Aspects of the ecology of feral cats (*Felis catus*) in urban Pietermaritzburg, KwaZulu-Natal, South Africa.

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ABSTRACT

With changing land use such as urbanization, certain species thrive and are successful despite changes in the modified landscapes. Therefore, study of the ecology, adaptations and survival of these species in an urban context is warranted. Often these species include alien invasive species. An example is the feral cat (*Felis catus*). The negative effects caused by feral cats generally include impacts on native species of wildlife because of their highly predatory nature and their ability to spread zoonotic diseases. Furthermore, it often becomes a public nuisance occurring at high densities in urban areas. Consequently the aspects of the ecology of feral cats were studied from March 2014 to June 2015 in an urban mosaic in Pietermaritzburg, KwaZulu-Natal, South Africa. The research was also undertaken to propose and assist with an effective management strategy that was deemed necessary to control high densities of feral cats existing in urban Pietermaritzburg. Feral cats were trapped and fitted with GPS-GSM-UHF tracking collars in order to determine their home and core range sizes within the urban mosaic containing varying degrees of green and urban areas. Additionally, the disease prevalence in feral cats was also documented by collecting blood samples from feral cats occurring in many areas of the greater Pietermaritzburg area. The information gained in this study allowed compilation of feral cat management recommendations and strategies in order to control the increasing feral cat communities already established in Pietermaritzburg.

Feral cat telemetry data showed that availability and abundance of food resources were the primary influencing factors affecting feral cat home range size and distribution as core areas contained at least one supplemental feeding site. There was considerable overlap of feral cats within the core areas. Overall home range size of feral cats was small but varied with individual cats. There was considerable overlap between and within the sexes. There were no significant differences in range size between sexes nor between day and night. However, diurnal ranges were generally smaller than nocturnal range sizes. Generally male feral cats had larger home ranges than female feral cats and nocturnal activity was higher across genders. Feral cats used urban areas more than green areas suggesting that the urban environment supports larger numbers of feral cats.

The disease prevalence in feral cats tested was generally low. However, some tested positive for Feline Leukaemia Virus (FeLV) (28.6%) and for Feline Immunodeficiency Virus (FIV) (7.1 %). There was no occurrence of Feline Corona Viruses (FCoV) in feral cats tested in Pietermaritzburg. The location of feral cats within the city had a significant effect on prevalence of FeLV infection in feral cats tested.

The findings of this study of feral cats in the urban mosaic of Pietermaritzburg showed that feral cats' habitat use and home range were mainly affected by supplemental food resources. Furthermore, disease prevalence in feral cats tested was generally low. Thus efficient, cost-effective and realistic methods need to be implemented to control high densities of feral cats in this urban area require the use of a low-key supplemental feeding programme with a combined sterilization programme. This proposed strategy should be adopted and sustained with involvement of all concerned stakeholders to ensure that the welfare and population of the cats is well managed and humanely controlled particularly as this is an alien, invasive species. Additionally, all cats that test positive for any disease should be removed from the population to stop the spread of diseases to other feral or domestic cats in urban areas of Pietermaritzburg.

PREFACE

The data described in this thesis were collected in Pietermaritzburg, Republic of South Africa from March 2014 to November 2015. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Professor Colleen T. Downs.

This thesis, submitted for the degree of Master of Science in the College of Agriculture, Science and Engineering, University of KwaZulu-Natal, Pietermaritzburg campus, represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any other University. Where use has been made of the work of others, it is duly acknowledged in the text. The thesis is structure with each chapter written in manuscript format with the aim to publish in certain scientific journals. Any repetition is unavoidable.

…………………………

Kerushka Robyn Pillay

December 2015

I certify that the above statement is correct and as the candidate's supervisor I have approved this thesis for submission.

…………………………..

Professor Colleen T. Downs

Supervisor

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DECLARATION 1 - PLAGIARISM

I, Kerushka Robyn Pillay, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and/or include research presented in this thesis.

Publication 1

KR Pillay, T Ramesh & CT Downs

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

Author contributions:

KRP conceived paper with CTD and TR. KRP collected and analysed data, and wrote the paper. TR & CTD contributed valuable comments to the manuscript.

Publication 2

KR Pillay, T Ramesh & CT Downs

Prevalence of diseases in feral cats in urban Pietermaritzburg, KwaZulu-Natal, South Africa

Author contributions:

KRP conceived paper with CTD. KRP collected and analysed data, and wrote the paper. TR & CTD contributed valuable comments to the manuscript.

Signed: ……………………………………………………

Kerushka Robyn Pillay

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CONTENTS

CHAPTER 1

Introduction

Background

Urbanization has led to an influx of human habitation and activity within a heterogeneous and transformed landscape (Bradley & Altizer 2007). The demand and pressure placed on urban environments by man are extreme, resulting in intensive landscape modification. McKinney (2006) has documented that urbanization is one of the leading causes of biodiversity loss causing many extinctions of species. Biodiversity loss is further escalated by the replacement of native species of wildlife by exotic and alien invasive species (Lepczyk *et al.* 2004; McKinney 2006; McKinney 2008; Shochat *et al.* 2010). Alien invasive species can adapt well to the modified landscapes and exploit available resources (Lepczyk *et al.* 2004; Clavero & García-Berthou 2005).

Alien invasive species are one of the major causes of biodiversity loss worldwide and second only to habitat loss alongside other major components such as habitat destruction, climate change, over-exploitation and pollution (Vitousek *et al.* 1997; Lowe *et al.* 2000; Baker *et al.* 2005; Clavero & García-Berthou 2005; McGeoch *et al.* 2010). The introduction of species that were deliberately or accidentally brought into areas beyond their natural geographic range has led to species endangerment and extinction (Lowe *et al.* 2000; Baker *et al.* 2005; Kümpel & Baillie 2007; McGeoch *et al.* 2010). Invasive species may also alter the evolutionary pathway of native species by competitive exclusion, niche displacement, hybridization, predation, and ultimately extinction (Mooney & Cleland 2001). Alien plant and animal species that have been introduced by humans pose a great threat to native species (Clavero & García-Berthou 2005; Baker & Harris 2007). Salo *et al.* (2007) revealed that alien predators have larger negative effects on prey populations than native predators. The most detrimental group among invasive species are mammals, which threaten native species through predation and the spread of diseases (Courchamp *et al.* 2003; Medina *et al.* 2011; Lepczyk *et al.* 2015). To understand what drives these mammals to thrive and persist in altered urban environments, we studied the ecological aspects of the feral cat (*Felis catus*) in urban Pietermaritzburg, KwaZulu-Natal, South Africa. Commonly known as the pet cat, this domesticated, carnivorous mammal has been documented to be quite destructive.

History and domestication of *Felis catus*

The feral cat (*Felis catus* Linnaeus, 1758) from the family Felidae is a descendant from the Arabian wildcat (*Felis silvestris lybica*) (Driscoll *et al.* 2007; Driscoll *et al.* 2009). Cat domestication began around 8 000 – 12 000 years ago (Driscoll *et al.* 2007) from a single locale originating in the Near East Mesopotamia (Driscoll *et al.* 2009). The dawn of agriculture in the Fertile Crescent allowed humans to value cats for their predatory instinctive behaviour and for their ability to control pests such as rats and mice found in the granaries; and for hunting rabbits which was a source of food (Baldwin 1975; Dickman 1996; Brickner 2003; Driscoll *et al.* 2007; Lyons 2014). Domestication of the cat took place fairly recently when compared to other companion animals (Driscoll *et al.* 2009; Lyons 2014) however some believed cats had never truly been domesticated (Tabor 1981). Cats were then transported on ships by the European and Roman colonists probably to control ship-borne pests, or kept as pets for companionship (Dickman 1996; Coleman *et al.* 1997). This initiated their dispersal across the globe and at major port cities (Lyons 2014).

Introductions in South Africa

Man has introduced the cat to almost every continent in the world, arriving as domestic cats and then becoming feral (Long 2003). Cats are a cosmopolitan species known to be extremely adaptable and establishing self-sustaining and wild populations existing in a wide variety of biomes which include deserts, volcanic islands, forests, grasslands, farms, wetlands tundra, rural and urban areas, and tropical to sub-Antarctic islands (Long 2003; Nogales *et al.* 2004; Tennent & Downs 2008; Doherty *et al.* 2015a). Feral cats occur in many areas of southern Africa that include the Kalahari, Botswana and Marion Island but usually around human habitation (Van Aarde 1980; Long 2003).

Defining cats

Based on their habitats, diet, and their relationship to people cats can be grouped into three main groups (Moodie 1995; Dickman 1996; Slater 2002; Slater & Shain 2005; Dickman 2009; Calver *et al.* 2011; Gosling *et al.* 2013):

Domestic – these cats are completely dependent on humans to provide all their food and shelter requirements living in close association with households and people.

Stray – are cats that have been dumped into the environment, and/or lost or abandoned pet cats. They are much friendlier and are known to have had contact with humans due to socialization as a kitten, they are partially provided with food or rely on scraps from surroundings.

Feral/Semi-feral – these cats are born outdoors and have reverted back to a 'wild' state; they can survive independently having little to no direct reliance on humans. They rely on acquiring food from the environment, hunting small prey.

Furthermore the literature has described two further categories of domestic cats' namely free-roaming domestic cats and housebound domestic cats (Moodie 1995; Turner 2000; Dickman 2009). In the context of the current study, we will use the term feral cats since most of the literature refers to stray cats that are fed by humans in urban areas as feral cats.

Problems of feral cats in urban areas

Overpopulation

The feral cat is a sexually dimorphic species where males are larger than females (Nutter *et al.* 2004). Cats breed from as early as 5 months old and if not managed the cat population growth has the potential to increase exponentially (Turner 2000; Nutter *et al.* 2004b; Gunther *et al.* 2015). There are approximately 600 million domestic cats worldwide (Peterson *et al.* 2012) with an unknown number of feral cats. Although there are no documented counts for the number of cats in South Africa, Euromonitor International (2014) estimates 2.2 million cats and is increasing annually based on the annual sales of cat food. Large densities of cats exist in colonies that are regularly fed by a caregiver of which is frowned upon by some but accepted by others in urban areas (Tennent *et al.* 2010; Jones & Downs 2011; pers. obs.). Overpopulation of feral cats results in the dumping of unwanted kittens at these sites (Jones & Downs 2011). Thus, the cycle of breeding begins resulting in higher numbers of feral cats. Additionally, territorial and mating rituals produce noise pollution and in turn become a public and health nuisance by spraying on property (Gunther *et al.* 2015).

An alien invasive species

The feral cat has been nominated as among "100 of the World's Worst Invasive Alien Species" on the Global Invasive Species Database managed by the Invasive Species Specialist Group (ISSG) of the International Union for Conservation of Nature (IUCN) Species Survival Commission (SSC) (Lowe *et al.* 2000). Alien & Invasive Animals – a South African perspective places cats in every part of South Africa (Picker & Griffiths 2011). In South Africa it is classified as a Category 1a invader on offshore islands in the National List of Invasive Species obtained from the National Environmental Management: Biodiversity Act (NEMBA) (2014). Island ecosystems are especially vulnerable to introduced species due to high proportion of endemic and specialized species (Bonnaud *et al.* 2007). Another invasive concern of the domestic cat is that it can hybridise with the African wild cat (*Felis silvestris*) and contaminate the gene pool; however a recent study showed that African wild cat populations in South Africa were still pure (Le Roux *et al.* 2015).

The impact of cats on native wildlife

Cats are opportunistic hunters (Hutchings 2003). On average, most of the prey items of cats are small and prey weighing several kilograms are seldom caught. The average size of cat-prey in the review by Pearre and Maass (1998) was 41.2 g. The impact of feral cats on native fauna has been one of great controversy between conservation ecologists, animal welfare advocates and cat lovers of the world (Natoli *et al.* 1999). Undisputedly, globally feral cats have contributed to recent extinctions and endangerment of bird and small mammal species (Barratt 1995; Barratt 1998; Woods *et al.* 2003; Beckerman *et al.* 2007; Baker *et al.* 2008; Sims *et al.* 2008). Islands are worst affected by feral cats as cats directly feed on many endemic species (Nogales & Medina 1996; Bester *et al.* 2000; Bester *et al.* 2002). The effects of which are felt long after cats are removed. Predation rates of feral cats in South Africa have not been documented. Contrary to the negative effects on biodiversity on island ecosystems, feral cats in urban environments can feed on rodents at dumpsites (Childs 1986; Bradshaw *et al.* 1999; Brickner 2003). However, this raises another concern for disease transmission between feral cats, other wildlife and even humans.

There are numerous studies on the negative impacts of feral cats carried out worldwide including New Zealand (van Heezik *et al.* 2010), Australia (Dickman 1996; Meek

2003; Molsher *et al.* 2005; Doherty *et al.* 2015a,b), Europe (Liberg 1984; Woods *et al.* 2003; Baker *et al.* 2005; Baker & Harris 2007; Baker *et al.* 2008; Sims *et al.* 2008), the USA (Levy *et al.* 2003; Hawkins *et al.* 2004; Schmidt *et al.* 2007; Loss *et al.* 2013), and on islands (Konecny 1987; Nogales & Medina 1996; Bester *et al.* 2002; Courchamp *et al.* 2003; Nogales *et al.* 2004; Bonnaud *et al.* 2007; Harper 2007; Bonnaud *et al.* 2010; Algar *et al.* 2011; Medina *et al.* 2011; Duffy & Capece 2012; Medina *et al.* 2014; Bridges *et al.* 2015). A few studies on feral cats have been carried out despite the high levels of biodiversity in South Africa. Home range and public perceptions of feral cats living in an urban conservancy were studied (Tennent & Downs 2008; Tennent *et al.* 2009; Tennent *et al.* 2010). Despite the abundance of literature that reveals the adverse impacts of both feral and domestic cats on native populations of wildlife, this issue still remains a highly contentious and an emotive subject (Fitzgerald *et al.* 2007; Tennent *et al.* 2010; Macki 2011; Lloyd & Hernandez 2012).

Diseases in *Felis catus*

Free-roaming cats of any sort (feral, semi-feral, or owned) have the potential to spread diseases and parasites to other cats, humans and wildlife such as toxoplasmosis, Feline Leukemia Virus (FeLV) (Jessup 2004), Feline Immunodeficiency Virus (FIV), cat flu, fleas, ear mites, tapeworms and various other parasites (O'Connor *et al.* 1991; Levy & Crawford 2004; Schoeman *et al.* 2005). Toxoplasmosis is one of the most reported cases of cat diseases contracted by humans (Webster 2001; Akhtardanesh *et al.* 2010; Spada *et al.* 2012; Sukhumavasi *et al.* 2012). The cat is the only definitive host for spreading this disease (Nutter *et al.* 2004a; Cong *et al.* 2015). Rabies is another disease that can spread across species from dogs, to cats, to bats and humans (Gordon *et al.* 2004). Without adequate treatment death is inevitable. These diseases not only affect the physiology and health status of the cats but overall other individual cats and species living in the ecosystem (Lepczyk *et al.* 2015). Most diseases are spread through physical contact, territorial fights or from mother to kitten (Möstl *et al.* 2015). Some diseases are also spread via contamination of the environment (Möstl *et al.* 2015). So even if feral cats are removed, the disease can still surface long after. In context of an urban setting, previous studies reported higher cases of disease prevalence in urban feral cats than those in rural areas (Shelton *et al.* 1989; Muirden 2002; Spada *et al.* 2012; Sukhumavasi *et al.* 2012; Muchaamba *et al.* 2014; Möstl *et al.* 2015).

Problems and Rationale

Invasive species are widely recognized as a major cause of recent biodiversity loss (Vitousek *et al*. 1997; Wilcove *et al*. 1998; Mack *et al*. 2000), and are thought to be responsible for more than 20% of the recent extinctions of vertebrate species (Reid & Miller, 1989). Studies have documented extensive feral cat predation on a variety of wildlife species including native birds, amphibians, and small mammals (McChesney & Tershy, 1998; Nogales *et al*. 2004; Dickman, 2009; Faulquier *et al*. 2009). As a consequence feral cats impact on local wildlife and environment (Smith, 1999; Bergstrom et al. 2009; Dickman, 2009) causing financial, emotional and health burden to communities (Levy *et al*. 2003; Tennent *et al*. 2010). Studies on the impact and ecology of feral cats on wildlife in the urban mosaic are relatively few and need further investigation.

Feral cats constitute a major negative impact on animal welfare, public health, and wildlife (Wallace *et al*., 2006; Dickman, 2009; 2011). The predatory impact of feral cats on native fauna has long been recognised and more recently as playing a role in disease transmission (Obendorf & Munday, 1990; Dickman, 1993). Feral cats are generalists and adapt to prey-source availability including human food waste (Coman & Brunner, 1972). Management of feral cats in urban areas is important because they have potential negative impacts on both human and local wildlife populations (Tennent & Downs 2008; Tennent *et al*. 2009). The feral cat can survive on artificial or natural food resources (Genovesi 1995).

Feral cat populations should be evaluated a priori which requires basic understanding of their ecology to manage their populations. The negative effects and their wide distribution have resulted in the cat being included in the list of 100 worst invasive species (Low *et al.* 2001) and presently infesting ecosystems throughout the world (Bergstrom *et al*. 2009; Dickman, 2009). The measurement of this impact (Kays & Dewan, 2004) will enable us to distinguish invaders that cause minor effects from those with profound effects in order to prioritize management efforts in invaded sites and those facing potential invasion. Although the removal of feral cat is a powerful conservation tool, the lack of readily available information on feral cat spatial movement, predation ecology and their impact in urban environments are likely to inhibit future measures on this species. Since feral cats are presently unmanaged, and little is known about their ecology and behaviour in urban Pietermaritzburg (Tennent *et al*., 2009; 2010; Jones & Downs, 2011) this study aimed to highlight these important issues.

Objectives

This project covered various aspects to meet its main objectives:

- Telemetry studies using GPS-GSM-UHF tracking collars on feral cats determined their home range and habitat use in an urban mosaic gradient in Pietermaritzburg (Chapter 2).
- The prevalence of disease in feral cats was documented from blood samples collected from feral cats in and around Pietermaritzburg (Chapter 3).
- The results were then used to develop a management protocol for feral cats in urban Pietermaritzburg. This was an effort to propose effective and cost effective strategies to control feral cat populations here (Chapter 4).

Aims

The aim of this study was to investigate aspects of the ecology of the feral cat populations, focusing on their spatial ecology, disease occurrence; and possible management strategies in an urban mosaic gradient of Pietermaritzburg, KwaZulu-Natal, South Africa.

Thesis structure

The chapters of the thesis are prepared as manuscripts for submission to international peer review journals and so some overlap was unavoidable.

The City of Pietermaritzburg

The urban sprawl of Pietermaritzburg city (Msunduzi Local Municipality) of KwaZulu-Natal includes a formal city, residential areas, industrial suburbs and informal housing. The second largest city in KZN, it consists of 163 993 households with an estimated population of 618 536 (StatsSA, Census 2011). The telemetry study to document home range of feral cats was conducted in the urban district of Scottsville (6.1km^2), which occurs south of the central business district. The altitude of the study site is ≥2,056 m above sea level. The convenience and accessibility of a large size of feral cat population made this city an appropriate representative of other cities in South Africa. The city of Pietermaritzburg hosts a large number of established feral cat colonies in various suburbs of which have been monitored over the years by volunteers. Evidence of establishment of these colonies is unknown due to no formal record being documented. Dedicated volunteers belonging to the Feral Cat Feeding group of Pietermaritzburg have had to cope with colonies through a religious feeding and an ad hoc sterilization programme funded entirely from their own pockets (M. Vida; A. Beaumont, pers. comm.). Upon contacting the Feral Cat Feeding group many cats at the various feeding sites had not been sterilised so an agreement had been taken to sterilise all cats caught that were to be used in the study. Four study sites in Scottsville, Pietermaritzburg in an urban gradient were reclassified into three distinct habitat types consisting urban, green and private land types, depending on the level of urbanisation and natural green spaces that occurred within each habitat where feral were cats collared. Feral cats from eight other sites in and around the greater city of Pietermaritzburg were used for disease testing.

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CHAPTER 2

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

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Summary

1. Feral cats (*Felis catus*) are one of world's worst invasive species and continue to be increasing in population size, particularly in urban areas. The effects of changing land use especially urbanisation can alter distribution and behaviour of feral cats. Additionally, resource availability can influence home range and habitat usage of cats. Consequently we determined the home ranges and habitat usage of telemetered feral cats (n = 11) within an urban mosaic of Pietermaritzburg, KwaZulu-Natal, South Africa.
2. Using Global Positioning Satellite (GPS) transmitting collars feral cats were followed for six months at a fix rate of one location every 6h. Activity and movement data were compared based on home range size and habitat use at four study sites along an urban mosaic gradient of varying degrees of urbanization and green spaces. Minimum Convex Polygons (MCP) and Kernel Density Estimates (KDE) were used as home range estimators to determine home range size and core areas.
3. Home ranges for feral cats were small in urban areas. Mean 95 % MCP ± SE was 5.97 ± 1.49 ha. There was no significant difference in 95% MCP ± SE between male and female feral cats (male cats MCP 7.72 ± 1.93 ha, female MCP 3.86 ± 2.11 ha). Nocturnal home range and core areas were not significantly different.

4. Core ranges of feral cats were small (1.57 ± 0.60 ha, 50% KDE ± SE) with overlap. Preferred habitat use of feral cats was significantly different with most time spent in urban habitats over green; although green habitats were used more than what was available.
5. Feral cats showed individual variation in home ranges despite supplemental feeding in the urban mosaic. Generally supplemental resources were the primary driver of feral cats' home ranges as these feeding sites where within the core areas of the cats. Furthermore, the green habitat types were seldom used.

Key-words: Home range, habitat use, habitat selection, *Felis catus*, feral cat, free-roaming cats, invasive, radio-telemetry, urban ecology

Introduction

Urbanization has led to an influx of concentrated populations of humans and activity within a heterogeneous transformed landscape and with this follows ecological consequences such as habitat and species loss, and resulting human-wildlife conflicts (Bradley & Altizer 2007; Aguilar & Farnworth 2013). Urbanization 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 have had replacement of native species by alien invasive species occurring across a rural to urban gradient (Lepczyk *et al.* 2004; McKinney 2006; McKinney 2008; Shochat *et al.* 2010). Alien invasive species are able to adapt and persist in different ways utilising these altered landscapes to their advantage.

The feral cat (*Felis catus*) is considered as one of a 100 of the world's worst invasive alien species with populations generally increasing in urban environments worldwide (Jessup 2004; Gosling *et al.* 2013; Lepczyk *et al.* 2015). Humans have transported cats onto almost every continent (Driscoll *et al.* 2009; Lyons 2014). Descendants of the domestic cat, feral cats are born and live without human contact in a variety of ecosystems (Bradshaw *et al.* 1999). These self-sustaining populations can exploit a wide range of habitats that include forests, woodlands, grasslands, deserts, shrublands, glacial valleys, equatorial to sub-Antarctic islands and urban areas (Doherty *et al.* 2015). Feral cats are noted as mesopredators in urban areas and are generally increasing due to the lack of apex predators (Ritchie &

Johnson 2009). Coupled with its successful invasive potential to colonize a wide range of habitats, its high fecundity and its ability to acquire vital resources independently from surroundings; has allowed the feral cat populations to reach a state of overabundance in some areas, particularly in many urban areas (Calhoon & Haspel 1989; Gunther & Terkel 2002; Baker *et al.* 2005; Finkler *et al.* 2011). Irresponsible pet ownership leading to the birth of unwanted kittens and the dumping of kittens has also led to this increase (Collins 1976; Gunther & Terkel 2002; Levy *et al.* 2003; Looney *et al.* 2008; Longcore *et al.* 2009). Feral cats in urban areas sometimes become a public nuisance by spraying and defecating in gardens (Remfry 1996). Additionally, feral cats also raise public health concerns 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). Further negative impacts include feral cats directly predating on native wildlife which include small mammals, birds and reptiles of which detrimental numbers have been recorded in previous studies (Woods *et al.* 2003; Natoli *et al.* 2006; Dauphiné & Cooper 2009; Duffy & Capece 2012). On the contrary, cat predation may be beneficial in urban areas and at dumpsites where pest species such as vermin, rats and mice occur in abundance (Thomas *et al.* 2014).

Feral cats are described in the literature as pet cats or stray cats that were abandoned and have reverted to a 'wild' like state adopting a free-living lifestyle that can survive in an ecosystem for many generations without human interaction (Remfry 1996; Bradshaw *et al.* 1999; Gosling *et al.* 2013). They can live solitary or in groups called colonies congregated at common food resources available at dumpsites, restaurants or shopping malls in urban areas (Putman & Putman 1989; Turner 2000). Populations of feral cats can display contrasting degrees of dependence on humans (Liberg *et al.* 2000). Feral cats are mainly crepuscular and nocturnal (Barratt 1997). In context of this study we denote feral cats as unowned cats ranging freely outdoors with little or no socialization to humans, which can receive supplemental feeding or not. In South Africa, feral cat colonies have been established in most major cities (pers. obs.). The distribution of resources such as food, shelter and reproductive mates can influence cat abundance and densities; and its overall spatial ecology (Liberg *et al.* 2000). There are approximately 2.2 million pet cats in South Africa (Euromonitor International, 2014) and no recorded documented data on the population of feral cats. With high densities of feral cat populations occurring in condensed and fragmented green spaces in an urban setting, several of the factors mentioned above can benefit managers with the use of movement data; in understanding feral cat populations through its spatial ecology.

Feral cat home ranges from rural and urban areas have been extensively researched across the globe in the USA (Hall *et al.* 2000), UK (Thomas *et al.* 2014), Australia (Edwards *et al.* 2001; Molsher *et al.* 2005) and New Zealand (Fitzgerald & Karl 1986; Langham & Porter 1991; Harper 2007; Recio *et al.* 2010). For many years the use the traditional method of Very-High-Frequency (VHF) radio transmitters were used to study the spatial ecology of mammals to assist managers and wildlife scientists to plan and implement effective management practises (White & Garrott 2012). The use of Global Positioning System (GPS) has allowed for wildlife radio tracking to be simpler, effective and user friendly (Hansen & Riggs 2008; Recio *et al.* 2010). Additionally, there is less physical engagement by a human researcher which reduces the act of tracking and disturbing the animal in study (Hansen & Riggs 2008). The use of this technological advancement in telemetry studies has developed smaller and lighter receiver units useful for body sizes like the cat (Hansen & Riggs 2008). This is the first study in South Africa to use a GPS tracking collar on feral cats.

There is little research on the home range and habitat use of feral cats in urban environments of South Africa. Consequently, the main aim of this study was to determine the home ranges and habitat usage of GPS collared feral cats within an urban mosaic. Habitat use and movement patterns between sexes, and day and night were compared, and habitat types and selection within an urban area were also determined. This study is of importance since it provides evidence on an invasive species in answering key ecological questions which are specific to urbanization. It was predicted that home ranges would be influenced by the level of urbanization and resource availability such as food and shelter. The sexes, as well as day and night differences between feral cats in urban areas were predicted to be different. It was also expected that time of day could influence home ranges when human activity was low. The objectives of this study were to understand movement patterns, habitat selection and behaviour of feral cats across in the urban mosaic with varying degrees of urban and green habitat types.

Methods

STUDY SITES

The study was carried out in Pietermaritzburg, South Africa (Fig. 1) (S29.642; E30.413). Feral cats to be collared were selected from areas with known feral cat populations. The study sites were then chosen in urban mosaics which were reclassified into three distinct categories urban, private, and natural based on the level of urbanisation and natural green spaces that occurred within the area. Seven cats were trapped from established feral cat colonies occurring at the Pietermaritzburg Airport, University of KwaZulu-Natal Main Campus and the Golden Horse Casino, respectively. These colonies were managed by the Feral Cat Feeding Group of Pietermaritzburg with an ongoing feeding and an ad hoc sterilization programme. Feral cats are regularly fed by a caregiver 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. These feral cats relied on acquiring food from their environment as there were no existing supplementary feeding sites. We observed cats nearby existing dumpsters hence trapped these cats in this locality.

TRAPPING AND COLLARING

In order to gain comprehensive movement data and habitat use of feral cats in Pietermaritzburg, eleven cats (6M 5F) were trapped, immobilized and fitted with a radio-collar (Animal Ethics Permit gained from UKZN (019/14/animal). Trapping took place between May and October 2014 usually in the early evenings as feral cats are generally crepuscular (Barratt 1997). Eight one-sided, open door live traps (35 x 40 x 60 cm) were used on a rotational basis during the study. The traps were baited with Lucky Pet™ tinned fish and CatNip and camouflaged against a wall or dustbin to maximise trapping effort. Cats that had an identification pet collar were not used for the study as these were considered owned cats and released. Dark blankets were used to cover traps once the cats were captured. All captured cats were anaesthetized by a veterinarian using with a combination of 0.2 ml/2kg Ketamine® and Domitor® (medetomidine hydrochloride) which was injected intramuscularly. The effects of which were reversed using Antisedan® (atipamezole hydrochloride). Each of the anaesthetized cats was aged, sexed, weighed, measured, and its body condition recorded. The cats were judged to be adults by the presence of large canine teeth and body size and were given to an accuracy of one year, or even to half a year for analysis only. Additionally cats caught, that was not previously sterilized, were neutered or spayed by the veterinarian because of agreement with the Feral Cat Feeding group of Pietermaritzburg that manages the welfare of the feral cats. Cats had their left ear tip removed as the universal sign that the cat had been sterilized and to avoid retrapping in the future. All cats both males and females that had undergone surgery through sterilizations were kept overnight at the Animal House Facility at the University of KwaZulu-Natal (UKZN) and released the day following the procedure.

Once anaesthetized, cats were fitted with GPS-GSM-UHF tracking collars (Wireless Wildlife, Pretoria) secured with an adjustable break-away material collar, weighing 50 g. The mass of collar was less than 2% of the body mass of adult cats which is below the recommended range of 3-5% of body mass without causing interference to normal activity or injury to an animal (Kenward 2000; Coughlin & van Heezik 2015). Due to unpredictable trapping success it was not possible to collar all cats simultaneously at a specific site or time for the study period therefore number of cats varied at sites. All cats were monitored until full consciousness and released back at their site of capture. The total collaring procedure took an average of 30 minutes to complete. Cat locations fixed every 6 h on a pre-set schedule were downloaded to UHF receiver using a solar powered base station which was placed at the highest point of each locality of the study sites on a rotational bases. Although, when unable to get a signal, GPS fixes would not record until a signal was re-established. GPS fixes were converted for use in ArcMap 9.3.1 (ESRI, Redlands, California, USA) which allowed us to clean the data and analyse it. Unusual points that were considered outliers not within the area of the cats' maximum home range and duplicated location points were removed manually. Each location was classified as day or night, calculated using the daily diurnal times, 8h00 and 14h00, and nocturnal times, 20h00 and 2h00, which was the pre-set times of the collars.

HOME RANGE ESTIMATION

Radio tracking gives detailed information on movements and home ranges of individual species (Kenward 2000). Originally Burt (1943) defined home range as the utilization distribution of an individual and more precisely where and how much time an animal spends in a particular habitat. The area in which an animal's home range usually comprises food, shelter and reproductivity success (Burt 1943). More recent kernel density information obtained from home range and habitat use became essential in designing efficient management studies of an alien invasive species like the feral cat. Data extracted can serve as a reference point to predict movement, densities and future impacts of the species and identify possible effects on native species in the urban environment (Doherty *et al.* 2015).

Home range estimates for feral cats were determined using the Home Range Extension (Rodgers *et al.* 2007) in ArcMap. Minimum Convex Polygon (MCP) is one of the extensively used methods to estimate home range area in cat studies (Seaman *et al.* 1999; Tennent & Downs 2008; Thomas *et al.* 2014). The fixed MCP was constructed for 100, 95 and 50% polygons. To determine the core areas used by each cat a fixed Kernel Density Estimator (KDE) was used to calculate 95, 90 and 50% contours using the reference bandwidth as the smoothing factor. Smoothing parameters (*h*) ranged from 8.83 – 53.02. KDEs are considered one of the more reliable methods for home range analysis and so were used for this study (Worton 1989; Seaman & Powell 1996; Kenward 2000). MCPs and KDEs were calculated for each cat as well as for day and night. The means ± standard errors were reported. The 95% MCPs and 50% KDEs were computed onto layers for Pietermaritzburg and exported as maps for visual comparisons showing overlapping 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 home ranges and core areas utilised by feral cats. The 95% polygons used as total home range area, and the 50% kernels were used in statistical analysis as these determined the core areas that are widely used by feral cats. Factorial ANOVAS were used to determine differences between day and night amongst sexes. A paired sample t-test was used to determine any differences of GPS fixes during the day and night, of the total percentages recorded for the 50% KDE core area used by feral cats. GLM ANOVAS were run to test for significant differences in home range size and core range size produced by MCPs and KDEs. All mean values were presented as mean ± standard error and significance was assessed at a P value of 0.05.

HABITAT SELECTION

Each site where feral cats were caught was reclassified according to the amount of green, urban and private areas that occurred within a 20m by 20m grid overlaid onto Google Earth. The resolution of which was adequate in differentiating the different habitat types. This size grid deemed necessary since the feral cat home ranges were relatively small. 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 usage 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 is computed and the preference/avoidance is tested for each habitat, where 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 males, 5 females) from four locations around urban areas of Pietermaritzburg (Appendix 1) were determined for the study period between May 2014 and March 2015. The mean age of the cats collared was 2.6 ± 0.5 years with mean body mass 4.05 ± 0.35 kg (Appendix 1). The number of GPS fixes recorded for each cat varied because of the inability to obtain a location via the base station and satellite due to obstruction of high rise buildings, trees or at any time the cats went into hiding under buildings, manholes and drainage. Additionally, collars began to lose power over time and eventually failed (Appendix 1). A total of 2686 GPS locations were recorded during the duration of the study. Collared cats with mean number of locations were 244.18 ± 32.09, (range 100 – 427).

TOTAL HOME RANGE AND HABITAT USE

The mean home range size for all feral cats using 95% MCP was 5.97 ± 1.49 ha (Table 1, Appendix 2). The mean core range size for all feral cats using 50% KDE was 1.57 ± 0.60 ha (Table 2). Male feral cats had larger home range sizes (7.72 ± 1.93 ha) than females (3.86 ±

2.11 ha) for 95% MCP (Table 1, Appendix 2) with no significant difference between sexes (ANOVA, $F_{(1,9)}$ = 1.8167, P = 0.210, Fig. 2a). Core area (50 % KDE) used by male feral cats were generally larger (2.31 ± 0.78 ha) than females (0.69 ± 0.85 ha) but not significantly different between the sexes (ANOVA, $F_{(1, 9)}$ = 1.96, P = 0.195, Fig. 2b).

There were no significant differences between day and night MCP home ranges of feral cats in urban Pietermaritzburg (ANOVA, $F_{(1, 20)}$ = 2.61, P = 0.122). However, night 95% MCP home ranges (4.59 ± 0.97 ha) were generally larger than day 95% MCP home ranges (2.37 ± 0.97 ha). The mean diurnal and nocturnal home range sizes using 95% MCP for male feral cats were generally much larger at night (5.80 ± 1.30 ha) than during the day (2.94 ± 1.30 ha). Similarly female feral cats generally had larger night 95% MCP home ranges (3.13 ± 1.43 ha) than during the day (1.68 ± 1.43 ha). However, there were no significant differences between diurnal and nocturnal home range between sexes for 95% MCP (ANOVA, $F_{(1, 18)}$ = 0.259, P = 0.617, Fig. 3a). Feral male core areas, 50% KDEs were also generally larger at night (2.39 ± 0.72 ha) than during the day (1.40 ± 0.72 ha). Similarly females core areas at night (1.18 ± 0.79 ha) were generally larger than during the day (0.944 ± 0.79 ha). However, there were no significant differences between diurnal and nocturnal times between sexes of the 50% kernels (ANOVA, $F_{(1, 18)}$ = 0.242, P = 0.629, Fig. 3b). Overall males generally had larger home ranges and used larger core areas than females during the day and at night. However, there were no significant differences in home range sizes and core range sizes produced by MCPs and KDEs for male and female feral cats (GLM ANOVA, $F_{(6, 4)}$ = 0.793, P = 0.62). However, there was a significant difference of percentage GPS locations recorded during day than at night for the core areas used by feral cats (t-test, $t_{(8, 9)}$ = 3.134, P = 0.013, Fig. 4). Cats C5 and C10 were not used for this analysis as there was insufficient data to calculate KDEs, however comparisons were made using the MCP analysis. The quantitative analyses of sterilisation status were not conducted because all cats had been intact prior to the study so no differences could be made. Furthermore, no seasonal comparisons were conducted because of different collaring times during the year and the failure of collars.

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 3-6). 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 2). The Pietermaritzburg Airport having three cats collared, showed considerable overlap of home ranges of similar size (Table 1). All these cats shared the same core area which included one permanent feeding site and a sleeping area (the hangar) (Appendix 3). It was established that percentage of GPS fixes during the day were greater than at night in the core area. The female cat was inclined to stay within the airport, carpark and surroundings. The males expanded their ranges in opposite directions of the airport but still maintained similar overlap in home and core ranges. Male cat C1 moved into the grassland beyond the airport strip and C3 moved into the nearby residential area of Oribi Village (Appendix 3).

UKZN Main Campus collared feral cats were part of the largest colony of feral cats in this study with three permanent feeding sites. Feral cats C4 and C5 were two male cats with relatively small home ranges, core areas and overlapping home ranges (Tables 1 and 2) feeding at the same feeding site and were assumed to be brothers (Appendix 4). Female cats C6 and C7 fed at another feeding site on the campus grounds near the student residences and did not have any overlapping home or core ranges. Female cat C8 was a feral cat collared outside the campus that had a much larger home range compared with the campus cats. C8 moved actively into the Scottsville Mall and into a block of flats which was within the core area, possibly acquiring food from the dumpster (Appendix 4). The percentage of GPS fixes at night was higher than day fixes for C8. The campus cats GPS fixes within the core area were notably greater during the day than at night.

The male feral cat 9CC from the Golden Horse Casino was collared for three months as the collar had to be removed because of a skin infection acquired during the study. The cat was treated by a veterinarian and released. Data attained from this collared cat was sufficient to be included for the analysis. Although this feral cat was fed daily, every morning by a caregiver, 9CC would disappear for days and will suddenly appear at the feeding site. This was noted when we tried to re-trap the cat in order to remove the collar. 9CC had the largest home and core ranges from all feral cats in this study (Table 1 and 2). The core area of the cat included a large residential area and the edge of the horse racing track at the casino (Appendix 5). GPS fixes recorded in core areas were higher during the day than at night.

Two feral cats were collared at the Maritzburg Golf Course. Day home ranges of both feral cats had some overlap particularly around the dumpster outside the restaurant and along the footpath (Appendix 6). On the other hand, female C10 had the largest day home range from all female cats collared in this study, including the male C9 in this study site (Table 3). C9 had the smallest core area during the day over all the male cats. C10 used the same core area during day and night. C9 and C10 used contrasting core areas during the night when compared to each other but overlapped during the day (Appendix 6). C9 had different core area for the day alongside the trees on the footpath. C9 at night occurred within the vicinity of the dumpster and had a particularly larger range alongside the golf course and in the residential area which consisted of gated simplexes. Both feral cats often crossed the main road regularly. GPS fixes recorded in core areas were generally higher during the day than at night.

HABITAT SELECTION

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

Discussion

Our results describe unowned, free-roaming, feral cat movements in an urban environment of Pietermaritzburg which contained a mosaic of urban, green and private habitat types. The current study mean home range sizes (8.8 ha 100% MCP) and core sizes (1.57 ha 50% KDE) were relatively small when compared with previous studies. Feral cat home range varies from country to country 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 & Downs 2008). Genovesi *et al.* (1995) showed that feral cats living in greener areas have low densities and much larger home ranges than high density cats in urban areas. This study observed cats in greener areas having larger home ranges than cats occurring in densely urban areas; 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 95% kernels for males as 1418 ha and for females as 772 ha (Goltz *et al.* 2008) which was extensively larger when compared to this study.

The current study showed that gender had no influence on home ranges and core areas of feral cats but generally showed larger ranges for males than female feral cats which are conclusive with several other studies (Kays & DeWan 2004; Schmidt *et al.* 2007; Horn *et al.* 2011; Bengsen *et al.* 2012; Thomas *et al.* 2014). However, some studies have shown that gender can have an effect home range size (Haspel & Calhoon 1993). These findings highlight the variability that can be found across feral cats that occur in different areas 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, could account for no effects between sexes since potential mates are within reach. In the current study, this is 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. We could not test the effects of sterilization on feral cats. Studies have shown that intact males and females have larger home range size compared with sterilized cats (Kitts-Morgan *et al.* 2015). However, some studies showed no significant differences of sterilization against adult feral cats (Tennent & Downs 2008; Guttilla & Stapp 2010; Bengsen *et al.* 2015).

There were no significant differences between day and night home and core ranges of cats. Night home ranges were generally larger than day suggesting that cats moved further when human activity was low. 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 human and urban activity (per. obs.) also favoured cat movement at night. Feral cat C8, a female, was the only cat to have larger GPS fixes during the day than at night.

The mean core range distributions for all feral cats in this study were generally very small (1.57 ± 0.60 ha) and largely centred over 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 female 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 & Stapp 2010). Feral cats that receive little or no food from humans can hunt as up to four times more than domestic cats (Kays & DeWan 2004). Thus supplemental feeding could reduce this, however this was not documented. Feral cats that received no formal supplemental feeding had high home ranges over the cats that were not 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 for male feral cats in this study.

In our study, feral cats of habitat type preference located their home ranges in areas with more urban and/or private habitat types. Green areas were available in the urban mosaic but were not selected by feral cats as green habitat type was an observable small area. When cats did use the green habitats they used more of the area than was 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 types (Hutchings 2003; Horn *et al.* 2011). The role of predator avoidance in habitat selection by cats is unknown as we did not predict this. Most probably, food resources provided directly or indirectly by humans were exploited by all feral cats (Schmidt *et al.* 2007). Therefore it may be an effort to hunt for food in the green habitats and cats would rather acquire food from the residential areas or in garbage waste and dumpsters, similarly as found in other studies (Coman & Brunner 1972; Calhoon & Haspel 1989; Bradshaw *et al.* 1999; Brickner 2003; Hutchings 2003). This study highlights that cats will prefer built up areas over the green areas. There is no clear understanding as what 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 sterilised there will be too many individuals per a site which impacts the environment as a whole. Increased cat fights, spraying and defecating on public property will result in health risks to humans and other wildlife (Lepczyk *et al.* 2015). Disease transmission between individual cats is at a greater likelihood of spreading diseases in large colonies and can even spread to domestic pet cats (Möstl *et al.* 2015). (See Chapter 3)

In urban areas there is generally an abundance and concentration of food resources resulting in cats generally having increased densities and decreased ranges (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, cats will also tend to congregate in those areas (pers. obs.). Calhoon and Haspel (1989) found that cat densities were affected by shelter in the form of abandoned buildings rather than supplemental feeding. Feral cats are often seen seeking refuge under campus buildings, the hangar and abandoned areas at the casino and golf course, avoiding humans during the day and emerging at night (pers. obs.).

Feral cats in the current study selected urban areas since food resources were more easily available and accessible at supplemental feeding sites 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. Due to varying home ranges when compared to other studies, mitigation programmes to control population sizes need to be specific to local landscape level in urban areas of Pietermaritzburg.

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Figure legends

Fig. 1. Aerial photograph of cats collared in four study sites (orange boxes) inclusive of varying degrees of urbanised and green areas in Pietermaritzburg. Green dots indicate permanent feral cat colony feeding sites.

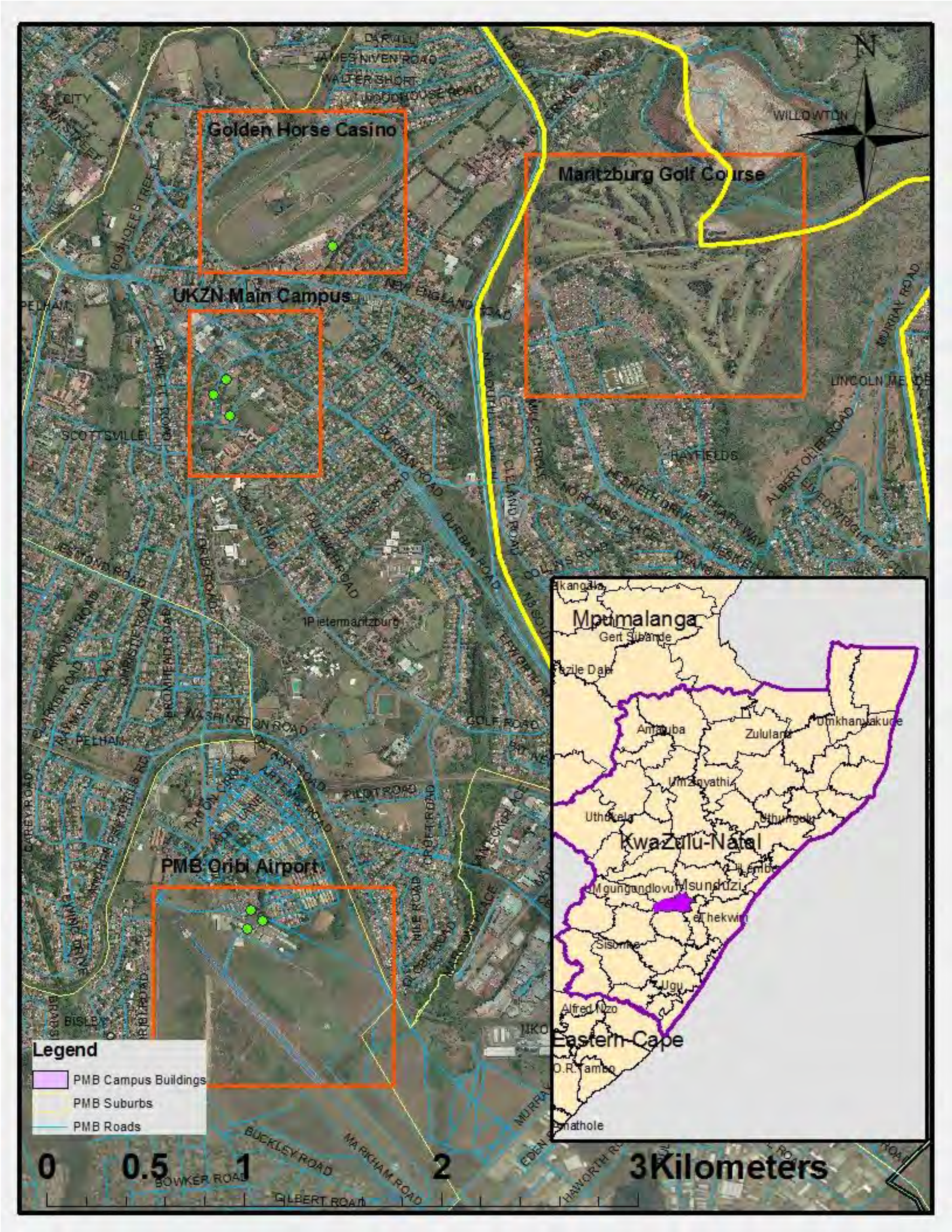
Fig. 2. Mean (± SE) a) 95% MCP home range and b) 50% KDE core range of male (n = 6) and female (n = 5) feral cats tracked in urban areas of Pietermaritzburg.

Fig. 3. Mean (± SE) day and night a) 95% MCP home range and b) 50% KDE core range of male (n = 6) and female (n = 5) feral cats in urban areas of Pietermaritzburg.

Fig. 4. Percentage of GPS fixes recorded for feral cats (n = 9) during day and night respectively in core areas (50% KDE).

Fig. 5. 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 urban Pietermaritzburg.

Fig. 6. Mean (± SE) percentage of habitat used and habitat available of feral cats (n = 11) in urban Pietermaritzburg.



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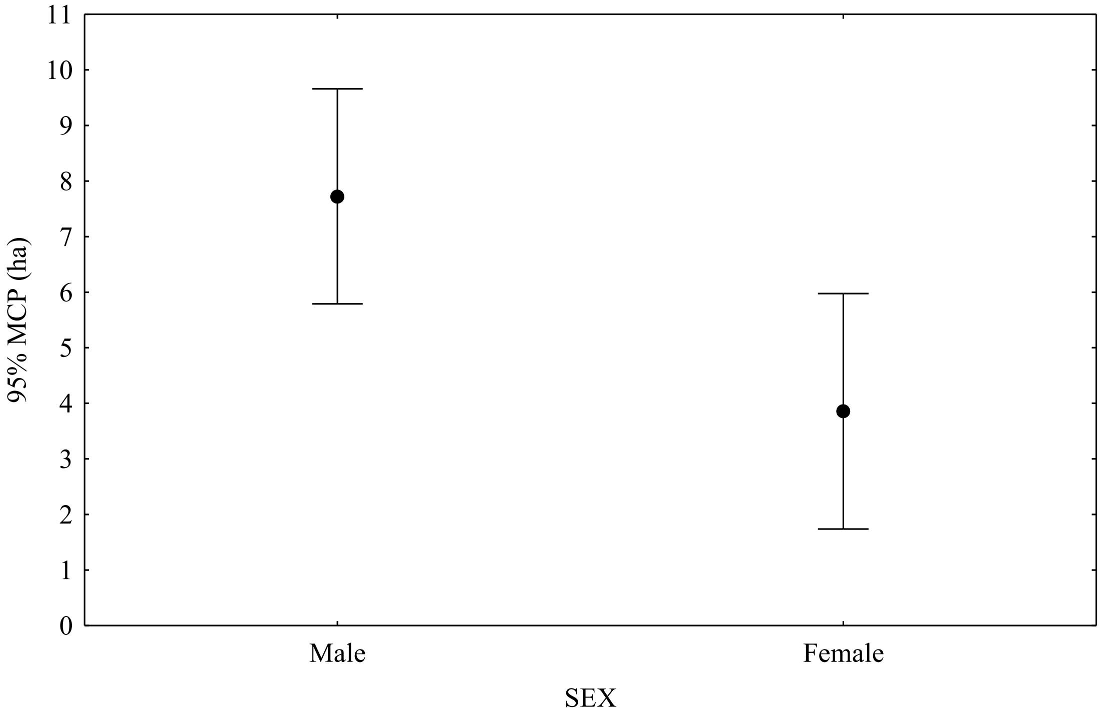
a)



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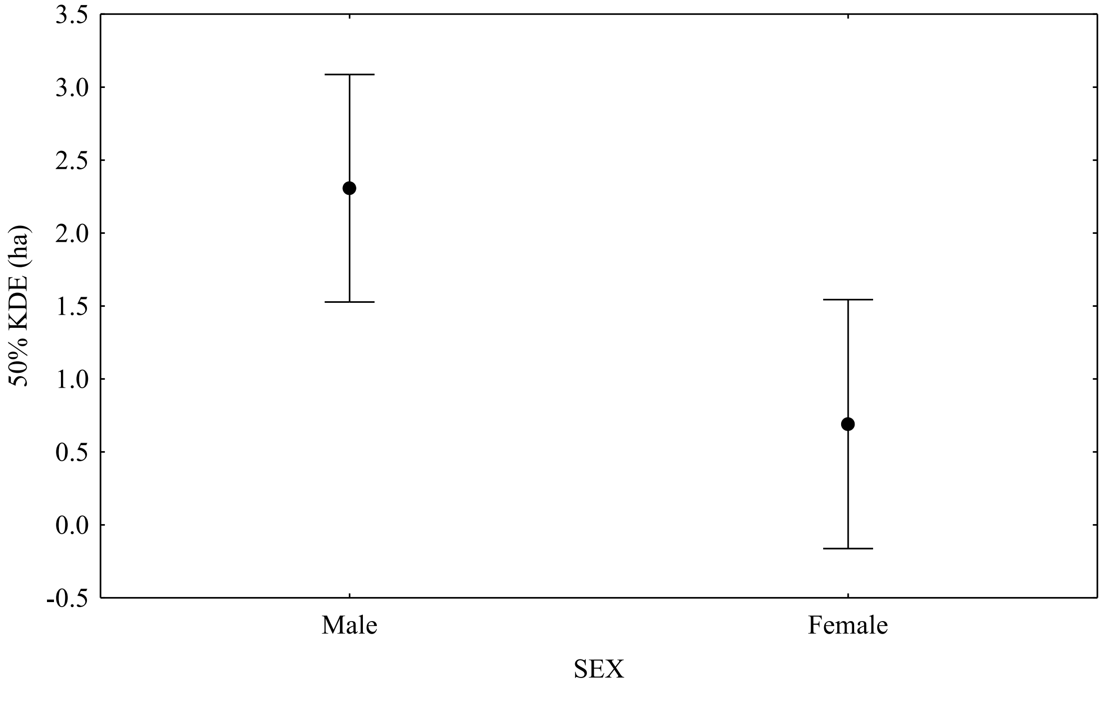

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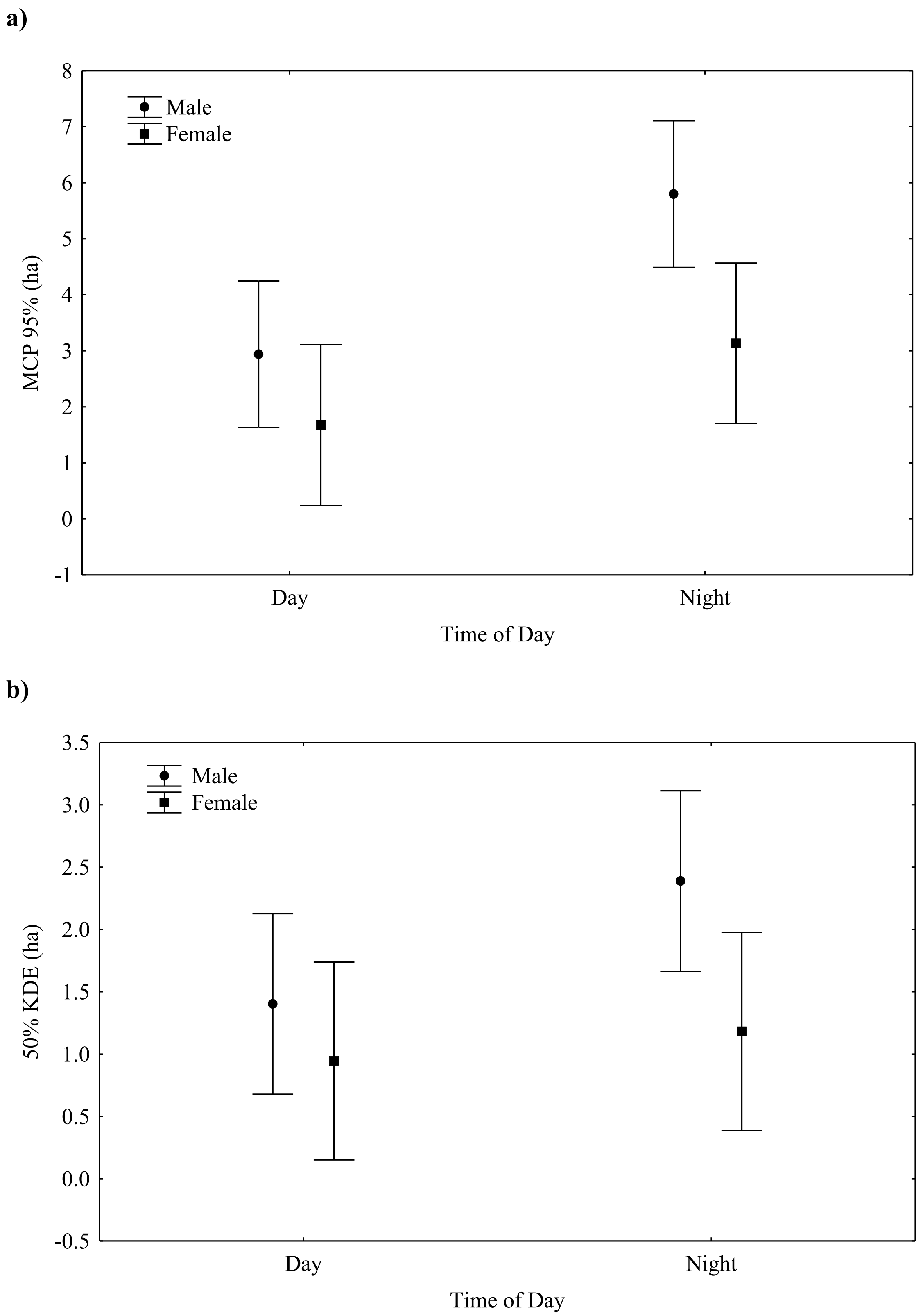

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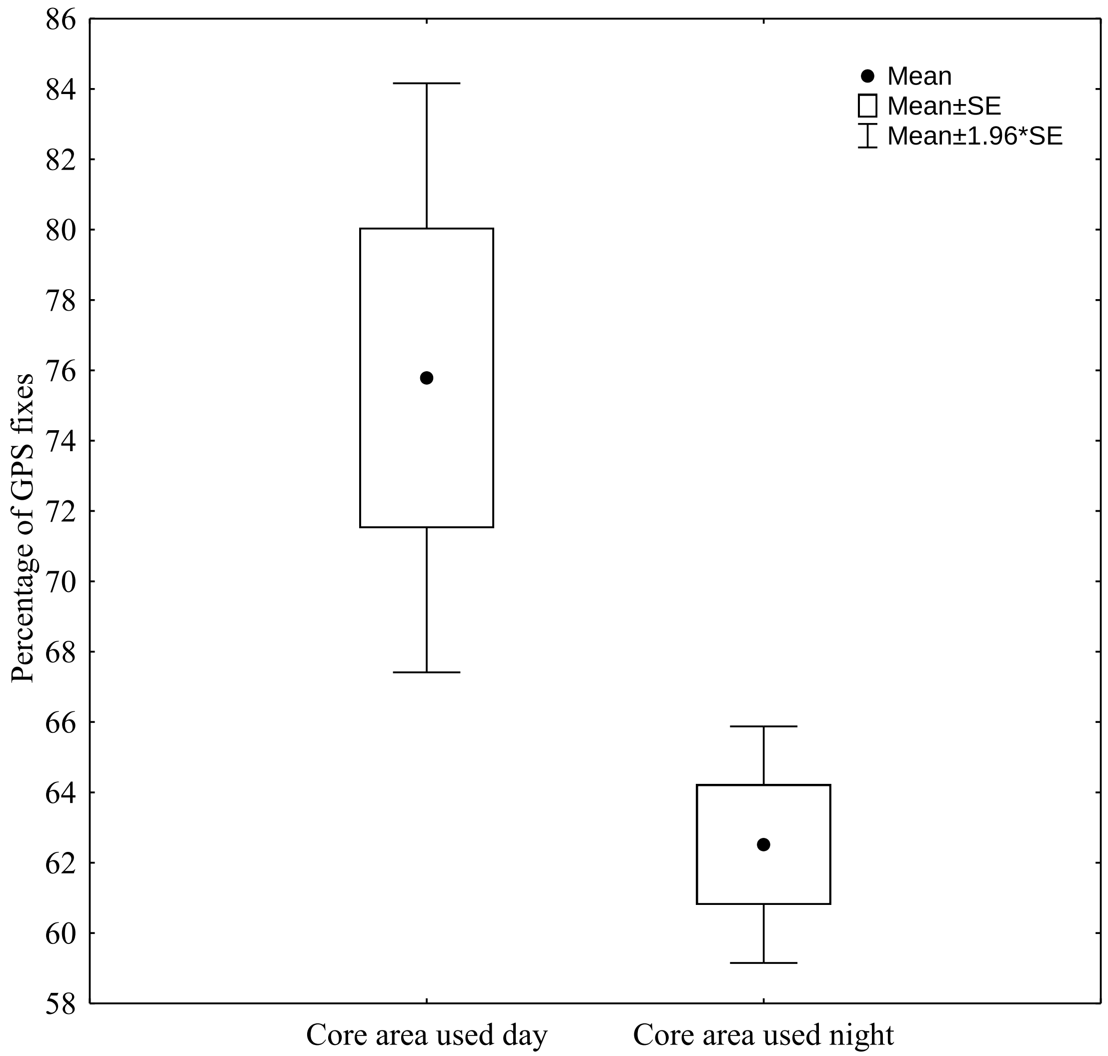

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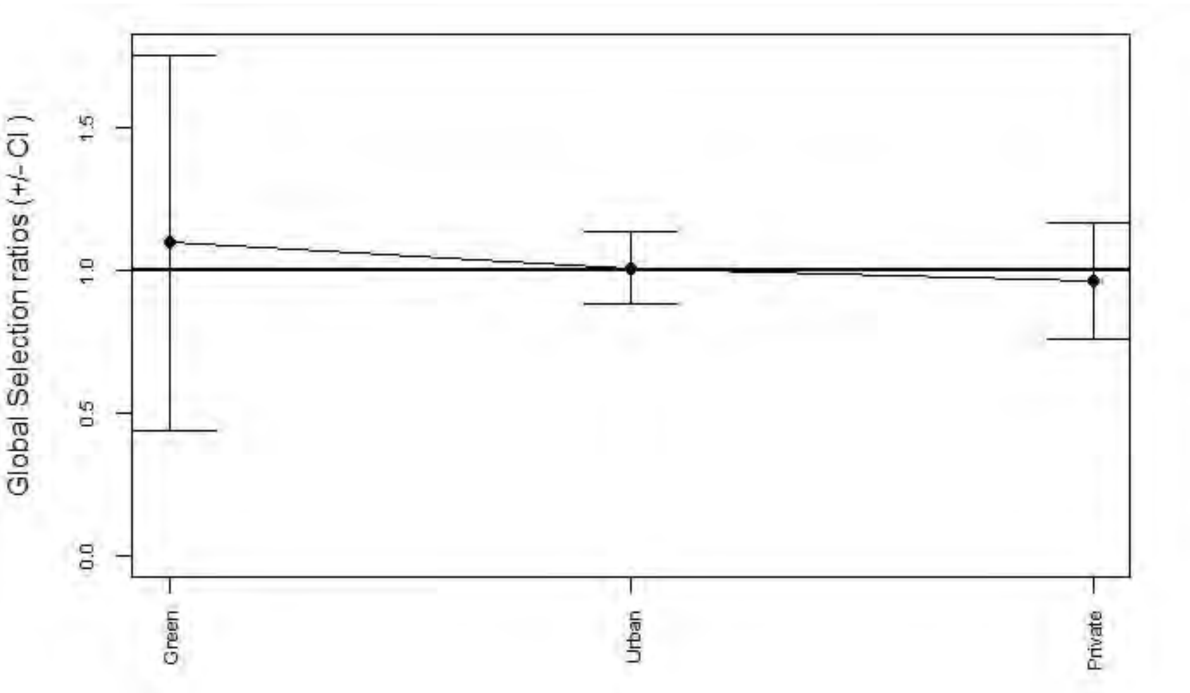
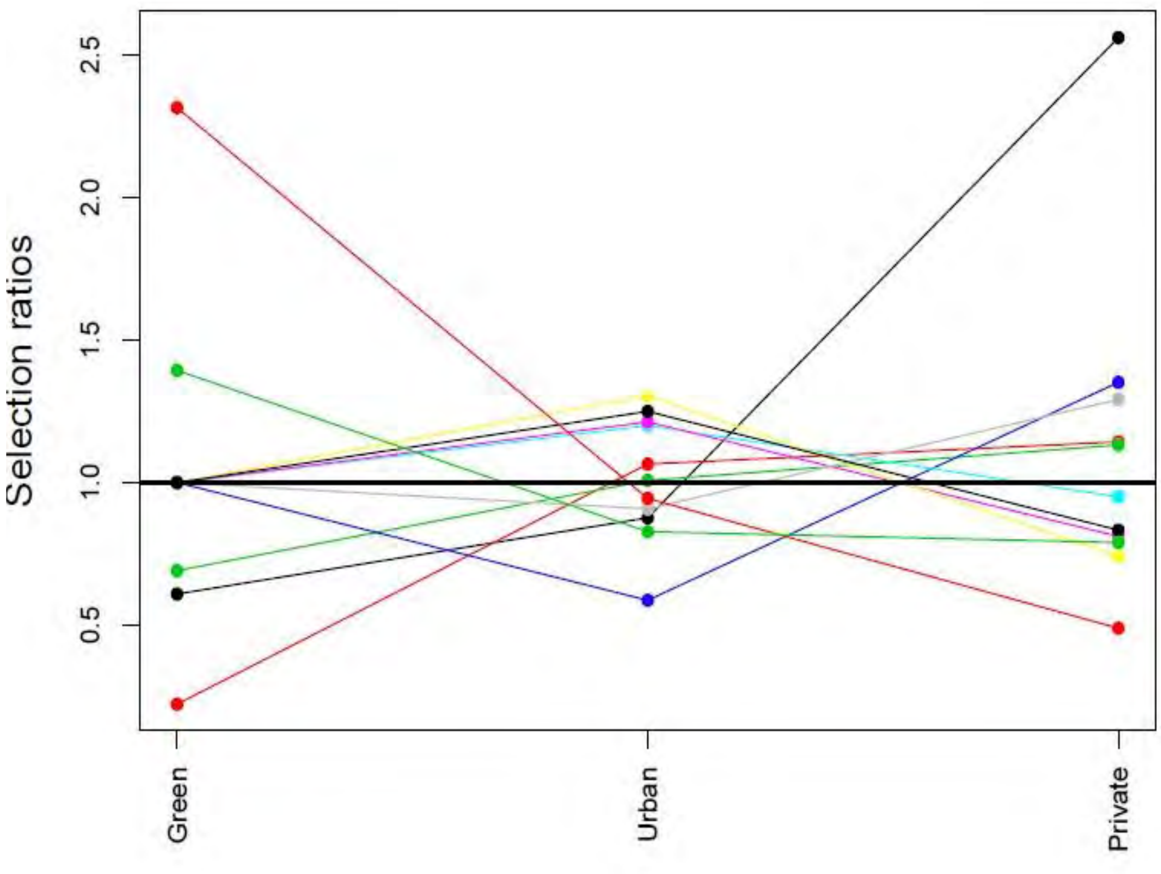
a)



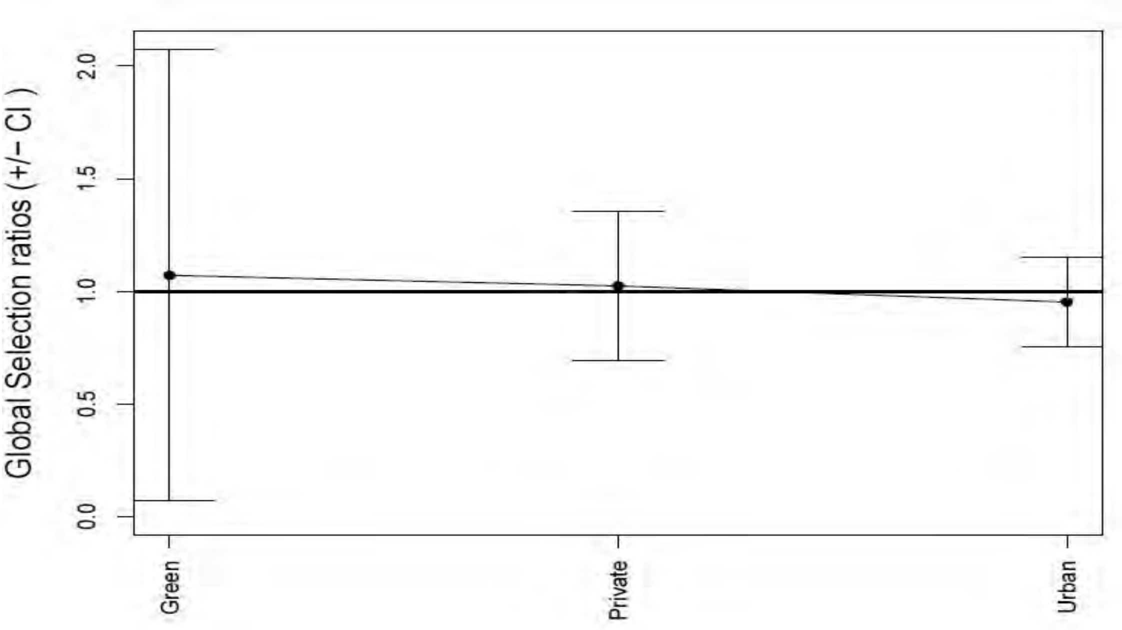
Global Selection ratios (+/- CI)
0.0
0.5
1.0
1.5
Green
Urban
Private

b)

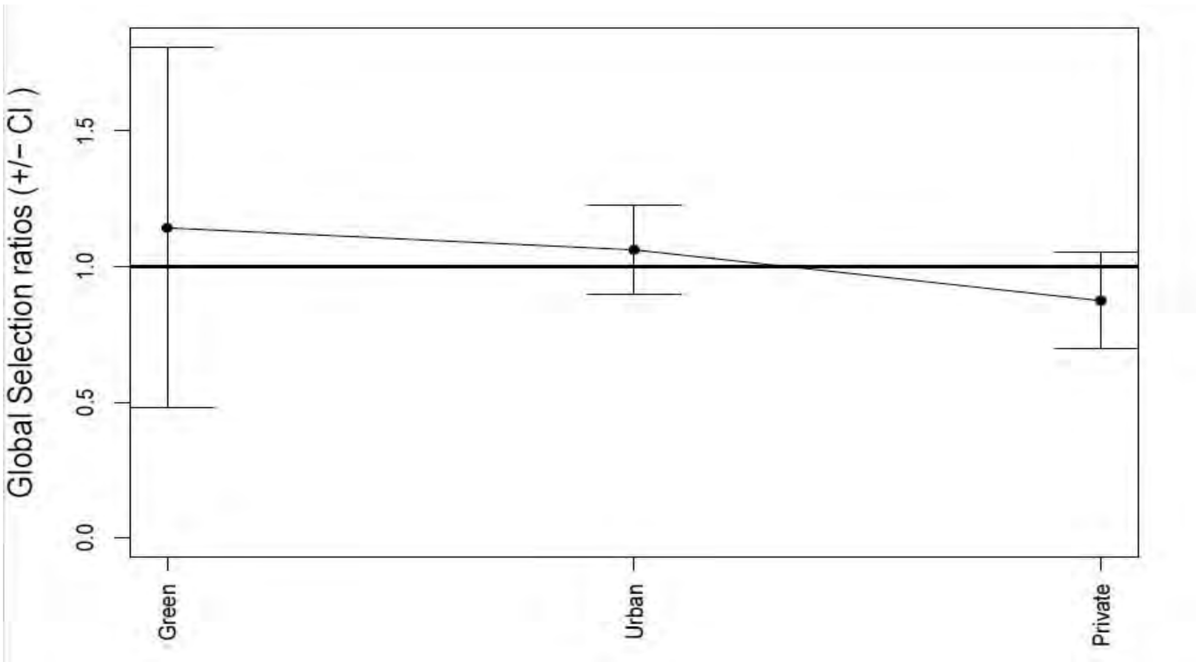


Selection ratios
0.5
1.0
1.5
2.0
2.5
Green
Urban
Private

c)



d)



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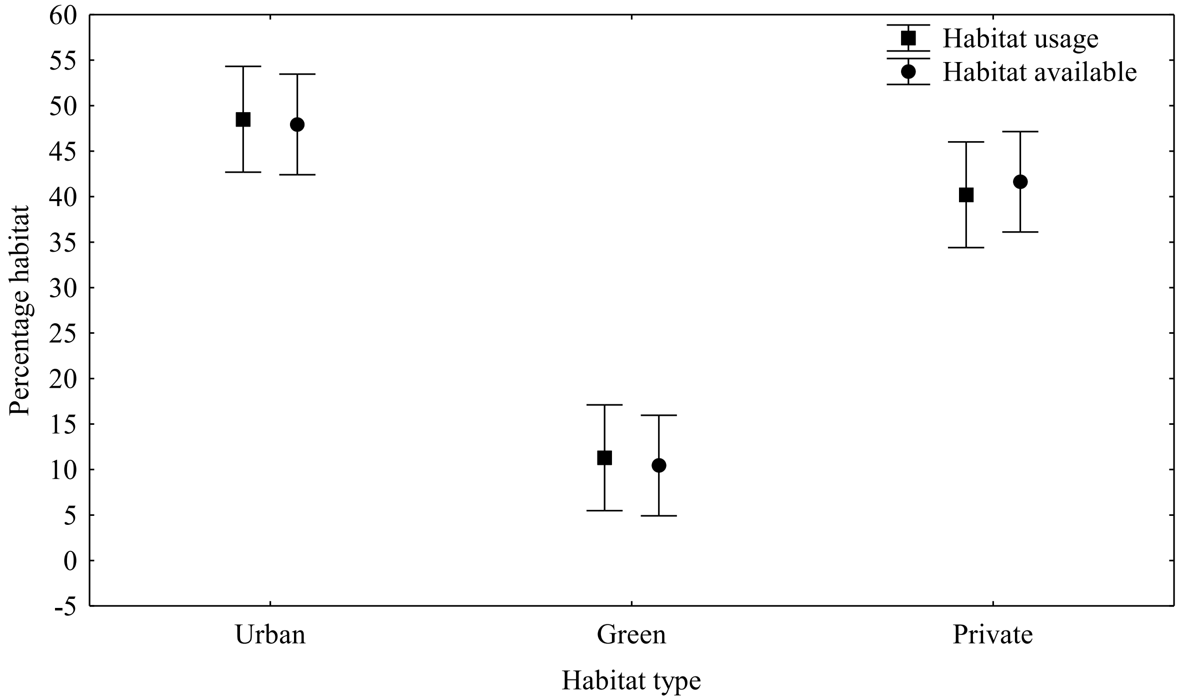


Fig. 6. Mean (± SE) percentage of habitat used and habitat available of feral cats (n = 11) in urban Pietermaritzburg.

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

Cat ID	Location	Age (years)	Sex	100% MCP (ha)	95% MCP (ha)	50% MCP (ha)
C1	Airport	6	M	12.38	6.65	2.25
C2	Airport	3	F	8.64	6.16	0.32
C3	Airport	3	M	9.79	7.75	1.30
C4	Main Campus	2.5	M	3.21	1.48	0.21
C5	Main Campus	2.5	M	1.13	0.94	0.12
C6	Main Campus	1	F	2.12	1.68	0.29
C7	Main Campus	1.5	F	4.21	3.50	1.44
C8	INR Checkers	1	F	4.76	2.50	0.63
9CC	Casino	5	M	17.64	13.72	4.49
C9	Maritzburg Golf Course	1	M	27.02	15.81	1.85
C10	Maritzburg Golf Course	4	F	5.87	5.44	2.36
MEAN		**2.77**		**8.80**	**5.97**	**1.39**

Table 2. Core home ranges of feral cats (n = 11) in Pietermaritzburg 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. (M = male, F = female).

Cat ID	**Age (years)**	**Sex**	**GPS fixes**	***h***	**95 % kernel (ha)**	**90 % kernel (ha)**	**50 % kernel (ha)**
C1	6	M	427	26.97	8.57	6.05	1.78
C2	3	F	256	19.68	5.50	3.35	0.53
C3	3	M	365	26.21	9.05	6.83	1.89
C4	2.5	M	360	n/a	n/a	n/a	n/a
C5	2.5	M	266	8.83	1.10	0.84	0.18
C6	1	F	214	12.80	2.13	1.63	0.38
C7	1.5	F	100	27.23	6.45	5.17	1.70
C8	1	F	251	17.12	3.90	2.88	0.85
9CC	5	M	129	53.03	25.08	20.03	6.79
C9	1	M	188	45.74	23.15	16.36	3.20
C10	4	F	130	n/a	n/a	n/a	n/a
MEAN	**2.77**		**244.18**	**21.60**	**7.72**	**5.74**	**1.57**

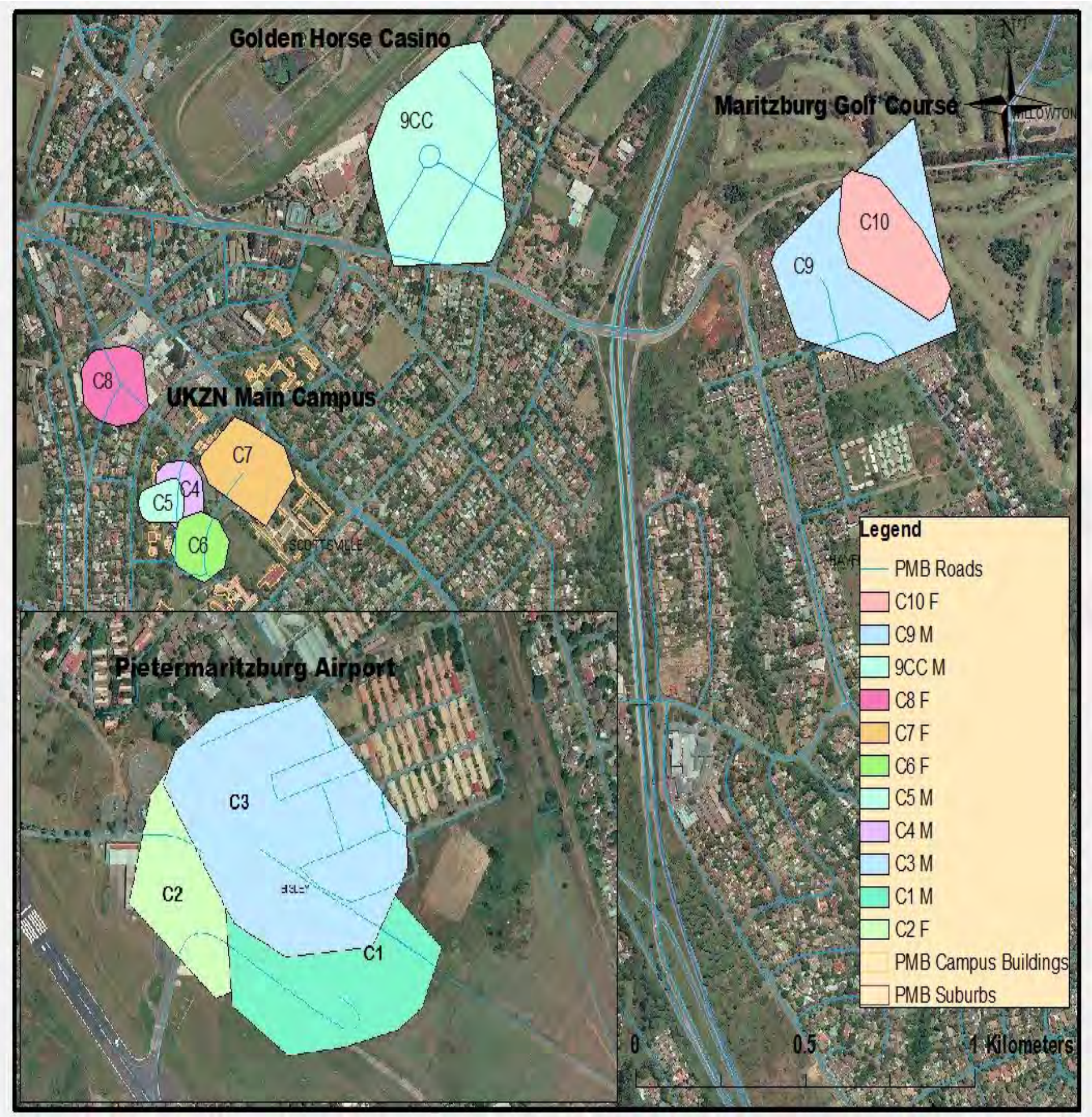
Table 3. Total day and night home range estimates for feral cats (n = 11) in Pietermaritzburg calculated using Minimum Convex Polygon (MCP) and Kernel Density Estimates (KDE) in ArcGIS. (M = male, F = female)

			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	3.25	1.43	5.66	3.58	1.8	5.99
C2	3	F	0.94	0.32	1.66	3.26	0.89	6.48
C3	3	M	4.02	1.18	6.14	7.09	2.15	10.04
C4	2.5	M	1.09	n/a	n/a	1.2	0.38	1.73
C5	2.5	M	n/a	n/a	n/a	0.92	0.19	1.19
C6	1	F	0.65	0.31	1.31	1.59	0.41	2.20
C7	1.5	F	1.13	1.07	4.01	3.5	1.93	7.04
C8	1	F	1.46	0.8	2.70	2.4	0.73	4.00
9CC	5	M	8.09	5.27	20.74	14.28	7.21	27.02
C9	1	M	1.2	0.53	3.58	7.73	2.6	13.05
C10	4	F	4.2	2.22	8.60	4.93	1.94	8.35

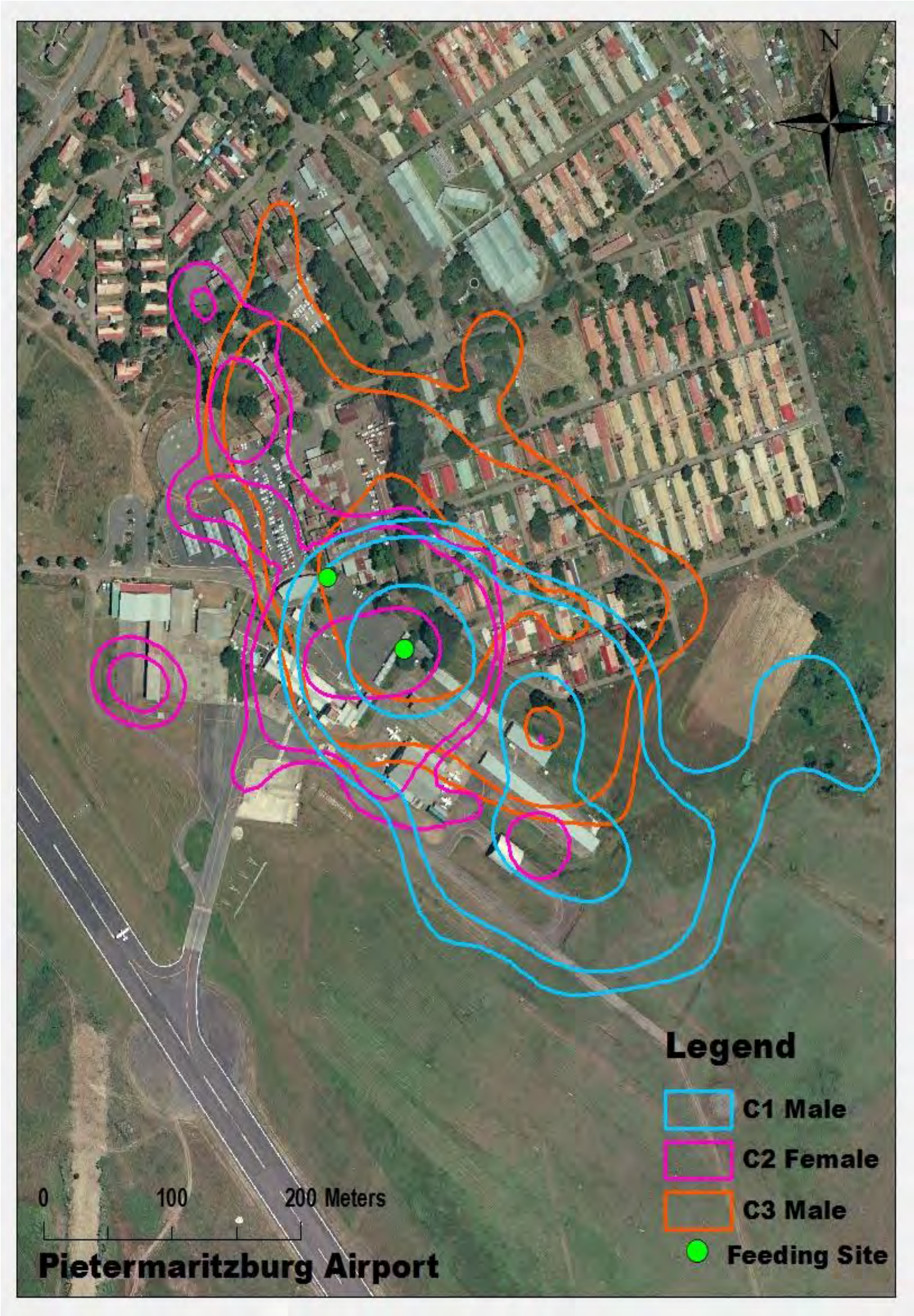
Appendices

Appendix 1. Feral cats collared over a 6 month period (May 2014 – March 2015) in Pietermaritzburg.

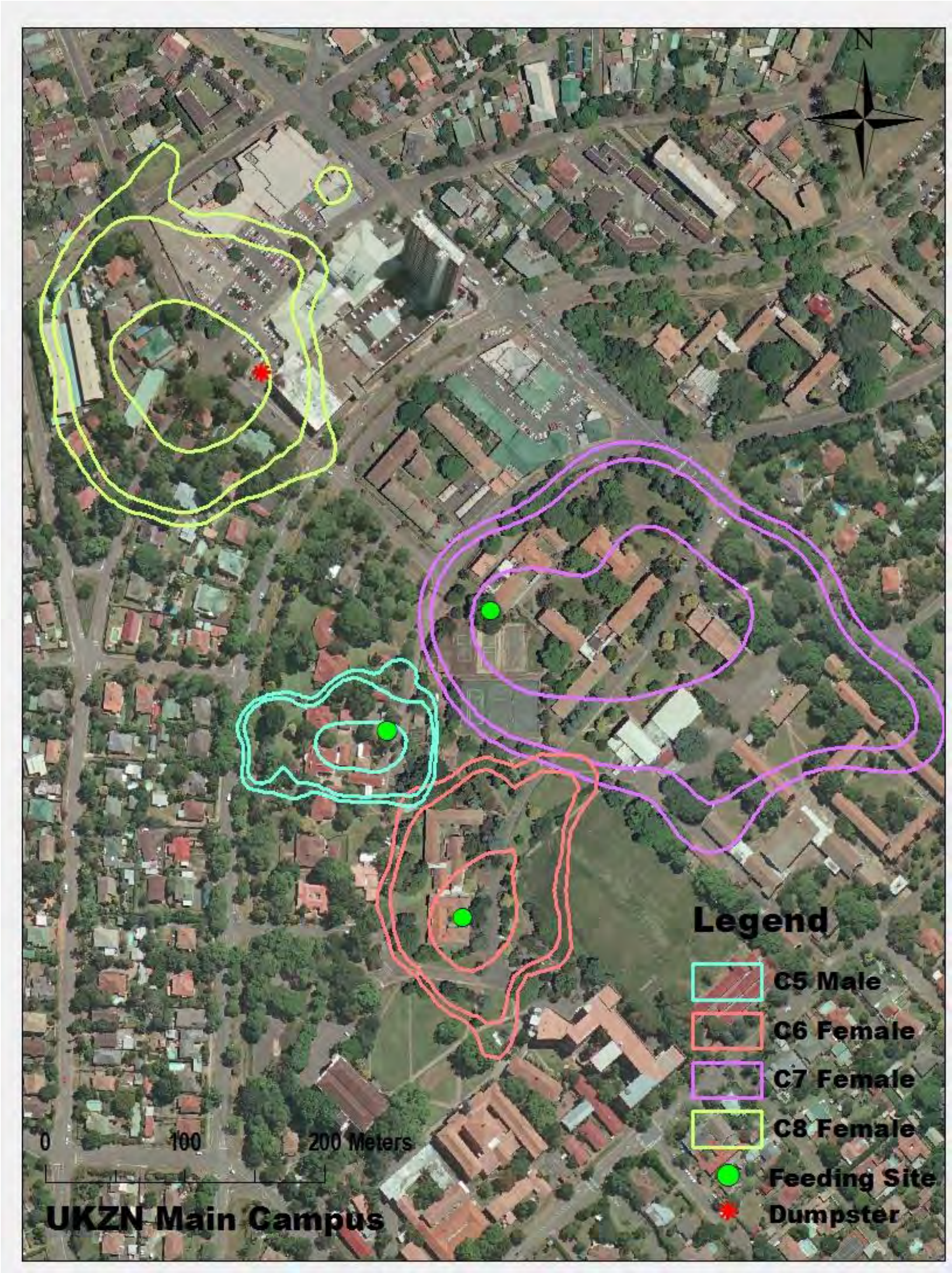
Location	**Feral cat ID**	**Body mass (kg)**	**Sex**	**Age in years**	**Capture date**	**No. fixes**	**GPS tracker fail**
Airport	C1	4.4	M	6	22-05-2014	427	24-11-2014
Airport	C2	5.4	F	3	24-05-2014	256	24-11-2014
Airport	C3	4.9	M	3	24-05-2014	365	24-11-2014
Main Campus	C4	3.65	M	2.5	28-05-2014	360	15-01-2015
Main Campus	C5	3.95	M	2.5	28-05-2014	266	01-12-2014
Main Campus	C6	2.45	F	1	17-06-2014	214	11-12-2014
Main Campus	C7	2.8	F	1.5	15-07-2014	100	09-11-2014
INR Checkers	C8	3.3	F	1	12-08-2014	251	29-01-2015
Casino	9CC	5.5	M	5	13-08-2014	129	08-11-2015
Maritzburg Golf Course	C9	5.5	M	1	13-11-2014	188	13-02-2015
Maritzburg Golf Course	C10	2.7	F	4	14-08-2014	130	06-03-2015
MEAN		**4.05**		**2.77**		**244**	



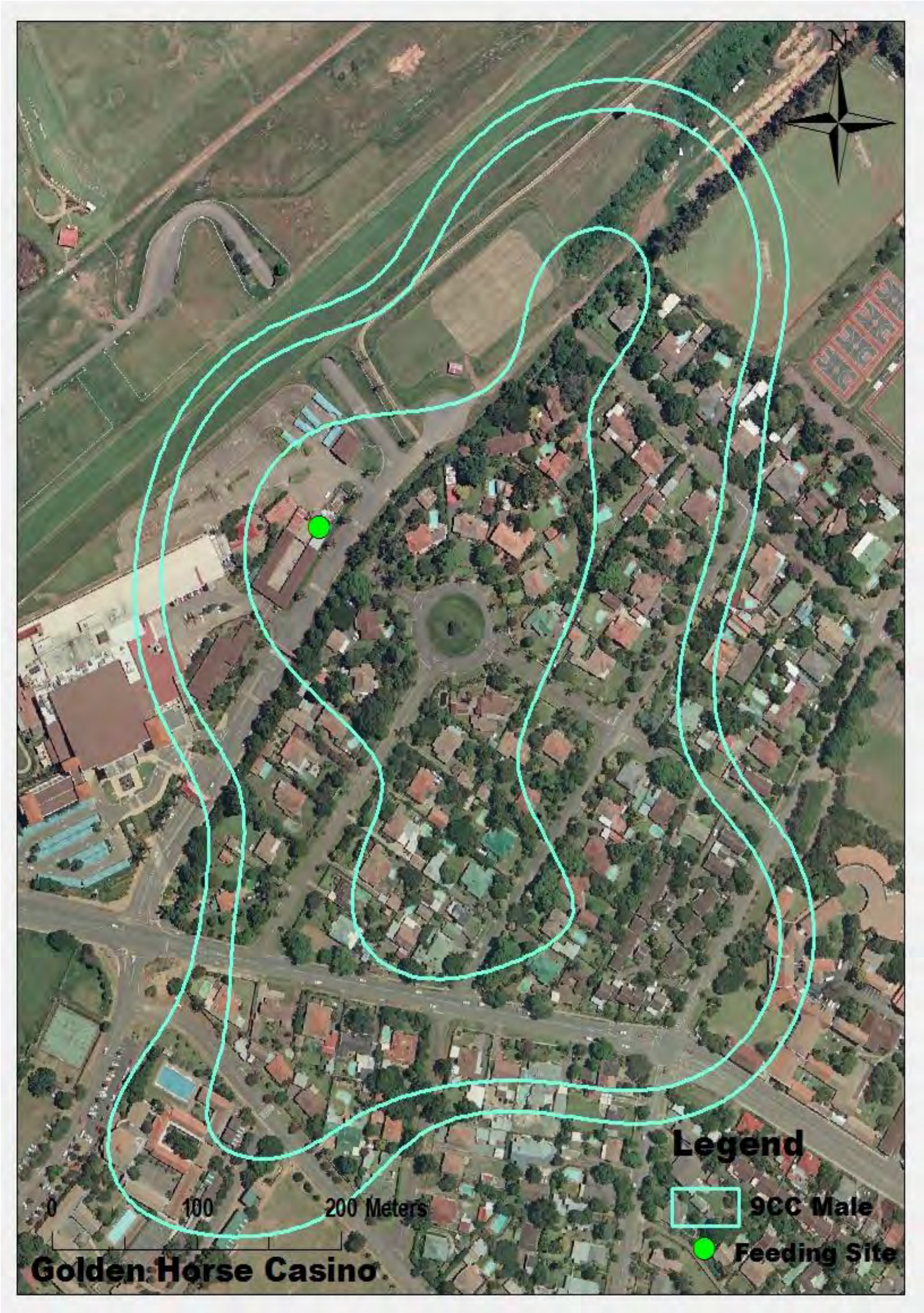
Appendix 2. Home range sizes using 95% MCPs of eleven feral cats collared in urban Pietermaritzburg, KZN. (M = males and F = females)



Appendix 3. Area utilised by feral cats showing overlapping of core areas using 50, 90 and 95% KDEs at the Pietermaritzburg Airport.



Appendix 4. Area utilised by feral cats showing overlapping of core areas using 50, 90 and 95% KDEs at the UKZN Main Campus in Pietermaritzburg.



Appendix 5. Area utilised by a male feral cat showing core areas using 50, 90 and 95% KDEs at the Golden Horse Casino in Pietermaritzburg.

Appendix 6. Area utilised during the day and night by male and female feral cats showing core areas using 50, 90 and 95% KDEs at the Maritzburg Golf Club in Pietermaritzburg.

Appendix 7. Land use categories reclassified for habitat usage of feral cats in urban Pietermaritzburg.

Urban land use	**Green land use**	**Private gardens**
Manmade surfaces	*Natural surfaces*	*Gardens within boundary of manmade structures*
roads	grassland	plant fences
pavements	open veld	ornamental gardens
paths	koppies	landscaped gardens
footpaths	native trees	crops
robots	natural forest	agricultural land
traffic circles	indigenous forest	orchards
traffic lights	untouched areas	golf course
structures	green belts	ponds
buildings	riverine	private lawn
roofs	wetlands	verges
carports	bush	pavement with green
awnings	bushveld	race course - casino
greenhouses	savannah	
garages		
homes		
houses		
outbuildings		
shacks		
informal settlements		
fences		
tracks		
driveways		
bridge		
archway		
sports field		
fields		
parking lots		
bins		
dump site		
shopping malls		
complexes		
simplex		
duplex		
restaurants		
schools		
bus stops		
taxi ranks		
halls		
place of worship		
swimming pools		

CHAPTER 3

Prevalence of disease in feral cats in urban Pietermaritzburg, KwaZulu-Natal, South Africa

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Abstract

Globally populations of feral cats (*Felis catus*) continue to increase, particularly in urbanised landscapes. Apart from the general negative impacts which include predation on native wildlife; feral cats also host a variety of transmittable diseases. Feline Leukaemia Virus (FeLV), Feline Immunodeficiency Virus (FIV) and Feline Corona Virus (FCoV) are the most common viruses leading to the most infectious diseases and eventually fatality in cats. Consequently feral cats (n = 42) from urban areas of Pietermaritzburg, KwaZulu-Natal were sampled for disease prevalence and to identify the influence of sex, age, and location of prevalence in 2014-2015. The overall prevalence of disease in feral cats tested was generally low with incidences of FeLV and FIV 28.6% and 7.1%, respectively. There was no documented occurrence of FCoV in this study. Sex and age had no significant effect on prevalence of disease in feral cats tested, but there was a significant effect of location on feral cats for FeLV prevalence. Feral cats from colonies that shared space and had close interactions, showed higher occurrences of FeLV prevalence. FIV was only reported in male cats. Currently there is no known documented data on seroprevalence of feral cat diseases occurring in urban environments in South Africa. therefore these results are important for disease management as man, domestic and wild animals exist in close proximity within a shared urban landscape.

Key words

Felis catus; FeLV; FIV; feline corona virus; seroprevalence; disease management; urban ecology

Introduction

Globally there are increasing rates of endoparasitic and ectoparasitic diseases particularly in urban areas (Jones et al. 2008). Urbanization results in habitat loss and fragmentation which has led to artificially high densities of wild felids in urban landscapes (Riley et al. 2003). Human-induced landscape changes through urbanization also increase exposure of diseases between other wildlife, domestic animals and man due to a decreasing habitat size (Daszak et al. 2000, Riley et al. 2003, Lepczyk et al. 2004). The feral cat (*Felis catus*) is host to a wide variety of zoonotic diseases which are transmissible to animals and humans. Urbanization also results in changing incidences of diseases resulting in reduced fecundity and increased mortality amongst feral cat populations (Brearley et al. 2013). The increasing number of feral cats occurring in urban environments is of concern, especially when interactions between man and wildlife exist in such close proximity thus leading to health concerns for humans and wildlife (Daszak et al. 2000, Luria et al. 2004, Gerhold and Jessup 2012, Lepczyk et al. 2015, Lohr and Duffy 2015). Due to precarious behaviour of feral cats there is increased risk of exposure to contracting diseases. Therefore effective management strategies need to be designed to monitor the welfare of cats and importantly, public health (Page and Bennett 1994).

A descendant from the domestic cat, a feral cat is one that has been born in the wild, lacks socialization and has had little to no human contact (Centonze and Levy 2002, Natoli et al. 2005, West and Benschop 2013). Feral cats are evasive and untamed, carnivorous mammals having unrestricted access to the environment subsequently acquiring food on its own (Turner 2000, Slater 2005). Feral cats living in urban environments generally occur at very high local densities within multi-male and multi-female social groups (Liberg et al. 2000). The growth of feral cat populations are limited by environmental resources such as food and shelter (Fromont et al. 1997). Feral cats that have unlimited access to outdoors can also become exposed and infected with diseases, contributing to environmental contamination (Dubey and Jones 2008). These cats can live in harsh environments without veterinarian care and can display risky behaviour directly declining its survival (Lutz et al. 2002). Some feral cats exist in colonies whereby a caregiver provides food and water at feeding spots (Turner 2000, pers. obs.). When food is provided by humans particularly in areas of existing feral cat colonies; increasing wild animal density or visitation rates will increase exposure and encounters for disease transfer causing human-wildlife conflict

(Daszak 2000, Bradley and Altizer 2007). Most household pet cats have unrestricted movement and are allowed to roam freely outside. If domestic cats come into direct contact with infected feral cats the possibility of disease transmission can occur (Daszak et al. 2000, Lepczyk et al. 2015). Feral cats pose many public health issues, including the zoonotic concerns of rabies, bartonellosis and toxoplasmosis (Luria et al. 2004).

The disease toxoplasmosis caused by the parasite *Toxoplasma gondii* is transmitted by the only definitive host which is the cat. Oocytes of *T. gondii* in cats' faeces directly contaminate the environment and the food chain (Webster 2001). Both man and animals can become infected by ingesting raw, uncooked meat, or coming into contact contaminated food, soil or water (Cenci-Goga et al. 2011, Tiao et al. 2013). Pregnant women who come into direct contact with infected cats or litter boxes can have prenatal infection and abortions caused by toxoplasmosis (Kravetz and Federman 2005, Dubey and Jones 2008, Cenci-Goga et al. 2011). Patients infected with human immunodeficiency virus (HIV) whom are immunocompromised and generally younger individuals can contract toxoplasmosis and this could lead to mortality if left untreated (Tiao et al. 2013). This is of particular concern since the total number of persons living with HIV in South Africa for 2014 is estimated to be 5.1 million (StatsSA 2014). The populations of feral cats are widespread particularly in urban areas of South Africa. There is no recorded information of the number of feral cats in South Africa.

Feline Leukaemia Virus (FeLV) and Feline Immunodeficiency Virus (FIV) were first reported in 1964 and 1987, respectively; and are widespread in feral and domestic cats throughout the world (Legendre 1996, Lee et al. 2002). FeLV and FIV are contagious and untreatable retroviruses belonging to the family Retroviridae (Courchamp et al. 2000, Levy 2009, Little 2011, Horzinek and Möstl 2015). Equally, FeLV and FIV infections cause several immunocompromised syndromes (Levy 2009). Diseases associated with FeLV and FIV may affect any organ, including the central nervous system, and cause secondary and opportunistic infections which include gingivostomatitis, blood dyscrasias, lymphoma, and ocular disease (Lee et al. 2002, Little 2011, Munro et al. 2014). FeLV can be spread vertically *in utero* or through the mother's milk (Muchaamba et al. 2014) or horizontally through direct contact, sharing of eating spaces and mutual grooming (Vobis et al. 2003, Levy 2009, Munro et al. 2014). The virus is shed in bodily fluids including saliva, blood, nasal secretions, tears, urine and faeces (Legendre 1996, Vobis et al. 2003, Duarte et al.

2010). Alternatively, FIV virus is spread via saliva and less likely spread by social interactions between cats (Legendre 1996). Transmission is commonly spread through bites and deep scratches from infected cats which are mostly spread by males during cat fights (Levy 2009, Duarte et al. 2010, Munro et al. 2014, Chhetri et al. 2015). FIV can also be transmitted from pregnant females to their offspring (O'Neil et al. 1995).

Feline Corona Virus (FCoV) belonging to the Coronaviridae family is a positive stranded RNA virus which spreads among domestic and wild felids (Herrewegh et al. 1997, Taharaguchi 2012). Classified as a Group 1 coronavirus, there are two known biotypes of FCoV which are Feline Infectious Peritonitis Virus (FIPV) and Feline Enteric Coronavirus (FECV) (Addie et al. 2004, Benetka et al. 2004, Akkan and Karaca 2009, Duarte et al. 2010). FCoV is a persistent virus shown to cause chronic infections which results in prolonged virus shedding (Herrewegh et al. 1997). Depending on its virulence FCoV can cause viremia in cats or only display mild eneritis (Herrewegh et al. 1995, Benetka et al. 2004, Akkan and Karaca 2009). FCoV is transmitted via the oral-nasal-faecal route and most often shed in faeces (Herrewegh et al. 1995, Benetka et al. 2004, Taharaguchi 2012).

Infected feral cats that continue to spend time outdoors in stressful environments are at increased risk for exposure to other viruses, parasites, and infections. Furthermore, feral cats are more likely to sustain wounds, injuries and ailments which fail to heal due to their weakened immune system. These diseases affect the health status of the cats and other species within the ecosystem (Lepczyk et al. 2015). If free-roaming domestic cats come into contact with infected feral cats there will be opportunities to exposure (Stojanovic and Foley 2011).

The aim of this study was to quantify the prevalence of disease in feral cats in the city of Pietermaritzburg, South Africa to enable prophylactic (Little 2011) and beneficial management measures. In particular we determined what diseases were present in urban feral cat populations and at what frequency do these feline retroviral infections occur. We expected that disease prevalence would be high in the various feral cat subpopulations in this urban environment (Bradley and Altizer 2007). Furthermore the data obtained would contribute to management proposals on appropriate methods to monitor and control the spread of disease observed in feral cats in this urban environment.

Materials and methods

Blood samples were collected from feral cats in the city of Pietermaritzburg, South Africa (30°22'45.7" E, 29°36'0.7" S) with University of KwaZulu-Natal (UKZN) Animal Ethics permission (Permit 019/14/animal). Feral cats from eight different locations with known feral cat populations based on information previously gathered from public knowledge were selected as representative samples of the feral cat subpopulations within the city. The feral cats in this study were defined as free-roaming, unowned, outdoor cats exhibiting undomesticated behaviour. Cats were generally trapped in the early evening. Data collection occurred between July and November of 2014.

Immobilizing cats and collection of blood

Eight one-sided, open door live traps (35 x 40 x 60 cm) were used on a rotational basis during the study to maximise trapping success. The traps were baited with Lucky Pet™ tinned fish and CatNip, and camouflaged against a wall or dustbin to maximise trapping effort. Dark blankets were used to cover traps of captured cats to reduce stress to the individual. All captured cats were anaesthetized by a veterinarian using a combination of 0.2 ml/2kg Ketamine® and Domitor® (medetomidine hydrochloride) which was injected intramuscularly, the effects of which were reversed using Antisedan® (atipamezole hydrochloride). While anaesthetized, captured cats were aged, sexed, weighed, measured, and body condition such as obvious injuries or abnormal physical findings were recorded. Adults were identified by the presence of large canine teeth and body mass. Cats were separated into three age categories; kitten (0-6 months), juvenile (>6 months – 2 years), and adults (>2 years). With aid of the veterinarian, body condition and health status was determined by overall weight, presence of abscesses, lesions, wounds and quality of skin coat of the cats. This was divided into four categories; underweight, fair, healthy and overweight. Each cat was also examined to detect for presence of any fleas, flea dirt, ticks or rectal worms. Gestation period of pregnant cats was estimated and the number of kittens that were removed during sterilizations was also recorded.

While sedated a venepuncture was performed on each cat and 2 ml blood was obtained from either the cephalic or jugular vein into a potassium EDTA tube. Overall 42 blood samples were collected. Additionally cats caught, that had not been sterilized, were neutered (males) or spayed (female) by the veterinarian prior to release due to an agreement taken with the Feral Cat Feeding Group of Pietermaritzburg that manages the populations of feral cats. Cats had their left ear tip removed as the universal sign that it had been sterilized. All cats were monitored until full consciousness and released back at their site of capture. The total procedure took about an average of 30 min to complete per cat. All cats, both males and females that had undergone surgery through sterilizations were kept overnight at the Animal House Facility at the University of KwaZulu-Natal (UKZN) and released the day following the procedure.

Serological testing

Blood samples were transported with cold packs to VetDiagnostix - Veterinary Pathology Services, Pietermaritzburg for serological testing. A nucleic acid amplification test was used to detect for the specific viruses. This method was selected since it was possible to detect low RNA yield, and is a highly sensitive and specific test for viral nucleic acid for FeLV, FIV and FCoV (T. Hill, pers. comm.). Testing for FeLV and FIV was often performed at the same time since clinical signs can be similar (T. Hill, pers. comm.).

Statistical analysis

The disease prevalence in feral cats was calculated as the number of cats in the population that tested positive for a specific disease as a percent of the total individuals tested. The non-parametric test of Pearson's Chi-square was used to test for differences amongst ectoparasites and body condition, and seroprevalence of diseases and compared against sex, age categories and location. Blood tests that failed virus detection were also included for this analysis. Morphometric measurements data were normally distributed so data was analysed using factorial analysis of variance (ANOVA). All statistical analyses were undertaken using STATISTICA 7.1 (Statsoft Inc, Tulsa, USA) software programme for windows. The means ± standard deviation was reported. Significance was taken to be one with P value of ≤ 0.05.

Results

Sample characterisation

Feral cats (n = 42) were trapped in eight different locations around Pietermaritzburg (Fig. 1) in 2014 and included 22 females (52.4%) and 20 males (47.6%). Trapped cats varied in age as kittens (n = 17, 40.5%), juveniles (n = 14, 33.3%) and adults (n = 11, 26.2%). Feral cats captured had a mean age of 16±2 months. None of the cats had concurrent infections of the diseases screened for prevalence. Of the total samples tested, 31.0% (n = 13) yielded invalid test results as virology testing failed for FeLV and FIV.

Body mass

Overall body mass of feral cats showed no significant difference between sexes (ANOVA, $F_{(2, 36)} = 3.0592$, $p = 0.08$). Mean ± SD body mass for trapped male feral cats (3.22 ± 0.24 kg) was higher than that of female feral cats (2.58 ± 0.15 kg). Mean ± SD body mass of kittens was 2.1 ± 0.39 kg (range: 1.5 to 2.9 kg), while juveniles was 3.0 ± 0.54 kg (range=2.3 to 4.0kg). Mean body mass for adult cats was 3.9 ± 0.89 kg (range=3.1 to 5.5kg). However, there was a significant difference between body mass of feral cats with age categories (ANOVA, $F_{(2, 36)} = 23.5304$, $p < 0.001$). Eight (19.0%) feral cats were found to be in a fair body condition, 18 (42.9%) were healthy, two (4.8%) were obese and two were underweight (4.8%).

Body length

Mean total body length for trapped male feral cats (80.73 ± 7.22 mm) was higher than that of female feral cats (77.07 ± 4.85 mm). Total body length of feral cats was not significant different between sexes (ANOVA, $F_{(2, 36)} = 3.15$, $p = 0.08$). However, there was a significant difference between total body length of cats with age categories (ANOVA, $F_{(2,36)} = 18.08$, $p = 0.001$).

Physical examination

Of the female feral cats sterilised, it was found that 36.4% (n = 8) were pregnant at time of capture. Based on enlarged mammary glands and nipples, and a healing uterus, 13.6% (n = 3) of female cats had recently given birth. Mean gestation period of pregnant females that were sterilized were 4 weeks with a mean litter size of three kittens which were terminated during sterilization. One of the previously pregnant female had severe burns on the lips, paws and tail with a foul vaginal discharge. One kitten which was extremely underweight had a swollen abdomen which oozed free fluid during the surgery. Three males had scratches and prior healing scars.

Ectoparasites and body condition

Thirty (71.4%) feral cats trapped had one or more ectoparasites including ticks, fleas and/or rectal worms which were not identified to species. Fleas were found on 24 (54.1%) cats of which the highest occurrences were from individuals with a healthy body condition (Fig. 2). Fleas and rectal worms were present on five cats (9.5%) which had healthy and fair body condition. Ticks were found on one (2.4%) individual. There was no significant difference between ectoparasites and body condition of feral cats ($\chi^2_{(9)} = 2.168$, n = 42, p = 0.988).

Disease prevalence

FeLV

The prevalence of positive FeLV infection rates in feral cats was 28.6% (n = 12) (Table 1, Fig. 3) which included six females and six males (Table 2). No statistical significance was found in relation to sex for FeLV infection ($\chi^2_{(2)} = 0.04$, n = 42, p = 0.98). Female cats that were positive in specific age categories were kitten (7.1%, n = 3), juvenile (2.4%, n = 4) and adult (4.8%, n = 1) (Table 2). Male cats that were positive in specific age categories revealed the same prevalence as female cats. Prevalence for FeLV for specific age categories were: 7.14% (3/42) for kittens, 2.38% (1/42) for juveniles and 4.76% (2/42) for adult feral cats (Table 2). No significant difference in seroprevalence of FeLV was observed with different age categories of feral cats ($\chi^2_{(4)} = 7.47$, n = 42, p = 0.112). Kittens had the highest positive results for FeLV. However, location of feral cats had a significant effect on prevalence of FeLV infection ($\chi^2_{(14)}$ = 32.17, n = 42, p = 0.003). Seventeen cats 40.5% were negative for FeLV (Table 1, Fig. 3). All feral cats that tested positive for FeLV infections, tested negative against the disease FIV.

The highest number of infected cats was from one colony of which 88.9% (8/9) individuals trapped were infected. The majority of these were juveniles and kittens, and mostly females (Table 2). All cats from this colony also had fleas only, or fleas and rectal worms. Of the three juvenile female cats in this colony, two were pregnant and one had given birth recently but no obvious weaning of milk by kittens was evident. The caregiver believed the kittens had died (V. Alex, pers. comm.). All positively infected cats had fair or healthy body conditions. One positive infected female kitten from another colony with a swollen abdomen was underweight. The two positive adult males that were infected were not fed but were considered healthy and muscular, as well as showed aggressive nature.

FIV

Prevalence of FIV infection in trapped feral cats was generally low with only three positive cats 7.14% (3/42) (Table 1) of which were all males (Fig. 3). One juvenile, 2.4% and two adult cats, 4.8% were positive in their respective age categories (Table 2). FIV seroprevalence showed no significant difference with sex and disease ($\chi^2_{(2)}$ = 3.605, n = 42, p = 0.164). No significant difference in seroprevalence of FIV was observed in different age categories of feral cats ($\chi^2_{(4)}$ = 6.765, n = 42, p = 0.148). There was also no significant effect of location with seroprevalence of FIV of feral cats ($\chi^2_{(14)}$ = 21.305, n = 42, p = 0.094). Twenty-six cats 61.9% tested negative whereas 44.8% (n=13) failed to produce any result for FIV (Table 1). A greater number of cats tested negative 51.6% than positive for prevalence of FIV.

Two adult male cats trapped that were positive for FIV were from one colony which had known feeding sites. They had fair and healthy body conditions with fleas present, respectively. One of the male cats was extremely aggressive and had to be further sedated by gas due to the sedatives not taking effect. The veterinarian predicted it to have FIV based on the pus filled wounds and scars from previous cat fights. The juvenile male from another colony was probably an abandoned cat by indication of a worn out old collar which had to be cut off due to it being on too tight.

FCoV

There were no cats (0%) that tested positive for FCoV (Table 1). Of all the trapped feral cats tested for FCoV, only 9.5% (4/42), three males and 1 female, tested negative (Table 2, Fig. 3). FCoV prevalence had highest failed tests 90.5% (38/42) from the samples collected (Table 1).

Discussion

Disease prevalence

This study investigated the presence of infectious diseases (FIV, FeLV and FCoV) in feral cats from urban areas of Pietermaritzburg in 2014-2015. Unfortunately the serology testing for thirteen individuals were inconclusive (Table 1). Generally disease incidence was low with FeLV having the highest infection rates in these subpopulations of feral cats followed by FIV. This feral cat subpopulations showed no occurrence of FCoV infection. However, many of the latter tests were reported as "failed" as probably these samples had degenerate nucleic acid resulting in the internal controls failing (T. Hill, pers. comm.). Thus under such circumstances these tests were considered invalid (T. Hill, pers. comm.).

Throughout the world cat populations infected with FeLV and FIV have been reported. The reported prevalence for FeLV and FIV in stray and pet cats was 11.3% and 9.1% in China (Cong et al. 2015). Globally, most studies recording prevalence of disease in cats for domestic pet cats with varying results for FeLV 2.9–7.24% and FIV 4–13.25% (Shelton et al. 1989, Fromont et al. 1997, Maruyama et al. 2003). Muirden (2002) reported the prevalence in all types of cat populations in England was 3.5% for FeLV, 10.4% for FIV and 22.4% in FCoV. Alternatively, disease prevalence in feral cats in Egypt, Iran and the USA had results ranging for FeLV 3.3–14.2% and FIV 3.5–33.9 (Lee et al. 2002, Luria et al. 2004, Akhtardanesh et al. 2010, Al-Kappany et al. 2011). In South Africa, Schoeman et al. (2005) found that 32% (n = 18) domestic sick cats were positive for FeLV antigen and 14% (8) cats were positive for FIV. However, there are no known documented studies for disease prevalence within feral cat populations in urban areas of South Africa. Our study found 28.6% and 7.1% for FeLV and FIV infection respectively for feral cats tested, so results were lower than domestic cat results reported in Schoeman et al. (2005). Overall it appears that feral cats in urban areas of Pietermaritzburg generally had low disease prevalence however this does not negate their potential to be reservoirs for these diseases in their domestic counterparts.

The FeLV prevalence rate was approximately 4 times the prevalence for FIV in this population of feral cats tested. Worldwide studies were done using different methodologies, sample sizes and population characteristics and this may also contribute to the varying degrees of disease prevalence (Cong et al. 2015). These observed differences can be explained by differences in population characteristics as well as geographical boundaries (Duarte et al. 2010). This could also indicate that feral cats in urban areas existing outdoors are more exposed to infection of FeLV and can vary widely from country to country (Kann et al. 2006, Duarte et al. 2010).

FeLV infection was not related to gender in our study as male to female proportion were equal which was also seen in other studies (Lee et al. 2002, Muirden 2002, Akhtardanesh et al. 2010, Chhetri et al. 2015). Kittens between 0 and 6 months of age had the highest prevalence of FeLV. FeLV can spread from infected queens to kittens and this could explain the high kitten incidences in this study; however this is rare (Allison and Hoover 2003, Levy and Crawford 2004). Similarly to this study FeLV antigen was common in younger cats under 1 year of age (Sukhumavasi et al. 2012). Significant low incidence of FeLV infection in adult cats can be explained by cats being more susceptible to the virus and succumbing to related diseases (Hosie et al. 2009, Lutz et al. 2009, Sukhumavasi et al. 2012). FeLV infected cats are known to have shorter lifespans not living to adulthood (Addie et al. 2000, Hartmann 2011). Generally young cats are more socially interactive and this intimacy between cats is the major route of transmission of FeLV (Fromont et al. 1997). High incidences of FeLV in one colony in the current study could also explain the aforementioned. Vobis et al. (2003) revealed that FeLV can also be spread by the cat flea by its bites and faeces. Similarly in the current study fleas were the main ectoparasites found on FeLV infected cats and could be a possible vector in spreading the virus. Previous studies described that cats living with FeLV would not live long once diagnosed with FeLV infection (Levy and Crawford 2004, Schoeman et al. 2005, Hartman 2011).

Essex et al. (1975) indicated that within a few months of sampling, cats can change from FeLV negative to positive and remain healthy without any signs of physical deterioration. The results in this study could be interpreted similarly due to higher negative test results even though cats that were infected lived alongside with positively infected cats from the same colonies. Likewise a considerable number of cats with healthy body condition had accumulated ectoparasites without showing any deteriorating physical appearances. Ectoparasites appeared to prefer healthy cats.

In South Africa FIV infection in cats is considered to be common (Kann et al. 2006). FIV prevalence was 3 times more likely to occur in male cats than female cats. The higher FIV prevalence in male cats likely reflects the nature of feral cats. Findings mirrored in studies show that male cats living outdoors were more likely to be infected with FIV than females (Lee et al. 2002, Maruyama et al. 2003, Hosie et al. 2009, Al-Kappany et al. 2011, Bevin et al. 2012, Sukhumavasi et al. 2012, Chhetri et al. 2015) which was also noted in this study as no females were positive. Similar to other studies, the prevalence of FIV infection was higher in feral cats' especially entire and castrated male cats when compared with the domestic cat population (Levy et al. 2006, Norris et al. 2007). The current study found FIV only in intact feral male cats as similar to Danner et al. (2007). Additionally the likelihood of high FIV prevalence in juvenile and adult male cats was due to their free-roaming and aggressive nature during territorial disputes and fights which were evident from wounds and scars identified from positively infected intact male cats caught in this study (Fromont et al. 1997, Muirden 2002, Levy and Crawford 2004, Chhetri et al. 2015). Since territorial instinct has not yet developed in kittens, this could have resulted in no prevalence similarly in this study (Levy et al. 2006). FIV positive adult cats can survive for long periods before ultimately killing its host, sometimes by other viruses contracted during its lifetime (Oliveira and Hilker 2010).

Previous studies show that a multi-cat environment, gender, age and the environment play a role in FCoV prevalence; however this study deemed otherwise (Cave et al. 2004, Akkan and Karaca 2009). Stray cats in the UK had FCoV antibodies in 22.4% of cats (Muirden 2002). In the USA the prevalence of FCoV in feral cats was 18.3% (Luria et al. 2004). There were no reported results for FCoV within this feral cat population. This population of feral cats had a low population density compared to other studies and did not appear to be a source or spread for the coronavirus. Feral cats living outdoors might bury their faeces in the soil as compared to pet cats using litter boxes which could also reduce the spread (Luria et al. 2004). Herrewegh et al. (1997) showed that FCoV is subject to immune selection during chronic infection and that chronically infected cats can shed virus for at least 7 months. We could not evaluate this due to the lack of invalid tests for FCoV.

Management

The present study has acquired substantial data for disease prevalence in feral cats in urban areas of Pietermaritzburg. It is recommended that all feral cats be sterilized from early as possible (Levy et al. 2003). Sterilising cats reduces cats from wandering and also decreases the potential for territorial fights by males (Levy and Crawford 2004, Levy et al. 2008). The only guaranteed way to keep cats safe from these viruses is to prevent exposure. Positively infected cats should be kept indoors to reduce the risk of contact with other feral and domestic cats (Levy and Crawford 2004, Horzinek and Möstl 2015). One could implement that positive infected feral cats should not be allowed to roam freely but this is not possible with cats existing in colonies. If a positive infected cat is restrained to a confined area, cats will not roam and threaten other cats thereby reducing the chances of infection (Legendre 1996). Cats that were screened and showed up with negative infection should be protected by keeping them isolated from other cats as these viruses are passed on via saliva (D. Clover, pers. comm.) Hughes and Slater (2002) proposed that positively infected cats should be extirpated during a sterilization programme such as the Trap-Neuter-Release (TNR). Although euthanasia seems like a practical solution, measures of cost and benefit must be accounted for, as an efficient strategy and if it will be feasible in an urban environment (Fromont et al. 1997). Economic and emotional costs of caregivers are warranted because of the emotional connection of cats (Fromont et al. 1997). Sustaining feral cat colonies is costly both monetarily and time consuming which causes strain on caregivers especially when the population of feral cats exceed their financial carrying capacity (pers. obs.). As a result sterilizations become problematic and the TNR plans fail. A comprehensive, long-term TNR programme proves effective by decreasing feral cat populations in urban areas over time thereby reducing risk of diseases spread (Levy et al. 2008). In an ideal world, if all feral cats are immunised against feline diseases from birth chances of a protected, uncontaminated colony is possible. However, this is impractical. Feral cats living outdoors with diseases are further exposed to contracting rabies. Rabies vaccinations may not act effectively due to weakening immune responses of infected cats; in addition rabies vaccinations should be administered every six months (Gerhold and Jessup 2012). Possible spread of rabies from infected cats to caregivers is also possible (Gordon et al. 2004) which further adds costs to caregivers for booster immunisation.

Treatment

No previous vaccinations were administered to feral cats caught in the current study as most were trapped for the first time based on them not been surgically sterilised. Interferon omega is the only treatment that has been shown to be effective in treating the FeLV and FIV, however reported cases of its effectiveness in naturally infected cat populations are low (Doménech et al. 2011). Interferon omega is not available in South Africa (A. Pybus, A. Zambelli, D. Clover, pers. comm.). Cats that are negative for FeLV can be protected against contracting the virus by multiple registered FeLV vaccinations commercially administered by veterinarians (A. Pybus, A. Zambelli, D. Clover, pers. comm.). The present study had a high number of negative results so further vaccinations of feral cats are needed to maintain this but this requires retrapping of individuals. There is no vaccination or known cure for FIV so preventative methods like neutering male cats are imperative when managing diseases (Natoli et al. 2005, Robertson 2008, D. Clover pers. comm.). There is no vaccine for FCoV and most cats develop FIPV which leads to death (Benetka et al. 2004). Colonies need to be disinfected well as FCoV is spread through faeces and can persist long after the cats have been removed (Addie et al. 2004). Infected cats longevity can be assisted by providing good quality nutrition as provided by caregivers which have been displayed nonetheless and regularly treating for endo- and ectoparasites which can worsen the cats' health status (Levy and Crawford 2004, pers. obs.). It is also important to deal with secondary bacterial infection swiftly such as dental, respiratory or skin infections and abscesses (D. Clover, pers. comm.). Most veterinarians were unanimously in agreement that feral cats living in colonies should be removed (euthanized) due to the fact that most cat diseases are spread through physical contact and within the confinements of living spaces (A. Pybus, A. Zambelli, D. Clover, M. Roach, pers. comm.). The alternative is to adopt infected cats and contain them in a closed environment without allowing any contact with other cats. However, this is not a practical situation and will not work for feral cats who have adapted to outdoor living conditions.

Urban populations of cats will show possible variations of prevalence of diseases and possible management strategies need to be altered to fit specific areas (Kann et al. 2006). A study like this can provide the foundation for suitable developments on managing feral and free-roaming cat populations in urban environments. These diseases do not only affect cats but other species in surrounding ecosystems as well. Since there is currently no data on infection rates of feral cats in urban areas of South Africa, these results are important for disease management and control. Unfortunately some of the samples had degenerate nucleic acid therefore the internal controls failed resulting in invalid test results. Ideally, provided funding allows it, it would be useful to re-bleed those animals if possible but hopefully the results that are valid will provide useful data.

Conclusion

The overall prevalence of disease in feral cats tested was generally low with incidences of FeLV and FIV 28.6% and 7.1%, respectively. There was no documented occurrence of FCoV in this study. Sex and age had no significant effect on prevalence of disease in feral cats tested, but there was a significant effect of location on feral cats for FeLV prevalence. Feral cats from colonies that shared space and had close interactions, showed higher occurrences of FeLV prevalence. FIV was only reported in male cats. Currently there is no known documented data on seroprevalence of feral cat diseases occurring in urban environments in South Africa. Therefore these results are important for disease management as man, domestic and wild animals exist in close proximity within a shared urban landscape. The findings of this study show disease exists, albeit it generally low in prevalence, in the feral cat subpopulations living in this urban area. Generally feral cats are considered carriers of diseases and can infect whole colonies of feral cat populations along with free-roaming domestic pet cats. So feral cats can threaten public and animal health particularly in towns and cities. This requires ongoing information on disease prevalence in feral cats to improve recommendations for disease testing and prevention. Raising awareness and educating feral cat feeders, pet owners and the greater public on feline diseases may impede the spread and control infections amongst all cats. Veterinarians could provide information on various testing procedures and vaccinations to feline networks in order to prevent increases in cat diseases in feral cat colonies.

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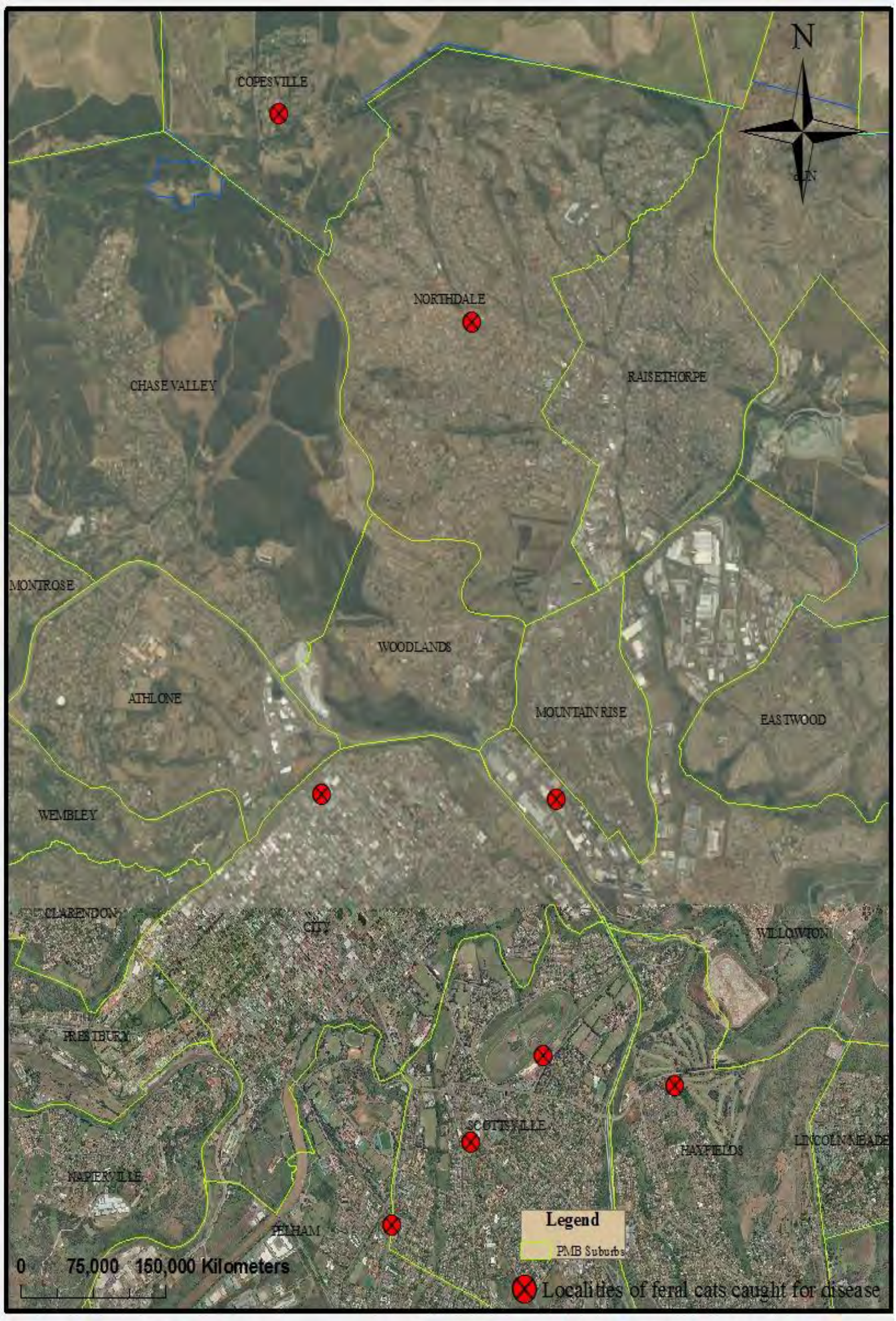
Figure legends

Figure 1: Localities of disease detected in feral cats (*Felis catus*) from eight selected from urban Pietermaritzburg, KwaZulu-Natal.

Figure 2: The frequency of ectoparasites on trapped feral cats (n = 42) of different body conditions from urban areas of Pietermaritzburg, KwaZulu-Natal.

Figure 3: Disease prevalence of a) FeLV; b) FIV and c) FCoV in trapped feral cats in urban Pietermaritzburg, KwaZulu-Natal in 2014 (n = 42).

Figure 1: Localities of disease detected in feral cats (*Felis catus*) from eight selected from urban Pietermaritzburg, KwaZulu-Natal.



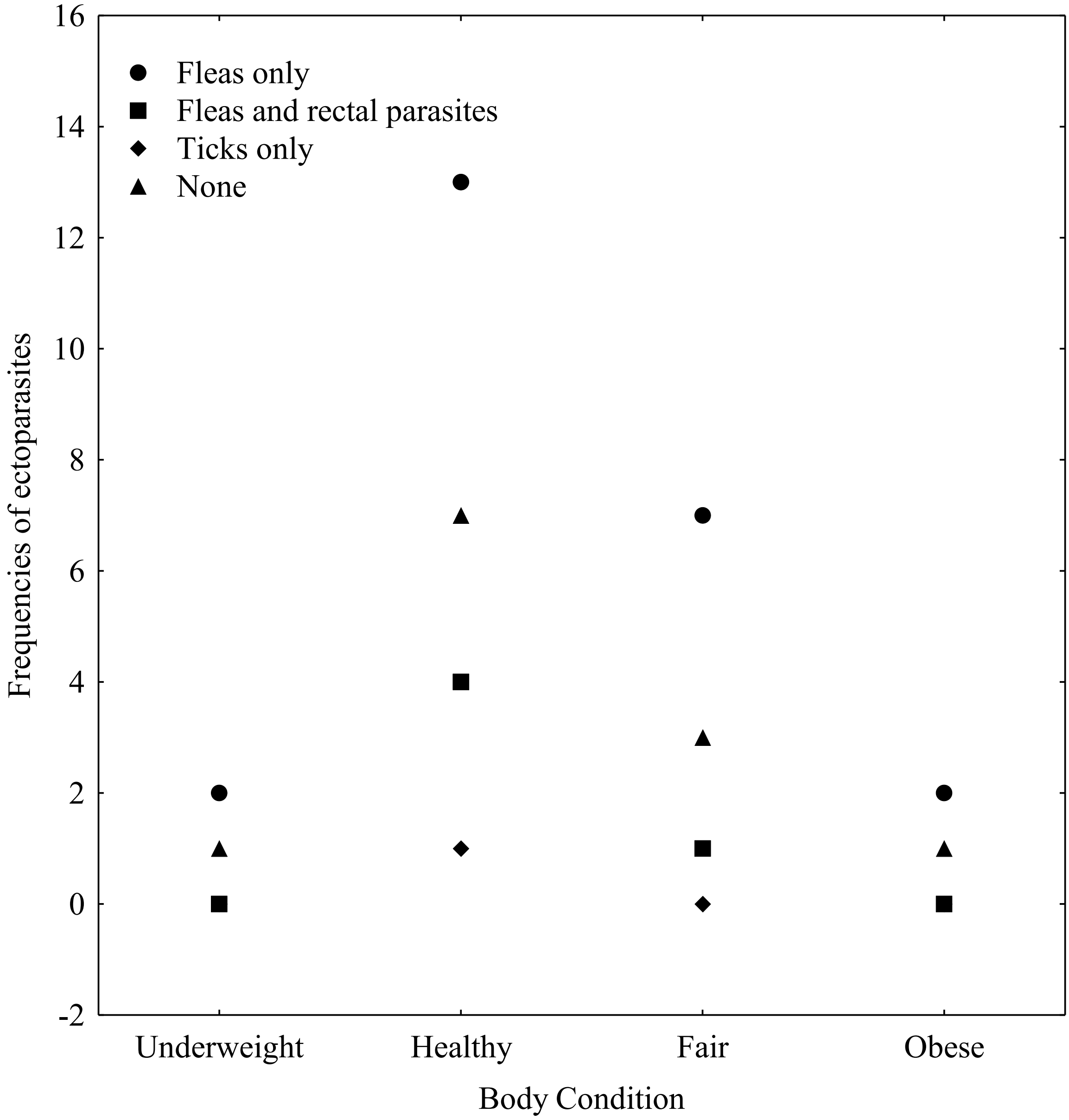
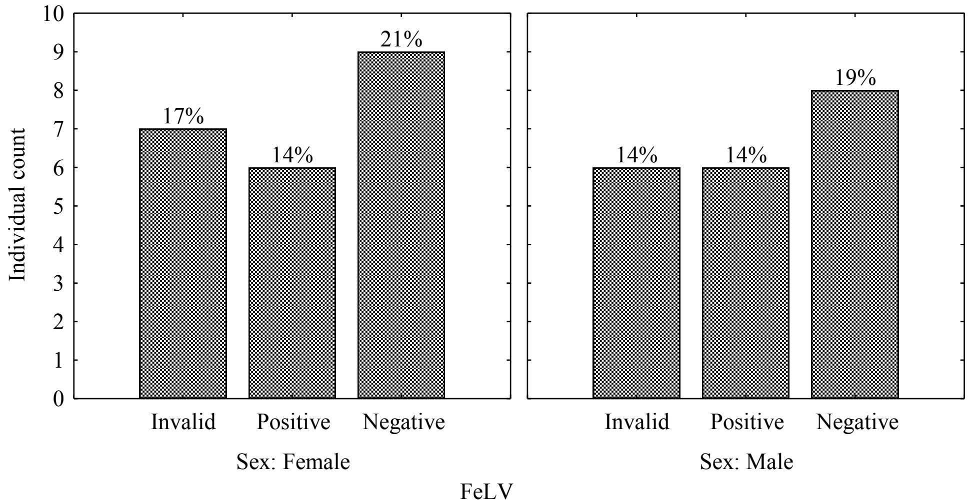


Figure 2: The frequency of ectoparasites on trapped feral cats (n = 42) of different body conditions from urban areas of Pietermaritzburg, KwaZulu-Natal.

a)



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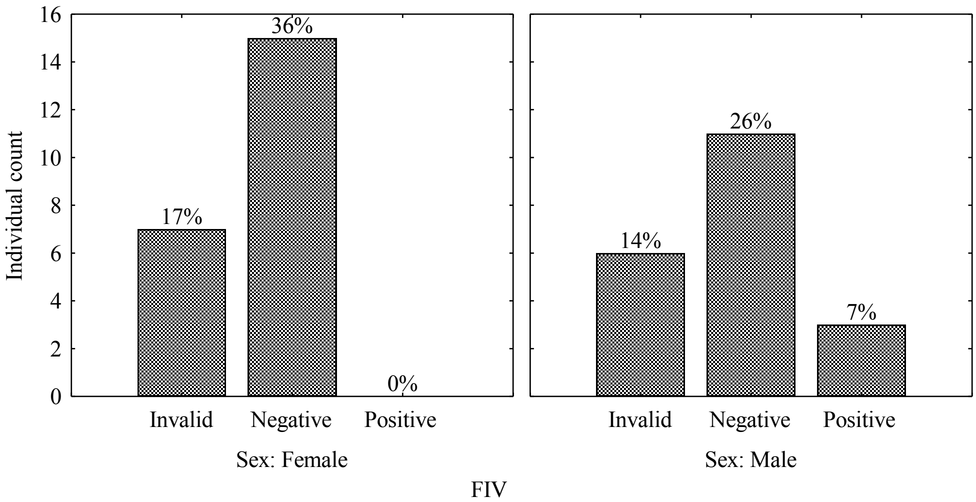

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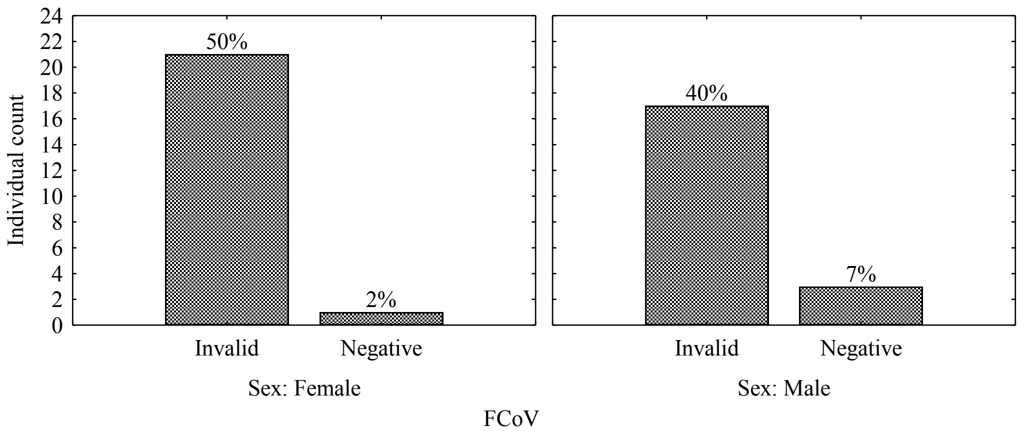

Figure 3: Disease prevalence of a) FeLV; b) FIV and c) FCoV in trapped feral cats in urban Pietermaritzburg, KwaZulu-Natal in 2014 (n = 42).

Table 1: Feline infectious disease prevalence in trapped feral cats in urban Pietermaritzburg, KZN in 2014 (n = 42).

Test results for disease prevalence	**FeLV**	**FIV**	**FCoV**
No. of individuals positive	12	3	0
% Positive	28.6	7.1	0.0
No. of individuals negative	17	26	4
% Negative	40.5	61.9	9.5
No. of individuals with invalid results	13	13	38
% Invalid tests	31.0	31.0	90.5
TOTAL	**42**	**42**	**42**

Table 2: Feline infectious disease prevalence, individual counts of different sexes of trapped feral cats in urban Pietermaritzburg, KZN in 2014 (n = 42).

Disease	Sex	Age Category	Positive	Negative	Invalid	Total
FeLV	Female	Kitten	3	2	5	10
		Juvenile	3	5	1	9
		Adult	0	2	1	3
	Male	Kitten	3	1	3	7
		Juvenile	0	4	1	5
		Adult	3	3	2	8
Total			12	17	13	42
FIV	Female	Kitten	0	5	5	10
		Juvenile	0	8	1	9
		Adult	0	2	1	3
	Male	Kitten	0	4	3	7
		Juvenile	1	3	1	5
		Adult	2	4	2	8
Total			3	26	13	42
FCoV	Female	Kitten	0	0	10	10
		Juvenile	0	0	9	9
		Adult	0	1	2	3
	Male	Kitten	0	1	6	7
		Juvenile	0	0	5	5
		Adult	0	2	6	8
Total			0	4	28	42

CHAPTER 4

Management recommendations for feral cats in an urban environment: Pietermaritzburg, KwaZulu-Natal, South Africa

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Abstract

The feral cat (*Felis catus*) has successfully colonised most habitats of the world allowing for populations particularly in urban areas to increase exponentially. Having established formal colonies at high densities due to easily attainable food resources and favourable living spaces in urban communities, cats have placed an overall burden on the environment impacting native wildlife through predation and disease. This alien invasive species has been documented to have negative effects particularly in urban areas which include animal welfare, public health and nuisance concerns. We have put forward a series of methods and recommendations in order to assist municipalities and key stakeholders in evaluating the presence of populations of feral cats. Additionally, we have provided potential strategies highlighting its pros and cons to manage increasing populations of feral cats in urban areas of Pietermaritzburg, KwaZulu-Natal, South Africa. Furthermore, the management recommendations put forth could be applied to other urban areas worldwide.

Introduction

The feral cat (*Felis catus*) has only recently been domesticated when compared with other human companion species[1]. The domestication process began about 12 000 years ago during the first agricultural developments in the Near East Fertile Crescent, when cats stalked mice and rats in granaries that stored food[2-4]. This commensal relationship developed a unique bond between man and cat because cats were able to hunt and control vermin, a trait favoured within human settlements[5]. Presently cats have not lost this predatory trait and can still actively hunt. This unique characteristic has allowed cats to live independently with or without people in a wide variety of habitats[6].

The total population of cats is uncertain. Approximately 600 million domestic cats exist globally with an unknown amount of feral cats[7]. Around the world feral cat populations have increased drastically over the years particularly in urban areas where human populations are dense[8-11]. The uncontrolled population is due to irresponsible pet ownership by not sterilising cats; and the dumping of domestic cats has led to this increase[12-14]. Owing to this, the once domesticated pet cat have reverted to a “wild-like state” similar to their ancestors existing completely or semi-dependently of man and are commonly known as feral cats[15,16]. Generally, feral cats are solitary in nature but in urban areas it can exist in high densities in groups termed colonies, usually surrounding available resources such as food, shelter and reproductive mates[17,18]. This group living is further exacerbated by supplemental feeding at designated feeding sites by a caregiver[18].

Feral cats living in urban areas can have both positive and negative effects on the environment[12]. Feral cats pose a significant threat to birds, small mammals, reptiles and insects that they prey upon[19-22]. There has been no recent data to support the direct impact of cat predation on wild prey populations in South Africa. However, predation by cats is well documented across the globe with major extinctions occurring on islands[23-26]. A local example during the early 1960’s revealed feral cats were the driving factor of declining petrel species on Marion Island[27]. A previous study has reported that the feral cat has had a higher predatory impact in rural than urban landscapers due to larger green space, lack of supplemental feeding and natural predators[28]. The home ranges documented in this study were relatively small and feral cats remained in the core ranges which encompassed supplemental feeding sites (Chapter 2). Additionally in Pietermaritzburg, feral cats used urban habitat types the most. Cats can also assist with vermin control in urban areas by direct predation on rats and mice[29]. Although in urban environments when food resources are in abundance cats rarely predate on rats[29]. A high concentration of feral cats in an urban setting leads to close contact with rodents, other wildlife and domestic cats which further increase the risk and exposure to zoonotic diseases[30]. This raise concerns mainly when humans and other cats exist in such close proximity of one another. This study has also documented that 35.7% of feral cats in urban Pietermaritzburg were prevalent for viruses of Feline Leukaemia Virus (FeLV) and Feline Immunodeficiency Virus (FIV). These viruses are generally transmitted in larger colonies through close contact and territorial fights between cats[31] (see Chapter 3). Hygiene and noise pollution are added problems at high density colonies due to territorial fights, spaying of pheromone-scented urine, and mating rituals particularly caused by unsterilized cats[32]. Feral cats are further exposed to the effects of urbanization such as high human activity, traffic volumes and attacks from dogs[33]. The welfare of the feral cat is questionable when cats are found diseased and/or suffering.

Overall, the presence of feral cats has more negative impacts and outweighs the positives[30,34,35]. Currently there is no 'one size fits all' approach for feral cat control management practiced in South Africa. In Pietermaritzburg, South Africa, there are a number of extant feral cat colonies in the urban mosaic depicting relatively small home ranges present with definitive diseases such as FeLV and FIV. After reviewing the evidence and the legislation of South Africa, it is clear that any management approach should address a distinct aspect of the problem by identifying appropriate management methods to reduce stray and feral cat numbers in colonies, and diseases in effect of preventing predation on native wildlife; for feral cats in South Africa.

Control Methods

Legislation

The feral cat has been identified as one of the "World's Worst Invasive Species"[36]. In South Africa it is classified as a Category 1a invader on offshore islands in the National List of Invasive Species obtained from the National Environmental Management: Biodiversity Act (NEMBA)[37]. Invasive species in this category must be controlled or eradicated on islands and the land owner has to allow an authorised official from the Department to enter and monitor, assist or implement the combating or eradication of the species[37]. Feral cat populations negatively affect the areas in which they exist as highlighted above. Even though feral cats are consider invaders by NEMBA, both rural and urban cats' welfare concerns and disputes fall within the jurisdiction of the National Council of Society for the Prevention of Cruelty to Animals in South Africa (NSPCA).

The NSPCA have inspectors whom are authorised to follow the Animals Protection Act 71 of 1962 to protect and serve all animals. With 45 branches countrywide, the NSPCA opposes cruelty and promotes the welfare of all animals through leadership, education and action as tools[38]. The Statement of Policy of NSPCA advocates responsible pet ownership and "discourages the keeping of domestic animals by those who do not have the facilities, time, financial means or level of interest necessary to ensure a satisfactory standard of care and husbandry for their pets"[38]. Population control is also a priority deemed necessary by the NSPCA. Well maintained and managed colonies of feral cats that are accepted by owners on their site should be sterilised. For colonies of feral cats it is the decision of the NSPCA to prescribe if the cats' welfare is prioritised and humane procedures adhered to for its existence[38] which is further determined by local by-laws in that particular area (C. Kuch pers. comm.).

Eradication

The SPCA movement's Statement of Policy "is opposed to the euthanasia of fit and healthy animals but accepts the reality that humane destruction is necessary and euthanasia must be carried out by qualified personnel using approved and humane methods and with the greatest compassion"[38]. When the welfare standards of feral cats are compromised euthanasia is considered necessary. Complaints from neighbours and the greater public could subsequently add pressure to the removal of feral cats from the area. Due to the influx of stray, abandoned and feral cats, most feral cats have to be euthanized as kennels space is limited and feral cats that lack socialization by humans may not be adopted from the SPCA (J. Pharazyn, pers. comm.).

The complete eradication of feral cats is unsuccessful[39]. Eradication is a commonly used management approach on islands which were successful through intensive, laborious and time consuming efforts [40]. Other methods that have been documented in the literature included lethal procedures such as trapping and euthanasia, shooting, poisoning through toxic baits; and/or introducing a disease to kill the population, like feline panleucopaenia virus (FPV)[22,30,41]. Costs are relatively low when using eradication to control feral cats but this is dependent on the eradication method used and duration of the programme[16,42]. However, these invasive methods have many disadvantages and are not feasible in context of an urban setting subsequently causing anguish and conflict between stakeholder groups and cat caregivers[15]. These methods raise serious ethical questions as cats experience pain and suffering before death[12]. Yet another problematic ecological consequence by eradication of feral cats, particularly in urban areas, is the cause of a process called the ‘vacuum effect’ which is filled by new individuals migrating onto this vacated, richly sourced environment (food and shelter) allowing the breeding process to start over[32,43,44]. There is some recent evidence that the ‘vacuum effect’ involves not just a replacement of cats that have been removed in a local eradication program, but an increase[45]. Furthermore this seems to come about if the dominant, territory-holding cats are removed which in turn allows a greater number of subordinate individuals to move into the newly vacated space[45].

Population control by sterilization

A viable and non-lethal approach to limit the establishment and control of feral cat populations is known as Trap-Neuter-Release (TNR) or Trap-Test-Vaccinate-Alter-Release (TTVAR) which involves humanely trapping individuals, sterilizing, (and or vaccinating), and returning cats to its original location. TNR prevents reproduction in cats by either surgical or non-surgical means and prevents unnecessary euthanasia[46]. The universal sign for permanent identification of sterilization status for feral cats is completed when the tip of one ear (often the left) is removed. The surgical approach termed castration and spaying is designed to permanently inhibit cats from producing offspring by orchidectomy for males and an ovariohysterectomy for female cats[47]. This method alters cat behaviour due to hormonal imbalances. The benefits of surgical sterilization allows for cats to have improved body condition[48] and cats are noted to adapt a friendlier, calmer nature allowing close interactions between other cats and caregivers[16,49-51]. Additionally, sterilised feral cats have decreased territorial behaviour and roam less resulting in fewer cat fights[51]. Another positive of TNR results in significant reduction in cat numbers over time in colonies in urban areas [50,52].

Non-surgical methods of sterilisation allow the use of pills and chemicals to interrupt pregnancy similarly to the effects of human contraceptives[39,53]. This method of controlling contraception can be safe, reliable, and reversible[47]. This choice of sterilization is used instead of surgical methods which can be labour intensive, time consuming and expensive for large-scale, high density colonies as feral cats need to be trapped[47]. Introducing pills orally in cat food or administering vaccinations given by caregivers is allowed without veterinarian supervision[54], reducing transportation costs to the veterinarian surgery and expensive sterilisation costs. Animal behaviour is not altered by the use of these contraceptive drugs and cats display normal instinctive nature. However, non-sterilisation do not reduce sexual urges when females come into heat and increased vocalizations, mating fights and spraying are observed during breeding seasons[51,54,55]. Consequently such methods of non-sterilization control are difficult to implement so other more effective control methods such as TNR should are advised, especially for feral cats in urban Pietermaritzburg. Although the Feral Cat Feeding Group of Pietermaritzburg follows TNR, this method should not be considered to be the most useful or effective method as a lot of researchers have provided scientific research contradicting TNR success[16,50,56,57]. TNR should be robustly used as an additional method to the other strategies mentioned herewith.

One of the shortfalls of population control of feral cats by sterilization is the releasing of feral cats back into the environment where it was caught as the feral cat colonies are maintained and as an alien invasive species they may continue to be detrimental to indigenous wildlife. These managed feral cat colonies also attract abandonment of pet cats and unwanted kittens by people who are aware that food and shelter is provided and feel little remorse to dump their cats[9]. This method does not stop the destruction of native wildlife, neither does it curb diseases. It has also been reported that intact members of the colony who elude trapping during TNR pose a threat to neutered males showing aggression and territorial behaviour[58].

Supplemental feeding

Studies have shown that abundant and concentrated food resources provided at established sites can influence feral cat populations. Cats are noted to have high densities and small home ranges[18,59,60] also observed in this study (Chapter 2). Cats tend to not be territorial[15,49] and convert to group living when a constant supply of food is widely available allowing colonies to reach concentrated and larger densities[16,59,60]. Supplemental feeding may reduce competitive behaviour for resources[50]. However, cats may still actively hunt and catch prey despite being fed[61,62]. Thus supplemental feeding is not predicted to significantly reduce a feral cat's hunting instincts but aids to deter it[61,63,64]. The benefit of the feeding program is to the cats only; not the reduction of the population.

Recommendations for feral cats in urban areas of Pietermaritzburg

The urban sprawl of Pietermaritzburg city is interspersed with many green spaces that include a formal city, residential areas, industrial suburbs and informal housing which includes approximately 163 993 households (StatsSA, Census 2011). Commonly in urban areas there are several established feral cat colonies of which some are fed and looked after by volunteer caregivers (Chapter 1). The home range size of feral cats was between 0.71 and 9.81 ha, with their core area being limited by various food resources such as a supplemental feeding site or dumpsite. Feral cats in Pietermaritzburg used urban habitat types the most over green areas, suggesting they rarely used the area, which is optimistic considering this is an urban setting. Cats were also found to actively move further at night than day, keeping in their behavioural characteristic of being nocturnal and when human activity was low.

A management plan must take into consideration all factors that lead to feral cat populations dynamics[42], particularly bearing in mind the caregivers who have claimed ownership to the cats in the colonies. The caregivers take pity on these animals and the belief of 'trying to save the sick and frail' cats was observed (pers. obs.) Centonze and Levy [65] reported that feral cat caregivers formed a strong bond with these animals although they do not consider them pets. This was also observed in cat caregivers from Pietermaritzburg.

Despite previous intervention plans of TNR put in place by the Feral Cat Feeding Group of Pietermaritzburg, prior to this study, they believed most feral cats had been sterilised. On completion of the study we had sterilised 81.5 % (53/65) of feral cats from ten different colonies in Pietermaritzburg. With the financial burden of veterinarian costs it seemed difficult to manage an active and ongoing sterilization programme and daily feeding by the group (pers. obs.). We found that disease prevalence was generally low in feral cats tested (FeLV (28.6 %) and FIV (7.1 %) Chapter 3), however this requires ongoing monitoring which is costly. Thus there is a need for an effective, economical, management strategy to be implemented to control densities of feral cat subpopulations and disease in urban Pietermaritzburg.

Despite feral cats been an alien, invasive species, their eradication in Pietermaritzburg would be difficult because of public opinion, particularly the caregivers of feral cats but also the greater public of Pietermaritzburg who often have domestic cats. Furthermore, the 'vacuum effect' from eradication can be an issue. There was a high number of unsterilized feral cats found in the current study despite the caregivers maintaining that all cats where supplemental feeding occurred were sterilised prior to this study. This could have resulted from repopulations of feral cats moving in from surrounding areas as older sterilised cats perished from old age or disease. Therefore once off eradication of already established colonies seems ineffective and costly in the long run if replacement occurs.

Disease prevalence in feral cats can increase in colonies because of group living and tease of disease transmission. There is then potential to spread disease to other feral cats, domestic pet cats, wildlife and humans. In many instances during TNR and TTVAR, feral cats are sometimes vaccinated against rabies and diseases, and dewormed[9,12,15,16,50,51,66,67]. However, feral cats are not normally screened for diseases due to financial constraints resulting in returning the problem 'blindly' back into the environment. Even if the TNR programme were to include vaccinations and deworming, the cat is only immunised for a limited period of time and is at risk again. There is a low trapping success rate for retrapping feral cats and since cats are not amenable to nursing, very sick and injured cats, will have a silent death[68]. Thus, once a cat has been sterilised and released into the environment it is still exposed and at risk of contracting and further spreading diseases. The stage at which a particular disease causes observable deteriorating physical health of a cat may be too late for effective treatment. Consequently it is imperative to have feral cats tested for disease regularly and positive individuals euthanized to prevent further infections in other cats or whole colonies since most diseases are contracted through close contact or shared living space[31].

Viral testing for diseases can be acquired at the veterinary clinic when cats are brought in for sterilization (A. Pybus, A. Zambelli, D. Clover, pers. comm.). The SNAP FIV/FeLV Combo Test can provide same day test results and cats that test positive can be dealt with by either adopting it and keeping it isolation or euthanasia on site at the veterinary. Cats would not have to be sterilised or returned to colonies if the latter is considered. Euthanasia procedures are inexpensive when compared to the costs of sterilizations of cats (D. Clover, pers. comm.). Although costs for virology testing are expensive, the welfare of the cats falls onto the caregivers who claim ownership of the feral cat colonies and will have to cover costs.

TNR or TTVAR programmes offer a suitable alternative under the conditions to control feral cat populations located in defined urban areas such as in Pietermaritzburg. It is a humane approach which is much viable when compared with eradication methods. Failure of

TNR has been observed with the 'vacuum effect' and when caregivers stop the TNR programmes completely. TNR programmes require continuous trapping and sterilization efforts and are only successful with dedicated caregivers volunteering their time and financial support.

Supplemental feeding provided by volunteer caregivers at established colonies may result in the reduction of cats preying on wildlife[17,64,69] and reduced public frustrations caused by territorial behaviour. However, sterilised cats can still hunt as it is in their nature[16,70]. Therefore this is another contentious issue which needs to be addressed. TNR programmes coupled with consistent and regular supplemental feeding can reduce cat densities and hence their overall impact on prey populations[64,69]. However, TNR does not eliminate feral cats from the environment, it just controls population size[57]. TNR is an *in situ* method of management that is promoted by the majority of Pietermaritzburg caregivers. Pietermaritzburg caregivers should be realistic and aim for large reductions in populations so that they are able to maintain smaller, manageable colonies[15]. TNR objectives are to "keep cats alive as long as possible through provisioning, veterinary care, and favourable legislation"[71] which is supported by caregivers. Further assistance and guidance by social scientists need to educate and inform caregivers and work with them to help reduce feral cat populations. It is possible that caregivers are unlikely to alter their expectations and aims without some external advice or encouragement.

Daily food provision may cause feral cats to become dependent on humans in order to survive[42]. It is imperative that caregivers know the financial costs involved and not become burdened by the task of providing a food for a feeding programme. Caregivers need to acknowledge the long term implications that are involved before they begin such programmes. Failing to provide a constant food supply may be seen as abandoning their duties which is ethically frowned upon. Feral cats are instinctive and can easily revert to feeding of their surroundings; as cats are not selective in their food choice if supplemental feeding becomes unavailable[62,72]. Feeding sites may also serve as attractants to other species of wildlife that may become dependent on food essentially provided for cats. We observed on numerous occasions hadedas (*Bostrychia hagedash*) and feral pigeons (*Columbia livia*) feeding from cat food trays during the day (pers. obs.). Thus an acceptable quantity of food should be provided and food trays be removed immediately after feeding to dispel scavengers[42]. The acknowledgement of established feeding sites tends to draw people to dump unwanted kittens and pets knowingly since it appears as an easy way out of euthanasia. Feeding programmes should not be visible to the public to avoid this scenario[50].

The NSPCA advocates the sterilising of animals as early as possible, for cats at eight weeks of age unless opposed by a veterinarian[38]. By allowing kittens to be sterilised at a young age it may become more socialised towards humans and is less likely to be aggressive to other cats[73]. Combined with TNR, the adoption and rehoming of feral new born kittens and friendly cats is another way to effectively reduce feral cat populations in urban areas and subsequently prevent euthanasia of healthy cats[74]. Supplemental feeding will follow positive trends collectively with an effective TNR programme in reducing feral cat densities in urban areas in Pietermaritzburg. TNR and feeding programmes are costly to caregivers who single handily care for most of the feral cat colonies from their own funding or rely on sponsors from the public. The NSPCA is a non-profit organisation that allows for sterilizations at a reduced rate of for caregivers. The problem of overpopulation of a once domestic animal falls onto the greater public and all stakeholders should be involved. The Msunduzi Municipality should be approached to draft a cohesive and cost-effective approach which is formalised and put forward to the city of Pietermaritzburg.

Conclusion

To ensure the control of feral cats in urban areas of Pietermaritzburg an effective and persisting sterilization programme such as TNR needs to be implemented and maintained in conjunction with supplemental daily feeding at each colony. Long term successes of such programmes are satisfying. Caregivers can easily manage the colonies by halting the population growth thereby reducing feral cat movements and allowing unnecessary euthanasia. Caregivers also benefit emotionally and financially by having smaller sized colonies to manage and providing individual attention to the cats. The risk of contracting diseases spread through contact is also reduced with sterilizations altering cat behaviour to a much gentler nature. Stakeholders that include the municipality, veterinarians, shelters, and the NSPCA must work together to ensure a long term solution is devised to humanely reduce feral cat populations whilst protecting the welfare of feral cats, the public, domestic cats, and most importantly the wildlife. Adoption and rehoming of unwanted kittens and pet cats can also manage reductions of feral cat colonies. By managing urban feral cat demography, combined with an effective educational campaign directed to citizens to reduce irresponsible cat ownership and by promoting population control through sterilising pet cats is a fundamental solution in reducing the source of feral cats' in the urban community.

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CHAPTER 5

Conclusions

With increasing urbanization it is necessary to know what drives species to be successful particularly in landscapes that are intensively modified. It is important to determine what factors promote species to thrive in and also what factors that limits their survival. Generally alien, invasive species persist well in urban areas. The feral cat (*Felis catus*) is one such species that flourishes in an urban setting. The area that supports feral cat populations has greater resources like food and shelter that promote its abundance. Despite high levels of urbanization observed in Pietermaritzburg, South Africa, one of the features that stand out in this city, are the various colonies of feral cats located in an around the suburbs, often being fed by a caregiver (pers. obs.).

A commensal relationship exists between cats and human (Driscoll *et al.* 2009). With an expanding human population occupying more remote areas, cats have been introduced to almost every continent, niche and biome around the world. Feral cats can impact wildlife by directly preying on birds, reptiles, amphibians and small mammals. Furthermore, cats act as reservoirs for numerous diseases, a health hazard for both wildlife and human populations (Lepczyk *et al.* 2015).

The present study investigated feral cat home range size and movement patterns in an urban mosaic environment. Previous research on home range of feral cats was extensive and included semi-arid woodlands of Australia (Jones & Coman 1982), farmlands in New Zealand (Langham & Porter 1991), the Galapagos Islands (Konecny 1987) and the hilly regions of Hungary (Biró *et al.* 2004) to cite a few. Most studies of feral cats' home ranges varied greatly in size. In contrast the current study had relatively small feral cat home ranges in comparison to past studies. However, feral cat home ranges were similar in size to feral cats that were fed in an urban conservancy in a previous study completed in Durban, South Africa (Tennent & Downs 2008). A possible explanation for such variations in feral cat home ranges is the availability of resources, specifically food. In some countries feeding feral cats is discouraged but in South Africa it is an accepted "norm" as a strategy observed by caregivers that is believed to deter feral cats from predating on native wildlife (A. Beaumont pers. comm.). Our results showed that urban feral cat home ranges and their core areas were generally small containing at least one supplemental feeding site. The availability of abundant food resources at permanent feeding sites or dumpsters around Pietermaritzburg primarily influenced feral cat home ranges. Home ranges of feral cats were not only influenced by food resources but also shelter availability. Cats that occur in large colonies have considerable overlap and generally small home ranges (Liberg *et al.* 2000). The current study showed that gender had no influence on home ranges and core areas of feral cats but generally showed larger ranges for males than female feral cats which are conclusive with several other studies. There was no difference between diurnal and nocturnal home range size. Furthermore, feral cats significantly used urban and private habitat types the most over green habitats (Chapter 2). It is necessary to discuss the spatial ecology of feral cats within the context of urbanization in South Africa and compare it with other movement studies conducted on urban feral cats. Our results describe unowned, free-roaming, feral cat movements in an urban environment of Pietermaritzburg which contained a mosaic of urban, green and private habitat types. The home range size and core areas were investigated to determine what drives feral cat movements in urban landscapes. The study revealed that feral cats move extensively from one habitat type to another by various physical restrictions caused by boundaries, human influences, predation, competition and occasionally other cats.

Generally, disease prevalence in feral cat populations of Pietermaritzburg sampled in 2014-2015 was low (Chapter 3). However, the diseases tested for FeLV had high prevalence rates, with kittens mostly infected. FIV was reported in only three male feral cats older than a year old. Occurrences of these types of diseases go unnoticed because cats can display a healthy physical appearance because these retroviruses work to suppress the immune system over time (Levy *et al.* 2008). The cats immune system is weakened which will eventually cause its death. This study also revealed that location had a significant difference in disease prevalence for FeLV. High density colonies generally have higher prevalence rates. If one individual feral is known to have contracted the disease, chances are the entire colony would be infected (Levy *et al.* 2006; Möstl *et al.* 2015). There were no reported occurrences for FCoV. Most of these viruses do not have a known cure, but cats caught early and vaccinated could be clear of contracting the viruses (Levy *et al.* 2008).

The implications of the findings for feral cat control are discussed in Chapter 4, providing sufficient literature to support our findings in the previous chapters. The reported data allowed us to propose strategies for feral cat management and control which included a recommended and managed feeding programme with a periodically monitored Trap-Neuter-Release programme. Similarly, other studies have made similar recommendations (Longcore *et al.* 2009; Tennet *et al.* 2009). However, during this study we trapped a high number of feral cats that had not been sterilised. It is imperative that if a feeding programme to be operated successfully and regulate feral cat populations, TNR needs to be implemented simultaneously to compliment the programme. Unsterilized cats tend to be aggressive and display wild behaviour, this increases the risk of roaming and subsequently cat fights. Furthermore, this exposes the risk of contracting diseases as mentioned above.

This study has raised awareness of the feral cat situation in South Africa. Many people from the public came forth during this project asking for financial assistance for sterilizations. Despite not having the financial means for veterinary costs, caregivers still felt it was right to feed the feral cats. Many countries enforce harsh rules and regulations regarding feeding wild animals and/or allowing an invasive species to breed. It should be paramount to reduce infections of diseases while keeping in mind the welfare of feral cats. Further studies include determining the number of feral cats in South Africa as well as if TNR effectively works during a long-term period since many cities have established feral cat colonies and claim that TNR programmes are successful. Additionally, the predation of feral cats was not studied and this needs to be investigated in an urban setting especially where many other pressures of urbanization exist.

Recommendations for further studies

It is necessary that the comparison of home range size between intact cats be studied because this study could not do so because of the agreement taken with the Feral Cat Feeding Group of Pietermaritzburg. The sterilizations and veterinary cost of cats captured were extremely expensive. Additionally, the costs of virology testing were also an additional expense. If funding allows it, more cats should be tested for disease. It would also be beneficial to know the disease prevalence in domestic pet cats and if diseases are spread amongst the two groups.

As collars failed due to a short battery life, we could not test seasonal differences between feral cats. Further work needs to improve this technological shortfall and an additional comparison between domestic pet cats and feral cats could be studied. This will answer further questions about factors that drive cat movement.

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