals, and the graded series of calls allows for the indication of a wide variety of motivational states (Winter, 1976).

1.3.7. Breeding and Reproduction

Female possums are dioestrous, almost always monovular and ovulation is spontaneous. The 2 cm long, hairless, blind, and virtually embryonic joey is born 15-18 days after conception, and crawls unaided to the pouch. Here it attaches to one of two teats for 4-5 months before venturing outside the pouch again. The major breeding season is from March to June, with a lesser season August to September or October. The pattern is, however, variable for reasons which have not been fully documented - although the bimodal peak is most common some areas have a single Autumn peak, whilst in others possums may breed all year round (Tyndale-Biscoe, 1955; Brockie, 1991; Green, 1984). Many females are sexually mature at 1 year old (Ward *et al.*, 1986; Winter, 1976), although in some areas maturity is delayed until the second year (Crawley, 1973; Cowan, 1990b, pg 87). Greater than 90% of sexually mature females conceive and rear a young to 4-5 months of age. Mortality of young increases rapidly from this age as the joey has reduced protection from the mother's pouch (Tyndale-Biscoe, 1955). Joeys become increasingly independent from 8-9 months of age, though some may remain with their mothers until 12-15 months (pers. obs. R. Jackson and B. Paterson), or return at dawn to share a den with the mother (Winter, 1976).

Male possums mature later than females and sexual maturity usually occurs during the second year of life. Bodyweights continue to increase for some months after the rate of weight increase in females levels off (Cowan, 1982; Winter, 1976). However, Broom (1898), Jones (1924), and Wodzicki (1950), (all cited in Tyndale-Biscoe, 1955) state that *Trichosurus vulpecula* is sexually mature at the end of 1 year. Tyndale-Biscoe (1955) concurs with these writers based on analysis of

the relationship of body weight and tibial ossification to fecundity, but does not link this to a specific age of maturity. There is a significant increase in the size of the testes at puberty, and a close correlation between the length of the testes and the presence of sperm (Cowan, 1982; Tyndale-Biscoe, 1955).

Dominant animals mate with most of the females (Winter, 1976). Males show little interest in anoestrous females, but will actively follow those in oestrus (Jolly, 1976b). Winter (1976) described a consort period of up to 40 days during which the female shows an increasing degree of tolerance towards the male, and which ceased no more than 1-2 days after mating. Female possums take a passive role in courtship and do not actively encourage the male. If the male approaches beyond a certain distance, she will threaten, and even fight, with the male generally retreating. During the consort period the male persistently follows the female. Although not denning together, in Winter's study consort males were found close to females soon after dark. The male sniffs at, and often scent marks (chesting and chinning) places where the female has been sitting. Males searching for an oestrous female used scent almost exclusively to find them, although post copulatory 'chatter' calls by males occasionally attracted other males (Winter, 1976). The female gradually becomes more receptive, and eventually allows the attendant male to attempt copulation, after which she again threatens possums approaching too closely (Winter, 1976). The consort relationship is not necessary for a fertile mating; Winter observed several aggressive matings as did Jolly (1976b). There are few other comprehensive reports of mating behaviour in the literature. Although the female is probably receptive to mating, the males in the latter observations had not spent much time with the female, and copulations often followed fights, and/or were accompanied by loud screeching.

Whether preceded by a consort period or not, the behaviour pattern of a mating attempt is similar (Winter, 1976; Jolly, 1976b). The male approaches the female, commonly head on and, ignoring threats which would normally result in retreat, climbs over the female's head on to the back. He turns himself around as he positions his hindquarters over the female's rear, and attempts intromission. The receptive female is initially aggressive, though considerably less so than when anoestrous, and may screech. As the male settles himself fully on her back, there is less and less response from her as she resigns herself to the fact. The female dislodges the male shortly after copulation.

Winter (1976) has made the most extensive observations of mother-joeys interactions and notes the relative indifference of marsupial mothers to their young (Kaufman, 1974 and Russell, 1973, cited in Winter, 1976). The female possum recognises the presence, and appears to know the location of her young, as indicated below - but, out of the den, the primary responsibility for maintaining contact with the female rests with the joey. After leaving the pouch the joey may ride on the mother's back for another 2-3 months, although attempting to retreat to the pouch on occasions (Winter, 1976). When the joey first leaves the pouch it clings to the mother's back as best it can. Within a few weeks the joey almost invariably assumes a longitudinal position, with head at the level of the mother's shoulders, whenever travelling. As the joey gains confidence it begins to spend more time off her

back but, if the mother moves away, will follow to maintain a separation of 1-2 m. Winter observed that, although the mother did not encourage the joey to either move off her back, or to remount before she moved away, the female did wait for the joey if they became separated. He also noted that if the joey was distressed, particularly by the presence of a male, the mother returned to the joey - although not always immediately.

During this period the joey gains more independence from the mother, and she begins to show an increasing degree of aggression towards her young. This is evident from an increase in the following distance of the joey, and a larger amount of scent marking by the female, especially using the cloacal scent glands (Winter, 1976). Den sharing by the mother-joey pair continued for 7-16 months in Winter's study, but averaged 8-9 months. Other adult possums also began to show more aggression towards the immature possums. By 10-12 months of age most of the joeys were independent animals attempting to establish their own home ranges. Most of the immature males either disperse or die, while a much larger number of surviving females remain in, or close to, their natal area. Winter attributed most of the disappearances of young males to dispersal, but disappearances of immature females to mortality. The greatest mortality of possums occurs during their first few months of independence, although the majority of adult possum deaths in New Zealand occur during winter (June to September), as a result of poor weather conditions, feed shortages, and as a consequence of energy expenditure by males during the mating season (Winter, 1976; Efford, 1991).

1.3.8. Dispersal

A major characteristic of all populations of possums studied is the emigration of immature male possums from their natal areas. Winter (1976) indicated that 9 of the 15 possums born in the area, and which disappeared after emerging from the pouch, were males. Similarly, 90% of immature adults attempting to establish home ranges in the area were males. Numerous investigators in New Zealand (Crawley, 1973; Dunnet, 1964; Green, 1984; Jolly, 1976b; Ward, 1985; and Ward *et al.*, 1986) all reported similar findings. A variation on this theme is presented by Little and Cowan (1992). They analysed records of possum captures on Aroha Island in the Bay of Islands, which is connected to the mainland by a causeway. Possums moved into the swampy and forested mainland adjacent to the island in the 1970s, and the first captures on the island were made in 1979. An equal number of male and female possums have been captured over 10 years, and most of these possums were 1-2 years of age. Possums have invaded the island all year-round, but with peaks in autumn and spring reflecting normal juvenile dispersal. The authors suggest that the lack of male bias may be due to the attraction of year-round fruit in an orchard on the island. They also point out that previous studies were in areas where possums have been established for many years, and there may be differences in behaviour in newly colonised areas (Little and Cowan, 1992).

Efford (1991) reviewed the available evidence on dispersal in New Zealand. Sixty-nine possums are known to have moved more than 2 km, with a maximum recorded distance of 41 km. The majority (78%) of dispersing possums are immature animals between 9 and 14 months of age, however, there

was also a significant number of mature adults. Median dispersal distance for males (3.7 km) was less than that of females (5.5 km), although male dispersers outnumbered female by 4.3 to 1 (Efford, 1991). It was found that female dispersers behaved differently to males - females were more likely to move repeatedly, as well as further. Efford suggested that female dispersers only settle permanently when they have found a 'vacant' site, whereas males are less sensitive to density. There is also evidence which indicates another, lesser, dispersal peak at 21-25 months of age for both male and female possums. The effect of differences in maturation rates of various populations, and how this affects time of dispersal is uncertain (Efford, 1991).

Causal factors initiating dispersal are uncertain for most species (Efford, 1991). Aggression from conspecifics, hormonal changes during sexual maturation, density related pressures, and genetic predisposition have all been suggested or implicated in some species. The proximate factors which lie behind possum dispersal are, as yet, unknown, but Efford suggests it may be useful to "...view dispersal as a behaviour undertaken by individual possums to maximise their Darwinian fitness, or imposed on them by other animals maximising their own fitness."

1.3.9. Summary

The preceding sections have discussed general aspects of possum behaviour relevant to this study. Specific behavioural patterns such as aggressive interactions, and the responses to other species will be fully described where appropriate in later sections. It is important to note that the majority of behavioural patterns are based on Australian studies, in an environment substantially different from that inhabited by possums in New Zealand. Comparisons between various habitat types have been noted, but the high density of possums at the bush/pasture margin, the much larger percentage of pasture species in their diet, and the lack of any significant number of den trees in many of these habitats is important when considering the mechanisms of disease transmission in New Zealand.

Chapter 2

A Radio-Tracking Study of Brush-Tailed Possums and Cattle

2.1. INTRODUCTION

The main aims of this study were:

- (i) to determine the movements of selected possums and cattle in the study area: and hence to estimate their activity areas and compare their patterns of use of the site and
- (ii) to radio-tag juvenile possums, track any dispersing juveniles and identify their new denning areas.

Major divisions of this chapter are as follows:

1. Introduction to the techniques used in the study
 - Section 2.2: A review of radio triangulation techniques, applications and equipment
 - Section 2.3: Discussion of home range estimators and their use
2. Materials and Methods
 - Section 2.4: Equipment and techniques used in the radio triangulation study
3. Measurement of error in the radio triangulation system used in the study
 - Section 2.5: Specific methods used in this section, followed by results and discussion
4. Results of radio triangulation study
 - Section 2.6.1: Presentation of home range data for the possums and cattle
 - Section 2.6.2: Movement of cattle in the area
 - Section 2.6.3: In depth results of movements and ranges of 7 frequently tracked possums
 - Section 2.6.4: Common use of habitat by possums and cattle
 - Section 2.7: Analysis of den use by possums
 - Section 2.8: Fates of radio-tagged juvenile possums
5. Discussion
 - Section 2.9: Discussion of data presented in this chapter

2.2. RADIO-TRACKING - A REVIEW

2.2.1. Radio-Tracking Defined

Radio-tracking or radio-location is a method of determining the location of a distant radio transmitter based on apparent changes in its signal strength. The signal may be physically tracked to its source; or bearings from at least 2 different points used to calculate its geographical position - the latter is radio triangulation. The radio signals may also convey information beyond simple location of the subject - such as activity patterns, stance or physiological parameters. This is often referred to as biotelemetry which in the literal sense means the measurement of biological parameters from a distance. Kimmich (1980) suggests that in its modern context biotelemetry means "...assessment or control of biological parameters from animals, subjects and patients with relatively little disturbance of the animal/subject, resulting in undisturbed and noise-free measurement of physiological parameters."

2.2.2. History

The earliest paper describing biotelemetric techniques came from Einthoven in 1903 (cited in Kimmich, 1980) who successfully recorded and transmitted an ECG (electrocardiograph) 1.5 km over public telephone wires. In 1910, Barker (cited in Kimmich, 1980) connected several hospital wards by wires into a specially designed system to monitor ECGs; while in the same year Brown (Kimmich, 1980) transmitted a phonocardiogram over a distance of 150 km. Wireless telemetry was first reported in 1921 when Winters (Kimmich, 1980) transmitted heart sounds via ship to shore radio. All these methods were limited by the size of the equipment necessary to record, and particularly, transmit the information. In 1948 Fuller and Gordon (cited in Kimmich, 1980) developed a portable wireless device which could be fitted to animals, and the following year Holter and Gengerelli (Kimmich, 1980) reported a similar system for humans. However, both systems were restricted by the size of the packages - weighing up to 50% of the subject's body weight they were impractical for field work on any but the largest animals.

The invention and subsequent availability of the transistor in the early 1950s revolutionised the electronics industry, as radios and other circuitry could be built which in their entirety were smaller than a single vacuum tube. The potential of the transistor was readily apparent and through the 1950s many journals reported new methods developed to measure and transmit physiological parameters from humans, particularly military personnel such as jet fighter pilots. Wildlife biologists, aware of the value of such techniques, closely followed developments, and in 1959 Le Munyen and others reported the design of a surgically implanted radio-telemetry device to monitor the heart rate of chipmunks. Eliassen (cited in Kimmich, 1980) reported attaching an externally mounted transmitter to record the heart rate and pulse pressure of free-flying mallard ducks, and Marshall *et al.* (Kimmich, 1980) attached transmitters to porcupines to determine the location and activities of the animals over time. The first feasible radio-tracking system, on which current techniques are based, was developed by Cochran and Lord in 1963 and used to monitor rabbits, skunks and raccoons -

since then species as diverse as crabs and elephants have been radio-tracked. Snakes have been followed (cited in Mech, 1983) to investigate thermoregulation and polar bears tracked via satellite for hundreds of kilometres (Kolz *et al.*, 1980; Messier *et al.*, 1992) as have dolphins (by Kuechle cited in Mech, 1983) and sea turtles (Mech, 1983). As well as the radio transmitter, modern packages may include sensors to detect whether or not the animal is active, its body position, for example if a bird is on the ground or flying, body temperature and other physiological data. A recent development has been the capture collar (Mech *et al.*, in press) where a standard radio-tracking collar has a receiver and a pressurised anaesthetic dart added to the package. On a signal from the tracker the dart fires, and the biologist can track the collar to recover the anaesthetised animal.

Biotelemetry has progressed far beyond the early experiments using wire leads and valve and tube circuits. Advanced miniaturised electronic components, CMOS⁴ integrated circuits, thin film technology, very small and efficient batteries along with improved construction techniques and, perhaps most of all, the commercial availability of 'ready to use' radio collars has made the application of this technology possible in a wide range of wildlife studies both in the laboratory and in the field.

2.2.3. Advantages and Disadvantages

There are many questions that need to be considered before a decision is made to use radio collars. Advantages need to be weighed against disadvantages and consideration given to other systems which may produce similar information but with less cost. Radio-tagging enables the researcher to closely follow individuals over time, but the large investment in time may be better used in placing visual markers on many animals and concentrating observation periods. Similarly, achievement of specified aims may need such a large number of radio tags that cost and time both become prohibitive. The use of visual markers such as beta-lights (Davey *et al.*, 1980), chemiluminescent tags (Buchler, 1976) or coloured flashing LEDs (Batchelor and MacMillan, 1980) are in some cases cost-effective alternatives. To track animals with small ranges, spools of fine thread may be attached, and can provide very accurate records of their movements (Miles *et al.*, 1981). The recent development of implantable passive transponders permits the unique identification of individuals and a simple method of recording the use of any particular area if activation coils can be placed effectively. The major advantages of radio-tracking are that it allows accurate identification of individuals and data collection about them from a distance, or when they cannot be directly observed, and potentially allows relocation of that individual. Individual identification is possible with techniques such as dye-marking, ear tagging or noting colour patterns of the species under study, but these methods rely on visually locating the animal in question. To relocate such a marked

⁴ Complementary Metal-Oxide Semiconductor

animal after initial capture can be a simple matter of waiting at a frequently used feeding ground, watering hole or near a known den site until the animal returns. However if the animal ranges over a great distance, is especially wary, or emigrates, then relocation may be difficult or impossible. Use of radio transmitters diminishes the need for extensive study of behaviour patterns to determine where the animal is most likely to feed or water at a particular time. The signal from the collar can be used as a guide to their location, and a careful approach made whenever the operator chooses. Similarly, radio collared animals can be tracked from a distance without the need to sight the individual to confirm its identity, and automatic recording equipment may be attached to the radio receiver for continuous or unattended monitoring.

The time required to develop radio-tagging and tracking techniques can be easily underestimated (Kenward, 1987). Techniques and methods must be understood to initially select appropriate technology and then both use and apply the equipment to the species under study. Detailed studies of the animals themselves may be needed to ensure meaningful interpretation of data obtained. Such data may come at a rate which is slower than anticipated, with consequent loss of animals from the study due to death, dispersal and transmitter failures.

Sufficient numbers of animals need to be captured for study, and if necessary recaptured for transmitter replacement or removal. Biases will be introduced if the radio-tagged animals are not representative of the study population, such as when a predominance of juvenile animals are tagged (Kenward pp. 3-4, 1987). If studying prey-predator relationships, which animal would be most appropriately tagged - the predator or its prey? Tagging the first requires less tags but may not provide sufficient information to determine the impact of the animal on its prey, whereas tagging the prey species will limit direct information obtained about the predators (Kenward pg 3, 1987).

The species of animal will dictate the size and design of the radio package. Packages weighing 500-700 milligrams are available and can be carried by animals weighing 7 g or more, but will only transmit for 10-15 days. As the requirement for longer radio life and higher transmitting power grows, so too does the size and weight of the package. Batteries become a major proportion of the total package weight, and although advances in design and performance have increased their usefulness tremendously, cells used in radio collars are primarily designed for other uses, such as hearing aids and watches, and not specifically to maximise the power to weight ratio. If the animal lives in conditions which affect signal transmission, options to increase transmission range may be limited by the need to keep collar weight down. Two-stage circuits which amplify the signal need greater battery power to maintain transmitter life and so increase the weight of the package. In many cases a compromise between radio weight and life span is required.

The habitat of the animal has a considerable impact on the signal characteristics. Sound waves travel best in open, flat areas, whilst dissected terrain can severely affect signal quality. Radio-tagged animals that live in open country, such as lions and cheetahs, are generally able to be tracked over greater distances than foxes or badgers that live underground or in broken country, and may only be

located over 1-3 kms. Aquatic species are difficult to tag due to their streamlined shape, and to track due to the effect of water on signal propagation. Fifty percent of signal strength is lost at a depth of 10 metres in freshwater and there is even greater attenuation in salt water as depth increases. The loss of signal may not present a problem in rivers and streams as the location of the animal will often be well defined and receivers can be appropriately placed. However, in salty or brackish water acoustic tags (sonar) are more appropriate due to signal characteristics although they do not work well in turbulent or shallow waters.

Radio-tracking is also relatively expensive, so its cost-effectiveness must be considered. Prepackaged and ready to attach radio collars are widely available, as are commercial multi-channel receivers. Buying ready made equipment may initially cost more than self designed and built systems, but the time taken to develop one's own equipment will often exceed initial costs of purchase unless special requirements must be met. The small size of the components and the experience required to build and adequately package the transmitters to protect them from animal and weather damage requires considerable expertise which the reputable supply firms already have. It is usually best that this be utilised.

2.2.4. Specific Application Of Radio-Tracking

Radio-tracking allows the precise identification of individuals and the ability to relocate that animal when needed, and so provides data on location and activity. However there are many other types of data that can be obtained from a tracking study:

1. As animals are tracked repeatedly over a period of time, information about their movement patterns is obtained. Home ranges can be identified, and spatial ecology such as the intensity of range use and habitat selection of the species can also be mapped. Longer term studies provide information about dispersal - seasonality, direction, distances, ages of dispersing animals and mechanisms of colonisation (Mech pg 5, 1983). Migration patterns of many species have also been better defined through the use of radio-tracking (Walcott *et al.*, 1979). Experimentation with migration, orientation, navigation and homing of animals is also possible (Fritts *et al.*, 1984, cited in Mech, 1983).
2. Behavioural studies of animals can be greatly enhanced by using radio tags. The tag may be used as a method of tracking a secretive animal to locate nesting or denning sites so that its behaviour can be observed, or the signal characteristics may be used to infer what activity the animal is engaged in at the time. Variation in the signal can often be used to determine if the animal is active or resting, and with the addition of other sensors - such as mercury switches - information can be gathered on activity such as whether a bird is flying, or posture such as tail position (Kenward *et al.*, 1982). It should be noted when using radio signals to identify

behaviour patterns from a distance that signal variation needs to be visually matched with the animals behaviour before inferences are made.

3. Predator-prey interactions and relationships can be intensively studied from different perspective's, depending on which animals are tagged. Putting a collar on the predator will give information about prey consumption, hunting success rates and proportions of species types in the diet, whilst tagging the prey species, (which generally entails tagging a large number of animals), will give data on mortality and survival of the species (Brand *et al.*, 1975). Fitting motion sensors to the collars can aid in rapidly alerting the researcher to the fact that an animal may have died.
4. Other uses for radio transmitters include their use in tranquilliser darts to locate those animals which move out of sight before full sedation, and will also aid in finding lost darts. Census techniques can be monitored by tagging animals in an area, testing their observability by overflying and adjusting results of an aerial census in the same area accordingly (Floyd *et al.*, 1979). Automatic radio-tracking systems have been built to sequentially cycle through frequencies and record on paper or magnetic media the signals which are located. This allows large amounts of data to be collected with relatively little manpower input (Cochran *et al.*, 1965).

2.2.5. Radio-Tracking - System Description

Radio-tracking systems have two main components - a transmitter and a receiver - each of which can vary considerably in their complexity and size. The transmitter comprises the electronics to produce a signal, an aerial and power source, protective packaging, and a system for attachment to the animal. The receiver can be either mobile or stationary and comprises an antenna, a power supply and signal-collecting electronics plus a recording device. The latter may be a mechanical, manual or electronic system.

The transmission distance of a signal is a result of a combination of the following factors:

1. The power output of the transmitter
2. Tuning of the transmitter in relation to the animal's body
3. Transmitter antenna length, position and type
4. Height of animal above ground
5. Elevation of transmitter in relation to general terrain
6. Vegetation and soil type
7. Sensitivity of the receiver
8. Type, number and elevation of elements in receiving aerial
9. Weather conditions

2.2.5.1. Transmitters

2.2.5.1.1. Frequency

The transmitter circuitry consists of an oscillator circuit and a pulse capacitor which determines the pulse duration and interval. Simple oscillator circuits using inductors and capacitors were used in early studies and are known as wide-band circuits because they transmit over a wide frequency range. This feature prevents accurate identification of tagged animals in the same area, but at short receiving distances can be used to identify an animal returning to a den, for example (Cochran, 1980). The basic circuit has changed little from the 1963 design of Cochran and Lord which used the ability of quartz crystal to oscillate at a specific and stable frequency when an appropriate current is applied to the circuit. The frequency is the number of times the signal oscillates in one second, and is generally millions of cycles per second (abbreviated as MHz).

A simple circuit with crystal and capacitors to control the pulse characteristics of the signal is known as a single stage transmitter. It is small, lightweight and uses relatively little power but is restricted in its transmission distance. A second stage can be added to the circuit as an amplifier to increase the power output and range. The greater power consumption requires an increase in battery size or power to maintain the same transmitting life as a single stage circuit. Advances in electronics have led to the use of multivibrators (Taylor and Lord, 1978) and CMOS circuitry to produce and maintain precise control over the transmitter (MacDonald and Amlaner, 1980). Thin and thick film technology has also been incorporated into radio tags, allowing the designer to decrease the component count and improve battery life.

The frequency chosen for the radio collars is an important consideration in designing the study. Although in many parts of the world there are official restrictions on frequencies which may be used, choosing the most suitable frequency for the purpose of the study, the animal species involved, and the terrain in which the project must operate is essential. Transmitter frequencies can be arbitrarily grouped into four ranges. The lowest frequencies used are in the 30-50 MHz range; a second range are between 140-160 MHz; the third range is VHF at 220 MHz; and finally UHF from 300-3000 MHz. Each of these ranges has characteristics which suit it for particular field work. The low frequency signals are little affected by vegetation or signal bounce, although the receiving aerials required need to be large to maximise gain, and large mobile aerials are cumbersome to move with in heavy vegetation. These low frequencies are effectively transmitted through fresh water and often used in studies of fish. As frequency increases the signal is more prone to distortion from vegetation, water and geographical features. The size of the aerials needed for the higher frequency ranges can be much smaller and still maintain high efficiency levels for both the receiving aerial and the transmitter antenna. Signals in the UHF range are best suited for long distance work where the signal is unimpeded by vegetation, buildings or topography, for example in tracking oceanic bird species.

2.2.5.1.2. Power supply

There are four main types of battery used to power transmitters - mercury and zinc-oxide, lithium, nickel-cadmium and solar cells, although solar cells are often combined with one of the other types.

Lithium cells have a much higher energy density per unit weight and volume, higher circuit voltage, long shelf life, and better operating characteristics in low temperatures than mercury and zinc type cells. As batteries are often 50% of the total weight of the transmitter package it is important to minimise battery weight whilst still maintaining an effective signal life.

Solar cells can be used to power tags for several years but will only operate when exposed to sunlight, unless backed up by a rechargeable battery. Using photoelectric panels rather than a dry cell in a tag design can lower the final weight of the package from 8 g when a conventional lithium cell is used down to 6 g for a single stage, daylight only, subminiature tag, enabling very small animals to be tagged. Solar panels used alone may cause problems when the animal takes shelter, is nesting or if the animal dies and falls so the panels are covered. Combining solar panels with battery backup prolongs the life of a transmitter years beyond that obtainable with dry cells alone. In reality problems with uncontrolled recharging patterns of nickel-cadmium batteries often affect the achievable lifetime.

The choice of battery type may be restricted by factors such as; power requirements, package size and weight limitations, the need to, or likelihood of, recapturing the animals fitted with the collars, the temperature extremes to be encountered, duration and aims of the study, and cost factors.

2.2.5.1.3. Signals

Frequency separation and pulse characteristics of the signal are important. Quartz crystals provide far greater frequency stability than inductors and capacitors alone permitting the use of 50 Hz bandwidth's (approximately the sensitivity of the human ear), although receiver electronics are generally only able to discriminate between signals 10 kHz apart. However, as the frequencies of some transmitters tend to drift due to temperature and battery changes, and receivers vary in where they pick up a given frequency, a 20 kHz separation between adjacent frequencies is more suitable for best discrimination (Cochran, 1980; Mech pg 23, 1983). Pulse width and interval are modified from the basic continuous carrier signal to aid in locating the source of a signal and to prolong battery life. In most cases a signal that varies regularly is easier to track than a continuous sound, and pulse rates of about 60 per minute with pulse width (length of signal 'beep') of 40 milliseconds are commonly used (Kenward pg 25, 1987). These values are generally best suited to humans tracking animals by sound and ensure an economical battery life.

2.2.5.1.4. Antennae

Two main types of antenna are used for animal tags - the loop and whip aerials. The aerial used will depend on several factors among which are the type of animal and its habitat, and the design and frequency of the radio collar. The most efficient system consists of a main whip $\frac{1}{4}$ of a wavelength long, with a ground-plane antenna mounted perpendicularly or in the opposite direction. As an antenna of ideal length would be too long, particularly in the case of a loop aerial, the effective range of the collar is decreased. Where the tag must be compact or the aerial may be damaged by the animal, eg. by wolves and other social carnivores (Mech pg 20, 1983), loop aerials are incorporated into the package. Loop aerials generally form part of the neck collar used to attach the transmitter to the animal or wind around the body of the tag in implanted transmitters. They have advantages over whips in their compactness and the extra protection offered to the aerial. Their disadvantages are that the effective straight line length of the aerial is less, and the amount of radiated energy is decreased due to absorption by the body. Both factors contribute to a shorter transmission range for the collar.

2.2.5.1.5. Transmitter Encapsulation and Attachment.

The final step in preparing a transmitter for use is protecting components from the environment and from damage by the animal. Encapsulation of the system is generally in dental acrylic, epoxy resin or in sealed metal cans. The compound is layered over the components, or, in the case of cans, the lid is sealed with solder and then coated. Wires leading to the aerial exit through holes which are closed with resin. The leads to the battery and aerial are common points of access for water in any tag design and extra care is required to protect them. Whip aerials are prone to breaking at the stress point where they emerge from the potting material, and are protected using a spring or flexible silicone sealant to reduce compressive pressures on the aerial wire.

It is important to attach the transmitter package to the animal in a way which has minimal effect on its natural movements, which does not wear and chafe, and avoids undue stress in capture and handling. There are three main methods of attachment to a subject - gluing, harnesses, or collars. Gluing the tag directly onto the animal's fur or feathers is commonly used in smaller species, and is particularly useful when only short periods of observation are required. The tags will be lost over several weeks as the fur or feathers moult. If the transmitter is still active it can be traced and reused.

Harnesses have been developed for many species, particularly birds and marine mammals, or those species with narrow heads relative to their neck size such as badgers (Kruuk, 1978b). The harness has loops to go around the limbs or wings of the animal, and is generally mounted with the transmitter on the animal's back. Harnesses are potentially life-long attachments for the animal and may slacken with time, be caught in bush, or twist and hinder the animal's movements. Harnesses for marine species are generally fitted with bolts designed to corrode, or a similar 'weak link' system, which releases the package when they break (Butler and Jennings, 1980; Loughlin, 1980). Young,

growing animals require a harness design which allows for their growth, is removed before becoming restrictive, or incorporates a weak link (Jackson *et al.*, 1985).

Collars or necklaces are probably the most commonly used method of attachment. The collar may be a leather or nylon strap (with or without an integral aerial) fitted to the animal's neck using rivets, or bolts, or a plastic cable tie embedded through the transmitter package. The weight of the encapsulated transmitter keeps a whip aerial upright above the animal's neck to maximise transmission distance. Fitting a collar needs as much care as a harness, especially on those animals that climb trees and may get caught on branches. If the collar is placed on a young animal allowance must be made for growth, either by recapturing the animal and removing the tag, using an expandable collar or one which will deteriorate over time and fall off (Kenward pg 112, 1987).

Modifications of the common attachment methods include tail mounted tags for birds, in which a tag mounted on a base plate is screwed onto another plate with several of the main tail feathers between the two (Kenward pg 105, 1987). Crocodiles were tracked in the Northern Territory of Australia (Yerbury, 1980) by attaching solar powered tags to the bony ridges above the ears with an external compression plate system which kept the transmitter at maximum height above the crocodile at all times. Fish tags are often internally implanted, but may be secured through a large muscle mass by sutures attached to the package. (Kenward pg 112, 1987).

2.2.5.2. Receiving System

2.2.5.2.1. Receivers

The basic design of a radio receiver consists of a power source, frequency selector controls, earphone and antenna jacks, gain control and often a signal strength meter. Simple receivers can be adapted from radios commonly found in the home, but these have limited frequency ranges and are seldom robust enough to withstand field work. Commercially available receivers offer much improved sensitivity, an increased range of frequencies, and accurate tuning allowing a larger number of tags to be used in the field. They are designed to cope with the rigours of outdoor work, and to maintain accuracy through variable weather conditions. Most of the receivers use internal rechargeable batteries with the capability to use external power. The frequency control knobs select a range of fixed frequencies on which the radio collars transmit and then a fine tuning control locates the signal for best reception. Some receivers use electronic digital tuning and others incorporate a programmable memory to scan through a number of fixed frequencies.

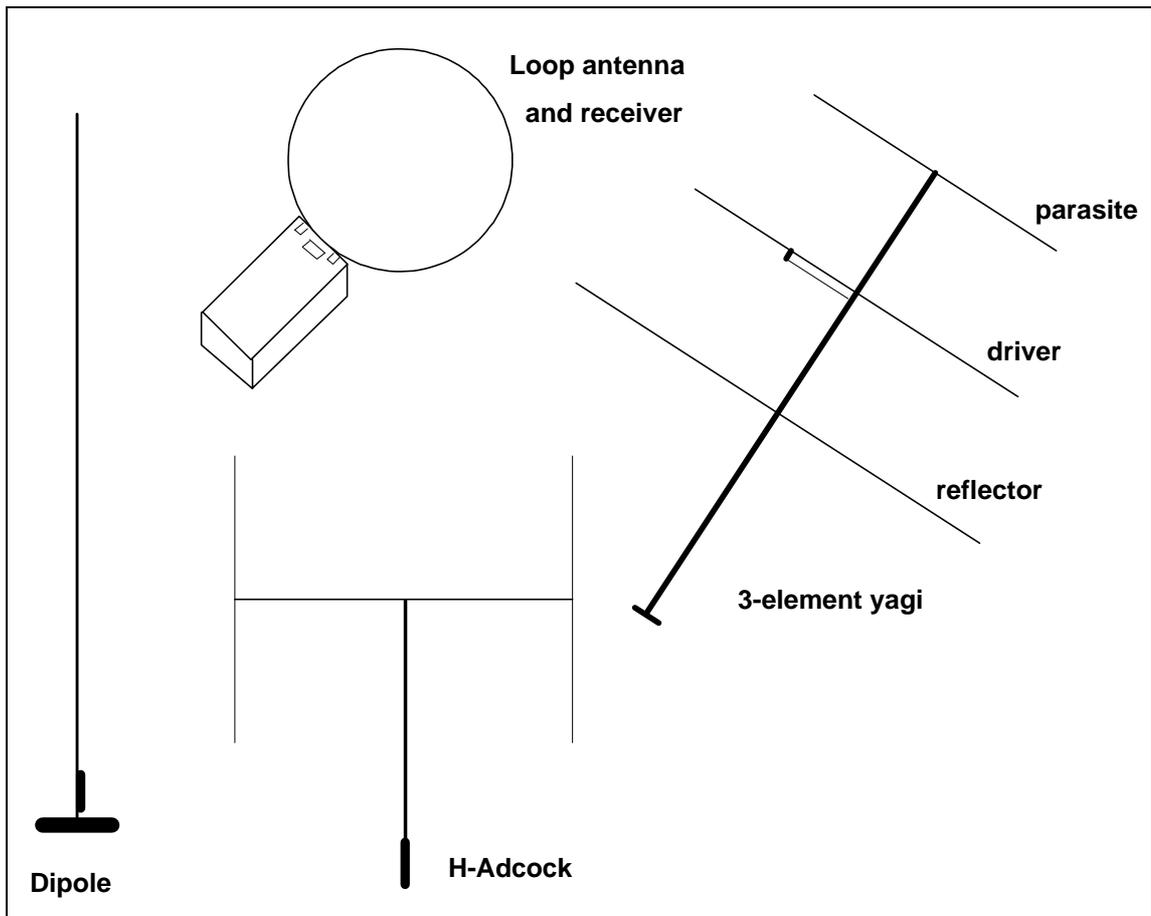
2.2.5.2.2. Antennae

The main functions of the receiving aerial(s) are to collect the signal and indicate its direction. If the presence or absence of a signal is the only requirement, then a non-directional aerial will suffice. Otherwise a directional system such as a yagi is needed. There are three basic types of receiving

antenna arrays. The first is a simple, generally vertically orientated length of wire, attached to the antenna input, and known as a whip or dipole. It is omni-directional since the direction of the signal from the transmitter cannot be confirmed without using another aerial placed some distance away. This type of aerial can be used to advantage in the centre of a study area to determine if an animal is present in the area. It has symmetrical signal peaks at right angles to the main axis and, if held horizontally, there will be symmetrical nulls along the line of the antenna (Kenward pg 15, 1987) making it difficult to determine true direction of the signal. The second type, the tuned loop, is often used for low frequencies of 20-50 MHz. A loop of wire, the size of which is determined by the transmitter wavelength, is attached to the receiver. A tuning capacitor may be placed in the circuit to improve reception and for higher frequencies. Like the dipole, there are symmetrical peaks through the plane of the antenna. However the nulls (at right angles to the plane) are more sharply defined. Although still requiring fixes from at least two directions, it is more accurate than the whip aerial. (See Appendix I for reception patterns).

The third type of receiving antenna is the Yagi which has a series of elements arrayed along an axial boom. Signal reception is strongly directional, depending on the number of elements, their spacing and length. At low frequencies these aerials are large and difficult to use for mobile tracking, and a design known as the 'Adcock' is more commonly used. These are 'H' shaped aerials with less directionality than a yagi but are often collapsible and easily transported in the bush. Yagi aerials consist of three different types of elements arranged at right angles to a central boom; (i) the driver or dipole which is powered - in the case of a receiving aerial supplying power (signal) to the receiver; (ii) one or more parasitic or director elements and (iii) a special type of parasite known as the reflector which is positioned at the back of the aerial array (Figure 2.1). Each of the elements is ideally about 0.5λ in length, with the reflector being slightly larger than the driver which in turn is longer than the parasites. As the number of parasites increases so to does the directionality - the power received is concentrated over a much narrower angle - and the gain also increases (Amlaner, 1980).

Figure 2.1 Antennae used for mobile radio-tracking (from Kenward, 1987)



When animals are tracked from fixed locations twin yagi aerials are generally used. Attached to either end of a cross boom the yagis may be vertically or horizontally orientated and connected in a null-peak system. A switch box enables the user to alternate between an in-phase signal, which produces optimum gain in the forward direction to approximately locate the animal, and then change to out-of-phase signals to produce a sharp null or minimal gain in the forward direction. The width of this null can be as small as one degree, thus enabling accurate bearings to be taken to the transmitter.

Building the receiving aerial can be as important as any other part of designing the radio equipment, as inefficient receiving aerials make it difficult to locate radio signals, radios with frequencies close together may not be able to be distinguished, and errors in location made and compounded. Leads and aerials need to be impedance matched to maximise signal quality, aerials correctly aligned, and regular checks made to ensure frequencies are accurately set.

2.2.5.2.3. Recorders

The final part of the receiving system is a recorder. This may simply involve noting down frequencies, times and bearings or locations by hand. Motor-driven paper recorders, attached to the

output jacks of the receiver, are less labour intensive; whilst electronic systems, where all recording is automatic - frequency selection, aerial rotation and data collection - allow unattended recording. Data from the latter can be downloaded to magnetic media or directly to computer for analysis. (Cochran *et al.*, 1965).

2.3. HOME RANGE ESTIMATORS - A REVIEW

Measurement of home range size, shape, and an individual's use of that area, have become an increasingly important aspect of ecological and behavioural studies since Seton introduced the concept in 1909 (cited in Sanderson, 1966). The idea has been refined several times over the intervening decades, and is now broadly accepted as "...that area traversed by the individual in its normal activities of food gathering, mating and caring for young..." (Burt 1943, cited in White and Garrott, 1990). Home range measures are necessary when determining population densities, habitat use, spacing of individuals, and most importantly for this study, interactions between individuals. The amount of emphasis that is put on the words 'normal activities' needs to be defined for each study, as does the method of calculation. This definition also needs to include the time period of the study and the status of individuals eg. age or sex (Harris *et al.*, 1990). The objectives of the study, the questions one has, and hypotheses to be tested, will determine these factors.

Home range is not *all* the area over which an animal moves in its lifetime, rather the area in which it *normally* moves. There are no generally accepted, objective, and biologically based, criteria for the selection of 'normal' point locations to be used in the calculation of a home range. White and Garrott (1990) identify two commonly used criteria; (i) a subjective evaluation by the observer (hardly objective and not repeatable by other researchers), and (ii) a probability level, eg. a 95% probability that the defined area will enclose a randomly selected single radio-location of the animal in question. The latter is objective, but also convenient - why 95 rather than 88%?

The majority of home range estimators require that locations be statistically independent. In most cases this is not possible, as a subsequent position of an animal is usually related to the present location. General rules of statistics are applied as much as possible, in that (i) a random sample of animals are chosen for tracking, and that any of them may be tracked at any time, and (ii) any point in time over the sampling period should have an equal chance of being sampled. Sampling interval can have a considerable influence on the home range estimate. Swihart and Slade (1985) found that, over a specified time frame, non statistical estimates (minimum polygons), became increasingly accurate as the number of observations increased, despite increasing autocorrelation. In contrast, bivariate normal estimators underestimated such ranges due to autocorrelation between locations.

2.3.1. Types of Home Range Estimator

There are 3 main types of home range estimator:

1. Minimum area polygons (MAP)
2. Bivariate normal estimators
3. Non-parametric methods

2.3.1.1. *Minimum area polygons*

These are the oldest, and most commonly used estimators (White and Garrott, 1990). There are several variations, the simplest of which is a polygon formed by joining all the outermost locations.

The method adjusts to any shaped area, is simple to calculate, and can cope with uniform distributions of animal locations. Disadvantages include, (i) an indefinite increase in home range size - there is always a probability that a subsequent location may be outside the area already defined, (ii) the method doesn't allow for autocorrelation as it assumes independence, and (iii) biologically incorrect ranges can be calculated - eg. a land animal living on the banks of a curved river may have the river included in its home range area.

Modifications to the basic method have been suggested. These include exclusion of outliers before data analysis, which can be time consuming as often all combinations of exclusion points need to be examined, (Kenward, 1987). Another variation is to use concave rather than convex polygons. Convex polygons join outer points at approximate angles of 180° , the interior angles between points for concave polygons may be 30° , but there are no objective criteria based on biological grounds (White and Garrott, 1990). (See Appendix II for figures describing range types)

2.3.1.2. Bivariate normal estimators

Bivariate normal models assume that animals move randomly about their home range, with the most probable locations being the centre - mean of the x and y coordinates. Jennrich and Turner (1969) generalised the shape to an ellipse. The method is not dependant on sample size - a 95% ellipse estimated from 100 points is expected to be the same size as one from 500. Home range size is more comparable between studies than is the case for polygon methods. Enhancements to the estimator include applying a weighting factor to each point based on its distance from the mean (Koepl *et al.*, 1977), or may take into account both distance and time of locations from the mean (Dunn and Gipson, 1977).

Bivariate models fail to adequately describe movements of many animal species as they do not move about randomly on a plane. Excursions from a centre of activity such as a den or nest - itself seldom in the centre of the range - are generally purposeful movements to food, water or mates. They are, however, easily calculated, and provide a probability estimate.

2.3.1.3. Non-parametric methods

Non-parametric techniques make fewer assumptions about the data distribution, or independence of points, but do not consider time, nor do they give confidence intervals (White and Garrott, 1990). The most commonly used method are harmonic means (Dixon and Chapman, 1980). Contours of area are calculated from a grid of nodes. Inclusion of a node within a probability contour are a function of its proximity to the radio triangulation locations. For example, if the reciprocal of the means to several locations from node A, is less than that from node B, then node A will be included inside a contour of higher probability of occurrence of the animal than B. Centres of activity are located in the areas of greatest activity, multiple centres can be defined, and no specific shapes are imposed on the estimator.

Other forms of non-parametric methods are grid cell counts and Fourier series. The former counts the number of locations found in each cell of a grid laid over the range area. The sum of the areas of the cells containing locations is taken as the estimate of home range. Disadvantages include difficulty in deciding the size of a grid cell - a coarse grid over-estimates range size - and problems with islands of cell locations. The islands are a result of sampling intensity, where an animal has moved some distance from one location to another, without being mapped in intervening cells. Subjective assessments such as including all cells in a line between the last 2 records are often made in these cases.

Fourier series smoothing is a result of an x-y plot with a 'spike' at each coordinate where the animal was located. A fourier transformation procedure mathematically analyses the spikes to produce a smoother surface representing the animal's use of an area. Home range is then calculated as the smallest area encompassed by 95% (or any other %) of the *volume* of the surface. This type of estimate perform best when 50% or less of the volume is taken as the home range estimate, as the areas at the edge of the home range (eg. 95% volume) are poorly estimated because of a lack of data (White and Garrott, 1990). Non-parametric models have lower precision than other types because fewer assumptions are made about the data. They ignore the time component of telemetric data, and most lack confidence intervals.

2.3.2. Summary

Home ranges are important and useful biological measures, but are often poorly defined. Rigid statistical methods either cannot, or have not, been applied to many of the estimators. Each model has been shown to have strengths and weaknesses. The techniques vary in precision, strength of the assumptions required, and biological relevance in various habitats. Home range is a function of time as well as space, and appropriate sampling methods are required to avoid bias. The autocorrelation which exists between consecutive locations must be considered if a random sample of the animals time is not taken. Home range estimates should be recognised as the estimates and data summaries which they are, and measures more specific to the research objectives, such as differences in distributions of animal locations, employed when indicated.

2.4. MATERIALS AND METHODS

The radio transmitters and receivers used in this study are primarily used to track individuals to den sites. Possums are caught in live-catch traps for 3 nights each month as part of a long-term population study in the area and radio collars routinely attached to clinically tuberculous individuals. Possums caught in the same area as tuberculous ones, animals trapped on the periphery of the area and juvenile offspring of tuberculous females are also radio-tagged. As part of the radio triangulation study 80% of the surviving juvenile animals known to be born on the site were radio-tagged during October 1991 to January 1992. These animals were regularly tracked to den sites both within and outside the area.

2.4.1. Materials

2.4.1.1. *Radio collars*

Transmitter packages were supplied by SirTrack Electronics, a division of D.S.I.R. Land Resources (now a Crown Research Institute), Havelock North, New Zealand. The packages were two stage units constructed on ceramic substrates set back to back and powered at 3-3.5 volts, with a 20 ms pulse length and approximately 60 pulses per minute. Transmitter frequencies were between 160.425 and 161.625 MHz. The circuit boards were covered with a rubber-silicone waterproofing and insulating layer. The whip aerials had a layer of heatshrink tubing applied over them for protection and insulation. Two designs of radio collar were used in the study, one for possums and the other for cattle. The possum collars were of two different weights - one for juvenile animals of 750 to 1500 g, the other for animals weighing more than 1.5 kg. The weight difference is primarily due to the battery used. Juvenile collars had a Tadarin ½ AA lithium cell of 850 milliAmp-hours (mAh) capacity, a life expectancy of 7-9 months, and a total package weight of 30 g; while the 42 g adult collar transmitted for 12-14 months, powered by a Keepers LTC 16P/T lithium cell rated at 1600 mAh - the transmitter circuit itself contributes only 2 g. During assembly the packages have a nylon snaplock tie attached to the circuit board, rubber-silicone sealant is moulded over the device, and a covering of epoxy applied and smoothed to approximate the neck shape of the animals. Collars received after May 1991 were sprayed with fluorescent paint before the epoxy was applied, and some of the aerials had coloured heat-shrink tubing in addition to the standard protecting layer. Both additions helped in collar identification, particularly in dark dens, though the epoxy resin did not adhere well to some of the painted collars and the outer layer lifted and cracked. The possums chewed these coloured packages more frequently than unpainted ones. The radio collars were attached to the possum using snaplock ties, adjusted to the individuals' neck size.

The transmitter package designed for cattle used the same circuitry and battery type as the adult possum collar, but had 2.5 cm wide nylon webbing and fastlock buckles to attach the package around the steers' neck. The whip aerial, which lay along the nylon, is protected by a sheath around the webbing and sealed with rubber compound at either end.

2.4.1.2. Radio Receivers and aerials

Model CE-12 radio receivers made by Custom Electronics of Urbana Inc., Urbana, Illinois, U.S.A. were used in the study. The units have 4 Bands, each with 12 available channels over a total bandwidth of 300 kHz. Channel centres are 25 kHz apart and as the receiver can distinguish signals 10 kHz apart it is possible to have 3 transmitters on each channel. However, due to tuning and crystal inaccuracies, as well as field limitations, only a single transmitter was used on each channel whenever possible. Power is supplied by internal rechargeable nickel-cadmium batteries or from an external 12 volt source. The signal was monitored through a panel mounted speaker or a set of headphones to minimise external noise (Figure 2.2).

Each of the permanent tracking sites had twin, six-element yagis mounted in a vertical configuration, 1.8 metres apart on the boom at a mast height of 3 to 5 m. Aerials were aluminium-alloy, with 84 cm wide parasitic elements and 93 cm reflectors. The driver or dipole was 88 cm in width. Each element was 38 cm apart on the 1.9 m long aerial (Figure 2.3). Each aerial mast fitted 80-100 cm down into a metal pipe of slightly larger diameter, and rotated on a bearing in the base. Pointers attached to the mast enabled compass bearings to be read off an engraved compass rose clamped to the supporting pipe. The compass rose was etched in one degree increments around the perimeter and annotated every 10 degrees. A handle bolted to the mast above the compass rose was used to rotate the aerials when tracking.

The hand held aerials used to track possums to their den sites were collapsible three element yagis made of aluminium-alloy, also supplied by SirTrack electronics. Dimensions were: 78 cm along the boom, and total widths of the reflector, driver and front element were 89, 83 and 80 cm respectively. A shaped wooden handle was fixed to the underside of the shaft.

Shelter for operators at the aerial sites was provided by metal frames covered with corrugated iron, and tied to the ground. The rectangular structures had a floor area of approximately 2 metres by 1.2 metres and a roof peak of 1.5 metres. Considerable effort was required to ensure stability due to frequent strong winds in the area. Two metre iron standards (waratahs) were driven into the ground on either side and at the back, and heavy gauge wire run between them over the roof of the hut to hold it down. Holes in the roof allowed the aerial masts to pass through into the support pipes inside the huts (and also occasional rain in onto the operators).

Figure 2.2 Radio receiver and compass rose inside hut



Figure 2.3 Radio triangulation site



2.4.2. Methods - Radio Triangulation

Preliminary investigation of the study site to determine the most effective locations for the fixed radio triangulation sites began in late 1990. Initially, tracking possums to den sites and discussions with an experienced radio-tracker aided in defining possible sites. Changes in weather conditions, in particular temperature, as well as relative positions of the tracker and the radio transmitter were known to result in considerable variation in signal quality and apparent direction. Figures 1.4-1.6 show the bowl shaped topography of the study site, with a central spur which protrudes into the paddock from the northern ridgeline. The spur, with a base of the disintegrating greywacke rock common to the East coast hill country of the Wairarapa, has a steep eastern face dropping into the confluence of several creeks and caused a varying degree of signal reflection. The ridgeline around the perimeter of the site has a steep grade from the northern ridge down to the lower valley, with gentler slopes from the southern and south-eastern ridges, and seemed to be suitable for the placing of the tracking towers. Ideally triangulation of an area using two towers would have them placed so that the baseline between the towers is not within the study area, (White, 1985) as locations of animals on this line cannot be determined. The topography of the area meant this ideal was unlikely to be achieved. Also of concern were the damaging effects of strong winds from the north-west which funnelled directly into the valley. Strong to gale force winds (50-75 km/hr) were common throughout the year and often continued for 2-4 days. Gusts greater than 100 km/hr are regularly recorded during these nor'westerly 'blows' (Meteorological office data). It would have been impossible to handle the triangulation aerials on exposed ridges or other points during such winds.

Potential sites were investigated by using one person to carry the transmitter through the site while the other took bearings with handheld aerials. Ease of access to the site and protection from the wind were factors considered as well as accuracy of bearings. The handheld aerials are far less accurate than the twin yagis used for triangulation but gave an indication of signal and bearing quality. Four sites were chosen as potentially suitable and several nights were spent tracking the signals from possums as they moved from their den areas to feed to determine if signal reception was similar to that experienced during the day. Only the two sites in the eastern end of the paddock gave adequate coverage, as possums spent considerable time close to the baseline between the other possible locations and there was signal reflection and distortion caused by the spur from the north ridge. The twin-yagi aerials were tested for accuracy using transmitters placed at surveyed points throughout the paddock as described in a later section. In all, 25-30 days spread over 6 months were spent developing a triangulation system in the area with another 15 days training operators, and gathering radio triangulation error data.

Radio triangulation was carried out at intervals from April 1991 to April 1992, with 6 animals tracked each night. Emphasis was placed on those possums known or suspected to have TB, possums which denned in the same areas as the TB animals, and in the latter stages of the study, immature animals. During the initial stages of the project there were up to 5 tuberculous animals in the area but not all were tracked during a session. All of the tuberculous possums died during 1991, hence there

are no complete 12-month records for these animals. At any one time, up to three steers carried radio collars. They were also tracked at intervals throughout the year. Achievement of the objective of the study - to determine home-ranges of individual animals and compare the patterns of use of these areas - was significantly affected by the building of a fenceline down the centre of the paddock, which prevented access by the cattle to the northern half of the study site.

2.4.2.1. Tracking procedures

Radio-tracking was targeted at 4 periods during the year:

1. Mating - April through May
2. When the joeys were back riding - August to October
3. When the joeys were becoming independent - November through December
4. Pre-mating - February to March

Each tracking session was over an average of 3 nights, and there were 2-3 sessions during each period. The aim was to track 3 tuberculous possums plus 2 clinically normal animals which denned in the same area. The 6th animal was either a steer, a juvenile possum or randomly selected possum. Tuberculous possums were tracked on each subsequent session, if possible, and 3 normal animals were also routinely tracked (at least 2 nights each session). As animals died, or radio signals were lost, other possums replaced them. Six to eight possums and 2 steers were selected as possible candidates before each tracking session. At dusk signals were rechecked and 6 of the animals chosen to work with that night. Animals were not tracked if the radio signal was unclear - possibly due to imminent radio failure or the position of the possum. Cattle were regularly tracked for 2-3 months but, after division of the paddock, only if feeding in the lower part of the paddock at dusk. On most nights the steers remained in 1 or 2 small areas, 700-800 m away from most of the radio-tracked possums.

Aerials and equipment in the field were checked for damage each day, and aerials recalibrated against fixed transmitters at known locations in the area. The settings were checked several times during the night. Radio triangulation began before dusk and continued until dawn, with each animal located once every 12 minutes. Two-way radios provided communication between trackers for support and consultation if subsequent bearings appeared unreasonable. As there were only 2 operators involved in the study bearings could not be mapped as they were taken, and any censoring of data was done later. Data from the check sheets was entered into a database and from there run through Telem88 (Telem88, 1990; Coleman and Jones, 1990), an analysis and mapping programme for radio-telemetry data. Results were checked for distances moved between observations and rejected if unreasonable (movement of more than 150 m between subsequent locations). Final (at dawn) den site locations were checked against daylight tracking locations, if available, as a further check on accuracy of the system. Data were summarised and analysed using Paradox version 3.5 (Borland Corporation, Scotts Valley, California, USA), Parastat (Financial Modeling Specialists, Arlington, Virginia, USA), Statistix version 4 (Analytical Software, St. Paul, Minnesota, USA) and

Telem88 (Coleman and Jones, Dept. of Fisheries and Wildlife, Virginia and State University, Blacksburg, Virginia, USA). Data was mapped and displayed in PCArc/Info version 3.4d (Environmental Systems Research Institute Canada Ltd., Don Mills, Ontario, Canada), and Idrisi version 4 (Clark University Graduate School of Geography, Worcester, Maine, USA),

2.4.2.2. Juveniles

A juvenile possums was fitted with a radio transmitter as routine if its mother was known to be tuberculous. Additionally, between September and December 1991, 25 juveniles were fitted with radio collars to determine their fate over the following 6-8 months. All of the possums had been tagged as joeys in the pouch and their mother's were regularly caught in the area. Several of the juveniles were tracked by radio triangulation at night but, as the main aim was to follow dispersing immatures, most of these animals were only routinely checked to determine their denning areas in the paddock. If they were not caught during a trapping week, or their position remained constant over 2 weeks, they were tracked on foot to confirm that they were still alive or the radio had not been lost.

2.4.3. Methods - Home Range Analysis

Several types of home range estimators were used in this study. The review indicates advantages and disadvantages of each type. Most analyses were completed using Telem88, which calculates convex polygon, harmonic mean, and 95% ellipse home ranges. Within Telem88, bearing, time, and animal identification data are used to calculate co-ordinates from each set of bearings. The bearings are then combined to produce estimates of the area over which the animal moved in a particular time period. Further analysis and plotting of data was done using Idrisi, PCArc/info and Paradox.

Convex polygon areas were generally used to describe data. Although tending to over-estimate actual range area, they are easy to understand and view. Comparing the home range area of a possum with the nightly activity areas will indicate the overestimate produced by the convex polygon. Possums move in an often complex, 3-dimensional environment, which makes calculations of true home range size and shape even more difficult. In some habitats the lack of consideration of the third dimension will have large effects (eg. in lowland forests such as the Orongorongo), whereas the more terrestrial possums of the Castlepoint site will be adequately represented by a 2-dimensional plot. A severe limitation of radio triangulation from fixed positions is apparent when there is also a height factor associated with locations.

2.5. RADIO TRIANGULATION ERROR

2.5.1. Aim

To determine error in the tracking system used at Castlepoint, map the error polygons, and to use the information to help interpret possum home range and movement patterns.

2.5.2. Introduction

The error inherent in any scientific experiment has often been ignored or cursorily reported in regards to radio triangulation (Springer, 1979). Cochran and Lord (1963), and Tester and Heezen (1965) mentioned that error was present in both the techniques and equipment used while Heezen and Tester (1967) indicated that the error has an area (or error polygon) associated with the animal's presumed location. The error polygon is obtained by calculating the angular error of each bearing to a presumed location and determining the area surrounding that location. Where radio triangulation is used as an aid to locate animals for observation, accuracy of the system is not of great importance. However, when activity patterns or assessments of habitat use are being determined from sequential radio-fixes, there may be times when movement is small compared to the size of the error polygon, hence considerable doubt must be held that the animal had in fact moved.

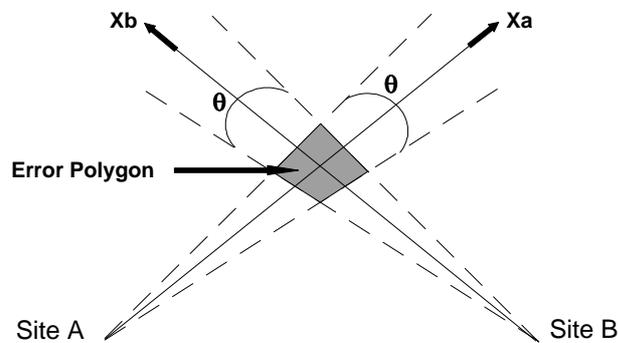
The accuracy of a radio triangulation system is determined by the location of receiving towers, the location of the animal in relation to the towers, and the precision of the bearings from the towers (White, 1985). Placement of radio towers is dependant on access, topology and environment. Optimally at least 3 towers are sited within the study area. If only 2 towers are used, the baseline between them should be outside the site, as animals moving through the baseline cannot be located. The most accurate locations are obtained at the 90° intersection of the bearing lines at the perpendicular bisector of the baseline (Heezen and Tester, 1967). The error polygon changes in size and shape as the animal moves away from this optimum.

In this study the number of aerials and availability of sites was limited by geography and manpower. Few possums moved through the baseline between sites, and therefore studies to determine radio triangulation error focused on the precision of bearings from tracking towers. As mentioned, locations of animals derived from bearings have often been assumed to be accurate, although there is an angular error associated with every bearing. The angular error is a combination of system and recording errors. The latter are generally operator errors - a result of transcription inaccuracies, inaccurate frequency selection and bearings not being taken simultaneously on an animal. System error is the difference between the observed bearing and the true bearing to the transmitter. It may be caused by faulty or damaged aerial elements eg. by wind, inaccurate alignment of the compass to reference transmitters, environmental effects (particularly changes in ambient temperature), and signal reflection or refraction. Effects of vegetation, water and topography have already been noted of which high frequency signal attenuation through bush, and reflection from rocky surfaces, were evident in the Castlepoint study area. An aerial also has inherent directional error in that each

bearing may be $\frac{1}{2} \cdot 2^\circ$ either side of the noted angle - the directionality of an aerial increases with the number of elements used, and whether a null or peak detection system is chosen. The aerial configuration used in the study has an accuracy within 1° using the null detection method.

The error arc of a point is formed by the confidence limits of the bearing to that particular transmitter location from the receiving station. Figure 2.4 shows an example of a location obtained by radio-telemetry. Sites A and B are receiver stations. X_a and X_b are bearings obtained from the stations. Angle θ forms the error arc, and is equal to \pm the total or angular, error. The dotted lines indicate the confidence limits of the bearing, and their intersections form the error polygon. (Springer, 1979). Using 95% confidence limits to set the error estimates for each single directional estimate results in a 90% probability (0.95 squared) that the true location of the transmitter is within the error polygon.

Figure 2.4 Example of error polygon and error arcs



2.5.3. Materials and Methods

Radio tracking equipment, aerials and location of sites are described in a previous section. Early experience obtained tracking possums to den sites was invaluable as it indicated areas where possums were denning in relation to the triangulation sites, and the nature of signals within the paddock. Although hand-held yagi aerials are inaccurate over long distances compared to the large triangulation aerials, their use at potential triangulation sites showed the influence of steep rocky hillsides on radio signals. The locations of possum den sites, and the feeding areas of possums identified from night observations, were used to place test transmitters around the paddock for error determination. Tests of signal reception were investigated by taking bearings from potential receiving aerial sites to an observer carrying a transmitter through the study area. Two-way radio communication between operators enabled immediate comparisons between the azimuth to the transmitter signal and hand-held compass bearings to the receiver. Where line-of-sight compass bearings were impossible locations were marked on aerial orthophotos, and bearings plotted later. Although crude in terms of accuracy several potential radio-tracking sites were discounted when large discrepancies between bearings were found. Two likely sites for the establishment of receiving aerials were selected which had good signal reception from areas of likely possum movement, and suitable access for observers. Areas within the paddock from which signal reception was poor were also identified.

2.5.3.1. Selection of point locations and surveying.

To calibrate the aerials and determine error for bearings taken in the field it was necessary to accurately plot locations within the study site. Points selected to survey were generally at, or close to, trap sites. The traps were in positions ‘most likely’ to catch possums, and hence were found in feeding areas, on possum runs⁵, in gullies and along ridge lines. Most of the trapping area was surveyed and attention was paid to areas where signal reflection was known to occur. In the latter places several points were chosen in close proximity to determine if bearings between them could be differentiated.

Surveying was carried out using laser theodolites by Russell Pye, from Tomlinson and Carruthers, Registered Surveyors, Masterton, New Zealand. The most likely triangulation sites were surveyed and tied into the Wairarapa grid system. From these sites, bearing and distance measurements were made to the points selected. A set of UTM (Universal Transverse Mercator) grid co-ordinates for each point location was thus obtained, and ‘true’ bearings from each radio-triangulation site to the point location were developed for later use in analysis.

⁵ Possums use regular routes as they move from den sites to feeding areas, resulting in the formation of hard-packed tracks (runs) through the bush, and which may extend onto pasture. The latter are particularly obvious when the grass is long.

2.5.3.2. Collection of Bearings for Error Data Analysis

The aerials were first calibrated using fixed transmitters at known map bearings to enable angles read off the compass rose to be used directly in producing UTM co-ordinates. The aerial was aligned on signals from a transmitter at the other tracking site and the compass rose adjusted so that the correct map-adjusted bearing to that site was read underneath the pointer. A second transmitter was then sought, also at a known bearing from the radio-triangulation site, to confirm the setting of the compass rose. The map-adjusted bearing is obtained by subtracting or adding the magnetic declination (variation from true or grid north), of a compass bearing. The magnetic declination varies with latitude and in the Wairarapa is approximately 23 degrees East. Twenty-three degrees is added to a compass bearing to obtain an azimuth which can be used on a map plot and eventually to calculate UTM co-ordinates. Aligning the aerials to give map bearings obviates the need to transpose figures later.

Data for error calculation were collected by placing transmitter collars at surveyed locations in the study area and taking multiple bearings on them from each radio-triangulation site. Each transmitter had the identifying radio-frequency covered with tape and was then placed at one of the selected locations. The packages were generally left at ground level with the aerial vertical to simulate the position of a feeding possum. To prevent observer bias the compass rose at each receiving station was covered with a cardboard shield as the observer located the signal of each transmitter, and the bearings were recorded by a second observer. The sequence of transmitters was run through 5 times and as the transmitters were collected from the field the frequency was noted on a worksheet against the corresponding point location identifier. The procedure was repeated until all surveyed locations were tested. In addition, at some of the locations, transmitters were strapped at calf level to a volunteer and bearings taken as the person moved slowly past the point to simulate the effect of the possums body and movement on signal transmission. It was found that, although there was variation in signal strength, there were no differences in the directionality of the signal. Analysis of bearings was done using Paradox and Statistix, and mapped in Idrisi and PCArc/info.

2.5.4. Results and Discussion of Triangulation Error

The first test was spread over 2 days, with moderate winds, rain overnight and during the first day, and temperatures below 8° C on the morning of the second. Some of the radio transmitters had been left out overnight and early bearings taken on these radios were difficult to fix and more variable than those taken the day before. Minor corrections to the aerials and position of the stations were made over the next 3-4 weeks and a second data collection run completed. The weather was fine and warm, though extremely windy, on that day. Figures 2.5 and 2.6 show the distribution of bearing errors for tracking stations J-1 and E-4 of the initial test, and the second, when the operators had more experience with the system. The overall mean error for bearings from J-1 and E-4 are shown in Table 2.1 (mean \pm S.D).

Table 2.1 Mean errors from 2 tests, for each triangulation station

	N	J-1 tracking site	E-4 tracking site
Initial test: mean error (degrees)	215	-0.91 ± 2.45	0.73 ± 2.1
Second test: mean error (degrees)	215	1.35 ± 2.66	-0.49 ± 1.49

The effect of the weather was noted on several more occasions during actual possum triangulation as the temperatures changed overnight and the transmitters cooled down with exposure to the atmosphere and moisture after the possums left their dens. Some radios appeared to drift in frequency and/or vary in pulse characteristics with temperature changes. Both of these changes were distinct from signal strength variation due to movement through the area (some of the variation could also be due to the receivers).

Figure 2.5 Distribution of Bearing Errors - Initial test

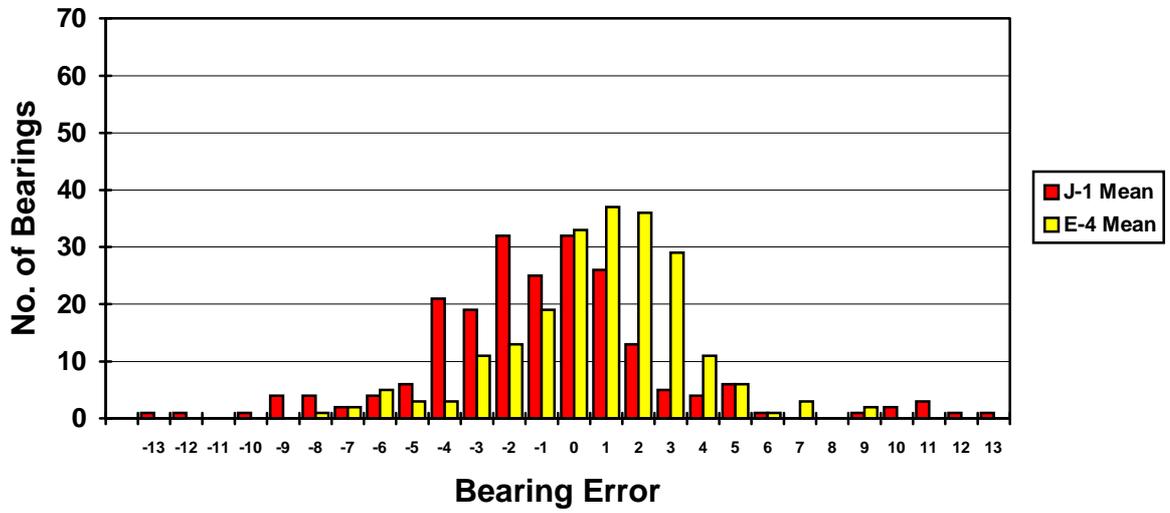
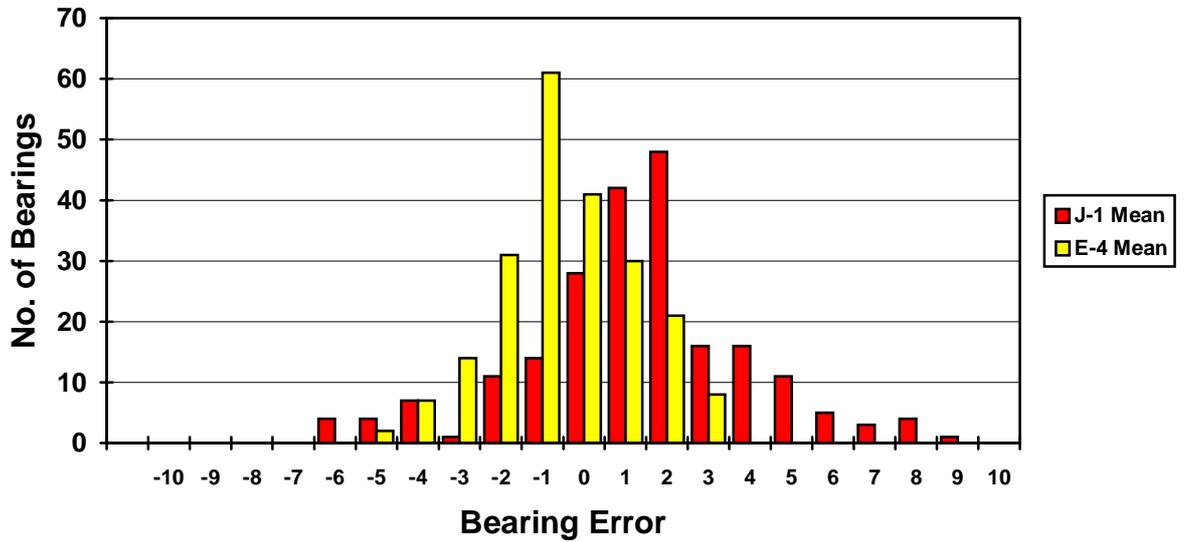


Figure 2.6 Distribution of Bearing Errors - Second Test



Note: J-1 and E-4 refer to the tracking stations used in the study.

Figure 2.7 shows the distribution of transmitter test locations and associated polygon areas. Test transmitter locations were divided into 3 groups - Group 1 in the lower part of the paddock (low arrow in Figure 2.7); Group 2 included transmitters west of and close to the rocky ridge (top arrow); and Group 3 the remainder. Groups 1 locations were difficult to receive from J-1 station and Group 2 from E-4. Most locations in these groups were out of sight of the respective receiving stations. Group 3 locations were spread throughout the site and almost all were line-of-sight to both stations. All bearings taken to transmitters in each group were included (5 for each point) to calculate the summary statistics in Table 2.2. Confidence or error arcs indicate the precision of bearings to a particular point and, except for signals received from the low part of the area by station J-1, arcs were $<10^\circ$ (95% confidence). These data are similar to that of Lee *et al.* (1985).

Table 2.2 Summary statistics of error test locations by group

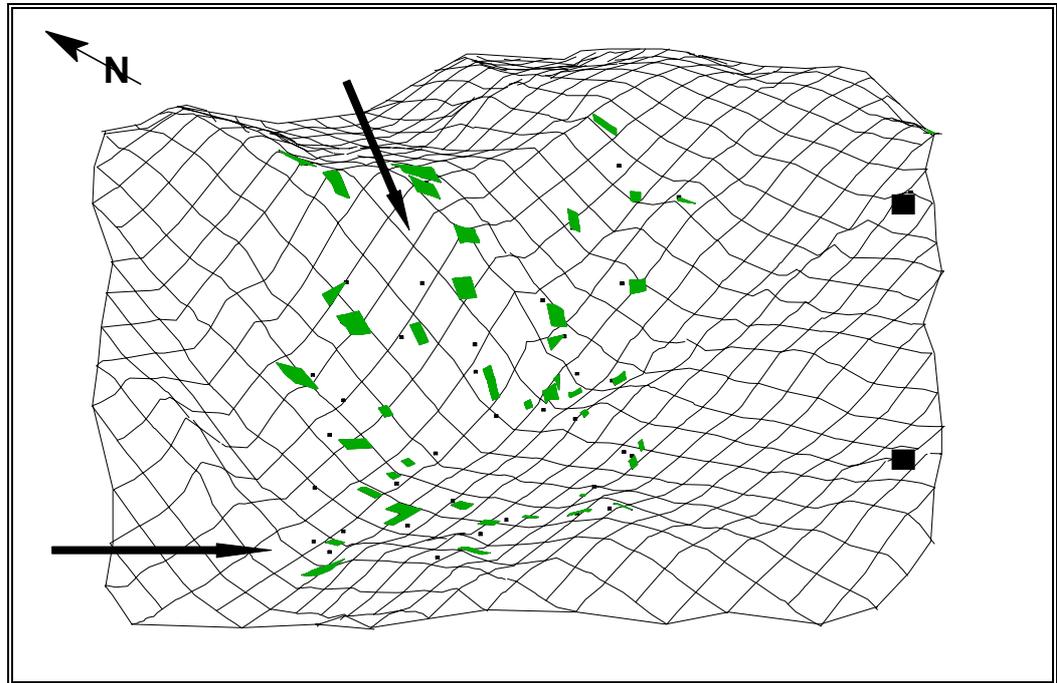
Group and Station location \Rightarrow	Group One		Group Two		Group Three	
	E-4	J-1	E-4	J-1	E-4	J-1
Number of bearings	95	95	40	40	80	80
Mean Bearing (deg.)	-0.65	1.95	-0.98	1.15	-0.08	0.69
Standard Deviation	1.49	3.74	2.01	1.27	1.64	1.44
Minimum Bearing	-4	-6	-5	-2	-4	-2
Maximum Bearing	3	9	2	3	3	4
95% Confidence Arc (\pm)	2.92	7.33	3.94	2.49	3.21	2.82

Variation in mean error was inconsistent throughout the site. Table 2.2 indicates angular error (confidence arcs) from tracking stations for each group, but does not define the shape of the area around a point location in which the transmitter (animal) may be found. Many of the reference points had considerable angular error associated with them but the effect of this varied between tracking stations. Figure 2.7 shows the section of Backdrop paddock where possums were radio tracked. At lower left is the flat entrance to the paddock and top left is the northern ridgeline. The 2 squares along the right margin of the surface represent the tracking stations. Small black squares mark points where reference transmitters were placed and the larger irregular shapes the error polygons associated with them. Where transmitter points are not seen, the error polygon overlays them. The largest deviation of signals is seen in the lower part of the figure (arrow) and was due to the thick scrub and slight ridge between the transmitters and the lower tracking station (J-1). Conversely the upper station (E4) had difficulty in obtaining accurate locations on transmitters placed to the west of the rocky spur (top arrow). Although mean angular error was less than 1° overall, it is clear from this

surface and Table 2.2 that a few point estimates may be 20-40 metres from their true location (note the grid size).

Figure 2.7 Error Polygons from Radio Triangulation Error Measurements

Note: The scale of the figure is not linear as it is a draped surface. However, each of the grid cells covers a 30 metre by 30 metre area. See Appendix V for a plane view of the same figure.



Two factors contribute to the locational error (size of error polygon) associated with the signal from a particular point. The first is the precision of the aerial - this is obtained from the standard deviation of the replicate bearings - and secondly the geographical characteristics of the point relative to the receiving towers. Each point and receiver combination has a confidence arc associated with it but it is the distance and surrounding topology of the point from the receivers that primarily determines the size and shape of the error polygon. Table 2.3 summarises mean error polygons for the 3 groups of locations.

Table 2.3 Error polygon areas (square metres) - means of groups

	Number	Mean	Std.Dev.	Minimum	Maximum
Group 1	19	134.82	97.12	19.56	339.93
Group 2	9	97.92	51.59	33.43	183.88
Group 3	15	299.39	240.61	36.46	995.91

Group 1 points have the largest error arc from J-1 station and the smallest from E-4. However these points included some of the closest to J-1, almost all were on relatively flat ground, and are line-of-sight even though at greatest distance from E-4. Overall the result is an average sized error polygon compared to group 3, which, although having small error arcs from both stations, includes many of the points on steep terrain. As the error polygons calculations are based on plane geometry this results in a relatively larger surface area for a confidence arc. For example, several of the locations were on ridges. A polygon which has 4 corners, each 30 co-ordinate units apart, centred on a point on the ridge extends either side of the ridge. This effectively increases the *ground* area of that polygon as it drapes down the hillside. Also, many of the points in Group 3 were farthest away from J-1 station and this resulted in maximum width of the error arcs at these points. Point locations in group 2 had average error arcs, and the smallest mean error polygon. These points were equidistant from both stations, and bearings to them often intersected at right angles, both of which factors helped to reduce errors. Although Group 2 locations were spread over dissected terrain (several creeks run through the area) and on a steep hillside, the size of the polygons was little affected because the short distance from the points to either station diminished the width of the error arc compared to locations in the other groups. There are also half the number of locations in the group and this may have contributed to the results.

2.5.5. Summary

Error values found in this study were consistent with those from published reports (Mills and Knowlton, 1989; Springer, 1979; and Lee *et al.*, 1985). Although observer accuracy was not specifically tested during training sessions, both observers took bearings on transmitters and after becoming familiar with the techniques there was seldom any actual difference between bearings and no statistical difference. Cochran (1980) warned against testing system accuracy solely on stationary transmitters if movement of the collars is expected. In this study blind testing of operators with moving transmitters resulted in comparable accuracy to stationary ones. With little experience the observer could tell that the collar was in fact moving, particularly in thick bush. The resulting signal was not as consistent as stationary transmitters but, except for a few areas which had difficult signals anyway, location and determination of an accurate (within system error) azimuth was possible.

Radio triangulation problems in this study area resulted from a combination of the confined nature of the site, characteristics of possum movements, and the topography of the area. Large areas of bush and slight, though significant, ridges between the transmitter and receiving aerials produced considerable signal bounce. As experience was gained much of the signal bounce became predictable. As many of the possums were repeatedly tracked, and their movements, from den sites to feeding areas, were consistent over time, signal loss or sudden, large-scale variations could be explained. For example, signals from a possum denning along a steep creek bank may have been easily located before the animal moved. However, as the possum moved the orientation of the

transmitter aerial changed, as did the effect of the terrain on the signal. Confidence in locations made during this time, until the possums signal again became clear, were higher when the animal was later located in a commonly frequented area.

The more subtle problem of refraction could not be overcome. This was associated with rising ground, and heavy bush, between transmitter and receiving station. It was apparent that small movements within an area prone to refraction could have a marked effect on apparent signal direction. As many of these problem areas were feeding areas examination of the distances moved between observations, and consideration of feeding habits led to some of them being excluded when inconsistencies were detected. Movements of possums through areas that were line-of-sight to both stations presented no problems.

Saltz and Alkon (1985) noted 4 principal applications for error estimation within a study:

1. to aid in the determination of equipment and field protocol to achieve study aims
2. to aid in selection of appropriate home range calculations
3. provide a guideline for data inclusion/exclusion decisions and
4. as an essential addition to the overall reporting of results

The data presented fulfil those aims and allows confidence in presenting analyses as well as bringing to attention the weaknesses of the system. A major improvement to the present system would be the inclusion of a third radio tracking station within the paddock based on knowledge and error arcs already obtained. This station would have provided bearings from those areas in the lower part of the paddock.

The difficulties associated with tracking an animal with a relatively limited home range in steep terrain have been indicated, but the importance of quantifying the precision of such a system to account for differences in observers, geography and signal quality is recognised. Assuming transfer of equipment *and* resolution from one study to another without recalibration is unacceptable scientific method.

2.6. RADIO TRIANGULATION RESULTS

Triangulation was initiated on 31 nights and 1 day. Twenty-two of the nights and the daytime session were successful. The remainder were abandoned, due to equipment failure and/or extreme weather conditions (generally high winds). Twenty-seven possums and 5 steers were successfully radio tracked during the 12 month period in a total of 219 hours of observations. There were 15 male and 12 female possums followed; 6 were classed as juvenile animals (less than 10-12 months old), 16 were clinically uninfected adults, and 5 were known tuberculous animals. Table 2.4 lists the animals tracked and their fate at the end of the study (August 1992), while Figure 2.8 indicates the periods during which they were tracked.

2.6.1. Possum Activity Areas and Home Ranges

Individual possums were radio-tracked at night 1 to 12 times (mean 4.4, S.D. \pm 3.3), and 3458 locations were identified with an average of 128 for each possum (range 36-458). Table 2.5 lists total home range sizes calculated by 4 different methods - convex polygons (Mohr and Stumpf, 1966), non-circular or 95% ellipse (Jennrich and Turner, 1969), capture radius method of Hayne (1949) and the harmonic-mean method (Dixon and Chapman, 1980). Home ranges were calculated based on the total number of acceptable locations⁶ available for that animal over the study period. Home range size was influenced by the different number of locations obtained for each animal, the time of year during which it was tracked, and others factors, such as weather conditions. For example possum 3712 was only tracked on 2 consecutive nights, both of which were extremely windy, and this probably contributed to the small home range for this animal.

Table 2.6 compares average male and female activity areas based on data from all the possums. The activity area is defined as that part of the total home range of an animal traversed during normal activities over a short time period - in this case 10-13 hours. The smaller areas covered by the females, both as a mean, and range contributing to the mean, is evident. Rank sum tests, (Mann-Whitney U and Wilcoxon rank sum statistics) were significant ($p < 0.05$) for Capture radius, 95% ellipse, Convex polygon and 95% harmonic activity areas.

Activity areas for male and female possums are detailed in table 2.7 in relation to time of year. Kruskal-Wallis analysis of variance indicated significant variation between female activity areas for the convex polygon method ($P < 0.05$). Males also varied ($P < 0.025$) when convex polygons were used with 50 and 80% harmonic areas also being significantly different ($P < 0.01$). Rank sum (Mann-Whitney) tests were then conducted on combinations of seasonal activity areas. Female activity areas showed significant variation ($P < 0.05$) between autumn mating (March to May) and winter (July to October) values using the 95% ellipse, convex polygon and 95% harmonic mean methods. Males

⁶ Telem88 discarded locations with angles of less than 20°, relative to the baseline between the aerials, to *both* observation towers.

showed significant variation between autumn and winter measurements for convex polygons and 80% harmonic means ($P < 0.01$) and 50% harmonics ($P < 0.025$). Autumn and summer (November to February) convex and 50% harmonic activity areas were also significant at $P < 0.05$ and $P < 0.01$ respectively.

Table 2.8 lists possum activity areas in reference to their status - whether tuberculous, juvenile, or normal adult possums. There were no significant differences detected between these possum groups, either in size of activity area, or of home range. However, some of the tuberculous animals were found to have smaller activity areas as the disease progressed. There was considerable variation between an individuals activity areas from one tracking session to the next and, in some cases, on subsequent nights. For example possum 3644 had a convex area of 0.27 ha on the 14th of May 1991, and 1.3 ha the next night. The latter points are demonstrated fully in a later section.

Table 2.4 Possums and Cattle radio-tracked during 1991/92 and their status at the end of August 1992

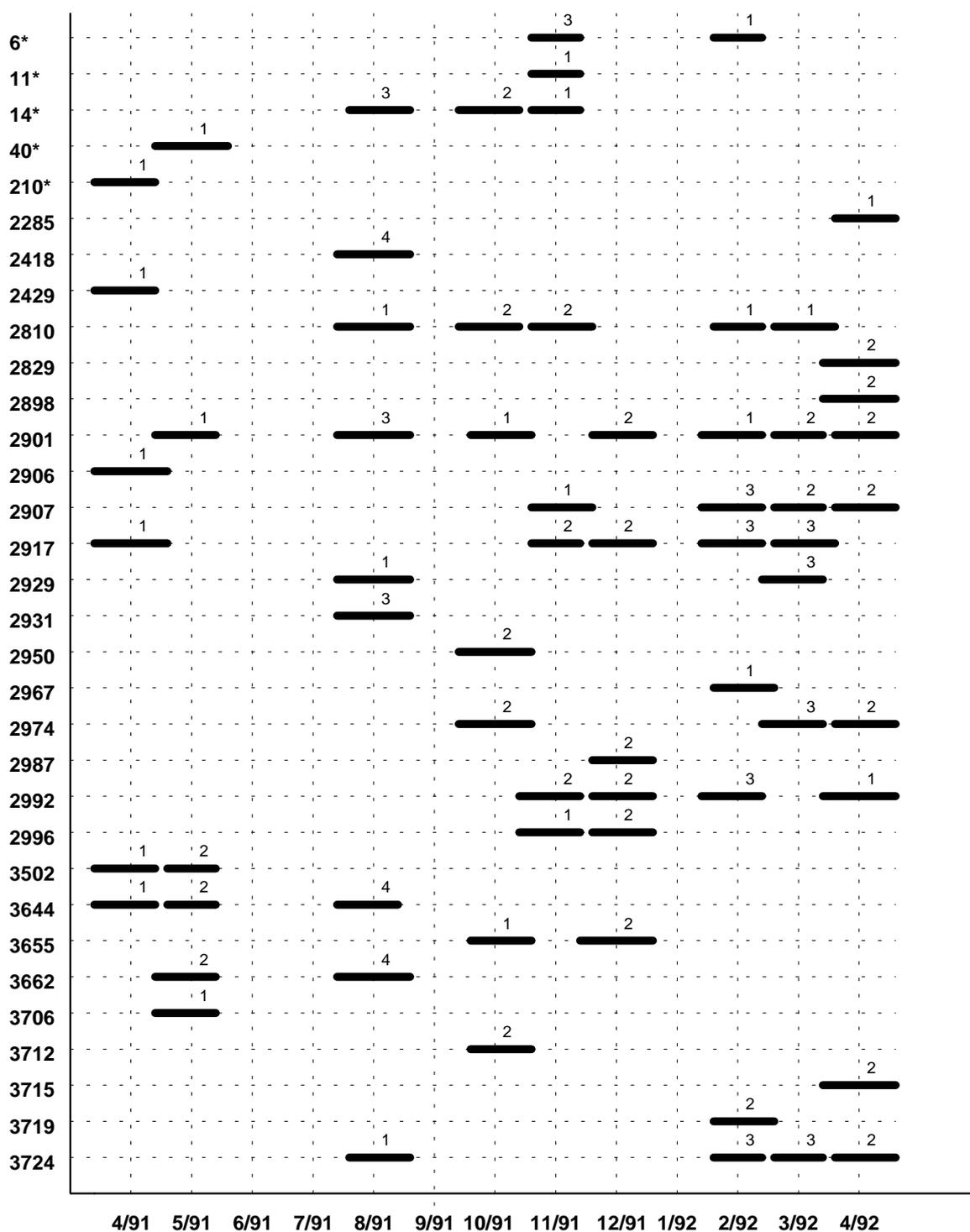
Animal	Sex*	Nights tracked	Current Status (September 1992)
6	Steer	4**	Removed from area 1992
11	Steer	1**	Removed from area 1992
14	Steer	6**	Removed from area 1992
40	Steer	1	Removed from area 1991
210	Steer	1	Removed from area 1991
2285	M, J	1	Alive
2418	F, A	4	Died Oct-91, unknown causes
2429	F, A	1	Died Jan-92, unknown causes
2810	M, A	7	Alive
2829	M, A	2	Alive
2898	M, J	2	Alive
2901	F, A	12	Alive
2906	F, A	2	Died May-91,
2907	M, A	8	Young adult, still alive
2917	M, TB	11	Died of TB April-92
2929	F, A	4	Died May-92, unknown causes
2931	M, A	3	Contact lost, Oct-91
2950	M, A	2	Died (TB?) Nov-91
2967	M, J	1	Died (TB?) March-92
2974	M, A	7	Alive
2987	M, J	2	Dispersed from site Dec-91
2992	M, J	8	Died of TB May-92
2996	F, J	3	Alive
3502	F, A	3	Died July-91, unknown causes
3644	F, A, TB	7	Died of TB Sep-91
3655	M, A	3	Alive
3662	M, A, TB	6	Died of TB Oct-91
3706	M, A	1	Radio failed mid 1991
3712	F, A	2	Died of TB Nov-91
3715	F, A, TB	2	Alive
3719	F, A, TB	2	Died in Mar-92, cardiac tamponade
3724	F, A	9	Alive

* Codes used in Table:

- A = adult possum
- J = Juvenile possum
- F = female possum
- M = male Possum
- Steer = cattle beast
- TB = known to be Tuberculous

** One of these tracking sessions was during the day

Figure 2.8 Graph showing time of year at which animals were tracked



This figure indicates the time of year possums and cattle were tracked. Each bar represents at least one tracking session during that month (indicated on the x-axis) and the figures above the bar specify the number of nights of tracking.

* These are cattle, the rest, possums

Table 2.5 Measures of total home range for possums and cattle - April 1991 to April 1992

Animal ID	Sex-code	Based on No. Locations	Area Convex method (ha)	Area 95% Ellipse (ha)	Area 50% Harmonic (ha)	Area 80% Harmonic (ha)	Area 95% Harmonic (ha)	Circumference of polygon (m)	Range Length (m)
6	Steer	144	18.54	51.31	5.36	13.93	22.86	1983.85	836.80
11	Steer	41	3.65	8.38	1.6	3.22	6.14	849.29	378.35
14	Steer	172	25.03	50.48	12.97	20.01	22.32	2400.12	916.56
40	Steer	46	0.77	1.07	0.22	0.63	0.99	369.85	158.60
210	Steer	34	0.48	0.72	0.1	0.19	0.77	393.84	184.38
2285	M	49	2.23	4.8	0.23	2.36	4.71	660	277.90
2418	F	177	4.68	7.09	1.07	5.44	11.85	1289.76	616.41
2429	F	45	1.36	1.85	0.37	1.40	2.22	532.35	237.24
2810	M	149	5.67	6.38	0.81	3.12	5.96	911.6	325.74
2829	M	97	9.53	13.26	2.62	8.23	12.65	1249.11	477.15
2898	M	47	1.85	3.03	0.86	1.62	2.67	546.38	213.21
2901	F	408	4.43	5.67	1.22	2.71	4.72	856.15	355.77
2906	F	43	0.46	0.8	0.19	0.29	0.53	296.58	120.83
2907	M	333	14.01	19.25	2.8	5.3	11.14	1531.89	569.23
2917	M	394	6.09	5.18	0.66	2.72	7.67	984.43	398.82
2929	F	174	3.62	3.09	0.69	1.32	2.53	828.75	314.03
2931	M	135	4.05	2.81	1.75	5.07	6.45	2461.8	491.52
2950	M	88	0.53	0.95	0.17	0.4	0.63	286.13	104.98
2967	M	38	1.18	2.17	0.2	2.9	4.76	715.18	350.54
2974	M	317	3.69	3.8	0.93	2.12	3.63	758.99	304.34
2987	M	73	0.42	0.52	0.12	0.25	0.54	263.42	99.82
2992	M	307	7.71	8.89	1.18	4.43	13.33	1151.29	486.78
2996	F	110	0.79	1.27	0.34	0.77	1.43	396.24	176.16
3502	F	138	4.37	12.26	1.45	2.64	4.47	915.13	361.99
3644	F	305	4.67	6.11	1.54	2.5	5.53	1070.69	477.77
3655	M	109	3.35	5.15	0.94	2.82	4.57	819.55	359.32
3662	M	275	12.76	14.39	3.39	6.87	15.31	1696.16	652.41
3706	M	46	1.69	3.68	0.61	1.86	3.06	631.13	274.15
3712	F	88	0.15	0.14	0.02	0.07	0.16	159.97	66.19
3715	F	97	1.28	1.94	0.36	0.96	1.74	458.08	196.24
3719	F	75	1.87	3.69	0.48	1.75	2.5	561.12	234.73
3724	F	381	3.15	2.88	0.79	1.61	3.21	768.66	354.37

Table 2.6 Average size of nightly activity areas, by 4 different methods, of male and female possums.

Females	Parameter	Count*	Mean	Minimum	Maximum	Range	Std. Error	Std.Dev
	Based on No. Locations	50	43.1	36.00	51.00	15.00	0.61	4.32
	Area Convex method (ha)	50	0.93**	0.05	2.32	2.27	0.08	0.54
	Area 95% Ellipse (ha)	50	1.89**	0.06	7.39	7.33	0.19	1.32
	Area 50% Harmonic contour (ha)	50	0.32	0.02	1.80	1.78	0.04	0.28
	Area 80% Harmonic contour (ha)	50	0.88	0.02	2.49	2.47	0.09	0.64
	Area 95% Harmonic contour (ha)	50	1.63**	0.03	4.61	4.57	0.15	1.06
	Circumference (m)	50	436.12	101.09	893.07	791.98	23.7	167.58
	Range Length (m)	50	290.98**	66.19	616.41			153.77
Males								
	Based on No. Locations	64	40.02	12	51.00	39.00	0.94	7.55
	Area Convex method (ha)	64	1.44	0.14	8.83	8.69	0.17	1.33
	Area 95% Ellipse (ha)	64	2.94	0.28	17.04	16.76	0.31	2.55
	Area 50% Harmonic contour (ha)	64	0.43	0.01	1.72	1.71	0.04	0.35
	Area 80% Harmonic contour (ha)	64	1.34	0.17	7.11	6.94	0.16	1.25
	Area 95% Harmonic contour (ha)	64	2.66	0.27	14.22	13.95	0.32	2.53
	Circumference (m)	64	519.64	194.67	1237.66	1042.99	28.5	227.961
	Range Length (m)	64	359.06	99.82	652.41			158.25

* The total number of night's data contributing to the activity area calculation

** These values are significantly different between males and females ($P < 0.05$)

Table 2.7 Variation in mean activity area (ha) by season

Females	Mating Mar-May	Joey's present Jul-Oct	Joey's independent Nov-Feb
Method			
Convex polygon	1.11*	0.7*	0.91
95% Ellipse	2.11*	1.55*	1.95
50% Harmonic	0.3	0.32	0.36
80% Harmonic	1.04	0.66	0.87
95% Harmonic	1.88*	1.25*	1.69
Circumference	462.08	411.02	418.37
Capture Radius	3.84	3.47	3.26
N ¹	23	16	11
Males			
	Mar-May	Jul-Oct	Nov-Feb
Convex polygon	1.98* [^]	1.12*	1.14 [^]
95% Ellipse	3.8	2.46	2.46
50% Harmonic	0.61* [^]	0.33*	0.33 [^]
80% Harmonic	1.77	0.99	1.17
95% Harmonic	3.1*	2.75*	2.22
Circumference	605.24	461.44	477.49
Capture Radius	6.02	5.7	4.26
N ¹	23	15	26

¹ These figures refer to the number of nights data from which the range means are calculated.

* The differences between these values are significantly different

[^] The differences between these values are significantly different

Table 2.8 Variation in mean activity areas (ha) according to status

Method	Non tuberculous Possums	Tuberculous Possums	Juvenile Possums
Convex polygon (ha)	1.27	1.16	1.08
95% Ellipse (ha)	2.62 (69) ¹	2.31 (28) ¹	2.2 (17) ¹
50% Harmonic (ha)	0.4	0.36	0.35
80% Harmonic (ha)	1.2	1.04	1.09
95% Harmonic (ha)	2.28	2.21	1.91
Circumference (m)	501.26	454.04	456.63
Range Length (m)	327.67	391.89	267.40
N ¹	69	28	17

¹ These figures refer to the number of nights data from which the means are calculated.

2.6.1.1. Effect of weather on Possum movements

The only climatic variable which had an obvious effect on possum movement was wind. There were insufficient nights of rain, extremely cold or hot weather, or frost etc. to compare these factors. Because of the seasonal variation in activity area size, comparisons were made on observations between August and November 1991, inclusive. There were 8 nights of radio triangulation, and 12 different possums were tracked a total of 39 times. The average activity area covered 0.84 ha (range 0.34-1.5 ha).

During this period there were 2 nights during which the winds remained at strong to gale force from before dusk until at least 0200-0400 hrs. On these nights the possums moved over an average of 0.36 ha. (range 0.14-0.7 ha.). If nights with winds greater than strong breezes are included (5 of the 8) the activity area size increases to 0.67 ha, compared with 1.16 ha for calm nights. Comparisons are difficult to make in that the same possums were not usually tracked on subsequent nights, so the comparison is between different animals not within the same animal. However, a few animals were tracked regularly over that time. Possum 2901 had activity areas of 0.7 and 0.41 on the most severe nights. On calmer nights, though still windy, areas of 1.71 and 0.88 were recorded. Also, on 2 sequential nights possum 2418 traversed areas of 1.17 and 0.46 ha respectively. The second of these nights had strong to gale force winds. The effect of rain is discussed in Chapter 3.

2.6.1.2. Possums movements in relation to habitat

There are few distinct bush/pasture margins in the radio triangulation area of the study site. Although many small areas of pasture exist under the taller tree canopy, and within open patches in the scrub, large areas of pasture were only found in the lower part of the paddock, and along the tops of the southern and eastern ridgelines. Any possum location in the area has an associated positional error, and the distances across open areas are often less than this error. Hence diagrams, such as Figure 2.9a, are only indications of the areas possums traversed. However, it can be seen that the possums tracked in the study utilise an area which includes dense gorse and bush (denning areas), through partially cleared, manuka-dominant habitat (most of the central paddock area), to open pasture (lower paddock and between patches of bush). The selection of possums to track was based on those caught in the area of paddock trapped in the longitudinal study. However, although animals from the periphery of this area were among those tracked, no animals moved in the south-eastern part of the study area. Figure 2.9b shows the limited areas that were used for denning. The den locations were taken from triangulations of the possum's position either the day before, or day after, night-time radio triangulation observations were carried out on it.

Figure 2.9a Possum location distribution overlaid with bush cover

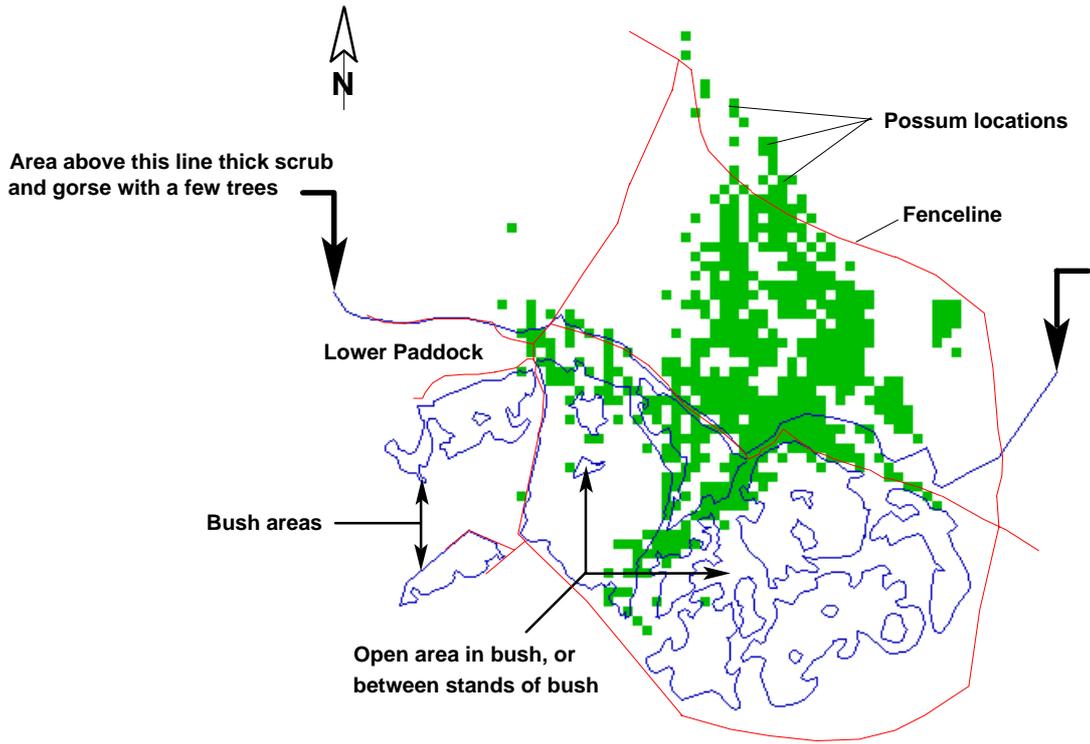
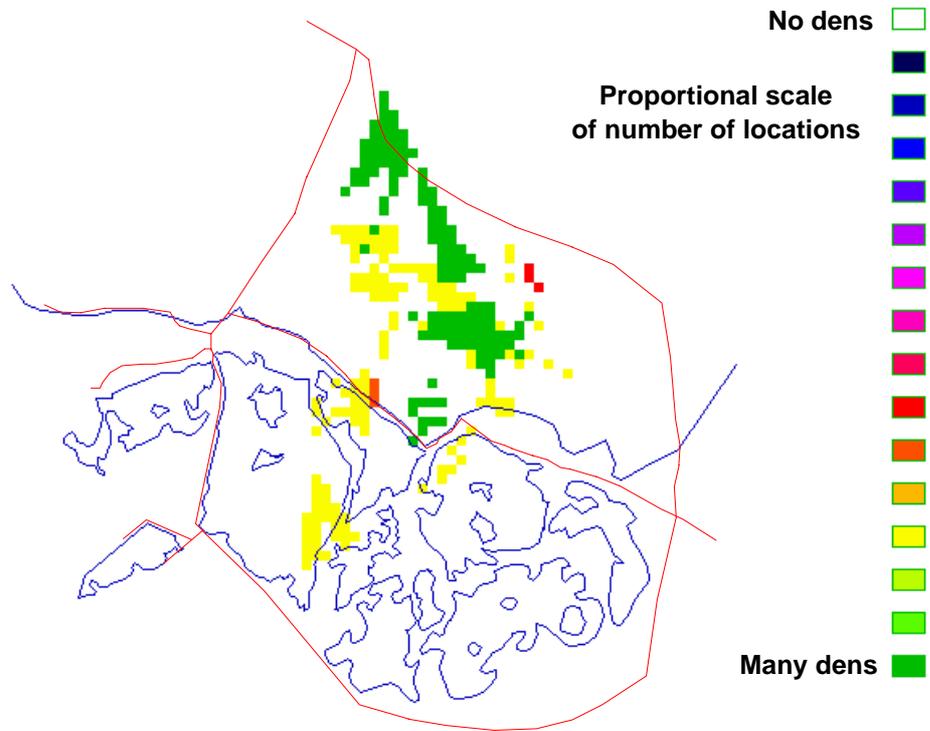


Figure 2.9b Common den-site areas of radio-tracked possums



2.6.2. Cattle Movements in the Area

Tables 2.9 and 2.10 show average cattle activity areas from all radio triangulation data. Daylight figures are from a single day's observations, and cannot be considered representative of the normal activity of the cattle. On this day the weather was windy and cold, with occasional showers, and the cattle remained in the lower, protected, area of the paddock - their normal movements were more extensive. The cattle generally ranged over the entire area through the day, often splitting into 2-3 groups. There were several locations, spread through the paddock, that the cattle favoured as camps⁷.

One of the steers had been tracked for 2 nights previous to the daylight observations and the average convex polygon values were 0.58, 0.32 and 2.92 ha for the 2 nights and day areas respectively. Steer numbers 14 and 6 were tracked 5 and 3 times respectively and their home range covers all of the available paddock area. After the new fence divided the paddock, cattle were commonly found at night in 1 of 3 camping areas, all of which were near the southern or eastern ridgelines, and away from the main feeding areas of the possums, although they occasionally camped in the lower part of the paddock. Prior to the erection of the fence the cattle had camped over much of the study area, in some cases close to the denning areas of the possums (eg. steer number 40, Figure 2.10). Only two nights of radio triangulation on cattle were completed before the fence was built, and steers were infrequently tracked once it was established they were seldom in areas frequented by radio tagged possums (at night). The practice was to note the location of the cattle on arrival at dusk, and if they were away from the possum areas not to track them. There were no significant differences between activity areas between animals, time of year or time of day. However, as data are very limited, little can be drawn from these facts. Cattle camped and grazed together (there were 14-17 steers in the area throughout the study), although they often split into 2 or 3 groups. From visual observations, and triangulation data, it was found the cattle moved about and grazed for some time after dark and then tended to remain in a small area in the 1-2 hours before midnight. More extensive feeding movements were often seen again in the early morning, tapering off towards dawn. Individual radio-tagged animals were noted to make long distance movements - more than 200 m in 12-15 minutes - on several occasions. In one case this was some 300-400 m across the paddock from a group grazing on the east ridge to near the radio-tracking tower on the southern slopes where the rest of the cattle were camped. Night activity areas were, in general, less than 1 ha but on 2 nights individual animal activity areas of greater than 2.5 ha led to average areas being high. If one considers the minimum areas though, it is seen that the night area minima are considerably smaller than those during daylight. The number of fixes was often limited as much of their time was spent near the baseline between the radio triangulation towers, and Telem88 rejected these bearings.

⁷ Camp - place where animals gather to rest or sleep

Table 2.9 Mean night-time activity areas for cattle

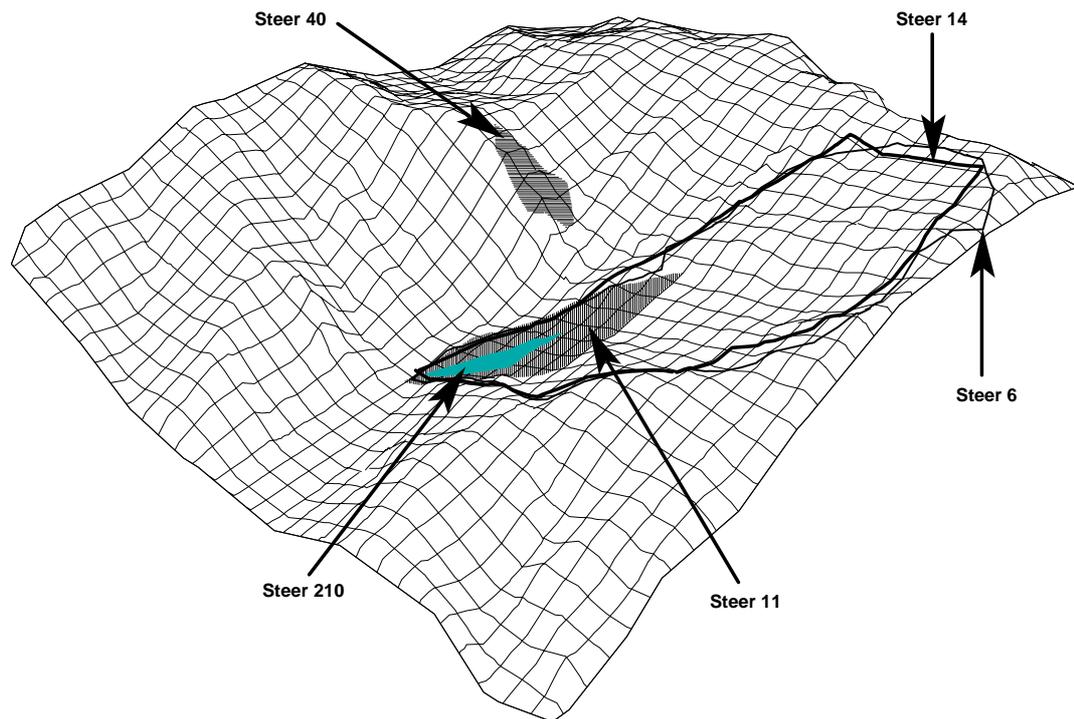
Method	Mean	Minimum	Maximum	S.D.
Based on No. Locations	35.3	11	46	9.40
Area Convex method	1.02	0.32	2.79	0.81
Area 95% Ellipse	1.96	0.72	5.06	1.53
Harmonic Mean 50%	0.56	0.05	3.27	0.98
Harmonic Mean 80%	1.87	0.15	8.79	2.67
Harmonic Mean 95%	6.01	0.60	37.93	11.39
Circumference	656.92	282.44	1918.0	483.85
Area Capture Radius	8.89	1.09	48.48	14.45

Table 2.10 Mean daily activity areas for cattle

Method	Mean	Minimum	Maximum	S.D.
Based on No. Locations	40.33	39	41	1.15
Area Convex method	2.88	2.06	3.65	0.79
Area 95% Ellipse	6.21	4.23	8.38	2.08
Harmonic Mean 50%	1.19	0.56	1.6	0.55
Harmonic Mean 80%	2.47	1.41	3.22	0.95
Harmonic Mean 95%	5.09	3.33	6.14	1.54
Circumference	758.9	601.41	849.29	136.88
Area Capture Radius	7.95	5.17	9.35	2.4

Figure 2.10 shows range areas of 5 steers calculated using the convex polygon method. Steers 6, 11 and 14 were radio-tracked over several nights, and on one occasion in daylight, thus accounting for the larger areas compared with numbers 40 and 210. The latter animals were tracked over a single night, and before the fenceline dividing the paddock was built. The range of steer 40 includes the rocky spur between eastern and western parts of the paddock, and also an area where a large number of possums den - including tuberculous possums.

Figure 2.10 Cattle range areas derived from all available triangulated locations



2.6.2.1. Distribution of Cattle radio-locations through the site

Figures 2.11 and 2.12 illustrate the distribution of radio triangulation-derived locations for the cattle through the study area. The indices to the right indicate the relative number of locations for a point in the paddock, based on a 15 square metre grid. The values in the grid cells are a scaled count of the number of locations in that position (each 15 sq.m area). Scaling proportionally reduces the number of categories in each image to facilitate printing (16 available tones or colours). The number of times a steer was located in any cell ranged from 0 to 23 during the night, and 1 to 6 during the day. There was a large variation in the number of locations obtained for individual steers, and the number of months over which an animal was tracked. These factors are most evident in the daylight figure, where only the lower part of the paddock shows activity.

Figure 2.11 Distribution of cattle radio locations through the area at night

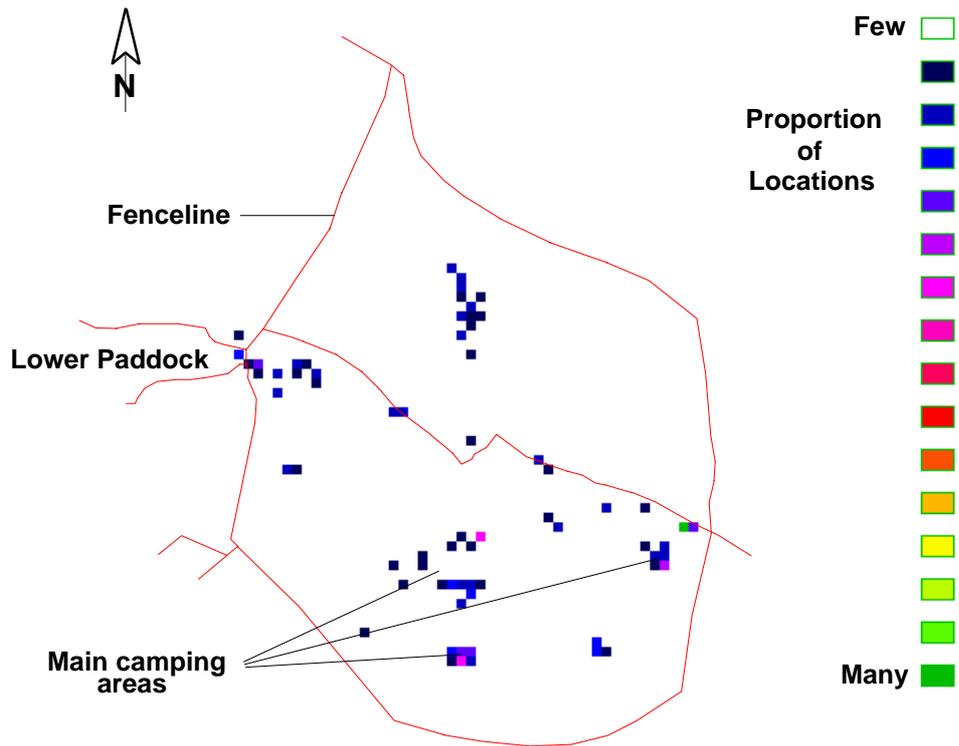
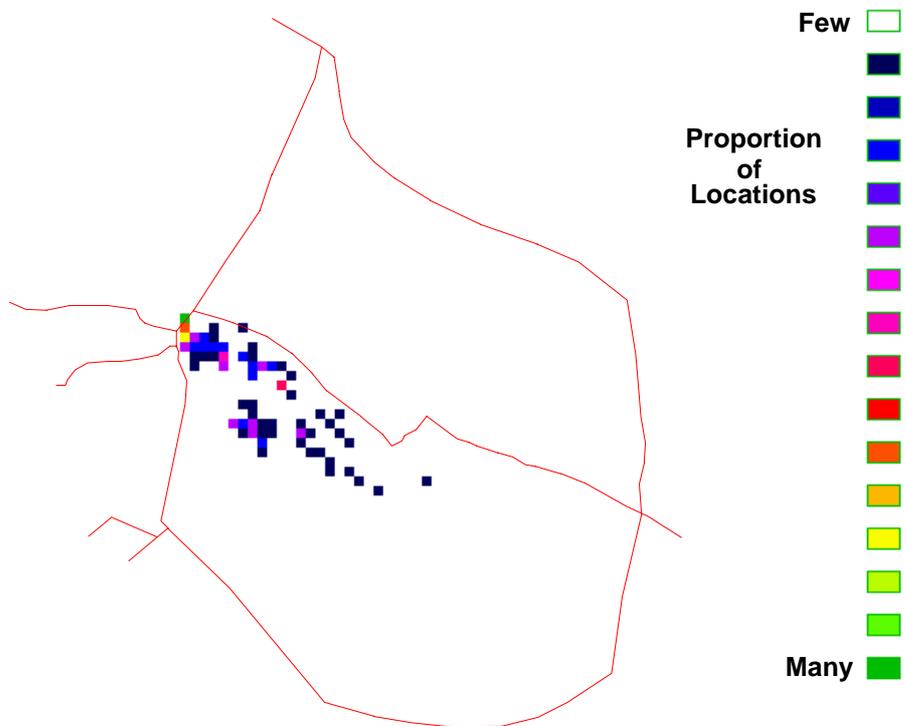


Figure 2.12 Distribution of cattle radio locations through the area during daylight



2.6.3. Movements of Seven Frequently Tracked Possums

The following section describes 7 possums in detail, 3 tuberculous and 4 apparently healthy (normal) animals. These animals were tracked on more than 6 occasions, generally through a major part of the year. Two of the possums, both tuberculous, were tracked over 5 months before they died, the remainder for between 6 and 12 months. Unless specified, the results do not include data on other possums.

Possum number 2810

Consistently trapped in the same area of the paddock since first tagged in October 1989. The animal was a mature male when initially captured. The activity centre of this possum was close to J-1 tracking tower and on several occasions it moved around the hut, making triangulation difficult. Its most common denning site was in root-rakings (piles of cut down manuka) along the edge of the bush. It was seldom found elsewhere although there are few suitable denning sites for possums other than root-rakings in this area. The possum is classed as healthy and was tracked over 8 months.

Possum number 2901

An immature female when first caught in January 1990 it has been caught repeatedly in the same area as its original capture site since then. The possum lives in flax and gorse bushes close to the confluence of several creeks in the site. Almost invariably found denning on the banks of a creek this possum has the second smallest home range of the 7 discussed. It is an healthy animal and was tracked over 12 months.

Possum number 3724

Regularly caught since September 1989 this female lives in the central area of the paddock and dens on the hillsides around the rocky ridge. Using a variety of den types the possum feeds in the middle part of its range area and has the smallest home range of those described. Tracked for 8 months, it is a normal animal.

Possum number 2917

First caught in January 1991 as an immature this male died of tuberculosis in April 1992. The home range was central to all the other possum home ranges studied. It denned in flax and gorse high on the rocky ridge. The possum became clinically tuberculous in November 1991 and was tracked extensively from then, although it had been tracked for a single night in May 1991.

Possum number 3644

This young adult female was first caught in August 1990, diagnosed as clinically tuberculous later that year, and tracked from April to August 1991 when it died. The possum's range was in the upper part of the paddock considerably higher up the creek than 2901. It did move down to the common feeding areas. The possum had 2 main denning areas, both on spurs off the main ridgeline, approximately 200 metres apart. The possum alternated between them during the time it was tracked, eventually dying close to one of the den sites.

Possum number 3662

A tuberculous animal when radio triangulation began, 3662 was radio-tracked for 5 months until the signal was lost in August 1991. The animal's body was found several weeks later beyond the ridge on the northern edge of the site. With a home range of 12 ha, it was the only animal not to frequent feeding areas in the lower parts of the paddock. Dens for this animal were found in 2 areas, one to the south of the northern ridge in flax, and the other on the far side of this ridge, in gorse.

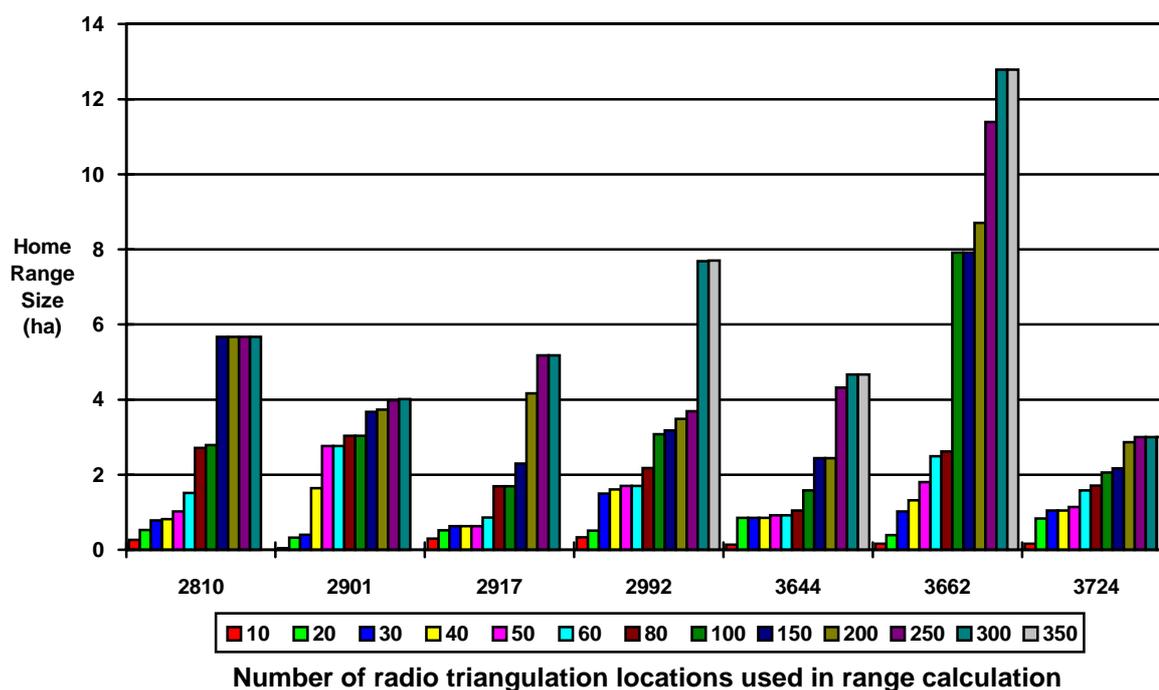
Possum number 2992

This healthy immature male was known to have been born in the study area (tagged as an in-pouch joey in September 1991), and was tracked from November 1991 to April 1992. Commonly found denning under shrubs and grasses on either side of the rocky ridge, the possum remained in the same area as its mother throughout the study period. It was caught with its mother several times in late 1991, and appeared to be independent by January 1992. The poor quality den sites chosen by this animal appear typical of juveniles. Many of the young animals tracked were found in dens with inadequate protection from the elements, compared with sites chosen by adults. Whether displaced by older animals, unable to locate adequate sites or for behavioural reasons - for example feeding for longer periods than adults and having to find shelter rapidly before daylight - it is possible that this factor contributes to the high mortality rate of immature possums.

2.6.3.1. Size of home range in relation to number of observations

Figure 2.13 shows the relationship between the number of radio triangulation locations for a possum, and the size of its home range. Each column, within the group for a particular possum, represents the cumulative home range calculated from the number of locations indicated in the legend. Home range area of 4 possums (2810, 2901, 2917 and 3724) began to stabilise after approximately 100-150 locations had been mapped. Possum 2992 began to show signs of stabilising range size at this level also, but there was a large increase in home range area after 250 locations. This was associated with a move from the natal denning area. Possums 3644 and 3662 (both tuberculous) continued to increase their range size throughout, although 3644 had a steady range area over the first month of radio triangulation. The latter had open, tuberculous lesions at this stage (April-May 1991). The open lesions had been healed for several months when 3644 was next tracked in August. These later results expanded the range size estimate, and were the last obtained before 3644 died in early September 1991. The body of 3644 was found close to a den it had been using over the previous 6-8 weeks. The home range area of 3662 continued to increase on each tracking occasion until its death. This possum was unusual, among those being tracked, in that it moved extensively in 2 directions - north and south. Most possums moved in a southerly direction, down the hillside from their dens, returning in the early morning. Possum 3662 denned close to the northern ridgeline, as did many others, but frequently ranged north, and often denned on the northern side of the ridge. However, ranges of both these possums may have been levelling off after 300 locations, possibly due to the effects of tuberculosis.

Figure 2.13 Number of radio locations in relation to home range size



2.6.3.2. Home ranges of Possums

Figures 2.14a and b show the convex polygon home ranges of the possums calculated from all radio fixes for each individual. There is extensive overlap in the overall ranges of the possums, except of No. 3662, although it must be remembered that convex polygon ranges include the outer points of an animal's range, thus including areas which may be seldom used. Also note that the range of possum 3662 extends beyond the mapped area, and the accuracy of locations at this distance (50-150 m beyond the map area) is untested. Juvenile 2992 shifted denning areas in March or April 1992 and this resulted in an extended overall home range (see table 2.11a).

Tables 2.11a and b aid in clarifying the amount of the home range area that is actually used. Convex polygon home ranges are calculated by joining all the outer location points for a possum - as can be visualised from the 'all areas' column in the figures. Where a possum has moved extensively in different directions (such as 2810), or shifted the focus of its range area (2992), potentially large areas are included in an overall home range figure, which have not been utilised by that animal.

**Surfaces of study site overlaid with home ranges of 7 most frequently tracked possums.
Includes all locations through study period.**

Figure 2.14a Home ranges of possums numbered 2810, 2901, 2917 and 3662

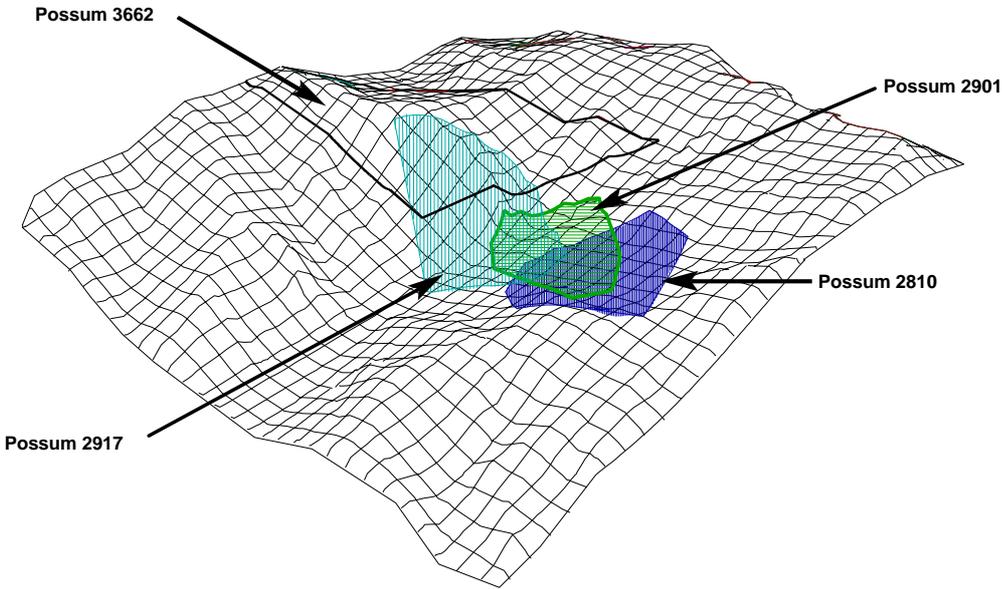
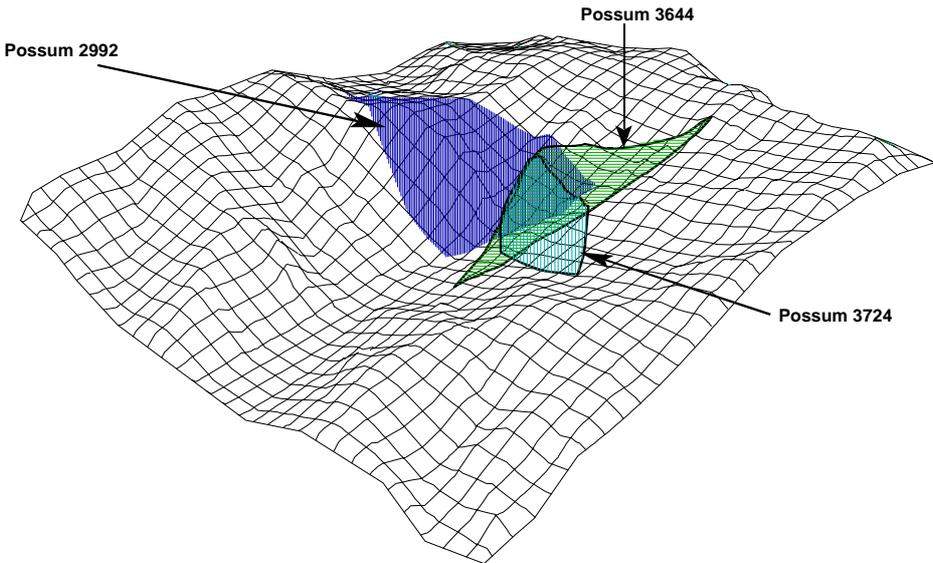


Figure 2.14b Home ranges of possums numbered 2992, 3644 and 3724



2.6.3.3. Possum activity areas

Tables 2.11a and b show the shape of possum activity areas at various times of the year. The combined area column has all the activity areas for that possum overlaid using the same geographic reference point for each area. Subsequent columns orientate the subsets of activity areas in relation to the whole. Each activity area is a convex polygon based on a single night's data, but the nightly activity areas within each grouping (March-June etc.) may be spread over the entire 4 months of the 'season'. In many cases an individual was tracked several times in a week, often on subsequent nights. However, there was often considerable variation in direction, and extent, of succeeding activity areas. For example, possum 2810 in July-October: Two of the areas, the smallest and the triangular shaped areas, were on following nights in October, and yet are quite different. Despite the differences on a nightly level, it is the similarity between activity areas, and the fidelity of a possum to an area over time, which is noteworthy. Large scale, but infrequent, movements (such as possum 2810 in March-June) serve to progressively increase the size of overall home ranges, but hide this underlying constancy in using a relatively small area for a high proportion of total activity.

Table 2.11a Variation in shape and extent of possum activity areas through the year

Possum	All	March-May	July-October	November-Feb
3644				
3662				
3724				

Table 2.11b Variation in shape and extent of possum activity areas through the year

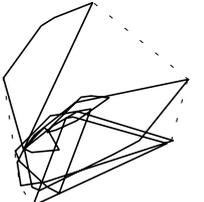
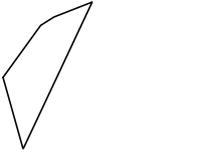
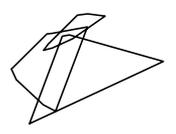
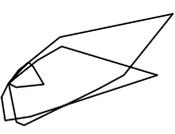
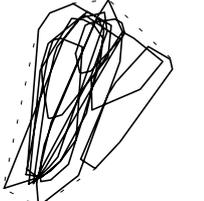
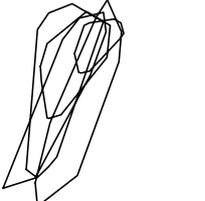
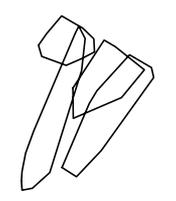
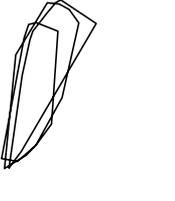
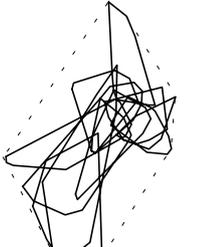
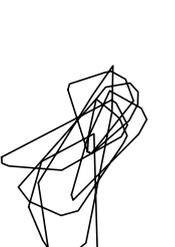
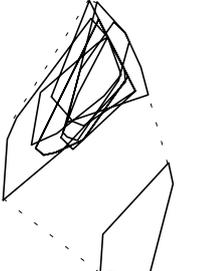
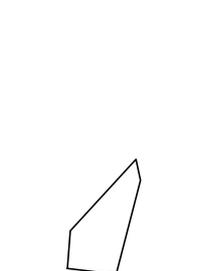
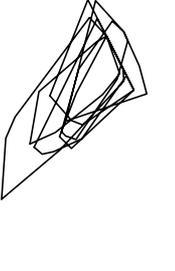
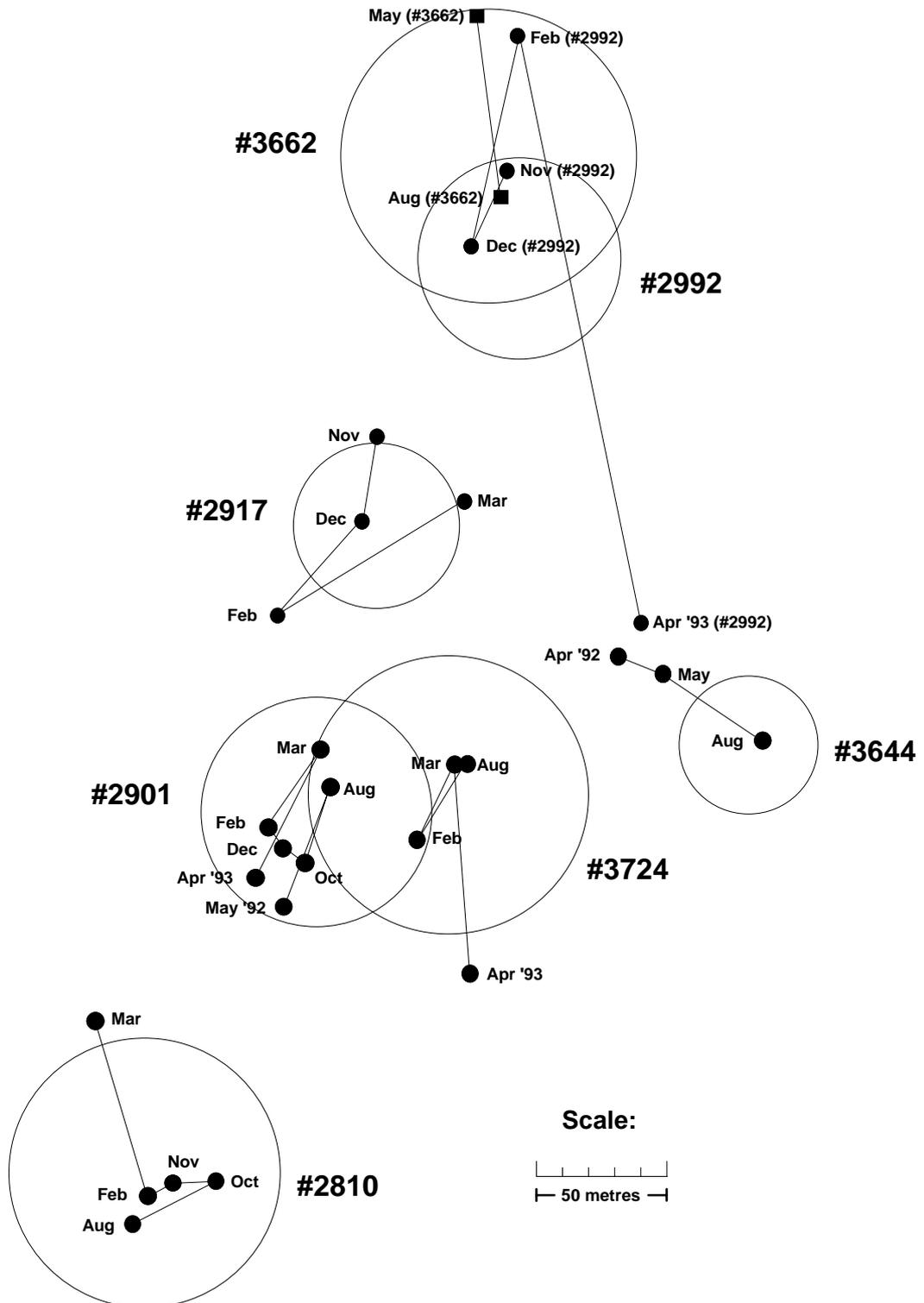
Possum No.	Combined areas	March-June	July-October	November-Feb.
2810				
2901				
2917				
2992				

Figure 2.15 illustrates shifts in monthly centres of activity (shown as \bar{y} and \bar{x}) which are means of 1-5 nights tracking. Circles equal in area to the size of the mean activity area (based on all tracking data for that possum) are shown to illustrate the distances of each shift. The circles are centred on the geometric centre of activity of the respective home ranges.

Figure 2.15 Shifts in centres of activity of 7 possums

Note: Mean nightly activity areas are circled around the annual centres of activity (after Ward, 1978).



2.6.3.3.1. Changes in the size of a tuberculous possum's activity areas

The area covered by a possum on a given night was highly variable. Inclement weather, either high winds or rain, appeared to restrict movements of most animals. However, the variation in size of activity areas between days within a week, and between months, was generally unpredictable for normal (non-tuberculous) possums (Table 2.12). Conversely, activity area size, for all radio-tracked tuberculous possums, decreased in the months before they died (Possum 3662 is assumed to have died in October 1991, based on its trapping record, radio signals and carcass condition when found). Unfortunately, due to a small sample size and time period, (many of the tuberculous possums died soon after diagnosis) it is not possible to confirm this trend. Common sense suggests it would be so.

Table 2.12 Change in size of possum activity areas over time (means, ha)

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
<i>Normal possums</i>													
2810					0.8		1.5	1.6			0.2	3.1	
2901		1.7			0.7		0.9		1.5		1.1	0.8	1.6
3724					1.1						1	1.3	0.8
<i>Juvenile</i>													
2992								1.1	1.8		1		1.1
<i>Tuberculous possums</i>													
2917	0.6							0.6	0.8		1.5	0.5	
3644	0.9	0.7			0.5								
3662		3.1			2.2								

2.6.3.4. Distribution of Possum Movements.

Mapping of home ranges and activity areas gives an understanding of the extent of movement, and possible overlap between species but it does not indicate the intensity of use of particular habitat areas unless calculated over short time intervals. Figures 2.16 and 2.17 are representations of the number of times possums were radio-located at points throughout the paddock. Figure 2.16 includes *all* possums in the radio triangulation study, Figure 2.17 only those 7 specifically mentioned in this section. To obtain the figures, all triangulated locations for each possum were plotted onto a grid and the count in each cell is incremented by one each time a location falls in that cell. The frequencies have been scaled to a range of 0-15, the actual ranges are 0-26 for Figure 2.16, and 0-23 for Figure 2.17. Each grid cell represents 15 m².

Figure 2.16 Distribution of radio triangulation locations for all possums tracked

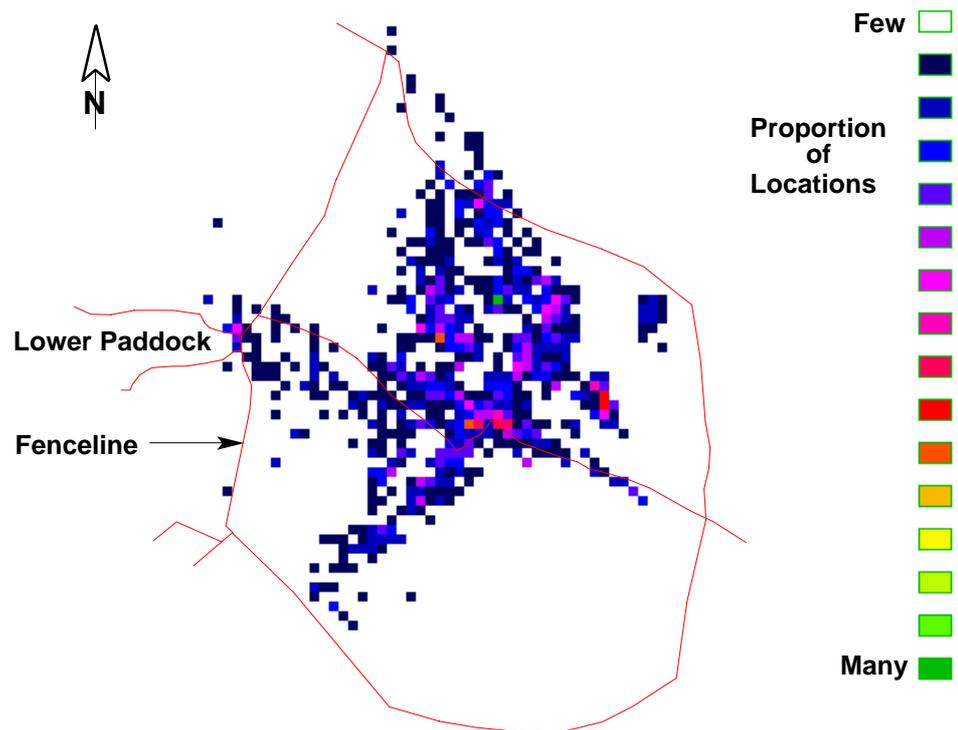
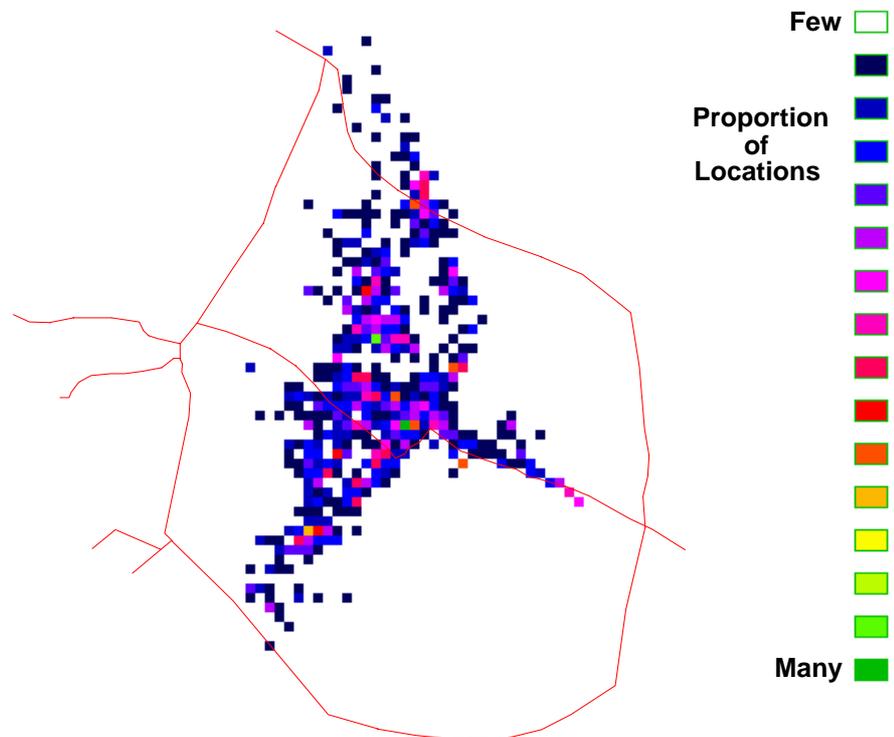


Figure 2.17 Distribution of radio triangulation locations of 7 frequently tracked possums



2.6.4. Common use of Habitat by Possums and Cattle

Radio triangulation and observational studies (Chapter 3) found that there was significant overlap between possums and cattle in the use of habitat in the study area. Cattle were initially able to gain access to all but the steepest, and densest, areas in the site, and this included tuberculous-possum denning areas (pers.comm D.Pfeiffer, T.Harris and pers. observations). However, radio-collar failures in the early stages of the project, and then the division of the site by a fence, limited the extent to which interactions between cattle and possums could be investigated. The fence denied cattle access to the major possum den areas, and prevented them from moving into the bush from the pasture margin. Also, with the small number of animals able to be tracked on any one night, it was unlikely for possums and cattle with radio collars to be in the same location at the same time. Cattle moved throughout the partially cleared manuka stands on the southern slopes, and the central and lower parts of the paddock where possums frequently grazed (Figures 2.10, 2.11 and 2.12 show that the cattle used the full extent of this area). Overlap in habitat use by possums and cattle was investigated by overlaying the radio-location distributions for both species. Proportions of locations for each species were summarised simply as whether or not the possum or steer had been located in that area, and then images for each species overlaid. The result is a map of the area indicating points where both cattle and possums had been found. A map based on proportions would be meaningless due to the considerable variation in numbers of animals, and locations, identified.

Two figures are presented; Figure 2.18 shows overlap in locations for all possums and the cattle, while Figure 2.19 describes only those 7 frequently followed possums. The differences between the figures is primarily due to the more extensive area covered by the larger number of possums in the first figure. Five of the 7 most frequently tracked possums were originally selected on the basis of their proximity to the TB denning areas, and the animals from this area tended to feed in the central area of the paddock, and on the northern slopes. The other 2 possums in this group were non-infected animals, remaining from a larger number, chosen as comparisons to the others. Because of the small number of animals tracked, possum deaths, and radio failures, these animals may not be representative of all possums in the area. It is apparent though, that overlap between possums and cattle occurs along the central fenceline, and in the lower part of the paddock. Had the cattle had greater access to the bush on the northern side overlap between the possums and cattle would have been more extensive.

Figure 2.18 Common use of habitat by Possums and Cattle (includes all possums)

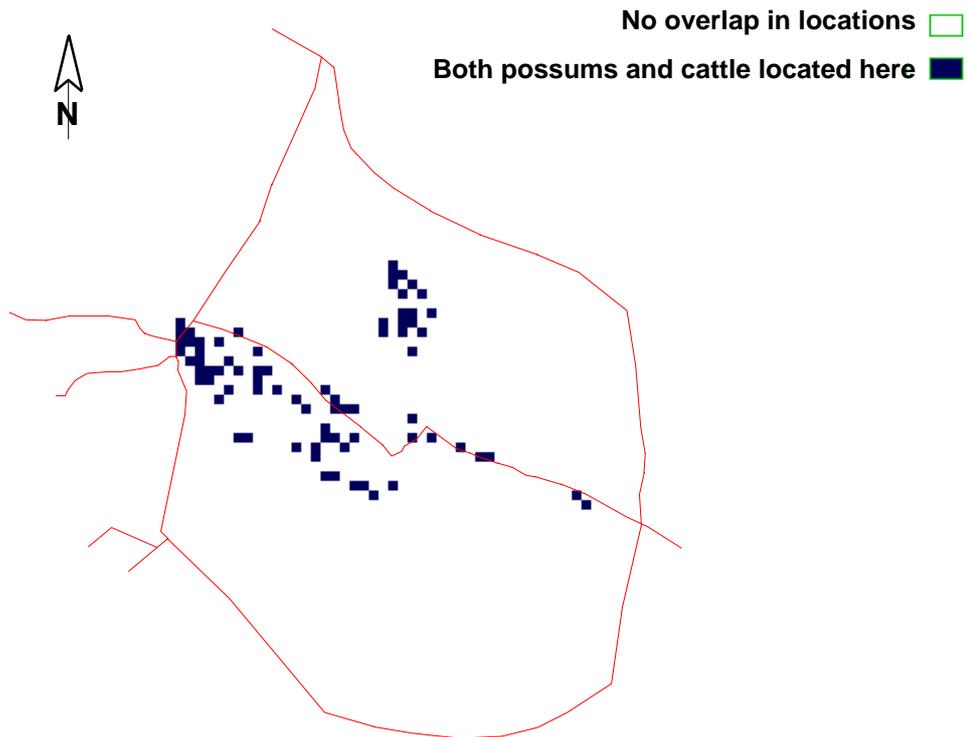
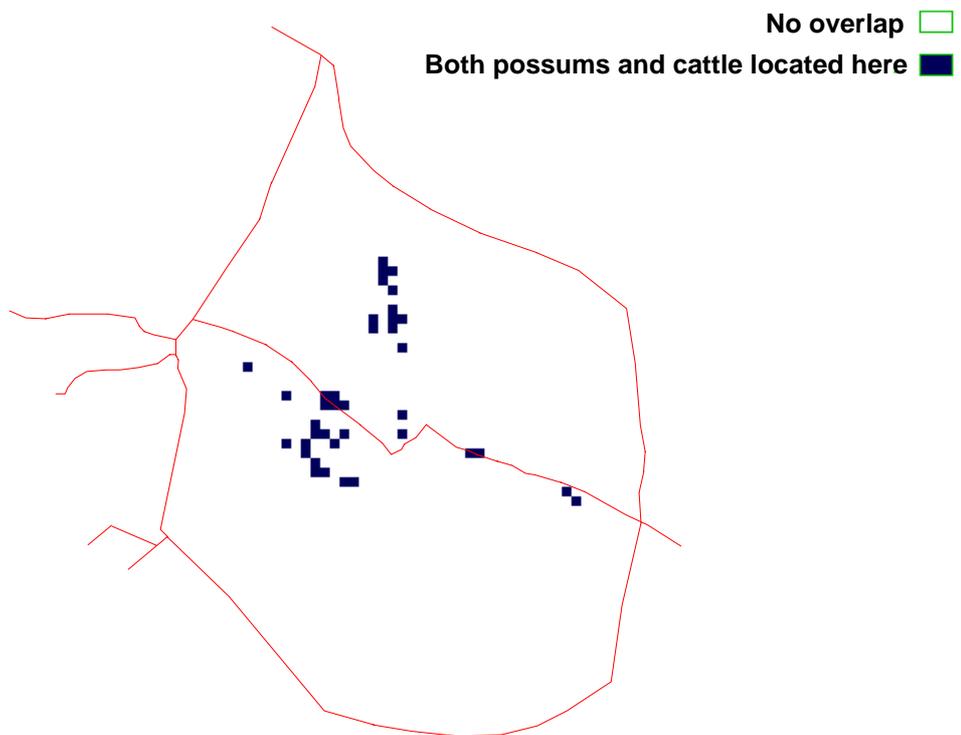


Figure 2.19 Common use of habitat by Possums and Cattle (7 possums only)



2.7. ANALYSIS OF DEN USE BY POSSUMS

2.7.1. INTRODUCTION

Den site data for possums tracked on foot as part of the longitudinal project at Castlepoint, as well as during the radio triangulation study for the period January 1991 to September 1992, was analysed. An outline of the equipment and techniques used is given in the introduction, and materials and methods sections of Chapter 2.

Not all radio-tagged possums were tracked on a regular basis, but an attempt was made to track every animal at least once a month. Possums suspected of being tuberculous were tracked every week, as were possums caught in the same area as tuberculous animal. Known den sites were not routinely checked, although they were often investigated if field staff passed close to them. Five artificial den boxes were also in the field during the study period. These were of wooden construction with a log ramp to the entrance. Although these were checked more frequently than any other 'den' location only 1 of the boxes was used by a possum during the day. However, they were frequently visited at night - see Chapter 3.

Difficult terrain and thick bush often resulted in the possum 'flushing' (fleeing from its den) before an accurate location could be determined. Several possums were particularly sensitive to noise and would flush ahead of the tracker, often quite slowly, thus leading one some distance away from the true den site before it was realised that the possum was actually moving. Den locations were physically marked (with large cattle ear tags) after sighting the animal in their den or, if the radio signal came from within a very small area (after having been circled by the tracker), dens were marked within that area. For example, if the possum was in a pile of root rakings or a burrow it was generally impossible to see the animal, but possible to circle the site and confirm the location of the signal. A quiet and successful approach to a den was frequently rewarded by being able read the possum's eartag.

Den site locations were plotted onto aerial orthophotos and digitised using Arc/info. Data was analysed in Paradox, Arc/info and Idrisi.

2.7.2. RESULTS

2.7.2.1. Den use by possums in the study area

2.7.2.1.1. Multiple use of den sites

Sixty-four possums were tracked to 209 different dens on 301 occasions from January 1991 to September 1992 (A further 7 were radio-tracked intensively - their denning behaviour is reported separately). Twenty-one of these 64 possums used the same den on at least 2 occasions, 5 possums used 2 dens on 2 or more occasions, and 5 animals used the same den at least 4 times. Of the possums that used the same den 4 times, the repeated use was spread over a 5 month period for 4 of them. The 5th possum used the same den on the 8th and 20th of August 1991, and again on the 10th and 11th of September.

There were other cases of possums returning on sequential nights to the same den, or within a few days of the previous use. Possum 2967 used den WG089 on the 7th, 10th and 11th of February 1992, possum 2987 used den BP032 on 4.12.91 and 5.12.91, possum 2950 used DD003 on the 2nd and 7th of November 1991, and possum 2855 slept in an artificial den box on the nights of the 5th to 7th of November 1991 (Tables 2.13 and 2.14)

2.7.2.1.2. Use of the same den by different possums

There were no examples of 2 possums sharing the same den at the same time - other than a female and her offspring - during the study period. However there were 2 cases of adult possums sharing a den before 1991. Excluding mother and joey den sharing, 6 dens were used by 2 different possums, and another 2 dens sequentially by 3 individuals. The minimum time between different possums using these dens was 19 days, the longest 6 months. For example, den WG050 was used by possum numbers 3724, 2462, 3724 again, and 2929, on the 10.11.91, 13.3.92, 28.4.92 and 20.12.92, respectively, and den WG003 was used by 3721, 3712 and 3537, on the 21st of July, 19th of August and 22nd of November 1991, respectively. The latter den was in the crown of a punga fern.

2.7.2.1.3. Classification of different den types

Possum den sites were grouped for analysis into those in flax bushes (commonly hollows in, or under, the base); root-rakings (piles of cut down bush, predominantly manuka); gorse bushes; burrows; and hollows in the grass (often sheltered by clumps of ferns). The latter type of den gave the appearance of providing little protection to the possum compared to the other types, and juvenile possums were commonly found in such dens in the months after they became independent. A few possums were found in trees. The majority of these were in the tops of punga ferns, some only 2 metres off the ground, others were found in the tops of cabbage trees.

Den types were used unequally. Flax bushes contained 48% of the 188 dens located and root-rakings provided a location for a further 19%. Burrows, gorse bushes, grass and trees accounted for 5%,

14%, and 8% and 6% of the dens respectively. The single artificial den box that was used by a possum amounted to less than 1% of the total. Individual possums appeared to show preferences for particular den types, but this may have been influenced by the habitat in which the possum lived. However, some possums tracked over a 4-6 month period denned almost exclusively in particular den types although alternatives were available in the same area. Possum 2216 was first tracked as a juvenile and denned in grass for about 2 months. Over the following 6 months (7 tracks) all locations were in trees, 3 of which the possum reused. Similarly possum 2462 denned almost exclusively in flax, although other den types, such as gorse, was available. The extra protection provided by the flax surrounding the hollows in the base of these bushes may have contributed to the preference for flax over gorse.

2.7.2.2. Analysis of den use by seven frequently tracked possums

Den use for 7 possums which were followed for an extended period is presented (possum numbers 2810, 2901, 2917, 2992, 3644, 3662 and 3724). The dens of these 7 animals were successfully located 84 times from February 1991 to September 1992 and 68 different dens were identified (Table 2.13). Possums were tracked on an average of 12 occasions (range 4-20) over an average 8 month period, and used an average of 10 dens (range 3-16).

Over the time these possums were tracked all of them returned to a den previously at least once. Possum 2810 reused 4 dens; 3 of them within a 4-5 week period, with 4 months between recorded reuse of the other den (Table 2.14). Possum 2917 reused 2 dens, one of these was used 4 times over a 4 month period, the gap between the last 2 occasions was 9 days. Figures 2.20a and b, and Figures 2.21a-g show surface plots of the den site locations in relation to the home ranges of the possums on the study area as a whole (Figures 2.20), and as enlarged sections of the area, centred on the individual possums home range, in Figures 2.21a-g. Five of the 7 denned within a small area of their home range throughout the tracking period (each cell on the surfaces is 30 metres by 30 metres), and the radio triangulation derived home ranges include all but 4 of the dens for these possums. The other 2 possums each had a single den which was more than 100 metres beyond the home range area, although the remainder of the dens were clustered within their home range. The dens beyond the home range of these possums (3644 and 3724) were both located before radio triangulation data was available for these animals.

Possum's numbered 2917, 3644 and 3662 were clinically tuberculous animals. Their denning patterns were generally similar to those of the non-tuberculous possums. It is not possible to tell from this data whether the latter's radio triangulated range size was affected by the progression of the disease, or the possum had moved its home range centre for other reasons before triangulation began. Possum 3662 only has 3 den sites marked although several others are known to exist for this animal. The approximate area in which these dens are located is marked on Figure 2.21f with the arrow. The area is beyond the boundaries of the study site and, as was indicated in the section on radio triangulation, bearings are inaccurate to this location. There is high bush covering the area and this

prevents identification of one's position on the aerial maps used to plot den locations. It was apparent, however, that possum 3662 had 2 major denning areas. The first, indicated on the figure, on the southern side of the northern ridge of the study site, and the second to the north of this ridge. Possum 2917 is unremarkable except that it lived in a very windy, exposed area high on the rocky spur.

2.7.2.2.1. *Distribution of dens among habitat type*

No possums in this group of 7 were found to den in trees. There was an uneven distribution of dens in each category, although this is biased by the number of dens found for each possum in a particular habitat area. Flax bushes provided 56% of the individual dens identified (38 of 68), while 25% of the dens were in root-rakings (17/68). Burrows, gorse and grass made up 3% (2), 8% (5) and 4% (3) of the dens respectively. Four percent (3 dens) were unclassified as to type. Den types used related to the home range location and its associated habitat. For example, possum 2810 was the only animal tracked to have a range centred on the southern side of the study area where there are few flax or gorse bushes. Much of this area has been cleared or opened up for pasture and possum 2810 took advantage of the many piles of root-rakings left as a result of the clearance, denning in them exclusively.

The home range of possum 2901 was centred slightly east (upstream) of the rocky spur, along the main creek draining Backdrop. The area had a range of suitable den types and the possum denned in flax, gorse, root-rakings, grass and in burrows along the creek banks, although preferring dens in flax bushes - nearly 70% of the dens were in this category. Possum number 3644 also ranged along this creek, although higher up the valley, and it used the full variety of den types listed with no clear preferences for a particular type. Number 3724 ranged over an area that was intermediate between the possums discussed in this paragraph, and those living further up the northern ridge (next paragraph). 3724 also used all the den types but appeared to have a preference for root-rakings as 40% of its dens were in this category - twice that of flax or gorse.

The other possums in this study lived on the steep northern slope of the paddock where gorse and flax were common throughout. Possums 2992 and 3662 used flax and gorse dens equally, although 3662 is poorly represented as the animal flushed easily when tracked and probably used flax dens more often than gorse when denning in the area indicated by the triangles in Figure 2.22f. When denning on the northern side of the ridge the possum was found in grass and, more commonly, gorse. The last, tuberculous, possum (2917) was tracked 20 times to 16 dens, 87% of which were in flax bushes. The possum denned in a relatively small area and there were few other available dens in this region of low stunted bush and steep slopes. Although 2917 ranged from the valley floor to the top of the north ridge, its dens were limited to a very small area of subjectively 'poor' habitat, bounded by a region with a larger number of potential dens.

Table 2.13 Den use by 7 frequently tracked possums

Possum No.	No. of dens used	No. of days tracked	Dens used per days tracked	Time period (months)
2810	9	13	0.7	8
2901	16	19	0.8	12
2917	16	20	0.8	6
2992	7	8	0.9	4
3644	7	8	0.9	4
3662	3	4	0.8	2
3724	10	12	0.8	12

Table 2.14 Dens used on more than one occasion by the possums

Possum number	Den code	Date of 1st use	Date of 2nd use	Date of 3rd use	Date of 4th use
2810	BP077	24.3.92	8.4.92		
2810	WG034	15.8.91	4.12.91		
2810	WG040	14.10.91	27.11.91		
2810	WG045	2.11.91	26.11.91		
2901	BP035	4.12.91	2.6.92		
2901	BP104	10.9.91	24.3.92		
2901	WG036	20.8.91	30.4.92		
2917	BP103	10.9.91	22.11.91	8.1.92	17.1.92
2917	WG084	28.1.92	18.2.92		
2992	WG085	28.1.92	11.2.92		
3644	THAA7	27.9.91	13.12.91		
3662	WG041	31.10.91	22.11.91		
3724	WG050	10.11.91	28.4.92		
3724	WG068	20.12.91	3.1.92		

Figure 2.20a Surface of study site indicating home ranges of 4 possums and their den sites

Note: See Figures 2.21a-g for enlarged views of the possum den locations

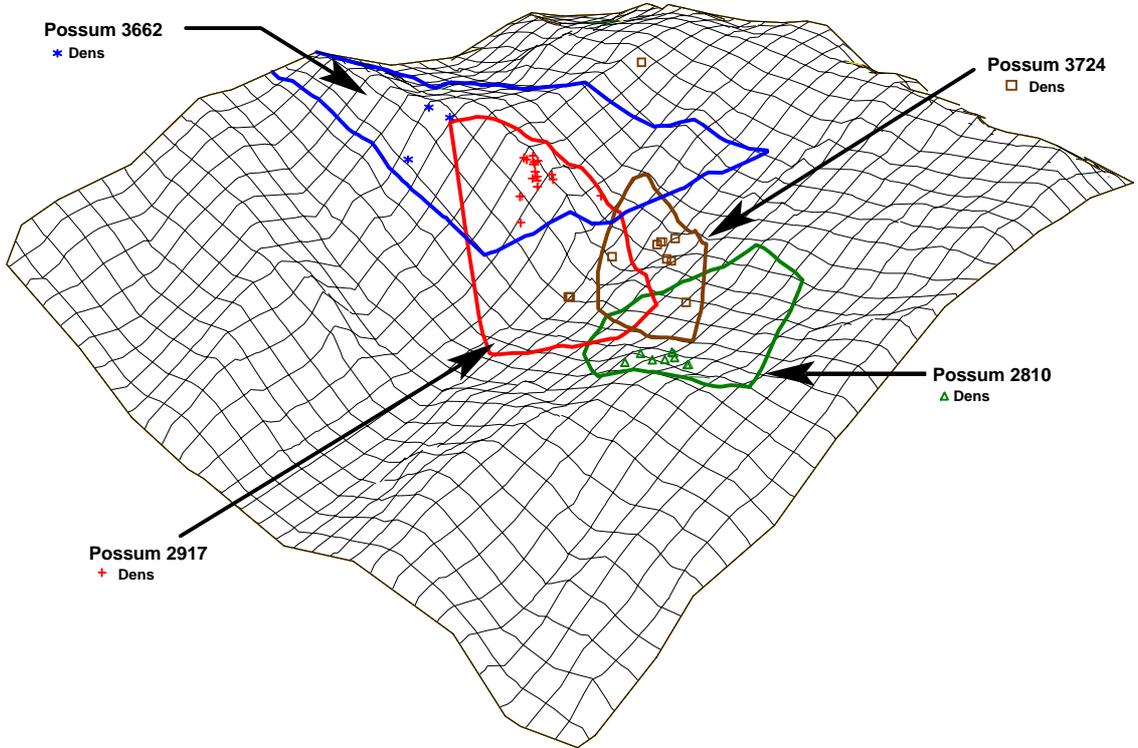


Figure 2.20b Surface of study site indicating home ranges of 3 possums and their den sites

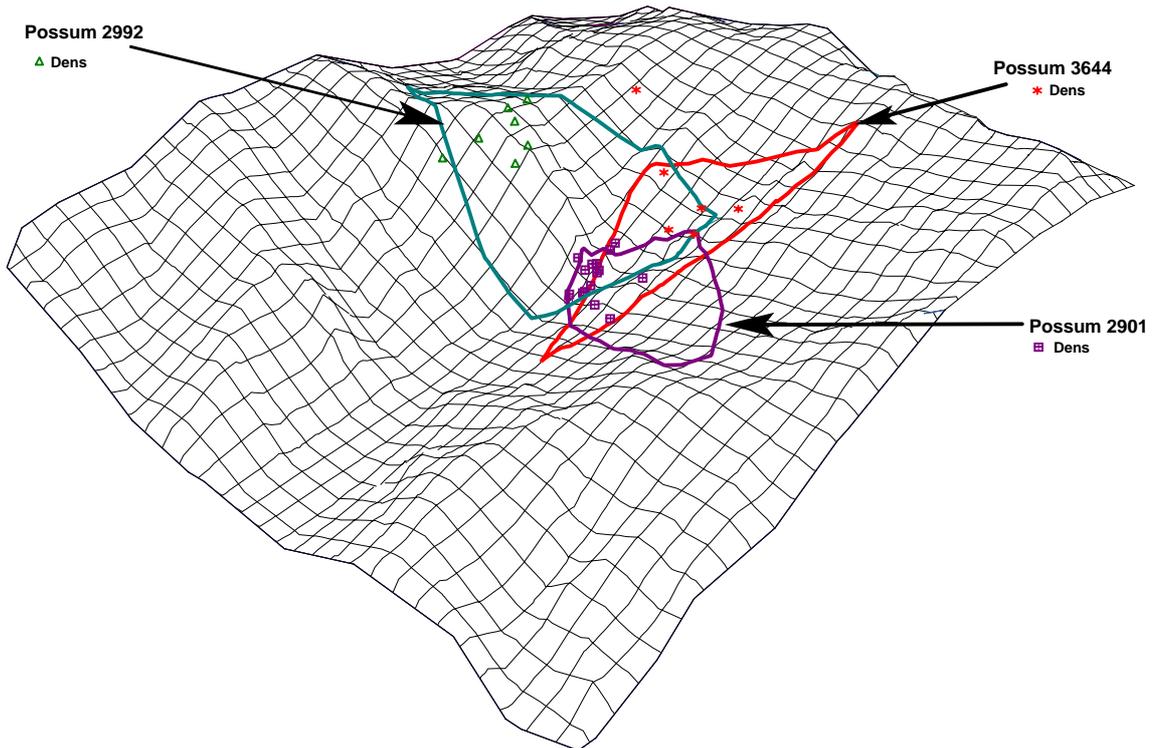


Figure 2.21a Enlarged view of home range and den site locations of possum 2810

Note: The small numbers next to some of the den markers on the figures refer to multiple use of the same den.

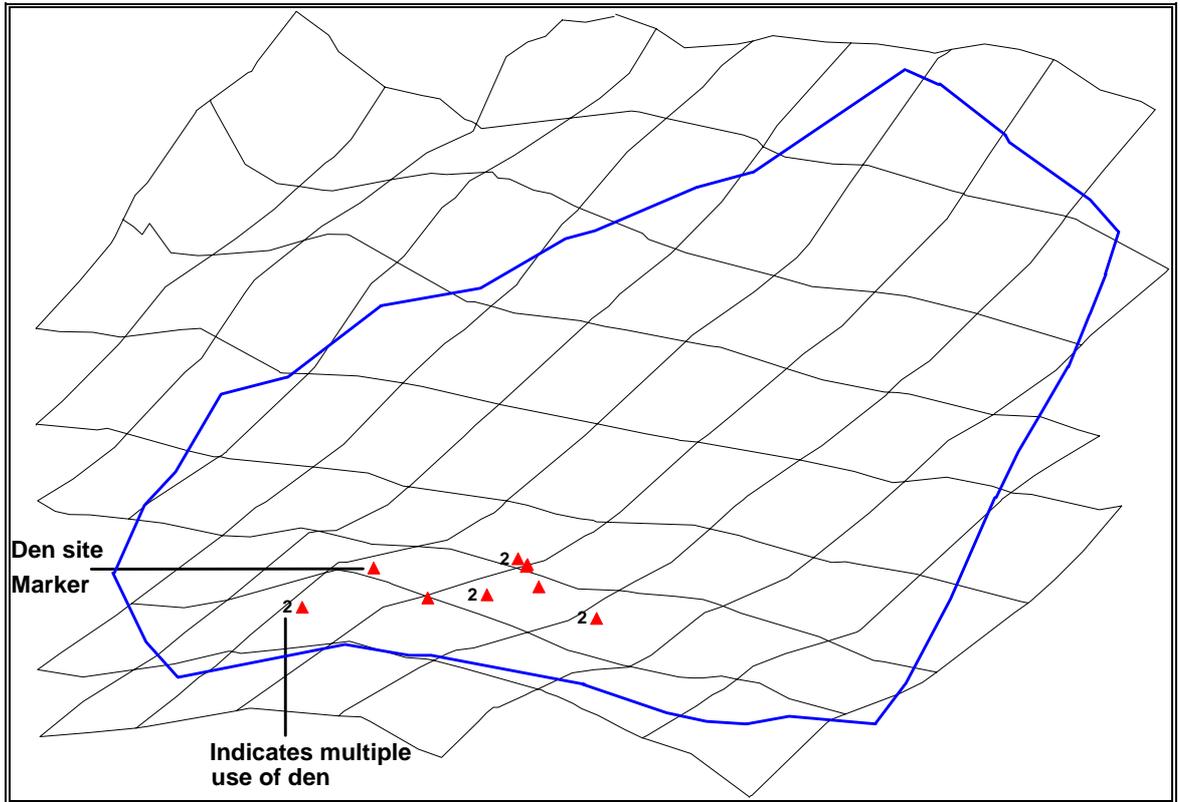


Figure 2.21b Enlarged view of home range and den site locations of possum 2901

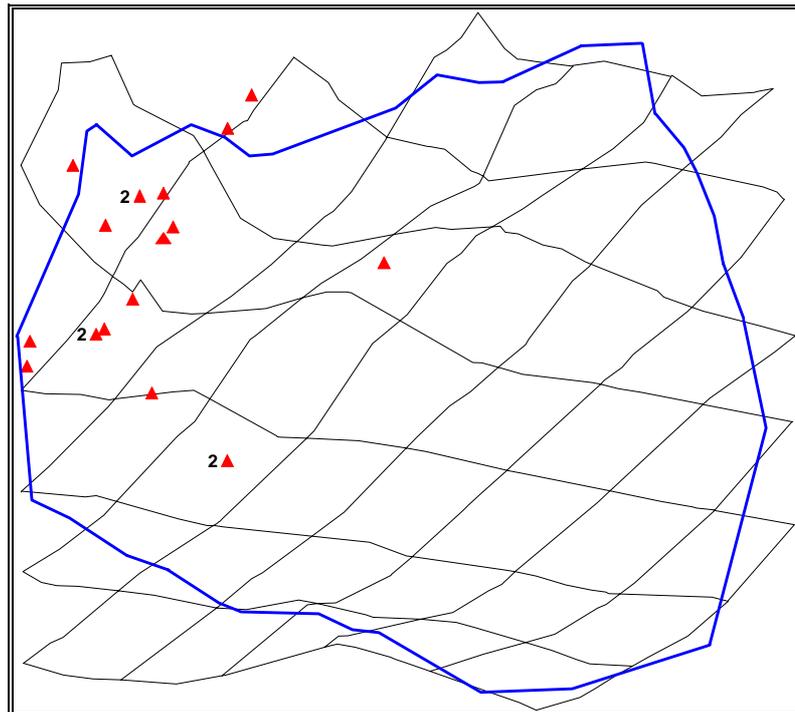


Figure 2.21c Enlarged view of home range and den site locations of possum 2917

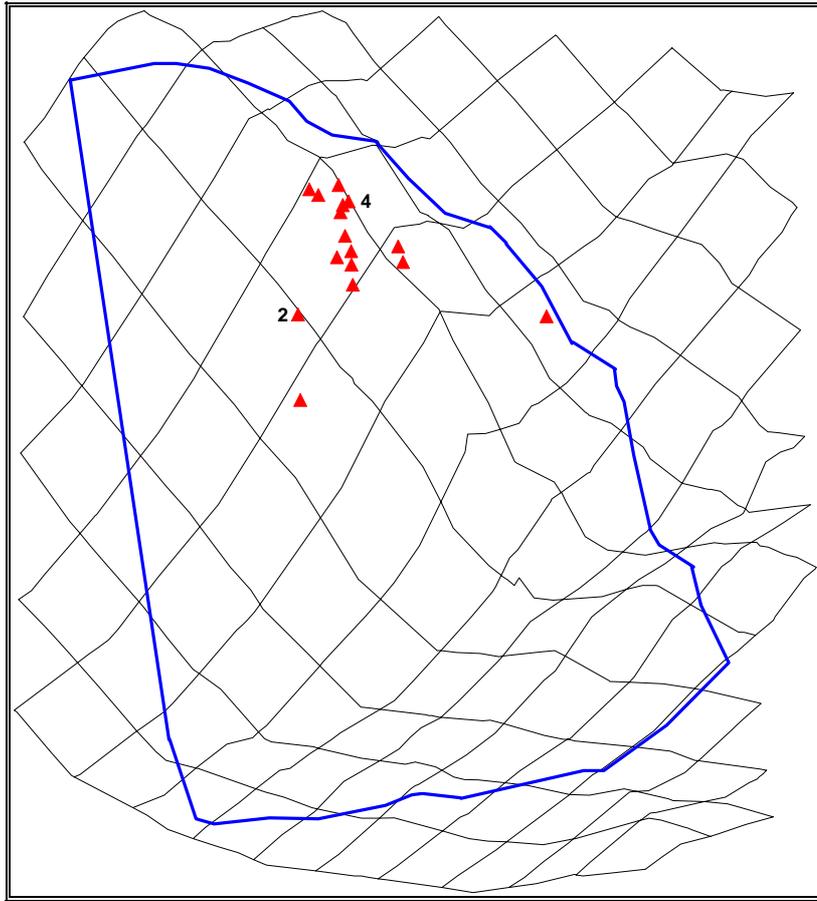


Figure 2.21d Enlarged view of home range and den site locations of possum 2992

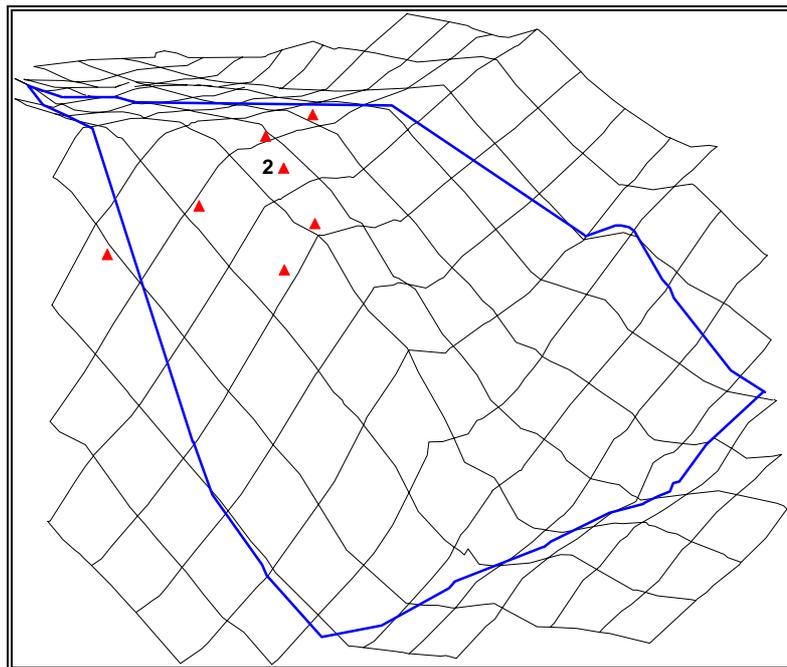


Figure 2.21e Enlarged view of home range and den site locations of possum 3644

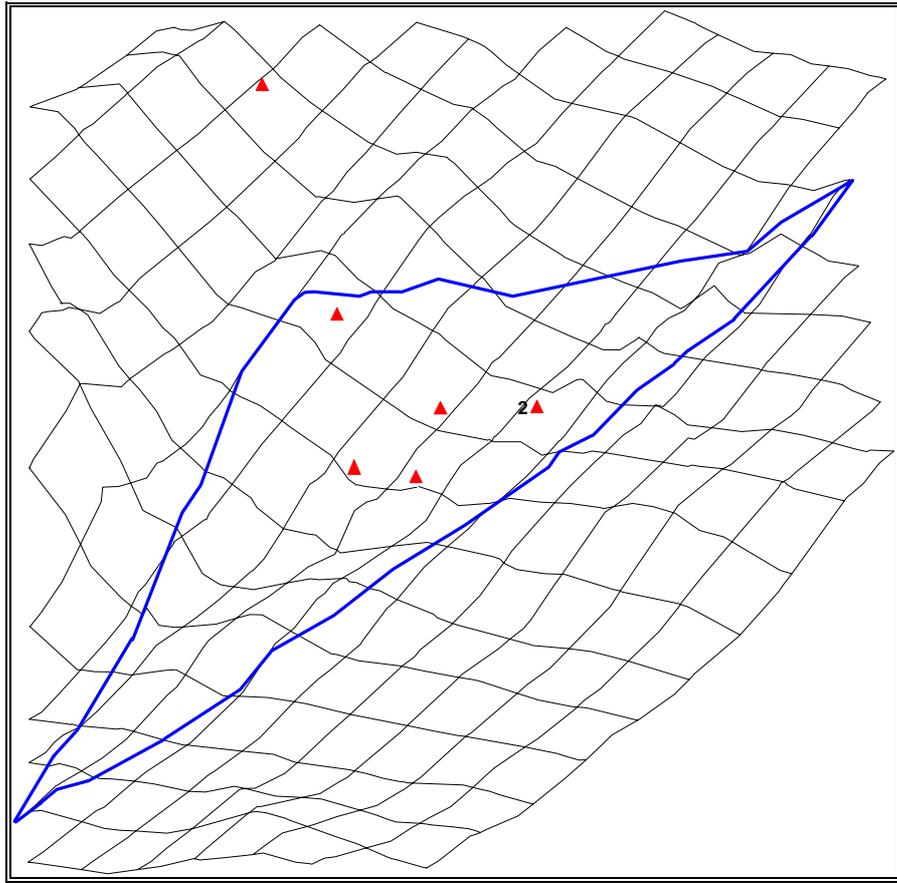


Figure 2.21f Enlarged view of home range and den site locations of possum 3662

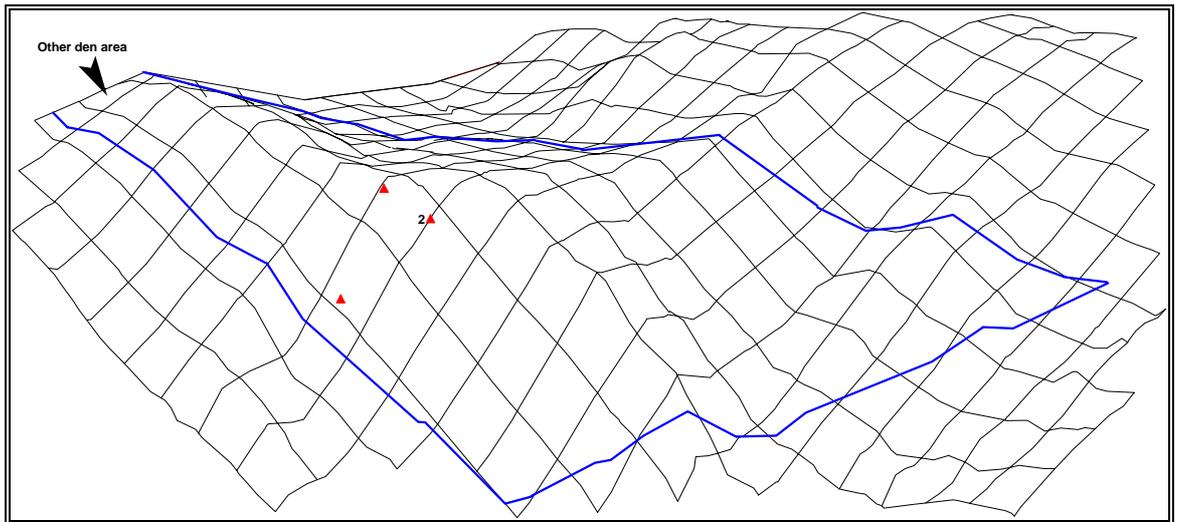
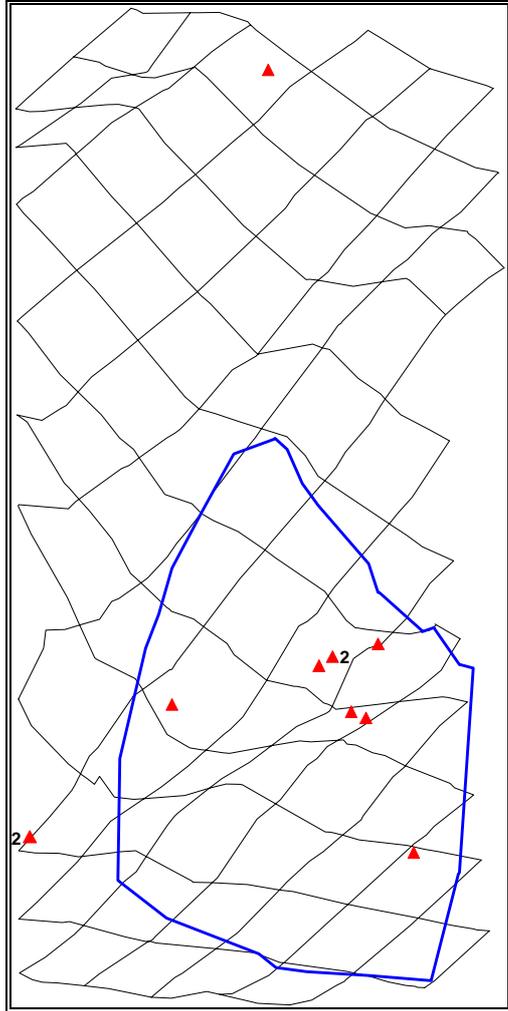


Figure 2.21g Enlarged view of home range and den site locations of possum 3724



2.8. FATES OF RADIO-TAGGED JUVENILE POSSUMS

2.8.1. RESULTS

Twenty-five juvenile possums were fitted with radio collars over a 4 month period in late 1991. Table 2.15 lists the numbers of possums tracked and comments on their fates, as of August 1992. Juvenile possums were radio-tracked to dens on more than 50 occasions. Their reactions when trackers came close were generally different from those of adults. Mature animals would flush readily if undue noise, or clumsy attempts to read their eartags, were made. They would often leave the den even after the observer had backed away, whereas the juvenile possums tended to 'freeze'. On several occasions when mother and joey were found together the adult would rapidly move off while the young flattened itself against the ground. On two occasions this enabled us to catch, and then tranquillise and examine the juveniles. The different reaction of young possums compared with older animals when tracked was also seen when possums were released from cages. Most of the cages were under or near trees and it was common for young animals - up to 12 or 18 months old - to climb a tree after release whereas adults, some of whom were more accustomed to being caught, tended to simply move away through the bush in the general direction of the denning areas.

Most of the juveniles radio tagged on the site were born around May 1991. They were ear tagged at approximately 3 months of age whilst still in the pouch and had radio collars attached when they weighed more than 1 kg (4-6 months old). Until November or December the young were often caught in cages with the mothers, or in some cases holding onto the outside of cages when the mother was trapped, and usually found sharing dens with them when tracked. After this time, when the juveniles were about 6 months old, they were generally found by themselves. Some young have remained with their mothers for at least 10 months (possums 2216 and 2210) while others separated at 4-5 months old (possum 2987 was denning alone from November).

Juveniles denning by themselves appeared to use more exposed and opportunist dens than adults. Although most combinations of shelter available in the paddock were used at some time by adults, most dens are under old gorse bushes, in hollows at the bases of flax bushes, and under piles of cut down manuka. Independent juveniles were often found in clumps of ferns or thick grass particularly in high use denning areas. There was partial overhead protection but the floor of these 'dens' was often damp or wet. This was probably one of the factors contributing to the deaths of 36% of tagged juveniles over 10 months (9 of 25). In comparison 3 of 23 radio-tagged adults died - 2 of those due to TB.

Table 2.15 Radio-tagged Juvenile Possums - April 1991- August 1992

Possum No.	Sex	Fate (8/92)	Comment
2206	F	Alive	Still being trapped in same area as when first tagged.
2210	F	Alive	Still being trapped in same area as when first tagged. Trapped with Dam in May 1992
2896	F	Alive	Still being trapped in same area as when first tagged.
2979	F	Alive	Still being trapped in same area as when first tagged.
2988	F	Dead?	Radio collar found buried in creek after flood. No sign of possum but not caught for 6 weeks - probably dead.
2989	F	Dead	Partly eaten remains found near trapline in April 1992. Cause of death unknown.
2991	F	Alive	Still being trapped in same area as when first tagged. Had pouch joey in May 1992 - at 10 months old
2996	F	Alive	Still being trapped in same area as when first tagged.
2216	M	Alive	Possum lives outside trapping area. Caught every 2-3 months. With dam until May 1992, and now denning near her in pines.
2285	M	Alive	Still being trapped in same area as when first tagged.
2299	M	Alive	Still being trapped in same area as when first tagged.
2878	M	Dead	Found dead in area where normally caught - May 1992. Cause of death unknown
2890	M	Alive	Still being trapped in same area as when first tagged.
2891	M	Dead	Regularly trapped in same area until March 1992. Found dead in debris in creek in April 1992
2894	M	Alive	Still being trapped in same area as when first tagged.
2897	M	Alive	Still being trapped in same area as when first tagged.
2898	M	Alive	Still being trapped in same area as when first tagged.
2969	M	Alive	Still being trapped in same area as when first tagged. There was a break between first capture in September 1991 and next capture in March 1992
2971	M	Dead	Died in November 1991 - carcass decomposing
2985	F	Dead	Dead December 1992 - caught on tree branch by collar
2987	M	Dead	Dispersed in January 1992. Remained in new area until death (starvation & exposure?) in June 1992
2990	M	Alive	Still being trapped in same area as when first tagged.
2992	M	Dead	Dam was tuberculous - Juvenile died of TB in April 1992 on edge of normal range area
2993	M	Dead	Dispersed in January 1992. Possibly killed by dog in May 1992
3000	M	Alive	Still being trapped in same area as when first tagged.

Figure 2.22 Map of Waio Station and dispersal from study site

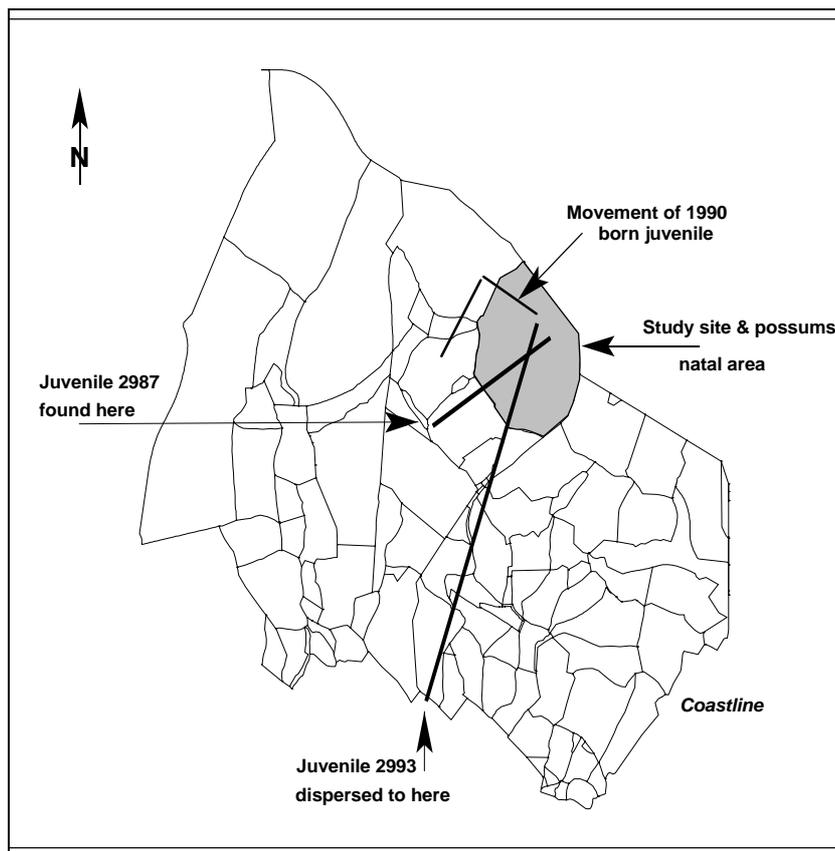


Figure 2.22 shows the final locations of 2 juveniles that dispersed in January 1992. These 2 were the only juveniles studied that moved permanently out of the study site. Of other possums in the area a young adult male (born in 1990) made several large scale movements in February and May 1992. This animal moved around the western side of the study area and spent several weeks on

the periphery of the trapped area (above punga gully), until moving 500 metres across a valley into bush on the next ridge. Two months later the possum came back to the north-western edge of the study site.

The 2 juveniles which dispersed, numbers 2993 and 2987, moved 2200 and 980 m respectively (straight line ground distances). Efford (1991) in a review of 69 recorded dispersals found median dispersal distances of 5.5 km for females and 3.7 for male, although most of his 'long-distance' dispersals were less than 5 km. The mode of the distribution of dispersal distance of males in Efford's (1991) review was 2-2.9 km and there were several records of possums moving only 1-2 km. The comparatively short dispersal distance of the Castlepoint possums may be accounted for by the 6-month period of observation, only 2 of 25 animals moving and that both possums died in early winter. However, the average home range of possums in the study area is 1.5 ha. This contrasts with 12 ha home range for possums living in swampy areas at Bridge Pa, Hawkes Bay (Brockie, 1987) and the range length of 1.5 km found for some possums on Mt Bryan O'Lynn, Westland (Brockie *et al.*, 1980). Differences in habitat and population density are also likely to affect the extent of dispersal movements; for example triangulation and observation data indicate possums on the site move down the hillside 100-150 metres to feed on pasture, with only occasional long distance movements to preferred foods such as pine pollen.

The eventual location of both dispersers from the site was south-east of their natal area. This contrasts with other possums known to have moved from the area over the past 3 years (3 animals) which have all moved in a northerly direction (pers.comm. D. Pfeiffer). A general east-north-easterly pattern of movement was also noted by Efford (1991). The rate and direction of travel for possum 2987 is unknown but it made several long distance movements south along the northern ridgeline, each time returning to its original denning area, before the possum dispersed. An assumption that possums would move north led to a delay in relocating the signals. When it was relocated, 2987 was living in a mass of bulrushes at the head of a narrow valley, which effectively masked the radio signal from many directions. The possum was also found to den in the fork of a large macrocarpa tree less than 1 m off the ground. Persistent rain through late April and May prevented trackers from visually locating the possum and when finally tracked to its den the possum was found, still in the rushes, but dead. Brockie (1987) noted the loss of one third of tagged animals from a swamp at Bridge Pa after a flood, most of which apparently drowned near their dens. It is likely that a similar fate befell this animal.

Possum 2993 dispersed some distance 1-2 nights after last being confirmed in the paddock (assumption after loss of radio signal). The movements of this animal can only be surmised but sufficient bush cover exists for the possum to have made an almost straight line movement to where it was found denning close to a road bridge across a large stream. Once relocated this possum spent 3-4 weeks denning in vines in a tree and on the ground among lilies, then moved across a road (and the stream) to den in hawthorn hedges and woodpiles until apparently run over, but not killed, by a car. The car was travelling slowly on a farm road, and witnesses noted the radio aerial before the car went over the possum. The animal ran off and was later located in a hedge. Ten days later the radio plus a large amount of matted fur and dry skin was found lying in the open, 5 m from the hedge. It is probable, whether due to its injuries or for other reasons, that the possum died and the carcass was eaten, probably by a dog, sometime during the previous 5-7 days. Unfortunately no positive identification of the remains was possible. Both this possum and 2987 were captured by hand and examined under sedation in April 1992. Their weights were above average compared to those in the study area at the time and they appeared in excellent condition.

2.9. DISCUSSION

The possums studied represented animals from a variety of locations within the study area, and of varying ages and health status. It is apparent that there are areas within the site that are used more extensively than others by the possum population. There is considerable overlap between animals in the areas through which they moved, and the denning areas of many animals were in a narrow band below the northern ridgeline. Although the area over which an individual moves in any one night varies, the home range of the majority of animals was relatively fixed, as has been described in other reports (Ward, 1978; Brockie *et al.*, 1987; Winter, 1976). Home range size also varied widely between individuals and, in this small study, some tuberculous animals were found to have considerably larger home ranges than healthy individuals. It is interesting to speculate whether the large ranges of some of these animals is a factor in the transmission of the disease. The fidelity of many of the possums to a particular area is noted, as has been found in other possum populations (Winter, 1976; Ward, 1978 and 1984; Jolly, 1976b), but so too are the occasional large scale movements of some individuals.

A similar relationship between sex and home range size, described by Winter (1976), Jolly (1976b) and Ward (1978), was found in this area. Females had smaller nightly activity areas and overall home ranges, relative to males, throughout the year. Long range movements to food resources were not specifically identified in this study, but there were significant variations in mean seasonal activity areas, in relation to the breeding season (Jolly, 1976b). Activity varied seasonally, decreased as dawn approached, and decreased also in strong winds and heavy rain. Jolly (1976b) found similar patterns, while Brockie (1987) indicated heavy frosts caused animals to return to their dens, whereas wind strength had no effect. The small areas of pasture scattered within the bush would have allowed the possums to feed under cover on windy nights, hence the lack of sightings in visual observation work.

There is a dearth of detailed literature on the denning habits of possums in New Zealand. Unlike Australia, where the majority of possums den in hollows in tree trunks and branches and can be easily seen (Winter, 1976), New Zealand's forest trees are often covered with epiphytes and surrounded by thick bush, making it difficult to identify precise den sites. In the scrubby environment which provides much of their habitat in New Zealand, possums also den on the ground, adding to the variety of potential den sites (Brockie *et al.*, 1987 and Brockie, 1991). The studies which have investigated possum denning habits indicate the adaptability of the possum. In lowland forest, with an abundance of standing trees covered with epiphytes, possums preferred to den above ground in trees - in the epiphyte bunches, although some may have been in holes in the tree itself (Cowan, 1989; Ward, 1978). Identification of the precise location of den sites was not possible in the latter studies. Green and Coleman (1987) studied possum dens in mixed hardwood forest in Westland where there were few epiphyte bearing trees. They found 73% of den sites located at, or below, ground level, with 44% of these in standing and fallen dead trees. In another study in a

different type of habitat, Brockie *et al.* (1987), found possums denning in fallen logs, clumps of flax, grass, blackberries and raupo, and in cabbage trees, in an area of open pasture surrounding a scrub-filled swamp. The results of the present thesis study concur with the findings of these studies in that possums make use of the available den sites in a particular area. This investigator, as have others reported in this paragraph, found possums to use a variety of dens over time, with some animals returning to the same den repeatedly. It is apparent that habitat plays an important role in the number of dens used by individuals in a possum population. In Cowan's 1989 study there were many apparently suitable den sites not used by possums such as fallen logs, yet the possums at Brockie's site utilised this type of den in the absence of large upright trees. Possum densities in the latter area were also considerably higher.

Ward (1978) found that den sites were usually on the periphery of a possum's nightly range. There was insufficient data to study such a factor in this study, but 4 of the 7 possums dens clustered on the periphery of their yearly home ranges. Two possums denned in the central part of their ranges, while the last - 3662 - was known to have 2 separate denning areas in the upper part of its range. Again this pattern may be explained by the nature of the Castlepoint site - a relative lack of denning areas in the lower parts of the site where the possums grazed pasture, with an abundance of sites on the upper slopes of the paddock. The preferences shown by some possums for particular den sites, particularly flax, may have some significance in control operations where such habitat predominates. However, as many other possums in the same area used alternative dens as readily as flax bushes, and those in regions lacking significant flax used root-rakings and gorse bushes, the adaptability of the possum would likely defeat the purpose of limited habitat modification.

The study of cattle in relation to possum movements has not been previously documented, and the results from this study are disappointing in that respect. The topology, man-made restrictions in the area, and natural tendency for cattle to remain in a social group overnight, restricted the movements of cattle within the site. It is evident however, that the cattle, given the opportunity, would range throughout the site into areas of high possum density, both in terms of dens, and high use feeding locations. Long distance movements of some individuals were noted over several nights.

The overlap pattern seen between possums and cattle is affected by the home ranges of the possums selected to track. However, the pattern is likely to be an accurate indication of the extent of overlap between the species in this area, as few possums den on the southern side of the paddock. Possums return to dens in the same area as those they left the previous night, and have ranges which remain constant over long periods of time. They do make extended forays beyond this standard area but these are generally for particular reasons, such as for food or mates. Similarly, cattle were found to use some areas of the paddock more commonly than others. It may be possible to target control measures, such as poison drops, bait stations or trapping efforts, more effectively in such areas, and to carry them out at times which maximise the benefits of the operations.

Dispersal of juvenile animals from natal territories is a common phenomenon in both birds and mammals. It is more common among male mammals, but the sex bias varies between species (Greenwood, 1980; Dobson, 1982). The precipitating reasons why young of many species disperse is unclear and causes are likely to vary between species. Aggression from conspecifics (Pusey, 1987), hormonal changes related to sexual maturation, population density and instinctive pressures to migrate in the absence of identifiable reasons (Harris and Trewhalla, 1988) have all been indicated as possible causes in one or more species. The tendency for immature possums to migrate has been of some concern in the control of tuberculosis. Cowan and Rhodes (cited in Efford pg 49, 1991) reported 19-22% of radio tagged individuals dispersed from a King Country study area and similar figures were described by Ward (1985) and Brockie (1991). Brockie's site contained both open pasture and swamp land with willows. He found more animals left open areas than the swamps and suggested the latter as being more favourable habitat with a higher potential carrying capacity. A similar situation exists at Castlepoint. Although relatively few large trees persist in the area there are large patches of gorse, many pine trees and small patches of grasses and herbs throughout the manuka/mingimingi predominant bush, as well as open pasture on the developed side of the paddock. Den sites abound, although some were used more often than others. Home ranges of these possums are much smaller than those found in Hawkes Bay (Brockie, 1987) and slightly larger on average than in the dense lowland forest of Orongorongo near Wellington.

Of the 25 juvenile possums radio tagged, 7 (28%), died within 10 months still in their natal home range. Two animals, 8% of the total, dispersed and subsequently died. Continued monitoring of other possums within this cohort will determine if more disperse at a later date, but it is possible that this population has not yet reached full carrying capacity, and/or natural turnover in this population allows many of the surviving juveniles to establish adult home ranges within their natal area. There is some evidence that dispersal of 1-2 year old animals may also be common. Keber (cited in Efford, 1991) noted dispersal of this age group and in the Bay of Islands Little and Cowan (1991) found most of the possums moving onto an island, connected to the mainland by a narrow causeway, were 1-2 years old, and at a nearly 50:50 sex ratio.

Most possums in New Zealand disperse between February and June, as did the juveniles born in 1991, and the possum from 1990. Hence the risk of dispersal of individuals from tuberculous possum populations is greatest at certain times of the year and the nature and extent of that dispersal may be dependent on factors which vary between season and habitat. The pressures on individuals to disperse as a result of population density, carrying capacity or innate urge to relocate require more extensive studies in a variety of habitats commonly used by possums. Long-term monitoring of individuals is often difficult, but essential, as effective control of populations will require that these aspects of population dynamics and distribution be taken into consideration.

Radio-telemetry was a useful addition to the techniques used to study this possum population. The ability to determine the movements of individuals about the study site, and track them to their den sites over a period of time, enabled more accurate determination of the structure of the population than that obtained from trapping data alone (see appendix VI). Although direct interactions between cattle and possums were not seen, the overlay of activity and home range areas demonstrates the shared use of a habitat. Deficiencies in the resolution of radio triangulation systems can be improved by the use of more tracking stations and analysis of the study area to better position tracking towers. Man-made obstacles, such as fences preventing animal access to an area, are more difficult to surmount, as are the costs of detailed and long term tracking studies.

Chapter 3

An Observational Study of Possums in a Bush-Pasture Habitat

3.1. INTRODUCTION

The possum is one of the most intensively studied marsupials. The small size of the animal, combined with ease of capture and a general acceptance of captivity allow it to be readily worked with. Although much is known of the animal's reproductive biology, habitat use and diet, there have been few quantitative studies of the possum's social behaviour and interactions with other species in its environment, particularly in New Zealand (Brockie *et al.*, pg 23, 1984). Captive animals have been observed, but studies of animals in their natural habitats are also essential, as caged possums may show a biased or incomplete behavioural repertoire possibly due to environmental deprivation, or as a result of being in captivity (Kaufmann and Kaufmann, 1963; Biggins, 1984; Biggins and Overstreet, 1978).

In their native Australia, the open canopy of the eucalypt forests allow relatively easy observations of possum behaviour, even at night (Winter, 1976; MacLennan, 1984; Dunnet, 1964). In New Zealand's more densely forested habitats, severely reduced visibility, and difficulty in moving through the bush, make it considerably harder to observe possum behaviour. Live-trapping studies of possums have been most common - notably the Orongorongo project near Wellington, and at Bridge Pa in Hawkes Bay (see authors; Bell, Brockie, Clout, Cowan, Crawley, Efford, Hickling, Kean, Pracy, Tyndale-Biscoe, and Ward, among others), although captive possums have been, and are, kept at several places in New Zealand (Kean, 1967; Brockie *et al.*, 1984). Radio-tracking has become a common feature of live-trapping studies and is used to track possums to den sites, and to determine home ranges. Many other similar projects, as well as kill-trapping studies, have been completed, or are underway (Brockie *et al.*, 1984; Livingstone, 1991). These studies provide information on population dynamics, reproduction, possum activity and movement patterns, dispersal of animals, den site use and preferences, and indications of the effect of poison control operations on possum populations. However, few direct behavioural observations can be made, and the nature of the studies often isolate the possum from factors important in disease transmission. They do not examine behavioural interactions between individual possums, or between possums and other species. Neither can aspects of behaviour influenced by environmental factors (such as season, weather, and availability of food), or the effects of diseases (such as tuberculosis) be easily assessed.

The aim of the work in this chapter was to describe and quantify specific behavioural patterns of, and particularly interactions between, possums and cattle at the bush-pasture margin and on open pasture, that may influence the spread of tuberculosis. Observation of animals in their natural environment was the primary method of study, although some studies of artificially induced interactions between cattle and possums were also done. These are reported in Chapter 4.

3.2. MATERIALS AND METHODS

3.2.1. Study Area

The choice of locations from which to observe possums was limited by the topography of the area. There are few areas with more than 20-30 metres unrestricted visibility on the study site, and the steepness of the terrain limits access to, and hide construction in, many areas. A permanent hide was necessary for protection from the weather, and finding a location suitable for this where possums and cattle were both likely to be found was the first priority. A previous survey in the area in February 1990 (Cowan and Hickling, 1990) indicated the difficulties of observing animals in the lower part of the paddock due to the numbers of trees and dissected topography. However, scans every 5 minutes generally found 2-3 possums in the area until 0100 hours over each of 3 nights. Cattle from the group kept in the paddock were also in the vicinity, although apparently more interested in the observers than the possums. Further casual observations in the lower paddock showed that many possums fed there, although the average time for animals to move across the 20-30 m wide area of pasture was only 10-15 minutes. Possums were seen in many of the 5-12 metre high manuka trees dotted over the pasture, and also in trees surrounding the area. Several of these animals stayed in the branches for more than 1½ hours. Possums were often seen on the periphery of the area just within the thicker bush along the edges of 2 creeks which ran down either side of the pasture. In other parts of the paddock bush and trees limited visibility, although possums were seen throughout the entire site.

All of the areas where the cattle camped at night, except one, were unsuitable for prolonged observations. The cattle generally camped at one of 3 locations below the eastern ridgeline, and several of the cattle were likely to move during the night (see Chapter 2, radio triangulation results). The camps were close to bush, but with limited visibility, and few possums were observed in the areas. During inclement weather, particularly high winds, the cattle often moved into the bush cover, further restricting observations. Cattle were also more easily disturbed at night, although generally moving rapidly away, they could in some cases also show intense interest in the observers' activities. The most suitable area for observations was the bottom of the paddock, although it is the lowest point in the paddock, subject to strong winds, and the cattle only occasionally camped in this area. However, the erection of a fence down the centre of the paddock also made it more practicable to pen cattle in the lower part of the paddock if necessary.

As it appeared from both night observations and trap-catch data that a reasonable number of possums used the area, a permanent hide was constructed in the narrow neck at the bottom of backdrop paddock. This gave an observation area of 60m x 40m, which had bush on the southern edge, an increasing number of trees on the eastern boundary where the ground began to rise up the valley, and on the north a fence 2-3m from the edge of the main creek draining the valley. The creek banks ended a few metres before the fence across the bottom (west) of the paddock. Outside of Backdrop paddock a wedge shaped field opened out with dense bush on the northern slopes and scattered bush in a steeply rising developed paddock to the south (Figures 3.1, 3.2 and appendix IV).

3.2.2. Possum Observations

A frame of 5-metre tall steel scaffolding with a floor at 4 metres, a corrugated iron covered roof and back (facing the west) and an open front was built. The sides were covered to $\frac{3}{4}$ height allowing visibility of 300° around the hide (Figure 3.2). Geographical features were used to divide the observation area into 3 regions as seen from the hide. To the left was an area along the fence-line and extending into the paddock 10-15m down a slope to where a small creek made a natural boundary. This area was wedge shaped with the wide end opening out to the east (up the valley) and included a stand of trees with poorer quality pasture and shrubs under them. The central region extended 30m further across and included the better pasture in the area. The region to the right was a small 10-15m wide terrace slightly raised above the central region. It began on the edge of an old stream bank and included the edge of the bush on the southern margin.

Observations of the possums were made through an image intensifying night-scope fitted with a Tokina™ 70-210 35 mm SLR lens and a 2x teleconverter. Binoculars were also used particularly when making observations in other areas of the paddock. Few observation nights coincided with a full moon, and despite the light gathering abilities of the night-scope it was almost always necessary to use supplemental lighting in the area. Two high density, 12 volt, lead acid batteries supplied power for two 50 watt spotlights mounted on the fence below the hide, and a moveable 100 watt tripod mounted spot, on the observation platform. Smaller gel-cell rechargeable batteries, carried in a back-pack, powered a 30 watt hand-held spotlight when moving around the site on foot. Lights were covered with orange or red cellophane to minimise disturbance to the possums. The high power light was fitted with a red filter and was used when filming the possums. If care was taken to use the edge of the beam few possums were disturbed by the light.

Observations were recorded on a check sheet supplemented with a voice-activated tape-recorder. Possums were filmed using an 8 mm Sony™ camcorder. Data was analysed using Statistix, Paradox and the Observer⁸ (The Observer, 1990) programs. Behaviours recorded were as follows:

1. Feeding - possums eating pasture. Many animals slowly moved about the paddock as they ate. This was recorded separately from stationary feeding, where possums fed in one place for a time and then moved to another location to resume feeding
2. Sitting - animals resting on ground (seldom) or in trees.
3. Movement - across area, distinct from moving while feeding.
4. Interactions - these are defined as vocalisations, grooming, agonistic interaction with other animals, and scent marking
5. Alert reactions - adoption of the alert posture was very common, but was seldom linked to any particular stimulus. If the stimulus appeared to be caused by myself, or the lights, it was excluded from the results

⁸A behavioural data-collection and analysis package

6. Contacts - regular scan of the area to note number of animals and distances between them and the focal animal

The initial recording system followed an individual possum for a maximum of 20 minutes or until that animal was lost to sight, and then switched to another animal. Animals selected for observation were those that were closest to a selected point on the fence-line through which many of them moved to feed on the pasture. A record of current behaviour was noted every 10 seconds, and a scan of the entire observation area was made every 5 minutes noting the number and species of animals present and their locations relative to the focal animal. Possums were seldom individually identified during observation. Several animals fitted with neck collars with reflective tape on an aerial, and those possums with radio collars, could be identified, but, except for 1 animal regularly seen feeding in the area such attempts at individual identification produced little return. The high intensity of 10 second sampling and the evident lack of variation in possum activity on the pasture led to a change in recording method to observations every 30 seconds and following of the focal animal until it was lost to sight without a maximum time limit. The intervening time was used to observe other animals.

3.2.2.1. Observations made through the study area

Regular walks were made through the site at night to observe possums in other areas of the site. Rough terrain prevented me from following possums as they moved through parts of the site, particularly from their denning areas, as they generally moved vertically up and down the steep hillside. Using a small spotlight and recording comments as I went, most parts of the paddock were visited over a 12-month period, concentrating on locations where the cattle were camping, along the bush margins where there were heavily used possum runs, and on possum den sites. Possum activity in den sites was difficult to observe, mainly due to restricted visibility. Although it was a simple matter to track radio tagged animals to their dens and set up equipment to observe the possum, and on many occasions see the individual emerge from the den, no animal was ever seen to return to an observed den. This was not unexpected as possums were known to use multiple dens and the presence of an observer, and sight and smell of equipment probably caused animals to subsequently avoid the den. Possums were heard moving and making noises close to the sites chosen, but none were seen due to thick bush in the area.

Figure 3.1 Main observation area - from above southern boundary



Figure 3.2 View of observation tower and area - looking east



3.3. RESULTS

3.3.1. Observation periods and weather conditions

Four hundred and fifty-one hours of observations were spread over 50 nights between October 1990 and April 1992. Just over half of that time was spent observing possums from the observation hide. Observations were spread through most of the year except for January and June. At least 3 nights observations were completed each month, except May to July 1991 when bad weather prevented, or stopped, several nights work. Observations were made in all types of weather except snow. If weather conditions on each night were divided into one of 4 classes (fine weather, drizzly overcast conditions, rain, or strong winds), where the predominant condition persisted for more than ½ of the night, there were 168, 154, 51 and 78 hours of observations in each class, respectively. Temperatures varied from near zero to 12-14°C with a minimum between 0200 and 0400 hours. Rainfall was not measured but on the worst nights was sufficient to fill a 7 cm deep thermos flask cup in under an hour. A night was classed as raining when water continually fell through the canopy and it remained dripping for several hours afterwards (the canopy in Backdrop was not thick). Drizzly weather was when there was occasional rain overnight without persistent rainfall through the canopy. Wind was common in the area and gusts of more than 125 km/hr were recorded during the study period. Strong north-westerly winds sometimes blew for days at a time and maintained speeds of 60-80 km/hr for several hours. Wind conditions such as these prevented one safely getting to the study area, let alone observing possums from 4 m up!

3.3.2. Activity of possums on pasture

Possums generally moved down the northern hillside from their dens and across a creek at its base along a relatively few well-worn tracks. When the grass was long, the exit points from the creek were obvious where possums climbed a 2-3 m bank. Along a 50-60 m stretch of grass (2-6 m wide) between the fence and the bank, 4-5 well worn tracks were seen year round. The fence was of 15 cm square netting, and although possums were seen to go *back* through other points in the netting, most of the observed animals came in through only 2 or 3 of the 15-cm square gaps (at ground level). Possum tracks became indistinguishable 1-2 m into the paddock as individuals moved in different directions to feed. Trees and bushes restricted visibility to less than 40-50 m up the paddock, and although possums were commonly seen beyond this distance, difficulties in determining their activities meant that these possums were not included in analyses. It was apparent, however, that many possums were feeding on pasture in that area and several animals subsequently moved down into the observation area proper.

3.3.2.1. *Movements about, and numbers of possums in, the observation area*

A consistent pattern of movement across the observation area was noted. Ninety-five percent of the possums seen approached through the fence on the left. The remaining 5% included animals that had either moved completely across the area, or had circled around the top of the pasture and were

moving back through the area. Also included are possums coming into the observation area from the paddock to the west, or the few animals that denned on the southern slopes and were moving down to feed. Most possums spent the majority of their time feeding in one of the areas. Two possums that could be reliably identified, and were regularly observed, appeared to have preferred feeding areas. One, a young adult male with an identification collar, generally entered the area from further up the paddock. It spent 82% of the time it was observed in the top part of the left region, feeding under or near the trees. The rest of its movements for the night usually led it across the upper part of the central region and into the bush. This pattern was repeated on 10 nights over 8 months. The second animal was a black possum with a white tipped tail, that spent more than 70% of the time it was scanned in the left region of the observation area. It usually moved gradually down the area and often went out into the paddock to the west, and fed along the creek. The possums followed as focal animals spent on average in the left, central, and right regions 20.82, 46.59, and 32.59% of total observation time, respectively. The actual time spent in a region varied markedly between animals. Some possums moved directly across the paddock from left to right regions to feed, while others spent most time in the left and central regions and then quickly moved across into the bush on the right. Time spent by individuals in any area ranged from 10-15 seconds (left region), up to 4.5 hrs (central region). The possum moving across the left area in 10-15 seconds took 35 seconds to cross the central area, and then spent 35 minutes grazing before moving into the bush on the far right. At no time did it appear in flight from another possum and there were only 2 other animals observed in the area at the time, both more than 20m from this animal.

Possums moved out of the observation area mainly towards the top and right of the right region. The banks of a creek provided a natural path for animals to follow, and it led through a light stand of manuka to another, more extensive, cleared grassy area, where possums often fed in cabbage trees and large kanuka trees. Few possums moved from the bush on the right back across the area. It is more likely that they circled around uphill from the observation area and back across the valley higher up, out of sight as was done by 3 radio-tagged animals on 5 occasions when followed on foot. All of these possums were near the creek on the northern side of the paddock by 0300 hrs which supports the finding that few possums were seen in the area around the hide after 0400 hrs. Table 3.1 shows average numbers of possums in the area over time from scan counts taken every 5 minutes. There were an average of 90 scans per night.

Table 3.1 Number of possums sighted during specified time intervals in observation area

Time period (hrs)	1800-2000	2000-2300	2300-0200	0200-0400	0400-0700
Mean	<1	3	5	3	<1
Mode	0	2	5	3	0
Range	0-2	0-6	0-18	0-5	0-2

The number of possums seen in the observation area was variable throughout the year, but the numbers of animals seen on pasture consistently peaked around the midnight hours. In some cases radio triangulation data supports this finding, in that possums moved smaller distances at the time, consistent with pasture feeding patterns. Typical movements of possums denning on the northern slopes were also down towards the observation area in the late evening, and then moving back up the hillside 2-3 hours before dawn.

3.3.2.2. Effect of weather on possum activity

Weather conditions had a marked influence on the numbers of possums sighted. Rain, particularly beginning before nightfall, reduced the number of possums seen. When rain continued until the early hours of the morning, no possums were seen grazing on open pasture, although some possums were known to be out of their dens (from radio signals and observations in the bush). For example, in October 1991 it rained heavily for 2 days before observations began, and continued for another 2. Only 2 animals *in total* were seen during the first 2 nights of observations (from the hide and walking around between 0100-0230 hours on the second night). The weather cleared on the third night and 4-6 possums were then seen on each scan from 2000 hrs to 0400 hrs. The greatest number of possums were seen late October and November 1991. Joeys were back-riding at this stage, but were not included in scan counts unless they were off the mother's back. However, even if they were excluded from the counts, more animals than usual were present in the area.

The effect of wind on numbers of possums seen, appeared to be related to wind strength. Very strong winds (greater than approx. 70 km/hr) reduced the average number of possums seen in the observation area for any particular time period. On the 9th of March 1992, strong winds began in the early afternoon, and continued until late evening (~2200 hrs) on the 12th. Only 3 possums were seen during the entire night of the 9th in the area around the hide. A similar pattern emerged on the night of 11th March (night of the 10th was too windy to observe) but, during a sweep inside the bush margin in the lower part of the paddock, at least 3-4 possums were always in sight as I circled the observation area. The sweeps were timed at 2300, 0130 and 0300 hours, and each lasted for 20-25 minutes. Late on the 12th of March the winds suddenly abated, and possums were seen in the observation area from about 0100 hours - generally 2-3 possums per scan. Observation periods on each of these nights were from 2000-0500 hours. Similar patterns were observed on 2 other nights of observation from the hide during strong winds, and on 4 nights of observations in other locations in the area.

Light winds seemed to have no effect on the number of animals seen, neither did light rain, cold, fogs or very warm weather. Similar numbers of animals were seen in all such conditions; however, on several occasions when conditions were such that many possums were expected to be seen, few were seen in the observation area. Casual observations in other areas of the paddock, and surrounding farmland, on such occasions found possums out feeding. It is possible that unintentional

disturbances by the observer caused possums to avoid the area. Extreme weather conditions did affect the presence of possums on pasture, but other factors are also likely to be involved.

3.3.2.3. Activity patterns of possums on pasture

The behaviour of a total of 180 possums was closely observed for 54 hours, over 29 nights (254 hrs) of observations (average 18 minutes per possum, range 1-230 minutes.). The behaviour of possums within the observation area was highly predictable in contrast to the numbers of animals seen in the area. Table 3.2 indicates the overall percentage of time possums devoted to the major categories while under observation, for both focal and continuous sampling methods.

Table 3.2 Percentage of time devoted to behaviour categories by possums

Focal animal sampling			Continuous sampling*	
Behaviour Category	Proportion (%)	n**	% (range)	n
Feeding in one location	61.63	180	55.72 (21-78)	10
Feeding, but slowly moving	25.90	180	28.52 (3-42)	10
Moving	4.27	180	8.12 (3-28)	10
Sitting still	2.44	160	1.10 (0-3)	6
Alert posture	2.63	169	5.22 (1-17)	10
Other***	3.13	18	1.32 (0-7)	4

* There were 2 hrs 22 minutes of video analysed

** refers to the number of possums (out of the 180) that exhibited this behaviour

*** Other behaviour included threat and agonistic interactions, as these were a small proportion of the behaviours seen.

As a comparison, the movements of 10 possums in the observation area, recorded on video until they were lost to sight, were analysed using a continuous sampling method and results were similar to those above (Table 3.2). Simple timing with a stop-watch of possums grazing in other areas of the paddock and out on open pasture gave similar results.

The only differences in time spent on behaviour categories between seasons were in the number of interactions between possums. Interactions in the observation area were only observed in October and November 1991, and in March 1992, and at these times there were many animals on the pasture. Of 180 possums observed, interactions were noted for 10 animals. Four of these were avoidance reactions on the part of the possum being observed, and 3 were where another possum avoided the focal animal. Avoidance took the form of a short period (3-8 seconds) of staring at the other possum and then moving to one side (Winter's (1976) 'give-way' action). Other instances were a scent-

marking response, probably to the presence of a dead possum nearby; an interaction between a female with a joey on its back and another small, presumably juvenile, possum; and a possum, apparently disturbed by another animal grazing nearby, which scent-marked on the pasture and was shortly thereafter chased by the nearest possum.

3.3.2.4. Interactions between possums

Interactions between possums *feeding on pasture* in the observation area were rarely observed, other than the alert posture (see definition in methods section). There were no physical contacts seen between possums feeding in the area, and only 2 instances noted during other observations. On many occasions possums fed on pasture within 2 m of each other with no apparent interaction. Similarly, two, or occasionally 3, possums were commonly seen in the same tree and no interactions observed. However, possums around their dens or on frequently used tracks were not observed continuously for long periods (more than 30-60 seconds). There are likely to be more interactions in these areas. When in observing in these areas sounds associated with agonistic interactions between possums were frequently heard (screeches and nasal grunting sounds), but were never heard from possums feeding on pasture.

The most common social interaction seen was assumption of the alert posture. While grazing possums regularly sat back on their hindlegs and tail, and raised their body to an upright position (the alert posture). The fore paws were generally crossed at the carpus and the animal tended to look in a particular direction. There is seldom a scan of the area around the possum as is seen with meerkats or gophers. The possum generally returned to grazing within 5-15 seconds. Occasionally a possum rapidly dropped to all fours and moved away, usually to feed in a new location. When several possums were feeding in the area an alert posture movement by an individual did not seem to affect the others - generally they continued feeding. Loud sounds (possums screeching or plovers squawking) occasionally caused 1 or 2 possums to be alerted, but not others. There was little apparent pattern to the behaviour. Some animals fed for 25 minutes without stopping, and then assumed the posture 5-6 times over the next 2-3 minutes; others stopped and assumed the alert posture as often as every 40-80 seconds. Such 'nervous' possums seldom stayed in the observation area for more than 10 minutes.

The greatest number of possums in the area occurred in October and November 1991 when adults and many back-riding joeys were in the area. More than 22 individual animals (mothers and joeys) were seen during scans and one count had 12 animals (including joeys) in a 15 m² area. On other occasions, 5-8 possums were seen feeding in a commonly used grazing area under a group of trees with no discernible interactions.

3.3.2.4.1. Descriptions of interactions seen

During the night of 31st March 1992, several possums fed on the pasture through until the early hours of the morning. They were generally widely scattered, except for 2 large animals which had

fed to within 5 m of each other. One of them frequently assumed the alert posture whereas the second fed for long periods between alert posture movements. At one stage, the first possum moved to within 2 m of the largest tree in the observation area and sniffed the ground over which the second had grazed 4-5 minutes previously; the second possum at this stage was about 5 m away. The first possum then humped its back, lowered its hindquarters, and rapidly brushed its tail sideways back and forth across the ground. This action was repeated 3 times over 20 seconds, and then the possum moved to within 2 m of the other animal and resumed feeding. Fifty-five seconds later the second possum, who had continued feeding throughout and at this time was facing away from the first, abruptly turned and chased that possum. Both ran towards the large tree and leaped 1-2 m up the trunk, though on opposite sides. The first possum dropped to the ground 20 seconds later, and was immediately chased back up the tree by the second who suddenly appeared around the base of the tree. This possum did not climb the tree, but moved 10-12 m away and resumed feeding. The first possum remained 5-6 m up the tree on a branch for another 8 minutes before climbing down and moving out of the observation area in the opposite direction to the second. The 3 other possums within 20m of this interaction continued feeding throughout.

During April 1992 the intact carcass of a possum was placed at the base of the only tree in the observation area which I had observed to be regularly climbed. Observations of the area around the carcass were made from 2000-0100 hrs the following night. In all, 8 possums approached within 5m of the carcass as they fed, with 3 of these animals distinctly sitting and gazing at it from 2-3 m away. A ninth possum approached the tree from behind and therefore it could not see the carcass (all others had been able to see the body from several metres away). As it rounded the base of the tree it immediately sat back in a bipedal threat posture with paw out. After slowly moving up to the carcass and sniffing up the length of its tail, the possum turned to the tree, reached up about 0.5m and marked it with the sternal gland twice and then began grazing. At this point another possum who had previously ignored the carcass approached from 2-3 m away, sniffed the tail, and then resumed grazing.

November 1991 saw the largest number of interactions observed, primarily because of the number of possums in the study area. On 2 nights, systematic observations from the hide were replaced by observations of groups of possums in a small area. Activities other than feeding behaviour were followed and recorded. Weather conditions were drizzly and cool with light cloud after heavy rain over the previous 2 days. Females were carrying back young and there were some independent juveniles about. Spring mating activity was probably occurring in the study area (R. Jackson pers.comm.). Seven avoidance interactions were seen between adult animals, none of which developed into a fight or involved vocalisations (observer 35 m away). The first indication of an interaction occurring was a variation in an individual's normal feeding pattern. The possum moved more rapidly for 10-15 m, and changed direction frequently. This animal was followed by another, and within 45-180 seconds (in 7 cases involving 3 different pairs of animals) the first possum turned and adopted a threat posture, and swiped at the other with its paw. In 2 cases the threat alone caused

the other to retreat; in 3 the following possum moved away after several swipes; and 2 interactions repeated the follow-the-leader, threat and swipe sequence before both animals resumed feeding.

There were a number of trees both within the observation area and many on its periphery but only the latter were consistently climbed by possums. Three trees standing apart from others were often grazed around although seldom climbed, whereas possums were frequently seen feeding in kanukas around the edges of the area in trees apparently no different from those within the observation area. A light placed in one tree early in the project was investigated by several possums over 2 nights, and yet the tree was only noted as being climbed by 2 animals over the next 18 months.

The most extensive use of a tree in the observation area was made by a mother and joey in November 1992. After grazing for 1½ to 2 hours with the joey on her back the female slowly climbed a tree in the left region of the observation area and remained sitting in the fork of a branch for over 2 hours. The tree was climbed again the next night. A mother came through the netting fence and, as she went through the gap, dislodged her joey. The joey ran after her and attempted to return to her back. After pairing up again the mother fed in a small area for 35 minutes before the joey dismounted and began to feed independently. The joey slowly moved across the area keeping close to the mother until it was at the base of a tree. It sat at the base, flicking its tail for 20-30 seconds. The young possum then leaped 0.5m up the trunk and scrambled up another 1-2m before dropping back to the ground 20 seconds later. It then backed away from the tree and repeated the manoeuvre, this time climbing 3 m up the tree in a circular fashion. Two more repeats of the procedure were made before the joey moved away from the tree and began grazing, by this time 12-15 m from its mother. Once again there was no reaction from the other 4-5 possums in a 20-30 m area around the tree. The joey eventually rejoined its mother 35-40 minutes later. Eleven mother-joey pairs were closely observed with many more watched less intensively. The behaviour of the mothers during this time was no different from that during the rest of the year except the contact distance between animals was much smaller due to the joeys feeding close to them. Seventy-five percent of the back-riding joeys left their mothers' backs to feed on pasture for some time but remained in close contact - as the females moved towards the edge of the pasture the joeys climbed onto their backs.

Interactions between possums feeding on pasture were infrequent but were more common along the bush-pasture margin, particularly where possum runs came out of the bush. No fighting was seen but pairs of possums were frequently seen gazing at each other, often with one of the animals on the top of a fencepost. Short chases regularly followed, with the chased animal often escaping up a tree. One possible mating attempt was seen in May 1991, and was the most violent of all interactions witnessed. A large grey possum was seen chasing a smaller, darker, animal. The chaser came up close behind and attempted to knock the other over, and then mount it. The first twisted clear, making no noise, and ran off at which stage both became aware of my presence and disappeared.

3.3.2.5. Interactions between cattle and possums

No interactions were seen between cattle and possums beyond an occasional steer showing interest in a moving possum (usually directly gazing at the possum, and following its movements with head and ears). The cattle camped in the right region of the observation area on 2 of the 29 nights, and no possums were seen in the observation area on either of those nights. With no cattle, and similar weather conditions on the following night, average numbers of possums were present in scans of the area. When cattle were present in the observation area possums fed on pasture on the fringes of the area and appeared to circle around the cattle. If possums approached the fence-line on the far left region, they stopped there as they became aware of the cattle. The possums then generally moved up the fence 40-50 m and into the pasture away from the cattle, or moved down through an area of long grass around the creek and out onto the narrow paddock beyond Backdrop. Cattle and possums were found close together in the bush but the possum was invariably in a tree (12 instances in 28 hours of observation). If a steer approached a possum the latter would move away and at that stage the steer might stand and watch the possum.

3.3.2.6. Possums - movements about their dens and the noises they make

The sounds of possums screeching in the bush was generally the first indication that the animals were moving from their daytime dens (radio triangulation also indicated movement at about the same time). Screeching began 30-60 minutes after dusk and was heard lower down the hillsides with time. The number of calls per hour decreased with time, 2-3 hours after dusk there were 1-2/hr compared with the initial 5-6. The number of sounds per hour increased again in the early morning (0200-0400 hrs) consistent with the possums returning to their dens. Possums feeding on the pasture made few sounds. On 2 occasions a soft 'chatter' (Winter, 1976) or 'Wuh-uh-uh-uh' (Kean, 1967) was heard from animals in the observation area but generally loud sounds were made from within the bush and on the hillsides around the main denning areas.

Observing possums around their dens was difficult, and there were few sightings. When I attempted to observe possums near their dens they quickly became aware of me, and rapidly moved away. During daytime tracking of possums to their dens it was often possible to reach into the den and read the possum's eartag, but possums were much more readily disturbed around their den at dusk. The majority of possums in the study site den on the ground under gorse, or in hollows at the bases of flax bushes (there are few large trees except on the valley floor).

Possums began to call at about the same time after dark, throughout the year, except for late February and March 1991. Sounds were heard before dusk each night over that time. Examination of possums during regular live-trapping showed that possums were mating about a month earlier than in previous years. Radio triangulation data also differed at the time with overall smaller areas covered by the animals at night and more erratic movements.

3.3.2.7. Miscellaneous observations

During work to develop radio triangulation techniques in the paddock several bright orange radio transmitter collars were left in the field overnight. The following day when the collars were collected it was found that many of them had been disturbed. Collars left hanging in trees and on the ground had teeth marks on them typical of those on radio-tagged possums. Several had been carried away from the original point and 2 needed to be 'tracked' to find them. Although other animals could have moved the collars, the marks on them indicated that possums were the culprits. It was found during the radio triangulation study that the brightly coloured collars were chewed more severely than plain dark packages.

A variety of other wildlife was seen during night observations. Hares and rabbits, generally in pairs, were most common, as well as small flocks of plover and a few Canada geese. The birds moved away from the observer and were not seen in the observation area, although they fed on pasture elsewhere on the property. Rabbits and hares occasionally grazed near the hide and hedgehogs ambled through, usually close to the fence, on several occasions. Neither they nor the possums responded to each other. Flight by the hares or rabbits provoked no reaction on the part of the possums except once when a hare hit the wires on a fence, and 4 of the 6 possums nearby adopted the alert posture for a short time.

3.4. DISCUSSION

The basic behavioural patterns of possums in this study area were similar to those described by Winter (1976), Ward (1984), Jolly (1976b) and others. Differences between studies in time spent by possums in particular activities are evident, but probably result from effects of habitat and food distribution. Diets of possums in Australia may consist of 20-30% eucalyptus leaves (depending on availability of other plant types), and the high energy requirement to digest them may account for their prolonged periods of immobility (Winter, 1976; MacLennan, 1984; Statham, 1984). Both Ward (1984) and Jolly (1976a and b) found pasture was an insignificant proportion of the diet at their sites, and palatable trees and shrubs were available throughout much of an animal's range. In the present study possums moved in distinct patterns down from the den areas onto pasture, and back again in the early morning. Grasses, herbs and clovers are available throughout the year in small areas scattered through the bush and on cleared areas of the paddock. The possums grazed to a far greater extent than reported for Australian possums, although they appeared to be far more selective in their grazing habits than sheep or cattle, and chose preferred items from within the sward, as also noted by Harvie (1973). Cowan (1990a) has described the food preferences found in forest possums, which have a very different diet from animals living at the bush-pasture margin as in this case. It was not possible in this study to identify which items were preferred, or why particular grazing sites seemed to be preferred. Understanding why possums congregate at particular food resources, or on particular areas of pasture may aid in more effective targeting of efforts to control possum numbers.

Interactions between possums which may potentially contribute to transmission of tuberculosis were uncommon on the pastoral areas of the study site. Contact between animals appears most common during the mating season (Winter, 1976), and to vary in frequency between habitats (Jolly, 1976b). The inability (despite varied approaches which were attempted) to gather information about the behaviour of possums when they were within the bush areas of the study site was a major gap in the present work. Possums in forest habitats have been frequently studied in New Zealand; however descriptions of possum populations in mixed bush/pasture areas, such as the Castlepoint site, are infrequent. The actions and responses of possums around natural den sites need to be determined to gain a thorough understanding of the epidemiology of tuberculosis. The relatively large expanses of pasture used by the possums allow the animals to avoid close contact with neighbours as they did almost universally in this study. Possums were seen to spread out across the field, and although there were peaks in the numbers of animals on the pasture through the night, if approached by another there was space to avoid conflict.

This careful avoidance which is characteristic of pasture behaviour cannot be maintained under all circumstances. Nevertheless, possums in this particular habitat - faced with another animal which cannot be merely avoided - seem to adopt conflict-minimising behaviours much more commonly than they adopt rank-establishment behaviours as seen in many species under such circumstances. For example, in areas such as the present study site where a network of tracks from den areas

coalesce into a few exits onto the pasture, there is opportunity for interaction between animals with limited space to 'give-way'. This may result directly in fights, or increase the frequency (and hence the density) of scent marking, both with potential for transmission of tuberculosis, particularly from animals with open discharging lesions. However, while such events did occur in the course of the study, on the limited observations which could be made at this site non-threatening interactions appeared to be much more common than threatening ones - at least in the vicinity of the grazing area.

What remains uncertain is the extent and nature of interactions among possums in the vicinity of dens, something which has proved difficult to investigate under field conditions. Possums on the study site tend to den within the same local part of the area most or all of the time, although not necessarily with a strong preference for a particular den or dens. From indirect and circumstantial evidence it would seem that interactions among possums which den in the same vicinity and hence come in quite frequent contact are much more active than among those which den some distance apart. For example, most of the vocalisations indicative of threatening interactions are heard from den areas, and have not been seen in the vicinity of the pasture. It would also seem that possums exhibit more strongly territorial behaviours in the denning areas. At several points on the hillside above the pasture certain trees, in particular mingi-mingi (*Leucopogon fasciculatus*) were heavily marked by possums. Horizontal teeth marks, scratch marks and some stripping of bark were seen. A few individual trees were marked, and a number of animals may have contributed to this damage. Winter (1976), and Biggins and Overstreet (1978) refer to bite and scratch marks on den trees in Australia. Difficult though it is to investigate behaviour in the immediate vicinity of dens, an understanding of this would be of great help in interpreting other data on the epidemiology of tuberculosis, since it seems likely that this holds the key to the process of transmission among possums.

The use of remote control low light or infra-red imaging equipment will be essential to record possum activity in bush and around dens. The difficulty of reaching these areas, coupled with the possums timidity in such situations requires that human presence is kept to a minimum. A large number of locations within a possum habitat need to be observed to fully record possum behaviour in such an environment and the use of manpower is an expensive and inefficient method. For example, despite observations over 3 nights of a tree freshly marked by possums, no animals were seen in the vicinity. The tree was marked again over the following week. Automated equipment could provide results in such situations. As for preferred areas on the pasture, marked trees and the area around them may be suitable areas for poison bait feeding stations or other control methods.

Chapter 4

Interactions Between Beef Cattle and Simulated Tuberculous Possums on Pasture

4.1. INTRODUCTION

Transmission of *Mycobacterium bovis* between possums and cattle had been suspected since before the first tuberculous possum was found in Westland in 1967 (Davidson, 1976). Control programs designed to limit and eventually eradicate the disease in domestic cattle have proven ineffective, and endemic areas continue to spread while new ones develop (Livingstone, 1988). That the possum is implicated in the maintenance and spread of bovine tuberculosis in New Zealand is unchallenged; however, the extent to which the animal contributes to this situation is ill-defined. Evidence from field work by the then Animal Health Division of MAF in the Hohonu ranges in 1976 (Coleman, 1988), and possum control operations from 1971-1976 in the Buller region (Animal Health Division, 1986), linked the possum to the presence of endemic tuberculosis in cattle, as have many investigations since then. This situation parallels that seen in the United Kingdom, where badger populations trapped close to persistent reactor herds are often found to have TB (Wilesmith, 1983; Wilesmith *et al.*, 1986a). Extensive control operations in England have also failed to adequately control the disease.

Tuberculous possums were unlikely to have been introduced into New Zealand, since the original Australian populations have never been identified as having TB. Infected cattle, probably imported from the U.K., are the most likely source of infection, and either directly, or via some intermediary, infected the possum - and certainly at several different times and locales. The transmission mechanisms between possums and cattle have been postulated upon, considered, and studied over the past 30 to 40 years. Pasture contamination from open wounds seen in many tuberculosis possums (Ekdahl, *et al.*, 1970), and direct investigation of dead possums by cattle (Davidson, 1976) are 2 possibilities, but there is little supporting evidence. The social behaviour of possums has been extensively studied by Jolly (1976a and b), Kean (1967) and Winter (1976), among others, as has their ecology, home range and use of den sites, but little is known of their behaviour, and of possum-cattle interactions in the natural environment. Other feral animals may also be important as carriers or reservoirs of tuberculosis. Areas which are endemic for TB in cattle often have high populations of feral deer and were a major source of stock for the fledgling deer industry (Livingstone, 1988). The boom in the deer industry in the 1970s led to the capture and transportation of many thousands of animals throughout the country, some of which were subsequently found to be infected with TB. More recently, infected possums have been found in association with tuberculous farmed deer in previously 'clean' areas, with indications that, once again, transmission of the disease has occurred into a feral population from domestic livestock.

This study was designed to examine and record interactions between simulated tuberculous possums and cattle in a natural situation to provide a better understanding of how transmission might take place under field conditions, given that there is normally little direct contact between possums and cattle. Night observations of cattle feeding and resting on pasture known to be frequented by possums indicated that possums avoided cattle if possible. However, terminally-ill tuberculous

possums (located by radio-tracking) have been observed moving about on pasture during daylight, and it was possible to record findings which are believed to be typical of behaviour exhibited at this stage of the disease. Such observations describe thin, weak animals, that move slowly, frequently stopping to rest or feed. A tuberculous possum observed in the lower part of backdrop paddock took 20-30 minutes to move 30 metres to partial shelter under a creek bank - it was found dead nearby the next day. During its progress across the field it was seen to fall over several times. The behaviour exhibited by sedated possums used in this study followed a similar pattern. A disproportionate number of tuberculous animals have been found dead on pasture in the course of the field study relative to the prevalence of tuberculosis in the possum population, suggesting that tuberculous animals wandered aimlessly at any time of the day or night, and dropped dead of the disease literally 'in their tracks'. These animals and their carcasses are possible sources of infection for cattle and other species such as feral pigs. This study was designed to test whether possums exhibiting such behaviour would attract the attention of cattle sufficient to expose them to potential infection.

4.2. MATERIALS AND METHODS

The study was carried out on farmland on the Wairarapa coast east of Masterton. The property and study site are described in Chapters 1 and 3. A 5 metre observation tower constructed for other work overlooked a roughly hour-glass shaped area where 2 paddocks met at a common gateway (see Chapter 3, Figures 3.1 and 3.2). Seventeen 18-24 month old beef breed steers, used as part of an ongoing study of the epidemiology of tuberculosis on this property, were exposed to the clinically non-tuberculous possums. Electric fencing was used to prevent the cattle moving more than 50 metres away from the gateway in either direction. There was adequate feed and water in this area for the cattle during observation periods.

Four days before the first observation period the cattle were moved into the more accessible of the two paddocks, and allowed free range over 5 to 8 hectares. The day before the first observation period the cattle were confined in the observation area and kept there for 3 days, then released into the 5-8 ha area for 2 days. Another observation period of 2 days followed before a break of 5 days. The experiment was then repeated but with a 2 day observation period, 3 days in the large paddock, followed by another 2 days of observation. This was intended to assess the extent to which habituation occurred with repeated exposure to possums.

Possums were captured in standard wire mesh live-trap cages placed along the bush-pasture margin in the vicinity of the observation area using apple coated with flour and cinnamon as bait. Traps were placed to maximise likelihood of capture and left in place during the study period. A total of 25 possums were caught in 56 trapping opportunities (7 cages open for each of 8 nights). Several of the possums were caught more than 3 times even after being used as experimental animals. All of these recaptures were released. Their body condition, sex and size were assessed before they were transported, in the cages, to an area near the observation tower. Selected animals were sedated with an intramuscular dose of Ketamine hydrochloride at a rate of 30 to 35 mg/kg, based on the approximate weight of the possum (cage plus possum weight, less the known weight of the cage). The possum was then re-examined to ensure neither clinically tuberculous animals nor lactating females were used. Within 15 to 20 minutes of injection the animal was placed in the observation area.

There was some variability among the possums as to duration and depth of anaesthesia which appeared to be largely related to their state of excitement when injected. A dose rate of 25-35 mg/kg (Pfeiffer, pers. comm.) is used in a longitudinal study of the possum population on the same property and provides adequate sedation for palpation, examination and blood sampling via cardiac puncture in most cases. Possums caught regularly and found relaxed in the trap are easily handled at this dose rate whereas those caught for the first time or aroused can be difficult. For this study the possum was required to remain where it was placed in the paddock until the observer was away from the cattle. Of 21 possums sedated and released, 18 did so.

Minimising disturbance was very important when introducing possums to the cattle. When the cattle were actively grazing or ruminating it was not difficult to move into the paddock with the possum concealed behind one's back, and place the animal on the ground. Sedated possums did not usually move for 10-20 minutes after release, and any disturbance caused to cattle or possum was thus insignificant. If the cattle were moving around the area, as often occurred in the mornings after the early grazing period, a decoy person was used to distract the steers' attention while another placed the possum in the paddock.

Each of the presentations was filmed using a tripod-mounted Sony Handycam video camera with a standard 6 times zoom lens and a detachable 1.5 times teleconverter to ensure a reasonable field of view. Comments on cattle and possum behaviour and other factors were dictated into a pocket recorder for later transcription. The observation period began when the possum was placed in the paddock and continued until the possum permanently moved out of the study area. Although the video recording concentrated on the possum and its immediate surrounds, periodic wide-angle scans of the whole area, and taped comments of the activities of cattle not in camera view were made.

Possums were released into the study area at different times of the day and on 3 instances at night. The time between releases was dictated to some extent by the reactions of the possum. For example, if the animal recovered rapidly or climbed a tree soon after release that run was terminated, the cattle allowed to settle down if necessary for at least 2 hours, and then another possum released into the area.

4.2.1. Behaviour Classification and Analysis

Video tapes were analysed using 'The Observer' (1990), an event recording and analysis program developed by Noldus Information Technologies (Wageningen, The Netherlands). Within the program, an event protocol is designed for coding and recording behaviours. A portable computer was used as an input device while the video tapes were replayed and behaviours recorded. Basic analysis, detailing frequency and duration, was done within the Observer program, with further statistical analysis using Paradox version 3.5, Parastat, and Statistix.

Two methods were used to record cattle and possum behaviour and interactions. The first was used to determine what types of behaviour occurred when possums were introduced to cattle, and involved a focal-animal sampling technique (Altmann, 1974) based on the possum. The timing of each change in the behaviour of the possum was noted (the behaviours are defined in the following section), as well as the reaction of the cattle towards the possum. Cattle behaviour was grouped into classes which concentrated on close approach, and actual physical contact with the possum. Although at times the majority of cattle may have been grazing, if 4 or more were interested in the possum the latter activity would be recorded. The second method was scan-sampling, where the activity of each individual steer was recorded at 20 second intervals. This technique allows one to

calculate the percent of time spent on various activities by individuals, and answer questions such as is one steer more likely to interact with the possum than another.

4.2.1.1. *Focal-animal sampling*

The behaviour patterns and activities recorded were divided into three broad categories or event classes, and specific activities are grouped within these. The main event classes were:

- Cattle Behaviour - the predominant activity of the mob of cattle as a whole but concentrating on the degree of interest shown towards the possum
- Possum Behaviour - the animal's activity level - related to its degree of sedation
- Interaction between possum and cattle - actual, or close contact between the animals

The following behaviours were recorded in the event classes:

Cattle Behaviour:

1. Grazing - active feeding, usually seen during definite intervals within a 24 hour period
2. Ruminating - most of the cattle either standing or lying down chewing their cud
3. Aware and watching - aware of and watching the possum but not moving
4. Aware and moving - cattle beginning to approach the possum, but still more than 15 metres away
5. Few interested - 3-5 of the steers were actively interested in the possum and within 5-10 metres⁹ of it
6. Most interested - 8 or more of the steers as in (5) above
7. Few in contact - 3-5 of the steers within 5 metres of the possum
8. Most in contact - 8 or more of the steers as in (7) above

For some analyses 1 and 2; 3 and 4; and 5-8 were grouped together

Possum Behaviour:

1. No movement - the possum is deeply sedated and only making small movements of its head and tail
2. Slow activity - sedation is less pronounced, the possum may move but is uncoordinated
3. TB type - slow but coordinated movement typical of a terminally ill possum¹⁰
4. Fast - possum showing only slight sedation, capable of rapid movement, but often could not (and did not) move long distances
5. Out of paddock - no physical contact with cattle possible ie. on other side of fence

Interactions between possums and cattle:

1. No contact - possum and cattle not directly interacting
2. Following - 1 or more steers trailing closely after the possum as it moves (within 5-10 m)
3. One metre - a single steer within 1-2 metres of the possum
4. One metre + - 2 steers within 1-2 metres of the possum
5. One metre ++ - 3 or more steers as above

⁹ Cattle were clustered around the possum as the main centre of interest and followed its movements closely.

¹⁰ This classification is based on descriptions of the movements of a terminally-ill tuberculous possum as seen by field workers involved in the Longitudinal TB study.

6. Knock - a steer knocks the possum with its head, a common, active, movement on the steers' part
7. Sniff/nuzzle or lick - physical contact with possum - generally sniffing, but some animals licked the possum
8. Sniff/nuzzle or lick + - 2 steers in contact
9. Sniff/nuzzle or lick ++ - 3 or more steers in contact

For some analysis the interactions were grouped as 1-2; 3-5; and 6-9

4.2.1.2. Scan-sampling

Each of the steers in the study group was individually identified using a large plastic eartags (Allflex Ltd, New Zealand). The type of contact each steer had with the possum was recorded at 20 second intervals, and the classification based on a set of distance categories between the steers and the possum. These classes were later grouped for analysis. Categories were as follows:

1. Physical contact between possum and steer - sniffing, licking etc.
2. Possum and steer less than 1 metre apart but not touching
3. Possum and steer 1 to 5 metres apart
4. Not in Contact - separated by more than 5-10 metres

Recording began when one or more of the steers became aware of the possum - generally indicated by the animal looking intently in the direction of the possum with ears forward. The end of the observation run was taken as 3 minutes after the last contact between possum and cattle, which in all cases analysed was after the possum had moved out of the fenced-in area. The data set was then adjusted to end 3 minutes after the last contact, which was usually with the possum and a steer 1-5 metres apart.

4.2.2. General Description of Behaviour Patterns

4.2.2.1. Possums

The initial period of deep sedation lasted 10-30 minutes and ended when the possum could hold its head above the ground and make attempts to move. Considerable tail movement at the time often resulted in the cattle becoming aware of the possum. Attempts to minimise this effect by releasing the possum from cages in the observation area, increasing the time from injection to release, or liberating the possum from outside the site were seldom successful.

The next stage of recovery by the possum, coded as 'slow activity', consisted of apparently random movements about a small area. The possum was unable to maintain either balance or direction for more than 60-90 seconds, particularly when attempting to move away from investigating cattle. During this stage, the possum often fell on its side and stayed there for 30-90 seconds. 'TB Type' and 'Fast' activity groups overlapped considerably, and in the analysis were eventually grouped together. They usually occurred twenty to forty minutes after sedation, when the possum was coordinated enough to move steadily across the ground for some distance, but still often fell over. After falling, the possum appeared disorientated, and this often resulted in the possum circling and

staying within reach of the cattle for prolonged periods. Activity was coded as 'fast' when the possum moved rapidly, and was often in response to close investigation from the cattle. This frequently resulted in following activity by one or more of the steers. As sedation wore off, possums moved towards shelter around the paddock edge. Cattle could not reach the possum and activity was coded as 'out (of paddock)'. On several occasions possums moved back into the paddock and observation periods continued.

4.2.2.2. Cattle

Most observation runs began with the cattle either grazing or ruminating. Both activities tended to occur at distinct times of the day - an early morning period of grazing from dawn to about 0900 hours was followed by 2-3 hours of rest and then more grazing. Movement of cattle in adjacent paddocks, or people about the area, caused some disruption to this pattern, most significantly when the cattle were in transition between states. The remainder of the behaviour types refer to reaction of the cattle to the possum's presence, as distinct from physical interaction between possums and cattle. When cattle noticed the possum, they first stood looking at it with ears pricked forward. 'Aware and watching' the possum was recorded when 5 or more of the cattle showed that behaviour: 'Aware and Moving' generally followed on from this, and was active movement towards the possum. The 'Interested' and 'Contact' categories are separated only by distance - interested when 3 to 5 (for 'few interested'), or 8 or more (for the 'most interested' class) steers were 5 to 10 metres from the possum, and 'in contact' when the nearest cattle were 1 to 5 metres away. The latter class did not necessarily indicate that the possum and steers were all in physical contact. Within this group some animals were likely to be in the possum-cattle interaction classes, which concentrated on particular animals rather than the number of steers.

4.2.2.3. Possum - Cattle Interaction

Interactions between cattle and possums were grouped into the three following categories:

1. Cattle and possums more than 2 metres apart.

No Contact - cattle were grazing, unaware of the presence of the possum, or more than 3-5 metres away. In some observation periods the cattle grazed close to the possum but made no move towards it. At other times, a steer, often attracted by movement from the possum, investigated it and then moved slowly away grazing.

Following - as indicated previously this action was most common when the possum was moving rapidly and the cattle followed 5-10 metres behind it. The steer trailed behind the possum with head held low, often appearing to sniff the ground over which the possum had moved. If the possum stopped, direct contact between the animals was common, such as sniffing of the possum by the steer.

2. Within 1-2 metres but not in contact.

A steer was only recorded in this group when it was facing the possum and within 2 metres. This class was split into 3 depending on the number of steers that were close to the possum. Groups were; a single steer, 2 animals and 3 or more. The particular beasts within 1-2 metres of the possum often changed rapidly as the possum moved, or interactions between steers resulted in displacement. However the emphasis in this part of the study was on contact between animals rather than individual identification. Analysis combined the three groups.

3. Physical contact between possums and cattle.

Three distinct behaviours were recorded - sniffing, licking, and knocking of the possum by the steer. Most of the contact was sniffing. A steer approached the possum steadily with head held low and outstretched, often making distinct snuffling sounds, particularly when it sniffed clumps of grass over which the possum had moved. The cattle were wary during the initial experiments, reacting extravagantly to fast movement on the part of the possum, compared to subsequent exposures. Steers sniffed all parts of the possum, though most often the lower abdomen and tail. However, as the possum was often trying to move away from the steer, this may have been coincidental. Licking the possum was a brief action, which was often temporarily hidden by the bulk of the head and so undoubtedly occurred more frequently than was noted. A few steers licked the possum extensively with the tongue protruding full length. In 2 cases licking by the steer pulled fur from the possum's back. In one case the steer also closed its lips around the possum and lifted it a short distance off the ground.

Sniffing and licking are common exploratory responses of cattle. Two or three of the steers 'knocked' the possum consistently. The action was similar to an attempt to gore or crush, but was not completed. Several of the possums were rolled over, however, as the steer swept its head around. The behaviour did not appear to have an aggressive intent and was infrequent overall. No possum suffered any injury from interaction with the cattle, and the steers treated the possums quite gently, despite the difference in size and the uncoordinated movements of the possum.

4.3. RESULTS

4.3.1. General Description of Trials

Twenty-one possums were sedated and released - 18 during daylight and 3 at night. Three possums released during daylight became hyperactive when put on the ground and immediately attracted the steers' attention - these runs were discarded. Seven more exposures were either terminated or not analysed due to possums climbing trees in the area, or prolonged sedation. The 3 releases at night, 1 of which was successful, are commented upon in following sections but were not analysed in detail because it was much more difficult to identify exact behaviour using the nightscope. The 8 successful observation runs were spread over two weeks with 4 runs in each week. They were classified as week-1 runs 1-4 and week-2, runs 1-4. Analysis of data was done on a day by day basis and also comparing between weeks. Photographs of interactions between sedated possums and cattle are seen in Figures 4.6 to 4.9.

Table 4.1 Parameters of observation runs which were suitable for analysis

Run Identification	Date	Time of Release	Duration of observations in seconds	Time from possum release to cattle awareness (in sec.)	Time from release to first contact (in sec.)
Week-1 Run 1	25.2.92	0845 hrs	2386	139	399
Week-1 Run 2	26.2.92	0900 hrs	981	342	927
Week-1 Run 3	26.2.92	1025 hrs	1494	526	559
Week-1 Run 4	27.2.92	1254 hrs	1165	37	84
Week-2 Run 1	3.3.92	1219 hrs	2934	865	873
Week-2 Run 2	4.3.92	1110 hrs	3600	989	2118
Week-2 Run 3	4.3.92	1239 hrs	3060	991	995
Week-2 Run 4	5.3.92	1000 hrs	2971	20	707

Weather conditions over the 2 weeks varied among the following - fine, warm conditions with no wind through light rain, cooler temperatures (13-15° C) and moderate to strong winds. All the runs analysed were on mild days with little wind, generally scattered cloud cover and no rain. In general there were few distractions for the cattle beyond the presence of the sedated possum in the area. On one occasion cattle (heifers and a bull) in a neighbouring paddock came within 5-10 m of the fence for 4-5 minutes. However this appeared to have little effect on the response of the animals. The bull was aware of the possum, at this stage on the same side of the fence some 25 m away, but moved off after the heifers.

4.3.1.1. Description of observation runs

Observation run 1 week-1: This was the first release of a possum into the area where the cattle were confined. Some of the cattle were grazing, others interested in the heifers and bull in the neighbouring paddock. The possum was released 30 metres from the nearest steer and remained stationary for 2 minutes. The cattle were aware of the observer moving in the area, and this may have contributed to the animals noticing the possum within 3 minutes of release. The cattle rapidly moved towards the possum and remained interested in it throughout the entire 40 minutes that it was within the study area .

Observation run 2 week-1: Most of the cattle were ruminating at the beginning and throughout the run. The cattle became aware of the possum within 8 minutes, but showed very little interest. The possum moved in a circular pattern through 30-40 metres before leaving the area a short time after the cattle made first contact.

Observation run 3 week-1: The cattle were grazing in the upper part of the area when the possum was released in the middle of the site. Interest in the possum was shown by a few animals after 8-12 minutes, but most of the cattle continued to graze. Steers which grazed near the possum made occasional contact, but only a few made deliberate movements towards the possum.

Observation run 4 week-1: This early afternoon run began at a time when the cattle usually began to graze again after resting and ruminating for several hours. The possum was active as soon as it was released. This attracted several steers' attention which resulted in an early contact between the animals and contacts continued throughout the run. The usual pattern was for 2-3 steers to move to the possum, investigate for a time, and then move away, grazing as they went. There were only short periods of continuous contact, but overall a large amount of either direct interaction or of possum and cattle in close proximity.

Observation run 1 week-2: The first run after a break of 5 days. The steers were grazing and there was less interest shown by the cattle compared with the initial run of the first week. The steers spent a similar amount of time 1-3 metres from the possum as in run 1 week-1, but this was mostly grazing around or slowly away from the possum. Steers which made a brief contact with the possum quickly lost interest and resumed grazing.

Observation run 2 week-2: All cattle were ruminating and only slowly became aware of the possum. Time to contact was 33 minutes, and then only by a few animals for a short time. The possum was quite active throughout the run and remained in the area for the longest time.

Observation run 3 week-2: The majority of cattle continued grazing throughout this run. Only 2 steers were involved in contact with the possum over the observation period. The possum was relatively inactive for 5-6 minutes after release but then moved around in the lower part of the paddock.

Observation run 4 week-2: The cattle became aware of the possum immediately on release but did not make contact for another 11 minutes. Although the animals were generally grazing at the beginning of the run there was very little grass in the paddock, and this probably contributed to the cattle being more active than expected.

Night observation Run: When the possum was released 10 of the 17 steers were resting. The movement of the observer into the paddock and subsequent release of the possum disturbed the cattle, and there was interaction between the possum and steers throughout the 26 minutes of the observation period. The cattle did not appear to contact the possum as often as during the daylight runs, but stayed close to the possum watching its movements. All steers made some contact with the possum, as distinct from the daylight runs where a few animals often dominated.

4.3.2. Focal Animal Sampling: Patterns of Interaction between Possum and Cattle.

4.3.2.1. Possum activity during observations

Table 4.2 summarises the amount of time each possum spent either stationary, moving around the area or out of the paddock. In all cases, except the third run in the second week, the possums spent most of their time actively moving about in the paddock.

Table 4.2 Activity of possums during observation runs - % of total time in particular activity.

Possum Activity	Week-1 Run 1	Week-1 Run 2	Week-1 Run 3	Week-1 Run 4	Week-2 Run 1	Week-2 Run 2	Week-2 Run 3	Week-2 Run 4
No Movement	34.78	5.58	35.66	4.13	45.46	16.68	46.37	3.41
Active	49.49	86.80	64.34	95.87	53.67	48.67	39.41	96.59
Out of area	15.73	7.62	0	0	0.87	34.66	14.22	0

4.3.2.2. Contact between possum and cattle

Total time the cattle spent in contact with the possum as a percent of total observation time is detailed in Tables 4.3a and b, and shown graphically in Figure 4.1. On average 7-8 (range 2-13) steers came into contact with the possum over the 8 analysed runs. Although individual runs varied widely, the trend is one of declining interest in the possum as the week's exposures continued. The variation can be partly explained by differences in the activity of the cattle when the possum was released. Run 4 Week-1 is an example where the possum attracted the steers' attention very early, the cattle were moving from a rest period into active feeding, and the possum maintained a high level of activity throughout the observation period. Taken together these factors led to a high number of

steers coming into contact with the possum (9 of the 17) during the run, and steers often moved only slowly away from the possum, thus staying within 2 metres for some time.

Table 4.3a Percentage of total observation time that cattle were in contact with possums during Week 1*

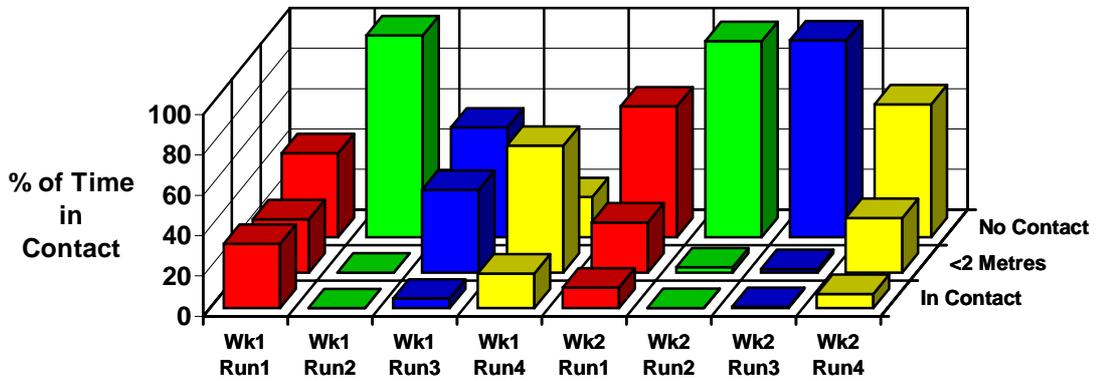
Type of Contact*	Week 1 Run 1	Week 1 Run 2	Week 1 Run 3	Week 1 Run 4	Week 1 Average
No Contact	41.59	100	54.31	19.89	53.95
< 2 Metres	26.51	0	40.95	62.9	32.59
In Contact	31.90	0	4.74	17.21	13.46

Table 4.3b Percentage of total observation time that cattle were in contact with possums during Week 2

Type of Contact*	Week 2 Run 1	Week 2 Run 2	Week 2 Run 3	Week 2 Run 4	Week 2 Average
No Contact	64.78	97.21	97.51	65.86	81.34
< 2 Metres	24.94	2.66	1.82	27.07	14.12
In Contact	10.28	0.12	0.67	7.08	4.54

*The contact types are based on categories described in cattle-possum interactions

Figure 4.1 Contact between cattle and possums during observation periods



4.3.2.3. Interest shown by cattle towards possums

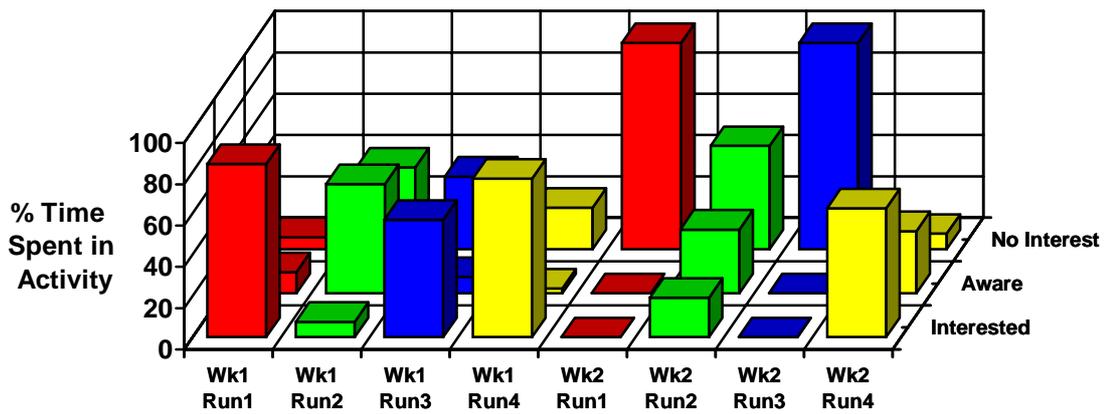
Table 4.4 and Figure 4.2 show how the cattle reacted to the possum in the paddock. The table describes the overall reactions of the cattle on the basis of the activity of the majority of the animals over a period of time. For example, steers which were in direct contact with the possum would be included in the ‘Interested’ group. Conversely, if most of the steers were grazing or ruminating the period would be classed as ‘No Interest’. However a trend of decreasing interest shown by the steers is seen as successive possums were presented.

Table 4.4 Interest shown by the cattle towards the possum

Note: Values are expressed as a % of total observation time.

Response of Cattle	Week 1 Run 1	Week 1 Run 2	Week 1 Run 3	Week 1 Run 4	Week 2 Run 1	Week 2 Run 2	Week 2 Run 3	Week 2 Run 4
No Interest	5.85	39.68	35.24	20.1	100	50.09	100	7.56
Aware	10.24	52.9	7.89	2.32	0	30.86	0	30.07
Interested	83.91	7.42	56.87	76.81	0	19.05	0	62.37

Figure 4.2 Change in levels of interest shown by cattle towards possum



Tables 4.5a and b, and Figures 4.3a and b, categorise cattle activity data in relation to the activity of the possum. Possum activity was grouped as: 'No Movement' (a variable period immediately following release), 'Active' movement around the paddock and 'Out' of area. The latter is important as possums moved under the fence-line and out of contact with the cattle but some steers remained at the fence watching the possum. The possum often returned to the paddock after a time and observations continued to allow for this. During week-1 (Table 4.5a; Figure 4.3a) the majority of steers watched the possum if it moved outside the fence, compared to week-2 (Table 4.5b; Fig 4.3b) when no interest was shown. In general, the cattle did not follow the possum as closely during the second week. The data in Tables 4.5a and b clearly indicates that the reaction of the cattle was stimulated by possum movement. Individual animals may have still been in contact or interested in the possum but not the majority of the mob.

Table 4.5a Reaction of cattle in relation to activity status of possum - Week-1

Note: Data is shown for 2 levels of interaction - interest in, and contact with, the possum. Values are means of the total observation periods for the week, expressed as a percentage.

Possum Activity Week-1	Interest shown by Cattle			Cattle-Possum Contact		
	No Interest shown	Cattle aware of possum	Steers Interested	No Contact	<2 Metres apart	Contact between animals
No Movement	10.27	1.89	5.85	17.14	0.98	3.92
Active Possum	12.31	14.85	46.99	33.33	31.25	9.53
Possum out of area	0.62	1.28	3.93	5.47	0.36	0.0

Table 4.5b Reaction of cattle in relation to activity status of possum - Week-2

Note: Data is shown for 2 levels of interaction - interest in, and contact with, the possum. Values are means of the total observation periods for the week, expressed as a percentage.

Possum Activity Week-2	Cattle Interest			Cattle Contacts		
	No Interest shown	Cattle aware of possum	Steers Interested	No Contact	<2 Metres apart	In Contact
No Movement	22.95	0.85	0.0	28.64	2.0	1.5
Active Possum	33.72	14.37	20.35	53.32	12.11	3.04
Possum out of area	3.55	0.0	0.0	3.55	0.0	0.0

Figure 4.3a Week 1: Possum activity versus cattle behaviour

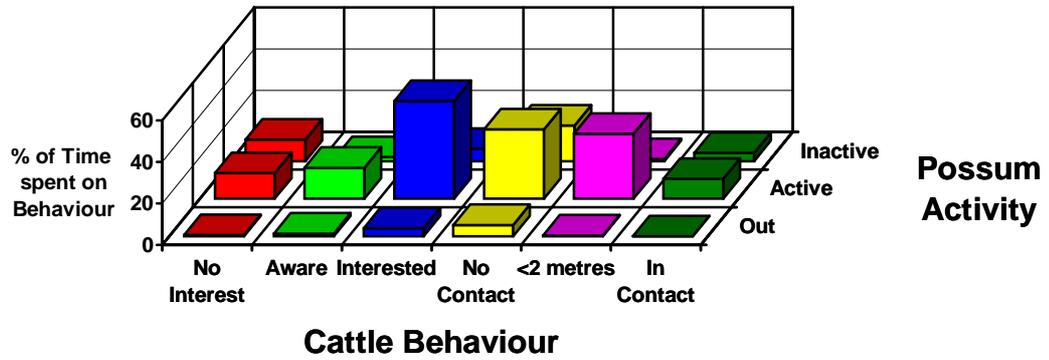
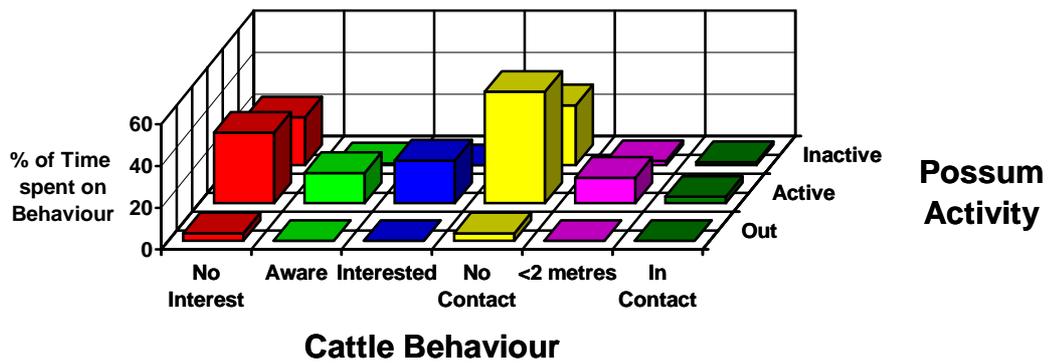


Figure 4.3b Week 2: Possum activity versus cattle behaviour



4.3.3. Scan Sampling Based on Individual Cattle Beasts

Analysis of observation data based on individual cattle behaviour was done on 6 of 8 observation runs. These were Week-1 runs 1, 4 and 5; and Week-2 runs 6, 8 and 9. They are identified as Wk-1 ID 1, ID 2, ID 3, and Wk-2 ID 1, ID 2 and ID 3 respectively. Sampling periods were at 20 second intervals and the total counts of each steer's behaviour type were divided by the number of sampling periods in each observation run, to give the proportion of time the individual spent on that activity. Figures 4.4a and b show the percentages of the total scan samples, summed for all runs in each week, of contacts by individual steers. There was considerable variation among steers, and between observation runs, in the extent of contact with the possum. Cattle numbers 1, 15 and 17 had very little contact over the 2 week period, while numbers 8, 13 and 16 came into regular contact throughout. Some animals, such as 10 and 12, were found close to the possum one week but not the other. The decline in contact between cattle and possums from week-1 to week-2 is again evident.

Figures 4.5a and b show individual steers for each observation run in terms of a 'risk' or exposure category for TB transmission, based on the degree of contact between steer and possum. The 4 classes of contact were given weighting's, ranging from the least risk (no contact) equal to 0; 5-10 m distance = 1; 2-5 m = 2, and touching the possum eg. sniffing or licking, equal to 3. The frequencies of different contacts for each steer were multiplied by the appropriate factor and then divided by the *total* number of sample periods in the observation run ((Total run in seconds ÷ 20) multiplied by 17) to give a value which indicated the amount of contact each steer had with a possum. The number of animals with a high risk score was considerably less in the second week than the first, and, in general, the cattle put themselves at less risk with each subsequent exposure to a possum. Specific risk analysis is reported later in this section.

Figure 4.4a Contact between steers and possum - Week-1 Totals

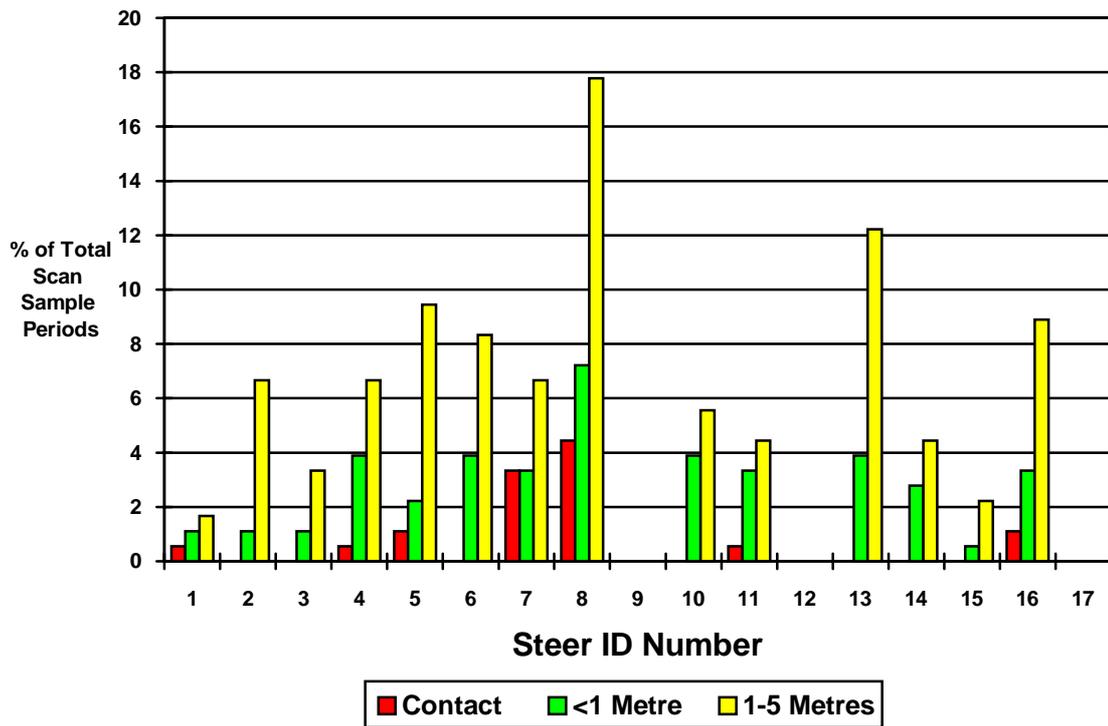


Figure 4.4b Contact between steers and possum - Week-2 Totals

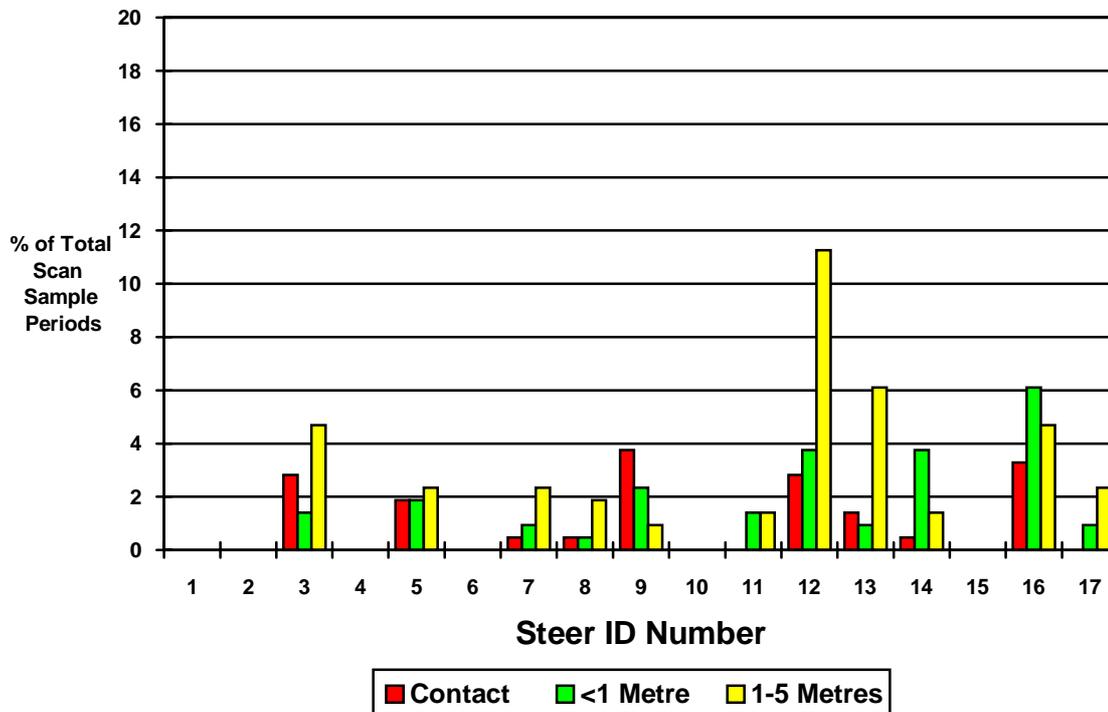


Figure 4.5a Degree of 'risk' to steers by observation period - Week-1

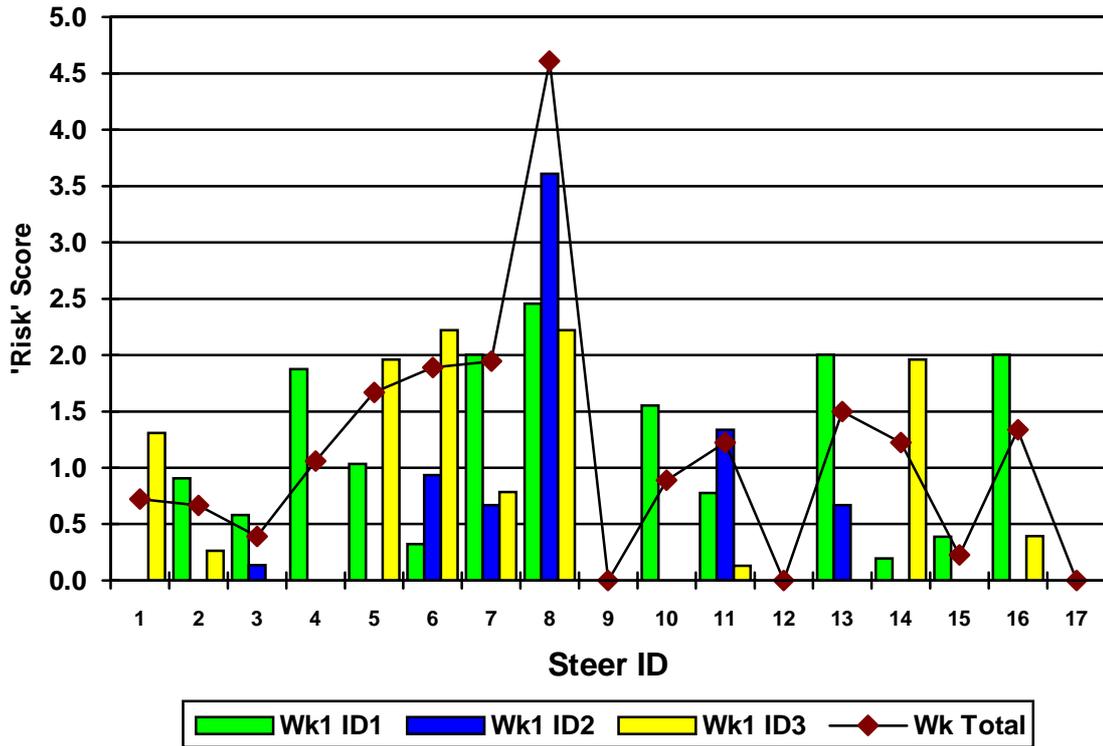
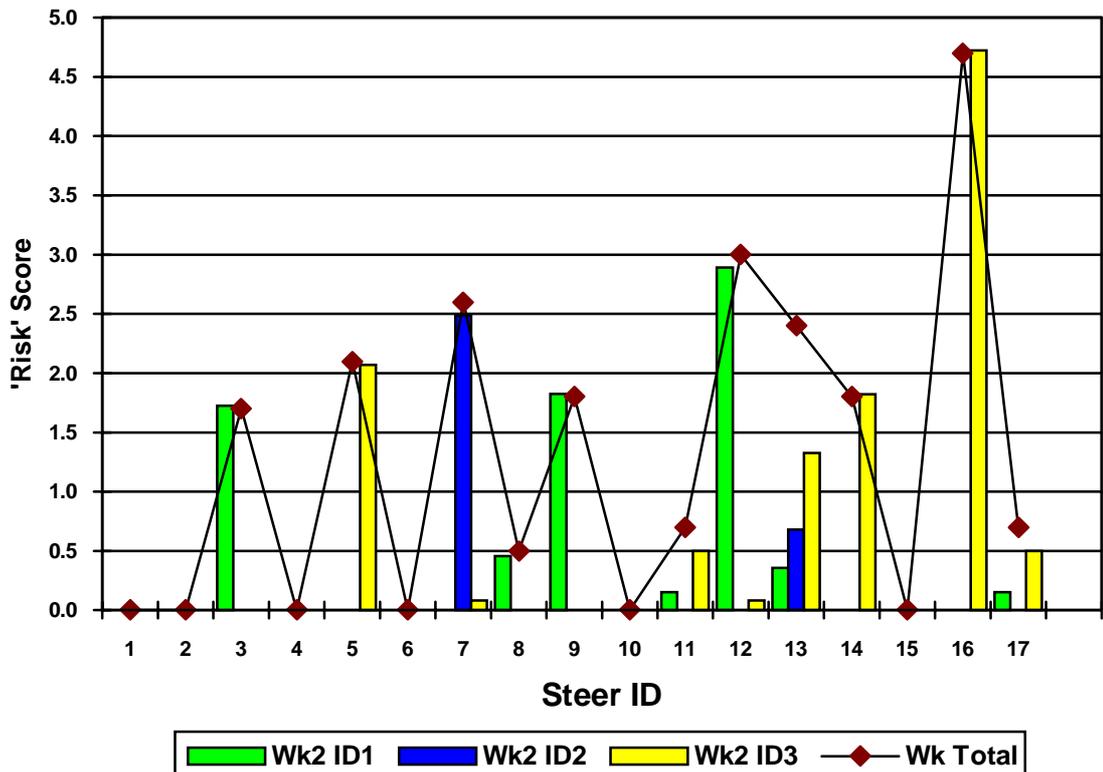


Figure 4.5b Degree of 'risk' to steers by observation period - Week-2



Further analysis of the 6 runs where cattle were individually identified was performed to explore risk to the cattle. Contact distances between cattle and possums were split into 2 categories; (i) Low risk if a steer was 2 or more metres from the possum and (ii) high risk if less than 2 m. A Chi-squared test on sequential observation runs (ignoring week of run) versus risk was significant for ID run 1 week-1, and ID run 2 of week-2 (cell chi squared values of 11.67 and 4.76 respectively; overall chi square 19.21, $p < 0.001$, d.f. 5). Week-1 ID 1 was significant due to more observed cases than expected (ie. more steers came within 1 metre of the possum than anticipated), however the significance of week 2 was due to less cases than expected ie. less interest in the possum.

Combining data on the basis of day of the week on which the observation was done - all cases of week-1 ID 1 plus week-2 ID 1 etc. - produced significant chi sqs of 3.06 for day 1 (more cattle in high risk group than expected) and 5.15 for day 2, again the second result having less observed than expected cases (overall chi square 8.66, $p < 0.01$, d.f. 2).

Table 4.6 shows a chi square of risk versus observation week confirming the trend of decreasing risk with subsequent exposures to a possum as an odds ratio of 0.70 may be calculated from the cross product of the cells (overall chi square 5.81, $p < 0.01$, d.f. 1)

Table 4.6 Chi square test of week of exposure to possum versus risk to cattle

		Low Risk	High Risk
Week 1 Observations	Observed	3048	97
	Expected	3064.27	80.73
	Cell Chi Sq.	0.09	3.28
Week 2 Observations	Observed	4240	95
	Expected	4223.73	111.27
	Cell Chi Sq.	0.06	2.38

4.3.3.1. Logistic regression of risk

The result of an unweighted logistic regression of risk on 3 variables is shown in table 4.7. The factors were the week of the run (=Week), the day during that week, ie first, second or third (=DayWk) and an interaction term of week and run number, first, second etc. (=WkRun). The coefficients indicate that 'risk' decreased from first to second weeks, and also during successive exposures of cattle to the possum. The interaction term has no effect on the level of risk.

Table 4.7 Unweighted logistic regression of 'risk' to cattle

Predictor Variables	Coefficient	Standard Error	P value	Odds Ratio
Constant	-2.948	0.234	0.0	
Week	-0.923	0.342	0.007	0.397
DayWk	-0.307	0.136	0.024	0.736
WkRun	-0.342	0.175	0.051	1.407

Degrees of Freedom = 7476

Deviance = 1774

P Value = 1.00

4.3.4. Responses to Possum Carcasses on Pasture

In addition to the studies already mentioned 2 fresh possum carcasses were placed on pasture accessible to the cattle. One of the possums was placed at the base of a tree which was known to be regularly climbed by possums at night (pers. observations, see Chapter 3) shortly before the cattle were released from the study area between observation weeks. The other was put in the open, flat half of the study area at the completion of the second week of observations. The latter carcass was cut open from sternum to pelvis and placed on its side - the abdominal contents were not removed. Both carcasses were undisturbed by predators for 36-48 hours, but within 3 days were essentially stripped of skin and meat probably by harrier hawks, ferrets or stoats.

The possum carcass lying near the tree was observed the night after it was placed in the paddock and 2 nights later when it was partially eaten. The cattle were observed for 4-6 hours from when they first had access to it, and watched again 2 days later, both times during the day. During the time the cattle were being observed none made directed movement towards the possum carcass. Over a 5-hour period 3 steers came into contact with the carcass as a result of them grazing near the body. Several more had come within 5-10 metres of it. Two of the animals grazed within 2-3 metres of the possum and then either saw or smelt the body and stepped towards it, smelt the fur for 15-30 seconds and then resumed feeding. One of the animals either mouthed or licked the tail of the possum enough to move the hindquarters slightly. This same beast returned to the carcass briefly twice more during the time it was observed. The third contact was by a steer initially feeding 10-12 metres away from the carcass from where it could not see the body. In response to one of the other steers investigating the carcass, it moved rapidly across and, after the first animal had threatened it (this animal was horned) sniffed the carcass briefly. The steer with horns then proceeded to sniff and lick the others head and ears for 8-10 seconds, both then continued grazing.

The steers were observed again 2 days later when the carcass had been partially eaten. There was a considerable amount of loose fur around, and little viscera remained. The cattle were grazing during most of the observation time. Only one steer made contact with the carcass in 3 hours of observations spread over 5 hours. This animal briefly sniffed at the fur lying near the carcass and continued grazing. One of the steers which had investigated the body 2 days before fed within 5-8 metres of the remains, but did not respond to its presence.

The second carcass was put in the paddock when the cattle were watching and where it could be seen. Over the next 4 hours the cattle slowly moved across the area grazing (there was little grass left at this time) and then began to rest and ruminate. Two animals, numbers 16 and 11, came to the carcass and sniffed it extensively. They had not moved directly towards the body but had obviously seen it. Both these animals showed more initial interest in the carcass than any steer had done with the other carcass, although their reactions were still considerably less than that shown to the live and moving possums. Both animals spent 40-80 seconds sniffing the carcass and then moved off. Two to 3 minutes later number 16 came back to the carcass, sniffed it, and then proceeded to sit down and ruminate less than 1 metre from the body, at one stage stretching its neck out full length on the ground and sniffing the carcass. While these are no more than unstructured observations they do reinforce findings from the main study that the movement and novelty of the sedated possums were the main factors in eliciting investigation by the steers.

Figure 4.6 Group of cattle showing interest in sedated possum



Figure 4.7 Steer sniffing and nudging possum



Figure 4.8 Steer licking possum



Figure 4.9 Interaction between steer and possum at night



4.4. DISCUSSION

The aim was to study interactions between possums and cattle in as natural a situation as possible. Although cattle were present in the study area continuously over 18 months there were few occasions during 38 nights of observations when stock either remained in sight of the observation tower, or possums and cattle were both in sight at the same time. This suggests that, normally, possums and cattle do not frequently interact. Possums, in fact, appeared to avoid cattle - at least in this situation.

To facilitate the study of possum/cattle interactions, contact was artificially induced by confining cattle, and releasing sedated possums into the area to simulate the few terminally-ill possums seen out in daylight over 3 years of study in this area. In May 1992 a radio tagged adult male was observed for 20-30 minutes as it moved slowly across an area frequently grazed by possums. The possum, identified as denning in an artificial nest box 50 metres away the previous week, was lethargic, it stopped often, and took no apparent notice of the observer. The possum moved 15-20 m along a creek bank to a slight overhang and then curled up and slept. The next day it was found dead, 20-30 metres away, on open pasture. The behaviour of this tuberculous animal is similar to that of an old female seen in the summer of 1991-1992. The possum had begun to den in a small hole in a bank, some 500-700 metres from her normal denning area, and several times over a 3 day period the possum was seen feeding in the open during daylight. The activity of these animals is similar to that of tuberculous badgers in the days before they died as described by Cheeseman and Mallinson (1981b).

Intramuscular doses of Ketamine led to patterns of behaviour mimicking that described for sick possums in more than 65% of the treated animals. The main deficiency in this approach was the disassociating effect of the drug. When possums and steer came face-to-face there was generally little reaction from the possum. By contrast J. Coleman observed that possums often stood their ground when approached by cattle, adopted a defensive-threat posture, sitting with paws raised and hissing and screeching at the cattle beast (cited in Benham and Broom, 1989). This contrasts with the efforts made by badgers to avoid cattle (Benham and Broom, 1989). Although the reaction of debilitated possums may be less vigorous than healthy animals, no sedated possum showed such behaviour. Occasionally, when the possum was knocked or fell over, and a steer sniffed its upper body, the possum extended its paws, but seemed incapable of further action. If the possums had responded by hissing or screeching, then those with lung lesions would be capable of infecting steers within the 180 cm aerosol transmission distance demonstrated by O'Hara *et al.* in 1976. Repeated viewing of the video tapes gave no indication of such behaviour - it is likely that the effect of the Ketamine inhibited this common response to a threat. In a natural situation a tuberculous possum may be unable to run away from cattle but able to produce an aerosol if it reacts to the threat (of a cattle beast).

The inquisitive nature of cattle, particularly young animals, is well documented (Wood-Gush *et al.*, 1985; MacKay & Wood-Gush, 1980; Hafez & Boissou, 1975). Nielsen & Luescher (1988) put baits

used in wildlife rabies control in a paddock with dairy cattle. Their interest and frequency of contact with the bait varied with the type of bait, and they became habituated over a 5 day period. The frequency of encounters and the proportion of directed encounters (where the head was orientated towards the bait) declined. They also found that baits in plastic bags and with a liver attractant were approached more often. Cattle in the present study also habituated to repeated releases of possums. Possums actively moving about the paddock engendered more interest from the cattle (mean of 34% of observation time) than inactive possums (3%). Activity levels of individuals are influenced by the presence of conspecifics (Boissy & Le Neindre, 1990; MacKay & Wood-Gush, 1980) and several times it appeared as though the action of individual steers investigating the possum initiated a response in others which were some distance away at the time. This was seen particularly when animals approached the possum carcasses. The activity of the cattle also affected their response to the possums. If the cattle were in a transition period between activities, higher levels of interest were shown than when steadily grazing or, more obviously, ruminating.

The degree and amount of contact between individual steers and the possum varied between animals and observation run. The cattle exposed themselves to more risk, overall, during the first week of observations. However, individual animals, such as number 17, 12 and 9, had no close contacts with the possum in the first week, whereas No. 12 spent 18% of observation time in the second week within 5 metres of the possum. Dominance structure was not formally investigated in the cattle but appeared to mirror the amount of contact between possum and cattle for the most dominant animals. Steers number 16, 13, 7, and 5 were large animals or had horns, initiated many mounting attempts, and reacted most aggressively to others close by - for example when several steers were clustered around the possum. These animals also had considerable contact with the possums through the 2 weeks and their risk scores were high. Although all 17 steers came within 5 metres of the possum at some time over the observation periods, the variation in risk indicates that some individuals are more likely to contract tuberculosis than others even if direct possum/cattle interaction and/or transmission of the disease is uncommon. Logistic regression and Chi-squared values confirm the trend of decreasing risk with exposure to possums.

The possum carcasses on the pasture were investigated by only a few of the steers over the observation periods. The body placed under a tree was not attractive to the cattle initially, or after 3 days, although the steers saw the fur and bones of the carcass from a greater distance after it had been scavenged. Steers did not see and were not interested in the carcass until they were within 1-2 metres and then only 3 animals approached it directly. This is similar behaviour to that seen when the sedated possums were immobile. The animals that did investigate the carcass touched it with their noses and probably also licked it. If the possum had been infected with tuberculosis the steer could have been infected, although the risk of receiving an infective dose by mouth in this way from a dead possum would be much lower than the risk of receiving an infectious dose by the respiratory route due to face-to-face contact with a live tuberculous possum, given both the greater chance of effective contact and especially the vastly lower infective dose reported by Francis (1958) and other

workers for the respiratory route (5 or less organisms) than the oral route (millions of organisms). Several of the tuberculous possums that have died in the Castlepoint study area have been found on open pasture, so there was opportunity for the cattle to find and investigate them. Most carcasses were scavenged within a few days, and with out doubt any mammalian scavengers were at high risk of becoming infected. Wild pigs in the vicinity have been found with TB lesions, as have ferrets, and it is likely that if the current opportunistic sampling of scavenger species were extended to a systematic study, infection would be found in a range of animals. However there is no evidence that these species are maintenance hosts (infection cycling within the species), and they are likely to be merely spillover hosts which do not commonly pass infection on to other hosts. The critical issues in relation to transfer of infection from possums to cattle is whether cattle are likely to become infected from newly dead possum carcasses, or from organisms in or around decomposing carcasses which are not scavenged but are available to cattle. If transmission is, as seems likely from the evidence, mainly by the respiratory route, then dying possums which behave as found in this study represent a very effective source of infection. Such transmission would produce the pattern of infection seen in cattle herds, with a mixture of predominantly retropharyngeal and thoracic lymph node lesions in small temporal clusters of cattle, occurring intermittently with little or no lateral spread from infected beasts to other cattle. While dead possums may be responsible for occasional transmission to cattle as well as to scavenger species, it is unlikely that more than one animal would become infected at a time from a dead possum, because cattle are less likely to investigate such carcasses and even if they do so, have only a low probability of becoming infected by the oral route.

Direct observation of cattle-possum interaction has not been described previously, although badger-cattle interactions have been studied in England (Benham, 1985; Benham and Broom, 1989) and the potential for transmission of tuberculosis via fomites has been given considerable attention (Davidson, 1976; Benham and Broom, 1991). The presumption has been, and remains, that transmission of TB from cattle to possum occurred, by some process undefined, after the animals were introduced to New Zealand. Why a similar situation has not occurred in Australia is unresolved and is discussed further in Chapter 5. The mechanism(s) by which possums infect cattle were initially presumed to be by grazing of cattle on pasture contaminated by discharge from open wounds, and investigation of infected possum carcasses by cattle. It seems unlikely that *M. bovis* can survive on pasture in sufficient numbers to be infective by that means. However, contact between debilitated possums and cattle has been demonstrated to occur in ways likely to promote disease transmission. Possums, like badgers, generally appear to avoid cattle. But sick or debilitated animals may be seen feeding during the day, and have a decreased awareness of their surroundings. Such animals are much more likely to come into close contact with naturally curious cattle. Individual cattle are likely to vary in their degree of risk. Some individuals, notably the dominant animals in a group, investigated the novel 'object' more thoroughly by licking, mouthing and sniffing at the possum. Such animals are at high risk of infection by the respiratory route and mutual grooming of herd-mates by these potentially infective animals could spread the disease via respiratory and ingestive routes.

The separation of cattle and possums by a fence or anything other than a large water barrier is unlikely to prevent overlap in habitat use by the 2 species. The possum is a natural climber, as the badger is a specialist digger, and although barriers will restrict very weak animals many of these will already have moved close to favoured, and accessible, feeding areas such as pasture where contact between cattle and possums is likely. At least 3 tuberculous possums which had previously denned elsewhere have transferred their denning area to a more accessible area on the edge of the pasture-bush margin during the final weeks of their lives during the Castlepoint study (pers. comm. R.Jackson, D.Pfeiffer). Cattle also make use of any preformed tracks in an area and those formed by possums could give access to areas in the vicinity of possum den sites and to favoured possum feeding grounds.

This study has shown clearly that when possums are sedated to behave in a way which simulates the behaviour of terminally-ill tuberculous possums, then their abnormal behaviour attracts the attention of cattle and produces interactions which place some, but not all, of the cattle at high risk of becoming infected. It has also shown that there is a definite but much smaller risk of transmission when cattle come in contact with a recently dead tuberculous possum.

Chapter 5

A Preliminary Study of the Diet of Possums on Waio Station, Castlepoint, New Zealand

5.1. INTRODUCTION

A long-term study of endemic tuberculosis in population of possums in association with a group of beef cattle is designed in part to study the behavioural ecology of possums and cattle, and hence to help identify factors which may facilitate the transmission of tuberculosis between these species. Radio triangulation and direct observation have been used to investigate possum activity throughout the study site as a whole, and to observe behaviour of possums and cattle on pasture.

Interactions between clinically normal possums, and between possums and cattle, were shown to be infrequent on pasture. Interactions at the bush-pasture margin appeared to be common and more intense, and it is likely this is due in part to a concentration of animals, particularly where frequently used 'runs' opened onto flat and open areas. Threat and warning vocalisations were more common in denning areas and within bush than on pasture, where very little noise was made. Davidson (1976) and others have identified high reactor rates in cattle grazing areas heavily used by tuberculous possums (in Davidson's example, pasture). In situations where cattle have access to bush they may also come into contact with bodies of dead animals, possum den sites, and concentrations of possums in preferred feeding areas such as around kamahi, pine trees (pollen) and fuchsia. Where food supplies are localised, and possums are competing for a resource, interaction between animals may be more frequent and the transmission of TB facilitated as a result of fights, or indirectly through specific forms of environmental contamination (particularly scent marking of trees by animals with discharging sinuses from tuberculous lesions).

Radio triangulation has identified the general areas of the paddock used by possums, and shown the extent of seasonal variation in activities. However, triangulation error does not allow one to assume point locations from any pair of bearings, and in this diverse habitat it is difficult for example to pinpoint an individual possum to a particular food tree, and hence determine the diet of that possum. Direct observation of animals to determine location and feeding activity can be accurate but requires intensive effort, whereas analysis of faecal samples is an efficient and generally accepted method by which diets of animals such as possums can be assessed. Where different food types are localised in an area or are only available at certain times, this technique can indicate where animals congregate. In association with other information, food preference data can give potential insights into some aspects of disease transmission.

The aim of this study was to develop and where necessary adapt methods for collection and analysis of faeces so that foods eaten by possums in the study site could later be identified. A botanical classification of the area was not carried out, and as yet few of the foods eaten by possums have been identified, but it is apparent that a few species are eaten all year round while others are taken advantage of when available. Several varieties of plant were eaten very seldom, either due to lack of access to the species, or specific avoidance by possums.

5.2. REVIEW OF RELEVANT LITERATURE

5.2.1. The Australian Brush-tailed Possum in New Zealand

Since its initial introduction from Australia in the 1840s or 1850s (Pracy, 1962) the possum has spread through most of New Zealand. Widespread release of animals bred in captivity by individuals and acclimatisation societies, particularly during the 1890's, and partial or complete legislative protection until 1946 aided their spread. Originally introduced to establish a fur industry the possum rapidly adapted to New Zealand's varied habitats, and reproductive and survival rates far exceeded losses due to trapping.

In its native Australia, the possum is found in a variety of habitats from dry sclerophyll forest to open woodlands and temperate rainforest (Fitzgerald, 1978). Predominantly an arboreal folivore the possum spends approximately 90% of its time in trees (Winters, 1976; MacLennan, 1984) and feeds predominantly on mature leaves of *Eucalyptus* species according to Green (1984), although it will take advantage of a wide variety of other species (including grasses and forbs) when available (Statham, 1984). Kerle (1984) indicates that comparatively little is known about the diet of Australian possums, but they are adaptable in their dietary habits (in contrast to other arboreal folivorous marsupials such as the koala bear and Leadbeater's possum) and hence colonise many different habitats. *Eucalyptus* is either absent or uncommon in the diet of tropical rainforest animals, represents only a small (less than 10%) proportion for animals from Tasmanian wet sclerophyll forest and open forest of the wet-dry tropics, and in south western eucalypt forests varies from 65% in an area with a variety of shrub species to 95% where the habitat contains only eucalypts and pasture. Plant species in Australia have developed in association with browsing animals and have characteristics which reduce their palatability or increase their resistance to defoliation. These include toxins, the ability to regrow rapidly at any time of the year, and reproductive strategies which ensure their survival - such as abundant seed, or protected immature forms (Fitzgerald, 1984a).

In contrast New Zealand, until European settlement in the mid to late 19th century, had no terrestrial browsing mammals and its native forest is hypothesised to have little protection against such animals, being differently adapted to protect it against the moas, which were large flightless folivorous birds. When ancestors of the Maori people discovered New Zealand, during the second half of the first millennium A.D., about 80% (25 million hectares) of the country was forested and the only large land species present were moas. Since Maori colonisation, and accelerated by pakeha (European) land settlement, indigenous forests have been burnt and cleared to provide farmland and space for towns. Less than 5 million hectares of forest remains, much of it at higher altitudes unsuitable for remaining native species of bird, or scattered in small pockets through the country, and on offshore islands (Fitzgerald, 1984b). Introduction of exotic browsing mammals, such as deer and goats, has resulted in a large proportion of the remaining forest being opened up, as understorey plants are eaten and immature trees cropped before they can grow beyond reach (Kean, 1953; Pracy, pers. comm.). Kean and Pracy suggested that the clearing of understorey in New Zealand forest aided

the spread of possums through our forests. Destruction of forest has led to isolation of populations into ever shrinking areas, a decrease in the diversity of that forest, and increased competition with introduced species.

As early as 1919 concerns about possum damage to native forest were reported (Kirk and Bendall, cited in Fitzgerald pg 142, 1984a). Research and inquiries between 1920 and 1940 often led to ambiguous or unsubstantiated conclusions. Perham in 1924 (cited in Fitzgerald, 1981) indicated that a search for damage by possums was unrewarding, and considered that their leaf eating habit, *if moderate*, (my italics) would have no bearing on the welfare of the forest as "...trees have been subjected to and withstood such from pigeons through many centuries." Cockayne (1928) thought that if possums were damaging the forest it would be obvious from the number of dead trees, and "...at any rate the value of possum skins would make control of the animal cost effective" (cited in Fitzgerald, 1981). However an increasing number of reports of damage to crops, as well as forest, led the government to remove all restrictions on killing possums in 1947, and to introduce a bounty from 1951 to 1960 (Zotov, 1949; Fitzgerald, 1978). The discovery of tuberculous possums in 1967 and their positive association with tuberculous cattle in 1970 further emphasised the need for possum control strategies.

5.2.2. Possum Diets

Possums in New Zealand, as in Australia, tend to feed selectively on a few species. Fuchsia (*Fuchsia spp.*), rata (*Metrosideros robusta* and *M. umbellata*), kamahi (*Weinmannia racemosa*), fivefinger (*Pseudopanax arboreus*), kohekohe (*Dysoxylum spectabile*), makomako (*Aristotellia serrata*) and titoki (*Alectryon excelsus*) are species common to all studies of possum diet in New Zealand (Mason, 1958; Fitzgerald, 1976; Fitzgerald, 1981; Leathwick *et al.*, 1983; Coleman *et al.*, 1985 Cowan, 1990a; and others). Often the possum eats many of the same plants as native birds, such as the kokako (Fitzgerald, 1984b), placing more pressure on these endangered species. Forbs and herbs (grasses) are a major part of the diet of possums living close to pastures. Tasmanian possums eat forbs and herbs when available (Fitzgerald, 1984a) and the effects of possums on grazing land in New Zealand has been of concern for many years. Gilmore (1965b) indicated that possums ate substantial amounts of pasture species at all times of the year. Coleman *et al.* found similar results, with pasture comprising 12% of the diet of possums living within 300 m of the forest edge, and individuals, particularly males, travelling up to 1000 m to graze on grass and clovers. Harvie (1973) found 30% of the diet of possums shot on farms near Waverley consisted of pasture species. The presence of possums on, and their willingness to travel considerable distances to, pasture may have greater ramifications than reducing stock carrying capacity. Davidson (1976) demonstrated that cattle could become infected from grazing on pasture used by tuberculous possum populations. Whether stock had access to bush surrounding that pasture is not indicated, but pasture/bush margins support the highest densities of possums of any habitat in New Zealand and also a high prevalence of tuberculous animals (Green and Coleman, 1986; Coleman, 1988). Possums spend most of their time

either gathering food or resting (Winter, 1976), and information about their locations and feeding preferences may indicate improvements in strategies to control the spread of tuberculosis.

5.2.3. Dietary Analysis

Four main methods have been used to analyse herbivore diets (Barker, 1986b)

1. recording changes in the composition of vegetation after grazing
2. observing animals as they feed
3. sampling plant material along the digestive tract
4. identifying plant remains in faeces

Tribe (1950) indicated the usefulness of direct observation of feeding as a means for determining optimal pasture types and improving the environment to maximise production, but also pointed out the limitations of this approach. Many factors contribute to a particular animal's selection of pasture species, and identification of pasture types in mixed swards is difficult. Similarly, changes in herbage composition after grazing may be due to factors other than simple grazing pressure by the animals and are difficult to assess in heterogenous environments.

Many studies have analysed ingested material at some point along the gut. Oesophageal and ruminal fistulae have been commonly used but are seldom practicable in wild animals, either due to difficulty in recapture and/or the excessive stress caused (Stewart, 1967). Comparisons between gut contents and faecal samples have been made for several species in attempts to determine the accuracy of the methods. Anthony and Smith (1974) found that rumen and faecal sampling in mule and white tailed deer gave similar results, as did Kessler *et al.* (1981) in pronghorns. Norbury (1988a) compared stomach and faecal samples from grey kangaroos finding that in captive animals fed prepared rations results were similar, but for free-ranging greys differences in proportions of plant species were such that faecal analysis may not be suitable for animals eating a variety of foods. McInnis *et al.* (1983) compared fistulas, faecal analysis and direct observation of forage utilisation in sheep and found significant variation in diets determined by the various methods. Oesophageal fistulas were most representative of species eaten by the animals. All studies indicate that differential digestion of plant species is important in affecting the accuracy of faecal and stomach sampling methods. Barker (1986a) noted that 4 assumptions are made when identifying remains of plant species under a microscope;

1. the number and size range of particles retained after sample preparation are unaffected by plant species
2. the proportions of particles that can be identified are independent of species
3. plant species are equally digestible and
4. if some of the above assumptions are incorrect then correction factors can be applied to reduce bias.

Results of his work indicated wide variations between plant species in the validity of the first 3 assumptions. Correction of data using index factors improved some analyses and exacerbated the

error in others. Dunnet *et al.* (1973) developed indices of resistance to digestion for many of the mature leaf types eaten by possums. They found wide variation in indices obtained for the same leaf type from different animals and noted possible causes for this such as the length of time the food remains in the digestive tract, which in itself may be influenced by the composition of the diet, or the amount of food ingested.

Various techniques have been used to minimise bias in faecal sampling techniques. Norbury (1988b) compared 3 commonly used methods - frequency of occurrence, the number, and the area covered by different fragment types. Although the literature indicates the most commonly used method - relative area of fragments - is most precise, it does not identify all fragments and he applied a correction factor based on the proportion of identifiable tissue. Barker (1986b) attempted to simplify analysis by categorising the amounts of plant species present into groups indicating that the normal methods are “not accurate enough to repay the work involved”.

Analyses of possum diets have been a common part of studies of the biology of the species, most commonly using stomach or faecal analysis. Many studies have corrected for variations in digestibility of plant species. Possums eat a wide variety of leaves, fruits, grasses, flowers, pollens, bark and possibly some insects, and accurate methods of assessing the dietary contributions made by each of these foods are unavailable. For the purposes of this preliminary project, identifying relationships between proportions of food in the diet may be sufficient to locate possums in certain areas of the site if the plant species in question is localised. Further work including a botanical survey of the study site and integration with geographical, home range and other data will be carried out by other researchers.

5.3. MATERIALS AND METHODS

5.3.1. Sampling Method and Preparation

Faecal pellets were collected from possums caught on the first day of each monthly trapping visit to the study area between December 1991 and October 1992. The site is roughly divided into eastern and western areas and trapped as 2 sections - samples were taken from 15-20 possums from each section (trap line). Fresh pellets were taken from underneath cages, or collected if the possum defecated during examination. Pellets from individual animals were stored in 10% formalin and identified as to date, identification number and trap area. Each trap line was analysed separately with a pooled 1 pellet sample drawn from each possum collected on that line forming a bulk sample for each month.

Bulk samples were drained of formalin, ground with mortar and pestle in a small amount of water, and put in a 150 ml container filled with concentrated domestic bleach (Sodium hypochlorite 52.5 g/l, sodium hydroxide 13 g/l, available chlorine approx. 40 g/l) as described by Norbury (1988b). Samples were soaked overnight and then gently rinsed with water through a 212 µm sieve. A 5 g sub-sample was mixed to a creamy consistency in a metal bowl with a small amount of water. Two ¼ teaspoon portions were placed into separate petri dishes marked with grid squares. Ten squares on each petri dish had all identifiable leaf and seed fragments in them counted. A total of five 5 g sub-samples were taken and processed from each bulk sample resulting in a total of 100 grid squares being scanned from each monthly bulk sample. Aliquots were thoroughly spread over the petri dish by gently rotating the dish to ensure even spread of the sample and observed through a binocular microscope at 40x magnification.

5.3.2. Reference Collection And Identification Of Species Eaten

Samples of vegetation were taken from throughout the paddock and identified. Emphasis was placed on woody plants and leaves likely to resist digestion; few grasses were collected. Samples were cut into 5-10 mm size sections and macerated in a combination of nitric and chromic acids (Dunnet *et al.* 1973). Specimens were left in the solution for a variable length of time depending on the clearance rate of the cuticle. After washing and neutralisation in dilute ammonia, they were stained with basic fuchsin, mounted on slides and dehydrated through an alcohol series. Photomicrographs of the slides provided an accessible reference collection. However, few specimens fitting the reference collection samples were able to be identified in the faecal samples. A second reference collection was subsequently made from leaf and seed fragments identified in a pooled sample of faecal pellets collected from the same possums over several months (March to August). Twenty-five unique specimens were found in this sample and then mounted and photographed. The majority of specimens have not been identified as to species at time of writing and are referred to as letters in the analyses. Results were collated in Paradox and analysed in Statistix.

5.4. RESULTS

Figure 5.1 shows the overall proportions of each type of plant identified. Fragments of every leaf type except codes L and N were found on at least one occasion but for types A,E,I,Q,R,S,T and W less than 10 fragments were seen of each and are combined for later analysis as plant ID=Z. Taken together, only 31 fragments of these were found out of 12,001 identified, comprising 0.26% of the total. Figure 5.2 indicates the proportions of plants found in samples from each sub-area. The similarity between areas is obvious - indicating that, over a year, possums throughout the site ate similar plant species in roughly similar amounts. Figure 5.3 shows the percentage of an individual plant type derived from each section of the study area. Only types Z, B, and Y appear to be eaten more frequently on the west side than the east. There was little difference in the number of fragments obtained from each section. The division between areas is based on geographical features and there is known to be overlap in possums movements between the sub-areas.

5.4.1. Seasonal Variations Of Plant Types In Faeces

Differences in availability of plant type and their acceptability to possums are likely to have influenced possum diet in the study area. Figures 5.4a and b show the proportion of each plant type in the combined samples for the areas in relation to time of year; for these data the year was divided into the 4 seasons - December through February (Summer), March through May (Autumn), June through August (Winter) and September to November (Spring). Patterns between areas are similar, with 2 types - F and V - making up most of the diet year round and 2-3 others - H, J, and P - mostly eaten in particular seasons. This is further illustrated in figures 5.5a and b showing seasonal use of individual plant types. Figures 5.6a and b show the same data but relating to the timing of the possum breeding cycle - March through May (Mating), June through October (Joeys present, also some spring breeding likely during this time) and November through February (Females in anoestrus). Figures 5.6a and b indicating the composition of faecal samples and 5.7a and b variation in individual plants through the seasons. Patterns for all graphs are similar, indicating possums from both areas have access to the same food types.

Figure 5.1 Proportions of plant types found in faeces- all samples

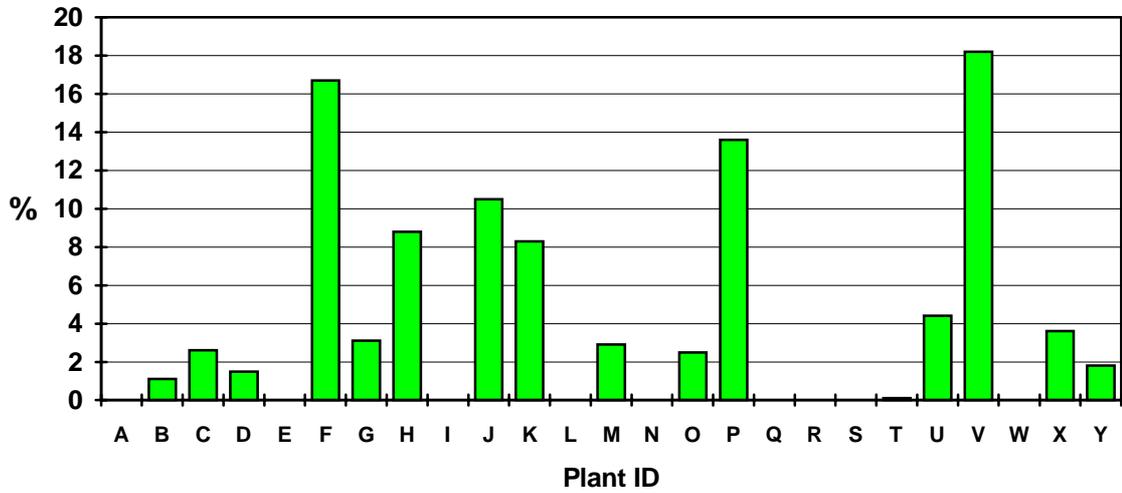


Figure 5.2 Proportions of plant types in faecal samples from each area

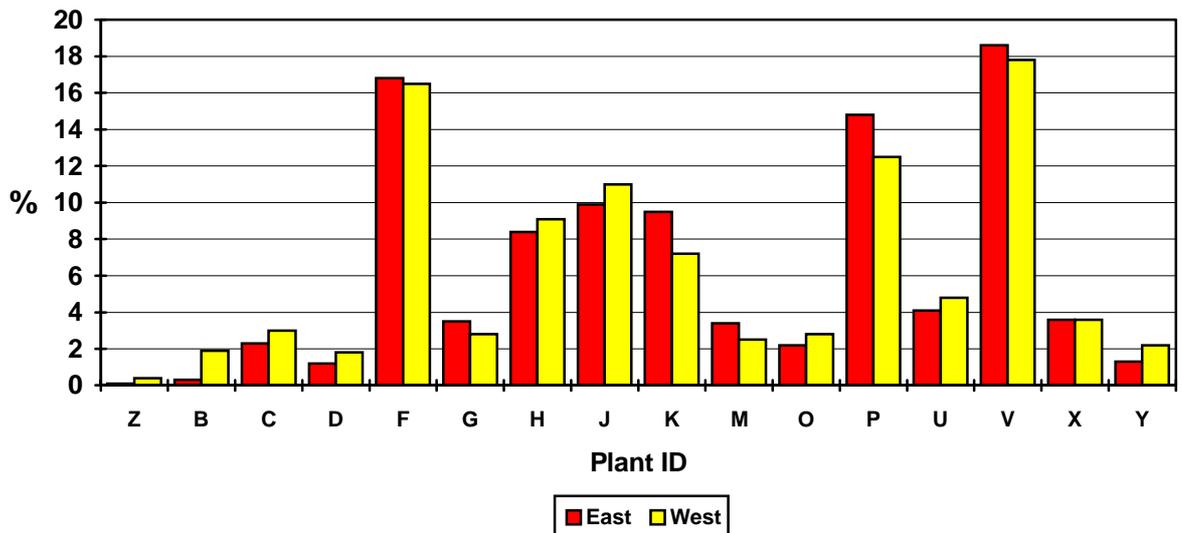


Figure 5.3 Plant type distribution between sample areas

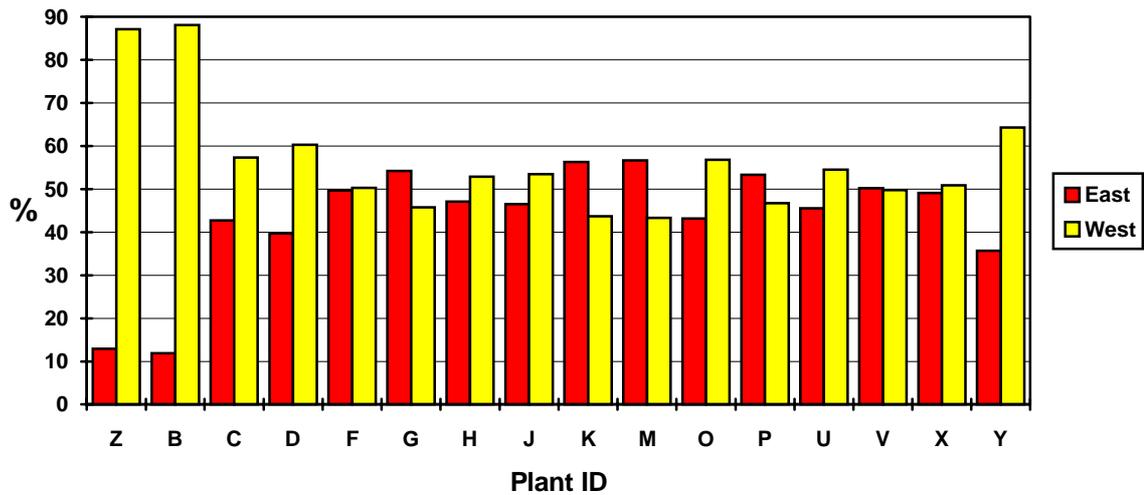


Table 5.1 Percentage of Plant types in possum diet each month

Note: All figures are in % except the totals which refer to the number of specimens found each month

Plant Type	Month of Year											Mean
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Dec.	
Z	0.6	1.5	0	0.1	0.2	0	0.1	0	0	0.1	0	0.2
B	0.5	4.7	0.1	0.2	0.2	1.4	0.4	3.4	0	0.7	0.1	1.1
C	4.9	4.3	4.4	1.8	3.3	2.7	1.3	2.1	1.5	1.2	0.1	2.6
D	3.1	2.4	1.9	0.9	1.6	1.4	0.5	1.3	0.6	2.5	0	1.29
F	12.6	13.4	13.3	18.5	12.3	17.1	19.6	19.2	18.9	18.4	23.3	13.3
G	5.5	14.3	3	0	7.4	0	0	0	0	0	1.3	2.8
H	0.3	0.6	8.6	10.2	8.1	8.6	6.8	19.1	16.2	18.3	0	8.8
J	17.1	15.6	10.8	18.7	15.9	0.1	0.1	5	3.2	5.6	23.3	10.5
K	15.4	7.4	10	3.2	8.6	9.7	15.1	0.5	9.5	3.8	8.5	8.3
M	4.2	2.2	0.5	7.2	6.9	1	0.9	2.1	1	2.8	3.4	2.6
O	1.4	0.5	10.2	0	0.3	4.6	0.2	2.4	3.8	3.5	0.1	2.5
P	1.4	10.1	16.3	18.6	15.1	17.2	12.4	19.3	18.6	18.4	0.8	13.5
U	7.5	5.4	3.6	2.1	3.5	1.6	1.9	5.9	7.3	5.9	4	4.4
V	16.9	15.7	17.2	18.7	16.6	17.1	20.1	19.2	18.9	18.4	23.3	15.6
X	0	1.8	0	0	0.3	17	20.5	0.5	0.6	0.3	0	2.3
Y	8.8	0.1	0	0	0	0.4	0	0	0	0.1	12	2.4
Total*	1172	1265	1154	1067	1167	1180	950	1040	1060	1086	860	

Figure 5.4a Proportion of plant types in samples by season - East area

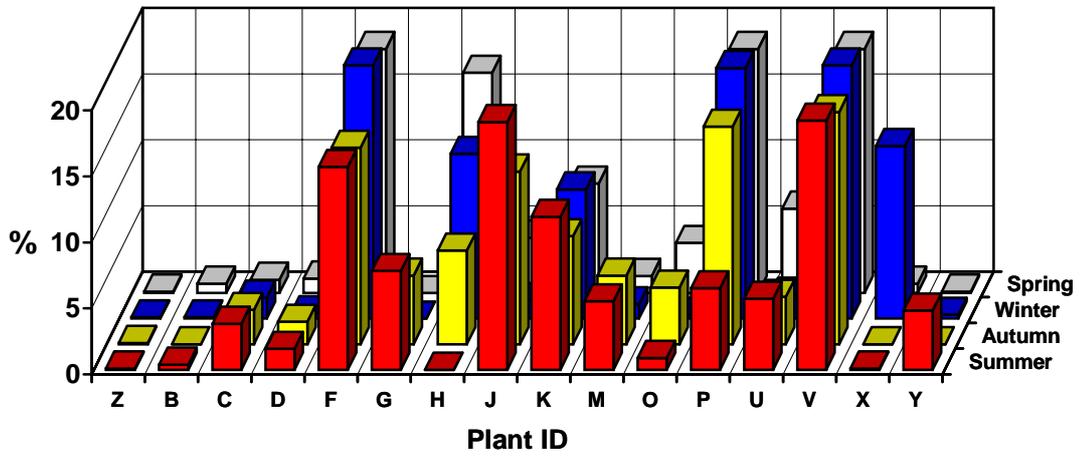


Figure 5.4b Proportion of plant types in samples by season - West area

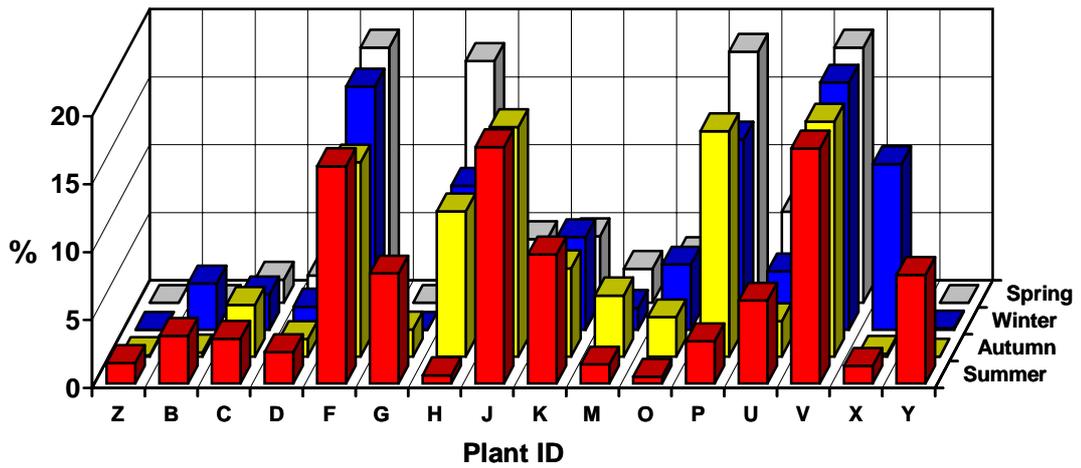


Figure 5.5a Seasonal distribution of individual plant types - East area

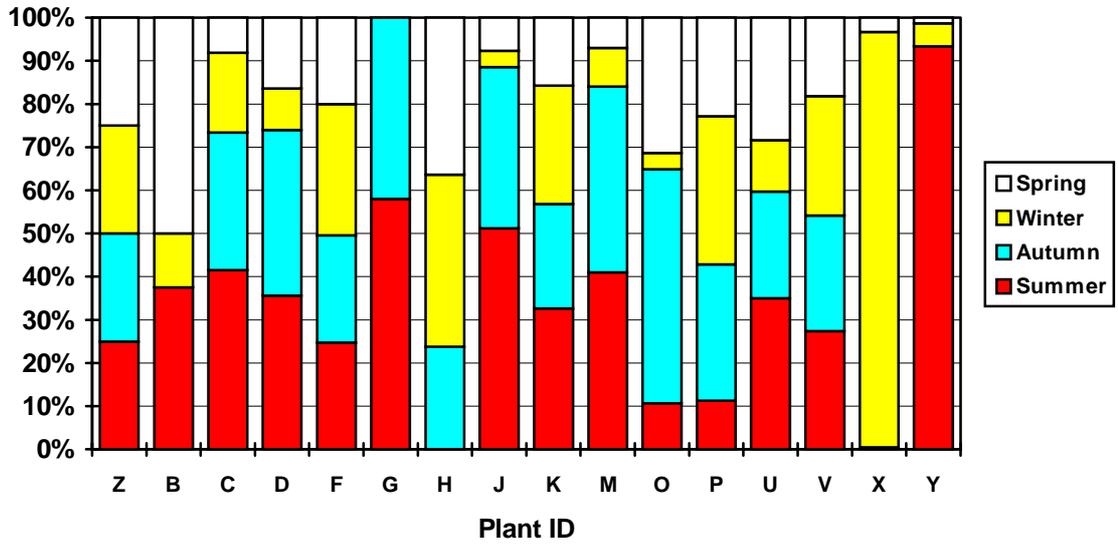


Figure 5.5b Seasonal distribution of individual plant types - West area

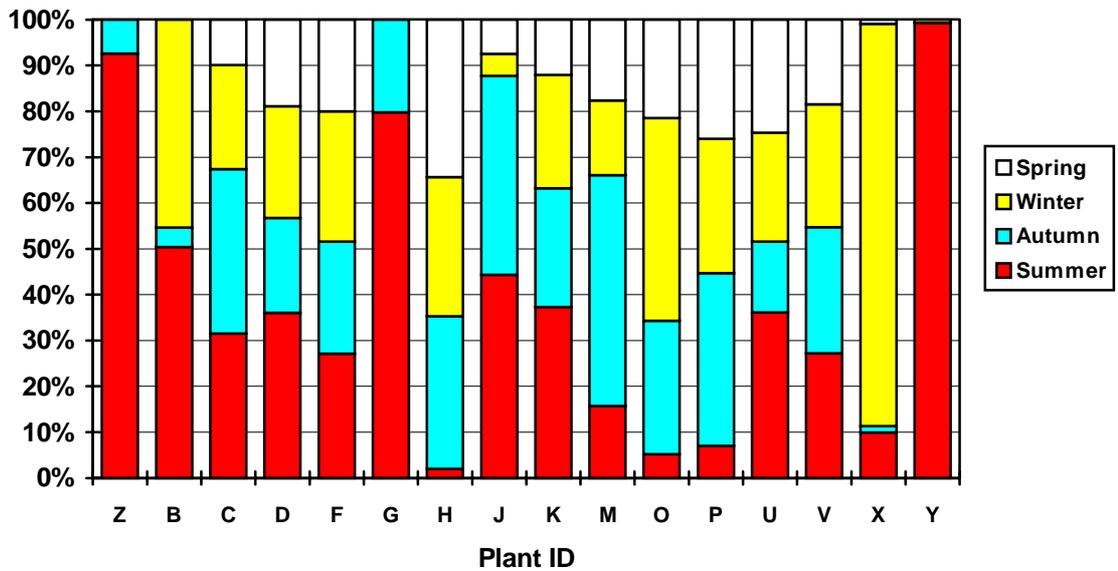


Figure 5.6a Proportions of plant types in samples in relation to the possum breeding cycle - East area

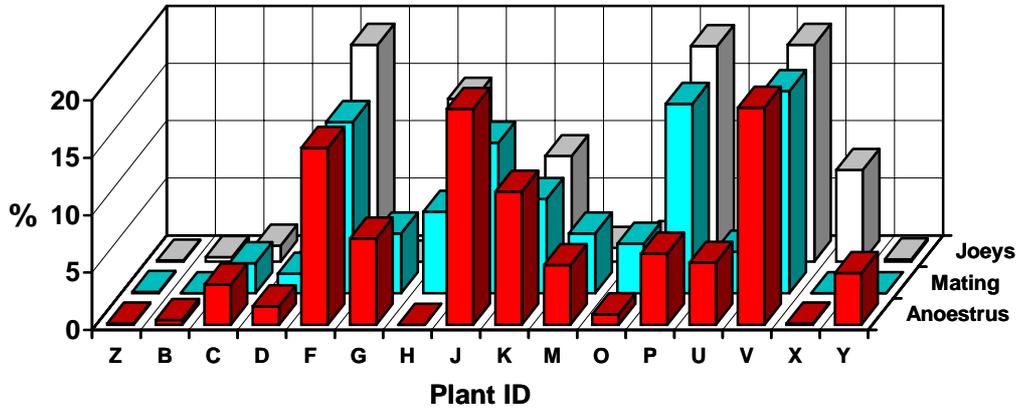


Figure 5.6b Proportions of plant types in samples in relation to the possum breeding cycle - West area

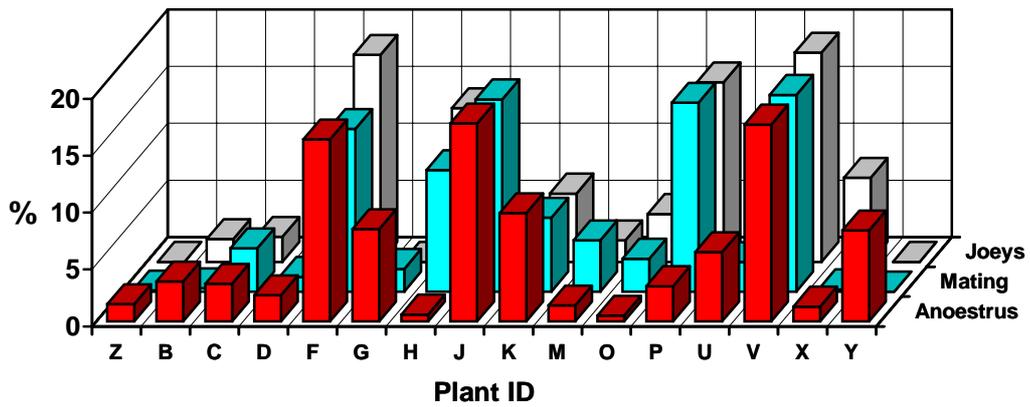


Figure 5.7a Seasonal distribution of individual plant types in relation to possum breeding cycle - East area

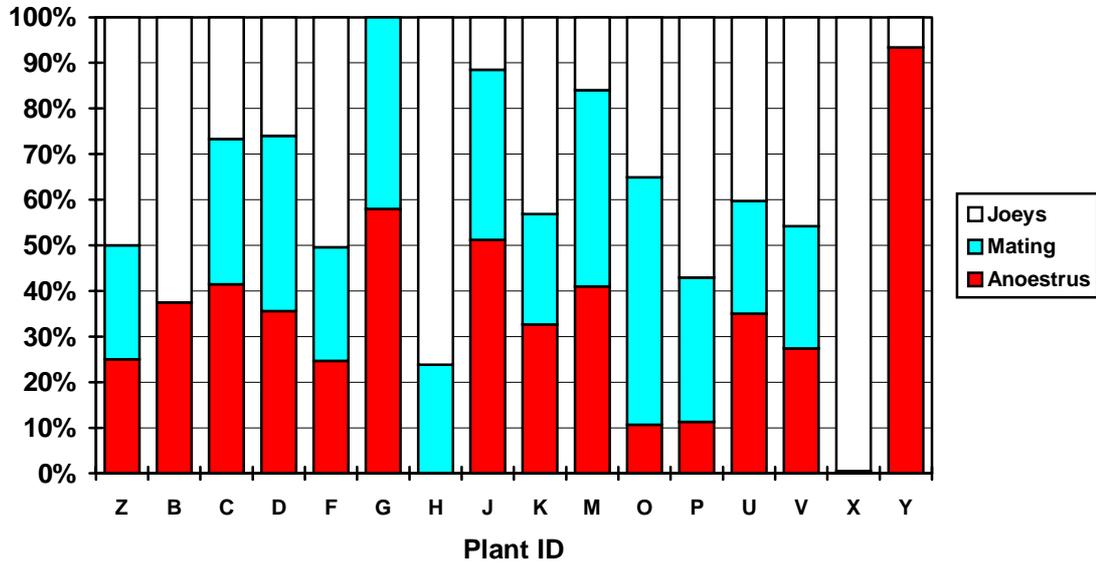
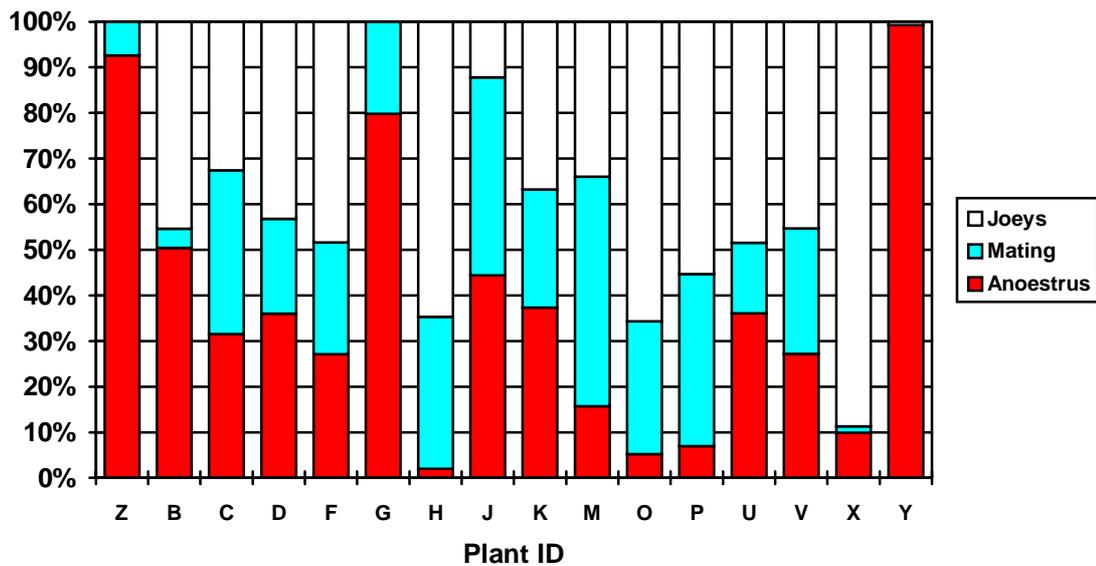


Figure 5.7b Seasonal distribution of individual plant types in relation to possum breeding cycle - West area



5.5. DISCUSSION

Variation in proportions of plant types in the diet is consistent with other studies of possums in New Zealand, as is the significance of a relatively few species out of many (Fitzgerald, 1978; Coleman *et al.*, 1985). Possums on the study area showed a clear preference for a few of many plant species in the area as was shown by Fitzgerald (1979) in Westland and again in Tasmanian bush (Fitzgerald, 1984). Twenty-five food types were identified in a bulk faecal sample and another 20 species were collected from the study area but 3 types (plants V, P, and F) made up 50% of the diet with 3 others forming another 25%. The overall proportions of each plant type eaten were generally similar on both sides of the study area. Several plant types found in small amounts, predominantly from the western area, are possibly restricted in their distribution. The most diverse region of bush in the site is found on the western edge of the west region, and the majority of possums sampled in the eastern region were never caught that far west, (data from trapping records), whereas several of the possums trapped in the western region are known to live close to that bush. The effect of trapping would alter normal possum movements in that trapped animals do not have access to the whole of their range if captured early in the night, however these faecal samples are generally indicative of the *previous* night's feeding (or in some animals even earlier) when possum movements are unaffected by traps.

Although plant types were not identified, seasonal variations in the proportions of particular types in the faeces may have been due, in part, to their availability. The plant types eaten most often remained consistent throughout much of the year. Plant type P was found in minor proportions in summer but was a major contributor the rest of the year, while types J and K were important in summer. Generally similar proportions of individual plant types were found in each area with some exceptions, notably types O, M and B, either specific to a small area or found in small numbers.

Several plant parts, such as gorse flowers and pine pollen, known to be eaten by possums in the study area, were not identified in the faecal samples. The stomach contents of possums killed near the paddock during January and February had large amounts of gorse flowers in them, although these may not survive digestion and hence not be found in the faecal samples. Similarly, pine pollen is apparently eaten from July to September, as the faeces are distinctly yellow at this time, and many possums are seen feeding in pine trees. Harvie (1973) indicated pine pollen was only rarely eaten by possums near Waverley, although Gilmore (1965a) found that possums on Banks Peninsula favoured it. Fresh faeces, from individual animals sampled in June and July, were initially used to test the analysis technique. They were found to contain large amounts of pine pollen. Subsequent investigation of these, and later samples, found no pollen grains. Faecal pellets were preserved in 10% formalin after collection and this may have affected the pollen in some manner, perhaps making it unrecognisable. This finding would have a significant effect on the proportions of plant types over the winter months but the significance of pine pollen to the possum is unknown. Nutritive values of foods eaten by possums in New Zealand have not been studied in depth. The attractiveness of

particular foods at the end of winter, when choices may be limited and body weights are often low, could be important in possum control strategies.

Problems inherent in diet analysis from faecal samples such as differential digestion of species, variation in rates of digestion between animals, the proportion of plant particles that are identifiable and different fragmentation patterns of plants, were not addressed in this study. Simple counts were made of identifiable species and this showed different use of various plant types and clear seasonal patterns. Botanical surveys and phenological¹¹ records from the site will be used in later studies to investigate possible associations between plant species and their use by possums. Transmission of tuberculosis in possums is most likely to occur where animals congregate or interact and, apart from den sites, food resources (particularly preferred species), may attract many animals at certain times of the year. Information such as this can be used to improve the management and increase the efficiency of possum control operations.

Figure 5.8 Damage to mingi-mingi as a result of possum bite and scratch marking



¹¹studies of the time of recurrence of natural phenomena - ie. when does that plant flower?

Chapter 6

General Discussion and Conclusion

6.1. DISCUSSION

The main aim of this project was to study the behaviour of possums to determine factors that may facilitate the transmission of tuberculosis between possums, and from possums to cattle. The study area chosen has been enlightening, and frustrating, in its suitability for the task. While the observation of possums in certain areas of the paddock (such as in the lower pasture) was made easier by the concentration of animals feeding in this area, the thick bush and steep terrain in others prevented close observation of possums. Radio triangulation studies in the area were made easier due to the general trend for possums to move down from their den sites into the valley to feed. Conversely, the dissected terrain contributed to poor signal reception in some areas.

Conducting the study in as 'normal' as possible a farming environment was considered very important. Most of the studies conducted in New Zealand to date have been in forest, or have concentrated on possum ecology in isolation from other factors, with few long term projects among tuberculous possum populations. Results from this project add to our knowledge, but application of them in varying habitats must be approached with caution.

6.1.1. Possums as a Wildlife Reservoir of Tuberculosis

The role of the possum as a wildlife disease vector is not unusual in the world. There are many species that act as a source of disease for domestic animals or man - for example the fox, skunk and raccoon (rabies), several species of insect (trypanosomiasis and malaria), and the badger (tuberculosis). However, the possum may be unique for several reasons: (i) it is present in large numbers, (ii) has a high reproductive potential, (iii) is highly adaptable and (iv) is an efficient vector for tuberculosis. The possum has a poor immune response to *M. bovis*, is most abundant at the pasture/bush margin, and its distribution overlays many of the areas used to produce one of the principal foreign exchange earners for New Zealand - agricultural products (Davidson, 1970; Hickling, 1991; Julian, 1981).

Tuberculosis in possum populations has been found to have certain characteristics. These include an uneven spatial distribution of infection through a population, seasonal variations in the prevalence of disease - both in possums and associated cattle, and the persistence of tuberculosis in possum populations in the absence of cattle (Coleman, 1988; Davidson, 1970; Efford, 1991; Pfeiffer and Morris, 1991). Possums are highly susceptible to *M. bovis*, experimental infection generally resulting in dissemination of the disease throughout the body, particularly involving the lungs and lymphoid tissue - specifically peripheral and hepatic lymph nodes (Bolliger and Bolliger, 1948; Corner and Presidente, 1980 and 1981). Many of these animals developed sinuses to the skin surface, and large numbers of bacilli were found in faeces and urine. The survival time of possums in such laboratory experiments is measured in weeks, whereas naturally infected animals may survive 4-6 months or more (D. Pfeiffer and R. Jackson, pers. comm.). Factors such as captivity, body weight and environmental conditions will alter the resistance of an animal to infection.

6.1.1.1. Possible Transmission Mechanisms

Our understanding of disease processes in the possum, and the dynamics of tuberculosis at the population level have improved, but there are still unresolved issues over the transmission mechanisms between possums, and between possums and cattle. Early findings of extensive, suppurating lesions, and the apparent infectivity to cattle of pasture grazed by possums led researchers to believe transmission to cattle occurred primarily through ingestion of contaminated pasture (Davidson, 1976; Ekdahl *et al.*, 1970). However, it is difficult to isolate *M. bovis* from faeces or urine of *naturally infected* possums. Several dead, tuberculous, possums have been found on pasture at Castlepoint, but few, now, are found to have extensive external lesions. This is in comparison to the first 18 months of the study when large numbers of tuberculous animals had such lesions. The severity of the winters in 1988 and 1989 may account for differences in the extent of lesions, and survival time of possums. Further epidemiological studies into the survival times of *M. bovis* on pasture are underway (Jackson, unpub.), although initial results (and those from the U.K.), indicate survival time on pasture is measured in days, rather than weeks (Anderson and Trehwella, 1985).

There are several possible mechanisms for transmission of *M. bovis* between possums, and by extension, to cattle:

- Respiratory route - aerosols and droplets (agonistic, courting and mating behaviours)
- Orally - through saliva, bites, and grooming behaviour (also includes territorial marking)
- Faeces - general environmental contamination
- Urine - general environmental contamination, includes scent marking
- Pseudo-vertical transmission to the young (milk, prolonged contact, grooming)
- Abscessation - general contamination of the environment, particularly in den sites, and on the animal's coat
- Carcasses - point source environmental contamination in potentially high concentrations (den sites, pasture)

If, as appears likely, general environmental contamination, through exudates on pasture, is insufficient to produce more than a very short term infective dose (if that), then more specific transmission mechanisms need to be investigated. It has been well demonstrated that aerosols are effective means of transmission over distances of 1-2 metres, as is prolonged, unhygienic, contact with tuberculous patients. Thus, behavioural related activities, such as rearing young, mating, agonistic interaction, and den sharing, as well as close contact between individuals may be more likely routes. Included in the latter category are activities such as territorial marking (bite and scent marks), and abnormal contacts (debilitated animals, examination of carcasses, and unusual behaviour).

6.1.2. Tuberculosis in Badgers

Bovine tuberculosis in the badger in the United Kingdom has many similarities to the situation in New Zealand, and a comparison is informative. Compulsory area eradication schemes for

tuberculosis were introduced in Britain in 1950, and by 1960 the whole of Great Britain was considered attested (technically free of tuberculosis). The incidence of infection¹² continued to decrease overall during the 1960s, but certain areas, notably in south-west England¹³, continued to experience higher herd infection rates than the rest of the country. A major source of bovine TB in England was controlled with the implementation of pre-export testing of Irish bred cattle in 1976 (Rees, 1976, cited in Wilesmith, 1983)¹⁴. However, many herd infections could not be attributed to common sources, and further investigations discovered infected badger populations associated with many properties. Badger setts in some of these areas were gassed, and repopulation prevented - subsequent freedom of infection in cattle in those areas firmly incriminated the badger. Badgers were first suspected as a source of infection to cattle in Britain in 1971 (Muirhead *et al.*, 1974), although bovine tuberculosis in badgers had been described in Switzerland as early as 1957 (Bouvier *et al.*, 1957, cited in Wilesmith, 1983), where it was thought that roe deer were the source of infection. Badgers in the United Kingdom probably became infected with tuberculosis during the 1960s (Wilesmith, 1986b).

It became apparent that cattle herds in areas of high badger density run an increased risk of infection. Infection is sporadic, and generally only small numbers (average 2-3 beasts per infected herd) are involved in an outbreak (Anderson and Trewhella, 1985; Wilesmith, 1983). The number of cattle beasts excreting *M. bovis* is often low as a result of the frequent testing of animals in 'high risk' areas, hence cattle to cattle transmission is insignificant in most cases. The link between badgers and tuberculosis in cattle herds is now firmly established, however, as in New Zealand, the precise transmission mechanism(s) from wildlife reservoir to cattle are uncertain.

6.1.2.1. Badger Ecology and Behaviour

Badgers are social, highly territorial, nocturnal, and omnivorous mammals, living in 'setts' or extensive communal burrows underground. The European badger (*Meles meles*) lives in groups (clans) of up to 12 individuals, in well defined, and stable, territories. Based on a main sett, and several outlying secondary setts, territory size in southern England varies between 22 and 80 ha, (Kruuk, 1978a; Wilesmith *et al.*, 1986b). Badgers are omnivorous, the major proportion of its diet consisting of earthworms (up to 61%). Wheat, acorns, and insects are also commonly eaten (Kruuk, 1978a). Territories are defended, although (as with most animals), this involves a large amount of ritual rather than overt aggression. Badgers are however, extremely aggressive animals, their large hooked claws, wedge shaped body, and weight of 6-10 kg makes a formidable adversary. 'Latrines', small areas in which badgers preferentially defecate, are scattered throughout the home range, and particularly on territory boundaries. This habit has aided researchers in monitoring use of an area.

¹² Number of new cases of infection over a defined period of time

¹³ Parts of Gloucestershire, Avon, Wiltshire, and Cornwall

¹⁴ Large parts of Ireland were later found to have endemic tuberculosis in its badger populations.

Coloured beads mixed with a bait are placed in group territories, and used in determining which animals frequent a particular latrine (Kruuk, 1978b; Wilesmith *et al.*, 1986b; and others). Under normal conditions the badger seldom strays into neighbouring territories, except when in search of oestrous sows.

There are several aspects of badger ecology and behaviour which aid in the maintenance, and transmission, of tuberculosis. Like the possum, the badger has a poor immune response to *M. bovis*, although the disease course is much longer in the badger, some individuals surviving for 2-3 years (Anderson and Trehwella, 1985; Little *et al.*, 1982). High concentrations of bacilli are found in the lungs, sputum and saliva, as well as the urine. Lower numbers of bacilli are found in faeces, with indications that such shedding is intermittent. Male badgers have a higher rate of infection than females in some reports (Gallagher and Nelson, 1979), while cubs had higher prevalences in others (Cheeseman *et al.*, 1981a; Wilesmith *et al.*, 1986b). These differences could be partially due to the higher potential contact rate for males (mating forays, etc), and that females of most species are immunologically more competent than males (Castro, 1974, cited in Wilesmith, 1986b).

Badgers urinate frequently on pasture (due to the high water content of earthworms), and the concentrated use of latrine pits can result in high levels of contamination in these areas. The communal underground life of badgers provides excellent conditions for the survival, and transmission, of tuberculosis. Warm, dark and moist conditions favour growth of *M. bovis* (MAFF, 1979 and Madlock, 1933; cited in Anderson and Trehwella, 1985). Badgers rely greatly on scent, and frequent nuzzling of conspecifics, mutual grooming, and communal sleeping groups increases the risk of contact with *M. bovis*, transmission being most frequent by the respiratory route (Anderson and Trehwella, 1985). Pseudo-vertical¹⁵ transmission is almost certainly important in the maintenance of infection in the badger population, as are unapparent carriers (Cheeseman *et al.*, 1988b). Transmission between social groups can occur through territorial aggression (bite wounds), mating activity between social groups, dispersal of individuals (particularly juveniles), and as a result of abnormal behaviour caused by infection with tuberculosis.

6.1.2.1.1. Characteristics of *Mycobacterium bovis*

The survival time of *M. bovis* on pasture is poorly documented. There are many factors that will affect the longevity of the organism in the environment. Some of these factors have already been alluded to (heat, humidity and light levels etc). Evidence indicates that although the organism may survive on pasture for more than 7 days in winter (U.K. conditions), in summer no organisms survived to 3 days (MAFF, 1979, cited in Benham and Broom, 1991). The large number of organisms excreted in the urine of an infected badger, represent significant environmental contamination.

¹⁵ Mother to cub

6.1.2.1.2. *Transmission of tuberculosis between badgers and cattle*

Benham and Broom (1989) found that normal activities of badgers would not result in direct transmission of tuberculosis to cattle. Badgers avoided close contact with cattle (minimum separation of approx. 15 m) and rapidly fled when approached. Badgers often took circuitous routes around mobs of cattle and closely monitored the position of stock in the area when feeding. However, cattle are inquisitive about the activities of badgers, and investigated sett entrances and, to a lesser extent, latrine pits (although there was no evidence to suggest cattle were attracted from a distance to investigate the latter). Benham and Broom (1991) investigated the responses of cattle to badger waste products (faeces and urine) on pasture, concluding that the majority of animals avoided such material. However, a few cattle beasts were far less selective in their feeding habits, and they suggested these animals may be at risk. They note that only small numbers of cattle contract TB in areas that are expected to have a high level of environmental contamination. A lack of selectivity in some individuals was suggested as a possible explanation for this.

Although badgers are nocturnal, and generally avoid contact with other species, there are several reports in the literature of badgers being seen in daylight, and in and around farm buildings (Cheeseman and Mallinson, 1981b; Muirhead *et al.*, 1974; Wilesmith *et al.*, 1986b). Commonly, badgers systemically affected with tuberculosis lose their fear of man and other animals, roam more widely than usual (through other clans' territory), and may sleep in farm buildings (byres, hayracks, troughs, etc). The potential for indirect transmission to other species (cattle) is obvious, as is the increased likelihood of aggressive interaction with other social groups. Wilesmith *et al.* (1986b) and others (cited in Wilesmith pg 24, 1986b) considered that 10-15% of tuberculosis badgers may have become infected through bite wounds.

6.1.2.2. *Summary*

The association between sett density and tuberculosis in cattle herds indicates that badgers play an important role in the transmission and maintenance of tuberculosis in an area. The foraging activities of the animal, coupled with prolonged periods of infection, excretion of large numbers of organisms, and the survival of the organism in the environment (water and feed troughs etc), are sufficient to facilitate transmission to cattle in some circumstances. However, it is likely that direct transmission (via aerosol) from terminally-ill badgers to cattle is the major transmission route. The capacity for tuberculosis to remain endemic in badger populations (even at low population densities), the difficulties and costs associated with complete control of infected populations (identification of infected animals, legal protection of the badger and opposition from animal protection organisations), mean that control of the disease is difficult and often impracticable using present control measures. Additional, or alternative, control measures may be necessary to control the disease in many areas, as well as continued research into many aspects of the epidemiology of tuberculosis in badgers and cattle.

6.1.3. Discussion of Study Findings

6.1.3.1. *Home range size and dispersal*

Results from this work largely confirmed those found elsewhere, taking into consideration the variation in habitat between study sites. Radio triangulation showed the possums remained in relatively well defined home ranges over long periods of time, with occasional sallies beyond those areas. Range sizes were consistent with those reported elsewhere in New Zealand and in Australia. They lie between the small areas found for possums in lowland forests (Ward, 1978), and the extended ranges of animals in predominantly pastoral environments (Brockie, 1987), or mixed hardwood forest (Coleman *et al.*, 1980). Variation in habitat type appears to be a major factor in influencing the range size of possums, and the importance of occasional long distance movements should be recognised. Detailed radio triangulation studies of tuberculous possum populations to determine differences, if any, between affected and healthy individuals are required. There was an indication that nightly activity areas of tuberculous possums decreased as the disease worsened, however there were large variations in area covered on a nightly basis for all possums. Indeed, tuberculous possums had some of the largest home ranges. Such possums may pose a serious risk of transmitting the disease to other animals.

Dispersal of juvenile possums from an infected population is considered to be an important means of spread of TB. The 2 individuals from the study area that dispersed in late summer appeared to succumb to the pressures of winter, as did many of their peer group. High death rates in juvenile possums are commonly found. The single tuberculous juvenile also had an infected mother, and died in early winter. Both of the dispersing juveniles, and the immature adult which moved range centres, were males, confirming the sex bias in dispersal found in earlier studies (Efford, 1991)

6.1.3.2. *Possum Activity on Pasture*

There have been few detailed observations of the activities of possums on pasture. Some workers have detected little, or no, use of pasture by possums (Jolly, 1976); while others have concluded pasture species form a large part of the animal's diet (Harvie, 1973; Fitzgerald, 1984). Possums used open pasture at Castlepoint frequently. The number of animals within the observation area at any one time varied considerably throughout the year, but with predictable patterns of use over a night. A similar impression was obtained from sweeps through the surrounding study area. Possums grazed over the entire observation area and large numbers of possums were seen on pasture during late spring, including many females with joeys. However there were distinct 'patches' within that area which possums favoured, with no apparent visual differences between frequent and low use patches. (Coleman *et al.* 1985). Possums are selective grazers and were apparently searching for specific plants in the pasture. Animals moved steadily across the area, spending more time in one place than another, and many were seen to move grasses aside with their paws, to reach other plants in the sward.

A surprising feature of possums feeding on pasture was the lack of interaction between animals. Even when large numbers of possums were feeding in the observation area, maintenance of personal space and avoidance of other individuals were accomplished without overt aggression. Those interactions seen were generally of short duration, with one of the animals 'giving way' to the other. The few significant interactions included short chases, and increased 'apprehension' shown by certain possums, generally to unidentified 'threats'. The latter was evidenced by frequent adoption of the alert posture, and rapid movement across the pasture, with few attempts to feed. A further indication of the lack of overt interaction between possums on pasture was the almost total absence of vocalisation. Possums occasionally responded to screeches from the surrounding bush by adopting the alert posture, but made no sound. Snuffling noises, and chirping sounds from 2 or 3 joeys, were the only sounds heard from possums on pasture. Possums observed in bush covered areas of the paddock away from the den sites were similarly quiet, although my presence no doubt affected the behaviour of possums on several occasions. Loud screeches were often heard, but tended to be clustered in the early evening and before dawn, times when possums are most likely to come into contact near denning areas. These findings are at odds with those of Jolly (1976), who in a bush/pasture environment in Canterbury found aggression common, and interactions often fierce. Habitat variation may be the most significant difference between the two studies in that food resources are widely distributed on the Castlepoint site, and denning areas relatively restricted. The opposite appears to be the case in Canterbury, and Jolly indicates that aggression was most common when possums were congregating at a common feed source, particularly during the mating season. I have noted in my study that possums appeared more nervous on the bush/pasture margin than when either actively feeding under the canopy, or out on pasture. Also, more groups of animals (2-5) were seen interacting at the bush margin than at any other location on the site.

The importance of visual, olfactory and vocal communication in the possum has been discussed by Winter (1976), Biggins (1984) and others. Winter concluded that a possum's vocal repertoire is predominantly a series of graded sounds, most of which occur during agonistic interactions. He also described several quieter, discrete sounds which are unable to be heard more than 2-3 m from the possum. Winter anticipated that species with a few discrete, stereotyped calls would display less integrated and complex social structures, suggesting that the range of situations in which individuals need to be in close proximity is limited. Biggins (1984) discusses the significance of graded versus discrete vocalisations in regards to the level of social integration of a species, and concludes (as did Winter) that generalisations should be considered with caution as other forms of communication must be considered. The relative importance of vocalisation over olfactory communication is difficult to assess, but in the possum, a solitary, nocturnal animal, well endowed with scent glands, and which doesn't defend a territory, it is likely to be biased towards the sense of smell.

6.1.3.3. *Interactions between Possums and Cattle*

In normal situations cattle and possums are unlikely to come into direct contact, although possums in some areas spend considerable time foraging on pasture (this thesis; Green and Coleman, 1986). As

with badgers, possums circle around the larger animal where possible (and climb trees if not). However, the actions of debilitated badgers and the responses of the few, terminally-ill, tuberculous possums observed were quite different. Disease processes, and/or the inability to find sufficient food during the night, lead the animal to forage during the day. The possum appears to lose awareness of its surroundings, and close contact with inquisitive cattle (or humans or dogs) is possible.

A temporary, sedative-induced state was used in an experiment to simulate the behaviour of tuberculous possums, and the reactions of cattle to them was observed. Although the behaviour of sedated possums was similar to that of sick possums the reactions of the possums were no doubt affected by the drug. However, the responses of cattle in this situation were considered to be similar to those in the presence of a truly infected (affected) possum. The inquisitive nature of cattle was evident. The type and degree of the contact between some steers and the possum would almost certainly have been sufficient for transmission of tuberculosis (McIlroy *et al.*, 1986; O'Hara *et al.*, 1976). The possums' reaction in these experiments was passive, their main response being an attempt to move away from the steers (if possible, considering the drug's effects), whereas the typical reaction of possums in a threat situation, where escape is not immediately possible, is to sit back on their haunches, raise the forepaw (or paws) up and outward, and screech. Aerosols containing numbers of *M. bovis* bacilli are likely to be produced from infected animals (lung lesions are common findings in tuberculous possums; Pfeiffer and Jackson, pers.comm; Coleman, 1988; Julian, 1981) and inhalation is the most common means of transmission of tuberculosis. Cattle characteristically exhale before investigating a novel object, and then inhale in an action distinct from normal respiration. This is thought to clear the nasal passages of stale air (eg. methane gas), and aid olfactory identification (McIlroy, 1986).

The response of cattle to possum carcasses was also observed as an aside to the main thrust of the project. Carcasses were not deliberately approached, but appeared to be 'stumbled upon' as the cattle grazed the paddock. The steers made a cursory investigation of the body in most cases, and continued grazing. However one animal was observed to move the carcass with its nose, and then lick the head and shoulders of a herd mate. External contamination of the possum carcass, either through an open lesion or as a result of predator disturbance, could at least in theory have resulted in transfer of organisms to the in-contact animal, and/or its mate. However, given the high infective dose required by the oral route (millions of organisms as against 5 or less by the respiratory route), and the very limited contact achieved between these cattle and the dead possums, it appears that transmission from possum carcasses is insignificant in the epidemiology of the disease. Evidence from Britain indicates that only a few cattle are infected (or are primary infections) in many herd breakdowns; these animals may be at higher risk, particularly due to behavioural characteristics, which result in them coming into closer contact with infected wildlife than their peers. The large numbers of possums on the bush margin, their use of the pasture in association with cattle, and the inquisitiveness of cattle are all factors that probably aid in the transmission of tuberculosis from infected possums to cattle.

6.2. CONCLUSION

This study has provided new insights into behavioural factors which may influence the transmission of tuberculosis. Findings concerning possum home ranges fit into the pattern reported by others, and home ranges measured by radio-triangulation fall between those previously reported for forest and those for open farmland. Trap-revealed home ranges were much smaller than those obtained by radio-triangulation.

It was shown that each possum dens repeatedly within (for most animals) quite a small area, frequently lying close to an edge of its home range. While most home ranges remained stable over the course of the study, a few animals changed their home range size by changing their behaviour patterns during the course of the study. Evidence from this study and related work on the same site suggests that possums in the terminal stages of the disease are among those likely to make changes in their movement patterns, in order to accommodate their increasing debility, and that these changes may exacerbate the risk of transfer of infection to cattle by increasing the likelihood of contact.

Possums which denned in different areas shared grazing freely, and there was no evidence from examination of faecal plant residues to suggest that possums which were trapped in different parts of the site had differences of any importance in the composition of their diets. When on pasture under visual observation, possums maintained a minimum distance from each other which was usually at least 2 m. There were virtually no agonistic interactions among possums on pasture, although mainly at the beginning and end of the night such interactions could on occasion be heard in bush areas, especially during the mating season when it was clear from radio-tracking that interactions and the level of activity were both greatly increased.

Evidence suggested that the behavioural patterns of possums would largely preclude significant transfer of infection during grazing, unless animals became infected from material deposited on pasture. From other pieces of evidence being gathered in the longitudinal study taking place at the research site, this seems most unlikely. The indirect evidence gathered in this study would suggest that transmission between possums would be much more likely when animals are away from pasture, probably in the vicinity of their dens. Since possums on the study site kept to the same limited denning area, this would help account for the spatial patchiness of the disease. It proved impossible to gather more than very limited opportunistic evidence on behaviour in the vicinity of dens, because possums were very wary and easily frightened in this situation, and no way could be found to make extensive observations on awake animals in and around their dens. The fact that possums used quite a variety of dens and therefore were unlikely to return to a den under observation within a reasonable number of nights of observation was a major component of this difficulty, compounded by the fact that if a possum was observed in the proximity of its den, the observation time was almost invariably very short.

However the various findings of this study in relation to possum behaviour are consistent with evidence from other parts of this total study, that the only circumstances under which possums are likely to come close enough to transmit infection directly by aerosol would be through social interactions with possums denning in the same vicinity, or through mating, or through fighting and threat behaviour among competitors, probably mainly males.

With regard to transmission from possums to cattle, strong evidence was obtained that possums in the terminal stages of tuberculosis infection offer the most likely principal mechanism of transmission. Such animals change their behaviour and become lethargic and apparently disoriented. They are also likely to graze during the day, as well as at night. This was found through direct observation of animals which died of the disease shortly afterwards. When healthy animals were sedated so that they behaved much as tuberculous animals had been seen to do, cattle grazing in the same paddock but some distance away, were attracted to the possum by its activity (both during daytime and in darkness), and some cattle from the group exhibited a variety of behaviours which would have liberally exposed them to aerosol infection, and possibly even to infection by ingestion if the possum had been one showing discharging sinuses. With repeated tests, cattle showed progressive habituation, with overall reduction of interest shown and a change in the composition of the "active investigator" group among the herd of cattle. When cattle were exposed to the carcass of a recently dead possum, either intact or with the body cavity opened, few animals took an interest and those which did showed only brief interest and the nature of their exploration would have offered only a small chance of disease transmission.

Thus it would seem that the mechanisms of transmission which have strongest evidence to support them are determined principally by the behaviour of the animals, not by indirect methods of transmission through various types of fomites which have been postulated in the past.

These findings have considerable implications for control of tuberculosis in New Zealand. Firstly, the fact that it seems most unlikely that transmission occurs through contamination of pasture simplifies the issues which must be taken into account in designing control measures. Moreover the very limited extent to which dead possums are likely to explain transmission to cattle further reduces the significance of pasture as a specific site where transmission occurs.

It seems that transmission among possums must occur principally in the vicinity of den sites, and must be associated with forms of interaction among possums which were not apparent on open pasture. This is a major factor in the maintenance of clusters of infected possums, which have been a prominent feature of field findings. Whatever factors may influence the initial creation of a cluster, possum behaviour then makes its maintenance highly likely. Control measures must take better account of this clustering, and aim to reduce possum density in such areas to sufficiently low levels that infection cannot survive. Although this is undoubtedly difficult, methods such as bait stations may offer one way of achieving it.

It is also important to keep cattle away from terminally ill possums, since animals at earlier stages of the disease probably do not impose much risk and the infectious period of a possum for cattle (as distinct from that for other possums) is probably quite short. Since the disease shows a seasonal pattern, it may be possible to graze cattle so that they do not come close to possum denning areas at critical times of the year, which appear to be spring and summer, when possums which became clinically tuberculous in early spring reach the terminal stages of the disease.

The role of infected juvenile possums is also crucial to an understanding of the disease. Only a few radio-tagged juveniles from the study site dispersed, but those which did followed patterns somewhat similar to those found by other investigators. Evidence from the longitudinal study shows that infected mothers almost universally produce infected progeny, but a substantial number of both infected and uninfected juveniles die before dispersal. Nevertheless, those which do survive to dispersal age offer an extremely effective way of creating new clusters of infection at sites some kilometres from their natal area, and control measures will have to take adequate account of this problem, which greatly increases the outward spread of the disease from a local focus.

Many factors contribute to the presence of tuberculosis in New Zealand's wildlife population, and the maintenance of that disease in the possum in particular. Behavioural, reproductive, and environmental factors are among those which need to be studied in order to control, and in some areas perhaps eradicate, the disease. Many questions remain unanswered despite decades of research into possum ecology, and the populations thrive in spite of millions of dollars spent on control operations aimed at the animals' destruction. Control of New Zealand's possum population is without doubt one of the most important challenges facing the environmental, scientific and regulatory groups in the 1990s and beyond.

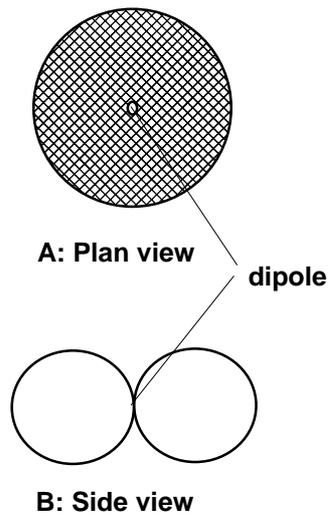
Appendices

APPENDIX I

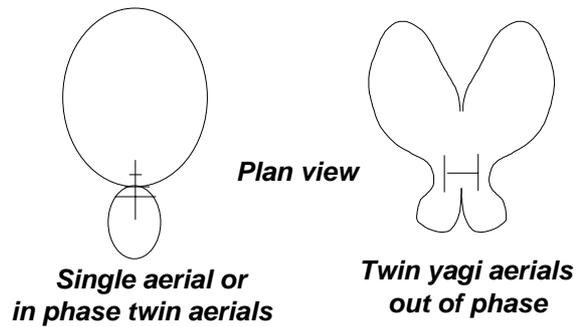
Figure A1.1 Reception patterns for various aerial configurations

Reception pattern for dipole (whip aerial)

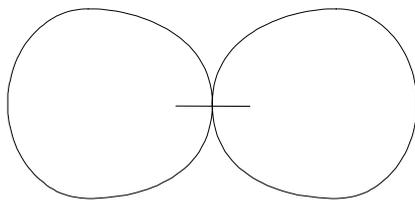
(A:aerial vertical)
(B:aerial horizontal)



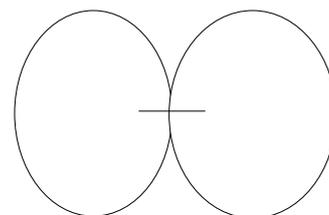
Yagi aerial reception pattern



Loop antenna
Aerial horizontal

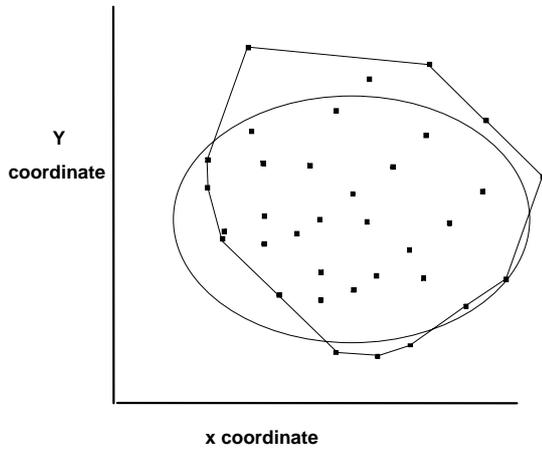


H-Adcock pattern
Aerial held vertically

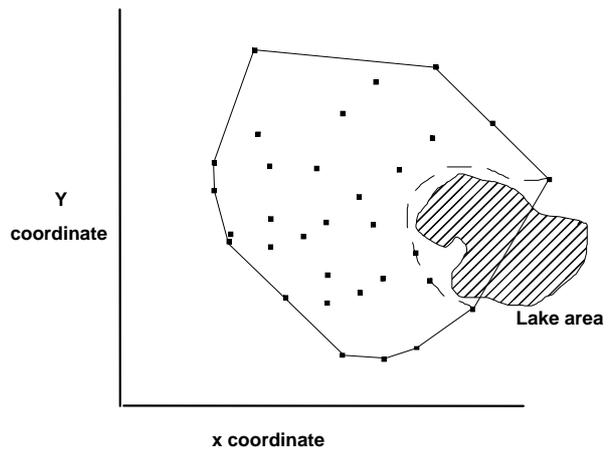


APPENDIX II

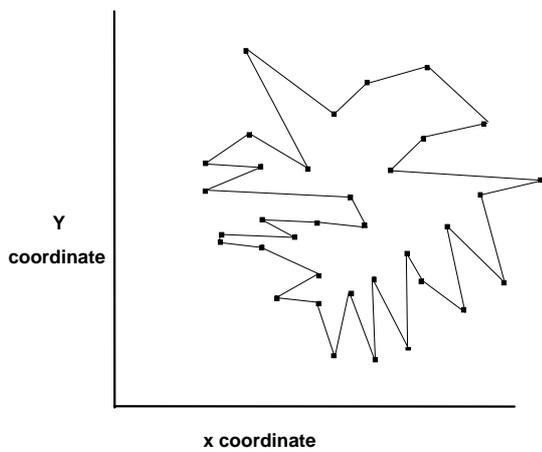
Figure A2.1 Illustrations of Convex and Concave home range types. From White and Garrott (1990)



Minimum area Convex polygon home range overlaid with a 95% ellipse (Jennrich-Turner)

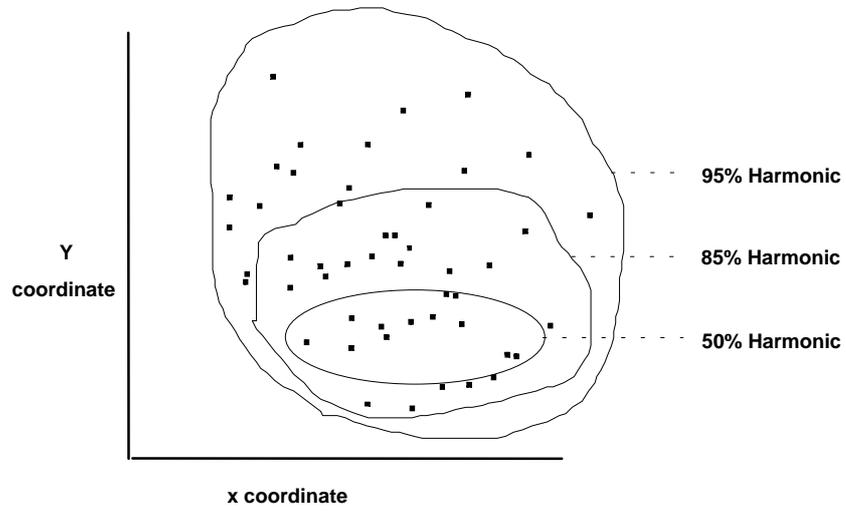


Biologically flawed example of a convex range area for a land mammal which includes part of a lake



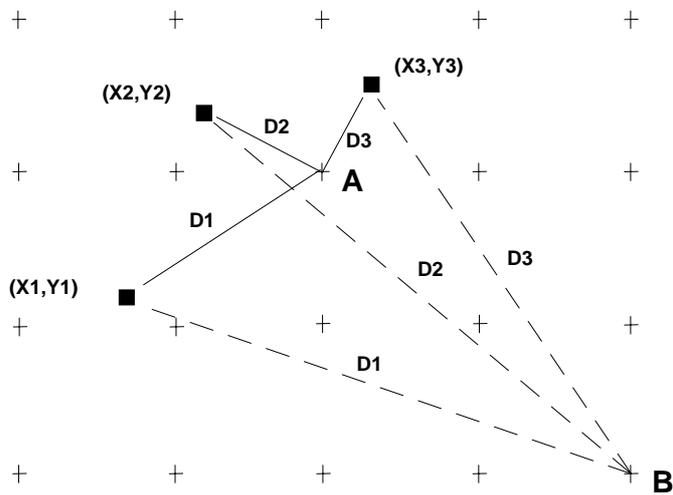
Concave polygon home range which connects all animal location points

Figure A2.2 Illustrations of the Harmonic Mean home range



Harmonic mean home range (Dixon-Chapman estimator)

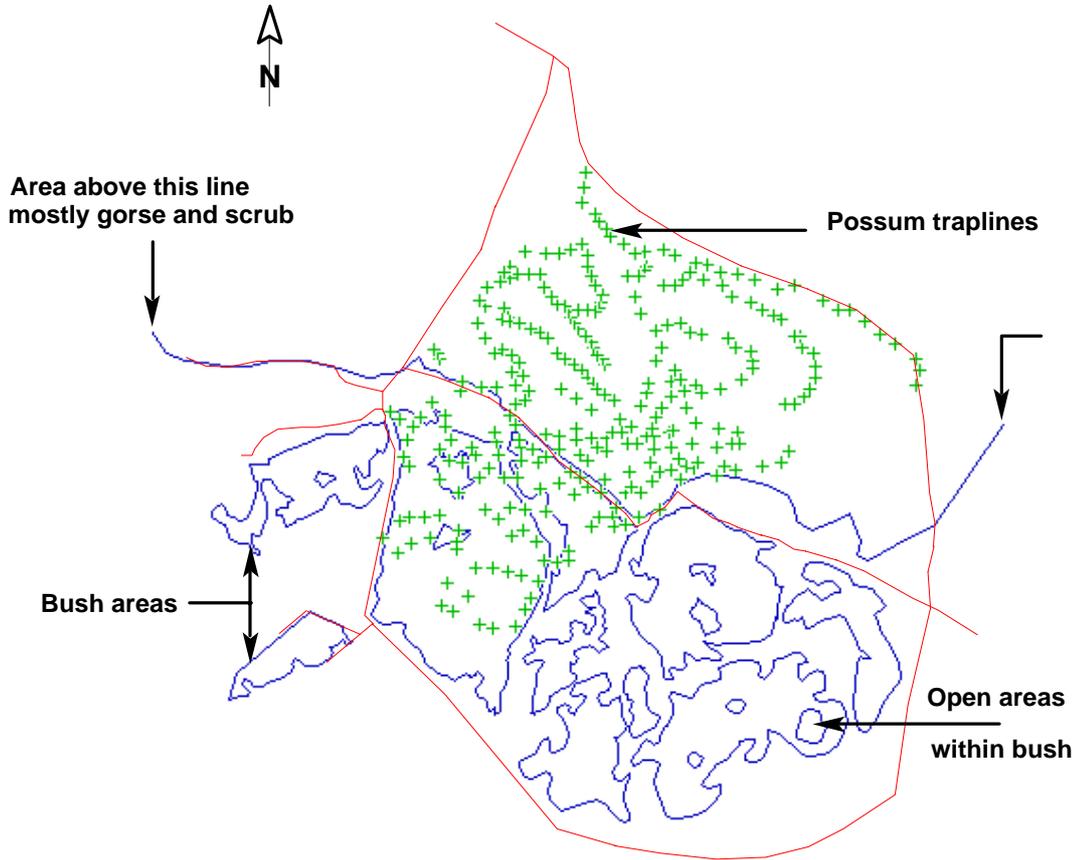
Note: contours are calculated based on distances of the animals point locations from nodes on a super-imposed grid (see below)



Method of calculating harmonic mean home range based on reciprocals of distances from various node points (crosses marked A and B, to point locations (squares) refer to text

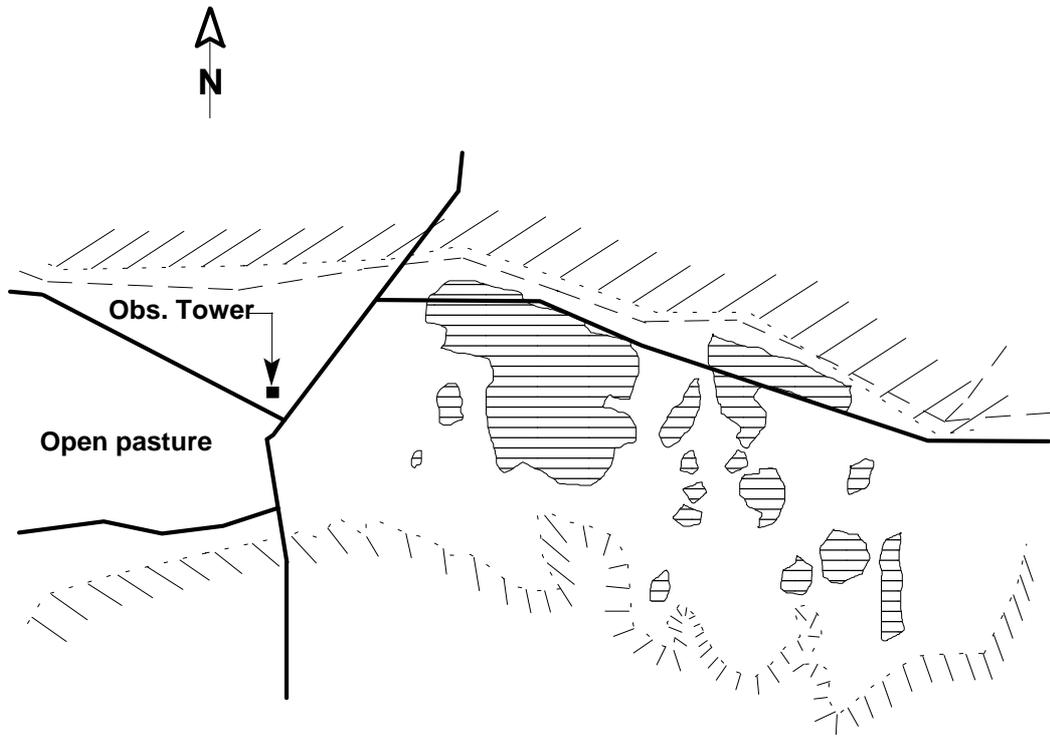
APPENDIX III

Figure A3.1 Castlepoint study area - bush regions, fencelines and trapgrid



APPENDIX IV

Figure A4.1 Bush and pasture around the Observation tower



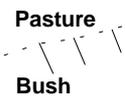
Key:



Areas of mainly Kanuka trees, but also some manuka and light scrub, with pasture underneath



Creeks



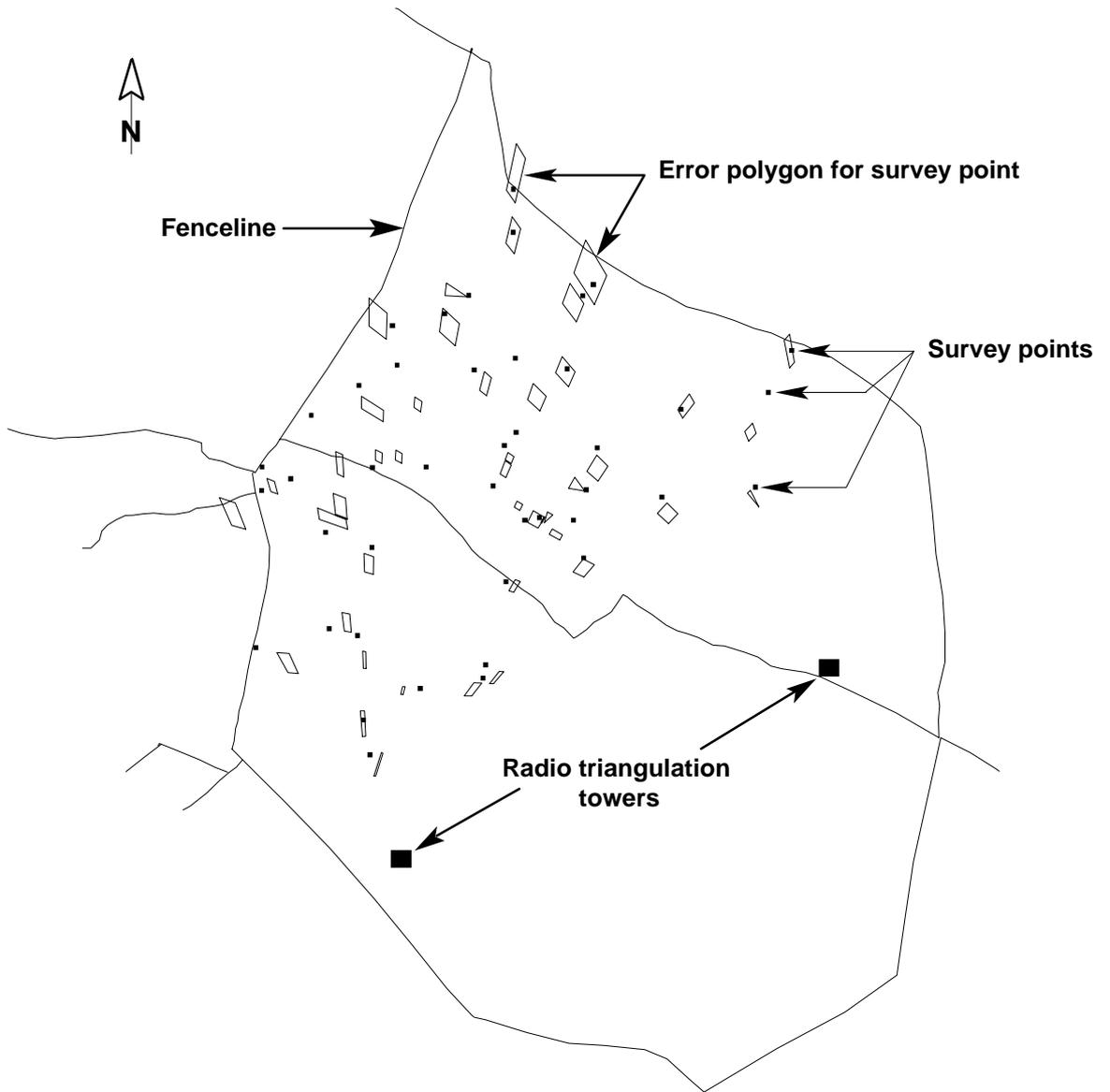
Bush-Pasture margin



Fenceline

APPENDIX V

Figure A5.1 Error polygons in relation to survey locations



APPENDIX VI

Comparison of trap and radio-revealed home ranges of the 7 most frequently followed possums in the study.

Home ranges of animals are conveniently, and most frequently, determined by live-trapping methods, but over the last 3 decades radio-tracking has been used to an increasing extent (Sanderson, 1966; Ward, 1984). Many authors appear to assume that trap-revealed ranges of animals approximate the true home range without providing evidence for this assumption (Ward, 1984). There are also few studies to determine the differences, if any, between trap and radio-revealed home ranges (Ward, 1984; MacDonald *et al.*, 1980).

Methods

Home ranges from the radio triangulation study described in Chapter 2 were compared with ranges calculated from trapping data during the longitudinal study at Castlepoint. Three time frames were analysed; (i) trap data from the same period as the radio triangulation study data (identified as the baseline period), (ii) trap data over the 12 months covered by the radio-tracking study (April 1991-April 1992 or 12 month period), and (iii) analysis of all trapping data to May 1993 (50 months of study).

Each trap in the study area is identified by a unique number and set of map co-ordinates. The locations of traps in which a possum is caught are used to calculate home ranges from a series of captures over a specific time frame. Data analysed using Telem88 (1992 version) and Paradox is shown in Tables A6.1-A6.4

Results

Comparison between trap-revealed and radio-derived home ranges

Trap-revealed home ranges were consistently smaller than radio triangulation derived ranges over the baseline time period, and also when 12 months of trapping data was analysed. Trap-revealed ranges varied from <1% to 27% of radio triangulated ranges over the baseline period, and from 1 to 61% of the radio ranges over the 12 month period. When all available trapping data was included in the analysis, trap-derived ranges were between 3 and 152% of comparable radio triangulated home ranges. These data are based on convex home ranges; trap-revealed concave ranges were an even smaller percentage of radio-derived home ranges.

Five of the 7 possums had trap ranges less than 28% of radio-triangulated ranges, even after 35 months of trapping, whilst the sixth (2901) had a trapped range of 45% of the radio-triangulated range. The latter possum was regularly caught from November 1991 to May 1993 and denned in an

area surrounded by traps. This contrasts with possums trapped on the periphery of the trapping grid (eg. 3662 and 3644), and may partly explain why the trapped range of 2901 is relatively large. The seventh animal, possum 3724, had trap-revealed ranges of 27%, 61% and 152% of radio home ranges for the baseline period, 12 month period, and all data periods, respectively. This possum was trapped over 36 months from September 1989 through to its death in September 1992, but was only radio-tracked for the last 8 of those months. The animal had shifted home range centre (calculated from trapping data), nearly 400 metres late in 1990, and this explains the smaller area derived from radio triangulation relative to trapping data

The discrepancy between trap- and radio-revealed home ranges were further investigated by comparing centre-points of the possums ranges. Centre-points are a geographic average of the distribution of locations, and indicate the intensity of use of an area. Centre-points for trap-revealed ranges were between 1 and 86 metres (mean 55 m, S.D. 28 m) distant from those calculated for radio-revealed ranges over 12 months, as were the points from the baseline time period. Centre-points for all the available trapping data were 45-88 metres (mean 64 m, S.D. 14 m) from the radio-derived locations.

Trap-revealed ranges with the inclusion of radio-tracked den site locations

Home ranges were also calculated from trapping data with the inclusion of known den site locations of the possums (Table A6.4). Home ranges calculated with this additional data added only a small area compared with trapping data alone for most animals (data for the baseline and the 12 month periods were similar). Possum 3644 showed a 5-fold increase in trap- and den site-derived home range compared to radio-derived range when all data was included. This is attributed to the location of some of its den sites, which were some distance from the nearest traps, thus increasing the range size.

The small effect of the inclusion of the den site locations is mirrored in the results for the range centre-points. Centre-points for trap-revealed ranges were between 21 and 86 metres (mean 56 m, S.D. 21 m) distant from those calculated for radio-revealed ranges over 12 months. Centre-points for all the available trapping data were 53-91 metres (mean 64 m, S.D. 14 m) from the radio-derived locations.

Summary

Live-trapping and radio triangulation are 2 methods for determining an animals home range, with the major difference being the invasiveness associated with trapping methods. Trapping may influence the movements of animals by luring them to an area not normally visited, or by effectively preventing further movement. Radio triangulation allows continuous sampling of an animals movements, although the lack of independence between such measurements should be recognised. Tracking will usually give a more accurate determination of an animals home range, although this is

dependant on the time over which an animal is tracked and the sampling interval. Discrepancies between ranges from trapping and tracking data, in terms of the physical location of ranges, can often be explained by home range shifts between sampling intervals.

Several methods to determine home range have been advocated which attempt to overcome the deficiencies in trapping methods (MacDonald *et al.*, 1980: Trevor-Deutsch and Hackett, 1980), but it is unlikely that techniques can be developed which will accurately measure trap-revealed home ranges (Ward, 1984). Although some methods can reliably measure mean trap-derived ranges (Ward, 1984), they may grossly miscalculate the size of an individual possum's home range. Live-trapping is a valuable tool in ecological studies, however other methods, such as radio-tracking are often more relevant for animal movement studies.

Table A6.1 Comparison between trap-revealed and radio triangulation determined home range (compared over the same time period) for each possum.

Method:	Possum Identification number						
	2810	2901	2917	2992	3644	3662	3724
Radio-determined convex area (ha)	5.67	4.43	6.09	7.71	4.67	12.76	3.15
Trap-revealed convex area (ha)	0.62	1.08	1.4	0.36	0.3	0.04	0.87
Radio-determined concave area (ha)	2.79	3.87	3.85	4.09	2.33	9.75	3.09
Trap-revealed concave area (ha)	0.1	0.6	0.02	0.00	0.00	0.00	0.31
Radio-determined circumference (m)	911	856	984	1151	1070	1696	768
Trap-revealed circumference (m)	323	437	468	264	257	148	416
Radio-determined centre-point (X,Y)	348431.3 708213.1	348510.5 708388.4	348538.4 708550.1	348606.3 708665.1	348702.8 708412.1	348588.3 708733.5	348564.9 708388.8
Trap-revealed centre-point (X,Y)	348416.5 708284.4	348514.8 708430.6	348570.5 708596.9	348566.1 708691	348679.6 708495.3	348518.9 708775.3	348566.6 708389.3
No. of radio-locations	149	408	394	307	305	275	381
No. of times trapped	12	37	19	9	6	6	26
Time period (months)	7	11	11	5	4	3	8

Table A6.2 Trap revealed data for the 12 month period April 1991-April 1992, including all trapping occasions for these possums (12, 3-5 day trapping occasions)

Method:	Possum Identification number						
	2810	2901	2917	2992	3644	3662	3724
Trap revealed convex area (ha)	0.7	1.08	1.4	0.36	0.3	0.06	1.94
Trap-revealed concave area (ha)	0.0	0.06	0.02	0.02	0.0	0.0	0.93
Trap revealed convex circumference (m)	339	437	468	264	257	152	825
Radio-determined centre-point (X,Y)	348431.3 708213.1	348510.5 708388.4	348538.4 708550.1	348606.3 708665.1	348702.8 708412.1	348588.3 708733.5	348564.9 708388.8
Trap-revealed centre-point (X,Y)	348416.5 708284.4	348514.8 708430.6	348570.5 708596.9	348566.1 708691	348679.6 708495.3	348518.9 708775.3	348566.6 708389.3
No. of times trapped	16	39	19	10	6	15	37

Table A6.3 Trap revealed data for the period April 1989-May 1993, including all trapping occasions for these possums (50, 3-5 day trapping occasions)

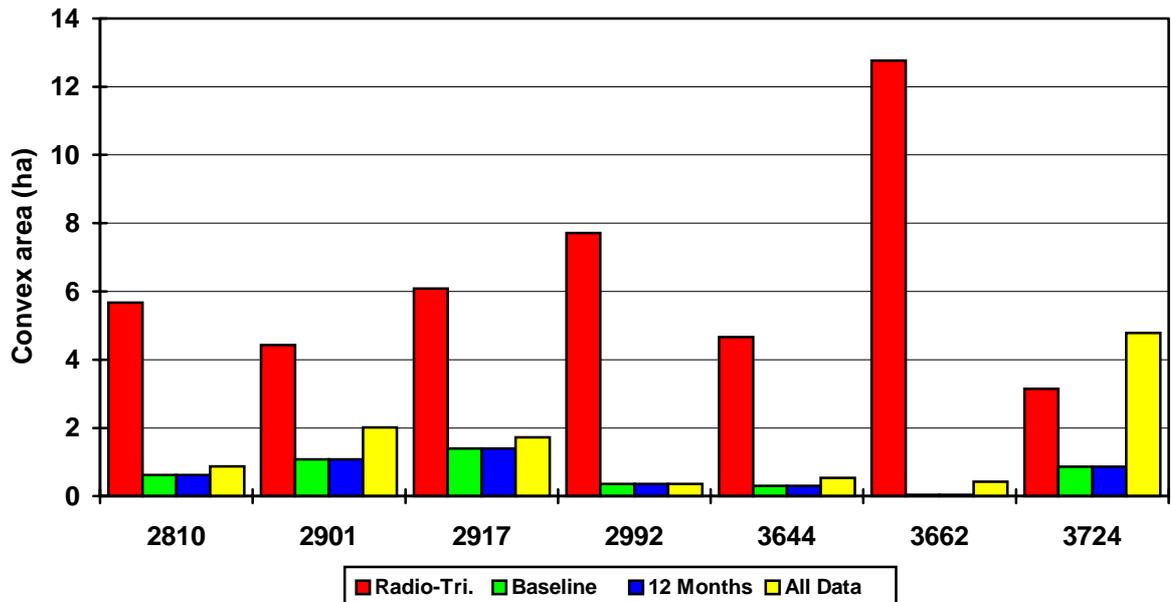
Method:	Possum Identification number						
	2810	2901	2917	2992	3644	3662	3724
Trap revealed convex area (ha)	0.88	2.02	1.73	0.36	0.54	0.43	4.79
Trap revealed concave area (ha)	0.0	1.3	0.04	0.02	0.08	0.03	1.1
Trap revealed convex circumference (m)	365	575	550	264	329	328	992
Radio-determined centre-point (X,Y)	348431.3 708213.1	348510.5 708388.4	348538.4 708550.1	348606.3 708665.1	348702.8 708412.1	348588.3 708733.5	348564.9 708388.8
Radio-determined centre-point (X,Y)	348406.2 708275	348527.2 708445.9	348574.9 708586.8	348566.5 708687.5	348662.9 708474.4	348522.2 708752.1	348632 708446
No. of times trapped	30	98	23	10	16	57	121
Time Period (months)	35	30	13	3	13	21	36

Table A6.4 Home ranges calculated from combining trapping and den-site locations for each possum. Data for 12 month (April 1991 to April 1992), and a maximum 50 month period (April 1989-May 1993), are presented.

Method:	Time Period	Possum Identification number						
		2810	2901	2917	2992	3644	3662	3724
Convex area (ha)	12 months	0.9	1.23	1.51	0.76	0.30	0.19	4.05
	All data	1.11	2.07	1.83	0.76	2.5	0.59	5.7
Concave area (ha)	12 months	0.23	0.80	0.38	0.23	0.0	0.0	1.16
	All data	0.25	1.33	0.48	0.23	0.53	0.06	1.77
Circumference (m)	12 months	398	453	498	384	257	202	986
	All data	423	580	555	384	705	348	1027
Trap-revealed centre-point (X,Y)	12 months data	348415.1 708268.9	348517.6 708440.6	348566.9 708604.6	348570.5 708689.8	348679.6 708495.3	348519.4 708760.8	348577.6 708405.8
	All data	348408.5 708266.3	348528 708450.8	348569.7 708598.5	348570 708689	348672.5 708471.5	348521..3 708752.4	348632.4 708449.9
No. of times trapped	12 months	27	52	39	18	6	19	45
	All data	41	114	43	18	26	62	132

Figure A6.1 compares the home range sizes calculated from radio triangulation data obtained during this study and the 3 time periods defined earlier in this appendix. Note that the areas for the baseline and 12 month data periods for possum 3662 do not show on the figure due to their small size.

Figure A6.1 Radio triangulation versus trap-revealed home range comparison



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