Urban Ecosystems (2018) 21:999–1009
https://doi.org/10.1007/s11252-018-0766-6

Home range and habitat use of feral cats in an urban mosaic in Pietermaritzburg, KwaZulu-Natal, South Africa

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Published online: 11 May 2018

Abstract

Feral cats (*Felis catus*) are one of the world's worst invasive species with continuing expanding populations, particularly in urban areas. Effects of anthropogenic changing land-use, especially urbanisation, can alter distribution and behaviour of feral cats. Additionally, resource availability can influence home range and habitat use. Therefore, we investigated home range and habitat use of feral cats ($n = 11$) in an urban mosaic with varying degrees of urbanisation and green spaces in Pietermaritzburg, KwaZulu-Natal, South Africa. Using global positioning cellular trackers, individual feral cats were followed for a minimum of six months. Minimum convex polygons (MCP) and kernel density estimates (KDE) were used to determine their home range, core area size, and habitat use. Mean home range (± SE) for feral cats was relatively small (95% MCP 6.2 ± 4.52 ha) with no significant difference between male and female home ranges, nor core areas. There was individual variation in home ranges despite supplemental feeding in the urban mosaic. Generally supplemental resources were the primary driver of feral cat home ranges where these feeding sites were within the core areas of individuals. However, the ecological consequences of feeding feral cats can increase their survival, and reduce their home ranges and movement as found in other studies.

Keywords Home range · Habitat use · Habitat selection · *Felis catus* · Urban ecology

Introduction

Urbanisation has led to an increase in concentrated human populations and human activity within a heterogeneous anthropogenically transformed landscape (Bradley and Altizer 2007; Aguilar and Farnworth 2013). Ecological consequences such as habitat and species loss, and human-wildlife conflict, are generally consequences of these anthropogenic changing land-uses (Bradley and Altizer 2007; Aguilar and Farnworth 2013). Urbanisation has been observed as one of the leading causes of species extinction (McKinney 2006). Furthermore, several studies show that expanding developments in urban environments have promoted biodiversity loss and often have native species replaced with alien invasive species (Lepczyk et al. 2004; McKinney 2006; McKinney 2008; Shochat et al. 2010). Various alien invasive species are able to adapt and persist in these altered landscapes. An example is the feral cat (*Felis catus*).

The feral cat is considered as one of the 100 world's worst invasive alien species with populations generally increasing, particularly in urban environments, worldwide (Jessup 2004; Gosling et al. 2013; Lepczyk et al. 2015). Humans have introduced cats onto almost every continent (Driscoll et al. 2009; Lyons 2014) with feral cats expanding in a variety of ecosystems (Bradshaw et al. 1999). These self-sustaining populations exploit a wide range of habitats including forests, woodlands, grasslands, deserts, shrublands, glacial valleys, equatorial to sub-Antarctic islands and often urban areas (Doherty et al. 2015). Feral cats are termed as mesopredators and populations generally increase due to the lack of apex predators (Ritchie and Johnson 2009). A combination of successful invasive potential to colonize a wide range of habitats, with high fecundity and ability to acquire vital resources independently from surroundings; has allowed feral cat populations to reach a state of overabundance, particularly in urban areas (Calhoon and Haspel 1989; Gunther and Terkel 2002; Baker et al. 2005; Finkler et al. 2011). Furthermore, irresponsible pet ownership leading to the birth of unwanted kittens and abandonment of

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11252-018-0766-6) contains supplementary material, which is available to authorized users.

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kittens has also led to this increase (Collins 1976; Gunther and Terkel 2002; Levy et al. 2003; Looney et al. 2008; Longcore et al. 2009). Feral cats in urban areas sometimes become a public nuisance with their spraying and defecating in gardens (Remfry 1996). Additionally, feral cats raise public health concerns with harbouring and spreading infectious zoonotic diseases (Luria et al. 2004; Levy et al. 2008; Duarte et al. 2010; Spada et al. 2012; Hajipour et al. 2015). Another major negative impact of feral cats is predation which is detrimental to native wildlife, these included small mammals, birds and reptiles as recorded in several studies (Woods et al. 2003; Natoli et al. 2006; Dauphiné and Cooper 2009; Duffy and Capece 2012). However, cat predation may be beneficial in urban areas, including dumpsites, where pest species such as rats and mice occur in abundance (Thomas et al. 2014).

Feral cats are described as pet cats or stray cats that have reverted to a 'wild like state', adopting a free-living lifestyle allowing survival in an ecosystem for many generations without human interaction/ dependence (Remfry 1996; Bradshaw et al. 1999; Gosling et al. 2013). They are mainly crepuscular and nocturnal (Barratt 1997). They live solitarily or in groups called colonies, and generally congregate at common food resources, especially dumpsites, restaurants, shopping malls or specific cat supplemental feeding sites in urban areas (Putman and Putman 1989; Turner 2000; Aguilar and Farnworth 2013). Populations of feral cats can display contrasting degrees of dependence on humans (Liberg et al. 2000). In this study, we categorised feral cats as unowned cats which roam freely outdoors with little or no socialization to humans, with possible access to human food waste or human provided food. In South Africa, it appears that feral cat colonies have established in most metropolitan cities (pers. obs.). There are approximately 2.2 million pet cats in South Africa (Euromonitor International 2015) but no estimates of the population of feral cats. Distribution of resources such as food, shelter and reproductive mates can influence feral cat abundance and densities as well as overall spatial ecology (Liberg et al. 2000). With high densities of feral cat populations occurring in condensed and fragmented green spaces in urban settings, understanding aspects of the spatial ecology of feral cat populations may assist with their management. Telemetry is a commonly used method to study the spatial ecology of mammals which also assists with planning and implementation of effective management practises (White and Garrott 2012), especially of alien invasive species (Goltz et al. 2008). Data obtained from this method can predict movement, densities and future impacts of the species and identify possible impacts to native species (Doherty et al. 2015).

Although home ranges of feral cats have been studied from rural and urban areas across the globe, these studies are mainly from the USA (Hall et al. 2000), UK (Thomas et al. 2014), Australia (Edwards et al. 2001; Molsher et al. 2005) and New Zealand (Fitzgerald and Karl 1986; Langham and Porter 1991; Harper 2007; Recio et al. 2010). Use of global positioning systems (GPS) has simplified wildlife radio-tracking to be effective and with minimal researcher disturbance to the animals (Hansen and Riggs 2008; Recio et al. 2010). Our study is the first in South Africa to use GPS telemeters on feral cats. There is relatively little research on home range and habitat use of feral cats in the urban environments of South Africa (Tennent and Downs 2008). Consequently, we determined the home ranges and habitat use of feral cats fitted with GPS trackers within an urban mosaic. Our objectives were to understand movement patterns, habitat selection and behaviour of feral cats across the urban mosaic consisting of varying degrees of urban and green space habitat types. Habitat use and movement patterns between sexes, and time (day and night) were compared, and habitat types and selection within an urban mosaic were also determined. It was predicted that home ranges would be influenced by the level of urbanisation and resource availability such as food and shelter, and time of day.

Methods

Study sites

Our study was conducted in the urban mosaic of Pietermaritzburg, South Africa (S29.642; E30.413, Fig. 1). We classified urban areas into three categories of decreasing urbanisation (urban, private, and natural) based on the level of urbanisation and natural green spaces (Appendix 1). Feral cats were trapped in areas where the existence of a population was known. Seven cats were trapped from established feral cat colonies located at the Pietermaritzburg Airport, University of KwaZulu-Natal (UKZN) Main Campus, and the Golden Horse Casino. These colonies were assisted by the local Feral Cat Feeding Group which provided supplementary food and an ad hoc sterilization programme. These feral cats were regularly fed at permanent feeding stations at these sites (Fig. 1). An additional two cats were trapped at the Maritzburg Golf Course and one cat outside the UKZN campus as these feral cats were reliant on acquiring food from their environment because there were no existing supplementary feeding sites at these localities.

Trapping and collaring

To obtain comprehensive movement, home range and habitat use data of feral cats in the urban mosaic of Pietermaritzburg, eleven cats (6 M, 5F) were trapped, immobilized and each fitted with a telemeter collar (UKZN Animal Ethics Permit −019/14/animal). We trapped between May and October 2014, usually in the early evenings as feral cats are generally crepuscular (Barratt 1997). We used eight one-sided, open-door live traps (35 × 40 × 60 cm) on a rotational basis. Traps were baited with Lucky Pet™ tinned fish and catnip, *Nepeta*

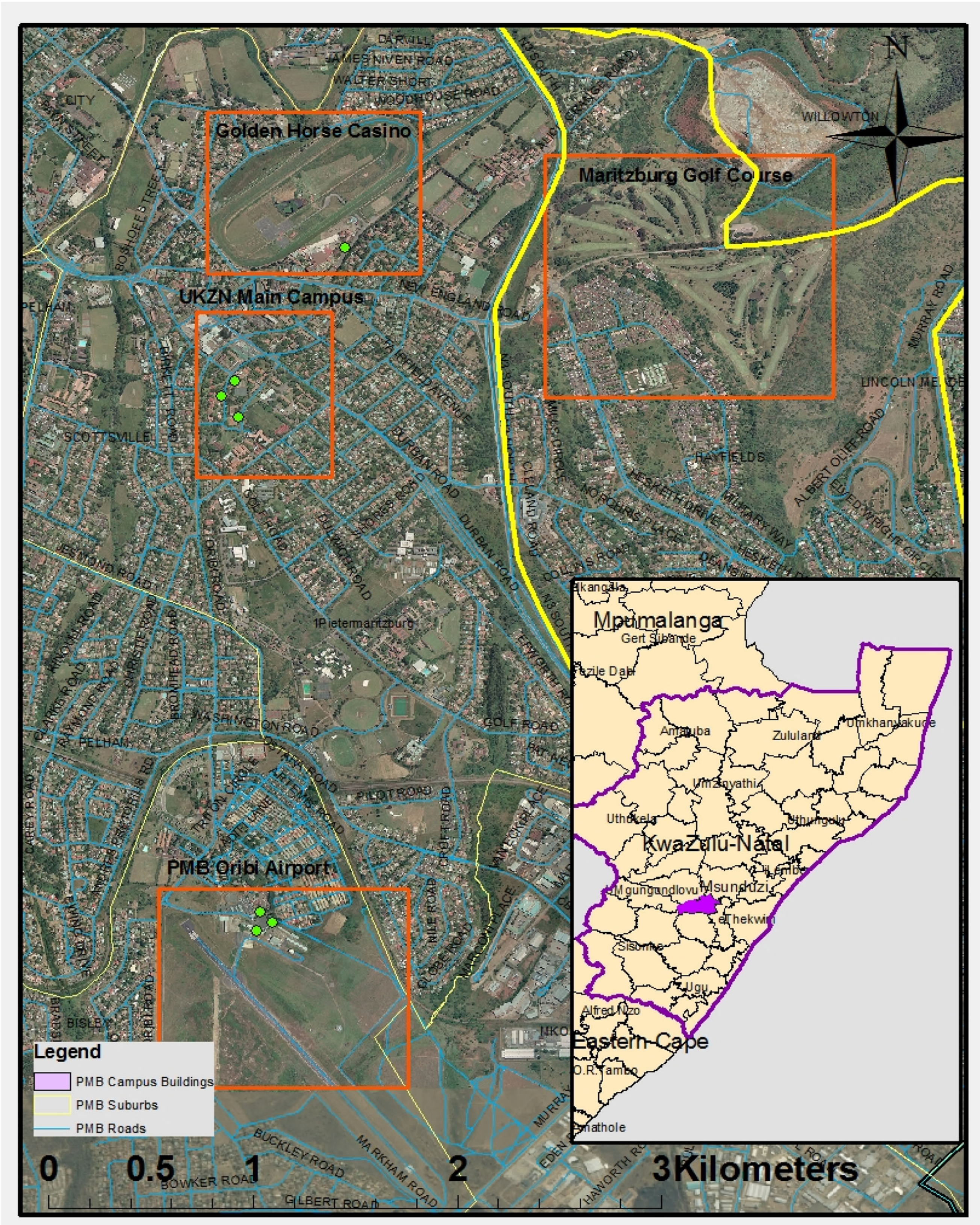

Fig. 1 Aerial photograph of the four areas (orange boxes) inclusive of varying degrees of urbanised and green areas in Pietermaritzburg, South Africa where feral cats were tracked. (Green dots indicate permanent feral cat supplementary feeding sites)

cataria. Cats with identification pet collars were considered as having an owner and released if caught. Due to variable trapping success it was impossible to collar all cats simultaneously at a specific site or time.

All captured feral cats were anaesthetized by a veterinarian using with a combination of 0.2 ml/2 kg Ketamine® and Domitor® (medetomidine hydrochloride) injected intramuscularly. Reversal was done using Antisedan® (atipamezole hydrochloride). Each anaesthetized cat was aged, sexed, weighed, measured, and body condition recorded before a tracker was fitted on adults. They were aged as adults by the presence of large canine teeth and body size. Each tracker (GPS-GSM-UHF; Wireless Wildlife, Potchefstroom, and Trackem, Pietermaritzburg) was secured with an adjustable break-away material collar, and weighed ~50 g in total which was <2% of body mass of adult cats and below the recommended range of 3–5% of body mass (Kenward 2000; Coughlin and van Heezik 2015). All cats were monitored until fully conscious and released back at the site of capture. Generally, the total procedure took ~30 min to complete. However, any unsterilized cats caught were neutered or spayed, and had the tip of their left ear clipped, by the veterinarian with prior agreement of the Feral Cat Feeding Group to indicate sterilization. All sterilized individuals were kept overnight at the Animal House Facility, UKZN, Pietermaritzburg to recover and released the following day at their capture site.

Feral cat locations were obtained every 6 h from trackers on a pre-set schedule and downloaded using a solar powered base-station placed at a high point in each locality. GPS fixes were converted for use in ArcMap 9.3.1 (ESRI, Redlands, California, USA). Any unusual location points that were determined to be errors from the trackers were considered outliers and were removed manually. Each GPS point location was classified as day or night, determined using the daily diurnal times from 08 h00 to 14 h00, and nocturnal times from 20 h00 to 02 h00, as per the pre-set times of the trackers. The trackers were designed to provide GPS fixes for a year with this pre-set time schedule.

Home range estimation

Originally Burt (1943) defined home range as 'that area traversed by the individual in its normal activities'. The area which constitutes an animal's home range usually includes its food, shelter and reproductive opportunities and their use (Burt 1943). The boundaries of this area are described by the Minimum Convex Polygon (MCP), one of the extensively used methods to estimate home range area in feral cat studies (Seaman et al. 1999; Tennent and Downs 2008; Thomas et al. 2014). More recently kernel density analyses have been considered for describing home range and habitat use as they allow for detailed home range and habitat use determination (Worton 1989; Seaman and Powell 1996; Kenward 2000), and were therefore also used in the current study. Consequently, home range size was estimated using two home range methods: Maximum Convex Polygon (MCP) and Kernel Density Estimate method (KDE). These were calculated using R package rhr in user interface R studio (1.2.909) to estimate 95%, 90% and 50% from the two home range estimate methods (RStudio 2015). The reference bandwidth (href) was the default bandwidth selection for our analysis (Walter et al. 2011). Overall MCPs and KDEs (means ± SE) were calculated for each cat as well as for day and night for individual cats. The 95% MCPs and 50% KDEs were computed onto layers for Pietermaritzburg and exported as maps for visual comparisons showing overlapping of home ranges of individuals.

Statistical analyses

One-way ANOVA's were run in STATISTICA 7.0 (Statsoft Inc., Tulsa, USA) to determine any significant differences in home range size between male and female feral cat home ranges and core areas utilized and the assumptions of the data were tested for normality. The 95% polygons were used as total home range area, and the 50% kernels were used in statistical analysis as these determined the core areas that were widely used by feral cats. Data using the 95% polygons and the 50% kernels for day and night home ranges and core areas were also tested for differences using a paired sample t-test. Additionally, this test was used to determine any differences in the number of GPS locations collected during the day and night of individual feral cats. All mean values were presented as mean (± SE) and significance was assessed at a P value of 0.05. Furthermore, a power analyses was run (RStudio 2015) to determine the effect size of the population for male and female feral cats for this study.

Habitat selection

The urban mosaic of study sites where feral cats were caught were reclassified according to the amount of green, urban and private habitat types that occurred within a 20 × 20 m grid overlaid onto Google Earth. The resolution of which was adequate in differentiating the different habitat types. This size grid was considered necessary since the feral cat home ranges were relatively small based on preliminary observational data and GPS fixes from the feral cats. This was used to calculate the total habitat types available for each location using the 95% MCP with GPS fixes from feral cats. This method was used to determine the percentage use and percentage availability of each habitat type for each feral cat. We implemented the 'adehabitat' in R package version 1.8.6 (Calenge 2006) for R version 2.11.1 (R Development Core Team 2010). To compare habitat use with availability, the Manly's selectivity measure was calculated to determine the choice of resource selected by feral cats of each habitat type. The Manly selectivity measures the differences and tests a selection ratio (= used/available) which was computed and the preference/avoidance tested for each habitat, where if the index is larger than one, selectivity for that resource is greater than its availability in the environment (Manly et al. 2007). A value around one indicates that the resource selection was noted (Manly et al. 2007). Habitats with the values around one for Manly's selectivity ratio were considered key habitats for the feral cats. Pearson's Chi-square test was used to test for significance between each individual in each habitat and adjusted by Bonferroni tests. Furthermore, we tested for differences between habitat type used and the habitat type available for each feral cat using a paired sample t-test.

Results

Home range estimates for eleven collared feral cats (6 M, 5F) from four locations within an urban mosaic of Pietermaritzburg (Appendix 2) were determined for the study period between May 2014 and March 2015. Mean (± SE) age of cats collared was 2.6 ± 0.5 years with mean body mass of 4.05 ± 0.35 kg (Appendix 2). Number of GPS fixes for each cat varied because of the inability to obtain a location via the base station and satellites, due to the obstruction of high rise buildings, trees, or if at any time the cats went into hiding under buildings, manholes and drainage lines. Additionally, trackers began to lose power over time and eventually failed (Appendix 2). A total of 2943 GPS locations were recorded during the duration of the study for all collared cats. Collared cats mean number of locations were 268 ± 105.9 (range 99–428).

Total home range and habitat use

The mean (± SE) home range size for all feral cats using 95% MCP was 6.2 ± 4.52 ha (Table 1, Appendix 3). Mean core range size for all feral cats using 50% KDE was 1.8 ± 1.87 ha (Table 2). Although males had larger home ranges (7.9 ± 5.45 ha) than females (4.1 ± 2.06 ha) for 95% MCP (Table 1, Appendix 3), there was no significant difference between sexes (ANOVA, $F_{(1,9)} = 1.035$, $P = 0.336$). Although core area (50% KDE) used by males were generally larger (2.4 ± 2.41 ha) than females (1.2 ± 0.75 ha), they were not significantly different between the sexes (ANOVA, $F_{(1, 9)} = 1.370$, $P = 0.272$).

There were significant differences between day and night MCP home ranges of feral cats within the urban mosaic of Pietermaritzburg (t-test, $t_{(9)} = 3043$; $P = 0{,}014$). Feral cat night home ranges, 95% MCP home ranges (6.1 ± 4.74 ha) were larger than day 95% MCP home ranges (3.2 ± 2.32 ha). There were significant differences between day and night core ranges of feral cats within the urban mosaic of Pietermaritzburg (t-test, $t_{(9)} = 2521$; $P = 0{,}033$). The 50% KDEs core area for feral cats at night (2.1 ± 2.02 ha) were generally larger than day 50% KDEs (1.4 ± 1.48 ha). Overall, males generally had larger home ranges and used larger core areas than females during the day and at night (Table 3).

There was no significant difference of GPS locations recorded during day than at night for the core areas used by feral cats (t-test, $t_{(20)} = -1.350$; $P = 0.192$, Fig. 2). Cat C7 was not used in the analysis as there was insufficient data to calculate its KDEs, instead comparisons were made using the MCP analysis. The quantitative analyses of sterilization status were not conducted because all cats had been intact prior to the study so no comparison could be made. Furthermore, no seasonal comparisons could be conducted because of different collaring times during the year and the failure of trackers.

Table 1 Home range estimates of feral cats (n = 11) in an urban mosaic in Pietermaritzburg, South Africa, calculated using Minimum Convex Polygon (MCP) in ArcGIS. (Note M = male, F = female)

Cat ID	Location	Age (years)	Sex	95% MCP (ha)	90% MCP (ha)	50% MCP (ha)
C1	Airport	6	M	8.9	6.2	2.3
C2	Airport	3	F	6.5	3.4	0.3
C3	Airport	3	M	8.9	6.0	1.4
C4	Main Campus	2.5	M	1.8	1.3	0.2
C5	Main Campus	2.5	M	1.0	0.9	0.1
C6	Main Campus	1	F	1.7	1.3	0.3
C7	Main Campus	1.5	F	3.9	3.2	1.5
C8	INR Checkers	1	F	2.7	2.1	0.6
9CC	Casino	5	M	13.7	12.8	4.5
C9	Maritzburg Golf Course	1	M	13.1	11.1	1.8
C10	Maritzburg Golf Course	4	F	5.9	4.5	2.4
Mean		2.77		6.19	4.80	1.41

Table 2 Core home ranges of feral cats (n = 11) in an urban mosaic in Pietermaritzburg, South Africa, calculated using Kernel Density Estimates (KDE) in ArcGIS. Shown are the numbers of locations (n) and the smoothing factor (*h*) used to generate these estimates. (Note M = male. F = female)

Cat ID	Age (years)	Sex	GPS fixes	*h*	95% Kernel (ha)	90% Kernel (ha)	50% Kernel (ha)
C1	6	M	428	28.10	8.93	6.18	1.82
C2	3	F	261	22.37	7.24	4.23	0.62
C3	3	M	370	28.12	10.23	7.45	1.92
C4	2.5	M	385	15.72	2.66	1.74	0.38
C5	2.5	M	274	11.27	1.46	1.02	0.22
C6	1	F	214	15.39	2.38	1.79	0.43
C7	1.5	F	99	36.95	9.27	6.82	2.07
C8	1	F	254	18.56	4.35	3.04	0.86
9CC	5	M	130	55.63	25.61	20.29	6.76
C9	1	M	188	45.73	22.51	15.98	3.13
C10	4	F	340	31.84	7.81	6.18	1.85
Mean	2.77		267.55	28.15	9.31	6.79	1.82

To determine whether the non-significant results from this study were due to a lack of statistical power within sexes, we conducted a power analysis with power (1-β) set at 0.80 and $\alpha = 0.05$. The power analysis indicated that a total sample of 19.2 cats would be needed to detect medium effects with 80% power using two-sample t-test between means. This analysis revealed that the sample sizes would have had to increase slightly for group differences of sexes to be statistically significant. However, there were significant differences between day and night home ranges of feral cats and the sample size ($n = 11$) for this study was adequate. There were high standard deviations of home ranges between feral cats because of high individual variation.

Home and core range distribution

We found considerable overlap of individual home ranges of feral cats using both the 95% MCP method and the 50% kernels (Appendices 3–7). Feral cats that were trapped and collared within the same vicinity (Pietermaritzburg Airport, UKZN Main Campus, and Maritzburg Golf Course, respectively) had considerable overlap of home ranges using 95% MCPs (Appendix 3). The Pietermaritzburg Airport had three cats collared, and these showed considerable overlap of home ranges of similar size (Table 1). Feral cat home ranges were not temporally different as movement of cats had overlap during day and night (Appendix 3).

Table 3 Total day and night home range estimates for feral cats (n = 11) in an urban mosaic in Pietermaritzburg, South Africa, calculated using Minimum Convex Polygon (MCP) and Kernel Density Estimates (KDE) in ArcGIS. (Note M = male. F = female)

			Diurnal			Nocturnal		
Cat ID	Age	Sex	95% MCP (ha)	50% kernel (ha)	95% kernel (ha)	95% MCP (ha)	50% kernel (ha)	95% kernel (ha)
C1	6	M	5.48	1.78	8.76	6.16	2.18	9.59
C2	3	F	2.21	0.45	3.54	8.98	1.38	13.11
C3	3	M	4.12	1.21	6.52	8.21	2.96	11.46
C4	2.5	M	1.50	0.28	2.09	1.47	0.41	2.28
C5	2.5	M	0.51	0.15	0.92	0.98	0.25	1.83
C6	1	F	0.65	0.33	1.46	1.59	0.41	2.17
C7	1.5	F	n/a	n/a	n/a	3.65	2.13	8.80
C8	1	F	1.50	0.91	3.16	2.94	0.77	4.95
9CC	5	M	7.77	5.13	19.81	15.49	7.29	28.14
C9	1	M	3.57	1.57	10.89	12.41	3.43	21.91
C10	4	F	4.19	2.21	8.73	5.52	2.04	8.82

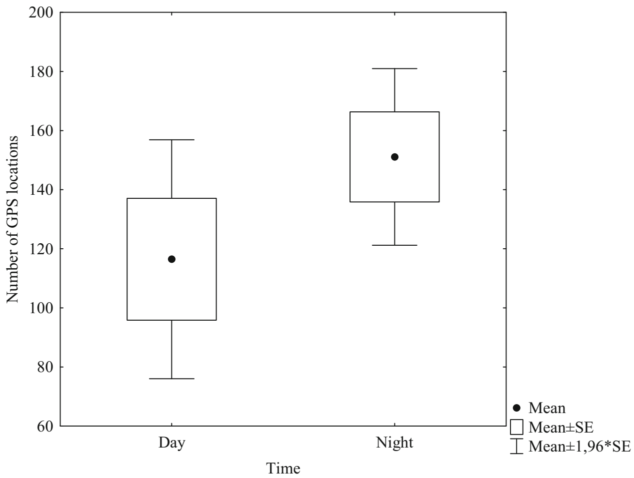

Fig. 2 Number of GPS locations recorded for feral cats ($n = 11$) during day and night respectively in an urban mosaic in Pietermaritzburg, South Africa

Habitat selection

Manly's Selectivity Measure showed that overall, all feral cats used green habitat types more over than what was available (Fig. 3a). However, there was no significant difference in the Manly's selection ratio (used/availability) (ANOVA $_{(11,3)}$ = 0.973, $P = 0.895$, Fig. 3a). In contrast, there was a significant difference in overall habitat type selected by feral cats according to percentage habitat type used ($\chi^2_{(11)} = 61.30$, $n = 22$ $P = < 0.05$, Fig. 4). Urban habitat types were most favoured and used by feral cats over private and green habitat types (Fig. 4). Use of the three habitat types green, urban and private between each feral cat detects varying trends of selectivity between each cat (Fig. 3b). Overall cats in the study area use less of the green habitat type than either urban or private habitat because there is less of this habitat type available. There were no significant differences for male cats, the Manly's selection ratio (ANOVA $_{(6,3)} = 0.944$, $P = 0.893$, Fig. 3d) and female cats, the Manly's selection ratio (ANOVA $_{(5,3)} = 0.768$, $P = 0.691$, Fig. 3d). The selection for a preference in habitat type was low. Both male and female feral cats utilised green areas (Fig. 3c, d). Males generally preferred private over urban habitat types (Fig. 3c) and females generally preferred urban over private habitat types as the second habitat type used (Fig. 3d).

Discussion

Our results describe unowned, free-roaming, feral cat movements within an urban mosaic of Pietermaritzburg which contained varying degrees of urban, green and private habitat types. The current study mean home range sizes (6.2 ha 95% MCP) and core sizes (1.8 ha 50% KDE) were relatively small

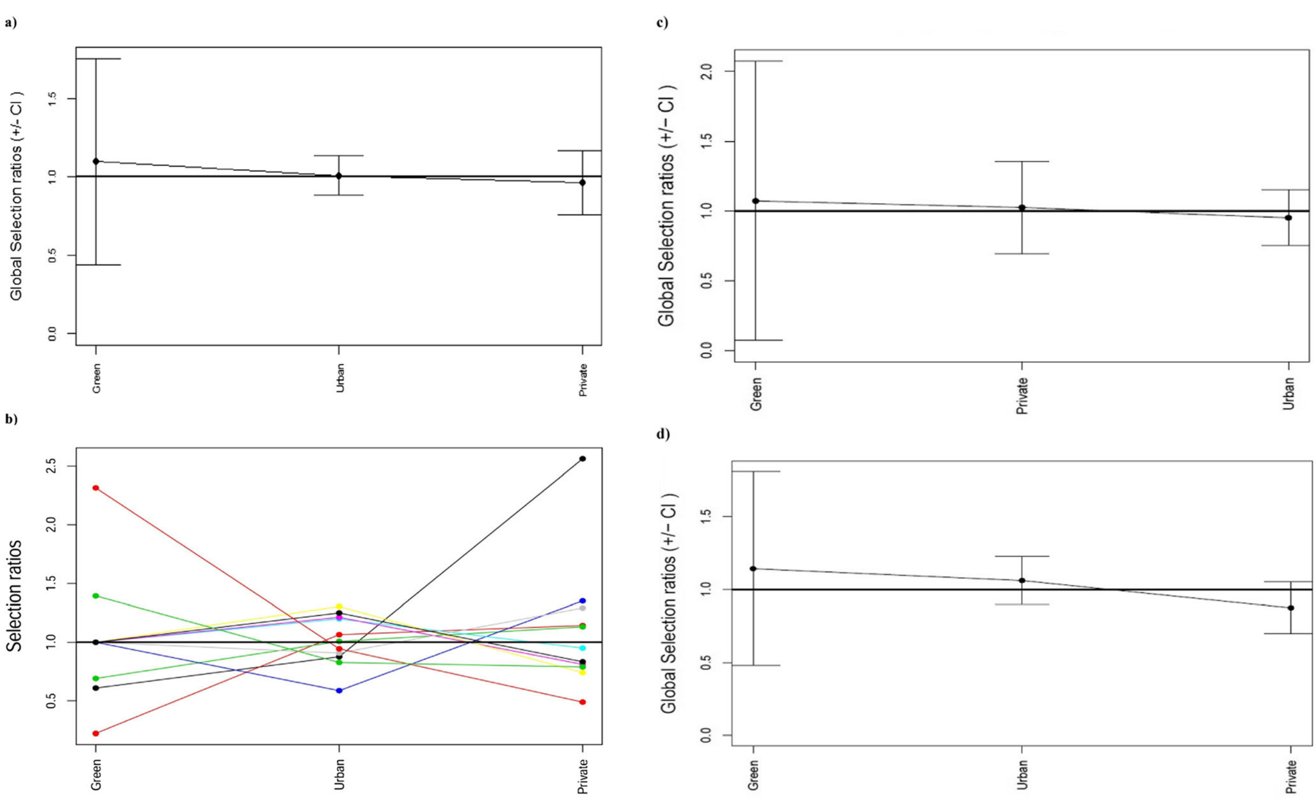

Fig. 3 Selection ratios of feral cats using the Manly's Selectivity Measure where (**a**) is all feral cats (n = 11), **b** individual feral cats (n = 11), **c** male feral cats ($n = 6$), and **d** female feral cats ($n = 5$) in an urban mosaic in Pietermaritzburg, South Africa

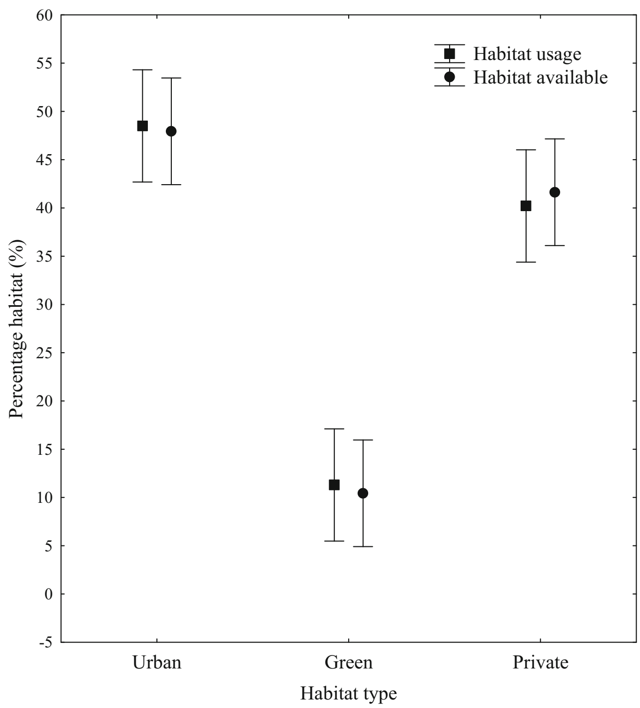

Fig. 4 Mean (± SE) percentage of habitat used and habitat available of feral cats (n = 11) in an urban mosaic in Pietermaritzburg, South Africa

when compared with previous studies. Feral cat home range varies from country to country overseas and range from 0.44–780 ha using 95% MCP (Yamane et al. 1994; Norbury et al. 1998; Bengsen et al. 2012; Moon et al. 2013; Kitts-Morgan et al. 2015). Feral cats in an urban to suburban gradient mosaic showed similar home ranges to this study (Barratt 1997; Tennent and Downs 2008). Genovesi et al. (1995) showed that feral cats living in greener areas have low densities and much larger home ranges than cats in urban areas with high densities This present study observed cats in green habitat types having larger home ranges than cats occurring in densely urban habitat types; however, population density estimates for feral cats were not recorded and the effect of population size could not be determined on home ranges. A study in the subalpine woodland of Hawaii estimated mean 95% fixed kernel home range estimates of feral cats (males 1418 ha; females 772 ha) (Goltz et al. 2008) which was extensively greater in comparison to the present study.

The current study showed that sex had no influence on home ranges and core areas of feral cats but generally showed larger ranges for males than female feral cats which was similar to several other cat studies (Kays and DeWan 2004; Schmidt et al. 2007; Horn et al. 2011; Bengsen et al. 2012; Thomas et al. 2014). However, some studies have shown that sex can have an effect home range size (Haspel and Calhoon 1993). These findings highlight the variability that can be found across feral cats that occur in different parts of the world. Generally, male home range sizes are influenced by the distribution of receptive females and food abundance, and female home range is affected by resource availability (Liberg et al. 2000). The lack of territorial responses of male cats, and with female cats existing in such close proximity of each other, could account for no effects between sexes since potential mates are within reach. In the present study, this was questionable as all cats that were caught had not been sterilised despite a sterilization programme being implemented by the Feral Cat Feeding Group. Feral cats are probably not competitive for reproductive mates as feral cat colonies are intermixed with sterile and intact cats. As mentioned, we could not test the effects of sterilization on feral cats. Studies have shown that intact males and females have a larger home range size compared with sterilized cats (Kitts-Morgan et al. 2015). However, some studies showed no significant differences of sterilization of adult feral cats (Guttilla and Stapp 2010; Bengsen et al. 2015).

There were significant differences between day and night home and core ranges of feral cats. Night-time home ranges were larger than day-time suggesting that they moved further when human activity was low. Generally feral cats are crepuscular and nocturnal in their diel activity being more active after sunset and early sunrise (Barratt 1997) which accounts for generally larger night ranges. Furthermore, the lower GPS fixes in the core area at night could account for feral cats moving out of the core area, which they are unfamiliar with, and expand into other areas. The reduced nocturnal anthropogenic activity (per. obs.) also favoured cat movement at night. Feral cat C8, a female, was the only cat to have more GPS fixes during the day rather than at night.

Mean core range distributions for all feral cats in this study were generally small (1.8 ± 1.87 ha) and largely centred around a common or potential food resource at each site. Core areas from this study were similar to Tennent and Downs (2008), where core areas of feral cats were condensed around permanent feeding sites, with overlap in home ranges by cats that were collared in the same vicinity of a feeding site. Male and female home ranges overlapped considerably which again suggests access to female cats was not limited by males. This could suggest that food availability was the primary reason that males left their territories possibly when food was depleted and possibly not when females were in oestrus (Harper 2007). In other studies, male cats were generally sedentary and lacked territorial behaviour which further increased the home range overlap amongst individuals (Guttilla and Stapp 2010). Feral cats that receive little or no food from humans hunt as up to four times more than domestic cats (Kays and DeWan 2004). Thus anthropogenic supplemental feeding could reduce feral cat impact on native diversity; however, we did not investigate this. Feral cats that received no anthropogenic supplemental feeding had larger home ranges compared with the cats that were fed. The male feral cat (9CC) that received food daily had the highest core range over all feral cats for day and night. This observable range difference may reflect age or social rank rather than its neutered status (Horn et al. 2011). Liberg et al. (2000) distinguished that subordinate males used smaller home ranges than dominant males which could also explain the variations in home range size as observed for male feral cats in this study.

In our study, feral cats' habitat type preference were located in home ranges where there were more urban and private habitat types rather than green habitat types. Green areas were available in the urban mosaic but were not selected by feral cats. It was observable that the green habitat type size was of a smaller area. When cats did use the green habitats they used more of the area than of what was available. Of 27 studies reviewed by Doherty et al. (2015) 26% reported that cats favoured 'infrastructure' habitat types over all others. Similar studies also showed that cats favoured urban environments over other habitat types (Hutchings 2003; Horn et al. 2011). The role of predator avoidance in habitat selection by feral cats is generally unknown, and we did not assess this as they were the top carnivore present with relatively few large avian raptors in the vicinity (pers. obs.). In this study, it is likely that food resources provided directly or indirectly by humans were exploited by all feral cats (Schmidt et al. 2007). Hunting for food in green habitat types may require more effort so cats would rather acquire food from residential areas, pet food left outside homes, or in garbage waste and dumpsters, which has been supported by other studies (Coman and Brunner 1972; Calhoon and Haspel 1989; Bradshaw et al. 1999; Brickner 2003; Hutchings 2003). This study highlights that cats will prefer built up areas over the green areas. It is unclear which mechanisms drive feral cat populations to exploit food resources while others do not. However, the ecological consequences by feeding feral cats can increase survival and reduce ranges and movement (Schmidt et al. 2007). If colonies are unmanaged and cats are not sterilized the increased local population can heavily impact that environment. Increased cat fights, spraying and defecating on public property results in health risks to humans and other wildlife (Lepczyk et al. 2015). Disease transmission between individual cats has a greater likelihood of spreading in large colonies and can even spread to domestic pet cats which come into contact with infected feral cats (Möstl et al. 2015).

Anthropogenic changing land-use, especially urbanisation results in a general abundance and concentration of anthropogenic food resources resulting in feral cats generally having increased densities and decreased ranges in towns and cities (Liberg 1980; Schmidt et al. 2007). This was seen in the cats that resided within the boundaries of the UKZN Main Campus. With additional and suitable shelter for protection from the elements, it appears that cats will also tend to congregate in those areas (pers. obs.). Calhoon and Haspel (1989) found that cat densities were affected more by shelter, in the form of abandoned buildings, rather than by supplemental feeding. Feral cats were often seen seeking refuge under campus buildings, the hangar at the airport and abandoned areas at the casino and golf course, possibly avoiding contact with humans during the day and emerging at night (pers. obs.).

Conclusions

Feral cats in the current study selected urban habitats since food resources were more easily available and accessible at supplemental feeding and garbage disposal sites which influenced their home ranges. Past studies which were observational or correlative experiments provided low evidence to determine the strength of factors that drive feral cat home range (Doherty et al. 2015). All food resources were within the core areas of feral cats which resulted in small home and core ranges. A few of the feral cats also revealed erratic movements which could relate to the nature of the individual cat and its experiences in that particular habitat, however this was not conclusively determined. Due to varying home ranges of feral cats when compared with other studies, mitigation programmes to control population size need to be specific to local landscape levels in the urban mosaic of Pietermaritzburg.

Acknowledgements The DST-NRF Centre of Excellence for Invasion Biology Invasion is thanked for financial support to K.P. We thank the National Research Foundation (ZA) for financial support. We are thankful to V. Hugo and Wireless Wildlife for trackers and technical services. We are grateful to the veterinarians R. van Deventer, L. Arnot, L. Pachonick and M. Roach for aiding sterilizations, general health checks and collaring of the cats. We are grateful to C. Smith, M. Vida, J. Pharazyn, A. Beaumont and D. Stewart for assistance with trapping as well as to the property owners for allowing us to work on their premises. We thank students from the School of Life Sciences, UKZN, for assistance with data collection. We are grateful to P. Singh and N. Senoge and the reviewers for constructive comments on the manuscript.

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