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Feral Cats in the Tall Forests of Far East Gippsland, Australia

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ABSTRACT: Much of the research on feral cats in Australia has occurred in the continent's arid and semi-arid regions. Consequently, little is known about the ecology of feral cats in tall forests. Using a combination of both VHF and 'store on board' GPS collars, feral cats were tracked in the forests of Far East Gippsland, Victoria, to investigate both home range size and movement patterns. The use of GPS collars to obtain accurate and high volumes of location data allowed the intra-home range movements of feral cats to be examined in ways not previously possible using conventional VHF radio telemetry. Male cats had significantly larger home ranges (MCP 100, mean $\pm$ se: 455 ± 126 ha) than females (105 ± 28 ha). Male home ranges overlapped those of females and female ranges overlapped with neighbouring females. Overlaps in female home ranges, in particular of the core areas, indicate that female cats in Far East Gippsland are tolerant of other females and do not actively exclude them. Feral cats in these productive tall forests have smaller home ranges than those in arid and semi-arid regions where food resources are sparse or limited, but larger ranges than those inhabiting farmland and grassland habitats where food resources are generally more abundant. Location data gathered at three different temporal intervals – 6 hourly, hourly, and every 15 minutes, showed that feral cats utilise a Lévy walk-style searching pattern as they move through their home range. Employing a Lévy walk increases the likelihood of encountering prey items that are distributed sparsely in the environment, in turn maximising the potential hunting return for effort expended. These findings will allow managers to adopt a more targeted approach when undertaking feral cat management programs in these habitats by providing information on where to deploy traps, baits or other control measures.

KEY WORDS: Australia, feral cats, *Felis catus*, forests, GPS tracking, home range, Lévy walk, movements, range overlap

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INTRODUCTION

Early European settlers introduced the cat (*Felis catus*) into Australia and facilitated its spread inland from multiple points on the coastline (Abbott 2002). The subsequent establishment of feral cats was aided in no small part by the European rabbit (*Oryctolagus cuniculus*) which provided a reliable and abundant food source following its successful release in 1858. Cats eventually formed self-sustaining feral populations that now occur over all parts of the Australian mainland, Tasmania, and on many offshore islands (Dickman 1996). Feral cats hunt a wide range of prey species and have been implicated in the decline and extinction of many native mammal populations (Dickman 2009, Risbey et al. 1999, 2000). The economic cost of feral cats in Australia has been estimated at AUD\$146 million annually, with the majority of this from their impacts on native wildlife (McLeod 2004). Feral cats have been identified as posing a threat to 117 threatened native species, including mammals, birds, reptiles and plants, in the state of New South Wales (Courtts-Smith et al. 2007). Christensen and Burrows (1995) found that, even at low densities, cats caused the failure of reintroduction attempts for burrowing bettongs (*Bettongia lesueur*) in the Gibson Desert. Densities of feral cats as low as 1/km² have caused the failure of both bettong and bilby reintroductions outside predator exclusion fences at Arid Recovery in South Australia (K. Moseby, Arid Recovery, pers. commun.).

Most research on feral cats in Australia has taken place

in either the arid (e.g., Burrows et al. 2003, Moseby et al. 2009) or semi-arid regions (Edwards et al. 2001, Hilmer 2010, Jones and Coman 1982). No research has been undertaken on home range size or range overlap of feral cats in tall closed forests, despite the prevalence of cats in such habitats and their probably deleterious impacts on native species (May and Norton 1996).

Using GPS technology to collect data has resulted in the ability to collect much greater volumes of data per animal than was previously possible using standard Very High Frequency (VHF) radio telemetry techniques (Recio et al. 2010, Rodgers 2001). This increase in both the quantity and quality of data has allowed intra-home range movement patterns to be both seen and examined in detail for the first time (Dassault et al. 2001, Kliskey and Byrom 2001, Robley and Gormley 2010). Several alternative hypotheses have been put forward to describe observed patterns of movement. These include random walks, composite Brownian walks (Benhamou 2007), Lévy walks (Viswanathan et al. 1996, 1999) and adaptive Lévy walks (Reynolds 2009). Random walks have a uniform distribution of step lengths and turn angles while composite Brownian walks use a combination of step lengths drawn from two random walk distributions where one has a short mean step length and the other a longer mean step length (Benhamou 2007).

The Lévy walk is characterised as multiple short distance movements interspersed with less frequent but longer range movements that result in a long-tailed power

law distribution - $P(l) \sim l^{-\mu}$ with $1 < \mu \leq 3$, where l is the step length and μ is the slope of the regression line of the log/log relationship between step length and frequency of occurrence. A Lévy style walk is apparent if $1 \leq \mu \leq 3$ with optimal foraging occurring when $\mu=2$ (Viswanathan et al. 1996). Brownian motion becomes apparent when $\mu > 3$ (Bartumeus et al. 2005).

Identifying how an animal moves through its environment is of particular relevance in the study of invasive animals that are operating in novel environments and which, in the case of introduced predators, can cause devastating declines in naive native prey species (Burbidge and Manly 2002, Burbidge and McKenzie 1989). Knowledge of the home range sizes of feral cats, of how much the ranges overlap, and how the cats utilise their home ranges is essential for managing their impacts on threatened native species. It gives an indication of the intensity and spatial extent of control effort that is required, and can inform managers about the utility of specific methods such as where to deploy traps, baits, or other control measures.

METHODS

Study Area

Research took place in the Southern Ark Project area located in Far East Gippsland, Victoria, south-eastern Australia (37.34° S, 149.09° E) (Figure 1). Most of this

10,000-km² area comprises steep forested hills with small areas of cleared private land that are used for agriculture. Mean annual rainfall is 970 mm (Buckmaster 2011). Data used this project were gathered between February 2007 and January 2010.

Feral Cat Capture

Feral cats were trapped using #1.5 and #3 Victor Soft Catch® rubber jaw traps (Woodstream Corporation, Lititz, PA; current manufacturer: Oneida Victor, Inc., Euclid, OH). Trap sets were baited with either meat (chicken or beef) or 'Pongo', an olfactory lure consisting of a blend of cat faeces, cat urine, and water (Algar et al. 2002). Captured feral cats were sedated and those over 2.7 kg fitted with either a GPS collar or standard VHF collar (SirTrack, Havelock North, New Zealand). GPS collars were tasked to take fixes at either a combination of 15-minute intervals and hourly intervals or at 6 hourly intervals. All cats were monitored using VHF telemetry. Re-trapping of feral cats occurred at the end of the expected battery life. Collars were also recovered from feral cats that died during the course of the study.

Data were downloaded using proprietary software from SirTrack and transformed to projected coordinates (UTM) using the DNRGarmin GPS Application (v. 5.03.0002) (Dept. of Natural Resources, St. Paul, MN) computer program. The GPS data contained an estimate

Figure 1. Map of the study area. The broken line indicates the approximate western boundary of the Southern Ark project. Background GIS data layers were provided by the Victorian Department of Sustainability and Environment (DSE), Melbourne.

of Horizontal Dilution of Precision (HDOP) for each fix (scale 1-100). Fixes with HDOP > 4 were removed from analyses because of the potentially lower level of precision achieved for these fixes (Moseby et al. 2009). The first seven days of GPS data for each cat were discarded from the movement pattern analyses to minimise bias from potential foot trauma incurred during trapping.

VHF Data

Each VHF fix for a feral cat was determined from at least 3 individual bearings taken within a 10-minute period. Compass bearings were adjusted from magnetic to grid system and entered into the Locate III Radio Telemetry Program (Pacer Computing, Tatamagouche, NS, Canada) to determine the location of the cat.

Data Analysis

Location data were analysed using ArcMap 9.2 (ESRI Inc) with Hawth's Analysis Tools for ArcGIS (Beyer 2004) and Home Range Tools (Rodgers et al. 2007) plug-ins used to determine the home range and movement patterns for each cat. ArcView 3.2 (ESRI Inc., Redlands, CA) with the Home Range extension (Rodgers and Carr 1998) and the Animal Movement extension (Hooze and Eichenlaub 2000) were used to determine site fidelity, turn angle, and step length and to undertake home range bootstrap analyses. Data points where the time since the previous fix was outside the parameters of 15 min $\pm$ 1 min, 1 hour $\pm$ 1 min, or 6 hours $\pm$ 1 min were discarded from the analysis. Data for the cats with a 6 hourly GPS sampling interval were combined to provide larger data sets. Home ranges for each cat were calculated using the 100% Minimum Convex Polygon (MCP 100) estimator (Mohr 1947). Forays outside the home range were excluded from the analysis (Laver and Kelly 2008).

Movement Patterns

Step length data were arranged into histograms with 200-m intervals for the 6 and 1-hour sampling intervals and 100-m intervals for the 15-minute sampling intervals. The frequency of occurrence at each interval was used in the analyses. Final data analyses were undertaken in Statistica 7 (StatSoft Inc. 2004).

RESULTS

Twenty-two feral cats were captured during this study. Eleven were fitted with GPS collars and a further 6 with VHF-only collars. Three of the GPS collared cats died during the study and the collars were retrieved from their remains. A further 3 cats were successfully recaptured. Sufficient data to provide meaningful results were obtained from 8 cats with a total of 2,243 successful fixes obtained from the GPS collars.

All cats showed site fidelity and exhibited more constrained movements than each of 100 generated random walks ($P < 0.01$). The home ranges of all cats used in these analyses reached asymptote.

Home Range

The MCP 100 home range varied from 53 to 816 ha with a mean male home range ($\pm$ SE) of 455 ± 126 ha and mean female home range ($\pm$ SE) of 105 ± 28 ha (Table 1).

Table 1. Home ranges of feral cats collared in this study.

Cat (sex)	Period tracked	Collar type	MCP 100* (ha)
Karen (F)	6 wks	GPS	141
Neil (M)	5 mths	GPS	410
Hans (M)	3 mths	GPS	370
Olof (M)	9 mths	GPS	816
Liz (F)	19 mths	VHF	166
Chris (M)	18 mths	VHF	226
Hayley (F)	11 mths	VHF	53
Danielle (F)	14 mths	VHF	60
Mean $\pm$ SE			280 ± 89
Mean female $\pm$ SE			105 ± 28
Mean male $\pm$ SE			455 ± 126

* 100% Minimum Convex Polygon (Mohr 1947)

Table 2. MCP 100 home range overlap between feral cats.

Cats	Area of overlap (ha)	Percentage of home range
Chris / Hayley	53	23.5 / 100
Chris / Danielle	2.2	1.0 / 3.6
Liz / Danielle	2.6	1.6 / 4.3
Liz / Sue*	37.7	22.7 / 60.9*
Mean $\pm$ SE	20.3 ± 10.4	27.1 ± 12.6
Mean F / F overlap $\pm$ SE		32.1 ± 16.4

* The home range area of the cat Sue did not reach asymptote; as a result, the volume and percentage of home range overlap is calculated based on the known home range area, rather than the full area.

Male home ranges were larger than female home ranges (Mann-Whitney U test $Z = -2.3$, $U = 0$, $P = 0.02$). Home ranges determined by GPS were not significantly different from those determined by VHF telemetry (Mann-Whitney U test $Z = 1.7$, $U = 2$, $P = 0.08$).

Home Range Overlap

Four of the cats that were tracked using VHF telemetry had home ranges that overlapped with a neighbouring feral cat (Table 2). The degree of overlap varied between cats with one female (Hayley) having her home range incorporated completely within that of a male (Chris). The home range of one female (Danielle) overlapped with that of the female Liz and with that of the male Chris. The home range of Liz also overlapped that of another adjoining female (Sue). No male: male range overlaps were found.

Movement Patterns

After removal of those data points falling outside the parameters detailed above, a total of 699 fixes at 6 hourly intervals, 326 fixes at hourly intervals, and 375 fixes at 15-minute intervals were used to determine movement patterns of the feral cats. A normal distribution of the step lengths and $\mu \geq 3$ that would be expected from simple Brownian motion were not apparent in the data. Instead,

Table 3. Mean step length and Lévy parameter for feral cats at each sampling interval.

Interval	Mean step length (m $\pm$ se)	r^2 ^a	μ ^b
6 hours	821 $\pm$ 26	0.64	1.49
1 hour	185 $\pm$ 11	0.93	2.02
15 minute	76 $\pm$ 6	0.90	2.09

^a r^2 is the coefficient of determination for the linear regression of the log/log relationship between step length and frequency of occurrence of the step length.

^b μ is the slope of the line for the linear regression of the log/log relationship between step length and the frequency of occurrence of the step length.

regression of the $\log_{10}$ relationship between step length and frequency showed the presence of a Lévy walk pattern - $P(l_j) \sim l_j^{-\mu}$ - at each temporal scale (Table 3). Movement patterns at both hourly and 15-minute intervals indicated an optimal foraging patterns by feral cats - $\mu = 2.02$ and $\mu = 2.09$, respectively. At the 6 hourly sampling intervals, a Lévy walk pattern was still apparent but was less obvious than at the other sampling intervals.

DISCUSSION

Home Ranges and Overlaps

This is the first study of the home ranges of feral cats in tall closed forests in Australia using either VHF telemetry or GPS receivers. VHF telemetry has been used in other habitat types for feral cats (Molsher et al. 2005), while GPS collars have been utilised on other feral cat populations on islands (Dirk Hartog Island - Hilmer 2010, Johnston et al. 2010; and French Island - Johnston et al. 2008) and mainland sites (Alcoa Lease site, Anglesea, Victoria - Robley et al. 2008; and Arid Recovery, South Australia - Moseby et al. 2009).

Compared with other studies in Australia and New Zealand, the home ranges of feral cats in the tall closed forests were smaller than those of cats in the arid and alpine regions. This is due most likely to fewer or poorer quality food resources in these latter areas. Conversely, home ranges were larger than those of feral cats living on farmland or in grassland habitats where food resources are usually greater or accessibility to food is easier (Molsher et al. 2005).

Generally, felids are solitary animals and congregate in groups only when there are sufficient resources to eliminate the need to compete for food, shelter, and mates (Creel and Macdonald 1995). Feral cats tend towards group living when there are high levels of rich, clumped food resources such as at rubbish tips (Denny 2005, Hutchings 2003) or where humans provide food (Natoli and De Vito 1991, Say et al. 1999) but are solitary when food resources are scarcer. Whilst the cats in this study appeared to be largely solitary, there was overlapping of home ranges both between adjoining females and between females and males. Because it is possible also that other uncaptured and uncollared cats were present in the study area, the overlap described here should be regarded as minimal. Male home ranges regularly overlap those of females (as reviewed by Liberg et al. 2000, Macdonald et al. 2000), as was also found also in this study. Adjoining females had a higher degree of home range overlap than

found by Molsher et al. (2005).

The extent of the overlap of the two females, Liz and Sue, indicates a high level of tolerance at least between these individuals. Denny et al. (2002) found that this tolerance usually reflected relatedness between the cats, but this possibility could not be tested in this study. If it is assumed that not all cats in the study area had been trapped and that food resources there were insufficient to allow the kind of group living observed in cats at resource-rich sites such as rubbish tips, the observed overlaps in home ranges of the female cats we studied suggest that females in the tall forests of Far East Gippsland are tolerant of each other.

If this is correct, females in the tall forest environment may be more tolerant of each other than has been reported in most other habitats. Such tolerance could be facilitated by the high structural complexity of the Gippsland forests, in the same way that high habitat complexity increases the ability of prey to escape detection by predators (Arthur et al. 2004, Sinclair et al. 1998). Complex habitat structures such as logs, litter, and varied densities of understorey cover could allow potentially intolerant females to avoid each other.

Movement Patterns

Lévy walk foraging patterns are found in many species in nature including micro-organisms (Levandowsky et al. 1988), honey bees, and moths (Reynolds et al. 2007a,b), marine animals (Sims et al. 2008), jackals (Atkinson et al. 2002), elephants (Dai et al. 2007), spider monkeys (Ramos-Fernandez et al. 2004), and human hunter-gatherers (Brown et al. 2007). A Lévy walk was apparent in all feral cats and at all sampling intervals in this study. Movement patterns at both hourly and 15 minute intervals indicated optimal searching patterns by feral cats - $\mu = 2.02$ and $\mu = 2.09$, respectively. At the 6 hourly sampling intervals, a Lévy walk pattern was still apparent in the movement patterns of feral cats but was less obvious than at the shorter sampling intervals. This indicates that this sampling period may be too great to detect searching patterns effectively, or that searching was interspersed with other activities such as rest that may have weakened the Lévy pattern.

The employment of Lévy style movement behaviour by predators optimises their chance of encountering prey items when prey are sparsely distributed across the landscape (Humphries et al. 2010, Viswanathan et al. 1996), while a Brownian (random) motion style searching pattern is more suited when prey are more abundant (Humphries et al. 2010). Invasive predators, such as feral cats, forage for diverse mammalian, avian, and reptilian prey items (Dickman 1996, Jones and Coman 1981, Triggs et al. 1984) that would not be distributed uniformly through the environment. The Lévy walk style of searching is also more advantageous if the predator is larger and faster than the prey item, while Brownian-style searches are more likely to increase encounter success when the target is larger and faster than the predator (Viswanathan et al. 2002). Feral cats prey on animals that are on the lower end of the Critical Weight Range (35 - 5500 g) (Burbidge and McKenzie 1989) and, in far eastern Victoria, generally take prey weighing less than themselves (Triggs et al. 1984).

CONCLUSION

Knowledge of home range size and overlap can assist in determining the amount and type of effort that is needed in a feral cat management program. Where there are large individual home ranges with little overlap, the density of animals is comparatively low. Conversely, where home ranges are small and overlapping, density of animals will be higher (Liberg et al. 2000). The home ranges calculated in this study were smaller than those found in the arid and semi arid regions (e.g., Burrows et al. 2003, Edwards et al. 2001, Hilmer 2010). This, together with the high degree of home range overlap, indicates that a higher baiting intensity may be required to manage cats in tall forested habitats compared with that required in arid or semi-arid regions. Additionally, population management through trapping or shooting would require higher effort per unit area than is required for cats in arid regions. As feral cats employ a Lévy walk movement pattern when moving through their environment, placing management devices such as traps or baits in a uniform manner across the landscape is not required. The Lévy walk movement pattern optimises the chances of a feral cat encountering sparsely distributed prey items and hence would similarly increase the chance of the cat encountering a bait or other management device.

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