Ecology of Feral Cats, *Felis catus L,* in an Urban Parkland Environment

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Summary

The Lane Cove River Valley and its surrounding region is an integral ecological component of the Lane Cove River National Park. It is important for the survival of sustainable populations of several species of mammals including predator species such as feral cats, birds, other vertebrates, and several species of invertebrates. A combination of radio-tracking, visual observation techniques and scat analysis of feral cats was undertaken between December 1995 and April 1997 in this area. This study was conducted in order to provide information on the home ranges, diet and activity of feral cats in an urban environment.

In this study, two methods were used to analyse home range areas : minimum convex polygons and the adaptive kernel, utilising 95%, 90%, 60%, and 50% isopleths. Based on the 95% isopleth, it was confirmed that overall mean home range areas were not significantly different between males and females. This could be the result of limited animals studied, limited time spent tracking for two males due to removal by local people or the nature of the surrounding study area such as its specific habitat and food availability. Based on mean monthly distance travelled, however, males showed greater range areas than females. It was also confirmed that differences in distance travelled occurred among two females.

On the basis of scat analysis, mainly on the identification of mammalian hair, together with conventional methods of direct observation, feral cat was found to use a wide dietary range. The major food categories in terms of percentage occurrence were mammals (80%), herbage materials (43%), household refuse (22%). Of those 80% containing mammal remains, rabbit was the most common prey item (18%), followed by the ringtail possum (16%), black rat (14%), and southern bushrat and house mouse both comprised (8%). Scat analysis was able to detect the presence of the uncommon

or inconspicuous species on two occasion, possibly the water rat. Non-mammalian items for the feral cat were birds (18%), insects (28%), other vertebrates (2%).

Finally, feral cats in this study were nocturnal although several daily movements were recorded. The percentage of time used varied with individual and hour of the night. Activity was mostly bimodal with peaks occurring between 20.00h and 23.00h and at early morning. Activity levels for males was greater in late summer while females showed increased activity in winter.

CERTIFICATE

I hereby certify that this thesis has not been submitted for a higher degree to any other university or institution.

24 July 1997

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Chapter 1
INTRODUCTION

In recent years there has been an increasing public awareness of the impact of feral cats on wildlife, in particular on small native fauna. Such awareness is possibly triggered by some recent findings which indicated a massive reduction in ranges and numbers of native species since early European settlement (Anon, 1977; Seebeck *et al.,* 1990; Dickman, 1993). While there is some evidence for changes to native fauna on offshore islands as a result of feral cat predation, there is a surprising paucity of information on their true impact and implication in the decline and extinction of species of native fauna on the mainland.

Most information on native mammals in Sydney bushland is based on isolated, unsubstantiated observation and speculation (Recher, 1972). As a result, the impact and levels of predation to some species are mostly unknown, unsubstantiated and tentative or very difficult to measure. In terms of cat predation, the figure can be further complicated by the fact of their behaviour. Cats tend to leave little sign of their presence and bury their faeces wherever substrates are soft enough. The latter has important implications for the study of cat's scat in order to get information on their diet, as in this study.

In an attempt to get more information on feral cat ecology, this study is focused on some ecological aspects of feral cats living in urban parkland environment with emphasis on diet, home ranges and time activities. And in order to have better understanding of their natural history, I will touch briefly their ancient story back to some 4000 years ago.

The most widespread terrestrial carnivore species on earth, the feral house cat, *Felis catus L.*, has been found from 55' N to 52' S and inhabits climatic zones ranging from Sub-Antarctic to desert (Apps, 1983; Konecny, 1983; Konecny, 1987). They are introduced predators in island ecosystems worldwide (Clapperton *et al.*, 1994) and extraordinary colonisers (Johnson, 1991), eking out a living at the expense of birds and smaller animals (Merton, 1978; Karl and Best, 1982; Van Aarde, 1984; Fitzgerald and Veitch, 1985; May, 1988).

Domestic cats, as the ancestor of feral cats, have been associated with man and human habitation for thousand of years. Egyptians originally domesticated (Mery, 1967; Jones, 1992) and worshipped cats some 4000 years ago. They were probably derived from the African wild cat, *Felis silvestris lybica,* (Dickman, 1993). Mery (1967) in his book "The Life History and Magic of The Cat" noted ... "The Egyptians, with their acute power of observation, stubborn patience and natural zoophilia mixed with respect and fear, succeed in soothing, taming and finally in training their new animal. The result would be the domesticated cat. From this time on, fed and protected artificially, the cat must have come to appreciate the advantages of living under the same roof as his masters. And in accepting this new life in their company he would come to identify himself so closely with them that he would make their enemies - the rats - his enemies. By the end of Middle Empire (2100 BC) the cat as fisher, hunter and ratter was already appreciated and widely used".

The feral cats, *Felis catus L.*, are those field or bush roaming domestic cats that are forced to secure their own food. Today the feral cat has spread throughout the Australian continent (Jones, 1992) and occupies most ecological habitats across the mainland and many offshore islands. However, there is still considerable speculation on the story of their arrival. Some authors (eg. Burbidge *et al.*, 1988; Jones, 1992) indicated that cats were originally brought to Australia by early European settlers probably in the first fleet althought no accurate records exist. And by the 1850's colonies of feral cats were established in the wild. However, there is some evidence that cats were establish before European settlement, possibly arriving in the 17th century on Dutch or Asian vessels that ran aground on the Western Australian coast. According to the fossil records, distribution factors and DNA analysis, feral cat may have appeared in Australia about 500 years ago (Wagner, in prep.). Very little information is known about the precise date of entry. From the Northern Territory perspective, however, it is said that feral cats have been found there for at least 100 years. The first record of feral cats was that by Winnecke (1884) who observed an animal in 1883 near the Queensland border on present day Tobermorey Station.

Intentional introduction of cats to the wild happened in the late 1880's in an effort to control another European introduction - the rabbit (Davies and Prentice, 1980; Jones, 1992), rats and mice. In fact cats did not stop the spread of rabbits, but rather exploited them as a major new food source. Feral cats have since spread to cover all of Australia.

In many ecological aspects, feral cat, resemble much and are identical to common house cats (Jones, 1992) and probably also stand closer to their wild ancestors than any other of common domestic animals (Liberg, 1980) in all respects except for their behaviour. They have shed all signs of domestication and live and hunt much like their small wild felid ancestors (Jones, 1992). However, one aspect where cats do differ from their wild ancestor is with their coat colour (Mery, 1967). During the process of domestication cats developed a large variety of coat colour and patterns, other than that of striped tabby, the original coat colour (Jones, 1992).

This study aims to investigate the ecology of feral cats living in an urban parkland environment. The underlying reason is that some previous studies conducted mostly in rural areas, suggested implicitly that predation by feral cat has been partly responsible for the decline in numbers of many Australian smaller species of native fauna (Delroy, 1974; Stephen, 1978; Delroy *et al.*, 1986; Johnson, 1991; Copson, 1991). However, very little work has been done to assess the importance of feral cat as predator of indigenous fauna or their role in an parkland urban environment (McKay Pers. Comm.) in Australia although studies in other countries exist (Childs, 1986; Calhoon and Haspel, 1989; Haspel and Calhoon, 1989; Jarvis, 1990).

The inner city offers a unique opportunity to study the activity patterns of feral cat in a highly modified environment where the activity of humans offers not only unnatural dangers, but novel opportunities for resource acquisition. Additionally, a populated urban study is unique in that cat activity can be observed at night (Haspel and Calhoon, 1993). Furthermore, the lack of ambient lighting in other environments limited observations in prior activity studies to daylight hours (Kunz and Todd, 1978; Panaman, 1981; Konecny, 1987). Finally, at the same time the cat's close connection to human habitation makes close observation possible.

Several studies on the ecology of feral cats in Australia have been conducted in a various semi-arid open environments such as Yathong Nature Reserve (Newsome *et al.*, 1989; Pech *et al.*, 1992) and the Victorian Mallee (Coman and Jones, 1981; Jones and Coman, 1981) including a few in rural and urban environments (Coman and Brunner, 1972; Bayly, 1976; Brunner *et al.*, 1976; Huxley 1987).

Studies conducted outside Australia include rural environments (Macdonald and Apps, 1978; Liberg, 1980; Panaman, 1981; Liberg 1984; Langham and Porter, 1991), urban environments (Churcher and Lawton, 1987; Proulx, 1988; Fitzgerald, 1990; Jarvis, 1990; Haspel and Calhoon, 1993) and in island habitats (Jones, 1977; Dilks, 1979; Karl and Best, 1982; Brothers, 1982; Fitzgerald and Veitch, 1985; Izawa, 1983; Van Aarde, 1984; Brothers *et al.*, 1985; Konecny, 1987; Catling, 1988).

In order to strengthen our understanding of feral cats ecology I will now review some information available on this species with emphasis on diet, home ranges and activities because most previous studies have dealt with food habits, with few details on activity and some of social behaviour.

The distribution of feral cats throughout Australia is a testimony to their adaptability and success as predator. Observations of prey taken by both domestic and feral cats have demonstrated that cats are capable of exploiting a wide range of prey types (Rose, 1975; Jones, 1977). They are capable of killing mammals as large as the Brush tailed possum or surviving in the desert regions relying on small reptiles and insects (Delroy, 1974; Rose, 1975; 1976; Friend, 1978; Strong and Low, 1983; Triggs *et al.*, 1984; Delroy *et al.*, 1986; Catling, 1988). They are very adaptable animals and there seem to be few environmental factors that limit their distribution. McKinnon (1991) even stated that every river and creek and nearly every man-made waters has got a resident cat population in the North. Coman and Jones (1981) consider that effective methods of control are difficult to formulate in particular even if feral cats are eradicated from any area, their eventual re-establishment by stray domestic cats is almost a certainty.

Even though several studies have reported on the diet of feral cats, *Felis catus L.*, in Australia and some found that feral cats prey upon a wide variety of native vertebrates (Coman and Brunner, 1972; Bayly, 1976; Jones and Coman, 1981; Triggs *et al.*, 1984; Catling, 1988), determining the true impact of feral cats on native wildlife on the Australian mainland is more difficult. It is complicated by other factors such as introduced herbivores like rabbits competing with native animals for food and shelters, grazing animals and of course urban development. Additional information and further research is clearly needed in order to understand the precise impact of cats on wildlife throughout Australia.

However, there are instances where feral cats have directly threatened the successful recovery of endangered species. In South Australia Delroy *et al.,* (1986) found that cats attributed the extinction of the South Australian brush-tailed bettong, *Bettongia penicillata,* from St Francis Island. There is also circumstantial evidence (Copley, 1991) that feral cats contributed to the extinction of dama wallabies, *Macropus eugenii* on Flinders Island. In the Lane Cove River Valley in Sydney, an area of bush surrounded by urban development, Stephens (1978) reported that feral and free-ranging cats play an important role in reducing the small mammal populations.

A study by Taylor (1979) on Macquarie Island found that feral cats are partly responsible to the extinction of a sub-species of the Red-fronted Parakeet. Possible because islands are usually small and isolated, then the presence and impact of feral cat is more obvious than it is on mainland, particularly if other predators are absent such as foxes and dingoes. In a survey of the opinions of National Parks District Officers on the threat posed and damaged caused to National Parks and Nature Reserves by feral and introduced mammals, feral cats were considered to pose the greatest threat to the preservation of Parks and Reserves (Tisdell, 1979), and 17 of 27 districts rated cats to be sufficiently serious pets in the National Parks to warrant control.

By far the most reported of Australian studies on the diets of feral cats are mostly limited on the prey items rather than analysing their impact on native wildlife. A considerable amount of reports have been published concerning this aspect.

The first major ecological work emphasis on food habits of the feral house cats in Australia was undertaken by Coman and Brunner (1972). They found that those 80 stomachs contained, mammals, chiefly rabbits, *Oryctolagus cuniculus,* small murids and phalangers comprised some 80%, by volume, of the total dietary intake. Birds and cold-blooded vertebrates were of secondary importance in the diet. They also found that grass and small twigs occurred frequently in the stomach with the volume represented was small. Feral cats from undeveloped bush areas relied heavily on small indigenous mammals, whereas rabbits and house mice, *Mus musculus,* were the main mammalian prey species eaten in improved and semi-improved agricultural areas. They did not find any remains of indigenous mammals in the stomach of cats from these latter areas.

A similar result was reported by Jones and Coman (1981) studying the diets of feral cats in South Eastern Australia. Cats were collected from the Victorian Mallee and Kinchega National Parks either by spotlight shooting, trapping and collected as fresh road kills. They found that introduced mammals, mainly European rabbits and house mouse, were the largest component of the diets. It was also clear from this result that native mammals were eaten. The common species eaten were common Brushtail possum, planigales, bats, southern bush rat, mountain Brushtail possum, brown antechinus and sugar glider. Other groups less represented were reptiles, amphibians, fish, arthropods, annelids and scavenged food comprising human food scraps and carrion. Both Coman and Brunner (1972); and Jones and Coman (1981), based on their work, stated that feral cat are opportunist predators and scavengers that are capable of exploiting a wide variety of food depending upon local availability.

Catling (1988) developed a comparative study in the diet of foxes, *Vulpes vulpes L.*, and cats, *Felis catus L.* He found that both foxes and cats mainly relied their diet on rabbits, *Oryctolagus cuniculus*, during the breeding season. Predation on rabbits was greatest on an increasing prey population during good pasture conditions and a decreasing during drought. However, Catling also found that foxes and cats differ to some extend on prey in which foxes mainly ate adult rabbits (Jones, 1977; Gibb *et al.*, 1978; Corbett, 1979) and cats ate young rabbits. They also responded differently to the prey concerning the drought season where foxes preyed heavily on adult rabbits while cats only consumed some rabbits and relied heavily on other food sources. Their supplementary prey were mostly similar on invertebrates, birds, reptiles and carrion.

In Sweden, food habits and prey impact by feral and house based domestic cats study has been done in a rural area with a relatively similar finding by Liberg (1984). He found that most cats obtained their food from natural prey with wild rabbits, *Oryctolagus cuniculus*, being the most important prey. It was also reported that cats responded functionally to changes in abundance and availability this prey. Small rodents were the second most important prey, while brown hares, *Lepus europaeus*, and birds were less important.

Relatively little is known about the relationship between the density of prey and predation by feral cats. Holling (1959) generally used 'functional response' to describe the relationship between the density of prey and the rate at which and individual predators consumes prey. For invertebrate predators, it is often initially a linear response which levels off at high prey density. For vertebrate predators the response is generally S-shaped, showing an initial lag in the response of the predator to increasing number of prey and a levelling off at high prey density. During the rabbit breeding season in winter and spring each year, foxes and cats exhibited an S-shaped functional response to rabbits (Catling, 1988).

The literature on dietary studies have also been reviewed by Fitzgerald and Karl (1979). It is indicated that small mammals, particularly lagomorphs and rodents, are the most frequent eaten prey, although other small mammals, birds, reptiles, amphibians, fish, arthropods, carrion, human food scraps and plant materials are all eaten.

However, Churcher and Lawton (1987) reported somewhat different finding from their study. On the basis of domestic cats studied in north-west of Bedford, England, they found that the most important items were woodmice, *Apodemus sylvaticus*, house sparrows, *Passer domesticus,* and bank voles, *Microtus agrestis,* instead of rabbits. Churcher and Lawton speculated that this difference in catch is partly due to habitat difference, with a suburban area supporting more birds relative to the mammals population than a rural area. George (1974) noted somewhat different speculation that cats are very unlikely bring home all of the prey that they captured. What proportion they do bring home has been little studied. Also, they found that old cats of both sexes caught fewer prey over the year than young cats. There was some indications in their data that cats caught fewer prey in areas where cat density was highest, but this effect was impossible to distinguish in the village. Jarvis (1990) speculated on this result that most of Britain's cat live at relatively high density in built-up areas with few opportunities to hunt on open land.

One would therefore expect relatively less prey to be caught per unit area in towns than in villages as a whole.

To summarise the diet aspect, it is clear to say that feral cats prey upon a wide variety of native fauna, even though this is not sufficient yet to conclude that they have adverse effect on it. Feral cats seem to be opportunistic predators but show some preferences for small mammals. In most Australian studies, rabbits, *Oryctolagus cuniculus,* constitute the single most important prey.

Determining the habitat use and temporal use of home range by an animal in its daily and seasonal movements is of particular interest in ecological studies. Harris *et. al.,* (1990) reviewed eighteen major scientific papers and found that those aspects are dominantly reported both in ecological and behavioural studies. It is worth saying that with the advent of radio-tracking techniques, there has been a considerable increase in data which can be collected and used to further analyse specific ecological and behavioural question like shape and internal configuration of home range, and behaviour of species like pattern of utilisation which may be important for a species management.

A typical telemetry study involves capturing, collaring and releasing animals and then periodically relocating them to find fix locations before plotting their position on the map. Ideally, tracking studies should have enough fixes to be efficiently handled and interpreted concerning the area of use. This area, home range, is defined as an area consists of a more or less restricted area within which an animal moves when performing its normal activities (Harris *et al.,* 1990), and it is typically calculated by connecting the outermost points to form an irregular polygon (Burt, 1943). However, following the introduction of radio tracking technique in the early 1960s (Cochran and Lord, 1963), various analytical techniques have been available (Jaremovic and Croft, 1987), and as a result the amount of information that can be gained and presented via telemetry studies has increased consistently.

In Australia, little is known about feral cats' home range. Jones and Coman (1982) conducted a home range study in the Victorian Mallee by radio- tracking the animals for about 8 to 21 months and found that males ranges were higher than those of females. Elsewhere (Dards, 1978; Macdonald and Apps, 1978; Corbett, 1979; Liberg, 1980; Konecny, 1983; Warner, 1985; Fitzgerald and Karl, 1986) reported similar results. Langham and Porter (1991) said that the reason for the larger home ranges of males are probably both behavioural and physiological. Adult males tend to occupy exclusive home ranges or territories which incorporate the home range of several females. They found that adult males had large territories in spring and summer when they were most likely to be actively mating and defending females within their territory. It is possible that dominant males seeking access to more females (Page *et al.*, 1992) and possibly due to males greater energy requirements for their greater size (Harestead and Bunnell, 1979).

In contrast, Haspel and Calhoon (1989) reported that larger male than female home ranges size could not be attributed to males seeking out oestrous females. Winter and spring are peak oestrous in cats (Scott, 1976); however, there was no significant difference in home range size between fall and spring. They then confirmed that larger home ranges of male than those of female is more a function of body weight of different gender.

The size of home ranges of feral cats in different habitat varies greatly. Fitzgerald and Karl (1986) reported an average length of 6.34 km^2 for males and 3.83 km^2 for females while those in Brooklyn had home ranges about 2.72 ha for males which was significantly larger than 1.77 ha of females. Jones and Coman (1982) reported the areas varied 3.3 to 9.9 km^2 for males and from 0.7 to 2.7 km^2 for females, and Page *et al.* (1992) found that home ranges size were similar for males and females, varied from 0.9 to 56.1 ha and 2.6 to 17.6 ha respectively.

Several investigators have examined the home range size of free-ranging domestic cats, *Felis catus l.*, in rural (Macdonald and Apps, 1978; Liberg, 1980; Brother *et al.*, 1985; Warner, 1985; Apps, 1986) and urban (Dards, 1981; Tabor, 1981; Childs, 1986) habitats. Urban cats consistently occupied smaller home ranges than rural cats. This difference was attributed to greater food availability in urban environments in the form of garbage and human handouts that urban cats did not depend on predation (Dards, 1981; Tabor, 1981; Childs, 1986). However, Haspel and Calhoon's (1989) work on food supplement experiment indicated that increased food availability did not modify home range size of cats, even though it did modify the distribution of population. At high resource levels there is no benefit to keep large ranges while at lower levels large home ranges may ensure at least more possibility of areas for searching food resources.

Cats may either be completely solitary (Kleiman and Eisenberg, 1973) or live at much higher density in a various kind of association. However, Leyhausen (1965) emphasised that solitary animals are not necessarily asocial and need not imply overt defence of or exclusive use of the territory (Kaufmann, 1983). Intruders are allowed to enter a territory if they retreat before the territory holder and do not attempt to utilise resources while they were in the territory (Wolf, 1970). Some studies (Dards, 1978; 1983; Liberg, 1980; Jones and Coman, 1982; Langham and Porter, 1991) showed that cat's home ranges either significantly or occasionally overlap. However, Page *et al.* (1992) reported that cats were mostly solitary rather than group living with little contact.

A considerable amount of work has been done on population density of the cat. It is found to have a correlation with the availability and dispersion of resources (Brother *et al.,* 1985; Carr and Macdonald, 1986). Where food is abundant and dens sites are common, high densities have been recorded (Oppenheimer, 1980; Izawa *et al.,* 1982; Dards, 1983; Natoli, 1985; Haspel and Calhoon, 1989). A study by Corbett (1979) who worked on cats without extra food found cats had density much lower than those cats with extra food. Jones and Coman (1982) worked in semi arid farmland in Victoria found density of cats was very low without supplementation.

By means of radio telemetry, some researchers have been able to track and analyse aspects of feral cat's activity (Corbett, 1979; Jones and Coman, 1982; Fitzgerald and Karl, 1986; Konecny, 1987; Page *et el.,* 1992; Godfree, 1995). It was found that feral cats were mostly active at night time with peaks in activity occurred between sunset and sunrise (Johnson and Franklin, 1991; Haspel and Calhoon, 1993). Brown (1962) and Estes *et al.* (1986) argued that carnivores often exhibit both sunrise and sunset peaks in activity which may be synchronised with the activity of their prey (Laundre and Keller, 1981; Zielinski *et al.,* 1983).

To summarise, it seems that size of home ranges of feral house cats in different habitats varies greatly. Also, based on the results of different studies conducted by researchers elsewhere indicate that to some extent several factors, like food availability, resources dispersion, habitat differences and season, have a correlation to some ecological aspects of cats such as their activity pattern and their home range.

Based on reviews given and in an attempt to provide more factual data on feral cat ecology, this study is aimed to discern the role played by feral cats in an urban setting regarding their diet, home ranges and activity patterns. Scat contents obtained over a-thirteen month collecting period are examined for dietary preferences. Fix locations obtained over an-eighteen month radio-tracking period of six collared cats are analysed to determine information such as home ranges and activity pattern.

Chapter 2
Methods

2. 1. Description of Study Site

2. 1. 1. General Description of Study Site

The principal study area of about 400 ha., including the 100-ha Macquarie University and wildlife refuge riverside of the Lane Cove National Park, lies adjacent to the suburbs of North Ryde in North Sydney, 33° 51' S., 151° 17' E. (Figure 2. 1). Details of the study site is shown in appendix 1.

About three-quarter of the study areas are covered by a considerable expanses of urban environment including densely populated areas which is indicated by significant blocks of buildings. General topography of the study area is characterised by low, flat and undulating reliefs with creeks contain moderately rugged terrain in some locations.

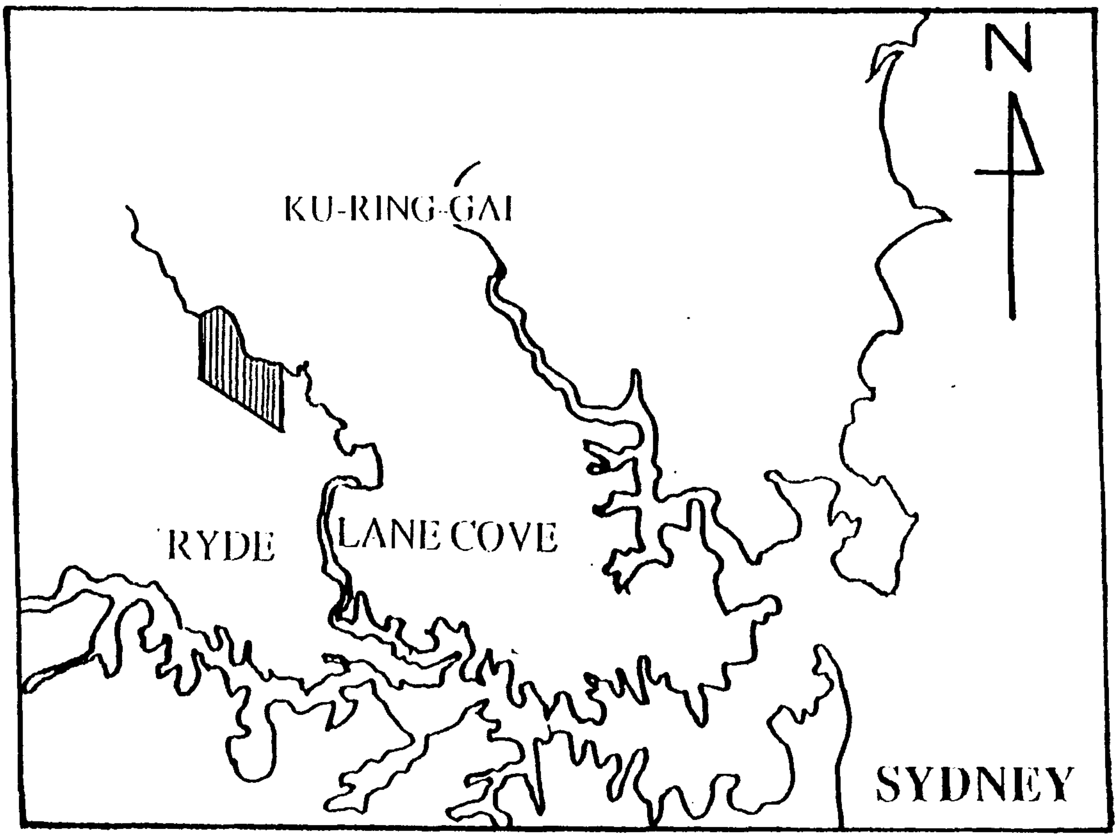


Figure 2. 1. Map of the Northern Sydney showing the location of study site (▥)

The eastern side of study, which extends from up around Devlin's Creek and continues to the De Burghs Bridge, is part of the Lane Cove National Park surrounding the Lane Cove River. The major vegetation of upper Lane Cove area has been described by Stephens (1978) with the flora of the region characterised is shown in table 2. 1. Although sub-urban environment has encroached very close to the river in many places, some areas of bushland are still preserved in a relatively natural state, particularly those which are very close to the riverbanks, apart from tracks, fire trails and the occasional water pipeline. The bushland is mostly a long, narrow strip hemmed in by the suburbs containing of major plant community. Eucalypts and acacia species are very common ranging from closed scrub, open shrub, and to open forest near valley bottom. Shifting in around 100 metres from the riverbanks there are growing exotic shrubs and grasses as a result of massive fire in 1994. This area is dominated by young *Eucalyptus gummifera, Eucalyptus pilularis, Banksia ericifolia,* and *Acacia sp*. etc.

Along the eastern site of study area there are at least two creeks, Mars Creek and Shrimpton Creek, flow into and join the Lane Cove river. These creeks carry a considerable amount of water after the infrequent heavy or long rainfall, but normally they are creeks with small volume of water. Another active creek sometimes does not reach the river around the summer time, instead it floods out into low land area of Macquarie University where water may be lost through both by percolation and evaporation. As the water course of the Lane Cove River is well located in a deep valley, some very steep slopes and large rock formations are

Table 2. 1. Vegetation types of the upper Lane Cove Valley characterised by Stephens (1978).

Structural Form	Dominant Species
Closed-Forest (With closed lower layer)	Upper Layer : *Eucalyptus pilularis, Angophora costata, Syncarpia glomulifera* Lower Layer : *Cerotopetalum apetalum, Callicoma serratifolia, Tristania laurina*
Open-Forest (upper slopes)	*Angophora costata, Eucalyptus pilularis, Eucalyptus gummifera, Eucalyptus piperita*
Open-forest (Near valley bottom)	*Eucalyptus pilularis, Syncarpia glomulifera, Casuarina torulosa*
Woodland	*Angophora costata, Eucalyptus gummifera, Eucalyptus piperita*
Low-woodland	*Eucalyptus haemostoma, Eucalyptus piperita*
Open-Scrub (to heath)	*Angophora caudifolia, Banksia asplenifolia, Petrophile fusifolia, Grevillea spp, Dillwynia spp, Lambertia formosa, etc.*
Closed-scrub	*Banksia ericifolia, Hakea sericea, Hakea teretifolia*

characteristic of the riverbanks.

However, this area has a high diversity of vertebrates species (Stephens, 1978). Potential mammalian species includes European rabbit, *Oryctolagus cuniculus L.*, common ringtail possum, *Pseudocheirus peregrinus,* brushtail possum, *Trichosurus vulpecula,* sugar glider, *Petaurus breviceps,* Bush rat, *Rattus fuscipes,* Stuart's marsupial mouse, *Antechinus stuartii,* long nosed bandicoot, *Perameles nasuta,* spiny ant-eater, *Tachyglossus aculeatus,* and numerous black rats, *Rattus rattus*. Large variety of avian species also were potential prey items for feral cats.

The western half of the study area is characterised mainly by expansions of urban settlements although there are small fragments of remnant bushland habitat suitable for birds and other animals. A considerable large area has been preserved for horse paddocks with grassland being its general characteristic into which two collared cats sometimes made excursions for several days. Taller eucalypts occur as isolates or in scattered pockets where the soil is suitable. The rest consists of urban parks and sport grounds that mostly borders with gentle slopes of gullies. Other vegetation in this area consists of low shrubs.

2. 1. 2. The Climate

In general terms, based on long term averages, the study site receives predominantly summer rainfall although it became slightly irregular in 1996.

Table 2. 2. Total Rainfall (mm) and Raindays in Month during January 1996 - March 1997 from Weather Station at Macquarie University, School of Earth Science.

Year / Month	Total Rainfalls for Months	Long Term Average	Raindays
1996 Jan.	166.8	141.4	18
Feb.	53.4	143.2	16
March	43.6	155.6	10
April	28.4	119.4	4
May	159.4	97.2	13
June	90.4	109.0	12
July	56.6	56.4	6
Aug.	158.6	68.6	7
Sept.	98.2	52.6	7
Oct.	28.8	93.6	12
Nov.	91.0	96.2	11
Dec.	43.4	73.6	8
1997 Jan.	185.2	130.2	12
Feb.	165.2	141	13
March	24.2	146.2	6

Table 2 . 3. Temperature (°C) records during January 1996 - March 1997 from Weather Station at Macquarie University, School of Earth Science

Years and Month	Mean Minimum	Long Term Mean Minimum (20 Years)	Mean Maximum	Long Term Mean Maximum (20 Years)
1996 Jan.	18.1	17.0	26.3	26.9
Feb.	16.1	17.0	25.5	26.8
March	15.0	15.4	25.0	25.4
April	10.8	12.2	23.7	23.1
May	11.0	09.1	20.6	20.2
June	08.2	06.4	18.1	17.2
July	06.1	05.0	17.3	16.7
Aug.	06.7	05.8	19.2	18.2
Sept.	10.0	08.0	22.4	20.7
Oct.	12.7	11.0	23.3	22.8
Nov.	12.7	13.2	23.7	24.4
Dec.	15.9	15.8	25.9	26.6
1997 Jan.	15.8	17.2	25.2	27.1
Feb.	19.1	17.1	27.1	26.9
March	16.5	15.3	26.1	25.4

The mean annual rainfall recorded from the weather station at Macquarie University is 1018.8 mm, lower than mean long term average. Rainfall was heavier in January and consistently decreased until April. Rainfall records from the weather station at Macquarie University for January 1996 to March 1997 are shown in table 2.2. The long term mean montly rainfall and number of raindays are also shown in table 2. 2.

The temperature is generally hot in summer. January is the hottest month, with a mean daily maximum of 26.3 ºC, while the coldest month, July, has a mean daily minimum of 6.1 ºC. Table 2. 3 shows the absolute monthly minima and maxima for 1996 to March 1997. It also shows the long term mean maxima and minima for 20 years record.

2. 2. Trapping

At the commencement of this study, on January 7, 1996, three feral cats had already been fitted with radio collars (Godfree, 1995), which allowed the immediate collection of fix location data for these animals. However, specific re-trapping activities were soon carried out as one of these collared cat emitted very weak signals when the transmitter battery began to fade and continued until the animal was caught.

Between January 1996 and December 1997, in an attempt to have more animals to be studied, a series of four additional trapping sessions was conducted (their dates are shown in appendix 2). The traps were normally placed for four nights before being shifted to new points. Each trapping session usually employed six to ten traps, and to maximise the effectivity, were placed in a track available or around the points favourable for cats. The first additional trapping period was between March 22 until April 21, 1996. The second additional trapping period was on May 27 until June 29, 1996. Both of these additional trapping periods resulted on trapping two more feral cats. Another was July 6 to August 3, 1996, and finally, the last additional trapping period was on October 21, to November 21, 1996. Some other free ranging domestic cats were captured and released again immediately after being checked in the laboratory. The last feral cat was trapped by Paul Wagner on December 4, 1996.

In this study, where rats tend to be active earlier than cats and as a result they were very often found entering cat traps, Elliott collapsible aluminium traps, of dimensions 9 x 10 x 30 cm, were used as an response for targeting and reducing those small mammal problems. These traps were baited with a blend of peanut and rolled oats and placed within 1 to 2 m around cat traps wherever land topography was favourable.

2. 2. 1. Baiting and Trapping Procedures

Baiting was performed in several areas where feral cat often seen and at historic sites where occupancy was confirmed such in along Mars creek, in eastern site of Christie Park, areas around Blaxland Waterhole and in along Shrimptons creek, by using a combination of cat food and canned tuna. Baits were put at dusk and checked at dawn and refilled in case all food had been eaten.

After four nights of baiting, cage traps 30 x 30 x 60 cm (Mascot Wire Works, Sydney), were normally set down at the same locations. Captured cats were subsequently restrained by use of crush-pen and anaesthetised with 10 mg kg^{-1} "Zoletil" (Tiletamine and Zolazepan) injected intramuscularly. The following information were recorded on captured cats :

i) Trap location

ii) Weight

iii) Gender

iv) Colour,

v) and other allometric measurements (cm) : head, body length, and extremities length to be used by another study (Wagner, in prep.).

Care was taken to ensure that the cats captured were feral animals by leaving the animals in the trap overnight and subsequently being tested for their aggressive behaviour. Each animal was fitted with a single radio transmitter, 31 x 48 x19 mm, and 45 g in weight (Titley Electronics, Ballina NSW). The flexible antenna cables were coiled onto the flank of neck-straps. These neck-straps as well as antenna cables were mounted in such a manner that movements of the cat were not hampered such as getting caught on branches. Before being released at the site of capture, the animals were detained for 8 to 10 hours to allow the effect of the tranquilliser to wear off. Total transmitter weight was only 1% - 1.5% of total cat weight, well below level suggested adequate for other animals. In most radio tracking studies, the transmitter used weighed about 5% of body mass (Hickey, 1992).

2. 3. Data Collection

Cats were tracked using a 3-element Yagi Antenna (Sirtrack Electronics, Havelock North, New Zealand) in conjunction with a Telonics ® receiver (Telemetry and Electronic Consultants, Mesa, AZ, USA), utilising a frequency in the 150 MHz band.

Locations of radio collared cats (fixes) were determined by triangulation, using simultaneous bearings taken from two positions, or by direct observation whenever possible. All of tracking activities was done on foot with the obeserver remaining close enough to the cats to maintain accuracy of fixes. Data such as date, time, activities and coordinates for each location were recorded. Fixes taken were then plotted as gridline coordinates on tracing paper overlays on maps scaled 1 : 10.000 produced by Central Mapping Authority of New South Wales 1985.

For the purposes of home range calculation, it is assumed that fixes plotted represent true locations of the animals. Each cat was tracked 24 continuous hours during tracking sessions and fixes were taken at each 2-hour intervals both nocturnal and diurnal for all study animals with 15 minutes observing time. The greatest single limitation stems from the fact that the majority of mammals are active at night. Thus, the tracking activities were arranged to work the same time frame regardless of my own normal activity patterns. Since feral cats are more active in night hours (Johnson and Franklin, 1991; Langham and Porter, 1991; Haspel and Calhoon, 1993), nocturnal ground-based behaviour were the primary focus of data collection.

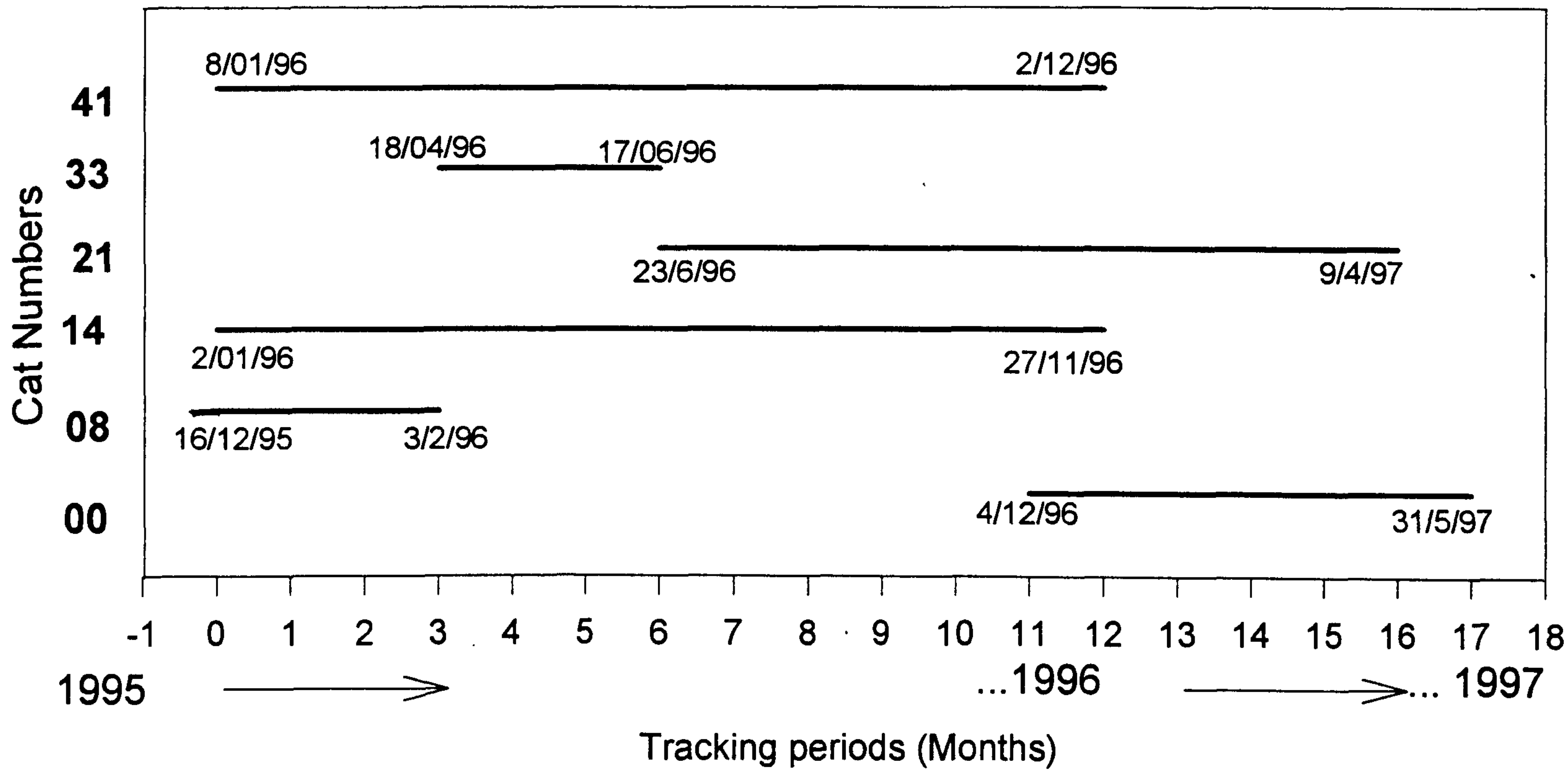
Cats were tracked from 8 to 40 days each over periods ranging from 2 to 12 months in length as shown in table 2. 4. The number of fixes per 24-hour period of tracking of each animal were similar. It was arranged to attempt to keep sampling level of fix locations equal for all studied cats, however, since three of these radio-collared cats were removed and killed by local people, the sampling effort of fix location was not spread equally. In this study, cats were sometimes located to within an area of about 10 metres diameter in order to observe the activity but because of dense vegetation were not often seen. Attempts to fix their position more accurately or to see the cats usually ended in them being disturbed and and moving away.

2. 3. 1. Scat Collection

Diet preference information was gathered by observing predatory activitiesand collecting faeces. Collection of scats for the diet studies extended from January 1996 to March 1997, and all scats were collected whenever found, although very old or obviously deteriorating scats were not taken. Obviously, all collared cats' scats deposited on the areas were not found, but conditions were favourable for a somewhat high percentage of recovery. Feral cats in this study are inclined to bury their droppings in the sun baked soil during the dry season closed to their rest site. Furthermore, cat scats do not disintegrated during the long summer and so remain susceptible to discovery for a long time.

The size, odour and location of scats were used to identify those of cat. In general, a cat' scats is between 2 and 2.5 cm in diameter while those of fox is no

Table 2. 4. Tracking activities for radio-collared cats during December 1995 -April 1997. Dates indicating periods of tracking



wider than 2 cm. The scats of large dogs are larger and may be as much as 4 cm in diameter (Triggs, 1996). Cats usually scratch sand, soil or leaf litter over their scats to cover up, and they often use the same sites regularly as most the case in this study. Large number of cat scats may be found at a site where the covers, drought sand, soil, and leafs, has disappeared. In the laboratory, the content of the scats serve as a check of the field identification. Cat scats contained a large amount of fine, powdery material, and any bone fragments were very small. Collection was mainly confined into the study area, in particular around the ranges of collared cats in an attempt to avoid non-feral scats, and all visible cat scats were picked up during the time of study.

2. 3. 2. Visual Observation.

Visual observation were attempted whenever possible in particular in order to gather information on cat activities.

2. 4. Analysis of Field Data

2. 4. 1. Home Range

Radio tracking has been in common use for wildlife research since about 1963 when Cochran and Lord (1963) devised a radio tracking system. Since then, this technique has revolutionised wildlife ecology studies. The most obvious of radio tracking is in following the movements of the subject animals, from which behaviour of the species, home range size, and pattern of utilisation can be determined. Also, mosaics of such data from several individuals in the same population provide considerable insight into the spacing and relationships among social units of the population.

A variety of analytical techniques exist to evaluate fixes of data location obtained by radio telemetry. For purposes on this study, data analysis are performed to two main objectives : the determination of feral cats home range size living in an urban parkland environment, spatial characteristics and utilisation by fix location and frequency, and of activity patterns within home ranges based both on overall minimum distance travelled and mean monthly minimum distance travelled (MDT ‹ave› ‹m›). However, it must be stressed that no one of those of the various analytical techniques currently used more frequently is perfect and each has a number of disadvantages (Harris *et al.*, 1990), and different methods can give different results even when analysing identical data. Therefore, since no one method is likely to be entirely satisfactory, at least two methods should be used with the data set. In this study, primarily, two different models were used to analyse data on the basis of fix location and frequency.

- **Minimum Convex Polygon (MCP),** is one of the earliest and simplest techniques for home range calculation. It is constructed by joining the outermost fix locations to form the smallest convex polygon. This method of home range construction encloses all fixes including occasional fixes well beyond the main area of activity. This means that the range size is strongly influenced by peripheral fixes although the range may include large areas never used by an animal. The outlying fixes may bias the size and shape of the home range, and it is dependent on sample size (Worton, 1987). Several authors have tried to reduce the disadvantages by using concave polygon (Kenward, 1987), or by correcting minimum convex polygon ranges by manipulating adjustments such as restricted polygons. Nonetheless, it remains the most common minimum area method utilised in the literature.

- **The Adaptive Kernel,** is a non-parametric estimation procedure that is applicable to a variety of home range estimation problems where the assumptions of a parametric model such as bivariate normal cannot be met (Worton, 1989, 1995). This model is free of the problems associated with the harmonic mean. It is not sensitive to the size of the grid although it requires a grid structure being overlaid on the data points. However the adaptive kernel requires intensive computation, and not all home range programs currently available offer the choice of this method (Larkin and Halkin, 1994).

Kie *et al.* (1996) have developed a program to compute home ranges using X, Y coordinates for a single animal called CALHOME (California Home Range) that include Minimum Convex Polygon, Bivariate Normal, Harmonic Mean, and The Adaptive Kernel. For each home range method, four different utilisation distribution can be selected, for example, 30% and 60% core areas, and 95% and 100% home ranges. In this study, home ranges were calculated as the isopleth that encloses 95%, 90% of fixes respectively in an effort to reduce the bias imposed by the outlying fixes, and 50%, and 60% respectively of feral cat's seasonal location in order to figure out the core area used.

2. 4. 2. Diet Analysis.

After collection, in the laboratory, the scats were treated as follow. All scats were dried at 110 ºC for 2 hours to destroy possible contaminating parasites. Each was soaked in water overnight, and were separated carefully on the day after. Indigestible food remains (hairs, teeth, and bone fragments) were separated to prepare to further examination.

With other food categories, birds, lizards, insects, and herbage, it was not possible to fully identify the species (Coman and Brunner, 1972). Bird remains usually consisted only a few feathers and claws, making further identification difficult. However, there is some instances where birds identification were possible, that is by visual observation on site attacks which mostly occurred very close to the rest site. Most remains of insects and lizard were severely damaged by digestion, and identification beyond the level of orders was not attempted. Instead, broad categories were used for these, and the four categories considered here are :

i) Insect exoskeletons

ii) Herbage materials

iii) Birds

iv) Other vertebrates

v) Household refuse.

The method of diet analysis for mammal remains, such hair identification, have been well studied by Brunner and Coman (1974). This technique rely mainly on a study of the cross-sectional appearance, scale pattern, and medulla arrangement of mammal hairs. The method of obtaining cross-sections has also been described by Coman and Brunner (1971). Scale pattern were produce by embedding hairs in a thin film polyvinyl chloride on a long glass cover slip. After 30 minutes at room temperature the embedding material was sufficiently dry for the hairs to be lift carefully from the glass. The resulting scale imprint was viewed from the underside with a microscope. The medulla arrangement was obtained by mounting the hair in DePeX or water on a glass slide and viewing directly under the microscope.

In this study, the data on the diet of feral cats have been arranged to show the relative importance of each food category on an occurrence basis, where percentage of occurrence refers to the ratio between the number of times a particular food item found in the scats and the total number of scats collected during the time of study. The percentage volume was not attempted. The reason was that all those scats collected were dry scats and it is not possible to separate and identify all contents to the level of species.

2. 4. 3. Activity Data

Radio-collared cats were followed on foot from January 1996 to May 1997. Their activities data mainly on the arrival and departure times at the most occupied areas were recorded during 24 hours for each. Other activities data such as sitting, sleeping, and searching or scavenging food were translated into active and inactive categories in an attempt to calculate the percentage of their activities in a daily basis. MDT ‹av› estimates, used to define feral cat activity within home ranges, were calculated as straight-line distances between fixes unless the path was clearly obstructed by a barrier. This takes into account movement around barriers, and thus differ slightly from conventional straight-line distances measures.

Additionally, the seasonal home ranges determined in this study will be compared with inferensial statistics using either **regression analysis** or **t-test** method. For this comparisons, range size, spatial mean, and minimum distance travelled areas are the respon variables, season is treatment variables and individuals are the blocking variable or the experimental unit ($\mathbf{P < 0.05}$).

Chapter 3

Results

3. 1. General Characteristics of Study Animals

During the 17-month study, six individual cats were radio-collared, three mature females and three mature males. One mature male was found dead after ten months of being tracked and two others were known to have been removed and killed by local people. Three mature females were present throughout the study, two being followed for 11 – 12 months, and the third being followed up to five months. The periods for which cats carried an active transmitter and were actively tracked are shown in table 2. 4.

Three cats, two mature females and one mature male, had been trapped and collared previously (Godfree, 1995). Cat 41, a 3.0 kg female, was first trapped in October 1994; subsequent attempts to recapture this animal were made when the battery expired around February 1996 until it was caught. Cat 14, a large 4.0 kg female, was captured in the southernmost region of Mars Creek on 3 August 1995, while cat 08, a large white 4.5 kg mature male, was caught on 21 October 1995 at a location very close to that of cat 41 (Godfree, 1995). Both of these mature females gave birth twice during 1996, which increase the number of feral cats in the study site at the present time.

Three other cats were captured during the study period with cat 33, a 3.3 kg mature male, was first captured on 18 April 1996 in the north west of the study area close to Marsfield Park. Cat 21, a large 4.0 mature male, was captured on 23 June 1996 around the Lane Cove riverbank; and Cat 00, a large 3.5 kg mature female, was the last cat captured on 4 December 1996 around the small bush fragment in the eastern part of study site. This animal had three kittens one month old in the natal den when it was trapped. The capture data indicating the number of fix locations and monitoring days information is presented in the table below.

Table 3. 1. Capture data for radio-collared cats in an urban parkland environment of North Ryde, Sydney

Cat Numbers	Status When Captured	Weight (Kg)	No. of Fix Locations	No. of Monitoring Days
00	Mature Female	3.5	240	20
08	Mature Male	4.5	84	7
14	Mature Female	4.0	378	34
21	Mature Male	4.0	302	25
33	Mature Male	3.3	89	8
41	Mature Female	3.0	318	33

Table 3. 1. Shows detailed capture data for each radio-collared cats. Most of the animals were monitored more than ten days with cat 14 and cat 41, 33 and 34 days respectively, were the longest with large number of fix locations obtained. However, due to removal by local people, two radio-collared cats, 08 and 33, were only tracked for seven and eight days respectively. This condition has resulted on unequal number of fix locations. These two animals had only 84 and 89 fix locations respectively.

The number of fix locations taken for three time intervals during the 24 hour period are shown in table 3.2. Approximately equal number of fixes were recorded between day time and night time. However, since all cats were more active during night time, fewer visual observations were recorded during the day time interval (06.00h – 18.00h). Instead, cats were located mostly by using radio telemetry. Overall, the frequency of sightings was greater in the 00.00h - 00.06h and the 18.00h - 00.00h time intervals than that in 06.00h - 18.00h (ratio 1 : 1.27). Therefore, comparisons of home ranges seasonal movement of each individuals feral cat for the remainder of this chapter refer to these night-time intervals.

3. 2. Home Range Characteristics and Utilisation

3. 2. 1. Monitoring

Table 3. 2 shows the total fix locations recorded for all cats. In total, 1411 fixes were obtained of which 35.7% (503) were made by direct observation. This is equal to 1006 hours observation time. From 345 fix locations in the time interval (00.00h – 06.00h) 170 (49.3%) were made visually which is similar in the

18.00h – 00.00h time interval where 192 (50.4%) of 381 fix locations were made visually, providing confident delineation of animal's activity home ranges. Such aspects for nocturnal animals like feral cat are normally defined by their night time activity.

Table 3. 2. Description of data obtained by both visual and radiolocation methods for each individual radio-collared cats during the study period.

Individual Radio-collared Cat	Methods	Time Intervals			Total
		0000-0600h	0600-1800h	1800-0000h	
00	Visual	27	26	26	79
	Radiolocation	33	95	33	161
08	Visual	13	7	14	34
	Radiolocation	8	34	8	50
14	Visual	33	30	56	119
	Radiolocation	56	154	49	259
21	Visual	36	29	29	94
	Radiolocation	39	121	48	208
33	Visual	14	9	18	41
	Radiolocation	7	32	9	48
41	Visual	47	40	49	136
	Radiolocation	42	108	42	182
Total	Visual	170	141	192	503
	Radiolocation	175	544	189	908

3. 2. 2. Home Range Sizes

Home range sizes (n = 84 - 378) were estimated for each individual cat from the total fix locations of six radio-collared cats and the results are summarised in the table 3. 3. Home range size for each animal, calculated by Minimum Convex Polygons utilising 95% isopleth, were 16.780 ha (cat 00), 54.590 ha (cat 08), 20.400 ha (cat 14), 85.070 ha (cat 21), 14.560 ha (cat33), and 14.120 ha (cat 41), respectively. By using a similar isopleth , the Adaptive Kernel method estimated somewhat larger home range size than MCP sizes with 23.890 ha (cat 00), 78.050 ha (cat 08), 27.680 ha (cat 14), 27.080 ha (cat 33), and 19.200 ha (cat 41), respectively, except cat 21 with estimated home range size was 76.780 ha, smaller than MCP result. The latest figure indicated one of a problem using MCP dealing with outlying fixes since cat 21 was wide ranging individual and temporarily moved out from the main occupied area for excursions of several days and as a result the large estimated range may contain areas never used by this animal. Radio tracking and visual observation revealed that for the few months first after being radio-collared, cat 21 was found exclusively around the trapping site. Movement out side this region occurred during November 1996 to May 1997 when it was found dead.

The overall mean home range areas (± SD) calculated by MCP methods were 51.41 ± 35.36 for adult males and 17.10 ± 3.15 for adult females; the difference was not significant ($t = 1.674$, $P = 0.169$). Similar result was found using Adaptive Kernel methods where mean home range areas were 60.63 ± 29.07 for adult males, and 23.59 ± 4.28 for adult females; there was no differences between the sexes in these ranges estimation ($t = 2.184$, $P = 0.094$). Since the animals in this study were strictly nocturnal and living in an confined area, it is difficult to assess the significe of difference of their ranges. Also the limited numbers of animals studied may have imposed similar problems because less data can be collected for the purpose of comparisons.

Based on the results presented in the table 3. 3, figure 3. 1, 3. 2, 3. 3, and 3. 4, it is clear that the home ranges were variable in size, shape and dispersion of fixes.The distributions were mostly heterogeneous, a result of fixes being clumped in one or more locations. These clumping resulted from unequal intensity of habitat use within the home ranges. Two individuals concentrated their activities within one core area (Figure 3. 4. a, 3. 4. b), three demonstrated a distinct bimodal pattern of usage (Figure 3. 3. b, 3. 3. c, and 3. 4. c), and one (Figure 3. 3. a) had several areas of intensive use.

Considering 60% and 50% isopleths as the core areas for centre of activity of cats, Adaptive Kernel Methods estimated smaller areas than those of MCPs except for cat 08. This result may have been caused due to small samples of fix locations taken for this animal. Presumably this is true, and to be more accurate, this methods needs a minimum number of samples to operate.

Based on fix locations and home ranges shapes obtained by both these methods, a few overall comparisons can be made. Firstly, fixes for cat 00, 08, and 21 were spread evenly and at low frequency over a much large areas (Figure 3. 1. a, 3. 1.b, and 3. 2. c). The MCPs estimation for these animals include large areas of suitable habitat which were almost certainty never used. MCPs estimation for cat 08 (Figure 3. 1. a) expands from the bush southern of Christie Park to the western section of Mars Creek close to the home range of cat 14, utilising 54.59 ha areas forming an elongate shape. Home range size predicted by Adaptive Kernel were 78.50 ha larger, than those of MCPs, forming dumbbell shape areas with two core areas (Figure 3. 4. c).

Table 3. 3. Calculated home ranges and core areas for individuals of radio-collared cat using Maximum Convex Polygons (MCP) and Adaptive Kernel Methods showing 95%, 90%, 60%, and 50% isopleths

Individual	Minimum Convex Polygon				Adaptive Kernel Methods			
Collared cat	95%	90%	60%	50%	95%	90%	60%	50%
00	16.78	12.29	5.47	5.46	23.89	16.63	6.13	3.45
08	54.59	48.34	25.95	22.55	78.05	65.86	31.85	23.36
14	20.40	18.50	11.81	11.59	27.68	16.42	3.98	2.26
21	85.07	78.68	44.97	23.56	76.78	62.68	25.12	21.39
33	14.56	10.86	4.17	3.27	27.08	16.59	2.67	1.81
41	14.12	10.40	5.27	5.06	19.20	12.77	2.31	1.25

Values are in hectares

Fixes for cat 00 were distributed uniformly inside the boundary which extends from southmost of Macquarie Park up to Balaclava Road very close to Christie Park and has an area of 16.78 ha. However, Adaptive Kernel methods estimation (23.89 ha) were slightly higher than MCP. Interestingly, Both of methods used produced much more similar home range shape even though Adaptive Kernel's has two divided core areas (Figure 3. 2. c, 3. 3.c).

Another animal, cat 21, has the largest home ranges estimation by both methods, 85.07 ha, and 76.78 respectively. This cat primarily controlled areas from

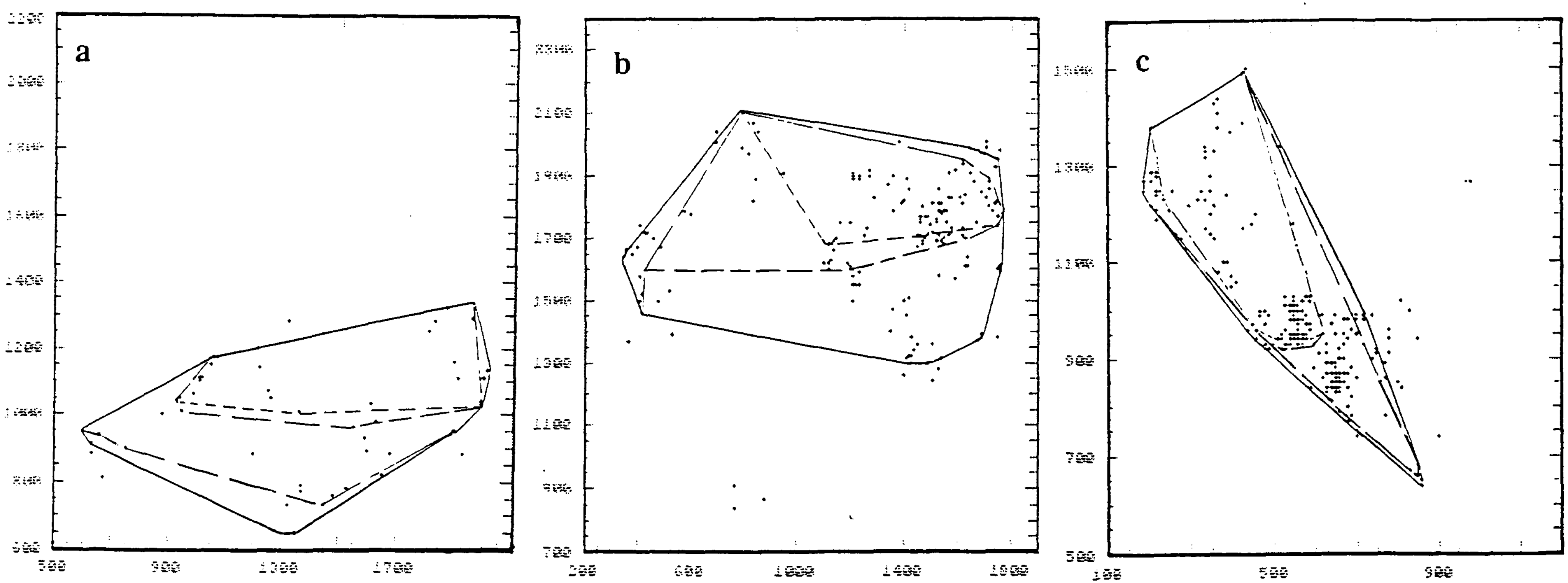


Figure 3. 1. Individual home range outlines estimated by Minimum Convex Polygon method utilising 95%, 90%, 60%, and 50% isopleths.
(a) cat 08, (b) cat 21, and (c) cat 14

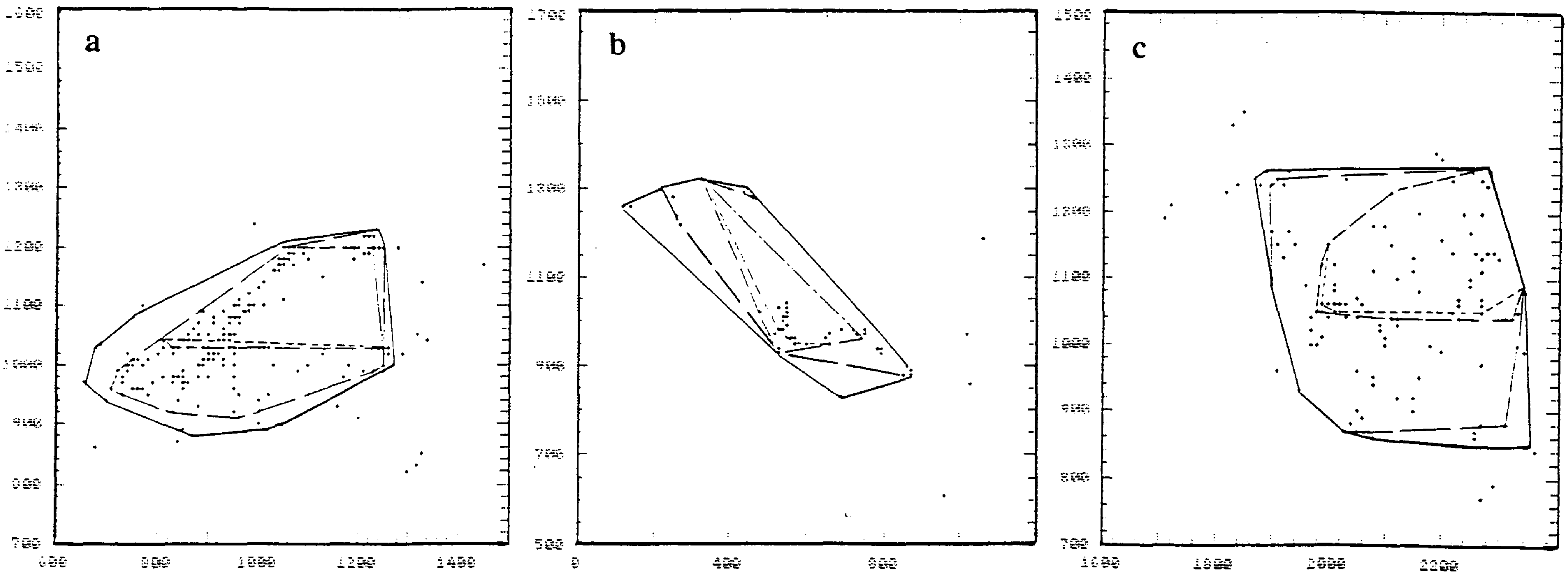


Figure 3. 2. Individual home range outlines estimated by Minimum Convex Polygon method utilising 95%, 90%, 60%, and 50% isopleths.
(a) cat 41, (b) cat 33, and (c) cat 00

Lane Cove riverbank extending to the Fauna Reserve of Macquarie University and regularly made excursion for several days around Marsfield Park. As a result, home range shaped for this animal forming a large area with three distinct location as shown in figure 3. 3. a. The core areas, however, were located in the largest occupied areas indicating that most of the activity were around Lane Cove riverbank.

Secondly, fix locations for cats 14, 33, and 41 were mostly clumped on some locations in western perimeters of their range boundaries (Figure 3. 1. c, 3. 2. a, and 3. 2. b), with eastern portions of ranges being relatively infrequently utilised in a more or evenly distributed manner. As a result, home range formation were more or less conical to elongate in shape. These figures resemble much and coincide to the formation of bush fragments around these areas, along Mars Creek and Marsfield Park. Fixes were most frequent around the den sites (Godfree, 1995). The majority of fix locations for cat 14 were concentrated in the small pockets around the middle of its range boundary (figure 3. 1. c), and its values is reflected in the Adaptive Kernels estimation using both 60% and 50% isopleths with small areas of 3.98 ha and 2.60 ha, respectively. The areas utilised by this animal extends from Balaclava Road up to Marsfield Park and has an area of 20.40 ha. Extensive use of the den sites occurred in the weaning period, that was on December to April each year, while excursions up to north close to the boundaries of male 21 and 33 took place before hand. Similar patterns was performed by cat 33 where both of methods used in this study produced resemble home range shape (Figure 3. 1. c. vs 3. 2. b, and 3. 3. b. vs 3. 4. b.). Estimated ranges produced using Adaptive Kernel methods were higher than those of MCP's even though MCP resulted slightly large estimated core areas.

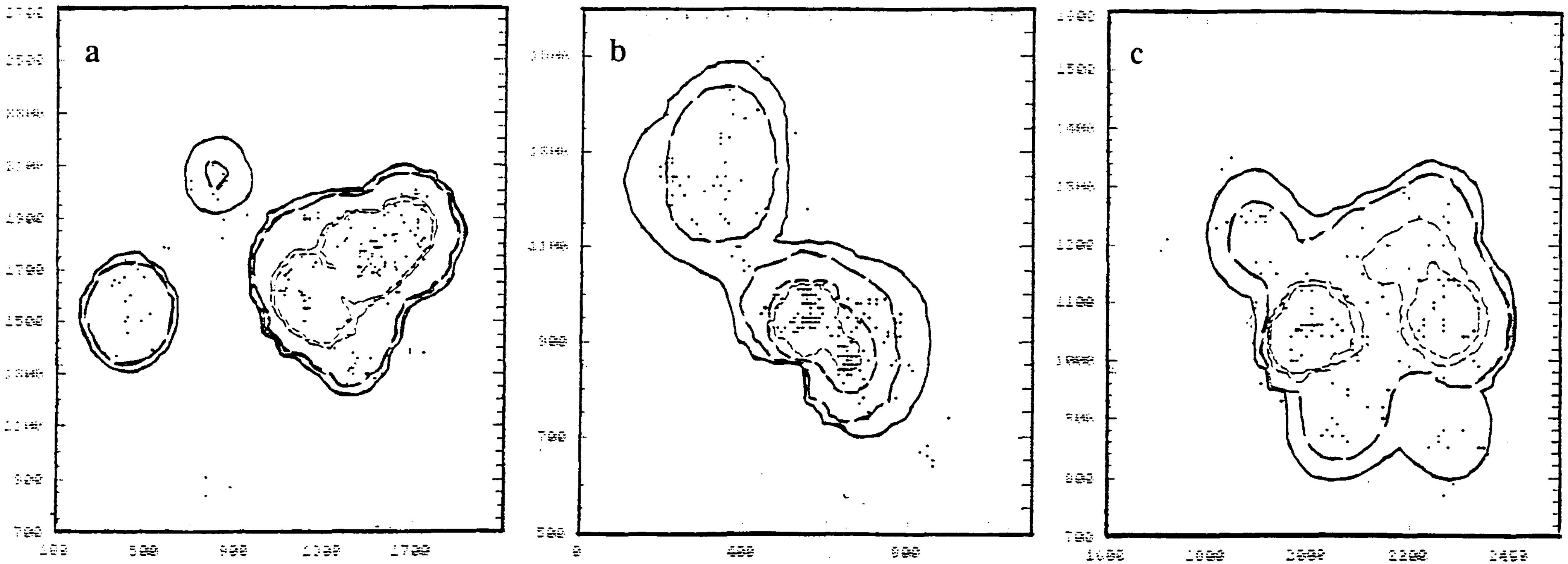


Figure 3. 3. Individual home range outlines estimated by The Adaptive Kernel method utilising 95%, 90%, 60%, and 50% isopleths.
(a) cat 21. (b) cat 14. and (c) cat 00

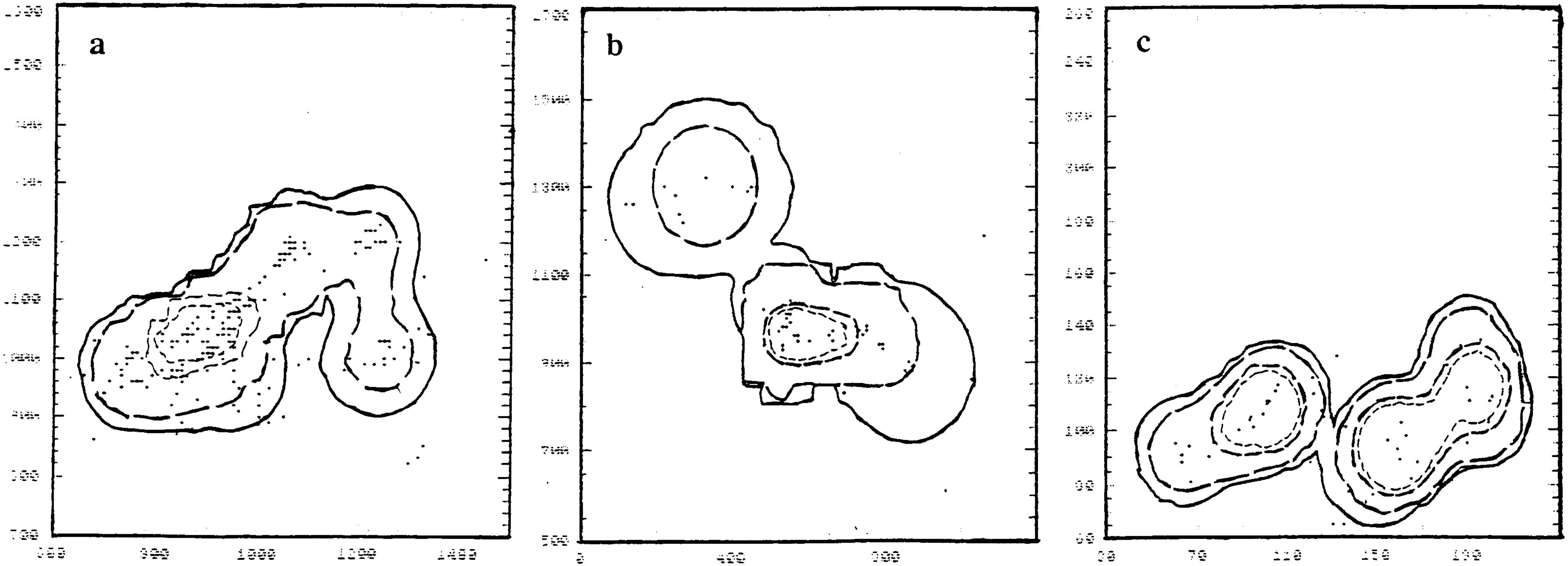


Figure 3. 4. Individual home range outlines estimated by The Adaptive Kernel method utilising 95%, 90%, 60%, and 50% isopleths.
(a) cat 41, (b) cat 33, and (c) cat 08

Finally, fix locations for cat 41 near the boundary of its range were mostly stretched along its north west perimeter, which indicated strong use of Mars Creek area. This area may either being used as den sites or visited as part of nocturnal movement. There was no excursion from the boundary recorded during the study period and it seems that this animal coexisted with a large number of rabbits around the University grounds. There was also strong evidence that this cat relied heavily on scavenging in open refuse containers as indicated by some of fixes observed clumped around the garbage bins locations. As a result, this animal has the smallest ranges estimated, 14.12 ha, 10.40, and 19.20, 12.77 ha for 95% and 90% isopleths respectively, by both methods.

3. 2. 3. Home Range Overlap

Even though mean home range comparisons calculated by both Minimum Convex Polygons and Adaptive Kernel methods were statistically not different as outlined earlier, home range boundaries delineation using MCPs 95% isopleth (Figure 3. 5) does clearly show greater proportion of areas controlled by males than those of females.

The home ranges of opposite sexes overlapped more than did those of members of the same sex. This may due to existence of the sexual-bonds between male and female particularly in the breeding season. On several nights of April 1996 cat 33, whose range includes almost the entire home range of cat 14, were followed from Marsfield park to the Mars creek where this animal picked up female 41. The following nights this animal was observed to go with cat 41 around the car park where another uncollared cat was present. Another animal, cat 08, had a large home range which included the entire range of female 41 and on several occasions the two were seen active together. In contrast, no contact was seen between male 21 and the rest of studied animals, and instead this lone male kept occupying exclusively large areas north of study site where some domestic cats existed, with very little overlap to cat 14. Visual night observations on this animal revealed that this cat spent much time feeding with an uncollared female cat.

Home ranges of feral cats in this study overlapped to some extent, however, aggressive interactions were never recorded between them although there was the potential. Instead, much higher levels of tolerance were evident in particular between female 41 and 14.These two neighbouring cats occassionally used overlapping areas of their home ranges in the same month. When this did occur, visual observation and fixes taken indicated that they were using similar areas but at different times. For male cat, cat 08's home ranges slightly overlapped with those of male 33. However, since the former had been removed and killed before the later was trapped, there was no contact recorded between these animals.

There were differences between sites in the amount of home range overlap. At the half western of study area, the home range of four cats overlapped extensively, where two individuals had home ranges that were completely enclosed by the home range of two other cats. On the other hand, eastern sites displayed a relative sparse distribution of home ranges with very small areas of overlap.

Another aspect that strongly existed among the studied animals considering the home range uses is that the fidelity to home range was extremely strong. The level of fidelity is outlined as the comparisons of animal's monthly distance travelled during the two different seasons which will be presented in the next parts.

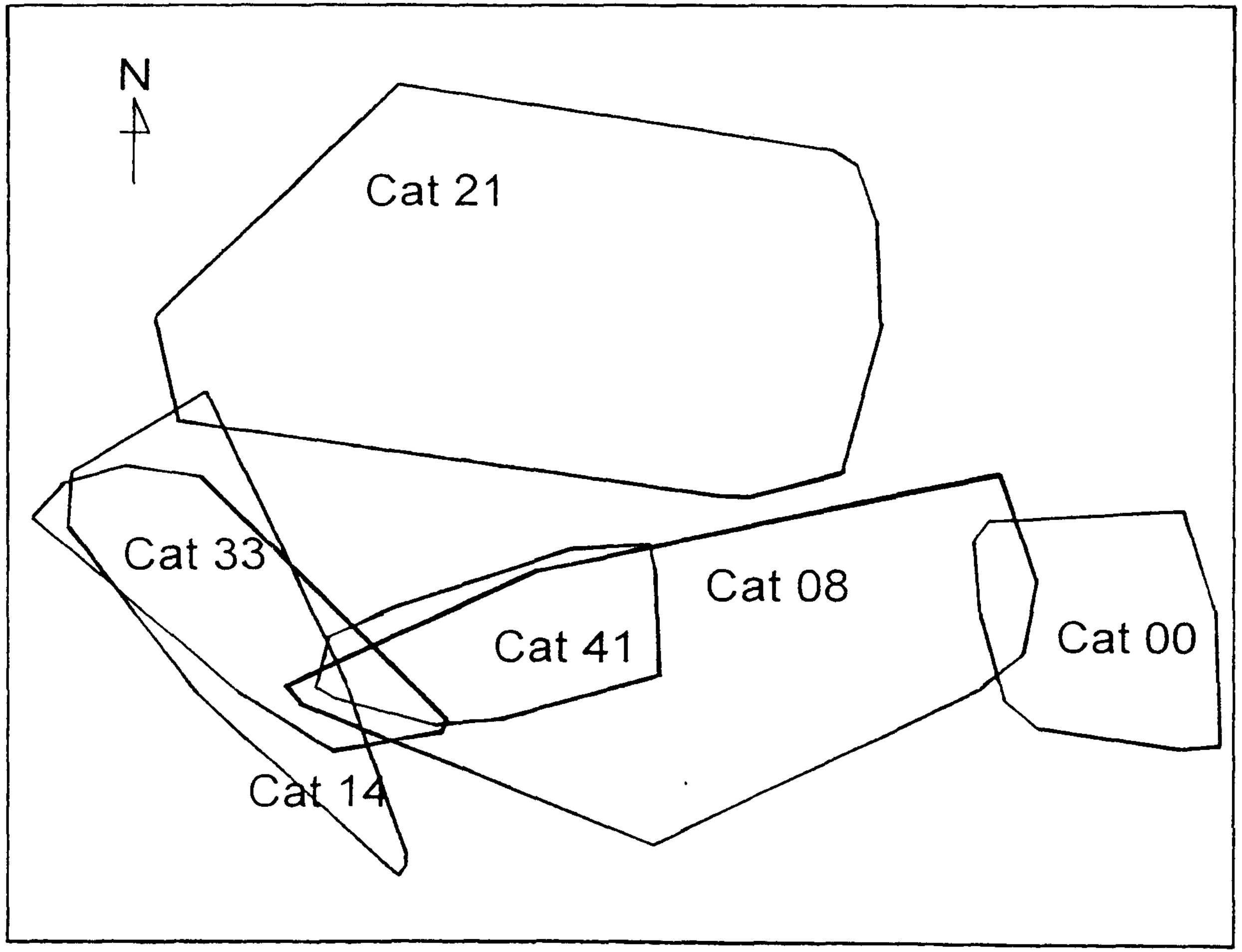


Figure 3. 5. Home range outlines of all radio-collared cats estimated by Minimum Convex Polygons 95% isopleth at North Ryde

Fortunately, three animals were able to be followed for one-year completely which provide such data for two consecutive seasons while three other studied animals provide insufficient data due to short periods of tracking. This technique may result in bias as the estimations rely on monthly averages, however, the problem can be reduced by confirmation of visual observations in which all the study animals were always being followed on 24 -hour basis so that any movement out of their ranges would have been observed.

3. 2. 4. Body Weight and Home Range Sizes

The distribution of body weight variations of trapped animals are shown in table 3. 1. There was no significant different body weight between males and females using t-test method (t value = 1.0271; P value = 0.362). Stabilised home-range estimates for males and females were therefore combined to calculate mean home ranges relations to body weight. All individual isopleths range estimations taken from both analysis, Minimum Convex Polygons and Adaptive Kernel Methods, will be considered except 50% isopleth.

Although home range size has been found to correlate positively with body size in mammals (Harestead and Bunnel, 1979; Lindstedt *et al.* 1986), this study found no significant relationships between body weight and total home range areas. Home range sizes (95% isopleth) produced by Minimum Convex Polygons and adaptive Kernels were correlated to body weights, the correlation were not significant with $r^2 = 43.2\%$; $F = 3.04$, $P = 0.156$, and $r^2 = 64.2$; $F = 7.16$, $P = 0.55$, respectively. Detailed illustration of regression results can be seen on Figure 3. 6 and 3. 7.

Similar results were found with 90% isopleth home range sizes estimation where r^2 = 43.8% ; F = 3.11, P = 0.152, and r^2 = 61.7% ; F = 6.44, P = 0.064, respectively (Figure 3. 8 and 3. 9). However, areas 60% isopleth by Adaptive Kernel Methods had slightly significant correlation with r^2 = 66.4% ; F = 7.89, P = 0.048 while MCP without significant effect r^2 = 44.3% ; F = 3.18, P = 0.149 (Figure 3. 10, and 3. 11). These unfavourable results may have been worsened by the fact that two studied males always have enormous ranges estimated and exceeded 2 to 5 times ranges of others studied animal, and therefore, the inclusion of their ranges in a linear regression resulted in a poor fit. If they were deleted, the figure might be different.

Based on these figures, regression of home range areas estimated by both methods utilising three different isopleths shows that Adaptive Kernel's were always higher than those estimated by MCP, even though its results still have no significant correlations yet. The results presented were not favourable given that mammalian carnivore mostly have relationship between area of home range and their body weight. However, since the animals in this study were urban animals that to some extent rely for their food sources on human handouts and hunt in patchy fragments of bush, the correlation estimate provided should be regarded as minimum figure only. It is expected that for carnivorous species, dependent upon prey availability, that increase in prey avilability result in a decrease in predator range size.

Another aspects that may well be considered given that weak correlations of body weight and home range areas in this study is the number of radio-fixes require to calculate animals' home range size in relation of determining at what point home range size reaches an asymptote. This is important as it is defined as the point after which additional locations result in a minimal increase in range size. When MCP areas are plotted against fix number for all studied animals, it is clear that the area increases most rapidly during the initial stages of the tracking periods, and decline as fix number increases. Appendix 3, 4, and 5 illustrates the estimates for individual home range reach asymptotes at different values and with a slightly different curves, depending on the patterns of home range utilisation range size for that particular animal. As can be seen, all female cats reach the asymptotes on the averaged of 50% fixes taken (cat 00, 50% ; cat 14, 58%; and cat 41, 53.5%), indicating small ranges utilised. In the initial stages of study, these animals performed very slow increase of their range because of on those times were weaning periods. Expansion of home ranges occurred after this stage continuing to the next mating season. For this reason, it is important to say that selected time intervals for the home range calculations is going to have better results if it is based on a period covering at least two seasonal range shifts.

One male, cat 21, reaches its final MCP area after 250 fixes (83%) indicating large number of fixes are needed to produce an asymptote for this animal (Appendix 6). On the other hand, two other males, cat 08 and 33, underwent a slightly different figures. These two animals seem not to have reached their final asymptotes yet with those number of fixes taken (Appendix 7 and 8). It is clear that this problem occurred clearly due to insufficient number of fixes, or in other words, a shorter time span spent for tracking and collecting fix data for these two animals were associated with their true home range. In this case, the data still possibly to be corrected to produce an asymptotic range estimated using regression equations calculated from asymptotic home ranges. However, the obvious disadvantage with this approach is that it changes a true home -range value into a hypothetical one. Therefore, it was considered impractical to correct the true values of home range for these animals.

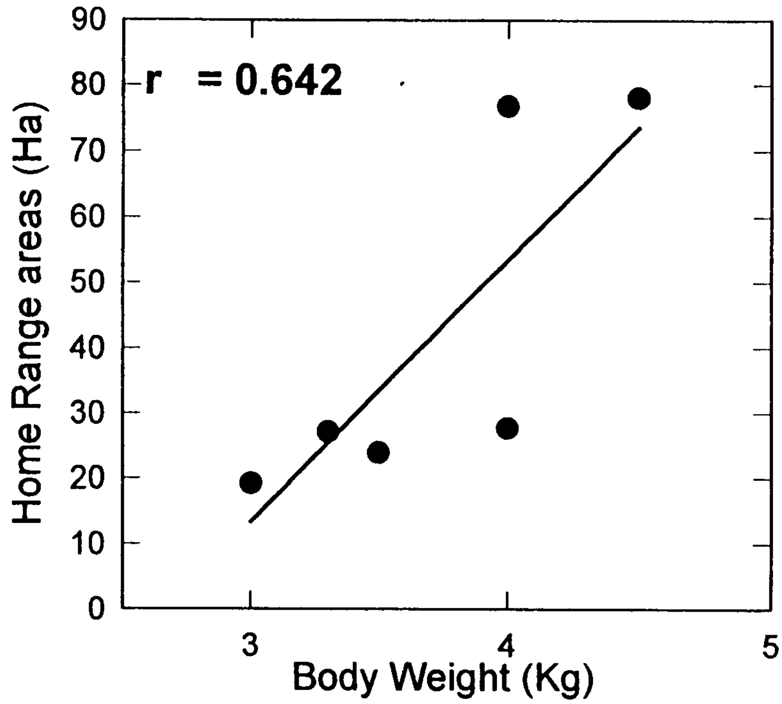


Figure 3. 6. Regression of home range area estimated by Adaptive Kernel Method 95% isopleth on body weights of feral cat

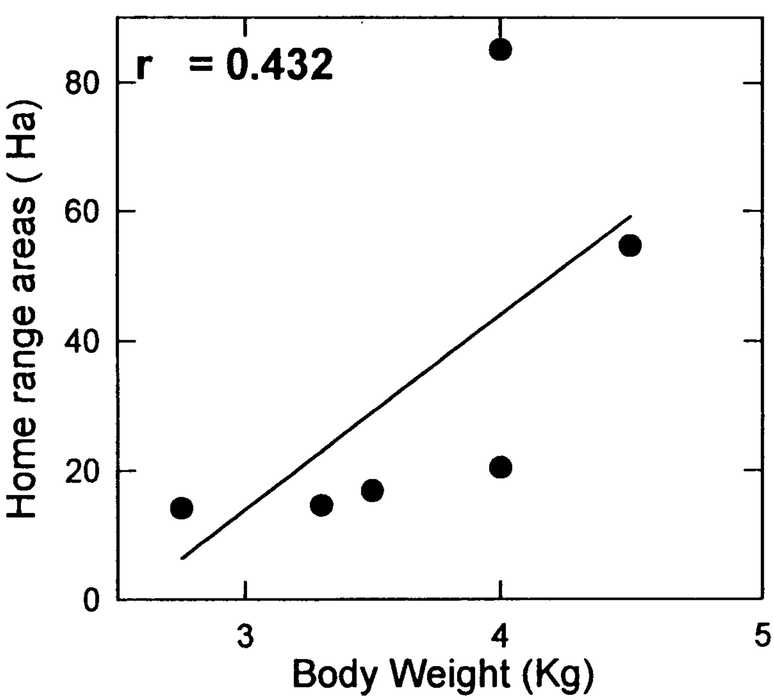


Figure 3. 7. Regression of home range area estimated by MCPs 95% isopleth on body weights of feral cat

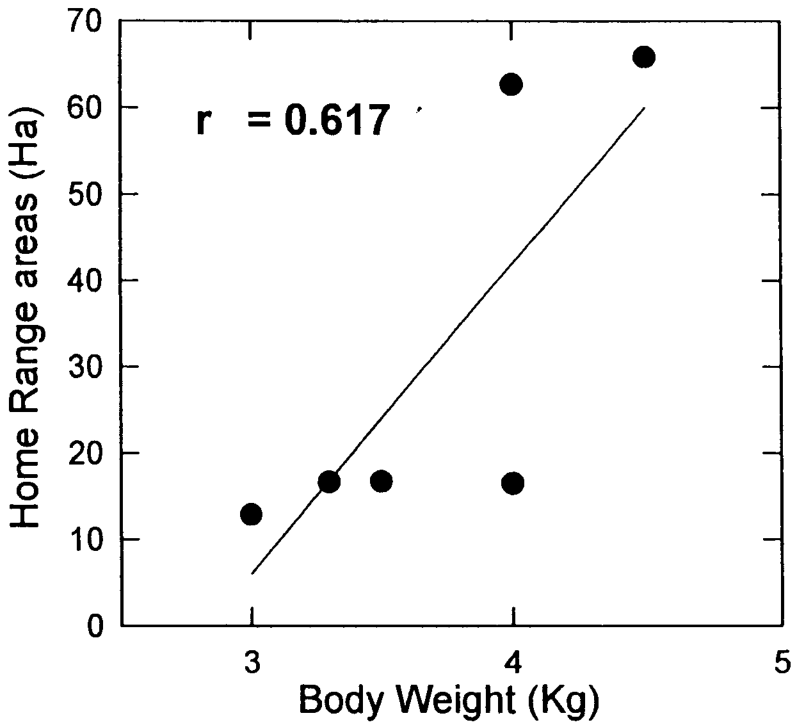


Figure 3. 8. Regression of home range areas estimated by Adaptive Kernels 90% isopleth on body weights of feral cat

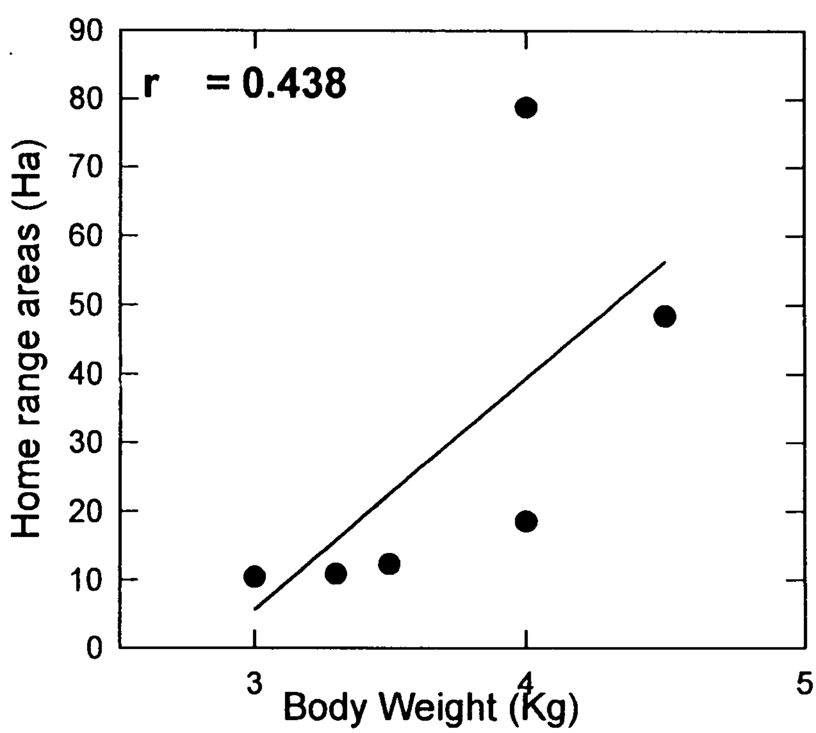


Figure 3. 9. Regression of home range area estimated by MCPs 90% isopleth on body weights of feral cat

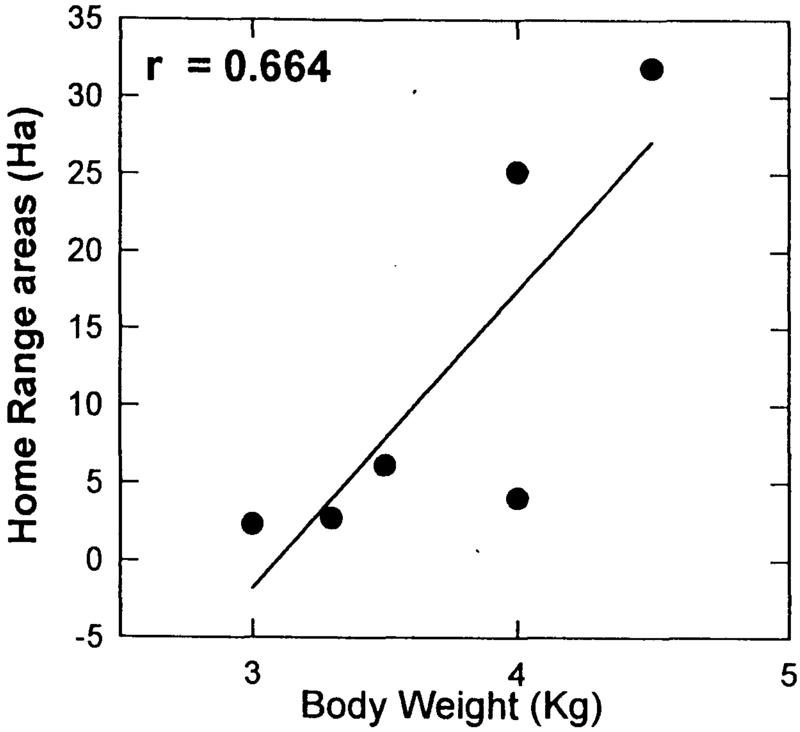


Figure 3. 10. Regression of home range areas estimated by Adaptive Kernel methods 60% isopleth on body weights of feral cat

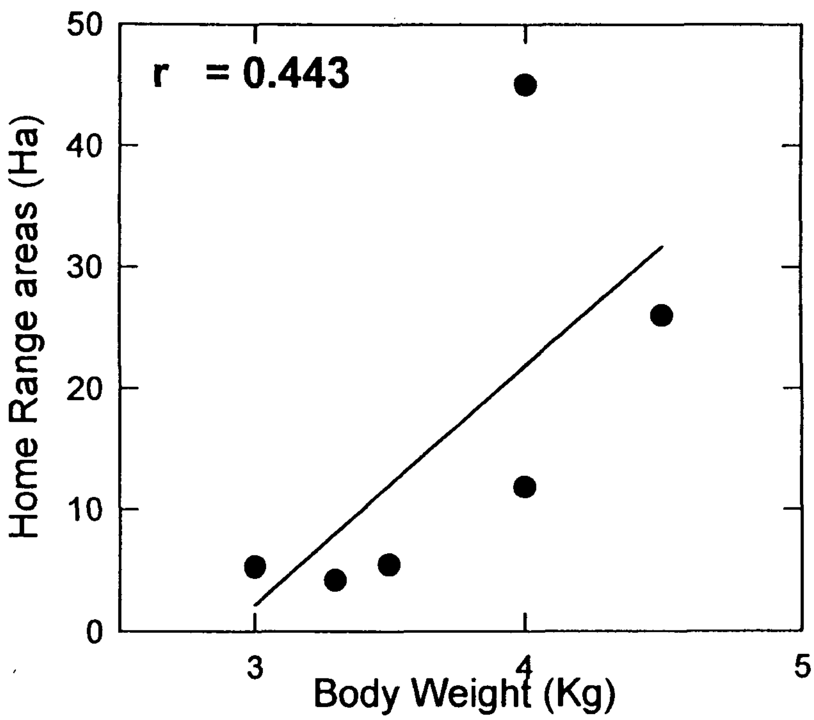


Figure 3. 11. Regression of home range areas estimated by MCPs 60% isopleth on body weights of feral cat

3. 3. Activity Patterns

3. 3. 1. Individual Movement

The time of initiation of activity for each individual animal studied and times of ceasing movement are shown in the table 3. 4. There was slightly different variation within average values of starting times of activities for individual cats with cat 14 was the earliest (17.09h ± 0.18' ; ranges from 15.53h to 21.36h). Based on ranges of initiation of activity for all animals, however, cat 08 was recorded having the longest time intervals of initiation (13.17h to 22.18h). Overall time of initiation of activity for studied animals was (± SE) 19.37 ± 0.47, while ceasing times average was 5.13 ± 0.11 providing large average time for activity of 10.24 ± 0.54 hours. For the details of other values of initiation times will be considered next in conjunction with individual patterns of animal activity within 24 hour periods. Average cessation times for all animals were much more similar with cat 21 was the longest to keep the activity (05.36h ± 0.15'). However, ranges for the cessation time values, cat 14 showed broader period and had range of 00.00h to 09.21h.

During the study, there were individual and seasonal variations in feral cats' behaviour considering their activity patterns, although all studied animals were generally found resting during midday. Daily journeys for some began as early as 3 to 4 hours before dark while others started moving just before dark. The journeys usually continued throughout of the night, and sometimes continued as late as one to two hours after down. There some evidences of expanded moving performed by the studied animals. Activity periods seems to be influenced by events and thus vary according to individuals. Therefore, for the purpose of accuracy on describing individual activity patterns, the following paragraphs give a detail account of the movements of six studied feral cats on individual basis.

Table 3. 4. Average times of arrivals and departures (± SD) of individual feral cat at North Ryde. Ranges of starting and ceasing time are in parentheses.

Individual Radio-collared cat	Activity Starting Times (Range)	Activity Ceasing Times (Range)
00	20.02 ± 0.30 (13.43 to 21.38)	05.18 ± 0.16 (00.00 to 06.53)
08	20.24 ± 1.20 (13.17 to 22.18)	04.58 ± 0.32 (00.00 to 05.07)
14	17.09 ± 0.18 (15.53 to 21.36)	05.30 ± 0.33 (00.00 to 09.21)
21	19.35 ± 0.29 (15.23 to 21.27)	05.36 ± 0.15 (00.00 to 06.32)
33	20.01 ± 1.34 (13.57 to 21.47)	05.18 ± 0.26 (00.00 to 06.58)
41	19.55 ± 0.26 (17.47 to 22.08)	05.22 ± 0.11 (00.00 to 06.03)

Figure 3. 12. shows detailed mean daily activity pattern for cat 00 observed from December 1996 to May 1997. During night time hours the percentage time spent actively varied. The greatest percentage per hour activity occurred after sunset with peak on 21.00h (87%), after which this animal continued to experience a decrease on time spent active at 23.00h (75%); 01.00h (50%), until it reached the

lowest at 03.00h (40%). The activity increased markedly again to 50% at 05.00h before it totally ceased at 06.53h. There was some evidence that this animal rested briefly during the night time journeys, such sitting in the car park or behind the building. Visual observations sometimes confirmed that this cat remained unchanged its position for 30 to 40 minutes, after which it was recorded as moving. Evidence of such resting at night is also confirmed from the figure 3. 12. where only 50% of 00.00h to 05.00h time intervals were utilised. When feeding at night, this cat moved a mean 92.5 m between successive fixes (2h apart). This aspect will be discussed more detailed on the seasonal movement.

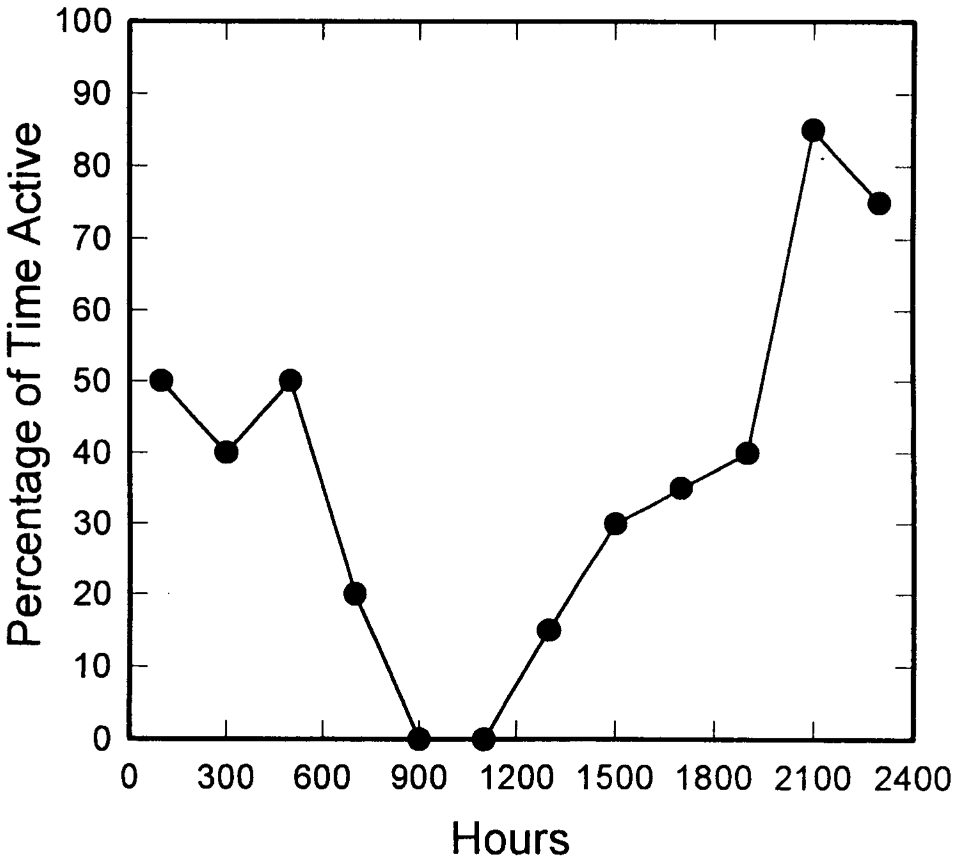


Figure 3. 12. Mean daily activity pattern for cat 00 observed throughout the study period

Similar patterns were performed by cat 41 (Figure 3. 13). This animal has the greatest time active at 23.00h (82%), continued active at 01.00h (73%). Another peak activity occurred on 05.00h (69%) after an evidence of long resting on 03.00h (42%). Expanded moving were recorded for this animal until near 07.00h. It is the fact that this animal started earlier on most days, however, since its den sites was located in Mars Creek of the university ground, the activities always postponed until the environment favourable for a feral animal to active. Instead, creek utilisation was obvious. Movement to and from feeding areas for this animals were highly predictable. Most departures were from den sites and generally move directly to the centre of home range or further. Movement was usually in stages, from location to location. During the mating season, this animal was often seen standing together with male 33 on the edge of creek before departing.

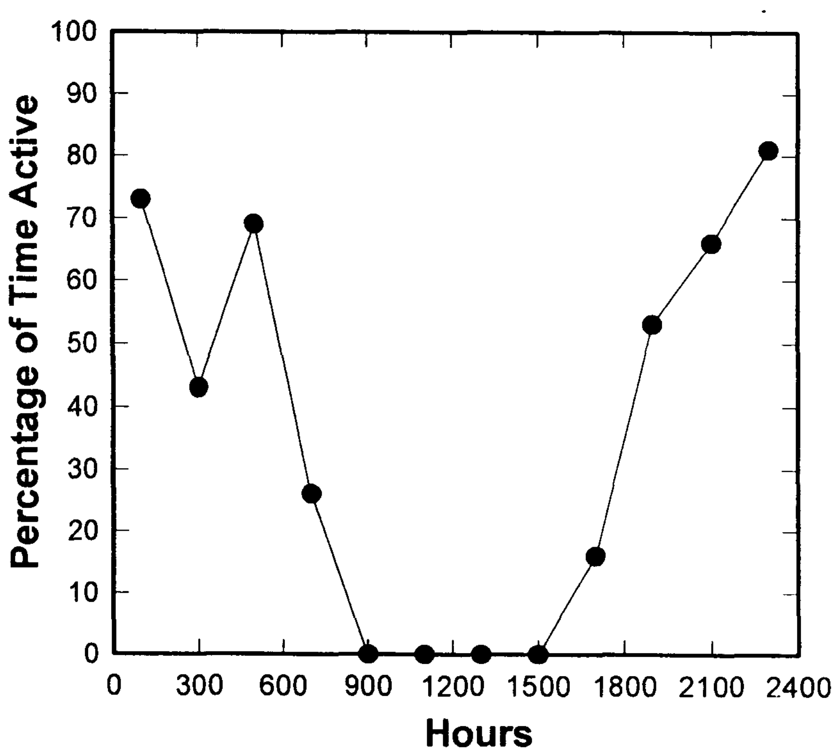


Figure 3. 13. Mean daily activity pattern for cat 41 observed throughout the study period.

Another studied animal, cat 21, also performed a similar pattern of activity (Figure 3. 14). The activity mostly began at about sunset and continued throughout the night with occasional resting periods. The greatest of time active occurred at 21.00h before followed by a period of reduced activity. The high activity values obtained for the 21.00h time interval for this animal was the result of certainty of departure patterns moving out from den sites along the creek nearby Lane Cove river or from the bush near the Christie Park. Another peak occurred between 04.00h and 06.00h in the form of expanded scavenging before fell consistently as the morning progressed. The maximum distance travelled between two consecutive fixes was 122.9 m. There was an evidence indicated that this animal was moving at midday. Of 150 day time fixes (Table 3. 2) obtained while tracking, 15 were classified as moving fixes. All these moving fixes were recorded in a short time at midday when the animal slightly changed its position.

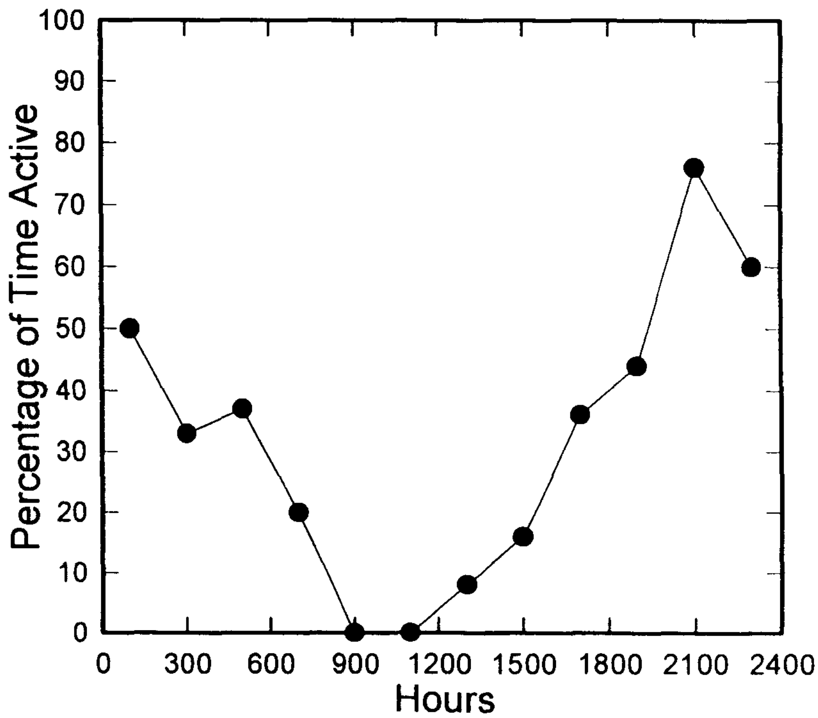


Figure 3. 14. Mean daily activity pattern for cat 21 observed throughout the study period

In some other studies (eg. Jones and Coman, 1982; Izawa *et al.*, 1982) feral cats were more active at night, with periods of greatest activity near the times of sunset and sunrise. A similar peak of activity associated with dusk which occurred between 20.00h and 22.00h time interval and dawn between 04.00h and 06.00h was found in this study on cat 08 (Figure 3. 15). It is an obvious that this animal performed midday moving. However the greatest time active was reached at 21.00h (75%). The form of midday activities between 13.00h to 17.00 time intervals were mostly the movement out of den sites closing in the target areas so that this pattern should be treated cautiously. For this reason, the animal was identified active only if the movements were continuous or lasting more than 15 minutes. From 41 day time fixes obtained (Table 3. 2), 13 was classified as moving fixes. As a result, this animal has the highest distance travelled among the studied animal (160.3 m). On two occasions this animal was found sitting with a freshly killed rat.

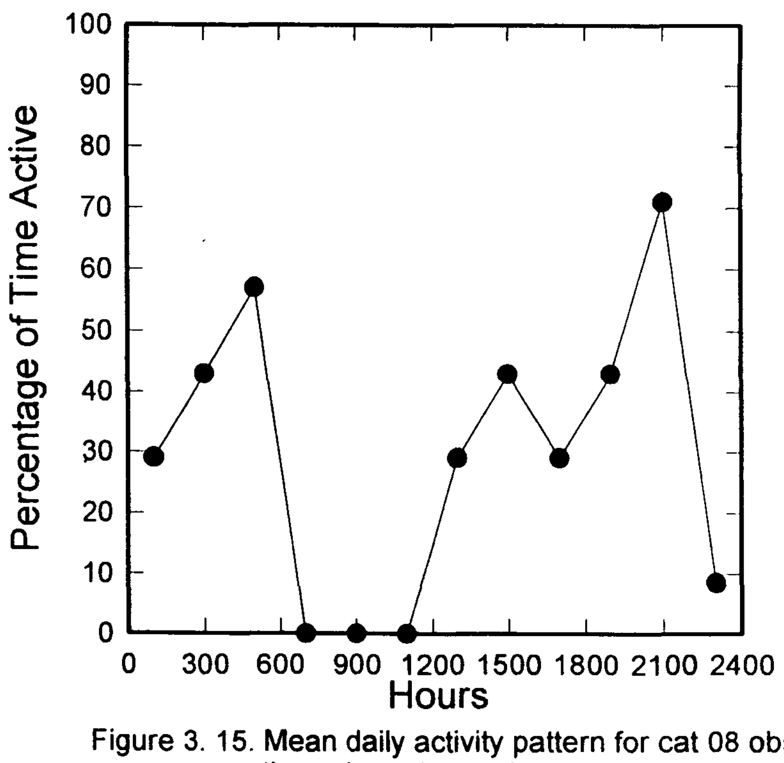


Figure 3. 15. Mean daily activity pattern for cat 08 observed throughout the study period

Similar pattern of activity to male 08 was performed by another male, cat 33, where this animal has periods of greatest activity peaking twice. Cat 33 was slow to become active in the early evening and continued until the greatest level of activity was reached between 22.00h and 24.00h. With overlapping home ranges and areas of concentrated activity to two other females, presumably it should have been with one of these females in the same areas simultaneously. An examination of daily movements revealed that most night time of this animal was spent with either one of females during the observation periods. The night time paths typical for this cat crossed female 14's range several times during the periods of tracking in order to be able to visit female 41, and mostly finished its night time activity relatively close to the origin. However, visual observation also revealed that this male spent on two tracking nights part of its night time with cat 14. Although some activities terminated near where these females, this male generally was never recorded spending mid day resting with females. Another peaking of activity for this cat

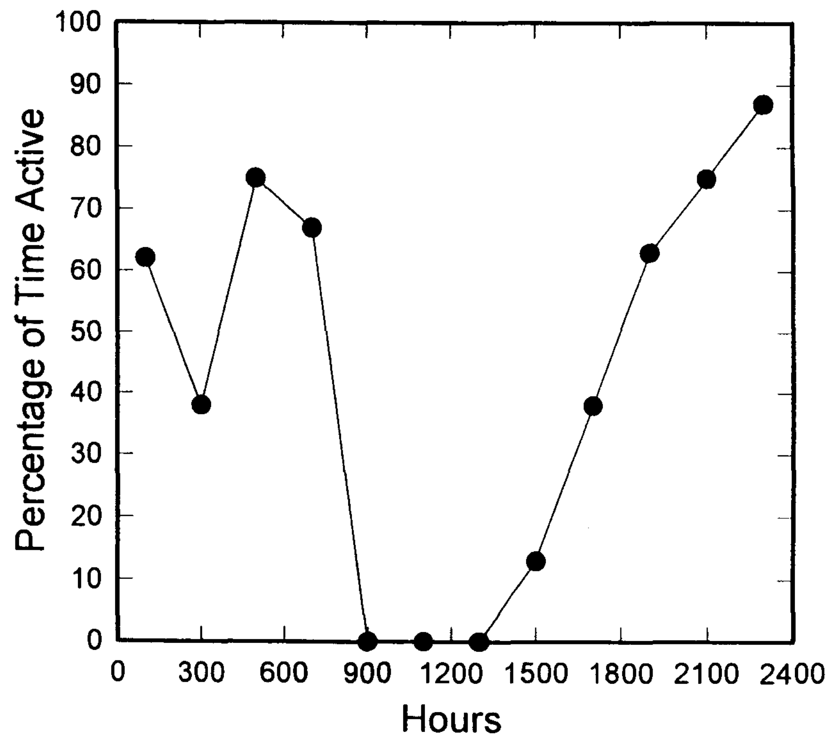


Figure 3. 16. Mean daily activity pattern for cat 33 observed throughout the study period.

occurred between 03.00h and 07.00h time intervals. This may be due to extended movements during the long night time in winter.

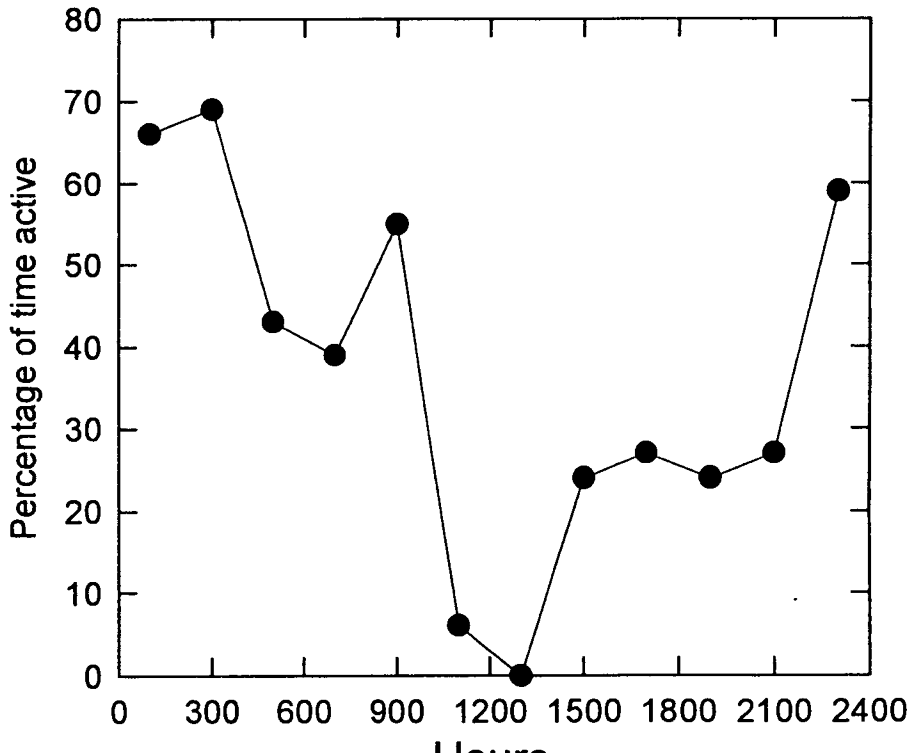


Figure 3. 17. Mean daily activity pattern for cat 14 observed throughout the study period

Figure 3. 17 shows mean daily activity pattern for female 14. Effective use of night time was higher with great utilisation occurred between 23.00h and 03.00h time intervals (average of 64%), and after sunrise between 08.00h and 10.00h (66%), while the least activity occurred near midday between 12.00 and 14.00h, less than 10%. Although this cat has been consistently associated with human habitation, evidence exist that bush fragments are important range component to be

used either for den sites or shelter before active. Sudden increase in time activity on 21.00h was attributed by the fact that this cat avoiding humans and such bush fragments were obviously used as the origin of departures. The high percentage of time spent active between 08.00h and 10.00h was due to playing with her young at the time of weaning.

3. 3. 2. Seasonal Movements

It has been shown earlier that there is no significant difference in overall mean home range areas both estimated by Minimum Convex Polygon and the Adaptive Kernel methods between males and females on yearly base. However, from individual basis, this study found that seasonal movements of three feral cats on mean monthly minimum distance travelled (MDT (ave) (m))showed considerable variability. These aspects are now discussed using data of three feral cats which were able to be followed for a complete year.

Mean monthly MDTs (± SD) calculation shows that female 41 travelled larger areas (105.04 ± 19.55) than female 14 (81.11 ± 22.4). This result is confirmed by t-test result ($t = 2.67$; $P = 0.015$). Mean monthly MDT between male and females on monthly basis are also significantly different ($t = 2.859$; $P = 0.013$). The details for three individual feral cats (cat 14, 21, and 41) will now be discussed. Figure 3. 18 shows mean monthly MDT (ave) (m) for female 14. There is some variation in its values of mean monthly MDT for this animal. The first three months indicated a decrease values being travelled before a slow increase. The lowest values of mean monthly MDTs occurred between March to April when this animal gave birth for the first time in the year 1996, while the greatest value occurred in

September as a result of large movements around this month up to Marsfield Park. Except in September, this animal mostly remained relatively close to its centre range and showed no seasonal expansions between summer and winter periods ($t = 2.11$; $P = 0.068$).

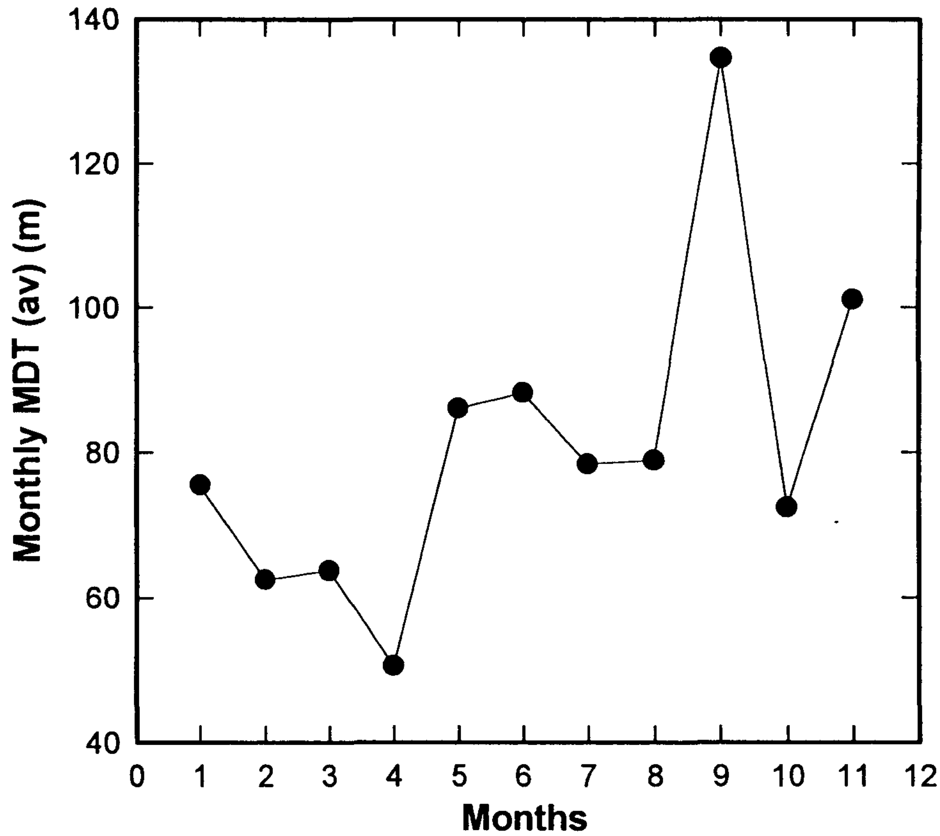


Figure 3.18. Mean monthly minimum distances travelled by cat 14 throughout the study period

Interestingly, female cat 41 performed much similar pattern on values of its mean monthly MDTs to those of female 14. The lowest values of its mean monthly MDT occurred in summer between January and February, similar values of those female 14 (Figure 3. 19). The greatest mean monthly MDT values occurred in winter between August and October before it started decrease again. The high values of mean monthly MDT recorded around this period was the result of expanded night movements during the mating season with an uncollared white male. There is also an evidence that this animal left its centre range for several days in the onset of that mating season, and as result, a significant different values on mean monthly MDT between summer and winter was recorded ($t = 2.47$; $P = 0.0381$).

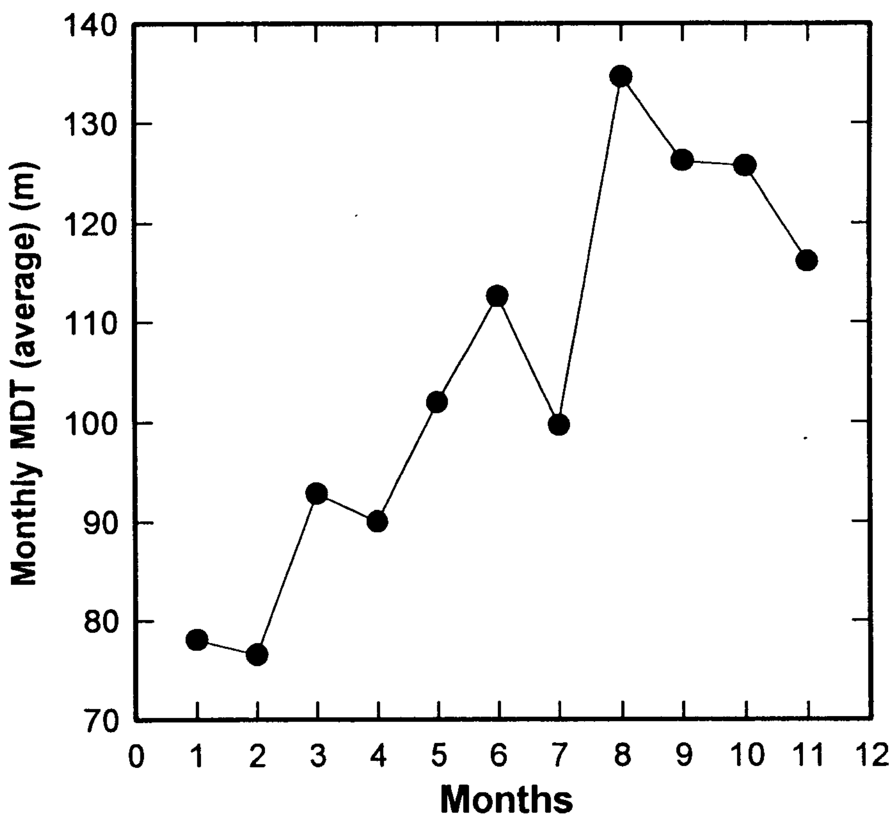


Figure 3. 19. Mean monthly minimum distances travelled by cat 41 throughout the study period

On the other hand, mean monthly MDT values and patterns of travelling for male 21 was different compare to those of female (Figure 3.20). While values on mean monthly MDT for females were lager in winter, this male showed larger values on its mean monthly MDT in summer. The greatest mean monthly MDT values occurred between February to March when this animal was recorded utilising Horse paddock area north of the study site to around Taranto Rd, while the lowest values occurred between May and July. Night time observations indicated that this animal was spending much time along with an uncollared black female cat during summer. Mean monthly MDT values are highly different between summer and winter ($t = 3.145$; $P = 0.019$).

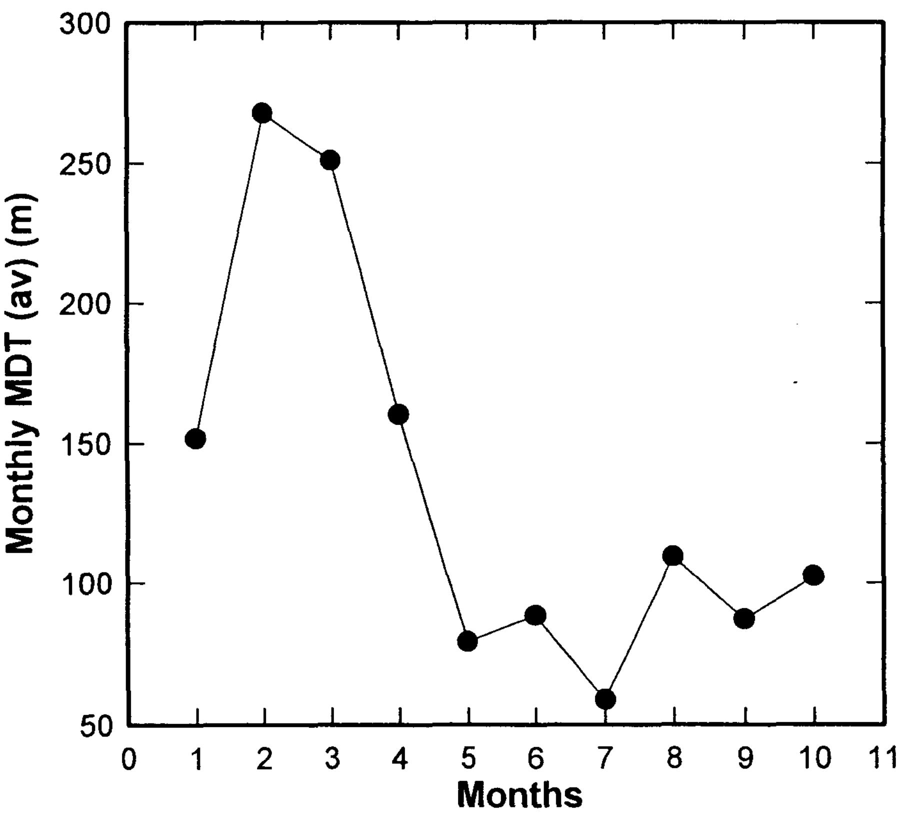


Figure 3. 20. Mean monthly minimum distances travelled by cat 21 throughout the study period

It is clear from visual observations that seeking oestrous females involved travelling a larger area by male, while spending time with males attributed similar effect on females. Therefore, there was no attempt to find out the effects of such temperature, wind velocity, and total monthly rainfalls to the values of mean monthly MDT of the studied animals.

3. 4. Diet Analysis

3. 4. 1. Details of the samples

Scat analysis consist mainly of identifying animal remains in a heap of scat such examining hairs and bones, teeth and claws, and feathers. Numerous methods and keys for such identification have been developed with various claims of success. This study, however, relied mainly on hair analysis technique provided by Brunner and Coman (1974) that enable large number of hair samples to be processed in a reasonably short time. On some occasions, visual confirmation from the site of attacks were used.

A total of 63 scats were collected from the study area. From these 51 were identified as cats scat while 12 were identified either of dog or fox scats. The general food categories identified from scats are shown in table 3. 5, which have been arranged in order of relative importance as determine by percentage occurrence of food items in the scats.

As can be seen from this table, the occurrence of items in the total sample was as follows; mammal was by far the most frequent prey species that comprised the bulk of food (80%) on percentage occurrence base, from which identification to the species level were made, followed by insects (27%), and birds (18%).

Table 3. 5. General food categories of feral cats living in an urban parkland environment of North Ryde, Sydney

Food Categories	Occurrence (%)
Mammals	80
Birds	18
Insect Exoskeleton	28
Other Vertebrates	2
Herbage Materials	43
Household Refuse	22
Cat Fur	12
Unidentified Materials	12

Other vertebrates were all relatively uneaten (< 5% of dietary). However, a considerable amount of debris was present in the scats, including treads, a torn pieces of plastics and paper bags and those was classified as household refusals (22%). Some hairs were identified as cat fur which occurred on about 12% in scats and was assumed that were from grooming. Similarly, unidentified materials also occurred on 11% in scats.

Because the ages of scats were unknown, these data cannot be presented on a seasonal bases. Instead, general identification on yearly base are used. Approximately 23.5% of the scats contained remains from more than one species. Of these, 58.3% included hairs from more than one mammal species. Mostly, the multiple occurrence encountered with wild board, common ringtail possum and black rat. There was not indication that rabbit occurred along with other mammal remains in a scat even though it is the single most important prey item found in this study.

3. 4. 2. Mammalian Materials

Table 3. 6 presents the mammalian species detected in 51 scats by hair analysis utilising method provided by Brunner and Coman (1974). Rabbit, *Oryctolagus cuniculus,* was the most frequently eaten and constituted the main item of diet (18%), followed by common ringtail possum, *Pseudocheirus peregrinus,* (16%), and black rat, *Rattus rattus,* (14%). Other species include *Rattus spp,* house mouse, *Mus musculus,* southern bush rat, *Rattus fuscipes,* and pig, *Sus scrofa,* were the secondary important prey items. Brown marsupial-mouse, *Antechinus stuartii,* and brush-tailed possum, *Trychosurus vulpecula,* were less important (< 5%) on the diet of feral cats in this study. There was 9% of hair remains could not be identified due to poor condition.

The high percentage of species of rabbit and common ringtail possum in the scats were supported by visual observation nights. These two species were abundant around the study area in that they almost being met on every night time tracking periods. Similarly, black rat were also were common in the area and occupied most of bush fragments. This species imposed problem on trapping activities such entering the traps and taking baits.

Table 3. 6. Specific food items of 51 scats resulted by using hair analysis provided by Brunner and Coman (1974)

Species Taken	Occurrence (%)
Mammals	**80**
• *Oryctolagus cuniculus*	18
• *Rattus spp*	10
• *Rattus fuscipes*	8
• *Rattus rattus*	14
• *Mus musculus*	8
• *Antechinus stuartii*	5
• *Hydromys chrysogaster (?)*	2
• *Pseudocheirus peregrinus*	16
• *Trichosurus vulpecula*	2
• *Sus scrofa*	8
• Unidentified Hairs	9
Birds	**18**

3. 4. 3. Other Materials

As outlined in the previous chapter that other food categories such birds, other vertebrates, insect remains, and herbage materials were not further identified due to damaging by mastication and thus were usually fragmentary where only limited identification could be made. Instead, general categories are used. Firstly, birds were usually represented by a few feathers or claws. In this study several scats contained feathers of unidentified bird. However, from the attack site perspective, which occurred within less than 5 m from den sites of female 14 and male 21, the fresh leg and foot of large magpies were found. On two occasions, this species was found entering the traps. One attack occurred exactly in the den sites of female 14 where she weaned the young the night before and was identified as a medium size lorikeet. Secondly, most of insects remains were severely damaged. From 28% occurrence of insects in the scats only two of them were identifiable as grasshopper thighs. Other occurrences were not possible to identify. Thirdly, herbage materials occurred 43% in scats on the form of green grass, dead grass, and seeds from unidentified plants. Finally, the two occurrences of other vertebrates in scats was unidentified as lizard skins.

3. 4. 4. Diet Preferences

The relationship between body mass of prey species and percent occurrence in scats was tested as shown in figure 3. 21. The value of regression analysis ($r^2 = 0.24\%$; $F = 0.01$; $P = 0.914$) shows that there is no relationship between size of prey and percent occurrence in scats. This result indicated that feral cats living in this area are not selectively preying on species according to body size, but rather show preference of utilising prey species according to its availability. However, as a group based on table 3. 6, small native *Rattus spp.* involving *Rattus fuscipes,* and possibly, *Hydromys chrysogaster*, and member of small Dasyurids, *Antechinus stuartii* altogether comprised higher percentage occurrence on diets (47%), while those other species including rabbit, and possums (36%). Pig occurred on 8% of scats and was not included in the regression analysis since this species could be the result of scavenging activities.

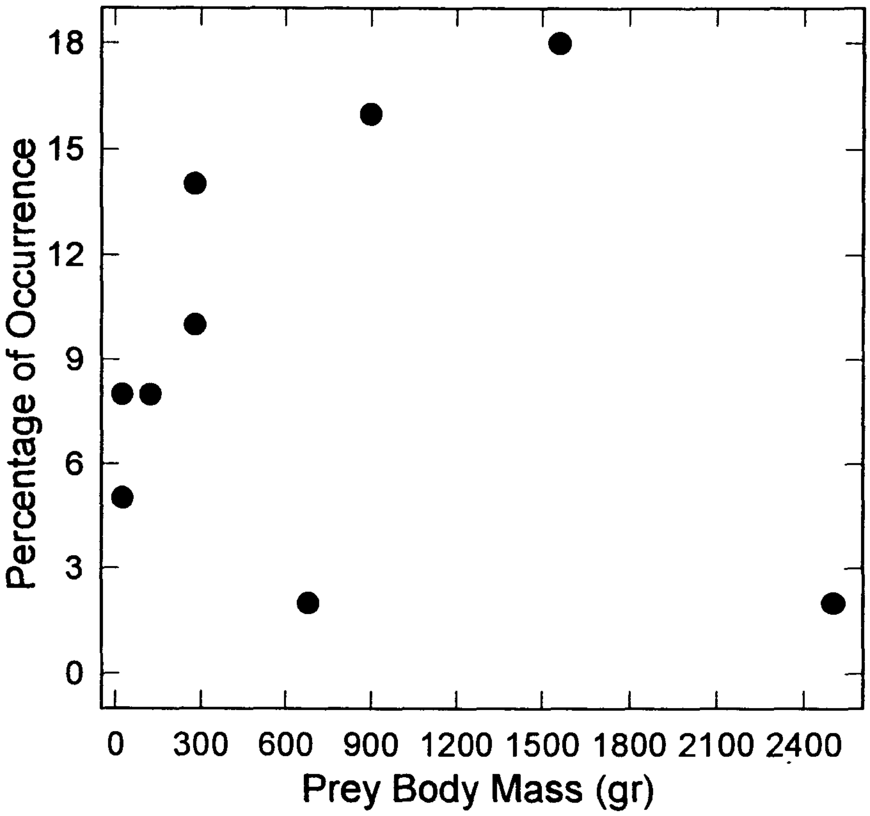


Figure 3. 21. Body mass of prey species and percentage of occurrence in the scats of feral cat

Chapter 4

Discussion

4. 1. Home Range and Activity of the Feral Cat

To describe an animal's home range, a recognisable individual must be located at successive points in time and its position recorded. Data of this sort can be collected using various methods of location such as trapping, radio telemetry, visual observation, and so on. In this study, the combination of visual observation and radio telemetry methods were used in order to obtain continuous tracking off individuals rather than occasional sampling of their locations.

The accuracy of fixes taken in this study is considered to be high since the instrumented cats were mostly located within a few metres, providing strong confidence of the delineation of home ranges. Also, the number of fixes for cats taken during this study were favourable compared to other studies. Turner and Mertens (1986) recorded less than 210 fixes for all tracked animals, while Liberg (1980) collected on average 243 fixes per animal in his study of free ranging cats. Similarly, Godfree (1985) recorded fix location between 70 and 244 and Konecny (1987) collected between 20 and 530 radio fixes. This point has to be considered prudently since some methods of home range delineation have constraints on the number of radio fixes required (Harris *et al.*, 1990). In addition, the fix locations of four radio-collared cats living in an urban parkland environment in the present study must be considered representative of their true home range sizes during the year of study given that asymptote levels, as required to calculate home range, were reached before tracking ceased.

Most home ranges studies of cats have used the Minimum Convex Polygon method (Langham and Porter, 1991), as in this study. In most previous studies, the radio fixes of feral cats were made during the day (Liberg, 1980; Jones and Coman, 1982; Turner and Mertens, 1986; Fitzgerald and Karl, 1986), while only some concentrated on nocturnal fixes (Konecny, 1987; Corbett, 1979; Langham and Porter, 1991). The present study, however, relied both on day time and night time fixes. Laundre *et al.* (1987) pointed out that night fixes are essential to describe the home range of nocturnal animal, and this was confirmed with cats in this study.

All radio-collared cats maintained home ranges and within each home range particular areas were favoured as day time refuges. These were invariably areas which provided good shelter such as under trees, in storm-water drains or in dense thickets along creeks and riverbanks. Individual differences in home range size were apparent; in general the larger the home range, the greater was the mean monthly distance moved between fixes. The extreme was shown by male 21, which had the largest home range and the greatest mean monthly distance between fixes, while the two females, cat 14 and 41, had the smallest. This does not necessarily mean that these females had a shorter nightly foraging distance than cat 21, but it does mean that they returned much more to the same or nearby refuges. This different in behaviour might have been caused at least partly by the necessity of returning after each trip to the litters since both these females gave birth twice during the study.

The hypothesis that males would occupy larger home ranges than females (Langham and Porter, 1991; Konecny, 1987; Warner, 1985) was not confirmed in this study but results were more similar to those reported by Jones and Coman (1982) and Page *et al.,* (1992). The difference found may be the result of differences in lengths of time the animals were observed (Mohr and Stumpf, 1966) as in this study, or could be a result of the limited numbers of animals studied. Another possibility considering lack of significant difference in home range size between male and female cats found in this study might be the presence of the pair bond. The two males and females were often seen active and fed in close proximity at night and as result home range reduced and overlapped into some extent. The long term measure of seasonal home ranges, however, was suggestive that males may range more widely than females over a longer period of time.

The size of home range among feral cats studied elsewhere varied greatly in both males and females. A summary of night home range calculated by Minimum Convex Polygon method is given in the table 4. 1. This study found that both males and females home ranges were lower compare than those reported elsewhere except with those of Haspel and Calhoon (1989). The reason for the smaller home ranges of feral cats living in an urban parkland environment in this study are probably mostly ecological and behavioural. The study area provides small fragments of bush and large expansion of urban settlement that in to some extent is not suitable for a feral animal living in it to have an extensive home range. Therefore, smaller home ranges would be understandable as reported by Haspel and Calhoon (1993) in their study of feral cats in Brooklyn.

Table 4. 1. Nocturnal home range of feral cats (ha) (mean ± s.d.) in comparison with other studies that used the MCP method

Females	Males	Source
17.10 ± 3.15	51.41 ± 35.36	This study
1.07	1.96	Haspel and Calhoon (1989)
154 ± 21	239 ± 97	Langham and Porter (1991)
112 ± 21	228 ± 100	Warner (1985)
35 ± 20	149 ± 146	Konecny (1987)
130 ± 114	407 ± 282	Konecny (1987)
42 ± 25		Corbett (1979)

Langham and Porter (1991) have shown that there may be a physiological aspect related to male home ranges. Adult males in the present study tended to occupy exclusive home ranges which incorporated the home ranges of neighbouring females as shown by both males 08 and 21, indicating seeking oestrous females is one component on male range formation. Since female cats, both radio-collared and those uncollared feral, were present in this study, home range of males are just large enough to control and visit the oestrous females. A recent study by Yamane *et al.* (1994) indicated that males expanded their ranges during the females oestrous season and Langham and Porter (1991) noted adult males had large territories in spring and in summer when they were most likely to be actively mating and defending females within their territory as indicated by this study. Males expanded their ranges during the females' oestrous season and therefore their seasonal mean range size calculated by monthly MDT (ave) (m) exceeded significantly the range size during the non oestrous female season. This result suggests that maintaining contact with females is important in determining male home range size during the oestrous season, and possibly more important than other resources.

The general pattern for small ranges of females in this study must be considered cautiously. It was clear that females either spent many hours in active around the core areas during the day or used garbage sites and utilised rabbits which are concentrated around the university grounds for feeding. Some authors (Konecny, 1987; Genovasi *et al.*, 1995) have reported the importance of resource availability in determining feral cat home range size. However, since such factors as predation rate were not measured specifically, their impact on females range could not be directly correlated to it. In addition, given the fact there was no seasonal difference in female 14's ranges while it did occur in female 41, and given that they are neighbouring cats that both littered twice, one can only speculate on the reason for this anomaly at the present time. It is possible that this is related more with the environmental condition rather than other factors.

The value of cover for some species has been indicated by Izawa and Doi (1993), and Johnson and Franklin (1991) studying feral cats, Croft (1991) in his studies of the euro, and Horsup (1994) on the Allied Rock-Wallaby. In this study, pockets of bush fragments around the study area were clearly used as a form of shelter by feral cats. This was evidenced by the highly predictable movements of studied animals from and to it at dawn and dusk. Feral cats increased the distance they moved between 18.00h and 06.00h time interval, and as a result, fixes became less recorded at refuge and rest site and spread over on their home ranges. The much longer movements showed by male 21 in the summer contrasted strongly with the considerable shorter movements of females. It is likely, for males, that higher mobility provides them with the potential to increase their reproductive success.

The activity patterns performed by feral cats in this study were generally nocturnal, indicating the importance of shelter, although some evidences existed of short daily movements during the day. Some authors (Dards, 1983; Jones and Coman, 1982; Izawa *et al.*, 1982) have shown that feral cats were more active at night with periods of greatest activity near the times of sunset and sunrise. A similar peaks of activity associated with dusk and dawn were confirmed in this study, although variations with the times of sunset and sunrise were apparent.

It is a fact that the ranges surrounding the study site were also used by feral cats that were nor radio-collared. Therefore, the overlaps outlined in the former chapter must be considered as minimum figures only. Two general patterns can be made based on these observations. Firstly, mating season home ranges would be expected to overlap more because of expansions of range by males as indicated by the presence of seasonal difference on male monthly MDT . Secondly, the actual temporal overlap of home ranges was reduced in the weaning seasons because all cats moved shorter distances and often returned during the night to the young. It was also evident in this study that male 33 took part in caring for the young of female 14.

Fidelity to home ranges was evident for feral cats, in particular for that of female 14 which is indicated by her overall mean monthly distance throughout the study. This was measured by comparing the mean distance travelled between the two seasons and no such significant difference was detected for this animal. On the other hand, the two others showed a significant difference in the mean distance travelled between the seasons. However, since these animals and others were always followed on foot on a 24-hour basis, the movements out of their home ranges were not recorded this may provide evidence of home range fidelity. Based on these two aspects, a general pattern can be drawn. Females showed stronger fidelity to their specific site or core areas throughout the year, providing an accumulative knowledge of the location of shelter site and escape routes, while males showed stronger fidelity to the specific core areas around the non-mating season.

It was postulated that feral cats' home range size may be the function of body weight as described for most carnivore species (McNab, 1963; Harestead and Bunnel, 1979). However, simple regression analysis of all home ranges estimated both by Minimum Convex Polygon and the Adaptive Kernel methods of various isopleths with feral cats' body weight did not indicate any significant relations. Besides the reasons that have been outlined in the previous chapter, another speculation may well being considered given this result. Since the studied animals in this study were living in a populous urban environment that would impose restricted movement, and given the fact that movement by an animal is the function of several factors, body weight is probably not a single good estimate of animal home range in this study. Therefore, it is worth taking into account the constraints concerning the study animal, its habitat and resources available such food resources, space availability, and other factors.

4. 2. Diet

A considerable number of studies have reported on the diet of feral cats (Marshall, 1961; Coman and Brunner, 1972; Bayly, 1976; Jones, 1977; Jones and Coman, 1981; Liberg, 1984; Konecny, 1987; Catling, 1988). The consensus is that this species is considered to be opportunistic predator and scavenger with the rabbit, *Oryctolagus cuniculus,* as its main prey species.

In this study, the percentage occurrence of mammals in the scats was 80% (Table 3. 5), higher than the 67% found by Coman and Brunner (1972), with rabbit as the most frequent prey encountered in the scats. This findings was consistent with the result of two other studies on the diets of feral cats from arid South Australia (Bayly, 1976; 1978) which noted that rabbit was the most important food by volume. Jones (1977) studying feral cat in Macquarie Island and Mahood (1980) from semi arid New South Wales also found rabbit was the most frequent species eaten.

Similarly, ringtail possum, *Pseudocheirus peregrinus,* was commonly recorded in the scats of feral cat. A recent study by Kennedy (1995) in remnant vegetation of Garigal National Park indicated that ringtail possum was frequently consumed by foxes. It is possible that the high occurrence of these two species in the scats analysed related to their availability around the study area. These two species are abundant and can be easily found. For example, *Pseudocheirus peregrinus,* was commonly found on the night tracking in the native trees, while rabbit mostly utilised open grounds. It is somewhat interesting given the ringtails are primarily arboreal with very little contact to the ground as Thomson and Owen (1964) stated that ringtails feed entirely in shrubs or trees, never on the ground. However, Pahl (1984) has pointed out that ringtails frequently come down to within one or two metres of the ground when feeding. It is possible that at this height they would certainly be vulnerable to predation to even with less agile feral cats.

Bird remains in the scats analysed were also high (18%). The only species specifically identified were magpies and a medium size lorikeet. It is not possible to determine when they were caught by the cats. However, given the cat is well able to climb trees and the presence of evidence of attacks, with fresh blood remaining in the early morning close to the area where the cat was recorded during night, it is possible to assumed that cats preyed on bird in the night. On one occasion female 41 was seen on the branch of a tree about one metre high in a stalking position. Another possible explanation is that it has commonly been supposed that feral cats prey on birds, particularly those the ground feeding species during the day. If this is the case then it may be that birds were preyed on by day.

A number of the species found occasionally in the scats of feral cat are largely ground dwelling mammals, such as Rats including *Rattus rattus, Rattus fuscipes, Mus musculus,* and Brown marsupial-mouse, *Antechinus stuartii,* and probably the Water rat, *Hydromys chrysogaster*. Stephens (1978) in her study of the impact of man on the mammals and birds of the Lane Cove River valley did not report this species although the habitat was suitable for it. If the occurrence of water rat in this study is true, then the technique used, hair analysis, should serve as a potentially valuable survey tool in mammal surveys.

It is surprising that evidence of reptiles and other vertebrates occurred in only 2% of occurrence in scats analysis which contained scales, probably those of small lizards, although visual observation indicated that several species were present in the study area. Presumably, other factors such as difficulty of capture might be responsible for the intake of other vertebrates or, simply, they may not be considered a preferred food items of diet. Given the abundance of rabbits, ringtail possums and rats, the latter may be the correct interpretation.

Finally, even though insect skeletons and herbage materials are common in the scats of feral cat, their value on feral cats dietary can not being judged. The two items, seemingly, are part of normal diet of cats and have been mentioned in most food habit surveys on the animal (McMurry and Sperry, 1941; Jackson, 1951; Coman and Brunner, 1972; Jones, 1977; Jones and Coman, 1981; Konecny, 1987). In addition, another item found in the scats of feral cat is the high prevalence of household refuse which agrees with visual observations. Cats in this study spent much time scavenging in open garbage at night.

Based on the data presented in this study, it is not possible to determine the importance of cats as predators of native fauna even though is clear that they showed a great capability of exploiting a wide variety of animals based upon local availability. This is supported by the analysis of correlation between body mass of prey species and percentage occurrence in scats that no such correlation was found. Long term studies in conjunction with studies in other habitats may well be needed to provide an answer to such a question. The limited samples of scats collected and the indication of other predators such as foxes around the study area is not entirely satisfactorily for assessing cats impact. In addition, given that rabbit, *Oryctolagus cuniculus,* and black rat, *Rattus rattus,* were common in the study area, any attempt on assessing cats impact on the native fauna is beyond the scope of this study.

4. 3. Overview of Home Range models Used

A variety of models to evaluate home range size and to determine patterns of home range utilisation based on sampling an animal's position along a time-base have become available since McNab's (1963) paper. Many papers have been published since then on the subject of home range estimation and reviews are given in, for example, Macdonald *et al.,* (1980), Worton (1987), Larkin and Halkin (1984), and the newest by Worton (1995).

In this last part of chapter 4 I am not evaluating the methods used to calculate home range of feral cats but, on the basis of this study, I wish to briefly comment on two techniques which have been used to estimated home range size of six radio-collared cats: the Minimum Convex Polygon and the Adaptive Kernel methods. The underlying reasons for choosing these two methods are given. The first method was chosen because it is one of the most commonly used method (Harris *et al.,* 1990), while the second method is the single recent non-parametric method.

As one of the earliest and the simplest technique for home range calculation, the MCP method received some criticism on the disadvantages it entails. These include incorporation of occasional fixes well beyond the main area of activity. In this study, it is clear that such a problem was encounter by cat 21. Since this animal is a wide-ranging male, the erection of straight line from peripheral fixes to form the boundary of a convex polygon, has result on inclusion of area never used by this animal as has been confirmed by visual observation. As a result, the home range estimated was very large. Additionally, problems of sample size bias (Jenrich and Turner, 1969) were recorded for cat 08 and cat 33 where home range of these two animals did not reach the asymptote after 80 and 90 fixes location. However, this problem appears to have been caused by the relatively short period of tracking.

The adaptive kernel, regardless that it is one of the newest techniques for home range estimation, is more ecological significant than the previous method. Home ranges delineation coincide and resemble much to the habitat formation of the study site, providing good representations of the home range of feral cats in this study. The core area formation within animal home range produced by this method is of particular interest, since some instrumented animals experienced a seasonal shift in their position. And such these changes position were depicted on home range delineation in particular to their core areas which lied well beyond the area where the animal moved. However, this model showed somewhat problem dealing with low number of fixes as the MCP. The extremely large home ranges estimation for cat 08 produced by this model should be treated wisely since some of those home area might include areas were not utilised as confirmed by visual observations.

4. 4. Conclusion

This study is the result of 18 months' research of the ecology of feral cats living in an urban parkland environment with emphasis on diet, home range and activity.

Estimations of home range indicated that feral cats utilised small areas of range compared to those reported elsewhere. A variety of factors was probably responsible for this result. These might include size of available habitat, food availability both in form of household refuse and the over-presence of the introduced European rabbits, the black rats, and the Australian ringtail possums although such these factors were not specifically analysed.

Specific diet analysis on the fauna consumed showed that items of animals taken were similar to those reported by previous studies, indicating that feral cats are capable of utilising a wide variety of species. This result is supported by the fact that prey size and body mass is not an important factor influencing the level of consumption. Given this fact, it is, therefore, wise to be considered that all feral cats should be treated similarly regardless their urban status.

Activity patterns of feral cats living in an urban parkland environment are influenced by the presence of shelter since they are very shy animals. This was confirmed in this study where instrumented animals showed strictly activities even though short diurnal movements were recorded. Seasonal movements were important for some individuals while others remained within a restricted range.

It is not possible to determine, from the data presented in this paper, the importance of the feral cat as a predator of native fauna in the study area. However, the data might provide some supplementary information or, at least, a useful insight for those who are very keen pursuing the impact of feral cat.

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Appendix 1. Lane Cove River Catchment Area produced by Lane Cove River Catchment Management Committee, 1995

Appendix 2. Dates of Trapping Sessions

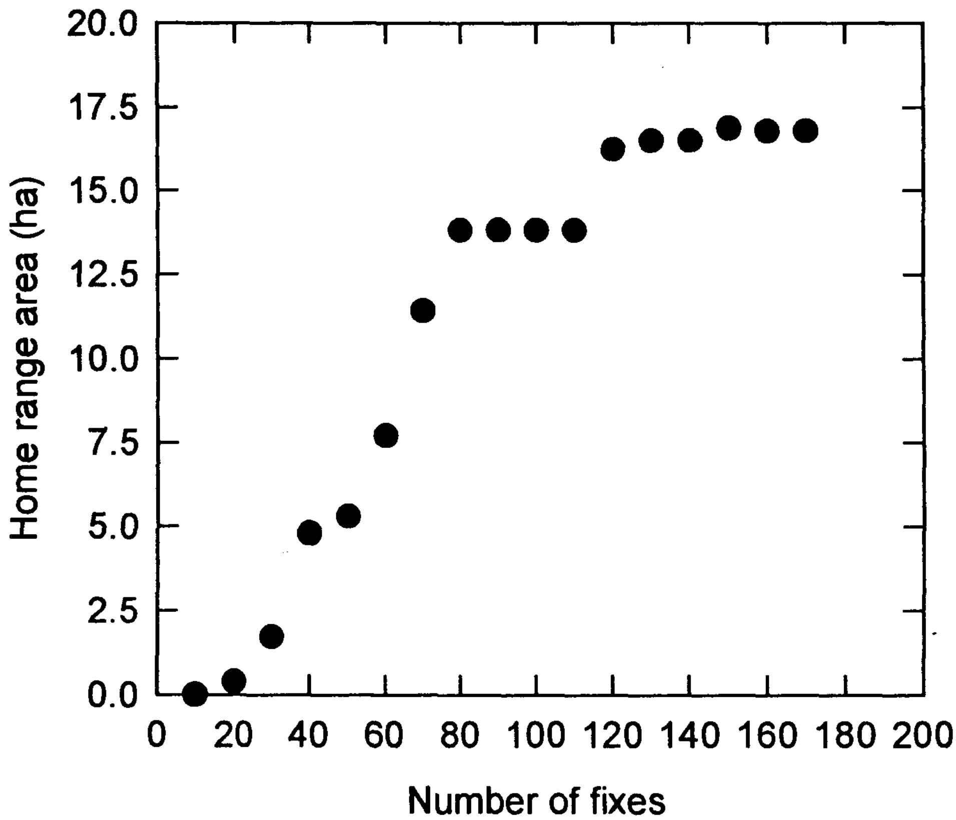
22. 3 - 21. 4. 1996

27. 5 - 29. 6. 1996

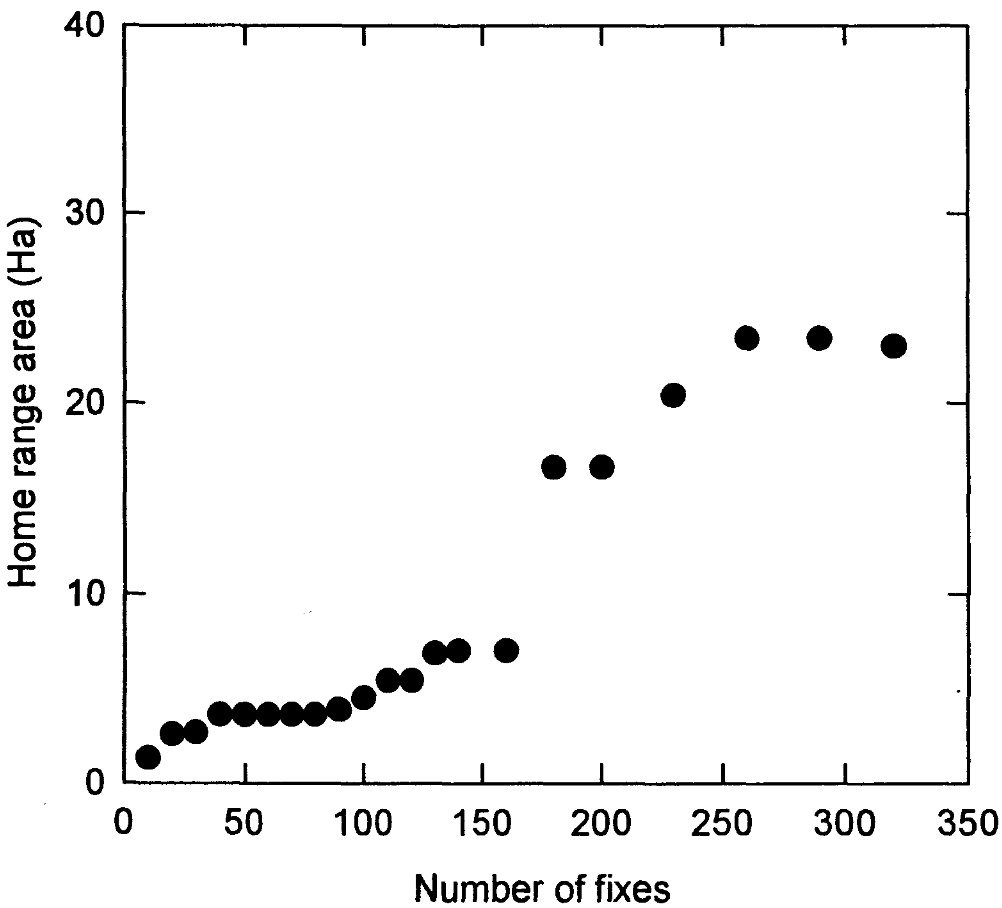
6. 7 - 3. 8. 1996

21. 10 - 21. 11. 1996

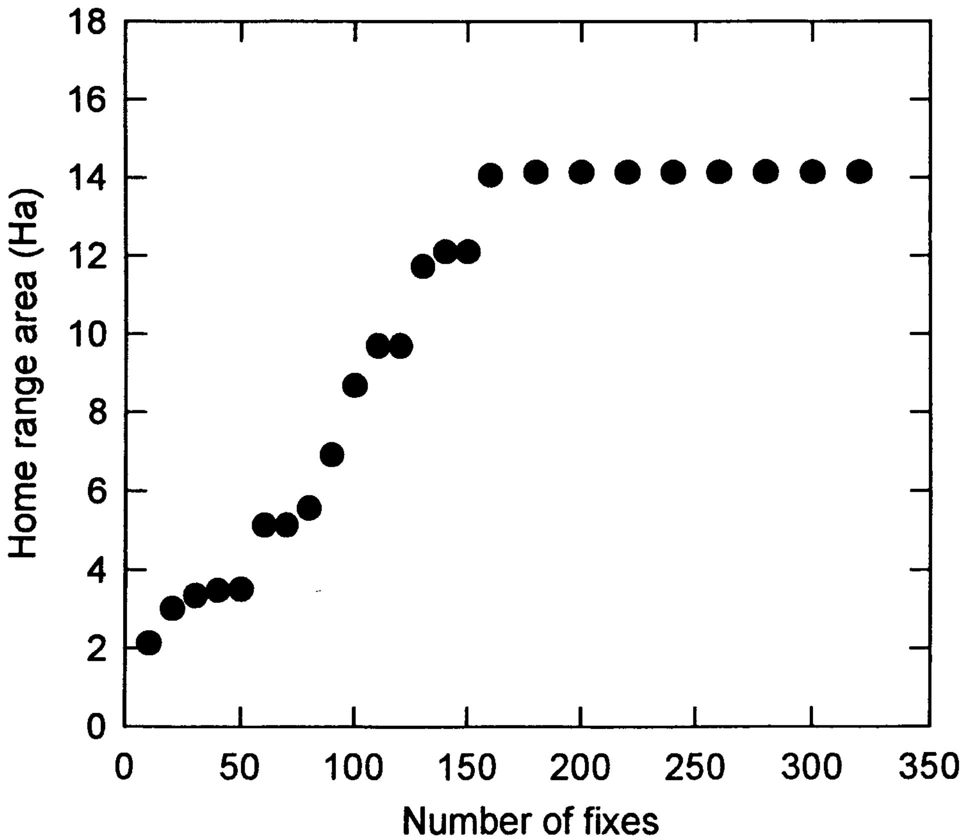
Appendix 3. MCP area vs fix number for cat 00



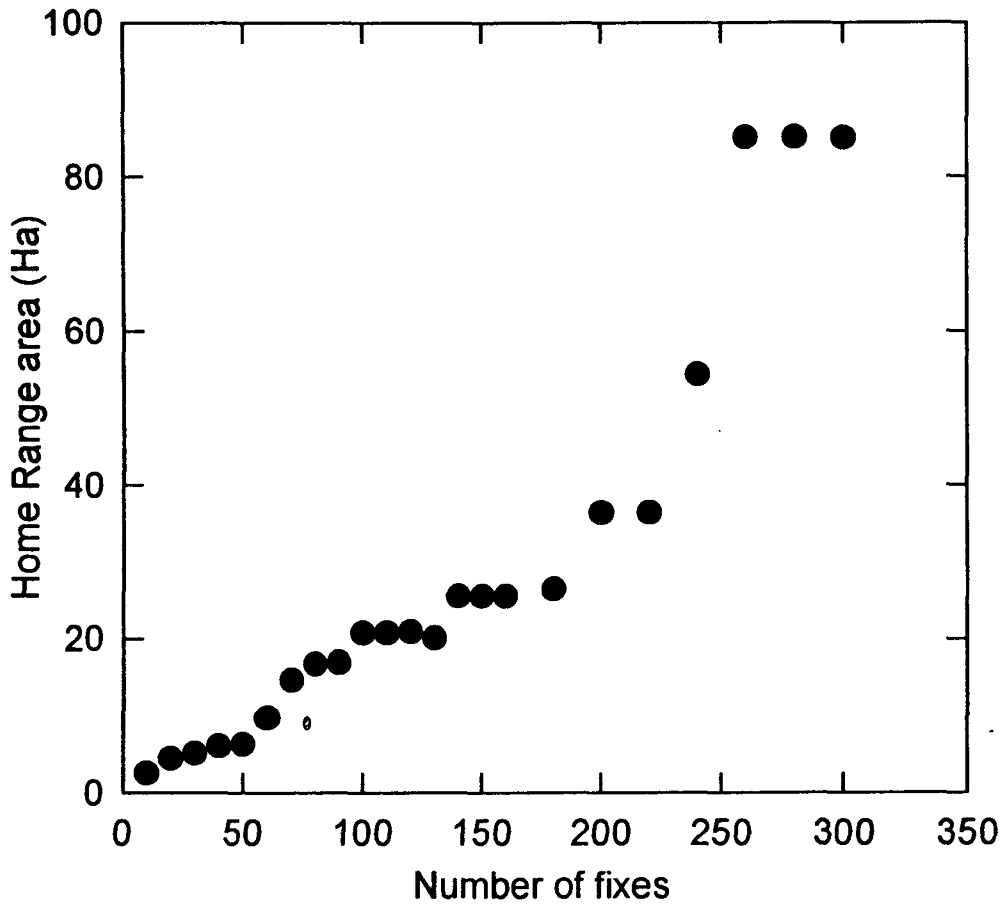
Appendix 4. MCP area vs fix number for cat 14



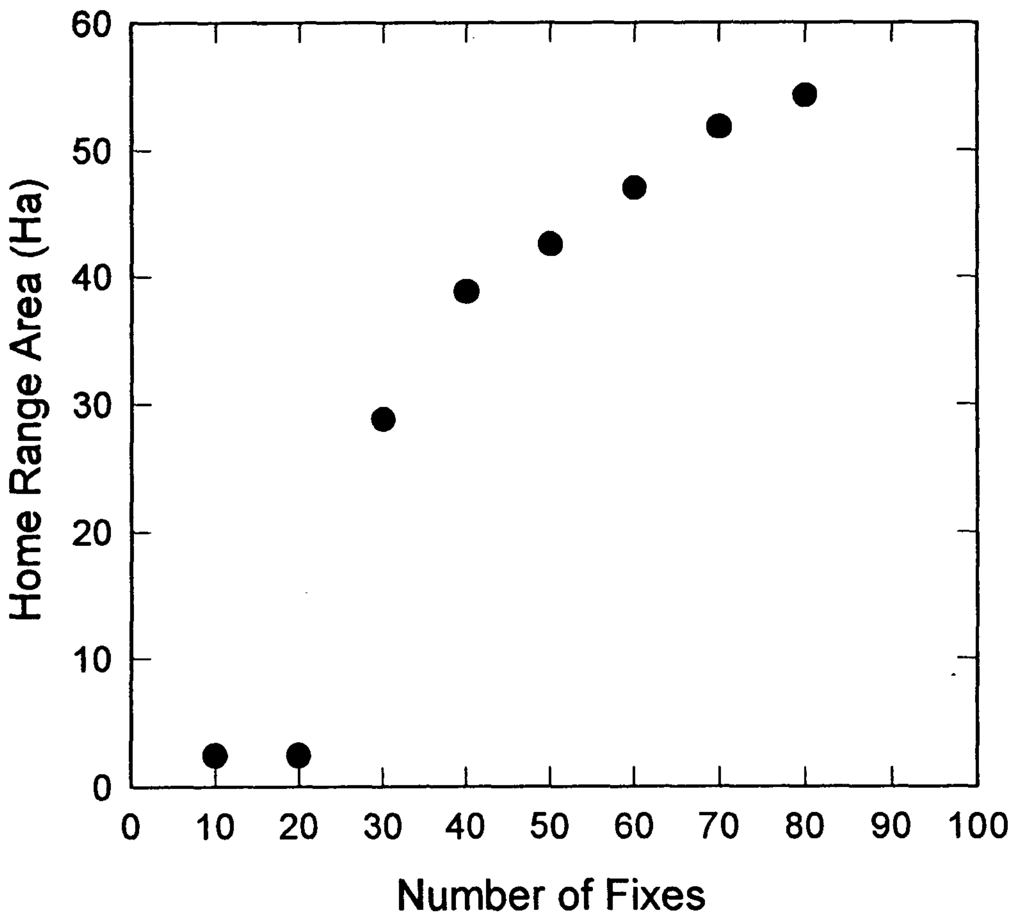
Appendix 5. MCP area vs fix number for cat 41



Appendix 6. MCP area vs fix number for cat 21



Appendix 7. MCP area vs fix number for cat 08



Appendix 8. MCP area vs fix number for cat 33