Cape Town’s Cats: Reassessing predation through kitty-cams

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A thesis submitted to the University of Cape Town in partial fulfilment of the requirements for the Masters degree in Conservation Biology

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February 2014

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Plagiarism Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my original work carried out in the Department of Zoology, University of Cape Town. It has not previously in its entirety or in part been submitted to any University. Any other sources of information are fully acknowledged.

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Date

Acknowledgements

Thank you very much to the National Research Foundation (NRF) for funding this project through Dr Rob Simmons.

I would like to thank my supervisors for their support, encouragement and guidance throughout the project and for providing valuable input on the various drafts of this thesis.

I would like to thank the following people who volunteered their cats for the study; Margie Thomas, Karen Cairns, Anchen Sass, Stephen Whitehead, Karen Gloor, Bernice Snaith, Marion Steenkamp, Zelda and Rory McCance-Price, Verity Hoff, Felicity Lotter, Pug and Margie Worthington-Smith, Teresa Thomson, Caroline Sedgwick. Thank you so much for all of the effort you put in. Thank you also for your never-ending patience in the face of the many technical difficulties.

Thank you to my Conservation Biology Masters class – you guys are the best. I wouldn't have been able to get through this year without you!

Thank you also to my tireless volunteers Christian Setzer, Dunyiswa Lumko, Gabrielle Leighton, Hana Petersen, Kristen Barnes, Megan Mehnert and Tshegofatso Pelego. I really appreciate you all giving up your holiday to help me with footage analysis.

I am also very grateful to my partner, Samuel Stephens, for accompanying me on my door-to-door surveys, reading through my drafts and for his support. Thank you also to my family for their support, company for door-to-door surveys and help with testing the collars, harnesses and equipment for the study.

TABLE OF CONTENTS

1. ABSTRACT 11

2. INTRODUCTION AND LITERATURE REVIEW 12
2.1. *Felis catus* – an introduction 12
2.1.1. Domestication of the cat 12
2.2. Why introduced cats can be problematic: 13
2.2.1. Exceeding carrying capacity 13
2.2.2. Declines and extinctions of native fauna due to cats 14
2.2.2.1. Island fauna 14
2.2.2.2. Continental fauna 14
2.2.3. Predation estimates 15
2.2.4. Is predation by domestic cats a problem for prey populations? 15
2.2.5. Additive or compensatory predation by cats 16
2.2.6. Other negative effects of cats 17
2.2.7. Beneficial effects of domestic cats 17
2.3. Control and management of domestic cats 18
2.3.1. Management of domestic cats 18
2.3.2. Legislation 21
2.3.3. Conversion/correction rate to predation estimates 22
2.4. This study 23
2.4.1. Study area 24
2.4.2. Hypothesis 24
2.4.3. Aims 24

3. METHODS 24
3.1. Study site 24
3.2. Study design 25
3.2.1. Population size and density estimates of domestic cats 26
3.2.2. Choice of domestic cats 26
3.1.1. Equipment 27
3.1.2. Study protocol 29
3.2. Data analyses 32
3.2.1. Prey type and prey rates 32
3.2.2. Questionnaire 32
3.2.3. Video analysis 33
3.2.4. Prey capture correction factor and overall predation estimate 35

4. RESULTS 36
4.1. Domestic cat density 36
4.2. Study cats 36
4.3. Prey brought home - questionnaires 37
4.3.1. Experimental vs. baseline stage predation 37

4.3.2. Prey composition 38
4.3.3. Predation rates 42
4.3.4. Average predation in Cape Town 42
4.4. Behaviour and habitat use by cats with kitty-cams 43
4.4.1. Predation success 43
4.4.2. Prey composition from kitty-cam footage 44
4.4.3. Predation rates from kitty-cam footage 45
4.4.4. Fate of prey captured, and correction factors 45
4.5. Re-assessing the overall predation impact of Cape Town's domestic cats 48
4.6. Activity budgets and habitat use 50
4.6.1. Day vs. night 50
4.6.2. Deep-urban vs. Urban-edge 52

5. **DISCUSSION** **55**
5.1. Kitty-cams 55
5.2. Correcting for prey not brought back to the home 55
5.3. Population size and density 56
5.4. Domestic cat predation in Cape Town 56
5.5. Corrected Cape Town predation estimate 57
5.6. Prey spectrum (kitty-cam vs. questionnaire vs. other studies) 57
5.7. Prey fate 59
5.8. Urban-edge and deep-urban cats 60
5.9. Day vs. night (habitat, behaviour) 60
5.10. Densities of cats vs. natural carnivores 60
5.11. Limitations and recommendations for further research 61
5.12. Conclusions and conservation implications 62

6. **REFERENCES** **64**

7. **APPENDICES** **73**

List of Figures

Figure 1 Map of study area: a) Location of Cape Town in the Western Cape of South Africa, b) Location of Newlands on the Cape Peninsula including the Table Mountain National Park, c) Locations of the 14 cats that were studied using kitty-cams in summer 2013……………………………………………………………………..….**28**

Figure 2 The Eyenimal Cat Videocam has infrared lights for recording data on cat movement and predation during daylight, in dimly lit places and during night-time forays. The plastic clip allows the angle of the camera to change when the cat moves its head. Markers were placed upon the back of the kitty-cam in order to facilitate identification and retrieval if lost…………………………………………………**29**

Figure 3 Participants were provided with an emergency release collar (not pictured) and a kitty pack which contained; a) two Eyenimal Cat Videocams (hereafter "kitty-cams"), b) a USB cable for attaching kitty-cams to a computer for charging and footage download, c) four 16 gb USB drives upon which to store kitty-cam footage, d) a kitty-cam instruction manual, e) re-sealable plastic bags in which to store prey for each of the five weeks of the study and f) a sachet of cat food to distract the cat from collar fitting……………………………………………………...…………..……..……..**30**

Figure 4 Commercially available break-away cat collars were used to suspend the kitty-cam from the cat's neck to ensure that cats would not harm themselves if the collar were to get stuck…………………………………………….……………………….**30**

Figure 5 The Eyenimal Cat Videocam hangs below the cat's chin, facilitating easy viewing of any prey captures………………..……………………………………………......**31**

Figure 6 Mean number of prey (with standard deviation) brought home by free-ranging domestic cats in the experimental and baselines stages of the predation component of the study in summer 2013 in Cape Town, South Africa……………….………….**38**

Figure 7 The total number of different types of prey (invertebrate, bird, reptile, amphibian and small mammal) that the 13 individual cats brought back to the home (recorded by owners) in 5 weeks in summer 2013 in Cape Town, South Africa………………….**39**

Figure 8 The total number of prey items in the different prey groups that were brought back home (recorded in questionnaires by owners) by 13 free-roaming domestic cats over 5 weeks in summer 2013 in Cape Town, South Africa…………………………..….**39**

Figure 9 Total number of prey caught by 10 free-roaming domestic cats monitored by kitty-cam video cameras over 3 weeks, in summer 2013 in Cape Town, South Africa………………………………………………………………………...…**44**

Figure 10 The proportion of prey caught by 10 domestic cats that was eaten, brought home or abandoned as monitored by kitty-cam video cameras over 3 weeks, in summer 2013 in Cape Town, South Africa……………………………..………………...….**46**

Figure 11 The fate (abandoned, eaten, brought home) of each taxon (small mammal, amphibian, reptile, invertebrate) captured by 10 free-ranging domestic cats as recorded by kitty-cams in summer 2013 in Cape Town, South Africa.………………..……………….**47**

Figure 12 Activity budget depicting the proportion of daytime and nocturnal time 13 cats devoted to different behaviours determined from kitty-cams, in summer 2013 in Cape Town, South Africa.…………………………………………………..…...………**50**

Figure 13 Activity budget depicting the proportion of daytime and nocturnal time cats spent in different habitats, determined from kitty-cams, in summer 2013 in Cape Town, South Africa…………………………………...…………………………………………**52**

Figure 14 Activity budget depicting the proportion of time deep-urban and urban-edge cats devoted to different behaviours while wearing kitty-cams in summer 2013 in Cape Town, South Africa……………………………………..……………………………**53**

Figure 15 Habitat use depicting the proportion of time 5 deep-urban and 5 urban-edge cats spent in different habitats in summer 2013 in Cape Town, South Africa (Summer 2013)……………………………………………………………………...……...…**54**

List of Tables

Table 1 The number of domestic cats that did not bring prey back to the home in studies by George (2010), Peters (2011) and an average between these in Cape Town, South Africa as well as sample size and season that the study was carried out…………..…**32**

Table 2 Habitats in which 10 free-ranging domestic cats were recorded over 3 weeks in summer 2013 in Cape Town, South Africa…………......…………………………...**34**

Table 3 Behaviours which free-ranging domestic cats were recorded performing over 3 weeks in summer 2013 in Cape Town, South Africa…………………….……………..…..**34**

Table 4 Demographic estimates for domestic cats in Cape Town, South Africa from George (2010), this study and corrected estimates. Estimates include the number of cat-owning households per 100 households (hh), cat density per household (as calculated from door-to-door surveys) and an average of each…………………………………**36**

Table 5 Total number of cats studied in Newlands, the mean number of cats per household and their sex. Figures in brackets represent ranges……………………………….....**37**

Table 6 Prey recorded brought home (questionnaires) over 5 weeks by 13 free-ranging domestic cats in summer 2013 in Cape Town, South Africa…………...…..………**41**

Table 7 Median number of prey caught (recorded in questionnaires by owners) of prey types over 5 weeks and their associated U, p and n values of deep-urban and urban-edge cats in summer 2013 in Cape Town, South Africa…….…………………...………..**42**

Table 8 Mean daily predation rate of free-ranging domestic cats in Cape Town averaged from three studies. Determined using the number of prey brought home, number of cats in the study (adjusted to include non-hunting cats in the case of this study) and number of study days from this study and the studies by George (2010) and (Peters 2011)…………………………………………………………………………………**43**

Table 9 Prey recorded caught using kitty-cam camera devices on 10 free-ranging domestic cats over 3 weeks in summer 2013 in Cape Town, South Africa……..……..………**45**

Table 10 Statistical values exhibiting no significant factor effect between prey size (small, medium, large) and prey fate (brought home, eaten, abandoned) of prey caught by 10 domestic cats as recorded by kitty-cams in summer 2013 in Cape Town, South Africa……………………………………………………………………47

Table 11 Corrected predation estimates for Cape Town, South Africa. This study found that domestic cats only bring back 22% of the prey they catch back to the home. Daily predation estimates were formulated from deep-urban cats (minimum), urban edge cats (maximum) and the two combined (mean) for George (2010). Daily predation estimates were formulated from a study in winter (Peters 2011) (minimum), this study which was carried out in summer (maximum) and the average predation of this study and those of George (2010) and Peters (2010). Predation estimates from this study were converted using the correction factor (4.55)……………………………………49

Table 12 Median hourly rates (seconds per hour) of behaviours determined from kitty-cams and statistical differences between day and night-time activity for free-roaming domestic cats in summer 2013 in Cape Town, South Africa……………………………51

Table 13 Median hourly rates (seconds per hour) spent in different habitats and statistical comparisons of day versus night-time habitat use for free-roaming domestic cats in summer 2013 in Cape Town, South Africa………………………………………………52

Table 14 Median hourly rates (seconds per hour) of behavioural activity by deep-urban and urban edge cats and statistical differences between them in summer 2013 in Cape Town, South Africa……………………………………………………………………53

Table 15 Median hourly rates (seconds per hour) of time spent in different habitats and statistical differences between 10 deep-urban and urban-edge cats in Cape Town, South Africa (Summer 2013)……………………………………………………………54

Table 16 Percentages of different prey types returned by owned domestic cats reported in the published literature. Averages and standard deviations included. Adapted from Loyd et al. (2013)…………………………………………………………………………58

Table 17 Likely densities of small- to medium-sized carnivores which may have lived in the Cape Town area before habitat transformation and hunting. Densities are taken from

populations of these animals in the Western Cape, where available, or in other similar regions (drawn from the literature)…………………………………….……..…..…**63**

List of Appendices

Appendix 1 Endemic and/or threatened fauna (including birds, amphibians and reptiles) occurring in the Table Mountain National Park and the Cape Peninsula which may be vulnerable to predation by domestic cats in Cape Town, South Africa (Branch 1988; Picker & Samways 1996; Barnes 2000)(adapted from George 2010)………..……...**74**

Appendix 2 Poster left at veterinarians and pet shops around Newlands to recruit participants for the study…………………………………………………………………….………..**75**

Appendix 3 Questionnaire for door-to-door survey in Newlands……………………..……..……**76**

Appendix 4 Timetable of study and questionnaire for participants to record prey home brought by cat……..…………………………………………………………………….………..**77**

List of abbreviations

CFR	Cape Floristic Region
TMNP	Table Mountain National Park
GPS	Global Positioning System
IUCN	International Union for the Conservation of Nature

1. ABSTRACT

Domestic cats (*Felis catus*) are abundant generalist predators that exploit a wide range of prey within and adjacent to the urban matrix. Cats are known to have contributed to the extinction and endangerment (mostly on islands) of a number of indigenous species, including birds, small mammals, reptiles and amphibians. Most research on this important topic has been carried out in the developed world, predominantly in Australia, New Zealand, the U.K., the U.S. and Canada with only four studies carried out in Africa. Of these, two studies in Cape Town suggest that domestic cats have a big impact on wildlife but these studies may have underestimated predation because they failed to account for the proportion of prey not returned to participants' homes. In this study I used kitty-cams in an attempt to provide a prey correction factor for urban cats in Cape Town, South Africa. I investigated hunting of wildlife by free-ranging domestic cats in Newlands, a suburb of Cape Town, South Africa over 5 weeks in 2013. I monitored 13 cats (6 deep-urban and 7 urban-edge) by questionnaire survey, asking cat owners to record all prey items returned by their cats. A total of 43 prey items were returned, 42% of which were small mammals, 30% invertebrates, 12% reptiles, 9% amphibians and 7% birds. Combining these data with two similar survey studies carried out in Cape Town I estimated that a total of 118 cats caught an average of 0.04 prey items per cat per day. Ten of the 13 cats were also monitored for 3 weeks using kitty-cam video cameras. Participating cats wore a video camera and all activity was analysed for prey captures and behavioural activity patterns. I collected an average of 39 h of footage from each cat (n=10) for a total of 394 h of diurnal and nocturnal footage. Predation rates of individual cats when wearing the kitty-cam were compared with the predation rate when not wearing kitty-cams and no evidence was found that kitty-cams affect the ability of cats to catch prey. Reptiles, in particular Marbled Leaf-Toed Geckos (*Afrogecko porphyreus*), constituted the majority of prey recorded on kitty-cams followed by invertebrates, small mammals and amphibians. Of 23 prey items recorded only 22% were returned to households; 65% were eaten in situ and 13% were abandoned on site. My results suggest that previous studies which have relied solely on prey returned to the home as a measure of predation have significantly underestimated predation rates of urban cats. I used my findings on the proportion of prey not brought home (78%) to produce a correction factor (4.55) for studies using only prey brought home. This increased the estimated number of prey items killed within the greater Cape Town area from 5.7 to 25.8 million prey items (range: 18 – 33 million) per annum across all studies. This suggests that introduced domestic cats are having a much greater impact on prey populations than previously estimated.

2. INTRODUCTION AND LITERATURE REVIEW

Domestic cats (*Felis catus*) have a long association with humans and in various forms have been with humans for millennia (Driscoll et al. 2007). That domestic cats have both benefits and costs to us and to the environment has recently become clear (Dauphine & Cooper 2009); yet the study of domestic cats in Africa has been completely neglected in favour of the rich wild fauna that still exists intact on the continent (George 2010). Here I provide a brief history of the commensal relationship between humans and domestic cats and the impact of domestic and feral cats on native fauna and the natural environment.

2.1. *Felis catus* – an introduction

2.1.1. Domestication of the cat

Genetic studies suggest that the domestic cat *Felis catus*, is descended from the Arabian wildcat *Felis silvestris lybica* (Driscoll et al. 2007) with domestication having occurred in the Fertile Crescent some 8 000 to 10 000 years ago (Driscoll et al. 2007; O'Brien & Johnson 2007). Humans at this time were domesticating a variety of plants to be grown as crops, including barley and wheat (O'Brien & Johnson 2007). In providing a concentrated source of primary production, predictable in both time and space, humans inadvertently favoured conditions for granivorous species such as mice and rats and the predators such as cats that feed on them (O'Brien & Johnson 2007; Driscoll et al. 2009).

The first unmistakable evidence of the domestication of cats comes from Egyptian paintings of the New Kingdom period, nearly 3 600 years ago (Driscoll et al. 2009). These paintings depict cats, sometimes collared or tethered, eating from bowls and seated under chairs (Serpell 2000). These paintings are so prolific that it is evident that cats had become a familiar member of Egyptian households by this time (Driscoll et al. 2009). Around 2 500 years ago, grain ships were sailing frequently from Alexandria to destinations throughout the Roman Empire. These ships were likely to be carrying domestic cats to control vermin on board as well as in the country of destination, allowing domestic cats to establish populations in port cities throughout Europe (Driscoll et al. 2009). As the Romans expanded their empire, about 2 000 years ago, so the domestic cats went with them (Driscoll et al. 2009). European colonists then actively introduced domestic cats to the rest of the world (Coleman et al. 1997), either for food, their ability to control ship-borne pests, or as pets (Dickman 1996). Brickner (2003) outlines four major introduction events of domesticated cats around the world that have impacted on the natural environment in different ways:

1. Introduction to New Zealand, in the nineteenth century (Thomson 2011) and numerous other oceanic islands, where there were no native mammalian predators.

2. Introduction to Australia in the mid-nineteenth century (Abbott 2002), where there were no native placental predators, but marsupial predators such as the native marsupial cat (*Dasyurus viverrinus*) existed.

3. Introduction to the "new world" (with the arrival of European settlers), where 12 native feline species occur.

4. Introduction to the "old world", where the ancestral wildcat occurs.

The resultant populations that arose after such introductions can be classified into three main groups, depending on their relationship to people (Calver et al. 2011);

- **Feral cats**: these cats are free-living and form self-sustaining populations with no direct reliance on humans (Moodie 1995; Calver et al. 2011)

- **Stray/Semi-feral cats**: these cats are free-living but are partially provisioned by humans (Dickman 2009; Calver et al. 2011)

- **Domestic (pet) cats**: these cats live in close association with a household and all their food and shelter requirements are intentionally provided by humans (Moodie 1995; Dickman 2009). This classification can be further split;

  - Free-roaming domestic cats are allowed to move beyond the boundaries of the household which provides them with shelter and food. They do not rely on hunting for food but they may still have an impact on natural fauna through predation (Dickman 2009).

  - Housebound domestic cats are confined entirely within their owners' property and have a negligible, if any, impact on native fauna (Baker et al. 2010; Calver et al. 2011).

2.2. Why introduced cats can be problematic:

2.2.1. Exceeding carrying capacity

The current global population of domestic cats is estimated at 600 million (Driscoll et al. 2009) making it the world's most numerous pet. In many countries, pet cats are independent of prey numbers and exist at population densities of approximately 300-400 cats/km^2 (Barratt 1997a;

Beckerman et al. 2007; Sims et al. 2008; Peters 2011; Thomas et al. 2012; Bonnington et al. 2013), although they may exceed 1500 cats/km^2 (Sims et al. 2008). These exceptionally high densities are largely attributed to supplemental feeding by high density human populations (Coleman & Temple 1993; Baker et al. 2005; Tschanz et al. 2010) in addition to the removal or suppression of natural potential predators (Crooks & Soule 1999; Dauphine & Cooper 2009) and provision of shelter and medical care (Tschanz et al. 2010). Furthermore because domestic cats are less wary of humans than their wild counterparts they can hunt in human-dominated environments throughout both the day and night (Brickner 2003; Dauphine & Cooper 2009) and can thus access a more diverse prey base. Although supplemental feeding may reduce individual predation rates (Fitzgerald & Turner 2000), domestic cats continue to actively hunt (Adamec 1976) and kill prey even when prey populations are low (Coleman & Temple 1993). Additionally, because domestic cats are fed they do not have to switch between prey species when the prey source becomes so rare that the cat would no longer be able to subsist upon it. Consequently many studies have expressed concern over the potential impact that domestic cats may have on natural prey populations (Baker et al. 2005).

2.2.2. Declines and extinctions of native fauna due to cats

2.2.2.1. Island fauna

On oceanic islands with few or no mammalian predators, prey species are particularly vulnerable to cats, as they lack the appropriate behavioural responses to avoid detection and predation (Courchamp et al. 1999; Fitzgerald & Turner 2000). Feral cats are known to have been introduced to at least 120 island groups where they have been responsible for at least 14% of the bird, mammal and reptile extinctions; and 8% of these groups being classified as critically endangered (Bonnaud et al. 2010; Medina et al. 2011). In New Zealand introduced cats are thought to have contributed to more than half of all avian species extinctions (Nogales et al. 2004; Maclean 2006); including the Stephens Island Wren (*Traversia lyalli*) (Dauphine & Cooper 2009). This species was extirpated by feral and domestic cats before the bird was ever reliably observed in the wild (Dickman 1996). On Marion Island, in the sub-Antarctic Indian Ocean, five introduced domestic cats bred so prolifically that 25 years later, a population of more than 2000 cats were depredating nearly half a million burrowing petrels (Family: Procellariidae) per year (van Aarde 1980).

2.2.2.2. Continental fauna

The negative impact of cats is also recognised on continents (Churcher & Lawton 1987; Lepczyk 2004; Krauze-Gryz et al. 2012) where the continuous predation pressure of domestic and feral cats has already resulted in numerous local extinctions in continental land birds (Crooks & Soule 1999; Hawkins et al. 2004; Dickman 2009) and mammals (Dufty 1994; Dickman 2009). However, the

impacts of cats on continental prey species is typically less than on islands because prey species are already adapted to mammalian predators (Maclean 2006). As domestic cats have coexisted with humans for centuries, Fitzgerald & Turner (2000) reason that any continental population of prey species that could not withstand predation by cats would have long since been extirpated. Furthermore, Mead (1982) reasons that some bird populations may actually suffer less predation following the arrival of humans and cats as a result of the reduction or removal of natural predators.

2.2.3. Predation estimates

May (1988), extrapolating from a study by Churcher & Lawton (1987) that investigated predation by 70 domestic cats in a small British village, suggested that the approximately 6 million cats of Britain may kill as much as 100 million birds and small mammals a year. Fifteen years later, in a larger study of 696 cats, Woods et al. (2003) estimated that the then 9 million pet cats in Britain killed 92 million prey items, including 57 million mammals, 27 million birds and 5 million reptiles and amphibians during a 5 month period. In Switzerland, Tschanz et al. (2010) estimated that 1.2-2.4 million mammals and 0.1-0.3 million birds could be captured by cats in an average spring month while Clifton (2001), cited by Gillies & Clout (2003) estimated that 16–24 million animals are killed each year by cats in New Zealand. A recent study in the USA estimates that free-ranging domestic cats kill 2.4 billion birds, 12.3 billion mammals, 478 million reptiles and 173 million amphibians annually (Loss et al. 2013). Together these estimates suggest that domestic cats are having a substantial impact on native and non-native prey populations with, in many cases, poorly understood ecosystem consequences. It is however important to acknowledge that these estimates (Barratt 1998) are extrapolated from small, localised studies (Barratt 1998; Nelson et al. 2005). Variation in cat densities, prey availability, cat management practices and climatic conditions across large areas may all impact on the accuracy of such estimates (Barratt 1998; van Heezik et al. 2010). There is clearly a need for experimental studies that assess the distribution, abundance and life history of prey populations before and after domestic cats are introduced to an area.

2.2.4. Is predation by domestic cats a problem for prey populations?

While it is well known that domestic cats kill large numbers of wildlife and hence have a measurable impact on prey populations (Churcher & Lawton 1987; Lepczyk 2004; Campos et al. 2007; Dickman 2009; van Heezik et al. 2010; Loss et al. 2013), some authors insist that cat predation has little effect on prey populations in the long term (Liberg 1984; Jarvis 1990). There are few studies which have managed to demonstrate a decline in prey populations unequivocally linked to predation by domestic cats (Lilith et al. 2006). It is possible that cat predation is simply observed more often than other natural phenomena because predation often takes place during the day and domestic cats have a propensity to bring prey items home (Patronek 1998).

The impacts of domestic cats on wildlife populations are difficult to quantify, confounded as they are by a variety of other factors including habitat disturbance, climatic variation, competition and other predators (Barratt 1997a) especially in highly modified and disturbed environments such as urban residential areas (Barratt 1998; Calver et al. 2007). The range of prey taken by cats is generally far greater in the countryside, away from cities, than in more urbanised areas (McMurry & Sperry 1941; Eberhard 1954; Churcher & Lawton 1987; Barratt 1998), probably reflecting the lower species richness of urban centres (McKinney 2008). Prey species in less disturbed areas, such as nature reserves and natural fragments, are likely to be more severely impacted than urban populations as they may never have been exposed to cat predation and lack learned behaviours to avoid it (Dickman 2009). However, most of the species killed by cats are short-lived and have high reproductive rates (Nelson et al. 2006), making it less likely that cats will be able to impact upon prey population growth rates through predation (Maclean 2006).

2.2.5. Additive or compensatory predation by cats

The impact of domestic cat predation on prey populations is dependent on the degree to which predation is additive or compensatory to other sources of mortality (Churcher & Lawton 1987; May 1988; Woods et al. 2003; Kays & DeWan 2004; Baker et al. 2005; Beckerman et al. 2007, Bonnington et al. 2013). Compensatory mortality assumes that domestic cats are simply occupying the role of a natural predator, i.e. by removing weaker individuals which would not have survived even without predation (Lepczyk 2004; Balogh et al. 2011). Additive mortality assumes that domestic cats kill more prey than would be killed by natural sources of mortality. It is the latter form of mortality that may be catastrophic for prey populations (Balogh et al. 2011), slowly whittling populations down to local or broad-scale extinctions. A study in Bristol, UK, found that across species, birds killed by cats were in significantly poorer condition than those killed following collisions (e.g. with buildings or cars) (Baker et al. 2008). The fact that domestic cats may selectively prey upon animals in poor condition is consistent with the hypothesis that domestic cat predation represents a compensatory form of mortality, as these animals would be expected to have high natural mortality rates even in the absence of cats. However, as the number of prey in an area increases, the distinction between compensatory and additive predation becomes increasingly redundant (Baker et al. 2008). Where large numbers of prey are being killed, predators would be killing a combination of prey with both high and low survival abilities. Populations in such areas would then be reliant on immigration for re-population, leading to source-sink dynamics (Baker et al. 2005, 2008; van Heezik et al. 2010; Balogh et al. 2011). In fact, recent population models indicate a low likelihood of population persistence for some prey species in habitats exposed to domestic cat predation (Van Heezik et al. 2010). Unfortunately, it is difficult to calculate the effect of domestic cat predation

without knowledge of the natural breeding success and mortality of prey populations (Gillies & Clout 2003), which are frequently unavailable.

2.2.6. Other negative effects of cats

Domestic cats may affect prey populations not only through direct predation, or lethal effects, but also through indirect, or sublethal, effects by altering prey behaviours; such as foraging patterns and habitat use (Lima 1987; Beckerman et al. 2007; Medina et al. 2014). Such altered behaviours may result in decreased adult and juvenile survival, and decreased clutch size or number (Lima 1987). These sublethal effects may be as – if not more – important than direct predation of prey (Beckerman et al. 2007; Cresswell 2008, 2011). Free-ranging domestic cats may also compete with natural predators, such as raptors (George 1974; Liberg 1984; Lepczyk 2004) for prey. While domestic cats themselves have been protected from disease through vaccination, they may act as reservoirs or vectors of diseases and parasites that jeopardise wildlife (Work et al. 2000; Brickner 2003; Eymann et al. 2006; Dabritz et al. 2006; Danner et al. 2007; Medina et al. 2014), especially endangered felids (Izawa et al. 2009). Furthermore, the domestic cat hybridises extensively with the wildcat (*Felis silvestris*), across almost the wildcat's entire range in Africa, Europe and South-West Asia (Driscoll et al. 2007). Although the wildcat is currently listed as "Least Concern" by the IUCN (Driscoll & Nowell 2010), there may actually be very few genetically pure populations of wildcat left in the wild (Driscoll et al. 2007).

2.2.7. Beneficial effects of domestic cats

The presence of domestic cats is not universally detrimental. Domestic cat predation may be beneficial when the chief prey are pest species, such as the common rat (*Rattus norvegicus*), house mouse (*Mus domesticus*) or common myna bird (*Acridotheres tristis*) (Barratt 1997b, 1998; Baker et al. 2005), especially on farms and rural properties (Barratt 1997b). Furthermore, as pets, domestic cats are valued members of households (McNicholas et al. 2005) where they provide a companion role that would have traditionally been provided by other cohabiting family members (Staats et al. 2008; Dauphine & Cooper 2009) in a less urbanised world. Aside from the emotional benefits, owning pets such as cats also confers health benefits such as lowering blood pressure and decreasing the incidence of heart attacks (Anderson et al. 1992). Pets, including cats may be of particular benefit to older people and people recovering from major illnesses (McNicholas et al. 2005). Clearly domestic cats provide significant benefits to society as a whole (Aguilar & Farnworth 2012) and this needs to be noted when considering management options to mitigate their negative impacts.

2.3. Control and management of domestic cats

2.3.1. Management of domestic cats

The strong public affection for domestic cats as companion animals (Grayson et al. 2002) combined with the limited evidence of their ecological impacts has hindered attempts to impose severe management options at an appropriate scale (Ash & Adams 2003; Gillies & Clout 2003; Maclean 2006; Dauphine & Cooper 2009; Dickman 2009; Longcore et al. 2009). A study carried out at Texas University found that many respondents did not recognise a potential conflict between domestic cats and the conservation of wild species and thus did not accept domestic cat predation as a legitimate reason for controlling cat population numbers (Ash & Adams 2003). There are a limited number of measures that can be taken to reduce the impact of domestic cats (Fitzgerald & Turner 2000) and I describe these measures below, along with their respective strengths and weaknesses.

2.3.1.1. Regular feeding

Although the simplicity of this approach is appealing, this method of control is unfeasible as several studies have shown that there is a lack of connection between hunting and hunger levels in domestic cats (Adamec 1976; Biben 1979). Although supplemental feeding may reduce individual predation rates (Fitzgerald & Turner 2000; George 2010), domestic cats continue to actively hunt and catch prey (Adamec 1976), thus regular feeding by owners is not predicted to significantly reduce a domestic cats' hunting instincts (Barratt 1997a; Fitzgerald & Turner 2000; Meek 2003).

2.3.1.2. Sterilisation

Sterilising domestic cats is an effective way to limit the establishment of feral cat populations by domestic cats which leave home (Coleman et al. 1997; Dickman 1996; Lilith et al. 2006). However, sterilised domestic cats still hunt wildlife (Meek 2003) and thus at most this approach should be viewed as part of a long-term solution aimed at reducing cat densities and hence their overall impact on prey populations (Meek 2003).

2.3.1.3. Providing food for birds in safe places

The British Trust for Ornithology, (Arnfield 2012) and Ruxton et al. (2002) suggest positioning bird feeding stations in places where they will have a clear view of any approaching predators. This approach however only mitigates predation at bird feeders and the feeding of wildlife presents other unintended knock-on effects.

2.3.1.4. Bells, CatBibs and other anti-predation devices

There are several devices available which aim to reduce a domestic cats' ability to catch prey. These include belled collars (Ruxton et al. 2002; Woods et al. 2003), pounce protectors (Calver et al. 2007) and collar-mounted electronic sonic devices (Nelson et al. 2005). There are many conflicting opinions on the efficacy of bells in reducing domestic cat predation. In Australia, early studies showed that bells had no effect on predation (Trueman 1990; Paton 1991; Barratt 1998). In New Zealand, Gordon et al. (2010) found that bells reduced domestic cat predation by up to 61%. In the UK, with the exception of a study by Maclean (2006), studies found that bells are effective at reducing predation ability by 34-48% (Ruxton et al. 2002; Woods et al. 2003; Nelson et al. 2005). Some studies report that bells are more effective at reducing predation of small mammals than birds (Gordon et al. 2010; Woods et al. 2003) or amphibians (Ruxton et al. 2002). Anecdotal evidence suggests that domestic cats may learn to compensate for the bell (Coleman et al. 1997), though this has not been apparent in studies spanning up to 5 months (Ruxton et al. 2002; Nelson et al. 2005).

Pounce protectors (e.g. CatBib™) are lightweight neoprene bibs worn on a collar which may function as a visual warning to prey and/or as a barrier to paws when pouncing. Calver et al. (2007) found that the CatBib™ reduced the numbers of birds predated by 67%, mammals by 44% and herpetofauna by 24%.

Sonic devices (e.g. CatAlert™) function by emitting an audible electronic "beep" every seven seconds, which may be compared to a bird alarm call; or using lights which are activated when the domestic cat pounces (Nelson et al. 2005). Nelson et al. (2005) found that the electronic device reduced predation by 38% for mammals and 51% for birds. However, Clark & Burton (1998) and Clark (1999) found that the device reduced predation rates of birds by up to 60% but did not affect predation rates on mammals and Maclean (2006) found the device had no significant effect on predation rates of either birds or mammals. There was evidence to suggest the electronic device may cause domestic cats to concentrate their predation upon juvenile birds (Maclean 2006).

Despite the clearly mixed results for each device, collectively such deterrent devices are nevertheless considered to be beneficial in overall efforts to reduce domestic cat predation (Ruxton et al. 2002; Calver et al. 2007). Much of the disagreement between studies is due to the fact that some studies were not well designed. For example, Woods et al. (2003) used a non-experimental approach to determine bell efficacy. The three well designed studies (Ruxton et al.

2002; Nelson et al. 2005; Gordon et al. 2010) all produced very similar results; namely that anti-predation devices are effective at reducing domestic cat predation.

2.3.1.5. Introducing buffers around protected areas

Hunting in relatively undisturbed habitat, especially isolated fragments of natural land may be particularly harmful because these areas may act as the last refuge for isolated populations of wildlife that cannot survive in transformed areas (McKinney 2008). Early studies proposed buffers of 1 km (Barratt 1995) or 500 m (Lilith 2007) in order to exclude almost all roaming domestic cats. A more recent study (Lilith et al. 2008) acknowledged that buffer sizes will need to vary with different regions and recommended a buffer of 360 m around nature reserves or sensitive natural areas, which would exclude a sufficient proportion of domestic cats. A study on the south island of New Zealand found that buffers in rural landscapes would need to be at least 2.4 km wide, while buffers in more urban areas would only need to be half as large due to the difference in home range sizes of domestic cats in rural versus urban areas (Metsers et al. 2010). However, a study in Armadale, Western Australia, found that residents were unenthusiastic about enforcing exclusion zones (Lilith et al. 2006) despite a growing awareness of the impact domestic cats have on native wildlife (Lilith 2007). Thus enforcement of buffer zones is likely to be even more difficult in countries without similar levels of environmental education.

2.3.1.6. Restricting time allowed outside

The British Trust for Ornithology suggests restricting the outdoor activity of domestic cats either spatially by confining them inside, or temporally, through the imposition of curfews (Arnfield 2012). Confinement is however unpopular with domestic cat owners (Grayson et al. 2002; Lilith et al. 2006), who believe that domestic cats will be deprived of essential stimuli and hence lead a less healthy life (Rochlitz 2005). However, provided that there is sufficient quantity and quality of space, domestic cats may live a healthy and long life indoors (Rochlitz 2005), protected as they are from road traffic, fighting conspecifics and potential predators (Rochlitz 2005; Calver et al. 2007; Loyd et al. 2013a). Furthermore domestic cats housed exclusively indoors will no longer be able to hunt and hence bring home prey, an act that many owners find distressing (Nelson et al. 2005). Imposing night-time domestic cat curfew is also an effective way of reducing mammal predation while not completely confining them to a life indoors. Domestic cats tend to move into natural habitat at night, exposing small mammals (which are predominantly nocturnal) to predation (Brickner 2003). Domestic cats that are kept inside at night bring home fewer mammals than cats that are allowed outside at all times (Barratt 1998; Woods et al. 2003) but continue to capture diurnal species particularly birds and reptiles (Lilith et al. 2006). Thus night-time curfews are likely to be less effective in areas with no native mammals, such as New Zealand.

An important phenomenon to take into account when reducing domestic cat numbers or restricting their movements however, is mesopredator release. Reducing predator numbers (or presence) can allow mesopredators, such as rats, to undergo a population boom which may force shared prey to extinction (Crooks & Soule 1999). Thus in areas where rats, or other mesopredators, are present alongside domestic cats it may be prudent to implement rat population management concurrently with management of domestic cats (Courchamp et al. 1999).

In summary the most effective measure to reduce both direct predation and sublethal effects is the physical exclusion of domestic cats through either housing them permanently indoors or rigorously enforcing exclusion buffer zones around natural areas (Metsers et al. 2010; Bonnington et al. 2013). Educating domestic cat owners, and the general public, about the risks to sensitive native wildlife from domestic cats should be an integral and ongoing part of any proposed solution (Gillies & Clout 2003), although this should not be the only approach as groups of people often have very entrenched views (Peterson et al. 2012). Stakeholders should be engaged in ways to collect and judge data on the predation impact of domestic cats (Peterson et al. 2012). Where this is not logistically possible results should be framed directly rather than abstractly, such as reporting "cats kill wild animals" rather than "cats contribute to global declines among songbird populations" (Peterson et al. 2012).

2.3.2. Legislation

Some local councils in Australia have implemented, or are considering implementing, regulations to reduce predation by domestic cats (Anderson 1994; Lilith et al. 2006). Legislation varies greatly between countries and even cities but typically includes provision for registration of pet cats, maximum numbers of domestic cats per property, prohibitions on domestic cats entering nature reserves, incentives for sterilisation and night-time curfews (Dickman 2009). In conjunction with such legislation many municipalities provide information packs to increase awareness on the impact of domestic cats on wildlife (Dickman 2009). Studies have indicated that surveyed communities support sterilisation of domestic cats and other such legislation that promotes responsible domestic cat ownership, but show less support for legislation for domestic cat exclusion zones or that restricts ownership (Grayson et al. 2002; Lilith et al. 2006). However, Lilith et al. (2006) found that domestic cat exclusion measures may be more acceptable to communities near nature reserves, especially those containing sensitive native wildlife. In Canberra, 24-h domestic cat confinement was chosen as the best way to allow owners to keep their cats and maintain domestic cat welfare while protecting threatened native wildlife in nearby conservation reserves (Baird et al. 2005). In 2011 Western

Australia introduced the *Cat Act 2011* which requires that all domestic cats that have reached 6 months of ages are microchipped, sterilised and registered with the local government (Government of Western Australia 2013). A study carried out in Armadale, Australia, took advantage of differing domestic cat regulations in different areas to test the hypothesis that prey species diversity and abundance is higher in areas where domestic cat ownership is restricted. The three regimes of regulation, in operation for over 10 years already, were a no-cat zone, compulsory belling along with a night-time curfew and no regulation. Intriguingly, they found that vegetation characteristics were more important in determining species abundance and diversity than the presence of domestic cats (Lilith et al. 2010).

2.3.3. Conversion/correction rate to predation estimates

When free-ranging domestic cats capture prey they may eat it at the capture site, leave it in the field or return it to the home and either abandon it or eat it (Fitzgerald & Turner 2000). Up until recently, most studies on domestic cat predation were based on counts of prey brought home (Churcher & Lawton 1987; Barratt 1997b, 1998; Ruxton et al. 2002; Woods et al. 2003; Gillies & Clout 2003; Lepczyk 2004; Baker et al. 2005, 2008; Morgan et al. 2009; George 2010; Gordon et al. 2010; van Heezik et al. 2010; Tschanz et al. 2010; Peters 2011; Thomas et al. 2012; Krauze-Gryz et al. 2012). This method thus provides an estimate of minimum prey captures as it excludes prey killed and either consumed or abandoned in the field. From 31 observed kills, Kays & DeWan (2004) estimated that kill rates were over three times higher than those estimated by counts of prey returned home while Maclean (2006) found that cats killed eight times more prey than they brought home. Krauze-Gryz et al. (2012) used both scat analysis and prey collection to determine predation rates of domestic cats in central Poland and found that the prey-brought-home method underestimated small prey, thus underestimating the overall predation rate for domestic cats. A study in Virginia, USA, monitored 55 domestic cats over a year using KittyCam video cameras. They found that only 23% of prey items were returned to the home, 49% of items were left in the field and 28% were eaten (Loyd et al. 2013b).

Prey type and prey fate may be intimately connected (Loyd et al. 2013b). Domestic cats may preferentially bring small prey items back to the home, eating large items at the capture site (Carss 1995). Palatability is another factor likely to influence prey fate (Krauze-Gryz et al. 2012) with for example highly unpalatable shrews (Family: Soricidae) being more likely to be brought home than better tasting voles (Subfamily: Arvicolinae) that are more frequently eaten *in situ* (Fitzgerald & Turner 2000). Invertebrates are eaten more often than they are brought home (Krauze-Gryz et al. 2012) and both reptiles and amphibians were either eaten or left at the capture site in 14 out of 16 cases (Loyd et al. 2013b). It is also possible that the further away the kill takes place from the home,

the less likely the domestic cat is to return it to the home (Maclean 2006). Clearly there is a need to determine the proportion of prey caught that is brought back to the home. This correction factor could be applied to predation studies that have focused only on prey brought back to the home, allowing us to improve our understanding of the total impact of domestic cat predation.

2.4. This study

The overwhelming majority of studies on the impact of domestic cat predation have been carried out in the developed world, predominantly in Australia, New Zealand, the U.K., the U.S. and Canada. To date, only four studies of this kind have been conducted on the African continent. Two of these focused on feral cats (Tennent & Downs 2008; Tennent et al. 2009) and the other two focused on domestic cats kept as pets (George 2010; Peters 2011).

Domestic cats are likely to have arrived in southern Africa in the early 18th century with the arrival of European colonists. However, unlike in Australia and New Zealand, prey populations in the area were already adapted to coexisting with a wide variety of small carnivores, including foxes, jackals, otters, weasels, polecats, meerkats, genets, civets, honey badgers and many species of wild cats (e.g. African Wild Cat, *Felis silvestris lybica*; Small Spotted Cat, *Felis nigripes*; Serval, *Leptailurus serval*; Caracal, *Caracal caracal*; Cape leopard, *Panthera pardus*). The presence of these carnivores may explain why the reported densities of domestic cats in Cape Town, South Africa, 80-300 domestic cats/km^2 (George 2010; Peters 2011) are lower than the 400 domestic cats/km^2 which is the typical density of domestic cats in Great Britain (Sims et al. 2008), where there are relatively few indigenous carnivores (Langley & Yalden 1977). Studies have shown that carnivores may be adversely affected by other members of the guild (Karanth & Sunquist 1995; Palomares et al. 1995) often through exploitative competition and interspecific killing (Caro & Stoner 2003). In Cape Town, it is possible that domestic cats may be constrained by the presence of several other predators which persist within Table Mountain National Park including caracal, several species of mongoose and many species of birds of prey. A preliminary study estimated that domestic cats in Glencairn, an outlying suburb in Cape Town, catch over 7000 prey items a year. A broader study, encompassing the Cape Peninsula, estimated that domestic cats in Cape Town kill 3.6 million animals a year. Both George (2010) and Peters (2010) based their estimates only on prey brought back to the home and thus may have dramatically underestimated predation. Therefore there is a need to produce a correction factor in order to derive a more accurate estimate of predation rates of domestic cats in Cape Town.

2.4.1. Study area

The study was based in the city of Cape Town in the Western Cape of South Africa. The city is home to an estimated 200 000 domestic cats (George 2010) occurring at densities of 80-300 domestic cats/km^2 (George 2010; Peters 2011), including an unknown (but assumed to be large) number of feral cats. The city surrounds the Table Mountain National Park (TMNP), a protected area which was proclaimed in May 1998 (Forsyth & van Wilgen 2008). There is no buffer zone between residential areas and TMNP making it accessible to both domestic and feral cats (George 2010). TMNP is home to a wide variety of native wildlife that may be targeted by domestic cats, many of which are red-listed by the IUCN or endemic to the region (Appendix 1).

2.4.2. Hypothesis

It is hypothesised that the prey returned to the owners' house by domestic cats is an accurate reflection of the predation rate in the wild.

2.4.3. Aims

This aims of this study were;

- To determine what proportion of prey domestic cats bring home compared to those caught but left or eaten in situ
- To provide a correction factor to determine more accurate domestic cat predation rates estimated from previous prey-return studies in Cape Town
- To determine activity budgets, hunting patterns and diet of domestic cats living on the urban edge relative to those living in a dense residential area
- To add to existing research on the potential impact of domestic cats on fauna within urban areas and TMNP.

3. METHODS

3.1. Study site

The study was conducted in the residential suburb of Newlands, in Cape Town, South Africa (Figure 1). Newlands (33.97°S, 18.45°E) is considered to be an up market residential area with approximately 2034 households providing housing for an estimated 5100 people (City of Cape Town 2012b). Most houses are free standing, single- or double-storey buildings with no high-density multi-storey apartments. Newlands is bordered on its western edge by TMNP, which includes endangered Granite

Fynbos vegetation, remnants of surviving indigenous afro-temperate forest and pine plantations. To the north and west is similar residential housing while to the South is the Kirstenbosch National Botanical Gardens.

TMNP extends from Signal Hill (S33° 55' 00", E18° 24' 16") in the north to Cape Point (S34° 20' 45" E18° 29' 14") in the south, along the mountain range that covers most of the Cape Peninsula. The national park covers a total area of 265 km² (Forsyth and van Wilgen, 2008) and is almost completely surrounded by residential suburbs (Hout Bay and the Atlantic seaboard in the north-west, Cape Town CBD in the north, Southern Suburbs in the east, and the South Peninsula in the south-east) and the Atlantic ocean. TMNP is part of the Cape Floristic Region, a biodiversity hotspot (Myers 1990) that supports a wide range of both flora and fauna (Appendix 1) endemic to the region. Despite the high conservation status of the region there are numerous threats to existing biodiversity including urbanization, fragmentation, spread of invasive alien species, climate change and pollution (Barnes 2000).

3.2. Study design

To obtain a sample of domestic cats for use in this study I was reliant on the voluntary participation of domestic cat owners in the study area. Recruitment of domestic cat owners was achieved using door-to-door surveys, neighbourhood mailing lists, online surveys, questionnaires and posters (Appendix 2) which were placed at veterinarian offices and pet shops in the area. Domestic cat owners were given a brief summary of the goals of the study and asked if they were willing to volunteer their domestic cats for participation. Similar to Loyd et al. (2013), when recruiting volunteers I emphasised that I was researching "what cats do and where they go", rather than "how their hunting behaviour may impact other fauna". This is potentially important when attempting to obtain an adequate sample size as domestic cat owners may be wary of how research can impact policy and legislation that may curb ownership and freedom of movement of their domestic cats (George 2010).

The questionnaire (Appendix 3) requested the following information:

- the number of pet cats owned;
- whether cats were fed once, twice or more per day;
- whether cats were allowed out during the day only, during the night only or during both the day and night;
- each cat's age, weight and sex;
- whether the cats had been sterilised;
- whether they wore a collar;

- whether they wore a bell;
- and whether each cat brought home prey or not.

The data from these surveys allowed me to firstly calculate the density of domestic cats in Newlands and secondly to select domestic cats for a comparison of the diet of urban edge versus deep urban cats.

3.2.1. Population size and density estimates of domestic cats

I estimated the average number of domestic cats per 100 households from my surveys and then multiplied this by the total number of households in Newlands (City of Cape Town 2012a) to provide a population size estimate for domestic cats in this suburb. I then divided this value by the total area estimate for Newlands suburb of 350 hectares to derive a density estimate.

3.2.2. Choice of domestic cats

The data from questionnaires were collated and a total of 14 domestic cats were selected for the behaviour and predation components of the study. Seven domestic cats were chosen from the urban edge, i.e. households with no barrier to movement into TMNP; and seven domestic cats were chosen from deep urban areas, i.e. households in built up areas greater than 500 m from the edge of TMNP and/or impeded by a four lane highway. The study cats were chosen to be as similar to each other as possible in order to control for potential confounding variables. Only free-ranging, sterilised active hunters between the ages of 1–7 years were chosen. The number of nights spent outside (Barratt 1998), sex (Maclean 2006) and age (Woods et al. 2003; Gillies & Clout 2003; George 2010; van Heezik et al. 2010; Loyd et al. 2013b) are considered to be the strongest predictors for differences in hunting behaviour and the number of prey caught. Younger pets are likely to capture a greater number of prey than older cats (Woods et al. 2003; Gillies & Clout 2003; George 2010; van Heezik et al. 2010; Loyd et al. 2013b). Choosing sterilised domestic cats is presumed to reduce sex-linked behaviours such as roaming and territorial disputes between males in particular (Maclean 2006). Households with domestic cats that met the selection criteria above (hereafter referred to as "participants") were contacted and asked if they would allow their domestic cat to participate in the study. When a volunteer owned more than one domestic cat that met the general selection criteria, I randomly chose one individual for inclusion in the analyses, to avoid pseudo-replication caused by non-independence of domestic cats owned by the same household (e.g. Nelson et al. 2005).

3.2.3. Equipment

To collect data on activity budgets, habitat use and predation events of free-ranging domestic cats I used the Eyenimal Cat Videocam (hereafter referred to as “kitty-cam”) (Figure 2). The kitty-cam is 4.1 cm by 4.4 cm by 2.5 cm, weighs 32 g and is mounted on commercially available break-away cat collars. The average domestic cat weighs approx. 4 kg (Ward 2007), thus the kitty-cam represents <1% of the body weight of the study animal. This percentage is well below the limit (5%) typically considered to be accepted for mammals carrying any recording equipment (Loyd et al. 2013b). The battery of the kitty-cam can record 2-2h30 of domestic cat activity before needing to be recharged. The camera has infrared LED lights enabling the recording of data in dimly lit places and at night-time. Video footage was downloaded by participants and then stored on 16 GB flash drives. The study design was vetted and approved by the University of Cape Town Science Faculty Animal Ethics Committee (2013/V28/RS).

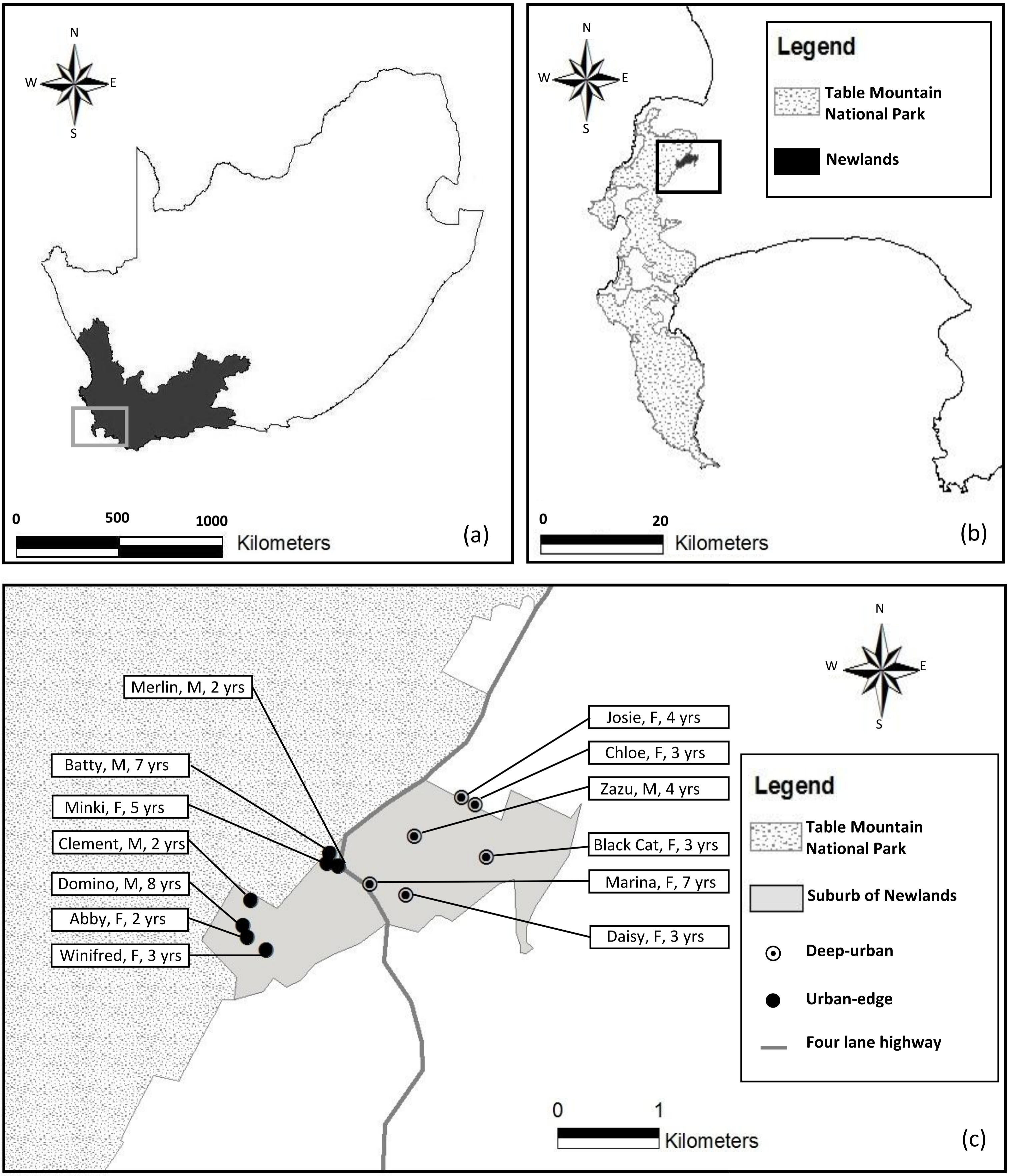

Figure 1: Map of study area: a) Location of Cape Town in the Western Cape of South Africa, b) Location of Newlands on the Cape Peninsula including the Table Mountain National Park, c) Locations of the 14 cats that were studied using kitty-cams in summer 2013.

Figure 2: The Eyenimal Cat Videocam has infrared lights for recording data on domestic cat movement and predation during daylight, in dimly lit places and during night-time forays. The plastic clip allows the angle of the camera to change when the domestic cat moves its head. Markers were placed on the back of the kitty-cam in order to facilitate identification and retrieval if lost.

3.2.4. Study protocol

The behaviour and predation components of the study had three phases; habituation, experimental and observational. During habituation, domestic cats were fitted with a kitty-cam and allowed to become accustomed to it over 48 h. Each domestic cat has its own routine, including patterns of feeding, socializing and preferred resting areas. If the domestic cat's behaviour did not return to normal patterns (as assessed by the owner) within the 48 h then the collar was removed and the domestic cat was excluded from the study.

Participants whose domestic cats habituated to the kitty-cams were provided with a kitty pack (Figure 3) which included a collar with emergency-release catch (Figure 4), two kitty-cams, a USB cable for downloading footage and charging kitty-cams, four 16 gb flash drives upon which to save the kitty-cam footage, sealable plastic bags for each of the five weeks of the study in which to store prey returned to the house and a sachet of cat food to placate the cat after fitting the collar. Participants were also provided with a study timetable, and a questionnaire (Appendix 3) for recording prey brought home.

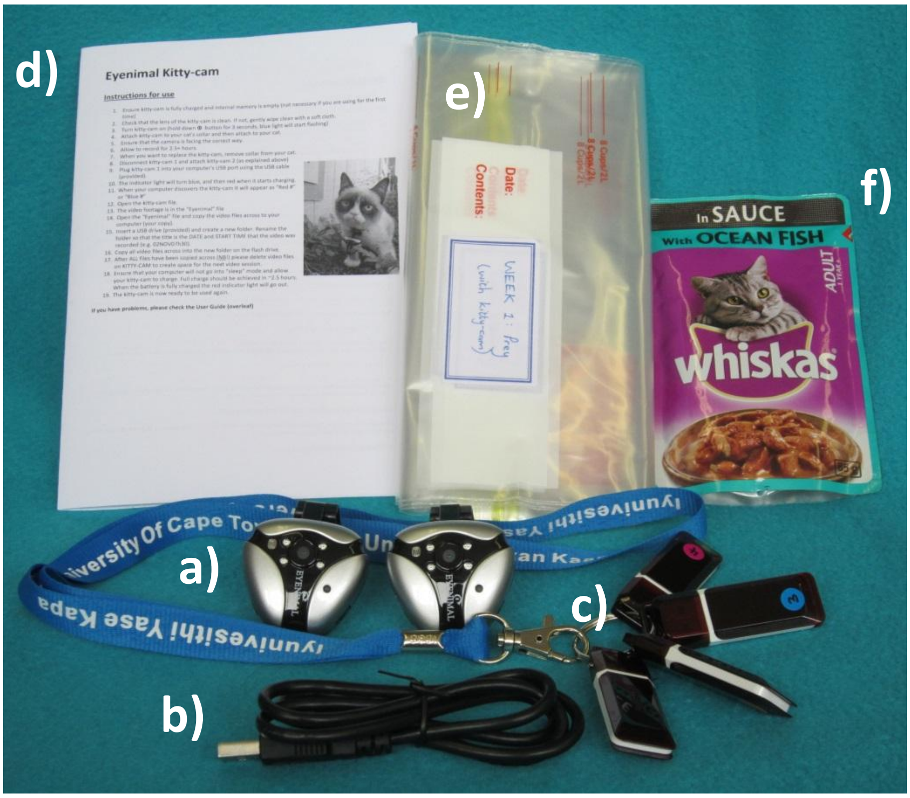

Figure 3: Participants were provided with an emergency release collar (not pictured) and a kitty pack which contained; a) two Eyenimal Cat Videocams (hereafter "kitty-cams"), b) a USB cable for attaching kitty-cams to a computer for charging and footage download, c) four 16 gb USB drives upon which to store kitty-cam footage, d) a kitty-cam instruction manual, e) re-sealable plastic bags in which to store prey for each of the five weeks of the study and f) a sachet of cat food to distract the cat from collar fitting.

Figure 4: Commercially available break-away cat collars were used to suspend the kitty-cam from the cat's neck to ensure that cats would not harm themselves if the collar were to get stuck.

The experimental stage ran for 3 weeks from 2-23 November. Participants placed kitty-cams on their cat as frequently as possible over the 21 day period (Figure 5). The provision of two kitty-cams allowed owners to use the devices in relay; charging, recording and downloading one camera while the other was deployed increased the total number of recording hours. Participants were requested to record footage during both the day (between 06h00-17h00) and night (between 20h00-02h00) within the designated time frames. Owners were asked to continually monitor and report any changes in behaviour while the cat was carrying the kitty-cam.

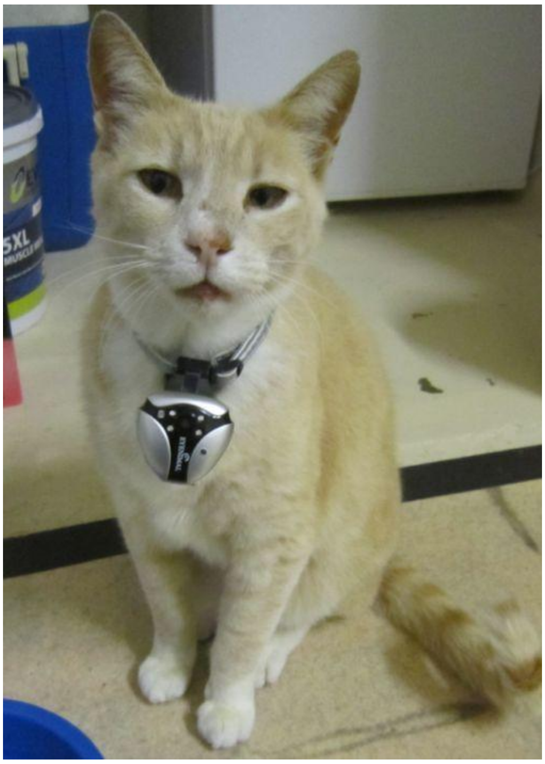

Figure 5: The Eyenimal Cat Videocam hangs below the cat's chin, facilitating easy viewing of any prey captures.

Participants were also asked to record the number of dead and living prey items brought in by their cat. The methods used for recording prey were similar to those employed by Churcher & Lawton (1987), Barratt (1998), Gillies & Clout (2003), Woods et al. (2003), Baker et al. (2005), Morgan et al. (2009), van Heezik et al. (2010) and (George 2010). Participants were provided with a prey questionnaire (Appendix 4) which requested information on:

- The date and time prey was returned
- Type of prey
- Number of prey items
- Status of prey (e.g. released, killed and left intact, partially eaten, or eaten)

Participants were also provided with plastic sealable bags (Figure 3) and asked to freeze dead prey items for collection and identification. Where prey items were returned to the home alive, participants were asked to take a photograph before releasing it. Prey for which there were not photographic records and which were described as for example 'mouse' or 'small bird', were classified by their taxa and the species listed as unidentified.

The observational stage was started immediately after the experimental stage and ran for 2 weeks, during which time kitty-cams were not worn by the cats. As in the experimental stage, participants

were asked to record the number of dead and living prey items brought in by their cat. This stage was used to assess whether prey capture and prey return rates by cats were affected by the cat wearing a kitty-cam/collar.

Emails, telephone calls and house visits were initially made at least twice a week to all participants. This was done in attempt to both encourage participants and standardise their data collections methods.

3.3. Data analyses

3.3.1. Prey type and prey rates

Prey items were grouped by taxonomic class and common major prey items were identified down to species level wherever possible. Prey were also classified according to whether they were alien or native species to the Western Cape.

3.3.2. Questionnaire

The study cats were all confirmed by their owners as being active hunters. Thus any overall predation rate formulated from the number of prey these cats brought home would overestimate the overall predation rate because it excludes the many cats that do not hunt. The estimate for total prey returned was therefore corrected by increasing the number of cats by 49% (Table 1). This figure is based on the ratio of hunters to non-hunters in the studies by George (2010) and Peters (2011) to provide a more representative overall predation rate (of prey brought home) for Newlands.

Table 1: The number of domestic cats that did not bring prey back to the home in studies by George (2010), Peters (2011) and an average between these in Cape Town, South Africa as well as sample size and season that the study was carried out.

Study	No. cats that did not hunt	Total number of cats sampled	Season	% cats that did not hunt
George (2010)	32	78	Spring/summer	41
Peters (2010)	19	27	Winter	70
Total	51	105		**49**

Using prey brought home, daily predation rates were calculated for both deep-urban and urban-edge cats by dividing the total number of prey items returned by the total number of record-keeping days. The overall daily predation rate was calculated by dividing the total number of prey items returned by

the total number of record-keeping days divided by the total number of cats (adjusted, Table 1). Hourly predation rates were calculated by dividing the total number of prey per day by 24 h. The proportion of prey items in each category (i.e. small mammals, birds, reptiles, amphibians and invertebrates) was determined for both deep-urban and urban-edge cats. Prey species diversity was calculated for both deep-urban and urban-edge cats using Simpsons indices. Hourly predation rates were also calculated for both deep-urban and urban-edge cats by dividing the number of prey recorded on camera by the total number of hours recorded.

Non-parametric tests were conducted on the data obtained from the questionnaires. Wilcoxon matched pairs tests were used to test for a difference in prey brought home between the experimental and baseline stage of the predation component of the study (to determine if the wearing of kitty-cams influenced predation rates). Mann-Whitney U tests were used to test for predation rates differences between deep-urban and urban-edge cats. Mann-Whitney U tests were also used to test for differences in Simpsons diversity indices between deep-urban and urban-edge cats.

3.3.3. Video analysis

Only cats for which at least 15 h of footage were obtained were included in the final analyses (n=10). I used seven volunteers to process the 400 h of video footage. In order to reduce observer bias I trained volunteers over two days to recognise behaviours, habitats and predation events. Each volunteer was then tested against my own analyses and were only allowed to proceed to analysing study footage once their observations were 80% (for behaviours) and 90% (for habitats) in agreement with mine. Solomon Coder 14.01.14 (http://solomoncoder.com/, Copyright 2014 by András Péter) was used to produce activity- and habitat-use budgets from the footage. The processing of video footage took a total of 13 days and the volunteer consistency tests were repeated on day 3 to ensure continued observer consistency. Each volunteer was assigned a specific cat which allowed them to familiarise themselves with that cat's environment and general behaviour and improved the speed with which these variables could be recorded. Volunteers were encouraged to take regular breaks in order to prevent error associated with viewer fatigue.

Volunteers recorded the behaviour, roaming habitat, duration of video recording, and all predation events for each cat for each day. Roaming habitat was categorized as house, garden, structure, road/pavement, greenspace and wild (e.g. within natural fynbos vegetation or pine forest within the TMNP) (Table 2). Behaviours included rest, groom, locomote, scan, feed, drink, socialise (person, cat or dog) and predation behaviours (stalk, carry, play or eat) (Table 3). Time spent in each habitat was quantified by summing the number of seconds spent in that habitat and this was converted to a percentage by dividing it by total number of seconds in that focal. Time spent engaged in each

behaviour was similarly calculated. I summed the video hours collected for each participating cat to define a ‘‘total video hours’’ variable. Each video session recorded, for each cat, was considered to be a single focal sample (mean number per cat= 17, mean duration=1.8 h, range=0.1-2.8 h) which was then classified as a daytime or night time focal. I averaged all day and night focals for each cat to derive an average activity budget and an average habitat budget for each cat. From these data I determined both the daily and hourly predation rate for each cat. I organised prey into three categories by the number of bites it would take to consume them: small (1-3 bites, included invertebrates and geckos), medium (4-30 bites, included amphibians, shrews, nestling birds) and large (30+ bites, included adult birds, squirrels, rats, and a Cape mole-rat).

Table 2: Habitats in which 10 free-ranging domestic cats were recorded over 3 weeks in summer 2013 in Cape Town, South Africa.

Habitat	Description
House	Inside the house
Garden	Inside the garden, e.g. lawn, patio, flowerbed, etc.
Structure	On top of a wall, window sill or roof
Road/pavement outside house	Outside of the garden and on the road, verge or pavement
Greenspace	Outside of the garden but still in green area, not natural
Wild	Outside of the garden and in native vegetation e.g. fynbos

Table 3: Behaviours which free-ranging domestic cats were recorded performing over 3 weeks in summer 2013 in Cape Town, South Africa.

Behaviour	Description
Rest/sleep	Resting or sleeping
Groom	Grooming e.g. licking fur, scratching, etc.
Eat	Eat e.g. cat food, grass (not prey)
Drink	Drink e.g. water
Scan	Staring and observing, occasionally glancing from side to side
Locomote	Locomotion e.g. walk, jump, etc.
Socialise	Socialising with person, cat, dog e.g. play, stroke, etc.
Predation	Prey handling e.g. stalk, carry, play, eat, etc.

Non-parametric tests were conducted on the data obtained from the kitty-cams. Wilcoxon matched pairs tests were used to test for differences between percentage time cats spent in different habitats or devoted to different behaviours between the day and the night. Mann-Whitney U tests were used to test for differences in the frequency with which deep-urban and urban-edge cats performed various

behaviours and their time spent in different habitats. Wilcoxon matched pairs tests were used to test for differences between hourly predation rates calculated from prey brought home and prey recorded on camera. I used a generalised linear model to test the relationship between prey size and prey fate. I used linear regression to examine the influence of demographic predictors (including age and video hours) on the number of prey captured by cats exhibiting hunting behaviour.

3.3.4. Prey capture correction factor and overall predation estimate

George (2010) calculated the overall predation impact of Cape Town's cats on prey populations as follows:

Minimum total prey take per year = 365 x N x PR (of DU)
Average total prey take per year = 365 x N x PR (of UE + DU)
Minimum total prey take per year = 365 x N x PR (of UE)

Where:

N = estimated cat population in Cape Town (City of Cape Town 2012a)

PR = daily predation rate

DU = deep-urban cats

UE = urban-edge cats

UE + DU

= deep-urban and urban-edge cats combined

In order to calculate the average impact of Cape Town's cats on their prey I averaged the overall predation rate of all cats (deep-urban and urban-edge combined) from this study and the studies by George (2010) and Peters (2010). This predation estimate used the rates only derived from the number of prey that cats brought home.

I produced an updated corrected predation estimate, including all prey caught (including prey brought home, eaten and abandoned) using my "kitty-cam" correction factor. The correction factor was calculated from the total proportion of prey that were not returned to the cat's home in my study.

I estimated the population of cats in Cape Town by multiplying updated census data on the number of households in Cape Town (City of Cape Town 2012a) by my updated estimates of the number of cat-

owning houses per hundred households and the average number of cats per cat-owning household. I then combined my predation estimate with that of George (2010) and Peters (2011) multiplied by the estimated population of cats and multiplied by my correction factor to produce a more accurate estimate of the maximum, mean and minimum prey killed per year by domestic cats in Cape Town.

4. RESULTS

4.1. Domestic cat density

Based on the door-to-door surveys of 106 households in Newlands, an average of 24.5/100 households had at least one domestic cat with an average 1.8 cats/cat-owning household. Similar results were obtained from 43 questionnaires (1.84 cats/house). With 2 034 houses in Newlands in an area of 350 ha the density estimate for cats in Newlands is 257 cats/km^2. An average of 18 cat-owning households per 100 households and 2 cats per cat-owning households was determined for Cape Town (Table 5) by combining density estimates from this study and that of George (2010). Using these estimates the density of cats in Cape Town (2 455 km^2) is thus 157 cats/km^2.

Table 4: Demographic estimates for domestic cats in Cape Town, South Africa from George (2010), this study and corrected estimates. Estimates include the number of cat-owning households per 100 households (hh), cat density per household (as calculated from door-to-door surveys) and an average of each.

Study	Area	Cat hh/100 hh	Cat density/hh
George (2010)	Glencairn Heights, Hout Bay	12	2.2
This study	Newlands	24.5	1.81
Average estimates		**18**	**2.0**

4.2. Study cats

The mean age (±SD) of the deep-urban cats (4 ± 1.5 years) was similar to that of urban-edge cats (4 ± 2.5 years). The median age of the deep-urban cats (3 years) was younger than that of urban-edge cats (5 years). There was a greater percentage of males in urban-edge cats (57%) compared with deep-

urban cats (17%) (Table 6). Of the 13 cats, 31% were fed twice a day and 69% were fed more than twice a day.

Table 5: Total number of cats studied in Newlands, Cape Town; the mean number of cats per household and their sex. Figures in brackets represent ranges.

	No. of cats	Average no. cats/household	Sex	
			Male	Female
Deep-urban	6	2 (1-3)	1	5
Urban-edge	7	2.1 (2-3)	4	3
Total	13	2.1 (1-3)	5	8

4.3. Prey brought home - questionnaires

4.3.1. Experimental vs. baseline stage predation

There was no significant difference (n=7, T=14, Z=0, p=1) in the number of prey brought back to the home (n=13) between the three weeks of the experimental (with kitty cams) stage (mean= 1.69 ± 2.78) and the two weeks of the baseline stage (mean=1.62 ± 2.22) (Figure 6).

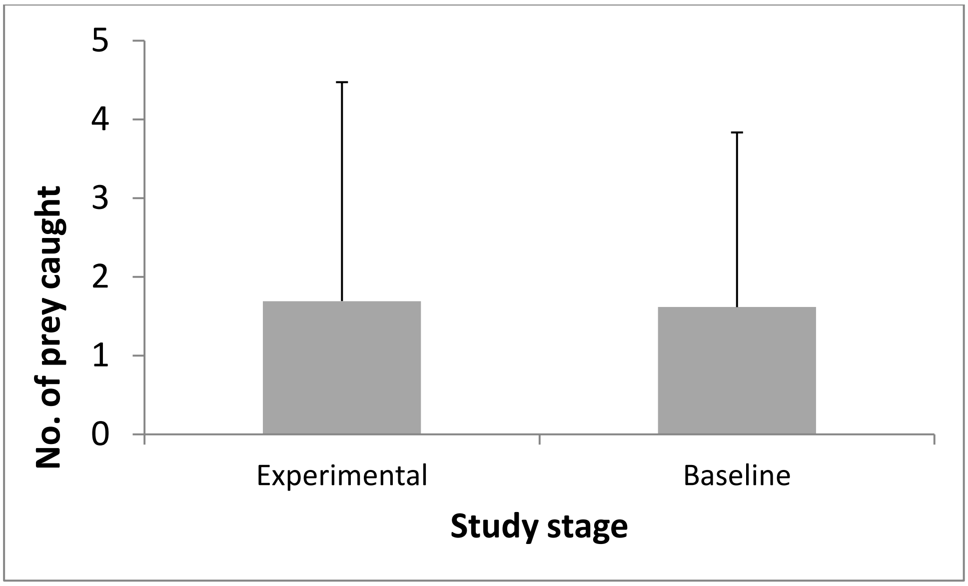

Figure 6: Mean number of prey (with standard deviation) brought home by free-ranging domestic cats in the experimental and baselines stages of the predation component of the study in summer 2013 in Cape Town, South Africa.

4.3.2.Prey composition

4.3.2.1. Prey type

Of the 13 study cats, six (46%) did not bring any prey back to the home and seven (54%), brought home at least one prey item during the study period (Figure 7). A total of 43 prey items were returned by these seven cats (Table 7), 42% of which were small mammals, 30% invertebrates, 12% reptiles, 9% amphibians and 7% birds (Figure 8).

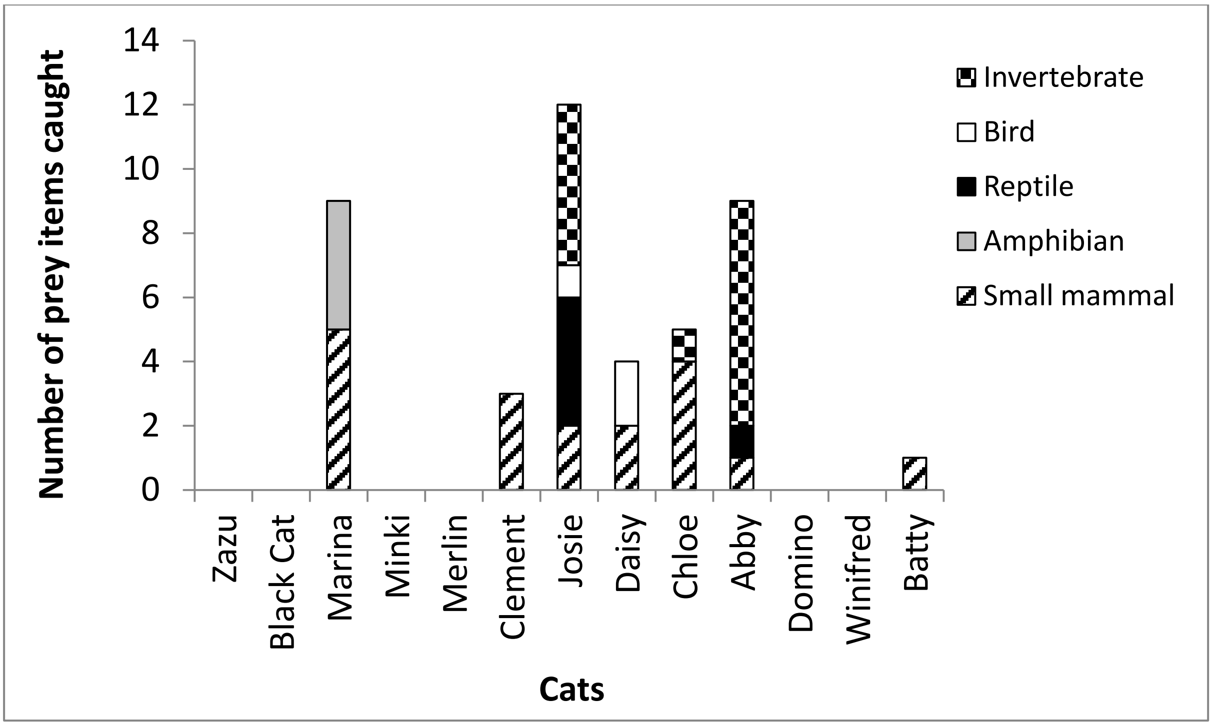

Figure 7: The total number of different types of prey (invertebrate, bird, reptile, amphibian and small mammal) that the 13 individual cats brought back to the home (recorded by owners) in 5 weeks in summer 2013 in Cape Town, South Africa.

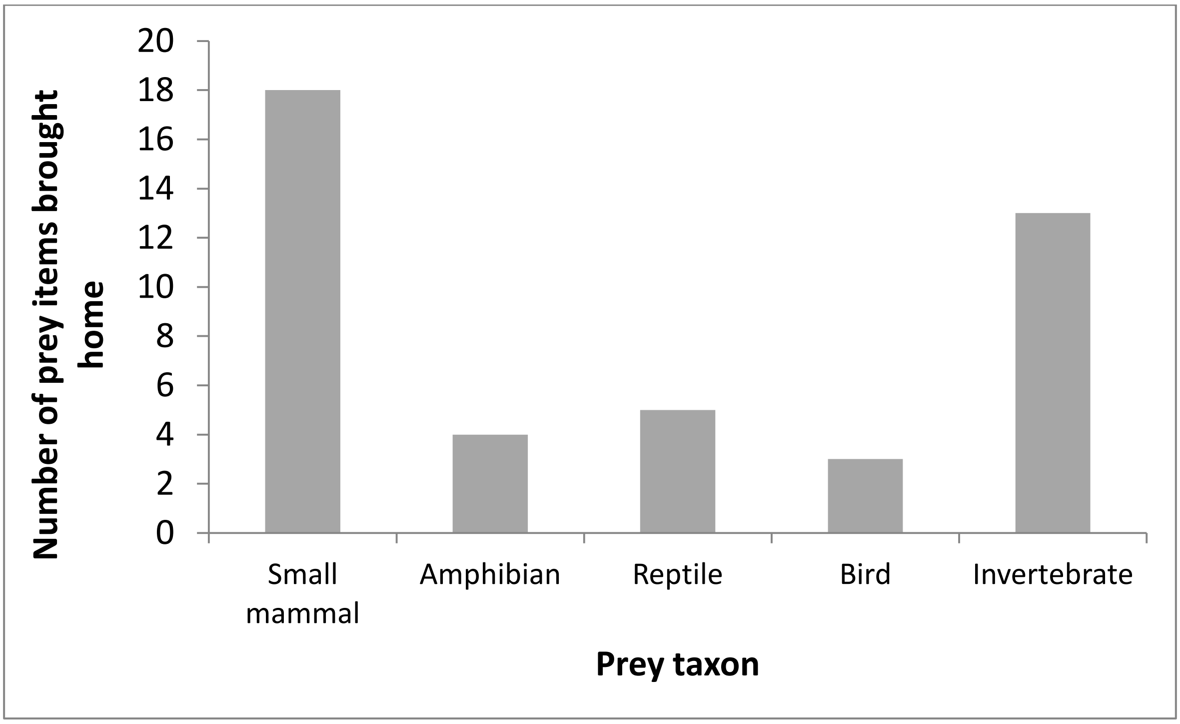

Figure 8: The total number of prey items in the different prey groups that were brought back home (recorded in questionnaires by owners) by 13 free-roaming domestic cats over 5 weeks in summer 2013 in Cape Town, South Africa.

4.3.2.2. Native vs. alien prey

Of the prey identified to species level, five small mammal species were apparent, in addition to two reptile species, one amphibian species and one bird species (Table 7). The most common species from each taxon were the Cape Golden Mole (*Chrysochloris asiatica*) (n=5), the Marbled Leaf-Toed Gecko (*Afrogecko porphyreus*) (n=4), the Cape River Frog (*Amietia fuscigula*) (n=4) and the Cape White-Eye (*Zosterops pallidus*) (n=1). Of the invertebrates recorded (n=13) 46% were butterflies, 15% were Melolonthid beetles, 15% were cicadas and the remainder comprised crickets, praying mantises and spiders. None of the identified prey were species of conservation concern (Table 7)

4.3.2.3. Deep-urban vs. urban-edge cat

Deep-urban cats (n=6) brought home a total of 30 prey items over a 5-week period. Of these 42% were small mammals, 20% were invertebrates, 13% were reptiles, 13% were amphibians and 10% were birds (Species are listed in Table 6). Urban-edge cats (n=7) by contrast, brought home less than half the number of prey (13 prey items) over the same time period, comprising 38% small mammals, 54% invertebrates and 8% reptiles. There was no significant difference between prey categories caught by deep-urban and urban-edge cats (Table 7). Neither was there any significant difference (n=13, U=14.50, p=0.391) between the Simpsons diversity index for deep-urban cats (Median = 0.67) versus urban-edge cats (Median = 0).

Table 6: Prey recorded brought home (questionnaires) over 5 weeks by 13 free-ranging domestic cats in summer 2013 in Cape Town, South Africa (UI = unidentified species).

Prey category	Common name	Latin name	IUCN status	No. of prey items captured
Reptiles	Marbled Leaf-Toed Gecko	*Afrogecko porphyreus*	Not listed	4
	South African Slugeater	*Duberria lutrix*	Not listed	1
	Total			5
Mammals	Cape Golden Mole	*Chrysochloris asiatica*	Least Concern	5
	Cape Mole-rat	*Georychus capensis*	Least Concern	1
	Lesser Dwarf Shrew	*Suncus varilla*	Least Concern	4
	Shrew (UI)	Family: Soricidae		2
	Four-striped field mouse	*Rhabdomys pumilio*	Least Concern	1
	Eastern grey squirrel	*Sciurus carolinensis*	Alien	1
	Rat (UI)	Rattus spp.	Alien	3
	Mouse (UI)	Order: Rodentia		1
	Total			18
Invertebrates	Christmas beetle (UI)	Family: Melolonthidae		2
	Butterfly (UI)	Order: Lepidoptera		6
	Cicada (UI)	Family: Cicadidae		2
	Cricket (UI)	Family: Gryllidae		1
	Praying mantis (UI)	Mantis spp.		1
	Spider (UI)	Class: Arachnida		1
	Total			13
Birds	Cape White-Eye	*Zosterops pallidus*	Least Concern	1
	Nestling passerine bird (UI)	Order: Passeriformes		2
	Total			3
Amphibians	Cape River frog	*Amietia fuscigula*	Least Concern	4
	Total			4
	Grand total			**43**

Table 7: Median number of prey caught (recorded in questionnaires by owners) of prey types over 5 weeks and their associated U, p and n values of deep-urban and urban-edge cats in summer 2013 in Cape Town, South Africa.

Prey	Deep Median no. caught	Edge Median no. caught	Mann Whitney U -test	p-value	n
Small mammal	2	0	12.00	0.225	13
Amphibian	0	0	17.50	0.668	13
Reptile	0	0	20.00	0.943	13
Bird	0	0	14.00	0.353	13
Invertebrate	0	0	18.00	0.721	13

4.3.3. Predation rates

The mean number of prey brought back by deep-urban cats (5.0 ± 4.82, n=6) was not significantly different (U=12.5, Z=1.14, p=0.25) to the mean number of prey brought back by urban-edge cats (1.9 ± 3.34, n=7). The mean daily predation rate of deep-urban cats (0.14 ± 0.14, n=6,) was not significantly different (U=12.5, p=0.253) to that of urban-edge cats (0.05 ± 0.10, n=7).

4.3.4. Average predation in Cape Town

An average daily predation rate of 0.04 prey items per cat in Cape Town was determined from prey brought home (Table 8). This estimate was determined using the sum of prey brought home (in this study and the studies by George (2010) and Peters (2010)) divided by the sum of the number of cats in the study (adjusted in the case of this study, see Table 1), divided by the sum of the number of study days.

Table 8: Mean daily predation rate of free-ranging domestic cats in Cape Town averaged from three studies. Determined using the number of prey brought home, number of cats in the study (adjusted to include non-hunting cats in the case of this study) and number of study days from this study and the studies by George (2010) and (Peters 2011) (SD = standard deviation).

Study	No. of prey brought home	No. of cats (*adjusted)	Study days	Prey/cat/day ± SD
George (2010)	286	78	84	0.04 ± 0.01
Peters (2011)	32	27	42	0.03 ± 0.03
This study	43	26*	35	0.05 ± 0.12
Average				0.04 ± 0.01

4.4. Behaviour and habitat use by cats with kitty-cams

All cats returned to their usual routine after 2 days of carrying the kitty-cam. I collected footage over a 3 week period from 10 of my 13 cats and included these 10 in my final video analyses. The remaining three cat owners collected very little or no video data due to continuous technical difficulties with the cameras. Over 50% of the cameras malfunctioned at some stage due to faulty connections (D. September, pers. comm., 8 December 2013). I nevertheless had an average of 39 ± 20 h (range=16-72 h) of footage per cat and a total of 394 h of footage.

4.4.1. Predation success

Nine cats (90%) were witnessed stalking or chasing prey and made a total of 23 successful captures (Table 10). I recorded 26 independent stalking or chasing events that did not result in a capture. Thus out of 49 (23 successful + 26 unsuccesful) stalking events the proportion of successful predation attempts preceded by stalking was 23/49, or 47%. The number of hours monitored before witnessing hunting behaviour varied widely by cat (Mean = 8.1 ± 5.8 h; Range 1-17 h). The number of prey items captured varied between cats (Mean = 2.3 ± 2.5; Range 0-8). Frequent hunters did not appear to specialise in a particular prey type (Figure 9). Two cats (Black Cat and Minki) were observed to catch prey when monitored by kitty-cam (Figure 9) but these two cats were never observed bringing prey home by owners (Figure 7).

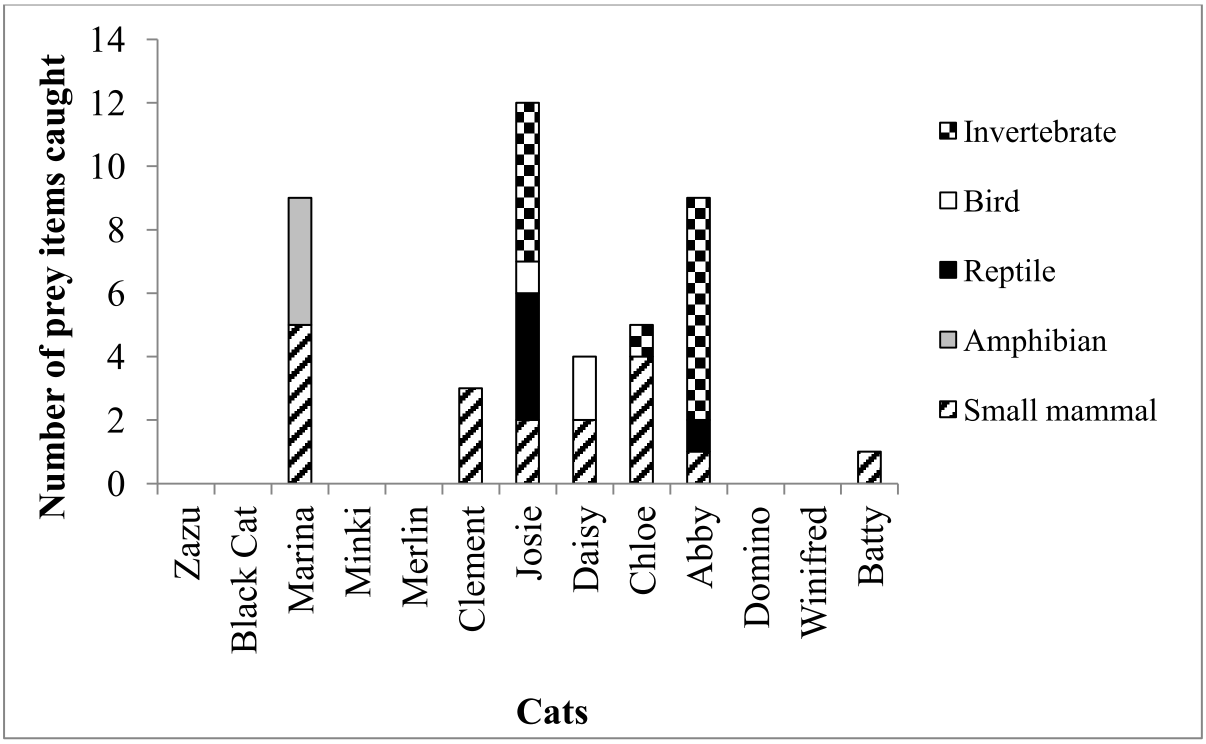

Figure 9: Total number of prey (n=23) caught by 10 free-roaming domestic cats monitored by kitty-cam video cameras over 3 weeks, in summer 2013 in Cape Town, South Africa.

4.4.2. Prey composition from kitty-cam footage

Reptiles were the most common taxa of prey captured (n=10, 44%) and all of these prey items were Marbled leaf-toed geckos (*Afrogecko porphyreus*). The second most common taxa of prey included invertebrates (n=6, 26%), followed by small mammals (n=6, 26%) and amphibians (n=1, 4%). Of the prey identified to species level, one small mammal species was apparent, in addition to one reptile species and one amphibian species (Table 10). The most common species from each major category were the Cape Golden Mole (*Chrysochloris asiatica*) (n=1), the Marbled Leaf-Toed Gecko (*Afrogecko porphyreus*) (n=10) and the Cape River Frog (*Amietia fuscigula*) (n=1). Of the invertebrates recorded (n=6) 33% were stick insects and the remainder comprised a bumblebee, butterfly, moth and an unidentified insect. None of the identified prey were of conservation concern (Table 10).

Table 9: Prey recorded caught using kitty-cam camera devices on 10 free-ranging domestic cats over 3 weeks in summer 2013 in Cape Town, South Africa.

Prey category	Common name	Latin name	IUCN status	No. of prey items captured
Reptiles	Marbled leaf-toed gecko	*Afrogecko porphyreus*	Least Concern	10
	Total			10
Mammals	Cape Golden Mole	*Chrysochloris asiatica*	Least Concern	1
	Rat (UI)	Rattus spp.		2
	Shrew (UI)	Family: Soricidae		2
	Mammal (UI)			1
	Total			6
Invertebrates	Bumblebee (UI)	Class: Insecta		1
	Butterfly (UI)	Order: Lepidoptera		1
	Moth (UI)	Order: Lepidoptera		1
	Stick insect (UI)	Order: Phasmatodea		2
	Insect (UI)			1
	Total			6
Birds	Total			0
Amphibians	Cape River frog	*Amietia fuscigula*	Least Concern	1
	Total			1
	Grand total			**23**

4.4.3. Predation rates from kitty-cam footage

The mean hourly predation rate (±SD) for deep-urban cats was 0.02 ± 0.03 and for urban-edge cats was 0.08 ± 0.09. The difference between hourly predation rates of deep-urban and urban-edge cats was not significant ($p>0.05$). There was no significant difference ($T=8.00$, $Z=1.718$, $p=0.086$) between the mean hourly predation rates calculated from prey brought back to the home (i.e. questionnaire data) (0.005 ± 0.005 prey per hour) compared with prey recorded caught on camera (0.050 ± 0.066 prey per hour).

4.4.4. Fate of prey captured, and correction factors

Sixty-five percent of all prey items seen to be caught (n= 23) were eaten, 13% were abandoned and only 22% were brought home (Figure 10). Thus of 23 prey known to be caught, the majority (78%)

were never seen by the cat owner. We can therefore use these estimates to correct estimates in previous studies that relied on questionnaires only. A study that has used prey brought home to estimate total prey caught and predation rates, may be corrected by multiplying the value by a correction factor of 1/0.22 or 4.55 in order to produce a true estimate of total prey caught.

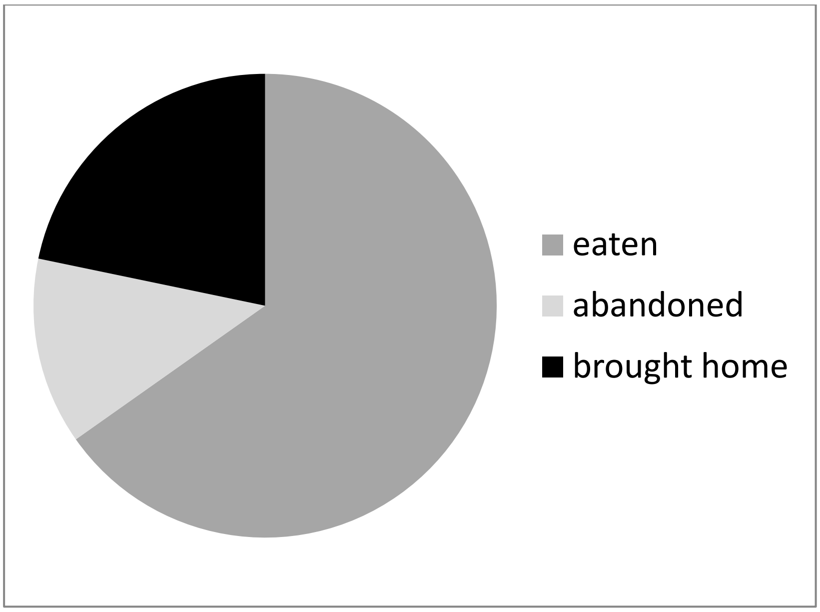

Figure 10: The proportion of prey caught by 10 domestic cats that was eaten, brought home or abandoned as monitored by kitty-cam video cameras over 3 weeks, in summer 2013 in Cape Town, South Africa.

Of the mammals recorded (n=6) 67% were brought home and 33% were eaten (Figure 11). All amphibians (n=1) (100%) were brought home. Ninety percent of reptiles (n=10) were eaten and 10% were abandoned. Of the invertebrates recorded 67% (n=6) were eaten, 33% were abandoned and none were brought home.

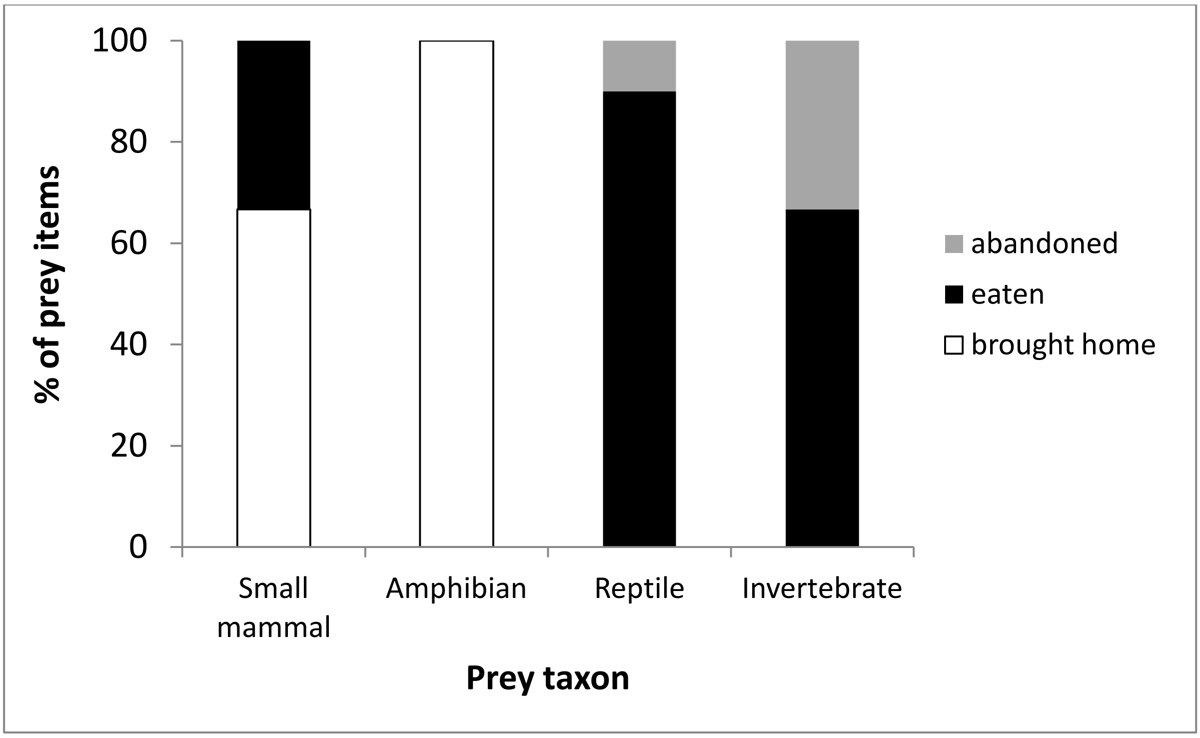

Figure 11: The fate (abandoned, eaten, brought home) of each taxon (small mammal, amphibian, reptile, invertebrate) captured by 10 free-ranging domestic cats as recorded by kitty-cams in summer 2013 in Cape Town, South Africa.

The proportions of prey brought home versus not brought home (i.e. eaten or abandoned) were significantly different (χ^2=31.95, df=1, p<0.001). The majority of prey not brought home was categorised as small (74%), 17% was categorised as medium and 9% was categorised as large. However, there was no significant factor effect between the size category of prey and prey fate (Table 10).

Table 10: Statistical values exhibiting no significant factor effect between prey size (small, medium, large) and prey fate (brought home, eaten, abandoned) of prey caught by 10 domestic cats as recorded by kitty-cams in summer 2013 in Cape Town, South Africa.

Prey item size	Z	p-value	n
Large	0	1	2
Medium	0.602	0.547	4
Small	-1.584	0.113	17

An increase in video hours recorded was not correlated with increased number of hunts (y = 0.029x + 0.7556, R^2 = 0.068, p = 0.80). Neither was cat age related to the number of prey cats caught (y = -0.0492x + 4.3805, R^2 = 0.020, p = 0.75).

4.5. Re-assessing the overall predation impact of Cape Town's domestic cats

Using a correction factor of 4.55, I corrected and updated total annual predation estimates formulated by George (2010) (Table 11). Using the average rate of predation for deep-urban and urban-edge cats combined in the Cape Town suburbs (0.04 prey/cat/day, Table 9), I estimated 25, 835, 506 animals are caught per year by domestic cats in Cape Town. The estimated predation impact of Cape Town cats thus averages about 26 million prey per year.

By averaging the prey spectrum caught while wearing kitty-cam video cameras I estimated the approximate impact on different prey types. The majority of these prey (44%) would comprise reptiles (11 million individuals). Invertebrates would account for 26% of all prey or 7 million individuals; small mammals would account for 26% or 7 million individuals and amphibians would account for 4% or 1 million individuals.

Table 11: Corrected predation estimates for Cape Town, South Africa. This study found that domestic cats only bring back 22% of the prey they catch back to the home. Daily predation estimates were formulated from deep-urban cats (minimum), urban edge cats (maximum) and the two combined (mean) for George (2010). Daily predation estimates were formulated from a study in winter (Peters 2011) (minimum), this study which was carried out in summer (maximum) and the average predation of this study and those of George (2010) and Peters (2010). Predation estimates from this study were converted using the correction factor (4.55) (hh = households; CT = Cape Town).

							Prey/cat/day			Prey impact/year		
Study	Census year	Population of Cape Town	Cat hh / 100 hh	Cats / hh	CT hh with cats	Cats in CT	Min predation	Mean predation	Max predation	**Min predation**	**Mean predation**	**Max predation**
George (2010)	2001	708 126	12	2.3	84 975	195 443	0.04	0.05	0.06	2 853 465	3 566 831	4 280 197
This study	2011	1 068 572	18	2	192 343	384 686	0.13	0.18	0.24	18 226 107	25 835 506	33 063 297

4.6. Activity budgets and habitat use

4.6.1. Day vs. night

Cats (deep-urban and urban-edge) exhibited similar activity budgets in both day and night time focals (Figure 12). Cats spent significantly more time socialising in the daytime than at night-time (Table 12). There was no other significant difference in the hourly rate devoted to behaviours between daytime and night-time (Table 12).

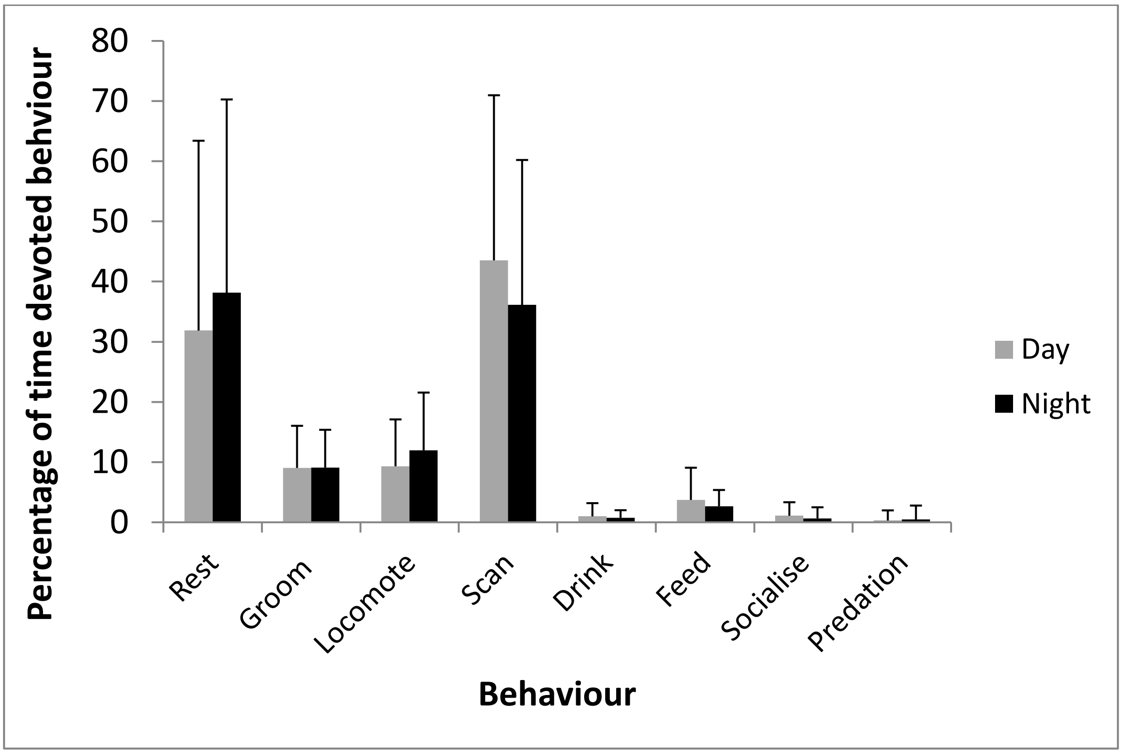

Figure 12: Activity budget depicting the proportion of daytime and nocturnal time 13 cats devoted to different behaviours determined from kitty-cams, in summer 2013 in Cape Town, South Africa.

Table 12: Mean hourly rates (seconds per hour) of behaviours determined from kitty-cams and statistical differences between day and night-time activity for free-roaming domestic cats in summer 2013 in Cape Town, South Africa.

Behaviour	**Day Mean rate/hr**	**Night Mean rate/hr**	**Wilcoxon matched pairs T -test**	**Z**	**p-value**	**n**
Rest	30.4	39.0	19	0.87	0.386	10
Groom	8.4	8.6	25	0.25	0.799	10
Locomote	9.8	12.7	13	1.48	0.139	10
Scan	45.4	35.4	14	1.38	0.169	10
Drink	1.0	0.8	13	1.48	0.139	10
Feed	3.7	2.5	12	1.58	0.114	10
Socialise	1.0	0.6	**2**	**2.6**	**0.009**	10
Predation	0.3	0.4	23	0.46	0.646	10

Cats in different environments (deep-urban vs. urban-edge) exhibited similar habitat use in the daytime compared with night-time (Figure 13). Combined however, cats spent significantly more time in the house at night and significantly more time in the garden during the daytime (Table 13). There was no other significant difference in the hourly rate spent in other habitats between daytime and night-time (Table 13).

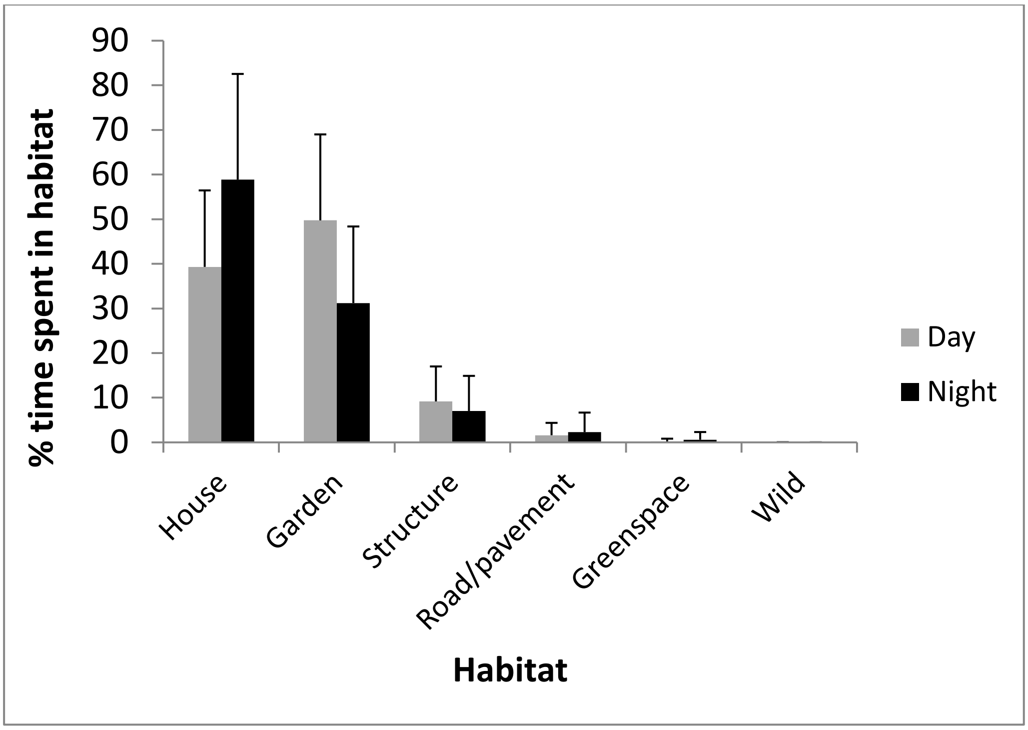

Figure 13: Activity budget depicting the proportion of daytime and nocturnal time cats spent in different habitats, determined from kitty-cams, in summer 2013 in Cape Town, South Africa.

Table 13: Mean hourly rates (seconds per hour) spent in different habitats and statistical comparisons of day versus night-time habitat use for free-roaming domestic cats in summer 2013 in Cape Town, South Africa.

Habitat	Day Mean rate/hr	Night Mean rate/hr	Wilcoxon matched pairs T -test	Z	p-value	n
House	39.3	58.9	**4**	**2.4**	**0.017**	10
Garden	49.7	31.2	**2**	**2.6**	**0.009**	10
Structure	9.2	7.0	17	1.1	0.285	10
Rd/pavement	1.6	2.3	10	0.1	0.917	10
Greenspace	0.2	0.6	1	0.5	0.655	10
Wild	0.0	0.0	-	-	-	-

4.6.2. Deep-urban vs. Urban-edge

Deep-urban and urban-edge cats exhibited very similar activity budgets (Figure 14). There was no significant difference (Table. 14) in the hourly rate deep-urban and urban-edge cats devoted to different behaviours in their different environments (Table 14).

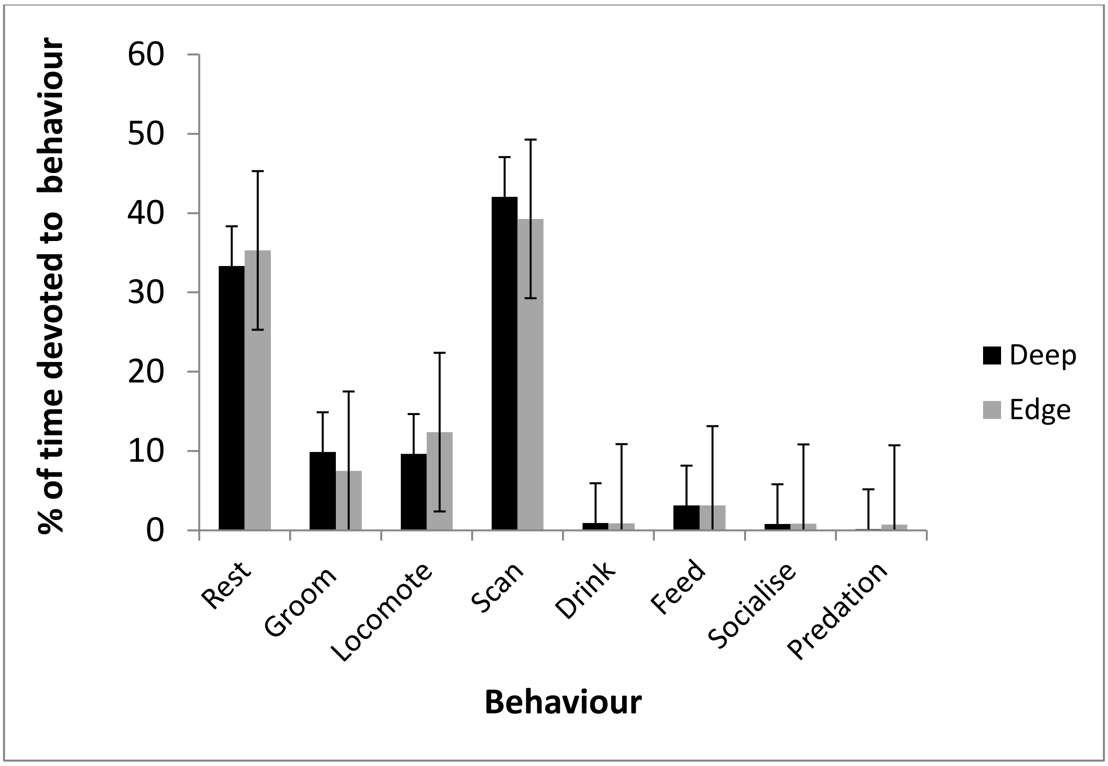

Figure 14: Activity budget depicting the proportion of time deep-urban and urban-edge cats devoted to different behaviours while wearing kitty-cams in summer 2013 in Cape Town, South Africa.

Table 14: Mean hourly rates (seconds per hour) of behavioural activity by deep-urban and urban edge cats and statistical differences between them in summer 2013 in Cape Town, South Africa.

Behaviour	Deep Median rate/hr	Edge Median rate/hr	Mann Whitney U -test	p-value	n
Rest	1422.2	1429.7	12	1	10
Groom	332.2	273.8	8	0.404	10
Locomote	329.4	424.4	7	0.296	10
Scan	1370.5	1296.3	10	0.676	10
Drink	28.4	25.8	11	0.834	10
Feed	91.4	100.9	12	1	10
Socialise	19.9	26.2	9	0.530	10
Predation	6.0	22.9	8	0.403	10

Deep-urban and urban-edge cats exhibited very similar habitat use (Figure 15). There was no significant difference (Table. 15) in the hourly rate of time spent in habitats between deep-urban cats and urban-edge cats.

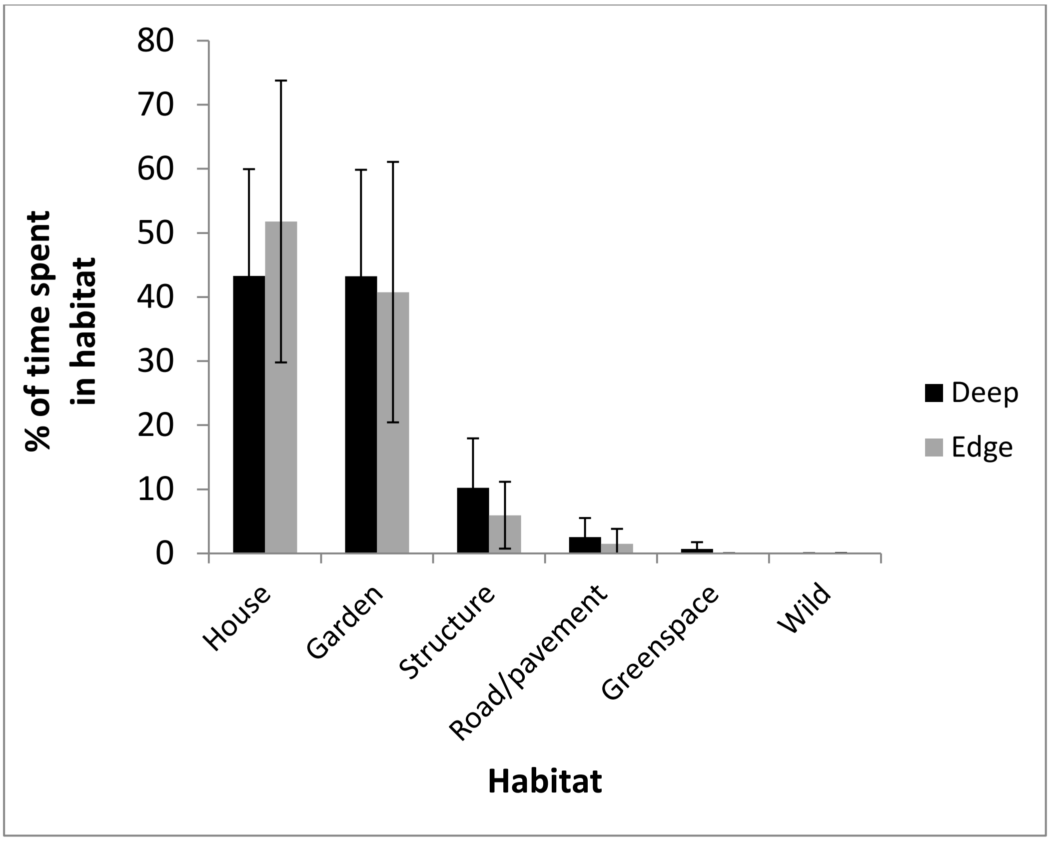

Figure 15: Habitat use depicting the proportion of time 5 deep-urban and 5 urban-edge cats spent in different habitats in Cape Town, South Africa (Summer 2013).

Table 15: Mean hourly rates (seconds per hour) of time spent in different habitats and statistical differences between 10 deep-urban and urban-edge cats in Cape Town, South Africa (Summer 2013).

Habitat	**Deep Median rate/hr**	**Edge Median rate/hr**	**Mann Whitney U -test**	**p-value**	**n**
House	1632.0	2030.6	7	0.296	5
Garden	1480.9	1297.6	9	0.531	5
Structure	367.7	224.2	7	0.296	5
Road/pavement	93.1	47.1	9	0.531	5
Greenspace	26.3	0.0	7	0.347	5
Wild	0.0	0.4	10	0.676	5

5. DISCUSSION

This short study was the first in Africa to use remote technology (i.e. kitty-cams) to determine what domestic cats are catching and how much of what they catch they bring home. Using these methods I have discovered that previous studies in Cape Town and further afield are likely to be underestimating the overall predation rate of cats when using only return-rate methods. This study also assessed activity patterns of cats using the kitty-cams and is the first study to produce an activity budget and habitat use budget for domestic cats. Here I assessed each of these techniques and compare my results with previous studies (Kays & DeWan 2004; George 2010; Peters 2011; Loyd et al. 2013b).

5.1. Kitty-cams

Ten cats were fitted with kitty-cams and all accepted these small and light devices. Cameras provided footage of sufficient quality to allow me to record all prey captures and to successfully identify most prey that were caught and their ultimate fate (i.e. eaten in situ, abandoned, brought home). The infrared lights on the kitty-cam allowed for an assessment of night-time predation too. The only downfall of this method was the poor quality of the cameras provided from Eyenimal. At least fifty percent of the cameras failed to charge or connect to a computer and would not work thereafter. This delayed the study while other cameras were acquired and led to a reduced final sample size of cat behaviour.

Kitty-cams are an effective tool for collecting data on what cats catch. Due to the location of the cameras (around the neck, just below the cat's chin) stalking, chasing and capture events were easy to identify. If prey was not visible during stalking or the chase, it was usually clearly visible once caught as it hung in front of the camera lens. Due to the frequency of release and re-capture events, there were often multiple opportunities to identify prey to species, or at least to identify whether it was native or alien to the area.

5.2. Correcting for prey not brought back to the home

Analysis of footage from the Kitty-cams found that cats bring home less than a quarter (22%) of the total prey they catch. My results thus support those of Loyd et al. (2013b) who reported that only 23% of prey were returned. This suggests that studies investigating predation by domestic cats, using only prey brought back to the home, may consistently underestimate predation.

Two cats which were never observed by owners to bring home prey were found to have caught prey using kitty-cams. This is important to establish because studies which assume that such cats do not catch prey would significantly underestimate predation rates (Baker et al. 2005; van Heezik et al. 2010). Conversely, three cats which were observed by owners to bring home prey were not recorded by the kitty-cam to catch prey. It is likely that this is an artefact of the small number of recording hours or possibly that kitty-cams affected the hunting ability of these cats more than other cats in the study.

5.3. Population size and density

By averaging cat density values from Newlands (this study), Glencairn (Peters 2011) and the greater Cape Town area (George 2010) I estimated the population of domestic cats in Cape Town to be 400 000 animals. This is likely to be an overestimate as the three areas sampled to date are middle- to upper income areas where cats are more common than, for example, in informal settlements (Y. Robson in George 2010). There are very few cats living in informal settlements due to the large number of feral dogs living in these areas (R. Simmons, pers. comm., 7 August 2013). I estimated the density of domestic cats in Cape Town to be 157/km^2 which is lower than cat densities recorded in other parts of the world (Baker et al. 2005; Sims et al. 2008). However, this is a very rough estimate and should be treated with caution.

5.4. Domestic cat predation in Cape Town

After adjusting my estimate to include cats that do not hunt I derived a predation estimate of 0.05 ± 0.12 prey items per cat per day. This summer-hunting predation estimate is greater than that derived in winter by Peters (2010) (0.03 ± 0.03 prey/cat/day) and that derived in spring/summer by George (2010) (0.04 ± 0.01 prey/cat/day). Domestic cats are known to hunt less in wetter seasons and catch higher numbers of prey in summer and autumn (Konecny 1987; Maclean 2006). Very few birds (7%) were caught in this study compared with George (2010) (13%). This may be because the previous study was carried out in spring, when many birds are fledging young in South Africa (Hockey et al. 2005) and the amount of time spent hunting birds is at its highest (Lepczyk 2004; Baker et al. 2005; Maclean 2006; van Heezik et al. 2010). Seasonal variation in catch is typical in other studies (Churcher & Lawton 1987; Barratt 1997b; Fitzgerald & Turner 2000).

In order to derive a predation estimate I assumed that all participants were equally competent and reliable in recording prey brought home. Participants may have been concerned about recording how much prey their cat brought home (and thus under-reported) in case the findings led to stricter

enforcement of pet cats (Maclean 2006). Emails, telephone calls and house visits were initially made at least twice a week to participants during the study period in order to encourage participants to remain diligent and consistent. Errors may also have arisen when a household contained more than one cat as prey items may have been assigned to the wrong cat. However, most cat owners seemed confident of which cat had brought in which prey item, because the cats often call attention to their prey.

5.5. Corrected Cape Town predation estimate

I derived an average overall daily predation rate of 0.04 prey per cat per day for Cape Town's cats by combining data from the predation component of this study with data from two previous studies in Cape Town (George 2010; Peters 2011). This estimate, based on a total of 118 cats over 3 different years, was then corrected for prey caught but not brought back to the home and converted to a yearly average predation rate. I estimated that a population of approximately 400 000 domestic cats in Cape Town catches over 25 million prey items per year. In the previous study, George (2010) used a correction factor of 3.3 as recommended by Kays & DeWan (2004) in order to account for prey not brought back to the home and estimated that cats in Cape Town may catch as many as 11.9 million prey items a year. This estimate is still less than half my corrected overall predation estimate for domestic cats in Cape Town.

It is essential to note that my estimate is subject to several assumptions. I assumed that the predation rate of cats in this study and those of George (2010) and Peters (2010) is representative of prey caught by cats in the whole of Cape Town. As the daily predation rates for this study and the previously mentioned studies were very similar, I concurred that it was safe to assume representativeness. The data used to formulate this new estimate were from studies carried out in winter, spring and summer (George 2010; Peters 2011) and so were fairly representative of the seasons. However, autumn predation has not yet been recorded. Autumn predation is likely to be lower than summer predation (Maclean 2006) and thus the estimate is once again likely to be an overestimate. In order to fine-tune this estimate, longer-term studies must be carried out in Cape Town, encompassing a broader range of suburbs.

5.6. Prey spectrum (kitty-cam vs. questionnaire vs. other studies)

Reptiles (45%) were the most common prey taxa caught in this study using kitty-cams. This was in contrast with many studies worldwide (Table 16) as well as a previous study in Cape Town (George 2010) which found that reptiles only make up a small percentage (25%) of prey caught. Importantly

Table 16: Percentages of different prey types returned by owned domestic cats reported in the published literature. Averages and standard deviations included. Adapted from Loyd et al. (2013).

Reference	Location	Mammals	Birds	Reptiles	Invertebrates	Amphibians	Season
Baker et al. (2005)	UK	86	11	0	0	2	All
Baker et al. (2008)	UK	75	24	0	0	0	All
Barratt (1997b)	Australia	65	27	7	0	1	All
Barratt (1998)	Australia	68	25	6	0	0	All
Churcher and Lawton (1987)	UK	65	27	7	0	1	All
George (2010)	South Africa	44	13	25	16	1	Spring/Summer
Gillies and Clout (2003)	New Zealand	32	14	8	47	0	All
Kays and deWan (2004)	New York, USA	86	14	0	0	0	Summer
Loyd et al. (2013b)	Georgia, USA	26	13	36	20	5	All
Mitchell and Beck (1992)	Virginia, USA	57	21	22	0	4	All
Peters (2010)	South Africa	19	3	62	0	16	Winter
Ruxton et al. (2002)	UK	74	21	0	0	5	Summer
Tschanz et al. (2011)	Switzerland	76	11	0	0	0	Spring/Summer
van Heezik et al. (2010)	New Zealand	34	37	8	20	1	All
Woods et al. (2003)	UK	69	24	4	1	0	Spring/Summer
This study	South Africa	40	7	12	31	10	Summer
	AVERAGE	58.4	19.0	12.3	6.9	2.4	
	STANDARD DEVIATION	22.0	8.7	17.4	13.5	4.2	

Loyd et al. (2013b) had a similar result when using animal-borne cameras on domestic cats in Virginia, USA suggesting that of all taxa reptiles have suffered from the most bias in questionnaire surveys. Reptiles, particularly Marbled leaf-toed geckos in this study, were eaten almost immediately when caught. Marbled leaf-toed geckos are abundant in the Western Cape (Branch 1998) and are likely to have successfully adapted to living in urban residential areas. They are thus not likely to be a conservation concern but, together with the findings of Loyd et al (2013), these results suggest that domestic cats are likely to have a much greater impact on reptiles than previously realised.

The spectrum of prey recorded by owners in questionnaires, was similar to that reported by George (2010). However, these findings differed markedly from the prey spectrum recorded by kitty-cams. Prey recorded in questionnaires in this study over-estimated the percentage of small mammals (42% brought home versus 26% caught) and underestimated the percentage of reptiles caught (12% brought home versus 45% caught). There was also a much greater diversity of prey caught in the South African studies; including this study, George (2010) and Peters (2011), than in studies carried out in other parts of the world (Table 16). This may be due to the proximity of the TMNP to most urban areas in Cape Town, providing cats with a wider range of native prey than cats elsewhere.

5.7. Prey fate

Unlike the study by Loyd et al. (2013b) I found that prey size was not a significant predictor of prey fate, however my small sample size may have lacked the statistical power to detect significance. Palatability has been considered to influence the tendency of cats to eat certain prey items in situ more readily (Krauze-Gryz et al. 2012). For example, shrews are considered to be highly unpalatable (Fitzgerald & Turner 2000; Krauze-Gryz et al. 2012) which may explain why more of these small mammals are brought home than eaten. Thus it might be the palatability of geckos rather than relative size that influences the cats' choice of eating it upon capture. Given that geckos make up a large proportion of the overall diet of the study cats it is possible that palatability may have confounded the predicted relationship with prey size. Carss (1995) suspected that cats only bring home prey that is easy to carry and leave larger more cumbersome items on site. Contrary to this theory, however, the fact that the majority of small prey (i.e. invertebrates and reptiles) are eaten in situ lends credibility to the hypothesis that small prey is more likely to be eaten than larger prey. This could be attributed to the fact that cats are bringing home prey as sustenance for their young, or often their surrogate human family, and thus show preference for bringing home larger prey.

5.8. Urban-edge and deep-urban cats

Unlike many previous studies (Churcher & Lawton 1987; Paton 1991; Dickman 1996; George 2010; Peters 2011) I did not find a difference in predation rates between cats on the urban-edge compared with cats in deep-urban areas. Similar to my findings, van Heezik et al. (2010) found that while cats next to extensive green-spaces often had larger home ranges, they did not catch more birds. Furthermore, there was no difference in prey diversity between the urban-edge and deep-urban areas (e.g. McMurry & Sperry 1941; Jackson 1951; Eberhard 1954; Fitzgerald & Turner 2000). Moreover, there was no difference in the time spent in different habitats or the time devoted to different behaviours between cats in the two areas.

It is possible that the lack of difference between urban-edge and deep-urban cats is due to the fact that gardens in Newlands are large and lush, thus providing less of an incentive to roam into TMNP. The urban-edge in Newlands is also predominantly comprised of pine plantation forest, whereas the urban-edge in studies by George (2010) and Peters (2011) comprised indigenous fynbos vegetation. Plantation fauna and flora are often considered impoverished compared with natural areas (Hartley 2002) and thus fynbos may provide a higher abundance of native fauna. Both factors (more prey diversity in the lush gardens, and lack of prey in the pine plantations) may have added to the lack of differences found in my study relative to George (2010) and Peters (2011) who did report higher rates of predation on the urban edge.

5.9. Day vs. night (habitat, behaviour)

Daytime and night-time behaviour was very similar in the study. The only significant difference was in socialising with non-conspecifics. Cats socialised significantly more during the day than at night. This is to be expected as humans were more available during daylight hours than night time to allow for social interactions with cats. Cats also spent significantly more time in the house at night-time and in the garden in the daytime. It is possible that this is because cats utilised the garden during the daytime when the family was not home and slept in the house at night-time when the family was home and sleeping.

5.10. Densities of cats vs. natural carnivores

Several studies have proposed that domestic cats are occupying the role of natural predators, many of which no longer live in urban areas (Lepczyk 2004; Balogh et al. 2011), and thus the predation rates on native fauna are likely no different to what occurred previously. Cape Town would have been

home to a variety of small- to medium-sized carnivores before extensive habitat transformation and hunting caused the local extinction of many species (Skead 2011). However, even assuming these carnivores were present at previously estimated densities of 20 carnivores/km^2 (Table 17) this is still more than an order of magnitude less than the density of domestic cats in Cape Town (157/km^2). It is unlikely that natural carnivores would be able to subsist in such high densities, however, as carnivores are known to negatively affect those of the same guild through competition and sometimes through direct interspecific killing (Caro & Stoner 2003). Thus the argument that cat predation is compensatory is highly unlikely in the context of Cape Town.

5.11. Limitations and recommendations for further research

My study incorporated a small number of cats over a short period of time. The small sample size means that the study is lacking in statistical power and significant differences may not have been recognised. A larger number of cats should be used in future studies over a longer period of time. Studies assessing predation should be at least a year long in order to assess seasonal changes in predation and hence arrive at more robust annual estimates. I attempted to incorporate seasonal variation into my estimates by combining my findings with those of two studies in the same Department (George 2010; Peters 2011). However, my study was carried out in a different area to those studied previously. As different suburbs likely contain different prey populations cats, as opportunistic generalist predators (Dauphine & Cooper 2009), are likely to catch prey in accordance with their both their relative abundance and ease of capture. There is also an urgent need to study the predation rates of feral cats in Cape Town as feral cats do not rely upon humans for their nutrition and are predicted to have a greater impact on prey populations than domestic cats (Brickner 2003).

Equipment should be well tested before being used in a study that requires public participation. The cameras in this study were very temperamental and this became very frustrating for participants, many of whom became disheartened. Equipment should be reliable and easy to use. A greater battery life of devices would also be helpful.

Concurrent studies on prey availability should be carried out in the areas where cats are studied (e.g. Liberg 1984; Kays & DeWan 2004; Sims et al. 2008; van Heezik et al. 2010; Thomas et al. 2012). This would allow us to explore whether cats are showing a preference for particular prey species.

5.12. Conclusions and conservation implications

Cats in Cape Town only bring back 22% of the prey they catch. My findings closely match those of a similar study in the U.S. (Loyd et al. 2013b) and thus they may be widely applicable as a conversion factor. This conversion factor can be used to correct predation estimates in studies relying only on prey brought back to the home. However, as this correction factor has been determined from only 400 h of observations I would suggest further studies to determine how consistent this factor may be across different continents and islands. An estimated population of almost 400 000 domestic cats in Greater Cape Town may be catching over 25 million prey items a year. The predation rate was extrapolated from a small number of cats in a few areas to all the domestic cats throughout city of Cape Town and thus may incorporate some biases. This estimate is, subject to several assumptions (seasonal differences in predation in particular) and should be taken cautiously. Almost half of these prey items are likely to be reptiles, with small mammals, birds, invertebrates and amphibians making up the balance. None of the prey species in the study were recorded as vulnerable by the IUCN and individually are not a great conservation worry. However, it is important to remember that some of these species may perform important functions within the urban ecosystem (Dearborn & Kark 2010) and they may also provide an opportunity for humans living in the area to interact with biodiversity (Baker & Harris 2007). These functions are important and worth protecting even if the species itself is not threatened (Baker & Harris 2007; Dearborn & Kark 2010). Deep-urban and urban-edge cats did not catch different prey or exhibit differences in habitat use or behaviour. This may be due to the fact that gardens in the study area were lush, providing an incentive for cats to remain inside, instead of venturing out into the national park. This study indicates that cats on the urban-edge in Newlands are not catching more prey or a greater diversity of prey. It is thus unlikely that cats in Newlands are impacting greatly on native species within the park.

Table 17: Likely densities of small- to medium-sized carnivores which may have lived in the Cape Town area before habitat transformation and hunting. Densities are taken from populations of these animals in the Western Cape, where available, or in other similar regions (drawn from the literature).

Common name	**Scientific name**	**Density (animals/per km^2)**	**No. in Cape Town**	**Reference**
Cape leopard	*Panthera pardus*	0.02	49	Cape Leopard Trust (2013)
Caracal	*Caracal caracal*	0.35	861	Avenant & Nel (1998)
African wildcat	*Felis silvestris*	1.2	2 953	Okarma et al. (2002)
Honey badger	*Mellivora capensis*	0.05	123	Waser (1980); Begg (2001)
Serval	*Leptailurus serval*	0.42	1 034	Stephens et al. (2001); Geertsema (1985)
Aardwolf	*Proteles cristata*	1	2 461	Anderson and Mills (2008)
Egyptian mongoose	*Herpestes ichneumon*	1.2	2 953	Maddock (1998)
Marsh mongoose	*Atilax paludinosus*	1.8	4 430	Maddock (1998)
Black-backed jackal	*Canis mesomelas*	0.37	911	Rowe-Rowe (1982)
Common genet	*Genetta genetta*	1.5	3 692	Waser (1980)
Bat-eared fox	*Otocyon megalotis*	3.5	8 614	Malcolm (1985)
Cape fox	*Vulpes chama*	0.3	738	Bester (1982)
Striped Polecat	*Ictonyx striatus*	0.15	369	Hendrichs (1972), cited by Stuart et al. 2008
Yellow Mongoose	*Cynictis penicillata*	6.55	16 120	Cavallini (1993); Cavallini & Nel (1995)
Cape Genet	*Genetta tigrina*	0.8	1 969	Prins & Reitsma (1989)
Total	**15 species**	19.21 animals/km^2	47 276	

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7. APPENDICES

Appendix 1: Endemic and/or threatened fauna (including birds, amphibians and reptiles) occurring in the Table Mountain National Park and the Cape Peninsula which may be vulnerable to predation by domestic cats in Cape Town, South Africa (Branch 1988; Picker & Samways 1996; Barnes 2000)(adapted from George 2010).

Category	Common Name	Scientific Name	Distribution	Conservation Status
Birds	Cape Sugarbird	*Promerops cafer*	Endemic to the Cape Floristic Region	Least Concern
	Orange-breasted Sunbird	*Nectarinia violacea*	Endemic to the Cape Floristic Region	Least Concern
	Cape Siskin	*Crithagra totta*	Endemic to the Cape Floristic Region	Least Concern
Amphibians	Table Mountain Ghost Frog	*Heleophryne rosei*	Endemic to TMNP	Critically endangered(Globally)
	Micro Frog	*Microbatrachella capensis*	Endemic to south-western W. Cape	Critically endangered (Globally)
	Western Leopard Toad	*Amietophrynus pantherinus*	Endemic to south-western W. Cape	Endangered (Globally)
	Cape Platanna	*Xenopus gilli*	Endemic to the W. Cape	Endangered (Globally)
	Cape Rain Frog	*Breviceps gibbosus*	Endemic to south-western W. Cape	Vulnerable (Globally)
	Cape Mountain Toad	*Capensibufo rosei*	Endemic to south-western W. Cape	Vulnerable (Globally)
	Cape Caco	*Cacosternum capense*	Endemic to the W. Cape	Vulnerable (Globally)
	Sand Rain Frog	*Breviceps rosei*	Endemic to coastal areas of the W. Cape	Least Concern
	Cape Mountain Rain Frog	*Breviceps montanus*	Endemic to the W. Cape	Least Concern
	Tradouw Mountain Toad	*Capensibufo tradouwi*	Endemic to the W. Cape	Least Concern
Reptiles	Kasner's Dwarf Burrowing Skink	*Scelotes kasneri*	Endemic to S. Africa	Vulnerable (Globally)
	Cape Sand Snake	*Psammophis leightoni leightoni*	Endemic to southern part of the W. Cape	Vulnerable (Locally)
	Yellow-bellied House Snake	*Lamprophis fuscus*	Endemic to S. Africa	Near-threatened (Globally)
	Namaqua Plated Lizard	*Gerrhosaurus typicus*	Endemic to S. Africa	Near-threatened (Globally)
	Hawequa Flat Gecko	*Afroedura hawequensis*	Endemic to S. Africa	Near-threatened (Globally)
	Gronovi's Dwarf Burrowing Skink	*Scelotes gronovi*	Endemic to S. Africa	Near-threatened (Globally)

Appendix 2: Poster left at veterinarians and pet shops around Newlands to recruit participants for the study.

Ever wonder what your cat gets up to when you're not around?

We are looking for cats in NEWLANDS to participate in a UCT Conservation Biology project.

Participating cats will have to wear a GPS tracker and a kitty-camera to determine:

- Where they go and when
- What they catch
- If cats far from the Table Mountain National Park make an effort to hunt there

If your cat is keen to get involved, please fill out a survey at **www.surveymonkey.com/s/L82C9XT** or contact **Frances Morling.**

Cell: 078 123 9892

Email: frances.morling@gmail.com

Appendix 3: Questionnaire for door-to-door survey in Newlands

Cape Town's Cats and their Prey – Part I

We need your help to estimate **how many pet cats live in NEWLANDS**

The results of this survey will be analyzed for a Master's project in Conservation Biology at UCT. All data and information provided will be treated with confidentiality.

Please fill out this form and I will collect it within 3 days
OR fill out your survey online at:
www.surveymonkey.com/s/L82C9XT

Basic information

1. Number of cats in household ________________
2. How often do you feed your cat(s)?
   - ☐ Once a day ☐ Twice a day ☐ More than twice a day/access to food at all times
3. Do you restrict the movement of your cat(s)?
   - ☐ No, they are allowed outside at all times
   - ☐ Yes, I only let them outside during the day
   - ☐ Yes, I only let them outside at night
   - ☐ Yes, they spend all their time indoors

Cat #	Age	Weight (1-5; 1= underweight, 5= overweight)	Sex (M/F)	Sterilised? (Y/N)	Collar? (Y/N)	Bell? (Y/N)	Brings prey home (Y/N)
1.							
2.							
3.							
4.							
5.							
6.							
7.							

Name and Street address ____

____

____

Email address ____

Contact number ____

Thank you very much for your participation!

Appendix 4: Timetable of study and questionnaire for participants to record prey home brought by cat

Cape Town's Cats and their Prey – Part II

Biological Sciences

We need your help to determine;

- **What your cat catches**
- **How much of what your cat catches is brought back home**

The results of this survey will be analyzed for a Master's project. All data and information provided will be treated with confidentiality. We will provide feedback on the study on completion of the project in 4-5 months time. Thank you very much for your participation!

Please see the study timetable below:

NOVEMBER 2013

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
					1	2 Day Night
3 Day Night	4 Day Night	5 Day Night	6 Day Night	7 Day Night	8 Day Night	9 Day Night
10 Day Night	11 Day Night	12 Day Night	13 Day Night	14 Day Night	15 Day Night	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

(Red) Recording with kitty-cam AND documenting prey brought home
(Blue) Documenting prey brought home

Please attach the kitty-cam to your cat (switched on) between:

DAY	**07h00-15h00**
NIGHT	**20h00-24h00**

… and note down the time you started recording on the timetable above

Kindly fill in the record sheet on p.2 with the prey your cat brings in.
Please freeze prey remains (in labelled bags provided) and we will collect them.

If you are <u>NOT</u> happy to freeze prey items, we will collect the prey item from you. For collection please contact:
Frances (contact details below) OR
Justin O'Riain (between 16-29 November) – at Justin.ORiain@uct.ac.za

If you have any questions or issues please do not hesitate to contact Frances Morling
Frances.morling@gmail.com
078 123 9892

Kindly fill in the record sheet below;
Please indicate the exact date for each entry
Please freeze prey remains (in labelled bags provided) and we will collect them
If your cat brings in live prey, please photograph it or tell us if it is a mouse, shrew, rat, bird, snake, lizard, frog or insect, etc.

EXPERIMENTAL (2 weeks) – with collar and kitty-cam

DATE and TIME	PREY TYPE (please describe in as much detail as possible)	PREY NUMBER
WEEK 1 (2-8 Nov)		
WEEK 2 (9-15 Nov)		

OBSERVATION (2 weeks) – no collar

DATE and TIME	PREY TYPE (please describe in as much detail as possible)	PREY NUMBER
WEEK 3 (16-22 Nov)		
WEEK 4 (23-29 Nov)		

Thank you very much for your participation!

If you have any questions or issues please do not hesitate to contact Frances Morling
Frances.morling@gmail.com
078 123 9892