Mitigating the impacts of pet cats (*Felis catus*) on urban wildlife

Catherine M. Hall BSc. (Hons)

This thesis is presented for the degree of Doctor of Philosophy of Murdoch University

- July 2016 -

Declaration

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

....
Catherine Hall

July 2016

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

ABSTRACT

Pet cats are a very important part of life for many people and provide companionship to millions of people worldwide, from small children to the elderly. However, wandering pet cats may affect wildlife populations through direct predation, competing for prey with higher order consumers, spreading disease to wildlife and humans, exerting sub-lethal effects such as changes in parental behaviour or reduction in clutch size of prey caused by the fear of cat predation, hybridising with wild felids or breeding with stray and feral cats to maintain feral populations. In addition, they may annoy neighbours by disturbing dogs, attacking pet birds, spraying, digging in gardens, fighting (including with other pet cats) and walking on cars. Pet cats that are allowed to wander are also at risk from disease, fights with other animals that may lead to injury infection, and from traffic accidents (one of the leading causes of pet cat mortality). Despite these risks to wildlife and their pets, many cat owners in Australia and other countries such as the UK and New Zealand are reluctant to restrict their cats to their properties at all times. The primary aims of this thesis were to investigate several different precautionary approaches to reducing the risks proposed by predatory interactions between cats and urban wildlife and determine what precautionary measures the wider community considers acceptable.

In association with colleagues from Australia and overseas, I assessed the social attitudes in Australia, the USA, the UK, New Zealand, Japan and China towards pet cats and cat ownership and responsibilities with a detailed survey. We found significantly different results between all countries, indicating that if any legislation was to be imposed regarding pet cats unique approaches would be required in each country. We confirmed that many cat owners will not keep their cats inside, and therefore other methods to prevent wildlife capture and reduce pet cat roaming behaviour are appropriate.

I then examined the effectiveness of the anti-predation collar cover the BirdsbeSafe® (BBS) in reducing predation by pet cats on birds. A range of different colours and patterns are available for this device and I found that some patterns (red and rainbow) were effective at reducing predation on prey with good colour vision (birds and herpetofauna) by 47 – 54%. However, yellow collar covers were not effective at reducing cat predation on birds. The BBS had no effect on the numbers of mammal prey captured. This device is useful for cats that catch many bird or herpetofauna prey and either do not catch, or their owners would like them to catch, mammals such as rats and mice. It is not suitable in areas where there are sensitive small mammal populations. Ninety-six per cent of cats adapted to the BBS within two days, indicating that it will not upset or impede on the welfare of the vast majority of cats as long as collars are correctly fitted and checked regularly.

Previous research on the anti-predation device the CatBib and my own research on the BBS indicated that these devices may alter the roaming behaviour of some pet cats, in most cases with cats reported as staying closer to home. This potentially provides another incentive for owners to fit their cats with these devices to reduce their wandering behaviour. I tested this hypothesis on 30 pet cats wearing either the CatBib or BBS with the use of GPS collars. In addition, I collected data from cats wearing GPS collars but no anti-predation device to determine factors that influence roaming behaviour. I found that neither the CatBib nor the BBS significantly changed the roaming behaviour of pet cats, supporting claims by the manufacturers of the CatBib and the BBS that the devices reduce hunting success while not restricting other behaviours. Thus they do not offer an option to owners wishing to restrict their cats' roaming. The most significant predictor of pet cat home range was housing density, with pet cats living in more rural locations travelling significantly further than pet cats in areas of high housing density.

In order to reduce uncertainty over factors that affect cat predation I used a meta-analysis and mixed linear models to compare all of the studies that used radio-telemetry or GPS to examine cat roaming behaviour. I found that despite most individual studies showing that male cats have larger home ranges than females but no statistically significant difference between the two, comparing all the data concluded that male cats do have significantly larger home ranges than females. I also found that mature cats (over 8 years old) have smaller home ranges than younger adult cats (2 – 8 years old), desexing has no influence on roaming behaviour, husbandry practices (providing vet treatment and socialising cats with humans) did not impact roaming behaviour, and cats living in areas with low housing density (e.g. farm cats or pets on rural properties) had larger home ranges than cats in higher housing density areas.

Ultimately, the best solution to prevent pet cats from impacting wildlife and for their own protection is to keep them confined to their owners' properties at all times. Since this is an unpopular option, education campaigns are required to change the community practices and attitudes towards pet cats so that owners either become more accepting of confinement or more willing to use predation deterrents. Since there are significant differences between different countries in how people perceive cats and the impacts of their wandering behaviour, different approaches are required in different locations. In Australia, and possibly New Zealand, people may change their behaviour based on the effects cats have on some wildlife. However, in countries such as the UK, campaigns should focus on the benefits to cat welfare.

ACKNOWLEDGEMENTS

There are many people whom I wish to thank for their help and support over the last few years.

Firstly, I would like to acknowledge the Murdoch University Research Studentship I received.

I am grateful to the many respondents who gave their time to completing the survey questionnaires. I also wish to thank all the cat owners who kindly volunteered their cats for the various studies and provided me with much entertainment and interesting stories to remember this time.

The BBS were purchased from BBSLLC. The proprietor, Ms Nancy Brennan, commented on an earlier version of the paper presented in Chapter 3 to ensure accurate description of the product and retail information, but had no involvement in study design, data collection, analysis, or the decision to submit the manuscript for publication. Dr Ric How, Ms Claire Stevenson and Mr Ron Johnstone of the Western Australian Museum identified the prey collected for the study presented in Chapter 3.

CatBibs were purchased from CatBib (Authorised Australian Distributor Cat Bib, Gooseberry Hill, Western Australia, http://catbib.com.au). The proprietors, Ms Nancy Brennan for BBS and Dr David Wood for CatBib, commented on an earlier version of the paper presented in Chapter 4 to ensure accurate description of their products. Neither had any involvement in study design, data collection, analysis, or the decision to submit the manuscript for publication. Dr Jeff Short kindly commented on the manuscript of Chapter 4 before submission.

I am grateful to the authors who responded generously to our requests for the original data behind their publications on roaming of pet cats presented in Chapter 5.

I am very grateful for the constant expertise and support provided by my two supervisors Associate Professor Michael Calver and Dr Kate Bryant. I sent many emails and made many phone calls over the last few years and I always received a fast and helpful response and they were always quick to provide constructive feedback on various drafts.

I am very thankful to my family for all the support they have provided me. I especially wish to thank my mother and my mother-in-law for the hundreds of hours of babysitting they have put in to give me a chance to study. And a special thank you to my husband Ben for the constant encouragement and the long work hours to give me a chance to do this and to my little daughter Jodie for her willingness to spend hours in the car visiting various ‘cat people’ and her patience when I had work to do.

To these people and many others I am very grateful.

1 GENERAL INTRODUCTION

This introduction begins with a background of the domestication of cats and the role they play in our society. This is followed by a description of their biology with particular reference to their hunting efficiency and their need for a specialised high protein diet. I then review the impacts that cats (feral, stray and pet) have on native fauna through disease transmission, hybridisation and predation and especially the impact on native fauna in Australia. Although the impact of feral cats on wildlife is well documented, the impact of pet cats on wildlife is more contentious. Since there are plausible risks to wildlife from pet cats I consider the precepts of the precautionary principle and how this can be applied to the situation while uncertainties regarding impacts are resolved. The chapter concludes with a statement of the main aims of the thesis and a description of the thesis structure.

1.1 BACKGROUND OF DOMESTICATION

The wild cat *Felis silvestris* is the ancestor of the domestic cat *Felis silvestris catus* (Faure and Kitchener 2009). *Felis silvestris* was previously divided into several species and races but is now considered one species. Although the domestic cat superficially resembles the European form of the wildcat, *F. s. silvestris*, it is confirmed to be derived from the North African form, *F. s. lybica* (also known as the Near Eastern wildcat), based on genetic, behavioural and archaeological evidence (Bradshaw et al. 2012, Driscoll et al. 2009a, Randi and Ragni 1991).

There is little evidence to determine the exact period of cat domestication from the wild cat *F. silvestris*. Until recently, the earliest known relationship between domestic cats and humans was from cats found buried in Egyptian tombs from 4,000 BC and Egyptian artwork from 1,600 BC where they are depicted participating in human activities such as meal times and hunting (Serpell 2000). By 950 BC they were part of Egyptian religion represented by the cat goddess Bastet (Bradshaw et al. 2012).

However, in Cyprus, remains of a wildcat were found in a shallow grave with an adult human and have been dated to 9,500 years ago (Vigne et al. 2004). However, there is strong debate as to whether this represents a significant relationship between humans and cats at the time or whether the cat was simply a commensal wild species (Linseele et al. 2007, Rothwell 2004, Vigne and Guilaine 2004, Vigne et al. 2004). Remains from a small felid found in Hierakonpolis, Egypt, are dated to around 5,700 years ago and show healed fractures which indicate that the animal was held in captivity prior to its burial. Linseele et al. (2007) argue that this pathology more clearly demonstrates attempts to tame cats than the Cyprus find.

Hu (2014) reports on cat remains found in the agricultural village of Quanhucan in Shaanxi, China, dated between 5,560 to 5,280 years ago. These cats were outside the distribution of the native cat species the Near Eastern wildcat (*F. s. lybica*) and biologically smaller, but within the size range of domestic cats. Analysis revealed substantial consumption of millet-based foods by humans, rodents and cats at the time supporting the theory that cats lived commensally with humans, catching rodents that ate the grain in return for safer nesting places and possible supplementary feeding by humans who encouraged their presence (Bradshaw et al. 2012, Hu 2014).

Domestic cats now can be allocated to different groups based on their behaviour and degree of association with humans: pet cats, semi-feral/stray cats and feral cats. The following definitions are based on Baker et al. (2010) and DSEWPC (2011). Pet cats live in close association with a household where their needs are intentionally provided for by humans. Semi-feral/stray cats rely only partly on humans for provision of their requirements and are free to wander unrestricted and are found roaming through cities, towns and some rural holdings. Feral cats survive without any human contact or assistance. This thesis is primarily concerned with the impact of pet cats on wildlife.

1.2 THE BENEFITS OF KEEPING A PET CAT

In the western world, cats are widely kept as companion animals (Albert and Bulcroft 1988, Selby and Rhoades 1981). In general, their popularity as pets is increasing (Lord et al. 2007, Woods et al. 2003), although ownership is decreasing in Australia (Chaseling 2001).

The extent to which pets are beneficial for human health and well-being is strongly debated, especially with regard to the elderly. Early studies reached positive conclusions about the benefits of pet ownership including fewer visits to the doctor (Headey 1999, Siegel 1990), better physiological health (Straede and Gates 1993) and slightly reduced risk of hospitalisation for female owners (Simons et al. 2000). Brickel (1979) also found that pet cats kept in a geriatric hospital provided pleasure to patients and increased patient responsiveness, which in turn provided satisfaction and encouragement to staff.

However, more recent studies cast doubt on these findings. Winefield et al. (2008) concluded that the health of older people was related to their health habits and social supports, not to their ownership or attachment to a pet. Wells and Rodi (2000) found elderly owners sometimes neglected themselves for their pets, for example by not going to the doctor or hospital because they did not want to leave their pets alone. This may account for fewer doctor's visits. Parslow et al. (2005) found that elderly pet owners were more likely to have poorer mental and physical health, use more pain relief medication and have higher levels of psychoticism.

However, pets (including cats), may also benefit their owners and the broader community through increased social interactions. Favour exchanges, civic engagement, perceptions of neighbourhood friendliness and a sense of community are all positive indicators of social capital associated with pet ownership (Wood et al. 2007).

1.3 SKELETON AND DENTITION

All felids are well adapted to a carnivorous lifestyle and the skeletal form of cats has not changed much with domestication from the wild *F. silvestris* (Bradshaw et al. 2012). They manipulate their prey using their forelimbs (Meachen-Samuels and Van Valkenburgh 2009a) and deliver a strong, killing bite. Based on their elbow and wrist morphology, the forelimbs of cats cannot travel in a 'pendulum' motion like some animals but instead travel in an arch away from the body (Gonyea 1978). The wrist and elbow joints are very mobile, which is indicative of the claw-equipped forelimb being used for hunting (Gonyea 1978). The forelimbs are also very mobile because of the reduction of the collarbone which, together with powerful muscles, gives cats the balance and strength to be very efficient hunters (Bradshaw et al. 2012). This effect is increased by highly mobile joints between the vertebrae (Bradshaw et al. 2012). In addition, cats have an abundance of loose skin between the forelimb and trunk so that when the cat's front leg is fully flexed, the elbow lies with a pocket formed by two layers of skin allowing the elbow to move freely (Brinkley 2007).

The forelimbs are also indicative of prey size preference for cats (Meachen-Samuels and Van Valkenburgh 2009b). Domestic cats have preferences for small prey and therefore have relatively less robust limbs with longer elements when compared to felids that specialise on large prey (Meachen-Samuels and Van Valkenburgh 2009b). Meachen-Samuels and Van Valkenburgh (2009b) suggests that these longer and thinner forelimbs provide a speed advantage for catching small and elusive prey in contrast to large-prey specialist felids that have more robust forelimbs for strength and force.

The skull is also well-adapted for predation. The eye sockets are very large, indicative of a visual predator (Bradshaw et al. 2012), and the skull is foreshortened to optimise bite force at the canines (Meachen-Samuels and Van Valkenburgh 2009a). Felids that specialise on small prey, such as domestic cats, have narrower muzzles, slightly longer jaws and smaller canines relative to felids that specialise on large prey. This gives them a speed advantage in catching their small and quick prey (Meachen-Samuels and Van Valkenburgh 2009a). Dental complexity is low, which is typical of obligate carnivores. However, the teeth are very distinct in shape and structure (Evans et al. 2007). The canines are long and laterally compressed for holding food and dislocating prey vertebrae (Bradshaw 2006) and are equipped with receptors to help sense the precise location for the delivery of the killing bite (Bradshaw et al. 2012). The canines are also sharp which allows them to penetrate the skin and sever the spinal cord (Meachen-Samuels and Van Valkenburgh 2009a). The large carnassials are designed for shearing flesh from bone (Bradshaw 2006) and with the help of the masseter muscle, they cut meat into swallowable pieces (Bradshaw et al. 2012).

1.4 DIET AND DIGESTION

Cats are obligate carnivores and therefore have requirements for nutrients present only in animal tissue (Bradshaw 2006). Unlike other carnivores, they eat no fruit or vegetable matter except for grass (Fitzgerald and Turner 2000). Their digestive system is adapted to carnivory with a short small intestine, rudimentary cecum and a very small colon (Sunvold et al. 1995). Unlike many other mammals, cats have a high requirement for dietary protein and a limited ability to utilise carbohydrates (MacDonald et al. 1984, Zoran 2002). Protein is used as an energy source to maintain blood glucose levels and for structural purposes. Beauchamp et al. (1977) also found that hydrolysed protein, emulsified fats and amino acid solutions strongly stimulate digestion, but that carbohydrates do not.

The ability of cats to digest and absorb carbohydrates is limited. McGeachin and Akin (1979) found that the levels of amylase (an enzyme required for starch digestion) were very low in the saliva. In contrast to some other mammals, amylase is not produced by the salivary glands and exists in substantially lower concentrations in the pancreas (the organ where amylase concentrations are highest in mammals). While is it possible for cats to digest some carbohydrates, when the digestive capacity of the small intestine is exceeded because of excessive starch intake, digestive disorders such as diarrhoea, flatulence and bloating may occur (Kienzle 1994).

The change in diet and lifestyle for cats through domestication (especially in the last few decades) is thought to be responsible for an increase in obesity, insulin resistance and diabetes in pet cats (Verbrugghe et al. 2012). Commercial pet foods often have moderate to high levels of carbohydrates. This has been accompanied by a shift from outdoor to indoor living and less physical activity because they no longer need to hunt (Verbrugghe et al. 2012).

1.5 SENSORY ABILITIES

1.5.1 Vision

Domestic cats have two subsystems for vision. There is a central channel that provides high spatial, temporal and intensity resolution, although this occurs only during daylight and with relatively slow transmission of these signals to the brain. There is also the peripheral channel, which provides effective detection of very weak, increasing and moving signals with rapid transmission to the brain (Shevelev and Polovets 1973). This peripheral system allows them to function at lower light intensities than humans and they are better tuned to detecting rapid movements (Bradshaw et al. 2012). However, they lack the visual detail and ability to discriminate between similar colours, responding to changes in patterns and brightness rather than colour (Bradshaw et al. 2012). Although cats do see colour under daylight conditions, it does not appear to be very meaningful to them. Some believe that cats are behaviourally colour blind, although it may be that they perceive other cues as more important (Bradshaw et al. 2012).

Felids, with the exception of tigers, are nocturnal predators, however changes in the ecology of domestic cats during the process of domestication has meant that they are active both during the day and night (Shevelev and Polovets 1973). Shevelev and Polovets (1973) suggest that the neuronal apparatus of daylight vision in domestic cats could have evolved as a result of domestication because of the strong changes in its ecology. Alternatively they suggest that since their daylight vision is not as effective as it could be, there may have been a partial evolutionary reduction in daylight vision across all cats in their transmission to a nocturnal way of life (Shevelev and Polovets 1973).

1.5.2 Hearing

Cats have one of the broadest hearing ranges of all tested mammals and are unusual in that they have extended hearing at both the high frequency and low frequency ends of the spectrum (Heffner and Heffner 1985). Unlike many mammals, cats do not make ultrasonic calls and therefore it is presumed that this ability allows them to detect these sounds emitted by small rodents (Bradshaw et al. 2012). Cats are also very sensitive to sounds in the middle frequencies (Bradshaw et al. 2012). The biological function of the very wide range of hearing sensitivity in cats is uncertain. Most mammals are only able to hear at either extreme and therefore it is considered very unusual (Bradshaw et al. 2012).

1.5.3 Touch

Cats have several types of mechanoreceptors on their skin which are sensitive to touch and pressure (Bradshaw et al. 2012). Different areas of the skin contain different numbers and proportions of mechanoreceptors, which influence the sensitivity of that area of the body. The nose and pads of the front paws contain the largest numbers and varieties of mechanoreceptors reflecting their use for hunting and manipulating food (Bradshaw et al. 2012). There are very high densities of various types of mechanoreceptors between the foot and toe pads causing very high sensitivity to the speed and direction of movement of a stimulus across the pad (Bradshaw et al. 2012).

There is also a very high density of mechanoreceptors around the face, which may be sensitive to air currents. The largest mechanoreceptors on the face are the whiskers and the large amount of nervous tissue devoted to processing and integrating the information they provide indicates their importance (Bradshaw et al. 2012). Their tapered shape also allows cats to sense the texture of surfaces they are touching (Williams and Kramer 2012). The facial mechanoreceptors may be useful for cats when moving in the dark or in confined spaces and may compensate for their long-sightedness when objects or prey are close to the nose (Bradshaw et al. 2012, Williams and Kramer 2012).

1.5.4 Chemical Senses

Cats have four distinct chemical senses: olfaction, vomeronasal, trigeminal, and taste.

Olfaction

Although there has not been much study into the olfactory abilities of cats, it is likely that they are similar to those of dogs based on their morphology (Bradshaw et al. 2012). The loss of this sense in cats can result in loss of appetite, change in toileting habits and no engagement in courtship (Bradshaw et al. 2012). The olfactory system is used by mothers to discriminate the odour of individual young and in turn regulates aspects of maternal behaviour (Lévy et al. 2004). Olfaction also plays an important role in the behavioural development of kittens, helping with orientation to their mother and locating the mammary area and nipples, assisting them in returning to their nest if they wander and inducing sleep (Mermet et al. 2008). As kittens age, their experience of their environment becomes more multimodal. However, there is a continual reliance on olfaction for discriminating between family members and other cats and determining edible foods (Mermet et al. 2008).

Vomeronasal

The vomeronasal organ occurs in most mammal species including cats, but not higher primates (Bradshaw et al. 2012). This organ is connected to both the oral and nasal cavities and the lower opening can be seen as a slit behind the upper incisors. The external sign that a cat is using its vomeronasal system is when it holds its mouth slightly open for a few seconds with the upper lip raised. This is known as the Flehmen response. In cats, the vomeronasal system is a single system, which is similar to other domestic or farm animals such as sheep, horses, dogs, goats and pigs. However, other mammals such as rodents have a two-path system (Salazar and Sánchez-Quinteiro 2011). Little is known about the purpose of the vomeronasal organ (Salazar and Sánchez-Quinteiro 2011). It was once thought that the olfactory system detected general odours and the vomeronasal system was specifically and/or exclusively for detecting pheromones. However, it is now known that there is considerable functional overlap between them, even though they are morphologically independent (Zufall and Leinders-Zufall 2007). Verberne (1976) tested the hypotheses that it was used to detect non-volatile chemical stimuli and for receiving pheromones, and found that it was suitable for both. Studies of the Flehmen response revealed that in heterosexual interactions, it is performed by males only. However, both males and females will perform it when examining urine markings and skin secretions if no other cat is present (Hart and Leedy 1987). Verberne and de Boer (1976) and Hart and

Leedy (1987) both found that hormone levels in both male and female cats alter the frequency at which they perform the Flehmen response.

Trigeminal

The trigeminal system provides several types of sensation to the face, mouth and nose as well as certain motor functions such as biting, chewing and swallowing. The trigeminal system in cats is not well studied (Bradshaw et al. 2012). However, all vertebrates have a chemo-sensitive trigeminal nerves in their nasal cavities, in addition to the trigeminal sensitivity to mechanical and thermal stimuli (Keverne et al. 1986). The receptors are free nerve endings of the trigeminal nerve and trigger protective reflexes in response to noxious substances, and may also play a role in odour sensation (Keverne et al. 1986). Sensations usually caused by the system include irritation, pungency, tickle, sting, warmth and pain. Physiological responses can include bronchodilation or broncho-constriction, bradycardia, reduction in cardiac output, vasoconstriction, an increase in epinephrine secretion and variable effects on blood pressure. They are often accompanied by withdrawal reflexes (Keverne et al. 1986).

Taste

The sense of taste in cats is well adapted for meat eating. Studies of the taste nerves in cats show that, unlike most mammal species, they cannot taste sugars even in high concentrations (Beidler et al. 1955, Li et al. 2006, Pfaffmann 1955). However, the tastebuds of the facial nerve are highly responsive to amino acids which may allow cats to be more sensitive to substances in raw meat such as monophosphate nucleotides. These nucleotides indicate the time since death of their prey, thereby allowing them to distinguish between meats of varying qualities (Bradshaw et al. 1996). Cats also have a low sensitivity to salt because most of their food has a high sodium content. In contrast herbivores are very sensitive to salt because many plant materials are low in salt (Bradshaw et al. 1996).

1.6 SOCIAL STRUCTURE

Although cats are generally seen as solitary animals, they do often live in groups (Bradshaw et al. 2012, Corbett 1979). Wildcats do not form colonies therefore it is likely that the capacity to form large groups has developed as a result of domestication

(MacDonald et al. 2000). Group living depends largely on food availability and distribution (Corbett 1979, Liberg et al. 2000, MacDonald et al. 2000) and exist mainly amongst stray/semi-feral or farm cats which rely on humans for at least some of their food even if they are not deliberately fed. For example, domestic cats living entirely on wild, dispersed prey, such as rodents and rabbits, tend to be solitary whereas cats with access to clumped food such as garbage bins, fish dumps and farms tend to live in groups although these cats may still hunt for some of their food e.g. mice in farm buildings and nearby fields (Liberg et al. 2000, MacDonald et al. 2000). The season may also influence food type and distribution and therefore cat preferences for group living. For example, Corbett (1979) found that free-roaming cats on the Monarch Islands live more communally during winter to exploit highly clumped food from farms rather than during summer when they could hunt and the prey was widely distributed.

Cat associations within a group depend on age, sex, social status and relatedness (MacDonald et al. 2000). Macdonald (1981) found that farm cats form groups with related females. Large colonies around a central resource have several lineages each consisting of related females and successive generations of offspring. Adult females associate within their lineage and will even suckle kittens of related cats (Macdonald 1981), but tend not to interact with individuals outside their lineage and may exclude them from resource areas (Liberg 1984, MacDonald et al. 2000). This was supported by Denny et al. (2002), who found that only four of the 14 juveniles and sub-adult cats living at the Oberon tip in the shire of Oberon in rural New South Wales were not related to the central female kin-group associated with the site. During the survey, no unrelated females became long-term residents of the site although adult males occasionally visited the site or became long-term residents (Denny et al. 2002).

Adult males are not associated with lineages, but are classed as central or peripheral based on how often they visit the 'central' resource (usually the source of food or shelter) (MacDonald et al. 2000). Liberg (1984) studied the home range and territoriality of farm cats and found four distinct social classes of males: novice, outcast, challenger and breeder. Novices are young cats (usually one to three years old) living at their natal home. They are often harassed and restricted in their movements by breeders and challengers and therefore avoid them. Many novices emigrate to new areas and settle as feral cats, independent of humans and becoming outcasts. Outcasts also avoid breeders and challengers because of harassment, which sometimes results in a continuous drifting of their home range. Novices may also grow up to become challengers, usually around two to four years of age. Challengers do not avoid aggression with other males and court females. A male cat may eventually become a breeder, which is the most dominant social class and the only class to reproduce regularly.

Social structure can create variability within the colony in the ability of cats to find food, which impacts on their health. Corbett (1979) found differences in the hunting success of cats based on their social status and suggested that this is because cats with lower social standing are excluded from good hunting grounds. MacDonald et al. (2000) recorded that central females (those within the lineage) had significantly less gingivitis (gum disease, indicating poor nutrition) and lower numbers of eosinophils (white blood cells, indicating infections) than peripheral females (those outside of the lineage), possibly because central females have better food. This may also be the reason for higher rates of reproductive success and survival with central rather than peripheral cats (MacDonald et al. 2000). In general however, cats living in colonies in urban areas have higher infection rates of disease-causing pathogens than owned cats (Longcore et al. 2009).

1.7 HOME RANGE

For group-living cats such as strays or farm cats, differences in the home range are based on sex and social status (Corbett 1979). Female home ranges are influenced by the abundance and distribution of food while male home ranges are generally larger because they tend to be more nomadic and overlap the distribution of females (Liberg et al. 2000).

Liberg (1984) found that females within the same lineage shared their home range, but there was very little overlap with females from other groups. However, the home ranges of male cats overlapped considerably although there was some spatial exclusion of competitors and cats occasionally changed their activities in areas where they had been defeated. He suggested that this was because females exclude competitors from their most important resources (food and shelter), which are highly clumped and easily defendable, whereas males are only able to partially exclude other males from their resource (females), which is more dispersed and less predictable.

In countries such as Australia and New Zealand where most pet cats are desexed, it would be expected that differing patterns in home range based on sex would be less apparent. However, in a study of pet cats in Canberra, Australia, Barratt (1997a) found that related females within the same household had completely overlapping home ranges whereas unrelated cats within the same household had overlapping core home ranges (house and yard) but their outer home ranges did not overlap at all. There was some spatial overlap between males, and males and females from separate households, but males seemed to avoid the core areas of other males. There was no overlap of home ranges between females of separate households (Barratt 1997a).

Feral cats have larger home ranges than pet and stray cats because they are self-supporting and have to hunt over large areas, whereas pet and stray cats rely on humans for at least part of their food provisioning, generally in the same location (Liberg 1984, Liberg et al. 2000).

1.8 HUNTING BEHAVIOUR

Domestication has had arguably less effect on the behaviour of cats than other mammals (Driscoll et al. 2009b). Driscoll et al. (2009b) suggests that this is because prior to domestication wildcats exploited human environments and were tolerated by humans and the process of domestication occurred slowly via natural selection. Domestication of other animals such as barnyard animals and dogs has been driven by artificial selection as they were more confined and humans controlled their breeding. However, even today pet cats still largely choose their own mates (with the exception of pedigrees). An example of the slow evolution of behaviour is predatory behaviour. Predatory ‘games’ and activities are practised by both kittens and puppies but the sequence is incomplete in most breeds of dog (i.e. most adult dogs do not become hunters) (Bradshaw 1992), whereas adult cats may become accomplished hunters (Caro 1980).

Behaviourally and morphologically, cats are best suited for hunting small rodents. Leyhausen (1979) found that prey capture, killing and consumption are independent. Approximately 50% of pet cats hunt, regardless of how well they are fed (Paton 1991, Perry 1999, REARK 1994b). Barratt (1998) found that the number of prey a cat caught was not significantly influenced by the amount of food it was provided. Prey type, however, is affected by food dependency, with cats that are well fed likely to spend time hunting small rodents which are easier to catch but less filling than rabbits which take a longer time to catch but provide a more substantial meal (Fitzgerald and Turner 2000).

Adult cats bring home larger prey than immature cats. This is because larger animals such as rabbits are more difficult to catch and therefore require more strength and experience than smaller prey (Fitzgerald and Turner 2000). Although feral cats need to continue hunting throughout their lifetime and die when they become ineffective hunters, as adult pet cats continue to age, they tend to hunt less (Churcher and Lawton 1987, Fitzgerald and Turner 2000).

The sex of the cat also influences hunting behaviour and prey preferences. Male cats tend to catch larger prey than females, but only when they comprise a significant part of their diet. Male pet cats or farm cats that receive enough food from humans are less likely to catch larger prey (Fitzgerald and Turner 2000). Mothers with kittens tend to be more successful and faster at catching prey than other females and males (Fitzgerald and Turner 2000). The hunting strategies of mothers and other females are also slightly different, with mothers spending less time waiting for prey to appear and more likely to move on sooner after an unsuccessful attempt at a particular location (Fitzgerald and Turner 2000).

Kittens learn hunting behaviour from their mothers in the first 3 months of life. Caro (1980) found that adult cats were more competent hunters if they had their mother with them when they were first exposed to prey as kittens. The ability for cat mothers to teach their offspring to hunt well may be a trait that is actively selected for in the wild (Caro 1980). Without help from their mothers, kittens may not learn the skills involved in predation and may be injured through inadequate prey handling. Incompetent kittens may have a higher mortality rate during weaning as they require more milk, increasing competition for milk between litter mates. Natural selection will therefore favour mothers that encourage their kittens to catch prey as early as possible (Caro 1980).

The perpetuation of wild behaviours such as hunting may be partly caused by the lack of control people exercise over cat breeding. Apart from specific cat breeds, generally cats are allowed to choose their own mates, with the possibility of mating with feral cats that are almost genetically identical to house cats yet still possess very wild behaviour patterns (Driscoll et al. 2009b). Bradshaw et al. (1999) suggests that the perpetuation of hunting behaviour in pet cats may also be linked to diet. Until recently, commercial cat foods alone did not comprise an adequate diet for cats (Bradshaw 2006, Bradshaw et al. 1996), so cats supplementing their diet with hunting and/or scavenging may have had a greater breeding success (Bradshaw et al. 1999).

Bradshaw et al. (1999) also suggests that we encourage the continuation of wild behaviour patterns in pet cats though continued adoption of feral kittens. High desexing levels in many developed countries (Bradshaw et al. 1999, Chaseling 2001, Chu et al.

2009) means that the supply of kittens does not keep up with demand. Bradshaw et al. (1999) found that in 1994 pet cats in the Shirley area of Southampton, UK could only produce enough kittens to maintain the population at about 25% of its present level. However, analysis of the age structure of the population showed that it was not in decline and therefore humans were maintaining the levels by bringing in cats from other areas or adopting strays.

1.9 CATS AND WILDLIFE

Since many pet cats are allowed to wander and there are substantial populations of feral and stray cats around the world there is the potential for pet cats to influence local wildlife. Even in areas where wildcats are a native species, domestic cats are genetically different and can impact wildcat populations as well as native prey species. This section describes the potential impacts of domestic cats, whether they are feral, strays or pets on their local wildlife.

1.9.1 Disease Transmission

Cats and other felids are the definitive host of the protozoan parasite *Toxoplasma gondii*, which cats contract by eating infected prey (Dubey and Lappin 2012). In Australia, only domestic and feral cats (and other felid species in zoos) can host this parasite. While infected cats are asymptomatic, the cysts of *T. gondii* generally live in the neural and muscular tissues of intermediate hosts, causing miscarriage and stillbirth in many mammals (Torrey and Yolken 2003). Intermediate hosts may also exhibit blindness, difficulty in walking and calcification of the heart (Tenter et al. 2000). In chronically infected animals, vertical transmission (transmission from mother to baby, often in utero but sometimes through breast milk) can occur (Dubey and Lappin 2012), including in Australian marsupials (Parameswaran et al. 2009b).

The genetic diversity of *T. gondii* in Australia is much greater than anywhere else in the world (Parameswaran et al. 2010). It is often fatal for Australian marsupials because of their recent exposure to the parasite (Eymann et al. 2006). Obendorf et al. (1996) found that eastern barred bandicoots (*Perameles gunnii*) are highly susceptible to infection and that it caused severe disabilities and death in some individuals. Eymann et al. (2006) found that common brushtail possums (*Trichosurus vulpecula*) are also susceptible to *T. gondii* infection and are unlikely to survive after infection. Smith et al. (2008) suggest that trypanosomes, possibly in conjunction with *T. gondii*, may predispose woylies

(*Bettongia penicillata*) to increased mortality because the combined effect increases the severity of *T. gondii* infection (Guerrero et al. 1997).

Infection by *T. gondii* may also make marsupials more prone to predation. Infected rats are more likely to explore unfamiliar stimuli in their environment than uninfected rats, thereby increasing their chance of being predated (Berdoy et al. 1995, Webster et al. 1994). Gonzalez et al. (2007) found that *T. gondii* reduces the mechanism of warning in rats, which therefore decreases their anxiety towards cat odours and in some cases causes them to become attracted to cats (Berdoy et al. 2000).

Intermediate hosts can easily become infected with *T. gondii* by feeding on the ground and ingesting food or water contaminated by cat faeces (Eymann et al. 2006) or by eating infected animals (Tenter 2009). The habit of many cat owners in allowing their pet cats to roam freely means that pet cats also risk contracting the disease, while the spread of urbanisation means that wildlife are living at the boundaries of urban areas and are picking up the parasite from not just feral cats but in peoples' back yards from their pets (Eymann et al. 2006). This is detrimental to wildlife populations and also humans, because *T. gondii* can be passed to kangaroos and other livestock in the meat trade and then passed to humans (Parameswaran et al. 2009a).

1.9.2 Hybridisation

Hybridisation between domestic cats and wildcats (*F. silvestris*) is also of conservation concern, especially throughout Europe. Local adaptations of wildcats may be lost through hybridisation, leading to less fit populations (Rhymer and Simberloff 1996). The loss of these adaptations could be difficult to detect because they may only be essential during occasional extreme environmental conditions such as storms, drought or fire (Allendorf et al. 2001). The principle has already been demonstrated in the extinction of several fish species (Rhymer and Simberloff 1996) and therefore is a legitimate concern where domestic cats and wildcats may interbreed.

In general, humans may facilitate hybridisation by introducing genetically similar plants and animals and fragmenting or degrading habitat (Rhymer and Simberloff 1996). Habitat fragmentation and degradation encourage hybridisation by removing suitable habitat for a species and forcing populations to live close together. All three of these situations are affecting wildcats in Europe but to different extents in different areas. In many areas wildcats exist in low numbers because of previous hunting and eradication attempts, as well as a lack of suitable habitat (Pierpaoli et al. 2003). Increasing urbanisation forces them to live on the outskirts of towns and cities where domestic cats live in high densities. The low density of wildcats coupled with the high density of domestic cats leads to on-going hybridisation in countries such as Hungary (Biró et al. 2005, Pierpaoli et al. 2003).

The extent of hybridisation between wildcats and domestic cats varies between different countries in Europe. Throughout most of Europe there are distinct gene pools for wildcats and domestic cats (Randi 2008). However, extensive hybridisation is found in both Hungary (Biró et al. 2005, Lecis et al. 2006, Pierpaoli et al. 2003) and Scotland (Beaumont et al. 2001, Biró et al. 2005, Corbett 1979, Hubbard et al. 1992). Corbett (1979) considers that hybridisation is a major threat for wildcats in Scotland because the numbers appeared to be increasing and Daniels et al. (1998) suggested that, based on morphological evidence, the degree of hybridisation in Scotland has reached the point where wildcats and domestic cats can no longer be considered distinct species. Low levels of hybridisation are recorded in Bulgaria, Belgium (Randi 2008) and Italy (Lecis et al. 2006, Randi et al. 2001). Portugal also recorded low levels of hybridisation (Oliveira et al. 2008b, Randi 2008). However, Oliveira et al. (2008b) found that low numbers of hybrids were found spread across the country and suggests that this may become a problem in the future. Oliveira et al. (2008a) also found that the genetic tools used became less reliable in determining hybrids in successive generations, so the true proportion of hybrids may be higher than predicted.

1.9.3 Predation

Prey Naivety

In many areas, prey naivety toward cats is not a big issue because potential prey species and cats have co-existed for centuries. Møller (2011) undertook a study in Norway, Denmark and Sweden and found that the heights in trees and foliage where birds choose to sing were significantly lower in rural areas (where raptors are the main predators) than urban areas (where cats are the main predators). In addition, Møller and Ibáñez-Álamo (2012) found that the escape behaviour of birds was significantly different between rural and urban sites and suggested that this was the result of differences in predation risk. Both studies showed a significant relationship with time since urbanisation, suggesting that these behaviours have changed over time (Møller 2011, Møller and Ibáñez-Álamo 2012).

Some mammal species have also been shown to change their behaviour because of cat predation. Duarte and Young (2011) showed that urban marmosets (*Callithrix penicillata*) in Minas Gerais, Brazil, select their sleeping sites based on the threat of cat predation. Marmosets chose sites that were in high trees, with high first branches and smooth or thorny bark. They also only reached their sites from adjacent trees, not by climbing from the base of their tree (Duarte and Young 2011). The urban marmosets did not choose trees that are predominately used by marmosets in their natural habitat, even though they were available in the park. Duarte and Young (2011) also found that the marmosets in their study did not choose sleeping sites based on easy food acquisition as other urban marmosets have been found to do in other studies (Pontes and Soares 2005) and concluded that this was because the predator density in their study was much higher.

For Australia, New Zealand and many oceanic islands, cats are a recent introduction to the environment and therefore prey naivety is a big issue when it comes to trying to protect them. For example, marine iguanas (*Amblyrhynchus cristatus*) from the Galapagos Islands have existed without predators for 5 – 15 Myr until some were exposed to cats and dogs about 150 years ago (Rödl et al. 2007). Rödl et al. (2007) found that the corticosterone stress response was absent in naïve animals although it was quickly restored with experience. Berger et al. (2007) also found that the iguanas showed behavioural and physiological plasticity associated with predation pressure and so could change their response as they became more experienced. Both studies however, concluded that the adjustments the iguanas could make would not be sufficient to protect them from exotic predators (Berger et al. 2007, Rödl et al. 2007).

In Australia, the ability of native mammals to overcome their naivety is debated. Griffin et al. (2002) found that tammar wallabies (*Macropus eugenii*) that had been taught to fear foxes generalised their response to include cats. However, they did not show this response towards goats and could not be taught to fear goats even when using the same technique as when they learnt to fear foxes. Griffin et al. (2002) suggest that this shows an adaptive predisposition to acquire a fear of predators.

This was supported by the work of Blumstein et al. (2000), who found that tammar wallabies respond to visual cues of new predators such as foxes and cats. They also found that tammar wallabies did not respond to the acoustic cues of these animals, although they did respond to native predators. Blumstein et al. (2000) suggested that this is because responsiveness to visual cues has been preserved under relaxed conditions as predator morphology is convergent, but vocalisations are not. Therefore, even in isolation, response to visual cues from predators has remained.

However, McEvoy et al. (2008) tested the response of Tasmanian swamp rats (*Rattus lutreolus velutinus*) to scent cues of native and feral predators and found the rats unresponsive to feral predators while recognising native predators. They suggest that the reason their results are different to other studies is because they assessed a wider variety of responses. They conclude that small, native Tasmanian mammals will be vulnerable to cat and fox introductions because of their lack of recognition and therefore lack of appropriate response.

In contrast, Mella et al. (2010) found that odours of introduced predators (cat and fox) evoked a greater response from tammar wallabies than odours of native predators (snake (*Aspidites melanocephalus*) and quoll (*Dasyurus hallucatus*). Mella et al. (2010) suggest that a long period of co-history is not required for detection of potential predators and that it is not an inability to detect and respond to introduced predators that is responsible for the decline of tammar wallabies.

In a comparative analysis of 90 studies on predation and prey populations, Salo et al. (2007) showed that alien predators have a greater impact on limiting prey numbers than native predators and are especially detrimental on the Australian mainland. Salo et al. (2007) suggest that even though Australia has a large variety of marsupial predators and therefore prey are not naïve to predation, placental predators are a recent introduction and may use tracking or hunting techniques to which native animals have little or no defence.

Predation by Feral Cats

Feral cats have had severe effects on many species, especially on oceanic islands (Fitzgerald and Turner 2000). Medina et al. (2011) suggest that "feral cats on islands are responsible for at least 14% of global bird, mammal, and reptile extinctions and are the principal threat to almost 8% of critically endangered birds, mammals, and reptiles." Some of the species that have become extinct because of feral cats include the Angel de la Guarda deer mouse *Peromyscus guardia* (Vázquez-Domínguez et al. 2004), the Socorro Island dove *Zenaida graysoni* (Jehl and Parkes 1983), the Guadalupe storm-petrel *Oceanodroma macrodactyla* (McChesney and Tershy 1998) and the Stephen's Island wren *Traversia lyalli* (Galbreath and Brown 2004).

Within Australia and its territories, cat predation has had a very high impact on many species. The Action Plan for Australian Mammals states that "…our assessment that predation by feral cats as the factor affecting the largest number of threatened and near threatened mammal taxa is without precedent" (Woinarski et al. 2014 pg. 870). There are 80 listed threatened species under the Environment Protection and Biodiversity Conservation Act thought to have been impacted by cat predation (Table 1.1). The list includes 33 birds, 35 mammals, 10 reptiles and two frogs. At least one species (Red-crowned Parakeet [Macquarie Island] *Cyanoramphus novaezelandiae erythrotis*) is thought to have become extinct primarily because of cat predation. Nine other species are also thought to have become extinct because of multiple factors including cat predation to varying degrees, including three bird species and seven mammal species. Five other species, Buff-banded Rail [Cocos Islands] *Gallirallus philippensis andrewsi* (endangered), Norfolk Island Green Parrot *Cyanoramphus cookii* (endangered), Southern Emu-wren [Eyre Peninsula] *Stipiturus malachurus intermedius* (vulnerable), Soft-plumaged Storm-Petrel *Pterodroma mollis* (vulberable) and White-bellied Storm-Petrel *Fregetta grallaria grallaria* (vulnerable), are all considered threatened primarily because of cat predation. Cat predation is currently considered a major threat (i.e. other threats are also impacting the species but cat predation is a having a considerable impact) for 26 species and a minor threat (i.e. cat predation is not the main threat but an additive pressure) for another fourteen species. The cause of decline for another 35 species is unknown but cat predation is considered a likely threat and may range from the primary cause of decline to a minor threat. The Australian government considers feral cat control to be a priority area in protecting Australian wildlife on the mainland and its islands and has developed a threat abatement plan to deal with this issue (DoE 2015).

Table 1.1: Listed Threatened Species under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act: Australian Government) that are Threatened by Cat Predation (Derived from EPBC Act Species Profile and Threats Database).

EPBC Act Category	Common Name	Species Name	Primary Threat[1]	Major Threat[2]	Minor Threat[3]	Possible Threat[4]
Extinct	Birds					
	Buff-banded Rail (Macquarie Island)	*Gallirallus philippensis macquariensis*		√		
	New Zealand Pigeon (Norfolk Island Race)	*Hemiphaga novaeseelandiae spadicea*		√		
	Paradise Parrot	*Psephotus pulcherrimus*			√	
	Red-crowned Parakeet (Macquarie Island)	*Cyanoramphus novaezelandiae erythrotis*	√			
	Mammals					
	Broad-faced Potoroo	*Potorous platyops*				√

[1] Cats are the primary cause of decline. Other threats may play a minor role

[2] Cats are one of several major threats to the species

[3] Other processes play a major role in the decline of the species but cats are an additive pressure

[4] Cats are considered a likely threat to the species but the level of threat (if any) is unknown

EPBC Act Category	Common Name	Species Name	Primary Threat[1]	Major Threat[2]	Minor Threat[3]	Possible Threat[4]
	Burrowing Bettong (inland)	*Bettongia lesueur graii*			√	
	Desert Rat-kangaroo	*Caloprymnus campestris*				√
	Lesser Stick-nest Rat	*Leporillus apicalis*		√		
	Rufous Hare-wallaby (SW mainland)	*Lagorchestes hirsutus hirsutus*		√		
	White-footed Rabbit-rat	*Conilurus albipes*				√
Critically Endangered	Birds					
	Herald Petrel	*Pterodroma heraldica*				√
	Orange-bellied Parrot	*Neophema chrysogaster*				√
	Spotted Quail Thrush (Mt Lofty Ranges)	*Cinclosoma punctatum anachoreta*				√
	Yellow Chat (Dawson)	*Epthianura crocea macgregori*				√
	Mammals					
	Gilbert's Potoroo	*Potorous gilbertii*		√		
Endangered	Reptiles					
	Alpine She-oak Skink	*Cyclodomorphus praealtus*		√		
	Arnhem Land Egernia	*Bellatorias obiri*				√
	Blue Mountains Water Skink	*Eulamprus leuraensis*		√		
	Guthega Skink	*Liopholis guthega*		√		
	Birds					

EPBC Act Category	Common Name	Species Name	Primary Threat[1]	Major Threat[2]	Minor Threat[3]	Possible Threat[4]
	Buff-banded Rail (Cocos Islands)	*Gallirallus philippensis andrewsi*	√ (on some islands)	√		
	Christmas Island Goshawk	*Accipiter hiogaster natalis*				√
	Emerald Dove (Christmas Island)	*Chalcophaps indica natalis*		√ (past)	√ (current)	
	Helmeted Honeyeater	*Lichenostomus melanops cassidix*				√
	Island Thrush (Christmas Island)	*Turdus poliocephalus erythropleurus*		√ (past)	√ (current)	
	Night Parrot	*Pezoporus occidentalis*				√
	Norfolk Island Green Parrot	*Cyanoramphus cookii*	√			
	Southern Emu Wren (Fleurieu Peninsular)	*Stipiturus malachurus intermedius*			√	
	Mammals					
	Dibbler	*Parantechinus apicalis*				√
	Mahogany Glider	*Petaurus gracilis*				√
	Mountain Pygmy Possum	*Burramys parvus*				√
	Northern Quoll	*Dasyurus hallucatus*				√
	Red-tailed Phascogale	*Phascogale calura*		√		
	Southern Brown Bandicoot (Eastern)	*Isoodon obesulus obesulus*		√		

EPBC Act Category	Common Name	Species Name	Primary Threat[1]	Major Threat[2]	Minor Threat[3]	Possible Threat[4]
	Southern Marsupial Mole	*Notoryctes typhlops*				√
	Woylie	*Bettongia penicillata ogilbyi*				√
Vulnerable	Frogs					
	Giant Burrowing Frog	*Heleioporus australiacus*				√
	Green and Golden Bell Frog	*Litoria aurea*				√
	Reptiles					
	Brigalow Scaly-foot	*Paradelma orientalis*				√
	Collared Delma	*Delma torquata*				√
	Five-clawed Worm-skink	*Anomalopus mackayi*				√
	Olive Python (Pilbara sub-species)	*Liasis olivaceus barroni*			√	
	Striped Legless Lizard	*Delma impar*				√
	Yakka Skink	*Egernia rugosa*			√	
	Birds					
	Antipodean Albatross	*Diomedea exulans gibsoni*				√
	Black-breasted Button-quail	*Turnix melanogaster*				√
	Blue Petrel	*Halobaena caerulea*		√		
	Fairy Prion (southern)	*Pachyptila turtur subantarctica*		√		
	Fairy Tern	*Sternula nereis nereis*		√		

EPBC Act Category	Common Name	Species Name	Primary Threat[1]	Major Threat[2]	Minor Threat[3]	Possible Threat[4]
	Golden Whistler (Norfolk Island)	*Pachycephala pectoralis xanthoprocta*		√		
	Lord Howe Woodhen	*Gallirallus sylvestris*		√ (past)		
	Mallee Fowl	*Leipoa ocellata*			√	
	Muir's Corella (southern)	*Cacatua pastinator pastinator*			√	
	Noisy Scrub Bird	*Atrichornis clamosus*			√	
	Northern Giant-Petrel	*Macronectes halli*			√	
	Pacific Robin (Norfolk Island)	*Petroica multicolor multicolor*			√	
	Plains-wanderer	*Pedionomus torquatus*		√		
	Soft-plumaged Petrel	*Pterodroma mollis*	√			
	Southern Emu-wren (Eyre Peninsular)	*Stipiturus malachurus parimeda*				√
	Squatter Pigeon (southern)	*Geophaps scripta scripta*		√		
	White-bellied Storm-Petrel	*Fregetta grallaria grallaria*	√			
	Mammals					
	Arnhem Rock-rat	*Zyzomys maini*				√
	Brush-tailed Rabbit-rat	*Conilurus penicillatus*				√
	Brush-tailed Rock-wallaby	*Petrogale penicillata*				√
	Burrowing Bettong (Barrow and Boodie Islands)	*Bettongia lesueur* unnamed subsp.		√		

EPBC Act Category	Common Name	Species Name	Primary Threat[1]	Major Threat[2]	Minor Threat[3]	Possible Threat[4]
	Burrowing Bettong (Shark Bay)	*Bettongia lesueur lesueur*		√		
	Chuditch	*Dasyurus geoffroii*				√
	Eastern Barred Bandicoot (Tasmania)	*Perameles gunnii gunnii*		√		
	Golden Bandicoot (mainland)	*Isoodon auratus auratus*		√		
	Golden Bandicoot (Barrow Island)	*Isoodon auratus barrowensis*		√		
	Long-nosed Potoroo (SE mainland)	*Potorous tridactylus tridactylus*		√		
	New Holland Mouse	*Pseudomys novaehollandiae*			√	
	Northern Brush-tailed Phascogale	*Phascogale pirata*		√		
	Northern Hopping-mouse	*Notomys aquilo*				√
	Piligia Mouse	*Pseudomys pilligaensis*		√		
	Southern Brown Bandicoot (Nuyts Archipelago)	*Isoodon obesulus nauticus*			√	
	Spectacled Hare-wallaby (Barrow Island)	*Lagorchestes conspicillatus conspicillatus*				√
	Spotted-tail Quoll (Tasmania)	*Dasyurus maculatus maculatus*				√
	Water Mouse	*Xeromys myoides*				√
	Western Ringtail Possum	*Pseudocheirus occidentalis*				√
	Yellow-footed Rock-wallaby (SA and NSW)	*Petrogale xanthopus xanthopus*		√		

Semi-feral/Stray Cats

Semi-feral cats in urban areas are also an important predator on wildlife. As these cats only partially rely on human provisioning, whether through humans deliberately leaving out food or by scavenging through rubbish, semi-feral cats may still need to supplement their diet though hunting. Even well-fed cats may still hunt as hunting has been shown to be independent of hunger (Fonberg 1982, Leyhausen 1979). The roaming of semi-feral cats is also not restricted by humans like pet cats, which are often kept inside for part of the day. Although feeding by humans reduces the home range size of semi-feral cats, it allows them to increase in density, thereby concentrating predation on wildlife in areas where feeding occurs (Longcore et al. 2009, Schmidt et al. 2007). This can be particularly detrimental to wildlife that exist in low numbers, as cats can maintain high densities even when prey numbers could not support such high levels of native predators (Soulé et al. 1988). In addition, groups of semi-feral cats can support high levels of disease and parasites (Dubey 1973, Lepczyk et al. 2015, Norris et al. 2007), which may be transferred to wildlife (Eymann et al. 2006, Tenter 2009) causing them to be more susceptible to predation and other forms of mortality (Tenter et al. 2000, Torrey and Yolken 2003).

Urban habitats, including yards, provide valuable habitat for migratory and resident birds and support both local and regional biodiversity (Angold et al. 2006, Seewagen and Slayton 2008). In Hobart, Daniels and Kirkpatrick (2006) showed that suburban gardens were important in the conservation of native birds including species that were threatened or uncommon. The continuing requirement for land for housing means that gardens will provide increasingly important habitat sites for many species (Davies et al. 2009, Gaston et al. 2005b). Therefore predation by both semi-feral and pet cats are an important concern in these environments (Longcore et al. 2009).

Pet Cats

There is also evidence that pet cats kill wildlife, with numerous examples world-wide including Australia (Barratt 1997b, Osborne and Williams 1991, Paton 1991), the USA (Balogh et al. 2011), the UK (Baker et al. 2005), New Zealand (Morgan 2002), Italy (Ancillotto et al. 2013) and Israel (Brickner-Braun et al. 2007). The extent to which this impacts wildlife communities is still contentious (Calver et al. 2011). Four biological concepts have been suggested in order to explain the potential effect of pet cats on native wildlife: doomed surplus, hyper-predation, mesopredator release and fear of cats.

Doomed Surplus

Introduced vertebrate predators pose a significant threat to endemic mammal species in Australia (Banks 1999, Glen and Dickman 2005, 2008, Saunders et al. 2010). Prey naivety can lead to heavy losses to introduced predators, which may be additive to natural sources of mortality that limit prey populations. Alternatively, predators may take only individuals that are surplus to the population i.e. the 'doomed surplus' (Banks 1999).

Within the natural environment, predation is a means of population control for many species (Errington 1946a, Salo et al. 2010). Errington (1946a) found that the loss of muskrats (*Ondatra zibethicus*) to non-predacious agencies such as drowning, disease and parental carelessness rose when predation losses declined and vice versa. In the event that predation and other causes of loss were low, intraspecific attacks became the dominant factor in controlling population numbers (Errington 1946a). However, Errington (1946b) suggested that predation falling into the category of special cases (e.g. predation by exotic species) was less likely to be offset by inter-species compensations in the loss and recovery rate of the prey and may therefore affect population numbers more substantially. This is supported by Salo et al. (2007), who found that introduced predators have double the level of impact on prey than do native predators. However, the effect that predators (both native and exotic) have on a prey species can be influenced by the biology of prey species. Salo et al. (2010) found for non-cyclic prey (prey that does not have regular, predictable cycles of population growth and decline over time) removing predators from the environment had a positive impact on prey populations and these populations continued to grow over time. In contrast, predator manipulation experiments on cyclic prey (prey with regular, predictable cycles of population growth and decline) had a positive effect on prey when prey was at low density levels but the impact was negligible when prey was at high densities (Salo et al. 2010).

Despite the potential for exotic predators to have a large impact on native species, this is not always the case. Banks (1999) found that fox predation on native bush rats in Australia was not a significant source of mortality. When the foxes were removed, bush rat populations did not increase even though at certain times of the year foxes preferentially eat them. This suggests that where predation pressure is low, not all predation mortality will be additive to prey populations even if it results from an introduced predator (Banks 1999).

Cats are often opportunistic feeders, taking prey that is easy to catch such as small, young mammals, ground-dwelling birds and especially animals that were previously sick or injured (Fitzgerald and Turner 2000). The same behaviour has been shown of pet cats, with Baker et al. (2008) finding that birds killed by cats were in significantly poorer condition than birds killed by other means such as collisions. Møller and Erritzøe (2000) also found that birds killed by pet cats had smaller spleens, and therefore weaker immune systems, than birds killed by other means. This causes some to argue that the animals pet cats killed were the surplus population and not an additive pressure.

This is supported by the argument of Fitzgerald and Turner (2000), who suggest that even when cats are known to be major predators of a species, they do not affect overall population levels because cats and wildlife have co-existed for a long time. Even in Australia where cats are a relatively recent introduction, Barratt (1998) found that crimson rosella (*Platycercus elegans*) and silvereye (*Zosterops lateralis*) populations were stable despite high levels of predation by pet cats.

An alternative argument is that the impact of cats is so rapid on susceptible species, that they disappear quickly and the loss is either not detected or not attributed to cats. Although the evidence is circumstantial, a long-term study by Bamford and Calver (2012) suggest that a single cat was responsible for the local extinction of the lizard (*Ctenotus fallens*) in just over two years, with most of the predation occurring in the first few months. No significant changes occurred to the property before or after the cat left and the lizard began to recolonise the area six years after the cat had moved away. This species is common in suburban Perth and has persisted through clearing, agriculture and urbanisation (Bamford and Calver 2012). However, increased urban density and therefore increased numbers of cats, could lead to more widespread extirpation of *C. fallens*.

Even in areas where cats have existed for centuries and many species have persisted, there are studies that indicate that pet cats may currently have a significant impact on native species, which is detrimental to their populations. An example of this is in Bristol in the UK, where Baker et al. (2005) found that predation rates for three bird species (house sparrow *Passer domesticus*, dunnock *Prunella modularis* and robin *Erithacus rubecula*) were high in comparison to their annual productivity and may be creating a dispersal sink for more productive areas. Baker et al. (2008) and van Heezik et al. (2010) also found that the estimated number of birds killed per year was high relative to the breeding density and productivity at many sites and in some areas was additive rather than compensatory. This causes populations to rely on immigration to persist.

Populations where reproduction is insufficient to balance local mortality, yet persist because of migration, are defined as ‘population sinks’. The more productive areas where the migrants originate are termed ‘source populations’ (Pulliam 1988). It is possible that pet cat predation is causing population sinks yet the bird populations appear stable because of continued migration from urban fringes (van Heezik et al. 2010). It is very important, therefore, that areas that are found to be source populations are carefully maintained and protected in order to prevent species from becoming locally extinct.

Hyper-Predation

Hyper-predation is the situation where an introduced predator is maintained at a high population density by an introduced prey evolved to cope with high predation pressure, leading to increased predation on native prey that are not adapted to cope with the high rate (Courchamp et al. 2000, Medina and Nogales 2009). This situation often occurs on oceanic islands where cats and a prey source, such as rabbits or rats, have been introduced. Cats have the ability to seasonally adjust their prey preference. During the year they eat introduced prey such as rabbits (which are suited to high predation pressure and exist in high numbers), which means the cat population does not fluctuate with prey availability and can maintain high numbers. However, when seabirds come ashore during the breeding season, they quickly become the preferred prey (Bonnaud et al. 2011, Courchamp et al. 2000, Zhang et al. 2006). Several examples of hyper-predation caused by cats have been found, including the potential extinction of a colony of Yelkouan shearwaters (*Puffinus yelkouan*) at Le Levant in the Mediterranean, the decline of sooty terns (*Sterna fuscata*) on Juan de Nova Island, Mozambique Channel (Peck et al. 2008), the decline of banded dotterels (*Charadrius bicinctus*) and endangered skinks in New Zealand (Norbury 2001, Norbury and Heyward 2008) and the decline and extinction of conilurine rodents in Australian (Smith and Quin 1996).

As domestic animals, pet cats can be found in very high densities, often exceeding densities attainable by native predators (Balogh et al. 2011). This situation is analogous to hyper-predation with the prey source being the food provided by humans. Although pet cats are fed at home, this does not reduce hunting behaviour (Fitzgerald and Turner

2000). In fact, Leyhausen (1979) found that killing was independent of hunger and sometimes overrode the desire to eat even when a cat had not been fed for several days.

Within Australia, pet cats (especially those bordering on native bushland) bring home a variety of small animals including mammals, birds, reptiles and frogs (Barratt 1997b, 1998, Osborne and Williams 1991) and often exist in densities known from studies in other countries to be influencing the local bird populations (Baker et al. 2005, Baker et al. 2008, Balogh et al. 2011). A study conducted in South Australia suggested that pet cats take at least 50% of the bird population present in urban areas and may also impact other animal species in nearby remnant bushland and in some cases indirectly affect plant species (Paton 1991). For example, honeyeaters are important in pollinating native plant species and were found to be the most common native bird species taken by pet cats, thereby indirectly affecting plant propagation as well as reducing bird numbers (Paton 1991). Barratt (1997b) also suggested that pet cats may have a significant impact on wildlife in small reserves, especially on small mammal species.

Hyper-predation by pet cats may also impact other predatory species. In southern Illinois, cats are an important predator of voles and other small mammals and, as cats exist in high densities, they reduce prey numbers more quickly than native predators would do (George 1974). This in turn affects native raptors, because they have insufficient prey for the winter months in these areas (George 1974).

Mesopredator Release

The theory of mesopredator release suggests that top or apex predators may control populations of other predators (mesopredators), whose populations will increase when the apex predator is eliminated (Crooks and Soulé 1999). Modelling of this effect suggests that, in some circumstances, eradicating the apex predator without controlling the mesopredator will just accelerate the extinction of prey (Courchamp et al. 1999, Fan et al. 2005).

Pacific rats (*Rattus exulans*) are an example of a mesopredator and have demonstrated this effect on Little Barrier Island with the Cook's petrel (*Pterodroma cookii*). When cats were controlled on the island, the breeding success of the petrel decreased severely because of the population explosion of rats that ate the chicks and eggs (Rayner et al. 2007). When rat numbers were subsequently controlled, the reproductive success of the petrels rose (Rayner et al. 2007).

There is some argument against this hypothesis, however, with Russell et al. (2009) suggesting that for long-lived animals such as seabirds, even when mesopredator release does occur, removal of the apex predator outweighs the negative effects of the mesopredator. This is because the apex predator predates on all of the life stages of the animal whereas the mesopredator only affects the early life stages. Using the example of Cook's petrel on Little Barrier Island, Le Corre (2008) suggests that although there was increased nest predation by rats, this may have been offset by the increased adult survival, which was not measured in Rayner *et al*. 's (2007) study.

Although keeping cats indoors will reduce (or eliminate) predation on wildlife by pet cats, it is possible that populations of introduced rodents (rats and mice) would increase as these also often form a substantial part of prey capture (Barratt 1997b, Fitzgerald and Turner 2000, Paton 1991). As rats and mice are also predators of small birds and their eggs, small lizards and invertebrates, Fitzgerald and Karl (1979) and Hansen (2010) argue that feral cats in New Zealand may suppress populations of these rodents and therefore allow birds to exist in denser populations than without cats present. A study undertaken by Dickman (2009) in Sydney demonstrated the complexity of this issue. Dickman (2009) found that artificial nests in forest remnants suffered less predation activity when cat activity was high, indicating that cats were suppressing the numbers of other nest predators such as introduced rats. However, the diversity of bird species was lower when cat activity was higher (Dickman 2009). This demonstrates the requirement to control mesopredators concurrently with cats in order to promote high diversity and reduce predation on native birds.

Fear of Cats

The theory of predation fear, and in this case fear of cats, suggests that even when predation is low, sub-lethal impacts caused by the prey's response to the fear of predation may be substantial and reduce population numbers. Preisser et al. (2005) argue that the consequences of these responses may be larger than those of predation mortality.

Predators influence prey by altering their behaviour including foraging behaviour, use of different habitats, diet, escape behaviour, mate choice and mating tactics. These in turn, can alter the adult and juvenile survival rate, clutch size and clutch number (Lima 1987, 1998). Some mammals are known to suppress breeding in response to high predation pressure as a means to stabilising their populations when predator density is high (Kokko and Ruxton 2000, Ruxton and Lima 1997). Similar long-term effects have been demonstrated in birds having smaller clutch sizes in environments with high predation pressure (Martin et al. 2000). Martin et al. (2000) suggests that this is because predation pressure restricts the rate at which parent birds deliver food to their young and therefore reduces the clutch size by limiting the number of offspring the parents can feed.

Schwagmeyer and Mock (2008) showed that provisioning of food by parents was positively linked to fledgling survival. Konarzewski and Starck (2000) also demonstrated that food restriction suppressed nestling growth. In patches of fragmented habitat on farms in the U.K. Dunn et al. (2012) demonstrated that chick condition and growth was negatively influenced by predator abundance as parents spent less time collecting food for their chicks and more time defending the nest. In this environment, corvids were the main predators and predated on nests when food from other sources was low (Dunn et al. 2012). In urban environments, a similar situation can occur because suitable wildlife habitat is fragmented and cats are maintained at high densities by human provisioning. However, as cat hunting behaviour is independent of hunger (Fonberg 1982, Leyhausen 1979) they can have a much larger impact than native predators.

Bonnington et al. (2013) found that parental provisioning rates in birds was reduced by one third when exposed to a cat model. They suggest that based on the work by Konarzewski and Starck (2000), reduced food delivery of this magnitude will reduce nestling growth rates by 40% and may have long-term consequences such as reduced clutch size, demonstrated by Martin et al. (2000). Bonnington et al. (2013) also reported increased levels of aggression by the parents when older chicks were in the nest and that the presence of the cat model for only 15 minutes at the nest significantly increased the chances of the nest being predated over the next 24 hours by corvids owing to the increase in alarm calls.

The reduction in parent provisioning and increase in predation by other predators demonstrates that even when cats are not directly predating on wildlife, there may still be severe impacts on populations (Beckerman et al. 2007, Preisser et al. 2005). Beckerman et al. (2007) suggest that the sub-lethal effects of cats may depress bird populations to such an extent that low predation rates simply reflect low population numbers. This also suggests that even cats that are not considered successful hunters still may be having a significant detrimental impact on wildlife.

1.10 THE PRECAUTIONARY PRINCIPLE

Despite the evidence that pet cats prey on wildlife, have the potential to transmit disease and may exacerbate hybridisation through contact with feral cats, there remains uncertainty about their true impact on wildlife populations. They may take only a doomed surplus of prey, or perhaps keep mesopredators such as rats and mice in check. This can lead to disagreement about how pet cats should be managed and hinders the implementation of regulations (Calver et al. 2011). This situation is the appropriate context to apply the precautionary principle which states that:

> "Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In the application of the precautionary principle, public and private decisions should be guided by: (i) careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment; and (ii) an assessment of the risk-weighted consequences of various options (DSEWPC 1992)."

Based on the model devised by Deville and Harding (1997), four steps should be considered when applying the precautionary principle to an issue.

Step 1: Are precautionary measures needed?

Under this step Deville and Harding (1997) suggest there are two questions that need to be asked:

1. Is there a threat of serious or irreversible environmental damage?
2. Is there lack of scientific certainty about these threats?

As previously discussed, there is the potential for pet cats to cause serious and irreversible environmental damage through loss of species and biodiversity in urban environments including remnant bushland. If cats are allowed to wander freely these issues can be exacerbated and spread to non-urban environments through contact with semi-feral or feral cats either through breeding, thereby increasing the populations of semi-feral and feral cats, which have a much greater potential for environmental damage, or through disease transmission, which can then be spread to other wildlife, pets or humans.

Although there are credible arguments that suggest that pet cats do have a significant impact on some species, there are a myriad of causes for wildlife decline in urban areas through the process of urbanisation and it is possible that cats are considered an easy scapegoat. Therefore there is scientific uncertainty about the true extent of the impact of pet cats on the environment.

Step 2: How precautious should we be?

How precautious we need to be depends on how serious or irreversible the threat is and how much uncertainty there is about the threat. The greater the significance of the threat and the more uncertain the threat is, the greater the precaution required (Deville and Harding 1997). As previously discussed, with increasing urbanisation there are many species that rely on urban environments at more than just the population level but also at the species level. Given the known impacts that feral cats have on species, especially in Australia and oceanic islands, there is the potential for pet cats to have a similar level of impact in urban environments. Although we are uncertain about the extent of the potential damage that pet cats can do, reducing their impacts may prevent the loss of wildlife in urban areas or at least slow it down so that other issues can be addressed. Therefore I believe that we should use strong precaution for this issue.

Step 3: What precautionary activities can you apply?

The effect of pet cats on wildlife populations can be reduced with better husbandry by cat owners. Many owners keep their cats indoors at night and, while this reduces predation on some animals such as mammals, it does not protect small birds as they are active during the day (Barratt 1997b). Ideally, owners should keep their cats on their properties at all times to reduce wandering into neighbouring gardens and bushland where wildlife may be present. Although in some countries owners are happy to keep their pets indoors at all times, for example Switzerland (Bradshaw 1992), the majority Australian owners won't keep their cats on their properties at all times (Grayson et al. 2002, Lilith et al. 2006) and therefore other methods to reduce predation on wildlife are required. Examples of this include anti-predation devices such as bells, alarm collars and pounce protectors (although there is popular concern about cats wearing these devices (The Cat Site.com 2015)).

Step 4: What precautionary activities should you apply?

This step is the final decision in determining what precautionary activities are the most appropriate to the situation (Deville and Harding 1997). This involves considering the views and abilities of the broader community e.g. opinions of cat owners, who will be responsible for implementing the prevention measures and ensuring they are adhered to and how easy and cost-effective they are to implement. Several jurisdictions around the world have legislated cat regulation effectively based on precautionary activities (Council of the Town of Coolee Dam 1988, Government of Western Australia 2011).

1.11 AIMS OF THESIS

This thesis sits primarily between steps three and four of applying the precautionary principle, but also aims to reduce some of the uncertainty surrounding the impact of pet cats on wildlife. The primary aims were to investigate several different precautionary approaches to reducing the risks posed by predatory interactions between cats and urban wildlife and determine what precautionary measures the wider community considers acceptable. This study involved both a survey/questionnaire of attitudes and practices towards cats in Australia and internationally, as well as field studies with domestic cats. Four specific objectives were examined in this study including:

i) Assess the social attitudes in Australia, the USA, the UK, New Zealand, Japan and China towards pet cats and cat ownership and responsibilities

ii) Assess whether the new collar-mounted anti-predation birdsbesafe cat collar cover is effective at significantly reducing cat predation on birds but not other prey

iii) Assess how collar-mounted anti-predation devices such as the CatBib and BBS work (i.e. do they work predominantly by alerting prey and interfering with prey capture or do they cause a change in cat roaming behaviour or activity)

iv) Examine available information on the roaming behaviour of pet cats and assess factors that influence roaming behaviour

In order to address the thesis aims, Chapter 2 compares the social attitudes of Australia with other countries towards cat ownership. Chapter 3 examines the effectiveness of the BirdsBeSafe cat collar. Chapter 4 examines the potential for anti-predation devices to change cat roaming behaviour and factors predicting cat roaming behaviour. Chapter 5 is a literature review and meta-analysis of the roaming behaviour of pet cats. A discussion of the implications of the findings is provided in Chapter 6.

2 COMMUNITY ATTITUDES AND PRACTICES OF URBAN RESIDENTS REGARDING PREDATION BY PET CATS ON WILDLIFE: AN INTERNATIONAL COMPARISON

Catherine M HALL, Nigel A ADAMS, J Stuart BRADLEY, Kate A BRYANT, Alisa A DAVIS, Christopher R DICKMAN, Tsumugi FUJITA, Shinichi KOBAYASHI, Christopher A LEPCZYK, E Anne MCBRIDE, Kenneth H POLLOCK, Irene M STYLES, Yolanda van HEEZIK, Ferian WANG, Michael C CALVER

This chapter has been published in the journal PLOS One as:

Hall, C.M., Adams, N.A., Bradley, J.S., Bryant, K.A., Davis, A.A., Dickman, C.R., Fujita, T., Kobayashi, S., Lepczyk, C.A., McBride, E.A., Pollock, K.H., Styles, I.M., Heezik, Y.v., Wang, F., Calver, M.C., 2016. Community attitudes and practices of urban residents regarding predation by pet cats on wildlife: An International comparison. PLoS ONE 11, e0151962.

ABSTRACT

International differences in practices and attitudes regarding pet cats' interactions with wildlife were assessed by surveying citizens from at least two cities in Australia, New Zealand, the UK, the USA, China and Japan. Predictions tested were: (i) cat owners would agree less than non-cat owners that cats might threaten wildlife, (ii) cat owners value wildlife less than non-cat owners, (iii) cat owners are less accepting of cat legislation/restrictions than non-owners, and (iv) respondents from regions with high endemic biodiversity (Australia, New Zealand, China and the USA state of Hawaii) would be most concerned about pet cats threatening wildlife.

Everywhere non-owners were more likely than owners to agree that pet cats killing wildlife were a problem in cities, towns and rural areas. Agreement amongst non-owners was highest in Australia (95%) and New Zealand (78%) and lowest in the UK (38%). Irrespective of ownership, over 85% of respondents from all countries except China (65%) valued wildlife in cities, towns and rural areas. Non-owners advocated cat legislation more strongly than owners except in Japan. Australian non-owners were the most supportive (88%), followed by Chinese non-owners (80%) and Japanese owners (79.5%). The UK was least supportive (non-owners 43%, owners 25%). Many Australian (62%), New

Zealand (51%) and Chinese owners (42%) agreed that pet cats killing wildlife in cities, towns and rural areas was a problem, while Hawaiian owners were similar to the mainland USA (20%). Thus high endemic biodiversity might contribute to attitudes in some, but not all, countries. Husbandry practices varied internationally, with predation highest where fewer cats were confined.

Although the risk of wildlife population declines caused by pet cats justifies precautionary action, campaigns based on wildlife protection are unlikely to succeed outside Australia or New Zealand. Restrictions on roaming protect wildlife and benefit cat welfare, so welfare is a better rationale.

Keywords

cat husbandry; confinement; desex; *Felis catus*; neuter; pet cat; predation; spay; urban wildlife

Author Contributions

This chapter had 14 co-authors. N. Adams and Y. van Heezik coordinated the New Zealand survey. K. Bryant, M. Calver and C. Dickman assisted me in coordinating the Australian survey. A. Davis and C. Lepczyk coordinated the survey in the USA. A. Mc Bride coordinated the survey in the UK. T. Fujita, S. Kobayashi and F. Wang translated materials into Chinese and Japanese and coordinated the surveys in these countries. S. Bradley and K. Pollock advised on statistical analysis and I. Styles advised on the Rasch analysis. C. Hall led and coordinated the writing.

2.1 INTRODUCTION

Cats (*Felis catus*) are widely kept as companion animals (Albert and Bulcroft 1988, Selby and Rhoades 1981) and their popularity as pets is increasing in many countries (Lepczyk et al. 2010, Woods et al. 2003). For example, in Australia, the UK and New Zealand, the proportions of households with a cat are 23% (ACAC 2010), 26% (Murray et al. 2010) and 35% (van Heezik et al. 2010) respectively. Cats have been introduced to most islands and continents across the world, where as pets they are often maintained at high population densities (e.g. > 100/km2 (Liberg et al. 2000, Sims et al. 2008)).

Pet ownership, including cats, confers numerous benefits to pet-owners but also creates problems for wider society. Benefits include better health and social connection of owners (Brickel 1979, Siegel 1990, Straede and Gates 1993, Wood et al. 2007), as well as opportunities to teach children responsibility, respect and compassion (Melson 2003, O'Haire 2010, 2013). The contribution of pet ownership to national economies through sales of pet food, accessories and veterinary care is also considerable (e.g. ACAC 2010). On the other hand, problems arise when cats roam without restriction. These include (i) unwanted hunting of wildlife (Dufty 1994, Loss et al. 2013b, van Heezik et al. 2010), (ii) transmission of disease to humans, livestock and wildlife (Hill and Dubey 2001, Tenter 2009, Torrey et al. 2007), (iii) potential hybridisation with native wildcats (e.g. in Europe Beaumont et al. 2001, Biró et al. 2005, Lecis et al. 2006), (iv) interbreeding with feral populations, and (v) nuisance to neighbours by fouling yards, harassing caged birds, fighting, spraying and jumping on cars (Jongman 2007, Toukhsati et al. 2012). Roaming cats also risk injury or death (Egenvall et al. 2009, Rochlitz et al. 2001) and these events are often financially and emotionally costly to owners (Rochlitz 2004a).

Given that pet cats are an important and beneficial part of many people's lives and lifestyles, the most productive approach to ameliorate these problems is to regulate cat husbandry practices to improve cat welfare, reduce nuisance and protect wildlife, while allowing people the pleasure of owning a cat. Tagging (e.g. microchipping) would improve the return of lost and injured animals as well as helping to identify specific nuisances. Desexing (except cats approved for breeding) would reduce the incidence of unwanted kittens, hybridisation with native felids and breeding with feral cats. Likewise, restricting wandering behaviour would decrease predation of wildlife, the spread of disease and traffic accidents involving cats. Understanding the attitudes of the general population towards cat husbandry, as well as the practices of owners, allows governing authorities to create effective regulations sensitive to local situations that are more likely to be accepted, and identifies areas where targeted education may encourage compliance.

Over the last 15 years, several authors have collected data on citizens' attitudes and practices with regard to cats (both owned and feral) and proposed regulations in several countries, including Australia (Grayson et al. 2002, Lilith et al. 2006), the USA (Lepczyk et al. 2004, Lohr and Lepczyk 2013, Lohr et al. 2014, Peterson et al. 2012), the UK (Thomas et al. 2012) and NZ (Farnworth et al. 2011). While surveys have differed in their questions, timing of administration and sample populations, and were often geographically restricted in each country, the data suggest marked differences between nations in attitudes and practices towards cats. For example, the incidence of confinement of pet cats ranges from 35% (American Bird Conservancy 2011a, quoting data collected in 1997) to 60% (Patronek et al. 1997) in mainland USA, compared to < 10% in Australia (Lilith et al. 2006, REARK 1994a, 1994b) or the UK (Sims et al. 2008). The prevalence of desexing is consistently > 90% in Australian studies (Dickman and Newsome 2015, Johnson and Calver 2014, Lilith et al. 2006, REARK 1994b) and UK studies (Thomas et al. 2012), compared to c. 80% in the USA (American Bird Conservancy 2011d, Chu et al. 2009) or 43% in parts of Italy (Slater et al. 2008). Moreover, Australian citizens, including cat owners, also seem more accepting that cats may be a threat to urban wildlife than UK citizens (contrast Grayson et al. 2002 and Lilith et al. 2006b with Thomas et al. 2012).

Given the variability across nations in how cats are treated and perceived, we sought to test if this variability was an artefact of differences in survey methodology or a true difference, and to greatly extend geographical coverage. We assessed international differences in attitudes and husbandry regarding restrictions and desexing of pet cats, as well as interactions between cats and wildlife, by administering a common survey to cat owners and non-owners in Australia, China, Japan, New Zealand, the UK and the USA. This approach allowed us to compare the attitudes of owners and non-owners in each country to questions such as the desirability of legislation, support for desexing and confinement, and the level of concern over predation by pet cats. We also assessed national variations in response to these questions. While the survey was predominantly exploratory, we also tested explicit predictions that: (i) cat owners would agree less that cats might threaten wildlife than non-cat owners, (ii) cat owners would value wildlife less than non-cat owners, (iii) respondents from Australia, China, New Zealand and the US state of Hawaii (all with high levels of endemic (distinct) wildlife biodiversity) would be more concerned about the potential impacts of pet cats on wildlife than respondents from the UK, the mainland USA and Japan, and (iv) cat owners would be less accepting of cat legislation/restrictions than non-owners[*]. A clearer understanding of citizens' attitudes will be helpful in deciding what, if any, legislative or community education steps might be acceptable in different countries to address perceived problems of predation by pet cats on wildlife.

2.2 MATERIALS AND METHODS

2.2.1 Ethics Statement

The Murdoch University Human Ethics Committee (permit 2012/195), the University of Sydney Human Research Ethics Committee (approval no. 15508), University of Hawaii (Manoa) Human Studies Program CHS#20333, University of Southampton Psychology Ethics Committee (Ethics ID: 5775), and University of Otago Human Ethics Committee

(Approval D11/297) all approved this study. Written consent was obtained from participants via completion of the first item of the survey form, which also gave documentary evidence of consent. Participants who declined to provide consent did not proceed past the first item.

2.2.2 Choice of Countries and Cities

The English-speaking nations share common cultural origins despite their current social and political diversity, while Japan is a developed Asian country and China a rapidly developing one. Australia, New Zealand, China and the USA state of Hawaii all have high endemic biodiversity compared to the other countries. We controlled the possibility that attitudes within countries might vary by including at least two cities in each country, where possible across a climatic range (Table 2.1). In the USA the survey was distributed in two mainland cities (Los Angeles and Chicago) and the Hawaiian Islands, which have significant concerns regarding conservation of endemic fauna. In Japan, respondents from Tokyo and Kanagawa were combined into the Japan Capital Area and respondents from the Japanese city of Osaka were combined with small numbers of respondents from other locations to form ‘Japan Other’. The Japanese city Shizuoka was the third city from Japan. Our focus on cities reflects the increasing trend to urbanisation globally.

Table 2.1: List of participating countries and participating cities from each country, with details of local climate, survey timing and response rates.

Country	Cities - Response rates (no. surveys returned/(no. sent - no. undeliverable)) are in parentheses	Climate	Survey Timing
Australia	Sydney (2.7%), Wollongong (5.3%)	Sydney: Warm temperate, summer highs average 27-30˚C and winter highs 17-21˚C Wollongong: Oceanic, summer highs average 26˚C and winter highs 17˚C	Dec 2012 – Mar 2013
New Zealand	Auckland (6.7%), Dunedin (15.9%)	Auckland: Oceanic, summer highs average 24˚C and winter highs 14˚C Dunedin: Oceanic, summer highs average 19˚C and winter highs 10˚C	Nov 2012 – Feb 2013
United States of America	Los Angeles (2.9%), Chicago (3.0%), Hawaii (6.8%)	Los Angeles: Mediterranean, summer highs average 29˚C and winter highs 20˚C Chicago: Humid continental, summer highs average 29˚C and winter highs 0˚C Hawaiian islands: Tropical, summer highs average 29-32˚C and winter highs 26-28˚C	May – July 2013
United Kingdom	Southampton (5.6%), Birmingham (2.6%)	Southampton: Oceanic, summer highs average 22˚C and winter highs 8.4˚C Birmingham: Temperate maritime, summer highs average 22˚C and winter highs 6.5˚C	Aug – Oct 2012
Japan	Japan Capital Area, Shizuoka, Japan Other (36.9%)	Tokyo: temperate with four distinct seasons, summer highs average 31˚C and winter highs 6˚C Shizuoka: temperate with four distinct seasons, summer highs average 24˚C and winter highs 11˚C	July – Nov 2013
China	Beijing, Harbin (47.1%)	Beijing: Humid continental, summer highs average 31˚C and winter highs 2˚C Harbin: Monsoon influenced humid continental, summer highs average 26˚C and winter highs -12˚C	July – Nov 2013

2.2.3 Administration and Design of Survey

Frame, Sampling Design and Contact Method

The survey was administered from spring to autumn in each country when cat activity and prey availability are likely to be high. Temporal effects were controlled by administering the survey in all countries within a 12 month period (Table 2.1).

For cities in all countries except China, invitations to participate were distributed amongst suburbs with a broad age range of citizens and a high proportion of employed people (i.e. a middle to upper-middle socio-economic demographic more likely to respond to an online survey (Goyder et al. 2002)). These people are also more likely to be politically engaged and hence more vocal in any discussions regarding regulation of the husbandry of pet cats (Foster-Bey 2008, Scott and Acock 1979). Within the chosen demographic in each city, 2,000 individuals were selected using simple random sampling without replacement from electoral rolls (New Zealand, UK) or marketing databases (Australia, USA) as the sampling frame. The survey administration method was online for reasons of cost, speed of analysis, alleviating problems with deciphering handwriting, and convenience of reply for the respondents (Hunter 2012). A personalised invitation letter was sent to all people selected with details of the online survey and an option for requesting a hard copy survey by mail, with a postage-paid reply envelope for its return. A reminder letter was sent two weeks later.

In Japan, 800 invitations to participate in an online survey were distributed at veterinary clinics and local shops (distribution of invitations at shops mitigated the probable bias that clients at veterinary clinics would own a pet of some kind) within suburbs matching the chosen demographic rather than mailed, because the local researchers believed that this was likely to elicit higher responses. Sakurai and Jacobson (2010) reported that mailed surveys in Japan rarely exceed response rates of 20-40%, and have been declining steadily since the 1970s. No follow-up was possible in this case. The researchers in China considered it very unlikely that Chinese nationals would respond to an unsolicited online survey from an unknown source: recent Chinese surveys often use interviews (Wei et al. 2014) or distribute questionnaires to assembled groups (Cheng et al. 2015). Instead, hired surveyors approached 500 people in Beijing to complete the survey. In Harbin, 500 people known to the researchers by acquaintance, and matching the chosen middle to upper-middle socio-economic demographic, were contacted directly by email and asked to return a completed survey. The decision to use convenience samples rather than probability samples in Japan and China was a trade-off between possible aversion to the probability sample approach in those countries and the lack of consistency in approaches across all countries.

Questionnaire Design

The survey was based on that developed by Grayson et al. (2002) and adapted by Lilith et al. (2006), with the goal of determining public opinion on aspects of cat husbandry, predatory interactions between pet cats and wildlife, and legislative regulation of cat ownership. For our study additional items were added to strengthen assessment of respondents' attitudes to interactions between cats and wildlife, and to restrictions on cat ownership or husbandry. Minor changes to the wording of some items occurred between countries in order to address differences in colloquial terms. There were 77 items overall, 44 assessing opinions and 33 assessing the characteristics of respondents and, for owners, their cat husbandry practices. Items were a mix of direct questions and responses on a five-point Likert scale (strongly agree, agree, disagree, strongly disagree, I don't know). No item in the online survey insisted on a response, because this might have led to respondents abandoning the survey (Stieger et al. 2007). However, it did cause variations in response rates for individual items. A copy of the Australian version of the survey is available in Appendix 1. Surveys for Japan and China were translated by the authors from those countries.

Eight key items (scored on a five-point Likert scale) were selected for individual analysis to provide insights into the attitudes and beliefs of owners and non-owners in each country on specific issues. These were:

- There is a need for cat legislation
- All cats should be kept in at night time
- Cats should be kept on their owner's property at all times
- It is important to have wildlife in cities, towns and rural areas
- Pet cats killing wildlife in cities, towns and rural areas is a serious problem
- Pet cats on farms are harmful to wildlife
- Pet cats in nature reserves are harmful to wildlife
- Except for a cat owned by a breeder, all cats should be desexed

Further questions relating only to owners were examined to determine differences in husbandry between countries and whether or not the cats had a history of catching wildlife:

- How many cats do you currently own?
- Has this cat been desexed?
- Does this cat live:
  - Solely inside
  - Solely outside
  - Solely inside during the night, but free roaming during the day
  - Inside and outside, but restricted to my property
  - Inside and outside, but free roaming
- Has this cat ever caught anything?

Using the Rasch measurement model (Bond and Fox 2007, Boone et al. 2014), three scales were constructed based on responses to the items on attitudes and practices: 1) Restrictions, dealing with regulations on cat ownership; 2) Wildlife, considering interactions between pet cats and wildlife; and 3) Desexing, covering issues related to desexing pet cats (see below for details). Respondents' scores on these scales were used as dependent variables indicating their attitudes.

The survey program iSurvey, from the University of Southampton, was used by respondents from Australia, New Zealand, the USA and the UK, with each country having its own customised survey and login. The Japanese survey team used Survey Monkey (https://www.surveymonkey.com). Results from China were compiled manually. Any paper surveys received were entered manually.

2.2.4 Data Analysis

Response Rates and Representativeness of the Survey

Response rates, defined as the number of surveys completed either online or on paper divided by the number of invitations sent minus the number returned as undeliverable (de Vaus 2002), were calculated for each city where invitations were mailed. In Japan, response rates were calculated as the number of surveys completed divided by the number of leaflets distributed, while in China they were calculated as the number of people responding divided by the number approached. Responses collected online may not be representative (Hunter 2012), so we tested the representativeness of the samples by: (i) comparing the proportions of cat owners in the responses for each country with recent independent assessments of the proportion of cat ownership in those countries, (ii) checking for non-response bias by comparing the responses of people responding promptly to those responding tardily to the survey, and (iii) comparing mailed and online responses. These measures apply only to our target middle to upper-middle socio-economic demographic and cannot be extrapolated beyond it.

We compared the proportions of cat owners and non-owners in the study to estimates of cat ownership in each country from data published within the last decade (Australia 23% (ACAC 2010); NZ 35% (van Heezik et al. 2010); UK 26% (Murray et al. 2010); USA 30% (AVMA - American Veterinary Medical Association 2012); Japan 10% (Mesago Messe Frankfurt Corp. 2014); China 15% (Euromonitor International 2004)). We used chi-squared goodness of fit tests with continuity correction to determine whether the relative proportions of cat owners to non-owners who responded were equivalent to the relative proportions in the general population for each country.

Armstrong and Overton (1977) argued that people who respond less readily to surveys, as indicated by a tardy response or a response only after prompting, are more likely to have similar attitudes to non-respondents. Therefore, if there are differences in characteristics or answers between prompt and tardy respondents non-response bias is likely, requiring a correction. We divided the respondents into early (responding within two weeks of the return of the first response) and late (responding after two weeks from the first response). This was undertaken on data for Australia, New Zealand, the UK and the USA as information on when the survey was completed was available. Those who completed a paper survey were excluded. Information on the timing of responses was unavailable from the Japanese data and not applicable to the Chinese data.

For each country separately, combining the results for cities within countries, we used a two-way chi-square contingency table with Yates' correction to determine if there was any difference between early and late respondents for i) the proportions of owners to non-owners and ii) the proportions of men to women. Secondly, we tested for differences in the average age between early and late respondents using either a two-tailed t-test after confirming homoscedasticity, or a two-tailed t-test for heteroscedastic samples. Thirdly, we used log-linear three-way contingency tables to test for associations between agreement (the proportion of respondents agreeing or strongly agreeing to an item), ownership (owners and non-owners) and promptness (whether the respondents answered early or late to the eight specific items above) in each country. Fourthly, for each country we correlated respondents' scores on the Restriction, Wildlife and Desexing scales with the length of time they took to respond (measured in days from the date of initial mailing of the invitation to participate). Correlations significant at $p < 0.05$ were interpreted as evidence of non-response bias.

We also tested for differences between online and paper surveys. There were too few paper surveys from Australia and the UK to analyse, so we analysed only respondents from New Zealand and the USA. Countries were analysed separately and cities within countries were combined.

We used two-way chi-square contingency tables with Yates' correction to evaluate associations between whether people responded by mail or online and the relative proportion of owners and non-owners, men and women, and employment status (working, retired or unemployed). We tested for differences in age between mail and online respondents using either a two-tailed t-test after confirming homoscedasticity or a two-tailed t-test for heteroscedastic samples. We also used log-linear three-way contingency tables to test for associations between agreement (strongly agree and agree combined)/disagreement (strongly disagree and disagree combined) to the eight specific items above, owners/non-owners, and online/paper survey.

Analysis of Specific Items for All Respondents

We divided all responses simply into agree or disagree to avoid problems caused by limited responses in some of the finer categories, as well as avoiding problems of cultural differences in preferences for selecting middle or extreme values (Harzing et al. 2012). Respondents who answered “I don’t know” to a particular item were excluded from analysis for that item only.

For each item, we used chi-squared homogeneity tests (Zar 2010) to determine whether the proportion of agreement for owners and non-owners between cities in the same country was the same and therefore whether the data for the cities within each country could be pooled. Those respondents who did not indicate what city they were from were excluded from this analysis. We then used a Generalized Linear Model (GLM) in Statistica 12 (Statsoft Inc. 2013) to assess relationships between the predictor variables (Country, Cat ownership (i.e. cat owners and non-owners) and the Country x Cat ownership interaction) and the dependent variable of agreement with the statement. As there were only two possible answers to each question (agree/disagree), we evaluated the binomial distribution with a logit link function. For countries where the cities were homogeneous according to the previous test, the data were pooled. If not, the cities of that country were analysed separately for that item only. If the cities were considered homogeneous, data from respondents who did not indicate which city they were from were included in the totals for their country. If cities were not homogenous for an item, these respondents were excluded for that item.

Analysis of Specific Items for Cat Owners

For each of the items specific to cat owners we used chi-square contingency tables to evaluate if (i) there were any differences between cities in the same country and therefore whether data could be pooled, and (ii) whether there were any differences between countries. If cities within countries were not significantly different at the 0.05 level, respondents who answered these items but did not disclose what city they were from were included in the totals for that country. Otherwise, they were excluded. For the question 'how many cats do you currently own?' responses were divided into 1 cat, 2 cats and > 2 cats because few owners owned more than two cats.

The survey asked owners to provide information on up to four of their cats if applicable. Information for all of the cats mentioned was used in the analyses. For example, for the question 'has this cat been desexed?', if an owner provided information on three cats, all three cats were recorded and contributed to the total sample size.

Construction of Rasch Scales

The Rasch measurement model was used to establish the psychometric properties of three scales (Restriction, Wildlife and Desexing) using RUMM2030 (Andrich et al. 2013). This examines the fit of a set of data to a linearised uni-dimensional model, which, if the data fit the model, places survey questions and respondents' attitudes relative to one another on a single equal-interval continuum. This produces locations (scores) for each survey item and every respondent. These locations are directly comparable with each other and, since they are linearised, are more appropriate for use in common statistical tests than raw scores. Respondents scoring more highly on the Restriction scale were more supportive of cat legislation, including items such as limiting the number of cats that can be owned per household or opportunities for cats to roam. Those scoring more highly on the Wildlife scale were more likely to be concerned about negative impacts of roaming cats on wildlife, while respondents scoring more highly on the Desexing scale were more knowledgeable about desexing and cat behaviour, more supportive of desexing their own pet cats, and more supportive of requiring others to do likewise.

Analysis of the Rasch Person Locations on the Three Scales

Each of the three scales was analysed separately as a dependent variable in a nested GLM using Statistica 12 (Statsoft Inc. 2013). Country, City (nested within country), Cat ownership status and the Country x Cat ownership interaction were used as predictor variables to test relationships with the dependent variables. We did not extend the analysis to consider, for example, differences in responses between men and women or between people of different ages because inclusion of large numbers of variables in relation to sample size risked overfitting in statistical models. Significance levels for the tests were set at $p < 0.01$ to compensate for heteroscedasticity that could not be corrected by logarithmic transformation (Tabachnick and Fidell 2001). Respondents who did not indicate their city were excluded from these analyses. However, if city was not a significant predictor alone or in interaction, we then repeated the analyses excluding city as a predictor and included respondents who did not give a city.

2.3 RESULTS

2.3.1 Representativeness of the Survey and Non-Response Bias

Characteristics of Survey Respondents

In the presentation of results that follows and in the discussion we refer simply to categories of respondent by country and by cat ownership status, without reiterating that our respondents belong to a specific middle class demographic. They cannot be considered representative of other demographics in the populations of these countries.

There were 1720 respondents across the six countries. Most responses were from China (471 – 47.1% response rate) followed by New Zealand (347 - 11.5% response rate), Japan (295 – 36.9% response rate), the USA (282 - 5.0% response rate), Australia (160 - 4.3% response rate) and the UK (156 - 3.9% response rate). More women responded to the survey than men in all countries except the USA. On average, the respondents from Australia, the UK, New Zealand and the USA were in their 50s. Respondents from Japan and China were much younger with average ages of 31 and 36 respectively (Table 2.2).

Proportions of Cat Owners

In Australia, the USA and China cat owners were represented in the sample in the same proportions as expected based on ownership for the population ($p \geq 0.22$ in all cases). In New Zealand, the UK and Japan, cat owners were over-represented in the sample (χ_1^2 = 30.11, p <0.0001, χ_1^2 = 10.04, p = 0.002 and χ_1^2 = 119.57, p < 0.0001, respectively; Table 2.2).

Non-Response Bias

The proportions of owners and non-owners, men and women, and age categories did not vary depending on whether people responded early or late from each country (p > 0.10 in all cases). Similarly, agreement/disagreement with seven of the eight specific items was not associated with whether people responded early or late. The exception was 'All cats should be kept in at night time', where late cat owners in Australia were more likely to agree (G_2^2 = 6.32, p = 0.042,), while late cat owners in the USA were less likely to agree (G_2^2 = 6.2, p = 0.045). These trends were borne in mind when interpreting the analysis of this item. Non-response bias was not detected in the other questions. No significant correlations were found between respondents' scores on the Restriction, Wildlife and Desexing scales and the promptness with which they responded to the survey ($r \leq 0.215$ in all cases), so there was no evidence of non-response bias in these scales.

Given the almost total absence of evidence for non-response bias for Australia, New Zealand, the UK and the USA, we assumed no non-response bias for Japan (where individual survey timing information was unavailable) and in China, which had the highest overall response rate. Undetected non-response bias may exist, but with no evidence of the direction in which this might be operating no correction was possible.

Table 2.2: Characteristics of respondents in each country.

City and Country	n	Male	Female	Owner	Non-owner	Mean age[1]	Early[2]	Late[3]	Online[4]	Mail[5]
Sydney	53	25	28	11	42	56±13	31	20	51	2
Wollongong	108	54	54	22	86	60±14	60	45	105	3
Unspecified	8									
Australia Total	169	79	82	34	132	59±14	91	65	156	5
Auckland	99	42	57	53	46	48±16	56	36	92	7
Dunedin	225	84	141	114	111	53±16	126	61	187	38
Unspecified	23									
New Zealand Total	347	126	203	175	164	52±16	182	97	279	45
Chicago	62	42	20	18	44	54±13	27	33	60	2
Los Angeles	61	33	28	26	35	54±14	23	35	58	3
Hawaii	140	91	48	42	98	56±14	65	56	121	18
Unspecified	19									
USA Total	282	167	101	91	182	55±14	115	24	239	23
Southampton	107	52	54	42	65	50±18	65	47	105	7
Birmingham	49	17	32	15	34	52±18	27	22	51	0
Unspecified	0									
UK Total	156	69	86	57	99	51±18	207	193	156	7
Japan Capital Area	87	32	55	17	70	28±8	N/A	N/A	N/A	N/A
Shizuoka	101	25	75	36	65	38±14	N/A	N/A	N/A	N/A
Japan Other	65	15	50	16	48	25±13	N/A	N/A	N/A	N/A
Unspecified	42									
Japan Total	295	72	181	82	190	31±13	N/A	N/A	N/A	N/A
Beijing	143	147	148	53	220	37±16	N/A	N/A	N/A	N/A
Harbin	305	49	90	6	115	34±15	N/A	N/A	N/A	N/A
Unspecified	23									
China Total	471	203	245	61	350	36±15	N/A	N/A	N/A	N/A

Mail Survey Respondents

Similar proportions of owners and non-owners (NZ: χ_1^2 = 0.01, *p* = 0.92; USA: χ_1^2 = 0, *p* = 1) and men and women (NZ: χ_1^2 = 0.11; *p* = 0.74; USA: χ_1^2 = 0.88, *p* = 0.35) responded online or by mail. However, there were significantly more retired people in both New Zealand and the USA who responded by mail ($p \leq 0.0001$ for both countries), with mail respondents significantly older by about 20 years in New Zealand and 10 years in the USA than online respondents ($p < 0.0001$ for both countries). Mail survey respondents from the USA were more likely to agree 'That there is a need for cat legislation' (G_2^2 = 6.8, *p* = 0.03) and disagree with 'It is important to have wildlife in cities, towns and rural areas' (G_2^2 = 9.24, *p* = 0.01). New Zealand mail survey respondents were more likely to agree that 'Except for a cat owned by a breeder, all cats should be desexed' (G_2^2 = 8.48, *p* = 0.01). There were no significant differences in responses for the other specific items. Online and mailed responses were pooled for analysis of specific items and development of Rasch scales.

2.3.2 Responses to Specific Items for All Respondents

For most of the specific items, cities within countries were deemed homogenous with only three exceptions. For 'There is a need for cat legislation' and 'Except for a cat owned by a breeder, all cats should be desexed', Hawaii was significantly different from Los Angeles and Chicago. In these instances, Hawaii was treated as a separate country but Los Angeles and Chicago were pooled to form mainland USA (after passing the homogeneity test). The cities within Japan were all significantly different for 'It is important to have wildlife in cities, towns and rural areas' and were treated separately for this item.

There is a Need for Cat Legislation

There were significant effects for country, ownership and the country x ownership interaction (Table 2.3). Non-owners were more supportive of the need for cat legislation than owners everywhere except in Japan (Figure 2.1a). Australian non-owners were the most supportive (88%) followed by Chinese non-owners (80%) and Japanese owners (79.5%). The UK respondents showed least agreement, especially cat owners (25%). The difference between cat owners and non-owners was most marked in New Zealand and Hawaii; conversely there was almost no difference in the results between owners and non-owners on the mainland USA (Figure 2.1a).

Table 2.3: Results of analysis of specific survey questions. Cities within countries are combined, unless responses were shown to differ between cities.

Question	Countries	GLM Result				Interpretation
			Wald Chi-Square	df	Sig.	
There is a need for cat legislation	Australia, New Zealand, UK, USA Mainland, Hawaii, Japan, China	Intercept	36.696	1	<0.001	Non-owners were more supportive of the need for cat legislation than owners everywhere except in Japan.
		Country	81.173	6	<0.001	
		Ownership	23.061	1	<0.001	
		Country* Ownership	35.790	6	<0.001	
All cats should be kept in at night time	Australia, New Zealand, UK, USA, Japan, China	Intercept	37.651	1	<0.001	Owners were less supportive than non-owners, except in Japan where owners were more supportive and in the UK, where owners and non-owners had similarly low agreement.
		Country	142.813	5	<0.001	
		Ownership	16.112	1	<0.001	
		Country* Ownership	25.651	5	<0.001	
Cats should be kept on their owner's property at all times	Australia, New Zealand, UK, USA, Japan, China	(Intercept)	2.07	1	0.150	Owners were generally less supportive than non-owners except in Japan, where this was reversed.
		Country	130.148	5	<0.001	
		Ownership	35.159	1	<0.001	
		Country* Ownership	31.005	5	<0.001	
It is important to have wildlife in cities, towns and rural areas	Australia, New Zealand, UK, USA, Japan Capital Area, Shizuoka, Japan Other, China	(Intercept)	0.000	1	0.997	Support for retaining wildlife in settled areas attracted strong agreement irrespective of cat ownership.
		Country	75.670	7	<0.001	
		Ownership	0.000	1	0.999	
		Country *Ownership	2.945	7	0.890	
Pet cats killing wildlife in cities, towns and rural areas is a serious problem	Australia, New Zealand, UK, USA, Japan, China	(Intercept)	0.946	1	0.331	Non-owners were more supportive than owners in all countries, although in Australia 62% of owners agreed.
		Country	123.967	5	<0.001	
		Ownership	55.927	1	<0.001	
		Country *Ownership	10.002	5	0.075	
Pet cats on farms are harmful to wildlife	Australia, New Zealand, UK, USA, Japan, China	(Intercept)	80.946	1	<0.001	In all countries, owners were less likely to agree than non-owners although all respondents from Australia and New Zealand, regardless of ownership, were more likely to agree than respondents elsewhere.
		Country	113.130	5	<0.001	
		Ownership	33.847	1	<0.001	
		Country *Ownership	11.461	5	0.043	
Pet cats in nature reserves are harmful to wildlife	Australia, New Zealand, UK, USA, Japan, China	(Intercept)	52.070	1	<0.001	Owners were less likely to agree with this item than non-owners. Support was very high in Australia and New Zealand, weaker in the USA and the UK, and lowest in Japan and China.
		Country	187.618	5	<0.001	
		Ownership	10.929	1	<0.001	
		Country *Ownership	2.409	5	0.790	
Except for a cat owned by a breeder, all cats should be desexed	Australia, New Zealand, UK, USA Mainland, Hawaii, Japan, China	(Intercept)	80.082	1	<0.001	In each country agreement was generally higher for this item from cat owners, excepting Hawaii and China, where non-owners were more supportive.
		Country	113.569	6	<0.001	
		Ownership	4.486	1	0.034	
		Country *Ownership	14.884	6	0.021	

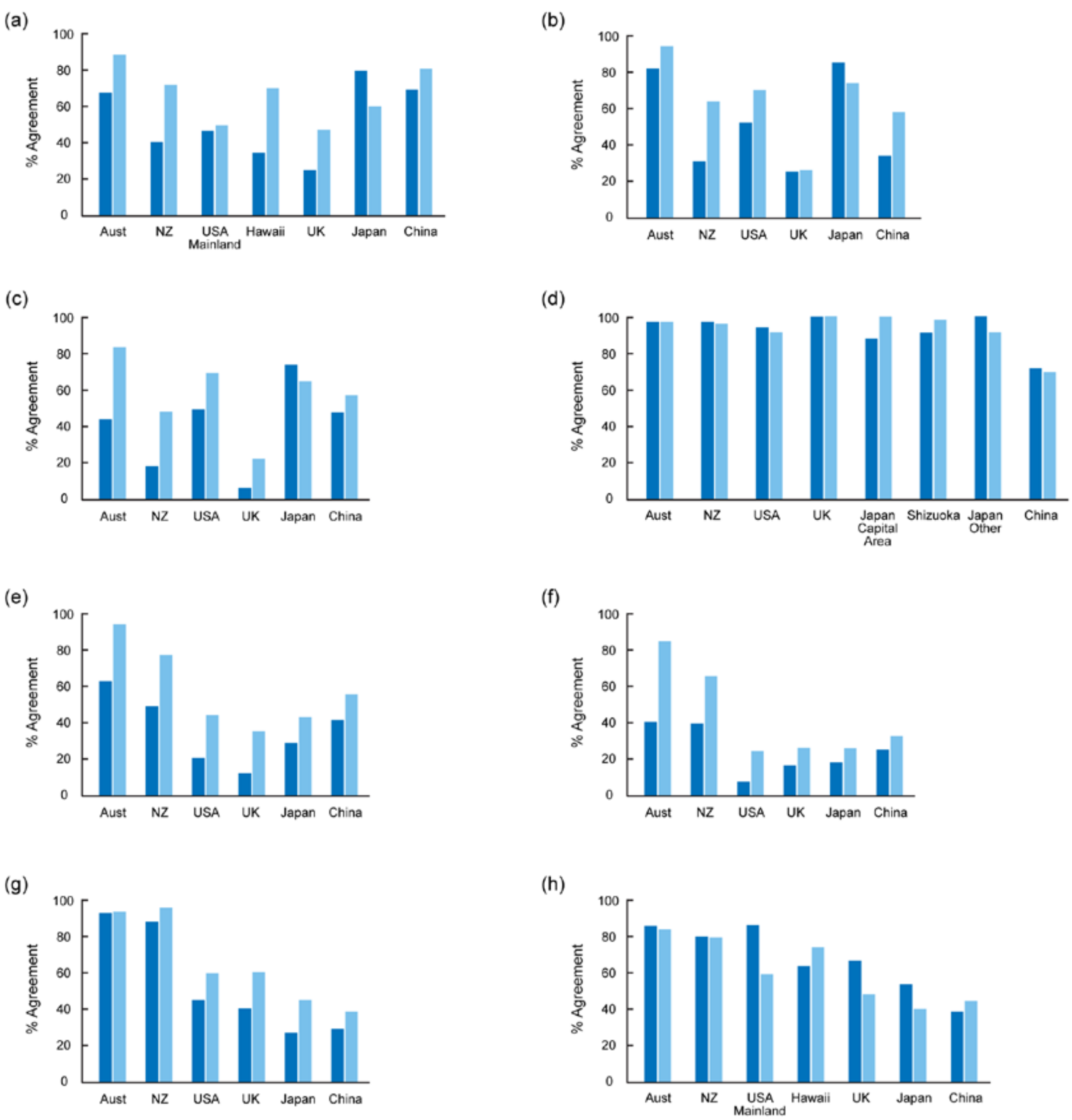


Figure 2.1: Percentage agreement of cat owners (dark blue) and non-owners (light blue) in each country to eight survey items: (a) There is a need for cat legislation (b) All cats should be kept in at night time (c) Cats should be kept on their owner's property at all times (d) It is important to have wildlife in cities, towns and rural areas (e) Pet cats killing wildlife in cities, towns and rural areas is a serious problem (f) Pet cats on farms are harmful to wildlife (g) Pet cats in nature reserves are harmful to wildlife (h) Except for a cat owned by a breeder, all cats should be desexed.

All Cats Should be Kept in at Night Time

There were again significant effects for country, ownership and the country x ownership interaction (Table 2.3). Generally, owners were less supportive than non-owners, except in Japan where owners were more supportive and in the UK, where owners and non-owners had similarly low agreement (Figure 2.1b). Agreement was highest in Australia, followed closely by Japan with over 80% agreement from all Australian respondents and Japanese owners. Support was lowest in the UK, with respondents showing less than 30% agreement irrespective of cat ownership.

Cats Should be Kept On Their Owner's Property At All Times

There were significant effects for country, ownership and the country x ownership interaction (Table 2.3). Owners were generally less supportive than non-owners except in Japan, where this was reversed (Figure 2.1c). Australian non-owners were the only group that showed above 80% agreement, while lowest agreement was for New Zealand owners (18.6%), and both owners (6.9%) and non-owners (22.7%) in the UK.

Although both this item and the previous one consider restricting cat wandering behaviour, confining cats to their owners' properties at all times was less popular amongst the majority of respondents, with the exception of owners and non-owners from the USA and Chinese non-owners where responses remained approximately the same. The differences between cat owners and non-owners were also much stronger for this item except in the USA and Japan, where the differences remained about the same (Figure 2.1c).

It Is Important to Have Wildlife in Cities, Towns and Rural Areas

There was a significant effect of country but no effect of ownership or the country x ownership interaction (Table 2.3). Support for the retention of wildlife in settled areas was very high and, irrespective of cat ownership, attracted over 85% agreement in all countries except China, where only approximately 65% of respondents agreed (Figure 2.1d).

Pet Cats Killing Wildlife in Cities, Towns and Rural Areas is a Serious Problem

There were significant effects for country and ownership, but no significant effect of country x ownership interaction (Table 2.3). Non-owners were more supportive than owners in all countries, although in Australia 62% of owners agreed (Figure 2.1e). Overall, support for this item was highest in Australia followed by New Zealand and least in the UK, where only 12% of owners and 38% of non-owners agreed.

Pet Cats On Farms are Harmful to Wildlife

There were significant effects for country, ownership and country x ownership interaction (Table 2.). In all countries, owners were less likely to agree than non-owners, especially in Australia and New Zealand (Figure 2.1f). However, all respondents from Australia and New Zealand, regardless of ownership, were more likely to agree with this item than respondents from any other country. Support was lowest from cat owners in the USA (8%). With the exception of owners and non-owners from the UK, support for this item was consistently lower than for 'Pet cats killing wildlife in cities, towns and rural areas is a serious problem' and 'Pet cats in nature reserves are harmful to wildlife.'

Pet Cats in Nature Reserves are Harmful to Wildlife

There were significant effects for country and ownership, but not for the country x ownership interaction (Table 2.3). Owners were less likely to agree with this item than non-owners (Figure 2.1g). Support was very high in Australia and New Zealand, with more than 88% of owners and non-owners in each country agreeing that pet cats in nature reserves are harmful to wildlife. The USA and the UK formed a second group with support c. 40% for this item for owners and 60% for non-owners, with Japan and China forming a third group with support c. 30% for owners and 40% for non-owners. For owners and non-owners from Australia, New Zealand, the UK and the USA, support for this item was consistently higher than for 'Pet cats killing wildlife in cities, towns and rural areas is a serious problem' and 'Pet cats on farms are harmful to wildlife.'

Except for a Cat Owned by a Breeder, All Cats Should Be Desexed

There were significant effects of country, ownership and country x ownership interaction (Table 2.3). In each country agreement was generally higher for this item from cat owners, with the exception of Hawaii and China, where non-owners were more supportive (Figure 2.1h). Levels of support were highest among cat owners from Australia, New Zealand and the mainland USA, and lower for UK non-owners, Japan and China.

2.3.3 Responses to Specific Questions for Cat Owners

How Many Cats do You Currently Own?

The number of cats owned by households varied significantly between countries (χ^2_{10}= 92.99, p < 0.0001). With the exception of Japan, the largest ownership category was single-cat households (Figure 2.2a). In China, the proportion of single-cat households was especially high (80%) compared to other countries, with New Zealand next (64%). In the USA, the number of households with only one cat (44%) was only slightly higher than the number of households with two cats (40%). In Australia, New Zealand and the UK there was a drop of at least 25% between one and two cat households. China had a 73% drop between one- and two-cat households. China and Japan had more 'more-than-two-cats' households than two-cat households (Figure 2.2a). Households in the UK were the least likely to have more than two cats (8%). Japan was unusual in that most households (51%) had more than two cats followed by single-cat households (32%) and then households with only two cats (17%) (Figure 2.2a). Some cat owners in Japan owned very high numbers of cats. Ten households (13%) reported owning 10 or more cats with the highest number being 99[1] and the next highest 27.

Does this Cat Live: …

This question targeted whether cats were kept either solely inside, solely outside, inside at night but free roaming during the day, inside and outside but restricted to the owner's property, or inside and outside but free roaming. There was a significant association between confinement and countries (χ^2_{32} = 453.6, $p < 0.0001$). This item was also highly variable within countries, with Australia divided into Sydney and Wollongong, the USA into mainland USA and Hawaii, and Japan divided into Shizuoka and Japan Rest. Cats in Sydney (53%), the mainland USA (66%) and both locations in Japan (75%) were most likely to be kept solely inside (Figure 2.2b).

Although Sydney and Wollongong were significantly different from each other, cat owners in Wollongong still favoured restricting their cats' wandering behaviour either by keeping them in at night (34%), or by restricting them to their property (29%). However, owners in Wollongong were more likely to let their cats be inside and outside but free roaming (20%) than owners in Sydney (8%). Cat owners in New Zealand and the UK reported similar patterns: most cats were "free roaming inside and outside" (67% and 64% respectively), followed by cats kept in at night (14% and 23% respectively). On the mainland USA, cat owners favoured restrictions by keeping their cats solely inside (66%), inside and outside but restricted to their property (19%) or inside at night but free roaming during the day (8%). However, in Hawaii, although cats were predominantly kept

[1] Although possibly an error, the value might indicate a person claiming ownership of a cat colony

solely inside (56%), 20% "were free roaming inside and outside". In Japan most cats were kept solely inside (75%), but the second option preferred by Japan Rest was for cats to be inside and outside but free roaming (14%), compared to inside and outside but restricted to their property in Shizuoka (11%). China showed the least variance. Although 32% of cat owners preferred to keep their cats solely inside, even their lowest two preferences of "inside at night but free roaming during the day" (12%) and "free roaming inside and outside" (12%) were more popular than the second preference in Shizuoka, which was "inside and outside but restricted to owner's property" (Figure 2.2b).

Has this Cat Been Desexed?

There was a significant difference between countries in the proportion of cats desexed (χ^2_7 = 284.4, p < 0.0001), and high levels of variability between cities in China and Japan. Shizuoka was separated from the other Japanese localities, which were all combined into Japan Rest. Beijing and Harbin were considered separately. In general, desexing rates were very high (over 94% in Australia, New Zealand, the USA, the UK and Shizuoka (Figure 2.2c)). Cats in Japan Rest had lower desexing rates than Shizuoka (83% and 99% respectively). China had much lower desexing rates than the other countries (43% in Beijing and 0% in Harbin (Figure 2.2c)).

Has this Cat Ever Caught any Vertebrate Prey?

There was a significant difference between countries in the proportion of cats that had been known to catch prey at least once in their lives (χ^2_6 = 124.1, p < 0.0001). The highest proportions were in the UK (82%) and New Zealand (79%), followed by Hawaii (67%; Figure 2.2d). Respondents from Japan (32%) and the USA Mainland (38%) reported the lowest proportion of cats that were known to catch prey.

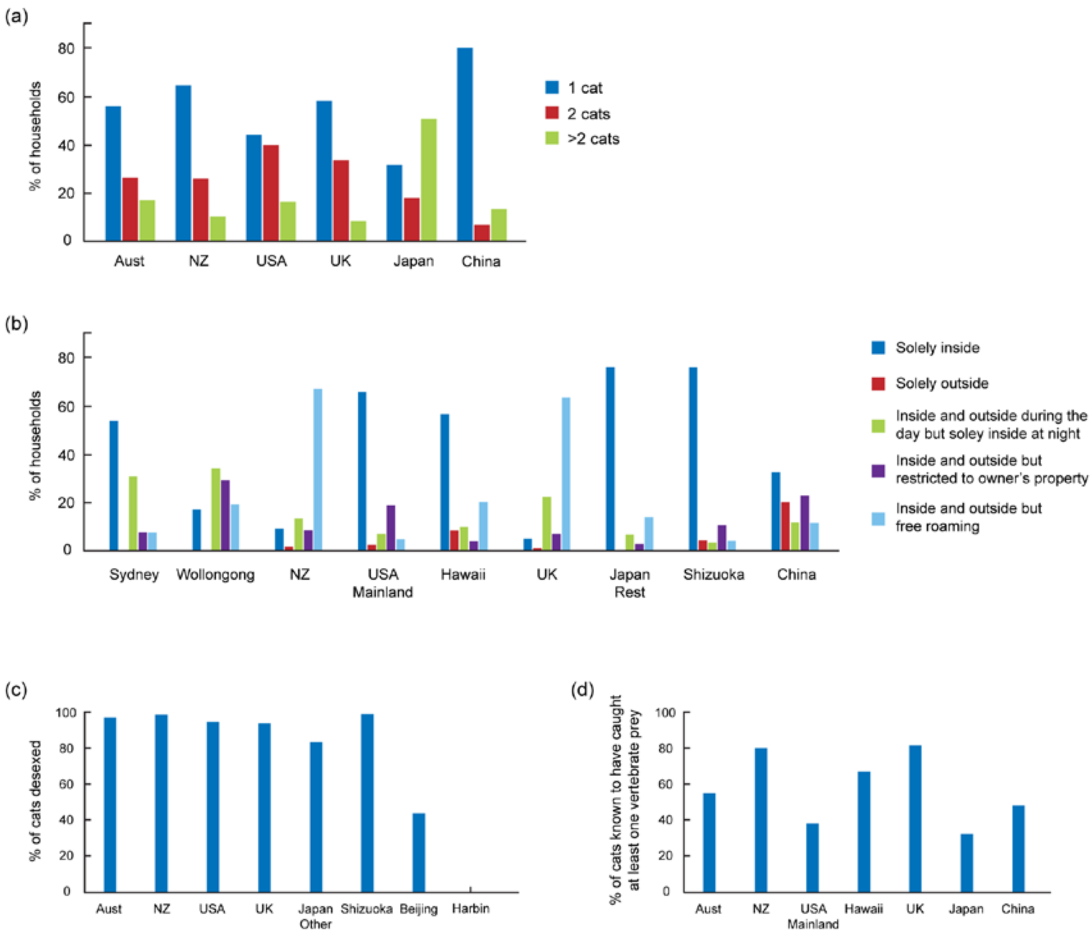


Figure 2.2: Cat husbandry practices in different countries. (a) Percentage households that own one, two or more than two cats (b) Percentage of cats kept in different conditions of confinement (c) Percentage of desexed cats. (d) Percentage of cats that have ever caught vertebrate prey.

2.3.4 Analysis of the Rasch Person Locations for Three Scales

Overall conclusions about the scales' internal consistency and reliability are provided. All but two items (R14 and R16) in the Restrictions scale showed good fit to the model and these were deleted from the final scale as they are measuring a different variable. The Person Separation Index (an index of reliability) was high at 0.856, indicating that this scale provides valid and reliable person measures. To obtain good fit to the Rasch model, one item (W11) was deleted from the Wildlife scale, and two items (S5 and S9) from the Desexing scale. Both scales had lower reliability than the Restriction scale (0.589 and 0.605, respectively). They would benefit from a greater range of items to improve their reliability: at present the items are too homogeneous, relative to the respondents. Analysis of a combination of all three scales (with items S5, S9, R14 and R16 deleted) showed they may, for particular research contexts, be considered as a single scale representing attitudes to cat care and control. The Person Separation for the combined scale was high at 0.847. Using the person locations from each of the three scales separately, traditional statistical techniques were carried out as follows.

With a significance level of 0.01, cities within countries gave consistent results for all scales (Restriction: $F_{(8,1525)} = 1.94$, $p = 0.050$), Desexing: ($F_{(8,1476)} = 1.32$, $p = 0.226$), Wildlife: ($F_{(8,1485)} = 2.24$, $p = 0.022$). Therefore analyses were repeated without cities nested within country as a predictor and respondents who did not indicate a city were included.

On the Restriction scale, there were significant effects for country ($F_{(5,1599)} = 20.43$, $p < 0.001$), ownership ($F_{(1,1599)} = 208.53$, $p < 0.001$) and the country x ownership interaction ($F_{(5,1599)} = 7.53$, $p < 0.001$). In each country non-owners were more supportive of restrictions than owners. This was especially so in Australia, but much less so in Japan. Australian non-owners were more supportive of restrictions on cats than non-owners from other countries, and the same was true for Australian owners compared to owners elsewhere. Support for restrictions was lowest in the UK. The significant country x ownership interaction was driven strongly by the contrast between Japan, where there was only a very small difference in the opinions of owners and non-owners, and Australia, where there was a large difference between owners and non-owners (Figure 2.3a).

On the Desexing scale, there were significant effects for country ($F_{(5,1547} = 11.42$, $p < 0.001$), ownership ($F_{(1,1547)} = 9.97$, $p = 0.002$) and the country x ownership interaction ($F_{(5,1547)} = 4.93$, $p = 0.003$). Owners were more supportive of desexing than non-owners except in China, where non-owners tended to be more supportive. Support for desexing was highest in Australia and lowest in China (Figure 2.3b).

On the Wildlife scale there were significant effects of country ($F_{(5,1555)} = 45.13$, $p < 0.001$), ownership ($F_{(5,1555)} = 109.26$, $p < 0.001$) and the country x ownership interaction ($F_{(5,1555)} = 5.25$, $p < 0.001$). In each country non-owners showed higher scores than owners. This difference was especially marked in Australia and New Zealand, but much less in China and Japan. Internationally, Australian and New Zealand non-owners had the highest scores compared to other non-owners, and the same was true for owners (Figure 2.3c).

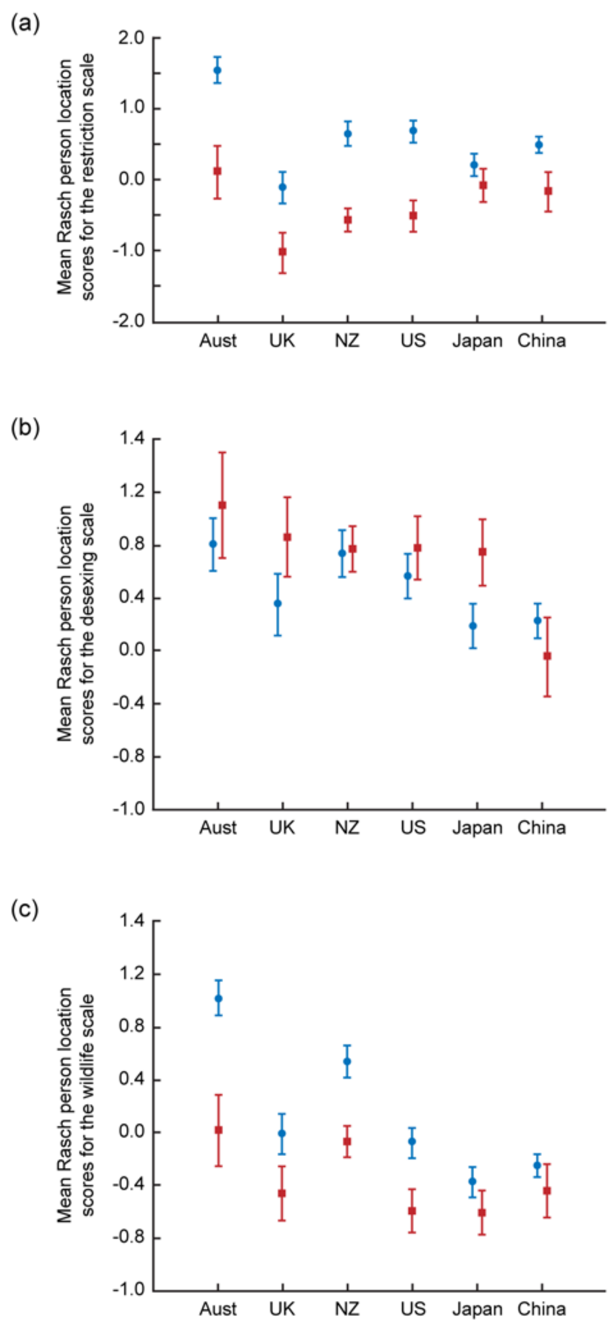


Figure 2.3: Mean Rasch person location scores, ± 95% confidence limits, for owners (red) and non-owners (blue) on (a) The restriction scale (b) The desexing scale (c) The wildlife scale.

2.4 DISCUSSION

2.4.1 Tests of Specific Predictions

Our predictions that cat owners would be less accepting of statements implying that cats threaten wildlife than non-owners and be less accepting of cat regulation were largely fulfilled. In all countries non-owners were more likely than owners to believe that pet cats killing wildlife were a problem in a range of locales, while legislation was supported most strongly by non-owners everywhere except in Japan. We have no specific evidence of why owners were less likely to believe that pet cats killing wildlife was a problem. Where the predominant practice of owners was to confine their pets at all times, this belief likely rests on the sound premise that confined cats cannot hunt wildlife, although wildlife protection need not be the motivation for confinement. In other cases, owners presumably believed that predation by pet cats was an insignificant factor in determining the distribution and abundance of prey species. Alternatively, they chose to value the convenience of their pets over wildlife. However, the prediction that owners valued wildlife less than non-owners was not supported. Significant differences between countries were identified, offering partial support for the prediction that respondents from Australia, New Zealand, China and the US state of Hawaii (all with high endemic wildlife biodiversity) would be more concerned about impacts of pet cats on wildlife than respondents from elsewhere. Even large proportions of Australian (62%), New Zealand (51%) and Chinese owners (42%) agreed that pet cats killing wildlife in cities, towns and rural areas was a problem (although Hawaii matched the mainland USA). Hawaiian non-owners, though, were more supportive of cat legislation and desexing pet cats than non-owners on the mainland USA. Overall, the pattern of responses seems to be determined by a complex of historical and cultural conditions.

2.4.2 International Differences in Attitudes to Cats and Wildlife

Marked national differences occurred in responses to individual questions and in the analyses of the Rasch scales. These have implications for any attempts to regulate cat ownership in each country. We discuss these in the context of research in different countries that has attempted to quantify any impacts of pet cats on wildlife. We did not extend the analysis to consider, for example, differences in responses between men and women or between people of different ages because inclusion of large numbers of variables in relation to sample size risked overfitting in statistical models. However, these variables may also have an influence.

Australia

The popularity of cats as pets in Australia is declining, with the pet cat population estimated at 2.93 million in 1994 and 2.35 million in 2009. The percentage of households owning a cat declined from 24.6% to 22.8% over the same period (ACAC 2010). The second highest reason for Australians not owning a cat (after dislike of cats) is concern about wildlife (Baldock et al. 2003, Chaseling 2001). Thus it was unsurprising that

Australian owners and non-owners scored highly on the wildlife Rasch scale and were likely to believe that pet cats are harmful to wildlife in cities, towns and rural areas and nature reserves. Most Australian non-owners (85%) were also likely to believe that pet cats are harmful to wildlife on farms, but not owners (41%).

Australians have a special preference for their native fauna compared to citizens from the UK, the USA, India and South Africa (Macdonald et al. 2015b). Exotic predators such as cats and foxes (*Vulpes vulpes*) are accepted as significant threats to Australian fauna (Kinnear et al. 2002, Risbey et al. 2000), with feral cats now assessed as endangering more threatened and near threatened Australian mammalian taxa than any other factor (Woinarski et al. 2014). Concern about predation by feral cats on wildlife is manifested in significant paintings by contemporary artists and in museum displays, with some extending to predation by pet cats. Such sustained messages in varied media are reflected in high concern by both owners and non-owners that predation by pet cats on wildlife in cities, towns and rural areas endangers wildlife. Such concerns are at least 25 years old (Paton 1990, 1991).

Research on the effects of pet cats on wildlife populations in Australia has resulted in more ambiguity than popular opinion would suggest. Urban habitats provide important refuges for threatened species that are vulnerable to cat predation, including a legless skink (*Delma impar*) in suburban Canberra (Osborne and Williams 1991) and the eastern barred bandicoot (*Perameles gunnii*) in Hamilton, Victoria (Dufty 1994). However, in the case of the eastern barred bandicoot traffic was even more of a threat than predation by cats (Dufty 1994). Barratt (1998) and Grayson et al. (2007) concluded that pet cats kill mainly common vertebrates that persist in cities despite predation, although they acknowledged that problems may be more severe near remnant vegetation or on urban fringes. Thus, while pet cats may depress some prey populations, they are also a convenient scapegoat for more intractable causes of wildlife decline (Chaseling 2001, Lilith et al. 2010, Nattrass 1992).

New Zealand

Cats are popular household pets in New Zealand, with 35% of households owning at least one (Aguilar and Farnworth 2013). These cats co-exist with a predominantly endemic native fauna, although in urban areas nearly half of bird species and most individuals are exotic (van Heezik et al. 2008). With the exception of bats, there are no native mammals. New Zealand respondents were concerned that their fondness for cats could impact their native wildlife, leading to them having the second highest score on the wildlife scale and high agreement that pet cats are a serious problem for wildlife in cities, towns and rural areas, and in nature reserves. Non-owners were also likely to believe that pet cats are a serious problem on farms. This is consistent with popular cultural messages related to responsible pet ownership such as Crew (2008), a children's story recounting the fate of the Stephen's Island wren (*Xenicus lyalli*) at the claws of the lighthouse keeper's cat.

Whether cat husbandry should be regulated to protect wildlife proved more contentious. Although support for legislation amongst non-owners was high (70%), support from cat owners was substantially lower (40%) and New Zealand owners scored the second lowest on the restriction scale after UK owners.

Despite the ambivalence of owners towards restrictions, there is evidence that predation by pet cats in New Zealand is likely to be additive (increasing the overall mortality) rather than compensatory (removing individuals that would otherwise die from other causes) for at least some species of New Zealand birds, with urban populations likely being sinks replenished from source habitats with less predation (van Heezik et al. 2010). A New Zealand study also provides the most comprehensive record of predation by one pet cat over its lifetime: in 17 years, the desexed female brought home 558 prey, including mice, rats, rabbits, hares, weasels and birds (Flux 2007). The author did not believe that this predation had negative effects on the local wildlife.

USA

Few respondents in the USA considered pet cats a threat to wildlife in cities, towns and rural areas or on farms, but about half considered pet cats a threat in nature reserves. American respondents also scored the lowest of the western countries on the wildlife scale, although it may be that given the high incidence of confinement in the USA respondents had in mind that cats were not a threat because they were likely to be indoors. Respondents were ambivalent about the need for legislation regulating ownership and husbandry of pet cats, perhaps reflecting strong community divisions on the issue (see Peterson et al. (2012) for coverage of these issues as related to managing colonies of feral or semi-feral cats). On the one hand, conservation groups advocate regulations to enhance cat welfare, reduce public nuisance and protect wildlife (e.g. American Bird Conservancy 2011a, 2011c), while on the other hand lobby groups such as the Cat Fanciers' Association resist regulations they perceive as unreasonable, even offering the support of a legislative committee (http://www.cfainc.org/Legislative/LegislativeGroup.aspx). The primary motivation for much existing legislation appears to be the reduction of public nuisance (e.g. Council of the Town of Coolee Dam 1988). Within Hawaii, where many of the cats are free-roaming, there is strong potential for interaction with feral cat colonies as well as opportunities to depredate native wildlife, including endangered species. Thus conservation of Hawaii's unique fauna may be important in shaping attitudes there.

Wildlife mortality from pet cats in the continental USA is estimated at 684 million birds and 1,249 million mammals annually (Loss et al. 2013b), while the American Bird Conservancy (2011b) estimated that 500 million to one billion birds are killed each year by pet cats. As an example of effects at the level of a single species, Balogh et al. (2011) determined that predation accounted for 79% of mortalities of post-fledging grey catbirds (*Dumatella carolinensis*), with 47% of these mortalities caused by domestic cats (not necessarily pets). While they acknowledged that they could not determine if this mortality was compensatory or additive, the successful development of collar-worn predation deterrents by USA businesses (Calver et al. 2007, Hall et al. 2015, Willson et al. 2015) shows that many cat owners in the USA wish to curtail their cats' hunting behaviour.

UK

Respondents from the UK were the least supportive of introducing legislation and scored lowest on the restrictions scale. They were unlikely to believe that pet cats are harmful to wildlife in towns, cities and rural areas or farms, and only 61% of non-owners and 41% of cat owners believed that pet cats are harmful to wildlife in reserves. However, the UK had the highest proportion of cats known to have hunted vertebrate prey on at least one occasion, probably because most cats are kept either inside or outside but free roaming (64%), or only confined at night (23%). Requiring owners to restrict wandering behaviour by either keeping their cats in at night or keeping them confined to their owner's property was very unpopular amongst both cat owners and non-owners. Requiring owners to desex their cats was only supported by about 66% of owners, although the actual desexing rate was very high (93%). These results are in close accord with independent findings that UK cat owners from two small rural communities disagree that cats harm wildlife populations and are unsupportive of most cat management actions other than neutering (McDonald et al. 2015). The similarity of attitudes to those from the urban populations we surveyed suggests a characteristic position for UK citizens irrespective of place of residence. Historically, there is a strong tradition in the UK of keeping farm cats to control vermin, so responses are consistent with this view of the function of cats.

UK responses are consistent with the finding that UK citizens respond even more positively than people elsewhere to felids as symbols of nature (Macdonald et al. 2015b).

They also match the official message from bodies such as the Royal Society for the Protection of Birds (RSPB) that '... there is no scientific evidence that predation by cats in gardens is having any impact on bird populations UK-wide. This may be surprising, but many millions of birds die naturally every year, mainly through starvation, disease, or other forms of predation. There is evidence that cats tend to take weak or sickly birds.' However, there is acknowledgement that: 'Cat predation can be a problem where housing is next to scarce habitats such as heathland, and could potentially be most damaging to species with a restricted range (such as cirl buntings (*Emberiza cirlus*)) or species dependent on a fragmented habitat (such as Dartford warblers (*Sylvia undata*) on heathland)' (RSPB 2014).

Studies of predation by pet cats in the UK have moved from estimates of nationwide losses based on extrapolations from local or regional mortality (e.g. Churcher and Lawton 1987, Woods et al. 2003) to assessments of population risk that support the conclusion that at least some populations are affected by cat predation (Baker et al. 2005, Sims et al. 2008, Thomas et al. 2012), sublethal effects from cat presence (Beckerman et al. 2007), or cats mediating the effects of other predators (Bonnington et al. 2013). However, the attitudes expressed by our UK respondents and the RSPB position endorse the opinion that 'Management of the predation behavior of urban cat populations in the UK is likely to be challenging and achieving this would require considerable engagement with cat owners' (Thomas et al. 2012 pg. 1).

Japan

Japan was the only country where owners were more supportive of restrictions than non-owners. The cultural issues underlying this may be complex, because welfare issues such as reducing the incidence of cats being hit by cars or getting lost apply in urban environments elsewhere. Certainly, cats are very popular in Japan, with the phenomenon of 'cat cafés' where people engage directly with cats without owning them being '... a significant retail phenomenon throughout Japan, and in particular Tokyo' (Plourde 2014). The prevailing views seem well-expressed in an online guide to keeping pets:

'Cat owners are required by municipal authorities "to keep the cat in such a manner so as it won't disturb other citizens."

The three basic principles of keeping cats are:

- Keep your cat in a house.
- Use a collar marked with address and name of the owner.

- Have your cat sterilized.' (Tokyo International Communication Committee 2006)

Japan scored the lowest on the wildlife scale and respondents were unlikely to believe that cats were harmful to wildlife in any situation, although it may be that this was based on the assumption that cats were kept mainly indoors. The number of cats in Japan reported to have killed vertebrate fauna was the lowest across all countries, probably because most were confined. This may result from a high incidence of apartment living.

Studies of predation by pet cats in Japan are limited, although feral cats on offshore islands are significant predators of birds (Matsui and Takagi 2012). Research concentrates on stray (unowned) domestic cats in urban areas (Uetake et al. 2014).

China

China's biodiversity includes approximately 10% of known species (animal and plant), which is greater than Europe or North America (McBeath and McBeath 2006). Culturally, the Chinese have a long history of adopting a utilitarian approach to their biota, seeing them as resources first and other values second (Harris 1996). Infrastructures for sustainable use of natural resources and biodiversity conservation are still developing, but often include many staff and cover extensive geographic areas (McBeath and McBeath 2006, Wandesforde-Smith et al. 2014, Yeh 2013). Long-standing cultural perspectives and changing regulatory approaches may underpin the views of Chinese respondents. Furthermore, China's size and diversity can lead to substantial regional differences in attitudes and regulations (Wandesforde-Smith et al. 2014), emphasising that our results are restricted to the particular urban populations we surveyed.

While approximately 70% of owners and 80% of non-owners in China agreed that there was a need for cat legislation, their scores on the restriction scale were similar to those found in New Zealand, the USA and Japan. Perhaps the Chinese respondents did feel that there should be cat legislation, but not in the areas addressed in the survey. Animal welfare organisations are recent in China, with Animals Asia founded in 1998 and the Chinese Animal Protection Network (CAPN) commencing in 2004. They oppose eating cat and dog meat and support trap-neuter-return (TNR) programs to control cat numbers (Animals Asia 2015, CAPN 2015). Possibly, these are priority areas for legislation in the minds of Chinese citizens. While most Chinese respondents felt that wildlife is important in towns, cities and rural areas, they did not score highly on the wildlife scale. Chinese respondents were more likely than those from the UK, the USA and Japan to believe that pet cats endanger wildlife in cities, towns and rural areas, but less likely than people in these countries to believe they might affect wildlife in nature reserves.

2.4.3 International Differences in Cat Husbandry Practices

In most countries there is a link between the number of cats per household and the manner in which they are kept (e.g. solely inside, solely outside etc.). In Japan and the USA where respondents were most likely to keep their cats solely inside, households were more likely to have multiple cats. In New Zealand and the UK, where most cats had free access inside and outside all the time, households were more likely to have only one cat. It may be that in households where cats are not permitted outside and therefore do not have contact with other animals, owners have multiple cats to keep each other company when no people are home. However, in China the majority of households had only one cat regardless of how they were kept. Lepczyk et al. (2004) found a positive relationship between the number of people living at a residence and the number of cats in Michigan, USA, and suggested that larger residences are more likely to have children who own pets. This trend may occur elsewhere, but it would not account for the very high numbers of cats in many households in Japan.

Whether cats were allowed outside or not may also be related to urban density and perhaps to the likelihood of cats encountering dogs, traffic or other urban disturbances, or predators such as red foxes *Vulpes vulpes* or coyotes *Canis latrans* that enter cities or urban fringes. In Australia, significantly more cats were kept inside in Sydney, the larger city, than Wollongong. Similarly, in the USA cats in the large, mainland cities of Chicago and Los Angeles were more likely to be confined than those in Hawaii. Climate is not a factor, because Wollongong and Sydney have similar climates while Chicago and Los Angeles are very different (Table 2.1). Ironically for wildlife protection, while the less dense cities provide more urban gardens offering shelter and food for wildlife, the lower incidence of cat confinement may provide more opportunities for pet cats to encounter wildlife.

Of all the English-speaking countries in the survey, respondents in the USA were the most likely to keep their cats solely indoors (mainland USA 66%, Hawaii 56%). High rates of confinement between 30% and 60% are also reported in other North American studies (e.g. American Bird Conservancy 2011d, Dabritz et al. 2006, Patronek et al. 1997). Given that the American Veterinary Medical Association, the Humane Society of the USA (Rochlitz 2005), the American Association of Feline Practitioners (2007), the American Bird Conservancy (American Bird Conservancy 2011a, 2011b, 2011c, 2011d) and the Wildlife

Society (2006) support home confinement of pet cats in urban and suburban areas, professional endorsement of the practice may be important in its acceptance. Rochlitz (2005) and the American Association of Feline Practitioners (2007) also support enriching the indoor environment for cats. We found the highest incidence of confinement in Japan, possibly as a result of high urban densities, apartment living, regulation, and advice on responsible pet ownership (Tokyo International Communication Committee 2006).

Predictably, there is an association between how pet cats live (solely inside, solely outside, etc.) and whether they have ever been known to catch vertebrate prey. New Zealand and the UK, where cats were most likely to be free-roaming, recorded the most cats that have brought prey home at least once. Records of cats hunting were lowest in the mainland USA and Japan, where cats are predominantly kept inside. In Australia, Hawaii and China, partial confinement is more popular, so many cats have access outside at least some of the time. Although these cats may not hunt regularly, they still returned some prey.

There were high desexing rates of cats in all countries except China. Chinese respondents scored very low on the desexing scale and support for desexing cats that are not owned by breeders was also low. Only 39% of cats in Beijing and no cats in Harbin were desexed. These figures may reflect people considering they ‘own’ colony cats, or a cultural aversion to desexing. Considering that 45% of Chinese cats in our sample were allowed to wander away from their owner’s property at least some of the time, there are likely to be many unwanted kittens.

Despite widespread desexing of cats in countries other than China, the proportion of people who agreed with the item ‘except for a cat owned by a breeder, all cats should be desexed’ was much lower than the actual desexing rate amongst respondents' cats. For example, Japanese respondents were unlikely to agree that all cats should be desexed, but desexing rates were still high (91%). Even though cat owners choose to desex their pets, they are less likely to agree that everyone should be required to do so, despite being more supportive of compulsory desexing than non-owners (except in China).

Overall, the pattern of practices varies considerably across countries in response to a complex of environmental conditions and cultural attitudes, which we have described but not explained.

2.4.4 Representativeness of the Survey

Despite the low response rates, there was little detectable evidence of survey bias. New Zealand, Japan and the UK were the only countries where cat-owners were over-represented in the survey compared to estimates in the general population, although this does assume that the published figures for cat ownership are accurate. In the case of Japan, the disparity may be an artefact of distributing questionnaires through veterinary clinics and local shops. This may also be a reason why the mean ages of Japanese respondents were much younger than those reported in other countries and could mean that the survey missed an older demographic. The possibility that cat owners were more strongly motivated to contribute could also be a factor in Japan and elsewhere.

Further support for the representativeness of the survey comes from the broad similarity of our findings with others conducted in similar communities. For example, our findings about the reluctance of UK cat owners to take any action other than desexing their pets agrees closely with studies by McDonald et al. (2015) and Thomas et al. (2012). In Australia, which has had multiple surveys of attitudes toward cats this century, our finding that 62% of owners accepted that cats killing wildlife were a problem in cities, towns and rural areas was similar to findings of 50% in Grayson et al. (2002) and 63% in Lilith et al. (2006), both for a similar demographic. In New Zealand, our results are similar to those from New Zealand market research company UMR Research's 2013 survey on public attitudes toward cats (White 2013). For example, after being prompted with figures on the number of native birds killed by cats in New Zealand, 54% of UMR respondents supported some form of control that would reduce the future population of cats (*cf.* 55% of all respondents in our survey agreeing, without prompting, that some form of cat legislation was necessary). In the UMR survey 62% of respondents believed that all pet cats should be desexed, while in our study nearly 80% of all New Zealand respondents supported the less restrictive position that, with the exception of licensed breeders, all pet cats should be desexed.

There were significant differences in the demographics of people who responded by mail or online in New Zealand and the USA, as well as differences in their responses to some questions. Mail respondents were older and more likely to be retired in both countries. Thus it was worthwhile to offer a mail survey alternative as opposed to providing only an online option, because otherwise we would have missed a significant portion of the older demographic. The variations in responses to some questions in mailed responses relative to internet responses reinforce the importance of offering the option of a mailed response.

Overall, although we have no detectable evidence of non-response bias, we believe the most likely biases in our data are: (i) over-representation of affluent people in the Western countries (an acknowledged issue with internet surveys, although such affluent people may be more likely to enter social debate or have political influence (Macdonald et al. (2015b)); (ii) despite the offer of a mailed response to those invited to respond online, possible under-representation of older people; (iii) over-representation of responsible cat owners, as suggested by the high rates of desexing in their animals. Moreover, our results cannot be claimed to be representative of rural populations, or of socio-economic groups within cities other than our target demographic.

2.4.5 Implications for Wildlife Conservation

Empirical research from Australia (Dufty 1994), New Zealand (van Heezik et al. 2010), the USA (Lepczyk et al. 2004) and the UK (Thomas et al. 2012) has established that predation by pet cats threatens at least some elements of urban or rural wildlife. While uncertainty remains regarding the risk to populations of particular species in specific localities, a precautionary approach to cat ownership and husbandry is justified while research is undertaken (Calver et al. 2011, Grayson and Calver 2004). Our chosen middle class demographic represents people most likely to be politically engaged and therefore potentially willing to engage in debate over cat husbandry (Macdonald et al. 2015b). Therefore their views are significant.

Of the nationalities we surveyed, Australians are most likely to accept a wildlife-based rationale for restrictions on cat ownership. Most owners and non-owners accept that pet cats may endanger wildlife (irrespective of whether or not the proposition is true), and are more accepting of measures to restrict cats in the interests of wildlife protection. Elsewhere, with the possible exception of New Zealand, arguing for restrictions on cats to protect wildlife may be counterproductive. This is especially true of the UK, where even non-owners are likely to discount cat predation as a threat to wildlife, legislation is unwanted, and there is very little support for confinement of pet cats.

Welfare arguments addressing responsible cat ownership represent an alternative approach to protect wildlife in countries other than Australia (and possibly New Zealand) where cat owners are unlikely to accept legislation based on wildlife protection, but may be more responsive to arguments based on cat welfare. This is the approach advocated by the American Bird Conservancy (2011b, 2011c). Welfare-based arguments appeal to the cat-loving citizens of the UK, where even the concept of cat cafes is subject to careful welfare scrutiny (Bradshaw 2013). While not enhancing cat welfare, predation deterrents may also appeal to owners concerned about the welfare of prey. Bells, pounce protectors, battery-powered alarms and colourful collar covers all reduce predation by cats significantly for different groups of vertebrate prey (Calver et al. 2007, Calver and Thomas 2011, Dickman 2014, Gordon et al. 2010, Hall et al. 2015, Nelson et al. 2005, Ruxton et al. 2002, Willson et al. 2015), but do not stop all hunting. They could be promoted to reduce hunting success, especially if owners can be reassured that properly fitted safety collars are low-risk (Calver et al. 2013). However, support for them is modest amongst owners in the UK (Thomas et al. 2012), while in New Zealand the UMR Research's 2013 survey on public attitudes toward cats in New Zealand reported only 42% support for requiring all cats to wear a bell on their collar (White 2013).

The most effective way to protect wildlife from the potential impact of pet cats and to improve cat welfare by reducing the risk of road accident trauma and fighting is to restrict cats to their owners' properties, ideally within runs so that some of the garden is safe from cat activity. Most cats in our study from Australia (Sydney), mainland USA, Hawaii and Japan were kept inside only, as were a third of cats from China. It is unclear whether this was done for reasons of cat welfare or wildlife protection, although the views of American, Japanese and Chinese owners on the impacts of cats on wildlife suggest that the motive was cat welfare. Fewer than 10% of New Zealand or UK owners confined their cats. Welfare campaigns highlighting the risks to roaming cats might increase the acceptability of confinement in the UK and New Zealand, especially if accompanied by advice on environmental enrichment requirements for indoor cats (Machado and Genaro 2014, Rochlitz 2005), and the use of leash training and outdoor enclosures.

Of course, regulating pet cats will not be a panacea for wildlife protection. Although in some instances pet cats may pose a significant threat to local wildlife (e.g. Thomas et al. 2012, van Heezik et al. 2010), this is additive to many other impacts from anthropogenic mortality sources such as collisions with cars and other forms of transport, collisions with structures and windows (for birds), electrocution, pollution and over-hunting (Dufty 1994, Erickson et al. 2005, Loss et al. 2012, 2013a, 2014a, 2014b). The primary threat to wildlife near human dwellings is often habitat loss and fragmentation (Bender et al. 1998, Grayson et al. 2007, Lampila et al. 2005), while the decline in the average garden size and desire for houses with larger floor areas in many countries provide fewer resources for wildlife in urban areas (Gaston et al. 2005a, van Heezik et al. 2010, White et al. 2005). The substantial populations of unowned cats roaming in cities, sometimes fed deliberately by people, may also be a significant wildlife protection issue requiring unique approaches (Aguilar and Farnworth 2013, Farnworth et al. 2011, Lepczyk et al. 2010, Miller et al. 2014). Nevertheless, reducing the threat from pet cats will benefit some species and can be done while enhancing cat welfare. It is therefore an immediate and effective action that should be undertaken together with, not instead of, investigation of some of the more intractable causes of wildlife decline.

---

*As per the requests of examiners I have included references for predictions made in the introduction of this chapter. As this paper has been published I have included the information in the following paragraph rather than altering the text of the chapter.

(i) cat owners would agree less that cats might threaten wildlife than non-cat owners (Grayson et al. 2002, Lilith et al. 2006), (ii) cat owners would value wildlife less than non-cat owners (Grayson et al. 2002, Lilith et al. 2006), (iii) respondents from Australia, China, New Zealand and the US state of Hawaii (all with high levels of endemic (distinct) wildlife biodiversity) would be more concerned about the potential impacts of pet cats on wildlife than respondents from the UK, the mainland USA and Japan (Macdonald et al. 2015b), and (iv) cat owners would be less accepting of cat legislation/restrictions than non-owners (Grayson et al. 2002, Lilith et al. 2006).

3 ASSESSING THE EFFECTIVENESS OF THE BIRDSBESAFE® ANTI-PREDATION COLLAR COVER IN REDUCING PREDATION ON WILDLIFE BY PET CATS IN WESTERN AUSTRALIA

Catherine M HALL, Joseph B FONTAINE, Kate A BRYANT, Michael C CALVER

This chapter has been published in the journal Applied Animal Behaviour Science as:

Hall, C.M., Fontaine, J.B., Bryant, K.A., Calver, M.C., 2015. Assessing the effectiveness of the Birdsbesafe® anti-predation collar cover in reducing predation by pet cats on wildlife in Western Australia. Applied Animal Behaviour Science 173, 40–51.

ABSTRACT

Many pet cats hunt and, irrespective of whether or not this threatens wildlife populations, distressed owners may wish to curtail hunting while allowing their pets to roam. Therefore we evaluated the effectiveness of three patterned designs (simple descriptions being rainbow, red and yellow) of the anti-predation collar cover, the Birdsbesafe® (BBS), in reducing prey captures by 114 pet cats over 2 years in a suburban Australian context. The BBS offers a colourful indicator of a cat's presence and should therefore alert prey with good colour vision (birds and herpetofauna), but not most mammals with limited colour vision. We also interviewed the 82 owners of cats in the study about their experience using the BBS and their assessment of the behavioural responses of their cats. In the first year of the study, which focused on the effectiveness of different BBS colours, captures of prey with good colour vision were reduced by 54% (95% CL 43% - 64%) when cats were wearing a BBS of any colour, with the rainbow and red BBS more effective than the yellow when birds were prey. Captures of mammals were not reduced significantly. The second year assessed the rainbow BBS alone, and those data combined with rainbow data in the first year found a significant reduction of 47% (95% CL 43% - 57%) in capture of prey with good colour vision, with no effect of differences across years. We found no evidence that cats maintained a lower predation rate once the BBS was removed. Seventy-nine per cent of owners reported that their cats had no problems with the BBS and another 17% reported that their cats adjusted within 2 days. Fourteen owners reported that their cats spent more time at home and ate more while wearing the BBS. Two owners reported their cats stayed away from home more while wearing it. Sixty-four per cent of owners using the red collar, 48% using rainbow and 46% using yellow believed

that it worked. Overall, 77% of owners planned to continue using the BBS after the study had finished. The BBS is an option for owners wishing to reduce captures of birds and herpetofauna by free-ranging cats, especially where mammalian prey are introduced pests. To date, the BBS is the only predation deterrent that is known to reduce significantly the number of herpetofauna brought home. It is unsuitable where endangered mammalian prey or large invertebrates are vulnerable to predation by pet cats.

Keywords

pet cat; Birdsbesafe; predation; urban wildlife; *Felis catus*; predation deterrent

Author Contributions

This chapter has three co-authors. M. Calver and K. Bryante assisted with survey design and offered comments and direction in the production of the paper and J.B. Fontaine assisted with the statistical analysis.

3.1 INTRODUCTION

Pet cats *Felis catus* are recognised globally as wildlife predators (Baker et al., 2005; Gordon, 2010; Barratt 1997, 1998). Woods et al. (2003) extrapolated from their data that pet cats in Great Britain brought home 92 million prey over 5 months. Loss et al. (2013b) estimated the median wildlife mortality by pet cats in the USA at 684 million birds and 1,249 million mammals annually. In Canada, Blancher (2013) estimated that urban pet cats take approximately one-sixth of 100 - 350 million birds (95% of estimates in this range) killed annually by all cats, owned and feral. In South Australia, Paton (1991) argued that pet cats take ≥ 50% of the urban bird population each year and may indirectly impact other species in nearby remnant bushland.

Nevertheless, debate exists regarding whether wildlife populations are endangered by this predation. In Bristol, UK, predation rates of house sparrows (*Passer domesticus*), robins (*Erithacus rubecula*) and dunnocks (*Prunella modularis*) were high compared to their annual productivity, implying that cat predation regulated their populations (Baker et al. 2005). In Dunedin, New Zealand, population modelling of six bird species with different estimates of cat predation showed that the likelihood of local extirpation with any cat predation was high for blackbirds (*Turdus merula*), while fantails (*Rhipidura fuliginosa*) and silvereyes (*Zosterops lateralis*) would only persist if the predation rate was halved (van Heezik et al., 2010). Balogh et al. (2011) found that predation on gray catbirds (*Dumetella carolinensis*) in suburban Washington D.C., USA, accounted for 79% of all mortalities with 47% attributable to pet cats, but conceded that cats may take prey that would otherwise have died from disease or injury. In Hamilton, south-eastern Australia, Dufty (1994) found that cat predation was the highest cause of mortality for juvenile eastern barred bandicoots (*Perameles gunnii*) and the second highest cause of mortality for the population after road death. Even the presence of pet cats may alter prey behaviour, contributing to population declines (Beckerman et al. 2007, Bonnington et al. 2013). Other authors argue that pet cats hunt common species that cope with the impacts or take diseased or injured individuals, with the focus on cats deflecting attention from more significant causes of wildlife decline (Fitzgerald 1990, Fitzgerald and Turner 2000, Shochat et al. 2010, Sims et al. 2008, Siracusa 2012).

Calver et al. (2011) argue that documented predation rates and examples of significant risk to prey populations justify precautionary husbandry of pet cats. In some countries many owners always keep their pets indoors (for example, apartment owners in Switzerland (Bradshaw 1992)), preventing interactions between pet cats and wildlife. If cats are not indoors, then ideally owners should keep them on their properties at all times to reduce predation and nuisance to neighbours (Jongman 2007, Toukhsati et al. 2012). However, most Australian (Grayson et al. 2002, Lilith 2007), UK (Sims et al. 2008),USA (Dabritz et al. 2006), New Zealand (Farnworth et al. 2010) and Singaporean owners (Gunaseelan et al. 2013) neither confine their cats indoors nor on their properties. Keeping cats indoors at night reduces predation on nocturnal fauna, but not diurnal prey (Barratt 1997b). Collar-mounted predation deterrents that either impede predatory behaviour or alert prey are another option, although they are not acceptable to everyone (Thomas et al. 2012). Devices tested experimentally that reduce the numbers of prey brought home by ≥50% include bells, pounce protectors and battery-powered alarms (Calver et al. 2007, Gordon et al. 2010, Nelson et al. 2005, Ruxton et al. 2002).

A new device, the Birdsbesafe® cat collar cover (hereafter BBS) marketed by Birdsbesafe LLC, Duxbury, Vermont, USA, exploits songbirds' colour vision (Cuthill 2006) by giving a colourful indicator of a cat's presence (Birdsbesafe LLC 2009). No claim is made for prey other than songbirds, nor for songbirds outside a North American context. Nevertheless, predation by pet cats is a global issue, so it is of interest whether the BBS is effective outside North America. Moreover, many herpetofauna (amphibians and reptiles) have excellent colour vision (Olsson et al. 2013, Vorobyev 2004) and could be warned. Thus the BBS could be useful where owners wish their cats to hunt mammalian pests only, because many non-primate placental mammals have limited colour vision (Vorobyev 2004).

Using an experimental approach, this study used suburban cats in Australia to evaluate: 1) Does the BBS reduce the number of prey brought home? 2) Does the number of prey brought home vary by BBS colour? 3) Does the number of prey brought home differ by taxa according to their colour vision?, and 4) Do cats bring home fewer prey following treatment with the BBS (is there a lasting inhibition after a period without the reinforcement of a successful hunt)? Additionally, given the importance of owners' behaviour in the success of any anti-predation measure, we interviewed owners on their experiences using the BBS.

3.2 MATERIALS AND METHODS

In common with all other published studies of the effectiveness of predation deterrents, our dependent variable was the number of prey brought home by cats when wearing or not wearing the BBS. This is not the same as monitoring all hunting behaviour or all prey captures. It cannot account for the possibility that some prey are killed and left, or consumed. We also focused our attention on vertebrates and did not ask owners to note invertebrate prey brought home.

3.2.1 The Birdsbesafe® cat collar cover

The BBS is a 50cm tube of brightly coloured cloth that slips over a standard cat safety collar to appear as a brightly coloured ‘ruff’ or flared-out encircling cloth ‘clown collar’ about 5cm wide (Figure 3.1a). Between 2012 and 2013, the design changed to include a silver retroreflective strip around the outer edge. The safety collar with the BBS can be worn constantly or fitted when the cat is allowed outdoors. Multiple colourful prints are available, and designs change with customer feedback on perceived effectiveness. Striped patterns of various bright colours predominate in the current range. The current iteration of the BBS is patent pending in the USA and is similarly protected in a further 28 countries.

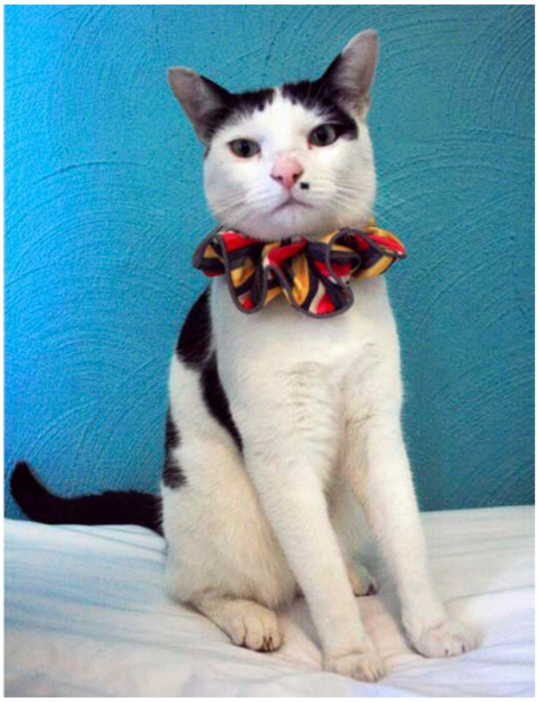
3.2.2 Study area

The study ran from October 2012 until February 2013 and from October 2013 until January 2014 (southern hemisphere spring to summer) in outer suburbs of Perth, Western Australia (31.95° S, 115.85° E) and including the nearby City of Mandurah and the towns of Harvey, Dwellingup and Manjimup. The mediterranean climate of the region, with fine, dry weather extending from late spring to early autumn, encourages outdoor husbandry of cats. In the second year, one participant was from Port Hedland (20.31° S, 118.60° E) in the north of Western Australia, which possesses a semi-arid climate and is warm year-round.

3.2.3 First year of study (2012-2013) - testing effectiveness of red, yellow and rainbow BBS

In the first year we tested all hypotheses in a trial involving three prints: yellow print with red, fuchsia and white abstract design, red-white paisley print, or a rainbow of stripes of red, yellow, grey, white or fuchsia; hereafter called yellow, red and rainbow respectively (Figure 3.1b). Forty-four volunteers were accepted from respondents to advertisements in local newspapers seeking owners of cats that were active hunters. Respondents whose cats did not bring home on average one prey every fortnight were declined. Sixty-one cats began the study but owners withdrew eight before it ended, so 53 cats (33 females and 20 males; 96% desexed) from 39 households completed the study. The results from multiple cats in the same household were combined because prey kills could not be ascribed confidently to a specific cat, resulting in a final sample size of 39. Therefore the experimental unit for the study is the household rather than the individual cat and no correction was made to the data for any household where more than one cat was present (that is, we did not divide the number of prey brought home by the number of cats in the household).

To assess the effect of BBS colour, cats were assigned randomly to a colour group: red, yellow or rainbow. To assess the permanence of any behavioural change, half of the cats were monitored with the BBS fitted for 3 weeks followed by 3 weeks without the BBS, while the others were monitored for 3 weeks without the BBS followed by 3 weeks with it. This ensured that all cats spent a period with and without the device, while allowing for possible effects of the sequence of treatments or changes in prey availability over time. We fitted new cloth safety collars with break-away buckles designed to release if the cat was snagged underneath the BBS unless the owner preferred another collar. Cats that had not worn a collar previously were given at least 2 days to adjust to wearing a collar before the BBS was fitted. Multiple cats in the same household had synchronous treatments. All collars and BBS were fitted initially during a home visit, in which the importance of correct fit for safety was explained to owners.



a)

b)

Figure 3.1: a) Cat wearing rainbow Birdsbesafe® cat collar. b) Colours tested during the trial; red, yellow, rainbow.

Owners collected corpses brought home by their cats and reported any instances where live prey were seen to escape. Owners were instructed to contact the investigators if prey were injured and required veterinary care, but no such referrals were made. Prey bodies were identified to species by staff at the Western Australian Museum. Most prey released after owner intervention were classed as mammals, birds or herpetofauna unless the owner provided a clear description identifying the species conclusively. They were counted as captured prey because they may well have died from shock, injury or infection. We excluded any obviously nestling birds from analysis because they would not have any opportunity to escape from a cat irrespective of whether or not it was wearing a BBS. Any household that completed the study, but where no prey at all were brought home, was also excluded. This eliminated any bias that may have been caused by including cats that did not bring home prey in the study. After the study, owners participated in a short interview assessing their reasons for volunteering and their experiences with the BBS. The interview comprised eight consistent, open-ended questions, pre-approved as part of the Human Ethics Permit, which sought to obtain owners' responses in their own words (Appendix 2).

3.2.4 Second year of study (2013-2014) - testing effectiveness of rainbow BBS and colour vision

Preliminary analysis of data from the first year of the study indicated that cats wearing the rainbow BBS showed the greatest proportional reduction in the numbers of birds and lizards brought home, so the second year assessed the rainbow BBS only. The hypotheses that the BBS reduces prey brought home, that prey brought home differ by taxa according to their vision (colour or not), and that cats bring home fewer prey following treatment with collars were relevant.

Seventy-one cats began the study, none of which had been involved before. Ten did not finish, so 61 (32 males and 29 females; 100% desexed) completed. Results from multiple cats in the same household were combined, again with no correction for the number of cats, resulting in a final sample size of 43 (we did not divide the prey brought home by the number of cats in a household). Otherwise, the methods for this study were identical to those used in the first year.

3.2.5 Statistical analysis

We used generalised linear mixed effects models in R to evaluate effect of the BBS, its colour and order of application on the numbers of birds, herpetofauna and mammals brought home and any lasting reductions in prey brought home. Our first analysis focused on the effects of BBS colour, prey taxon and order of BBS application using data from the first year of the study. Prey brought home were recorded by individual cat-household (hereafter simply called cat), prey type (bird, herpetofauna, mammal), and BBS status (on/off), yielding six possible combinations per cat. We did not consider the sex or the age of the cats given that cats were allocated randomly to experimental treatments and that multiple cats in the same household were treated as one unit. This approach permitted evaluation of change in prey brought home within cat; as expected, substantial heterogeneity in prey brought home existed between cats, rendering group-wide averages of little value.

We fitted a model containing a random effect of cat and fixed effects for BBS on/off, order of BBS application, BBS colour (red, rainbow and yellow), prey taxon (mammals, birds, herpetofauna), as well as interactions of prey and colour. Capture data were strongly right skewed (reflecting heterogeneity across individual cats), so we evaluated both normal and Poisson distributions. Analysis outcomes were the same with both distributions but with substantially better fit using a Poisson distribution, which we report. We then examined the full model for fit and any violations of standard assumptions following suggestions of Zuur et al. (2009).

To evaluate the effect of BBS colour we set our statistical contrasts as the effect of BBS colour relative to yellow (given that red and rainbow were more similar) and to evaluate the effect of prey taxon we set capture rates relative to mammals, which is the group with the poorest colour vision (Vorobyev 2004) (and reductions in mammals brought home were not claimed for the BBS).

We report graphical summaries as changes in prey brought home with BBS (on vs off) and statistical effects as changes in prey brought home overall (including an effect of BBS being worn). Estimates in the model are reported with their standard errors and changes in prey brought home with 95% confidence limits where lack of overlap with zero was interpreted as evidence of a significant effect.

Our second analysis used data for cats wearing the rainbow BBS in the first year of the study and also cats wearing the rainbow BBS in the second year of the study. Year (first or second year), order of BBS application (BBS applied first versus BBS applied second) and colour vision (birds and herpetofauna combined versus mammals) were included as factors. No contrasts were needed in this analysis because each of the categorical factors was binary.

3.2.6 Owner interviews

At the end of each year of the study, owners were interviewed regarding their experiences with the BBS, the response of their cat, and the likelihood that they would continue to use the BBS (Appendix 2). Owners' answers to the interview questions are described in text.

3.2.7 Ethical considerations

The work was covered by Murdoch University Animal Ethics Committee permit R2469/12 and Human Ethics Committee permit 2012/056. There are no conflicts of interest associated with this publication. As part of the requirements of the Human Ethics permit, all participating owners received a short report summarising the results shortly after the conclusion of the study. All owner interviews were completed before the report was distributed.

3.3 RESULTS

3.3.1 Features of cats and their husbandry

The mean age of cats that completed the trial in Year 1 was 4.4 ± 0.5 (SE) years and in Year 2 3.9 ± 0.4 years. In each year 60% were kept inside at night but were allowed out during the day, while the remaining 40% could go in and out when they pleased. All the cats were desexed except for two cats in the first year. Eighteen cats were withdrawn across the entire study for a diverse range of reasons (Table 3.1).

Table 3.1: Owners reasons for withdrawing their cats from the study.

Year	No. of Cats	Reason
Year 1	1	Moderate dermatitis attributed to the BBS
Year 1	1	Owner personal issues
Year 1	2 (same household)	Owner found BBS to be ineffective against mammals and she did not like her two cats bringing mice into the house and wanted to deter their hunting behaviour more generally
Year 1	1	Owner concluded that the BBS was not effective for her cat and it was rehomed
Year 1	1	Owner did not like the appearance of the BBS and her cat was not a regular hunter
Year 1	2 (same household)	One cat caught its safety collar (not BBS) in its mouth and in her distress, ran away and was presumed to be hit by a car. The other cat in the household was then withdrawn from the study.
Year 2	1	The cat would not adjust to the BBS
Year 2	1	Pet bird in household became too distressed by cat walking past wearing BBS
Year 2	1	Owner lived in a very hot climate and decided that the device would make her cat too uncomfortable
Year 2	2 (same household)	The owner had three cats, two of which were being targeted by a local feral cat and she felt that the BBS was a hindrance in a fight although she was happy to leave her third cat in the trial
Year 2	1	Owner could not be contacted
Year 2	1	One owner chose not to continue because he did not want his cat to be outside without any device that would stop it catching wildlife
Year 2	1	Cat was constantly catching his front leg through the collar
Year 2	2 (separate households)	Cat continually lost collars and BBS

3.3.2 Effectiveness of colour treatments in the first year

Five cats were excluded from analysis because they brought home no prey at all over the entire period of the study. The others brought home 68 birds (excluding five fledglings) from at least 15 species (13 native), 49 herpetofauna from at least seven species (all native) and 77 mammals from four species (one native) (Table 3.2). Almost all the herpetofauna were reptiles, with only one unidentified frog brought home (the owner did not keep the body).

On average, the cats that brought home at least one prey over the trial brought home 1.04 ± 0.21 birds, 1.18 ± 0.17 mammals and 0.72 ± 0.20 herpetofauna (mean ± SE). Although most of the prey species were native animals, the majority of individual mammals brought home comprised non-native mammal species (house mouse *Mus musculus* and black rat *Rattus rattus*). Only one species, the southern brown bandicoot *Isoodon obesulus fusciventer,* was of conservation concern (rated nationally as Least Concern (Woinarski et al. 2014), and as Priority Five (Conservation Dependent) in Western Australia (Department of Parks and Wildlife 2013)).

Of the total amount of prey brought home across the 6 week period, the cats in the red treatment brought home only 31% of mammal prey, 41% of bird prey and 36% of herpetofauna prey whilst wearing the BBS. The cats in the rainbow treatment brought home 50%, 28% and 4% respectively, while for the cats in the yellow treatment they were 58%, 54% and 20% respectively (Table 3.3). Combining all prey groups, there was a reduction of 37% (95% CL 29% - 46%) in the prey brought home by cats when wearing the BBS. Considering only the taxa with good colour vision (birds and herpetofauna), the reduction caused by wearing the BBS was 54% (95% CL 43% - 64%).

The full generalised linear mixed effects model showed that the order in which cats wore the BBS did not influence prey brought home (effect= 0.09, Z=0.4, P=0.71). Thus the effect of order of application was excluded from the reduced model with all other effects. Across all taxa cats wearing the BBS brought home significantly fewer prey (Table 3.4a, Figure 3.2). Fewer herpetofauna were brought home than birds or mammals. Across all prey taxa, rainbow and red BBS had similar effects to yellow (Table 3.4a). When prey taxon and BBS colour were considered together, cats wearing the rainbow BBS or the red BBS brought home fewer birds relative to mammals wearing the yellow BBS (Table 3.4a, Figure 3.2).

Table 3.2: List of birds, mammals and herpetofauna brought home by cats during the six week trials in Year 1 and Year 2 and which could be identified to species level. Common and scientific names are consistent with Clayton et al. (2006).

Prey Category	Common Name	Scientific Name	Years (numbers brought home)
Bird			
	Button-quail	*Turnix* sp. [b]	Year 1 (1)
	Laughing Turtle-Dove	*Streptopelia senegalensis*	Years 1 & 2 (3, 1)
	Spotted Turtle-Dove	*Streptopelia chinensis*	Years 1 & 2 (4, 3)
	Common Bronzewing	*Phaps chalcoptera*[b]	Years 1 & 2 (2, 2)
	Crested Pigeon	*Ocyphaps lophotes*[b]	Year 1 (2)
	Australian Ringneck (Twenty-eight Parrot)	*Barnardius zonarius*[b]	Year 1 (2)
	Red-capped Parrot	*Purpureicephalus spurius*[b]	Year 2 (1)
	White-browed Scrubwren	*Sericornis frontalis*[b]	Year 1 (2)
	Brown Honeyeater	*Lichmera indistincta*[b]	Years 1 & 2 (4, 2)
	Singing Honeyeater	*Lichenostomus virescens*[b]	Years 1 & 2 (2, 2)
	New Holland Honeyeater	*Phylidonyris novaehollandiae*[b]	Years 1 & 2 (2, 5)
	Red Wattlebird	*Anthochaera carunculata*[b]	Years 1 & 2 (1, 1)
	Willy Wagtail	*Rhipidura leucophrys*[b]	Year 1 (1)
	Magpie Lark	*Grallina cyanoleuca*[b]	Year 1 (2)
	Australian Magpie	*Gymnorhina tibicen*[b]	Year 1 (1)
	Grey-breasted White-eye (Silvereye)	*Zostergis lateralis*[b]	Years 1 & 2 (4, 1)
Reptile			
	Marble Gecko	*Christinus marmoratus*[b]	Years 1 & 2 (1, 5)
	Blind Snake	*Ramphotyphlops australis*[b]	Year 2 (1)
	Fence Skink	*Cryptoblepharus buchananii*[b]	Years 1 & 2 (4, 1)
	Two-toed Earless Skink	*Hemiergis quadrilineata*[b]	Year 2 (1)
		Hemiergis initialis[b]	Year 1 (2)
	Western Limestone Ctenotus	*Ctenotus australis*[b]	Year 2 (1)
	Common Dwarf Skink	*Menetia greyii*[b]	Year 2 (1)
	Tree Dtella	*Gehyra variegata*[b]	Years 1 & 2 (1, 4)
	Western Three-lined Skink	*Acritoscincus trilineata*[b]	Years 1 & 2 (1, 2)
	Bearded Dragon	*Pogona minor*[b]	Year 1 (3)
	King Skink	*Ergenia kingii*[b]	Year 1 (1)
Mammal			
	Black Rat	*Rattus rattus*	Years 1 & 2 (16, 23)
	Lesser Long-eared Bat	*Nyctophylus geoffroyi*[b]	Year 2 (3)
	House Mouse	*Mus musculus*	Years 1 & 2 (20, 13)
	Rabbit	*Oryctolagus cuniculus*	Years 1 & 2 (5, 2)
	Southern Brown Bandicoot	*Isoodon obesulus fusciventer*[a,b]	Years 1 & 2 (8, 6)
a Species of conservation concern			
b Native species			

Table 3.3: Total number of prey brought home by cats in each treatment group in each year. The number of cats (with cats in multiple-cat households counted as one cat and all prey summed) bringing home prey is given in parentheses.

Treatment	Year	Prey	Application	
			Treatment On	Treatment Off
Red	2012	Mammal	4 (3)	9 (5)
		Bird	13 (5)	19 (7)
		Herpetofauna	5 (4)	9 (5)
Yellow	2012	Mammal	14 (7)	10 (6)
		Bird	12 (6)	10 (4)
		Herpetofauna	2 (2)	8 (2)
Rainbow	2012	Mammal	20 (8)	20 (10)
		Bird	4 (3)	10 (6)
		Herpetofauna	1 (1)	24 (5)
Rainbow	2013	Mammal	49 (19)	51 (23)
		Bird	16 (11)	24 (15)
		Herpetofauna	26 (14)	31 (15)

Table 3.4: (a) Estimates from top model examining effects of wearing a BBS, BBS colour and prey type on prey brought home by pet cats, after removing insignificant effects from the complete model of all effects and interactions. Effects of prey taxon are assessed relative to captures of mammal prey and interaction effects of prey taxon x BBS colour are assessed relative to captures of mammals by cats wearing a yellow BBS. (b) Estimates from top model examining effects of wearing a rainbow BBS and prey colour vision (good colour vision, birds and herpetofauna; poor colour vision, mammals).

Term	Estimate	SE	Z-value	P-value
(a)				
BBS On	-0.46	0.15	3.1	0.002
Bird	-0.09	0.30	0.3	0.77
Herpetofauna	-0.87	0.38	2.3	0.02
Rainbow	0.32	0.34	1.0	0.34
Red	-0.58	0.42	1.4	0.16
Rainbow*Bird	-0.96	0.43	2.2	0.03
Rainbow*Herpetofauna	0.41	0.46	0.9	0.38
Red*Bird	0.99	0.45	2.2	0.03
Red*Herpetofauna	0.95	0.54	1.7	0.08
(b)				
BBS On	-0.32	0.12	2.6	0.01
Colour Vision	-0.72	0.12	5.9	<0.001

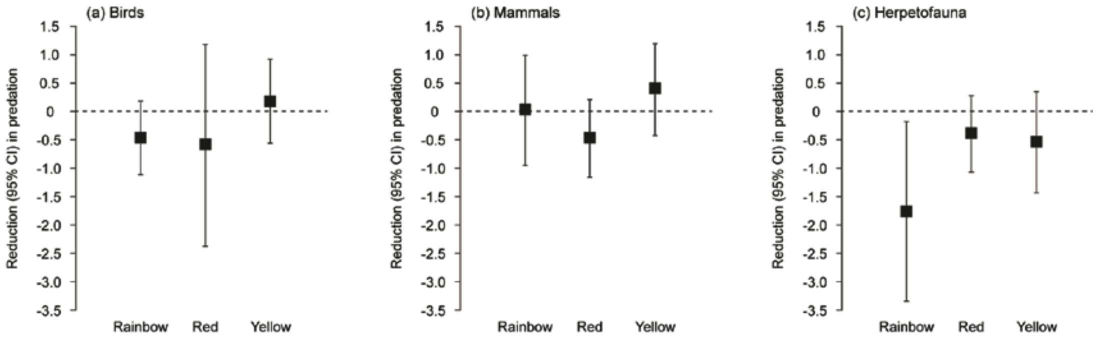


Figure 3.2: Means (± 95% cl) for the change in prey brought home for birds, herpetofauna and mammals for cats wearing three different colours of BBS in Year 1.

3.3.3 Effectiveness of treatments using rainbow BBS in both years

Four cats in the Year 2 sample were excluded from analysis because they brought home no prey at all over the entire period of the study. The others brought home 40 birds (excluding three fledglings) from at least nine species (seven native), 57 herpetofauna from at least eight species (all native) and 100 mammals from five species (two native) (Table 3.2). On average, the cats that brought home prey brought home 0.51 ± 0.09 birds, 1.28 ± 0.18 mammals and 0.73 ± 0.14 herpetofauna each (mean ± SE).

Of the total amount of prey brought home across the 6 week period, cats in Year 2 brought home 49% of mammal prey, 40% of bird prey and 46% of herpetofauna prey whilst wearing the rainbow BBS (Table 3.3). Combining all prey groups, there was a reduction of 14% (95% CL 9% - 22%) in the prey brought home by cats when wearing the BBS. Considering only the taxa with good colour vision, the reduction caused by wearing the BBS was 24% (95% CL 14% - 36%).

Generalised linear mixed effects models using data from both years for cats wearing the rainbow BBS found a significant reduction in the number of prey with colour vision (birds and herpetofauna) brought home relative to mammals with poor colour vision (effect=-0.72, Z=5.9, P<0.001, Table 3.4b, Figure 3.3). The order in which cats wore the BBS was not significant in its own right (effect=0.03, Z=0.16, P=0.0.88) nor in an interaction with another variable, nor was the effect of year (effect=-0.18, Z=0.9, P=0.38).

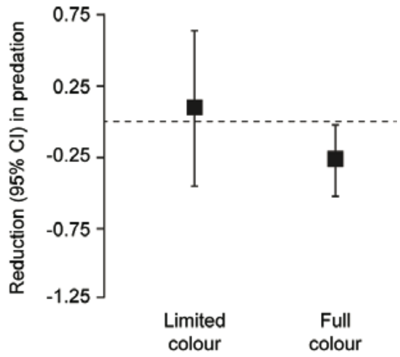


Figure 3.3: Means (± 95% CL) for the change in prey brought home for birds, herpetofauna, mammals and prey with full colour vision (herpetofauna and birds combined) and prey with limited colour vision (mammals) for cats wearing the rainbow of BBS in Years 1 and 2 combined.

3.3.4 Cat behaviour, prey behaviour, owner interviews and animal welfare issues

Cat Behaviour

Over both years of the study 79% of owners reported that their cat(s) had no problem adjusting to the BBS and another 17% said that their cat(s) adjusted within 2 days. One cat took 10 days to adjust and two cats did not adjust to the BBS during the trial. One cat was withdrawn from the study because her owner felt she was not adjusting to the BBS. Although her cat was not bothered by the BBS, one owner in Year 1 said that the pet dogs in the household were upset by the cat wearing the BBS and barked at him more. Owners were not prompted to assess specific behaviours in deciding whether or not their cats adjusted to the BBS, but made subjective judgements of their own.

Sixteen owners (*ca*.20%) reported that their cats' behaviour patterns changed while wearing the BBS. In Year 1, two owners reported their cats stayed out more and six owners from Year 1 and eight from Year 2 reported that their cats stayed closer to home/came in earlier for food. The owners reported that 14 of the cats that came in earlier ate more than normal and were more affectionate. Of these, five cats that wore the BBS for the first half of the trial reverted to their previous behaviour when the BBS was removed, while the others continued to be more affectionate. However, some owners changed their answer to this question when asked if their cats' behaviour had changed once they were given an example of what the behaviour change might be.

Prey Behaviour

Several owners mentioned that even though their cat had not brought home any birds during the study, birds surrounding their house tended to stay in the trees while the cat was wearing the BBS and give their warning calls earlier. When the BBS was removed birds often stayed on the ground even when the cat was close. One owner from Year 2 withdrew her cat after her pet cockatoo became distressed by the cat wearing the BBS and would not stop screeching. In contrast, two owners said their cats brought home birds for the first time ever while wearing the yellow BBS in Year 1. One owner reported seeing lizards freezing when the cat approached wearing the BBS, but this did not occur when the BBS was removed.

Owner Interviews

Of the owners whose cats completed the trial using the red BBS, seven (64%) believed that it worked, one (9%) did not believe that it worked and 27% were unsure. Of the owners whose cats completed the trial using the rainbow BBS in either year, 31 (48%) believed that it worked, 11 (17%) did not believe that it worked and the remaining 35% were unsure. Amongst owners whose cats trialled the yellow BBS, six (46%) of owners believed that the yellow BBS worked and six (46%) did not believe that it worked and one owner was unsure. These were subjective judgements by the owners based on their own experiences and they were not prompted to consider data from their own cat or from the study overall. Despite this, 77% of all owners over both years plan to continue using the BBS. The two most common reasons for not continuing to use the BBS were that the cat did not bring home many (if any) birds and therefore the owners felt it was not relevant to them (five owners), and that some owners did not like the look of the BBS on their cat (five owners). Eighty per cent of owners over both years felt that a retail price of $15 was appropriate but the remaining 20% felt that it was too expensive.

Two owners commented that they liked that the BBS does not make a noise, especially one owner who said that her cat's bell was constantly waking her newborn baby. In contrast, several owners wished to make the BBS more effective by adding bells as an auditory warning to all prey, including mammals. Two owners said they liked the bright colours and the retroreflective strip around the edge of the BBS to make the cats more visible to cars at night.

Animal Welfare Issues

Two cats from different households suffered from dermatitis attributed to the BBS. One had it very mildly and continued in the study but the other was withdrawn and needed minor veterinary treatment.

Two cats (one from each year) caught a paw through their collars. One suffered no ill effects, but the other caught its paw repeatedly and was withdrawn from the study. One cat caught the safety collar (not while wearing the BBS) in her mouth, ran away and was presumed to be hit by a car. One owner said that the BBS knotted her cat's fur under the collar and three owners said their cats were bothered when grooming.

3.4 DISCUSSION

3.4.1 Prey captures

Studies of pet cats' hunting behaviour show great individual variation and opportunism in their hunting behaviour (e.g. Barratt, 1997, 1988; Woods et al., 2003; Loyd et al., 2013). The cats in our study were similar, varying in the number and type of prey brought home. The preponderance of introduced rodents was expected, probably reflecting their availability in the environment and the hunting skills of cats (Fitzgerald and Turner, 2000; Meachen-Samuels and van Valkenburgh, 2009a,b; Bradshaw et al., 2012). The frequency of herpetofauna brought home reflected the availability of lizards in Perth over spring and summer. The birds brought home were mainly nectarivorous honeyeaters and wattlebirds or granivorous doves, pigeons or parrots, reflecting their abundance in suburban gardens. Given that the cats studied were a sample of known hunters, it is inappropriate to extrapolate from these data to estimate their impact on wildlife in Perth, although the results do indicate the prey species at risk. A full assessment of impacts on prey populations would also require demographic data on those populations.

3.4.2 Effectiveness of the BBS

Not all BBS colours were equally effective, but the rainbow BBS did lead to a statistically significant reduction in the numbers of prey with colour vision (birds and herpetofauna) brought home. This was driven substantially by reductions in herpetofauna prey, especially in Year 1, plus smaller reductions in numbers of birds brought home. Anecdotal reports from some owners of birds responding differently to the same cat with and without a BBS and of a caged bird being distressed at the approach of a cat wearing a BBS indicate that at least some birds detect and respond to the BBS. We are unaware of experimental evidence that other anti-predation devices significantly reduce the number of herpetofauna brought home (e.g. Ruxton et al., 2002; Woods et al., 2003; Nelson et al., 2005; Calver et al., 2007). For mammals, which comprised the majority of prey, the numbers brought home by cats when wearing or not wearing the BBS were similar. While there was no evidence that the number of prey brought home remains depressed if a cat ceases to wear a BBS, this hypothesis is worth further investigation. Training a cat to abandon hunting may be more attractive to owners than persisting with a device, and there is evidence of a decline in prey brought home when the reinforcement of successful prey capture was reduced (Calver et al. 2007). The effectiveness of the BBS in reducing prey brought home in a given situation will likely be driven by characteristics of the local prey community, the husbandry practices of owners, characteristics of cats, and the local prevalence of bird feeders. The most robust assessment of its effectiveness in reducing the number of prey brought home would come from a meta-analysis of multiple trials.

Regarding characteristics of the prey community, the lack of reduction in mammals brought home probably arises from a combination of their nocturnal habits and the prevalence of dichromatic vision with limited colour vision in non-primate placentals (Vorobyev 2004). However, among the Australian marsupials the southern brown bandicoot (a prey item in this study), the quokka (*Setonix brachyurus*), the honey possum (*Tarsipes rostratus*) and the fat-tailed dunnart (*Sminthopsis crassicaudata*) have trichromatic vision (Ebeling et al. 2010) and should, under the right conditions, discriminate colours in a BBS. Similarly, herpetofauna may be mainly diurnal or nocturnal, with nocturnal species unlikely to detect a cat wearing a BBS by colour, despite the prevalence of trichromatic or tetrachromatic colour vision in herpetofauna (Vorobyev 2004). Birds have predominantly tetrachromatic vision, with the fourth colour cone using UV-sensitive or violet-sensitive (UVS) pigments (Cuthill 2006). The ratios of different cone types vary between species (Cuthill 2006, Hart 2001, Ödeen and Håstad 2010), so different species may perceive the BBS differently and its effectiveness may vary. Irrespective of vision type, all birds are vulnerable at their roosts, so whether or not a cat is confined at night is important in the efficacy of the BBS. Although 60% of owners kept their cats indoors at night in this study, many of these cats were still outside at dawn and dusk when visibility is low, possibly reducing the effectiveness of the BBS. The BBS may also vary in effectiveness with factors such as the coat length of the cat.

Bird feeders attract birds (Daniels and Kirkpatrick 2006, Davies et al. 2009, MacGregor-Fors and Schondube 2011, Shochat et al. 2010) and could increase the opportunity to demonstrate reductions in prey brought home. However, in Australia, bird feeders are discouraged by government and conservation groups because of disease and attracting exotic species (Australian Wildlife Society 2014, NSW Government, Environment & Heritage 2014). In the USA, where bird feeding is popular and encouraged by government agencies (U.S. Fish & Wildlife Service 2001), there will be more opportunity for cats to hunt birds and a study may find larger effects.

Furthermore, collar-mounted video cameras confirm that pet cats bring home approximately 23% of their prey (Loyd et al. 2013b). Using collar-mounted cameras in conjunction with a BBS would be necessary to discount (i) that fitting a BBS simply discourages a cat from bringing prey home, or (ii) the BBS might reduce the number of prey killed that are never brought home (which would not be apparent using the methodology in our study). Sixteen owners reported changes in their cats' behaviour with 14 of these described as coming home earlier, eating more food and becoming more affectionate while wearing the BBS. Perhaps these cats usually eat their prey *in situ* and, unable to supplement their diet though hunting, they came home earlier.

Lastly, the BBS was developed to reduce predation on songbirds in a North American context. Thus the data reported here cover a dissimilar context and may not reflect the situation in North America. The cats in the study were volunteered as known hunters, but not necessarily accomplished bird-killers. Furthermore, given that the BBS product range is constantly evolving, the results of this study may not reflect the effectiveness of current designs.

3.4.3 Welfare Considerations and Cat Behaviour

Minor problems with cats catching paws or teeth in collars are common (between 27% and 62% of two groups of owners sampled had experienced these problems over a lifetime of pet ownership), while serious injury requiring veterinary attention was rarer (3% and 6% respectively for the same groups) (Calver et al. 2013). Problems are most likely if a collar frays or is fitted loosely, so regular inspection is important (Calver et al. 2013, Lord et al. 2010). In this study, problems arose from loose collars. The cases of dermatitis attributed to the BBS were unusual. Two cats did not adjust to the BBS at all, a problem that can occur with other predator deterrents (Calver et al. 2007). Whether a cat is perceived to adjust is a subjective assessment by the owner. The current packaging for BBS products advises owners to fit the BBS when the cat is inside and to monitor it closely.

3.4.4 Implications for Wildlife Conservation

Even though pet cats may not be the primary cause of wildlife decline in urban areas, they do hunt wildlife at levels unsustainable for some species in some places (Lepczyk et al. 2004, Thomas et al. 2012, van Heezik et al. 2010). While several deterrent devices reduce prey brought home (Calver et al. 2007, Nelson et al. 2005, Ruxton et al. 2002, Woods et al. 2003), the BBS uniquely reduces numbers of birds and herpetofauna brought home but not mammals. It is suitable for farmers who want their cats to catch rodents but not other vertebrates (Coleman and Stanley 1993), as well as in New Zealand where all mammals except bats are exotic (Gordon et al. 2010) but endemic birds and herpetofauna are at risk of predation by cats (Veitch 2001). If rats and mice are still hunted, birds and herpetofauna may benefit from reduced rodent predation (Dickman 2009, Fitzgerald and Turner 2000, Hansen 2010). However, the current study gives no indication about predation by pet cats on large invertebrates, which may be significant in invertebrate population ecology (Wehi et al. 2011) or conservation (Watts et al. 2011). This may qualify comments about the value of the BBS in New Zealand, where large invertebrates such as wetas (several insect species within the orthopteran sub-order Ensifera) are a conservation concern (Watts and Thornburrow 2009).

Almost half of the study cats brought home at least one lizard and, based on owners' observations, lizard predation goes predominantly unnoticed. However, cat predation may suppress lizard populations (Arnaud et al. 1993) and in one case a single pet cat caused a local extirpation of the lizard *Ctenotus fallens* on a suburban Perth property (Bamford and Calver 2012). This is particularly important in Australia, where the reptile fauna is diverse with many endemic species (Edwards et al. 2012).

However, simply reducing predation does not mitigate all potential impacts of pet cats on wildlife. Birds may experience life-history changes such as a reduction in fecundity when they perceive predation risk as high, even if predation is low (Beckerman et al. 2007). Bonnington et al. (2013) found that parental provisioning rates in birds were reduced by one third following exposure to a cat model, which could reduce nestling growth rates by 40%. Furthermore, the presence of the cat model for only 15 min at the nest significantly increased the chances of nest predation over the next 24 h by corvids detecting increases in alarm calls.

Free-roaming pet cats have greater risk of contracting the parasite *Toxoplasma gondii* by eating infected small mammals (Dubey and Lappin 2012). While infected cats are asymptomatic, intermediate hosts may suffer blindness, impaired walking, calcification of the heart, miscarriage and stillbirth (Tenter et al. 2000, Torrey and Yolken 2003). *T. gondii* is often fatal for Australian marsupials because of their recent exposure (Eymann et al. 2006). Although some anti-predator devices may reduce the risk of *T. gondii* infection to pet cats through reductions in mammal capture, the BBS does not reduce predation on mammals and will not reduce infection risk.

The best solution for reducing impacts is by restricting cats to their owner's property (Perry 1999). This also benefits cats' welfare by reducing fighting and road accidents (Rochlitz, 2003a,b, 2004). However, many owners object to keeping their cats on their properties at all times (Grayson et al. 2002, Lilith et al. 2006, Thomas et al. 2012) so deterrent devices provide an alternative. Wildlife conservation in urban areas will also require attention to other threats including high residential densities, failure to design wildlife-friendly gardens or parks, poor conservation of remnant native vegetation and traffic (Dufty, 1994; Grayson et al., 2007).

Unowned cats roaming in cities, sometimes supported by people feeding them, require alternative approaches (Aguilar and Farnworth 2013, Farnworth et al. 2011, Lepczyk et al. 2010). The recent assessment that feral cats (those forming self-sustaining populations without human support) endanger more threatened and near threatened Australian mammal taxa than any other factor (Woinarski et al. 2014) confirms that feral cats are a major problem in at least some environments (Medina and Nogales 2009, Wheeler and Priddel 2009).

3.5 CONCLUSION

Despite uncertainty about the contribution of predation by pet cats to the population dynamics of urban wildlife, individual acts of predation are well documented. Concerned owners who do not wish to confine their cats may consider a collar-worn predation deterrent instead. This study shows that the BBS has potential to reduce captures of vertebrates with good colour vision. It is therefore an option for owners concerned about predation on birds and lizards, but not mammals or large invertebrates.

4 DO COLLAR-MOUNTED PREDATION DETERRENTS RESTRICT WANDERING IN PET DOMESTIC CATS?

Catherine M HALL, Kate A BRYANT, Joseph B FONTAINE, Michael C CALVER

This chapter has been published in the journal Applied Animal Behaviour Science as:

Hall, C.M., Bryant, K.A., Fontaine, J.B., Calver, M.C., 2016. Do collar-mounted predation deterrents restrict wandering in pet domestic cats? Applied Animal Behaviour Science 176, 96–104

ABSTRACT

Roaming pet cats kill and harass wildlife, hybridise with wild felids, interbreed with feral populations, spread disease or annoy neighbours, and endanger their own welfare by fighting, being struck by vehicles or ingesting poisons. Confinement of pet cats is unpopular, so alternative methods to curb roaming behaviour would benefit wildlife conservation and pet wellbeing. Some owners whose cats participated in previous trials testing the effectiveness of the collar-mounted predation deterrents the CatBib and the Birdsbesafe collar cover (BBS) in reducing predation by pet cats reported that their cats stayed closer to home when wearing the devices. Therefore we tested whether these devices might curb roaming behaviour of pet cats as an alternative to confinement.

Thirty cats participated. Trials occurred in spring and autumn in Perth, Western Australia (southern hemisphere spring – autumn). Cats wore GPS collars for 10 consecutive days, wearing the GPS collar alone for five days and wearing either a CatBib (16 cats) or BBS (14 cats) as well for a further five days. Treatment order was determined randomly for each cat. We represented cats' home ranges with 95% kernel density estimates (KDE) (100% minimum convex polygon (MCP) provided for comparison with other studies) and 50% KDE (core home range). We also used data for all cats when not wearing either predation deterrent, plus data on a further four cats, to determine the relative effect of sex, age, night confinement, housing density, number of days of rain, total rainfall, and mean maximum temperature on both estimates of home range size.

Neither device reduced home range significantly. The mean home range (95% KDE) was 2.79 ha with the CatBib and 2.46 ha without. Figures for the core home range (50% KDE) were 0.63 ha and 0.71 ha respectively. The mean home range (95% KDE) with the BBS (where the sample included fewer cats from lower housing densities) was 0.58 ha and 0.50 ha without. The means for the core home range (50% KDE) were 0.15 ha and 0.14 ha

respectively. When cats were not wearing either device, 95% and 50% KDE were predicted most strongly by housing density, presumably a surrogate for cat density.

Owners may use a CatBib or BBS to curtail their cat's hunting behaviour, but curtailing roaming behaviour needs another solution. Confinement, although unpopular, remains the most effective option where unwanted roaming is a problem.

Keywords

pet cat; *Felis catus*; cat husbandry; CatBib; Birdsbesafe; home range

Author Contributions

This chapter has three co-authors. M. Calver and K. Bryant assisted with survey design and offered comments and direction in production of paper and J.B. Fontaine assisted with the statistical analysis.

4.1 INTRODUCTION

Wandering cats hunt wildlife (Baker et al. 2005, Hervías et al. 2014), compete for prey with higher order consumers (George 1974), spread disease to humans or wildlife (Eymann et al. 2006, Izawa et al. 2009, Torrey and Yolken 2003), exert sub-lethal effects such as changes in behaviour and reduced reproductive success via fear of predation (Preisser et al. 2005), hybridise with wild felids (Beaumont et al. 2001) or breed with stray and feral cats (Jongman 2007) to maintain feral populations. They may also be a nuisance to neighbours; disturbing dogs, attacking pet birds, spraying, digging in gardens, fighting (including with other pet cats) and walking on cars (Jongman 2007, Toukhsati et al. 2012). In some cases, legislation includes measures that can be taken against such 'nuisance animals' (Lilith et al. 2007 and included references) or offended citizens may take action directly (e.g. examples in Grayson and Calver 2004).

Wandering behaviour also impacts cat welfare. Traffic accidents are one of the highest causes of mortality for pet cats, especially juveniles (Egenvall et al. 2009, Rochlitz et al. 2001). Death or injury of cats in these events had considerable financial and emotional costs to owners in one region of the UK (see Rochlitz 2004a, 2004b). Given the high frequency of road accident trauma for cats elsewhere (Engenvall et al. 2009, Calver et al. 2013) financial and emotional costs are likely to be widespread. It can also be difficult to reunite lost cats with their owners. Lord et al. (2007) found that only 53% of lost cats were recovered, including those that returned on their own. Some animal agencies in the US note that only 2-5% of pet cats are reclaimed by their owners (Humane Society of the

United States 2011). It is possible that some cats are euthanized before their owners contact the agencies because of the expectation that cats may wander and go missing for a few days before returning home (Lord et al. 2007). Wandering of entire (not desexed) cats also results in unwanted litters. New et al. (2004) estimated that 68% of cat litters in the US during 1996 were unplanned by their owners. They estimated that 150,000 kittens were euthanized and 320,000 were surrendered to animal shelters. Loyd et al. (2013a) found that many cats exhibit risky behaviours when roaming, such as crossing busy roads, encountering strange cats, eating and drinking substances away from home, exploring drains and entering confined spaces beneath houses.

Despite these issues, cat owners are often reluctant to confine their cats at all times (Dabritz et al. 2006, Grayson et al. 2002, Lilith 2007, Sims et al. 2008). While the incidence of confinement of pet cats may be as high as 76% in Singapore (Gunaseelan et al. 2013), this compares to 50 - 60% in the USA as a whole (Rochlitz 2005), and less than 10% in Australia (Lilith et al. 2006, McHarg et al. 1995, Perry 1999, REARK 1994a, 1994b) and the UK (Sims et al. 2008). Estimates of the home ranges of free-roaming pet cats vary from 0.24 ha (Kays and DeWan 2004) to 0.92 ha (Meek 2003) to 2.63 ha (Morgan et al. 2009), with substantial variation between individuals (Barratt 1997a). Cats living in rural areas or adjacent to remnant bushland have larger home ranges than cats in highly urbanised environments (Lilith et al. 2008, van Heezik et al. 2010), probably because of fewer contacts with other cats than in more densely populated areas. If an inexpensive collar-mounted device could reduce roaming, then predation, disease transmission and general nuisance attributed to pet cats could be reduced, as well as the risks of road accidents, fighting and unwanted litters. While owners may have reservations about the safety of collars (Lord et al. 2010), the risk of serious injury or death is low for correctly fitted and maintained safety collars (Brinkley 2007, Calver et al. 2013, Lord et al. 2010).

The collar-mounted pounce protector the CatBib marketed by Cat Goods LLC, Portland, OR, USA (Cat Goods Inc. 2011) and the Birdsbesafe® cat collar cover marketed by Birdsbesafe LLC, Duxbury, VT, USA (Birdsbesafe LLC 2009) (hereafter BBS) may be devices that reduce roaming. The CatBib reduces the number of vertebrate prey caught by pet cats, presumably by physically interfering with coordination of the paws during prey capture (Calver et al. 2007). However, it may be that cats wearing CatBibs are not travelling to areas where they encounter wildlife. Calver et al. (2007) found that the number of cats reported as wandering (missing from home for at least two days) while wearing a CatBib was less than that of cats that were not. Although the result was not statistically significant, the authors suggested it might indicate a change in the roaming behaviour for some cats while wearing the device that warrants a more rigorous test of the hypothesis than anecdotal reports. The BBS is a bright collar cover that reduces the number of bird and lizard prey by providing a visual warning of the cat's presence, allowing prey to escape (Hall et al. 2015, Willson et al. 2015). During the Hall et al. (2015) study, 20% of owners anecdotally reported that cats wearing the BBS changed their roaming behaviour either by staying closer to home or staying out more than normal. If evidence of changes in roaming behaviour can be found, the CatBib and the BBS could potentially offer an affordable option to owners to reduce their cats' wandering behaviour without confining them, as well as protecting wildlife from predation. Therefore, this study used GPS radio-tracking to determine the home range size of 30 cats with and without a BBS or CatBib across a range of settings (rural-suburban-urban), evaluating evidence for shifts in roaming behaviour because of wearing the device, device type, and setting. We further evaluated environmental covariates of home range with a broader sample of cats to determine important factors predicting home range size. Findings underpin prior studies by investigating the mechanisms by which anti-predation devices function, potentially improving pet welfare and conservation outcomes.

4.2 METHODS

4.2.1 Ethics Statement

The study was conducted under permit R2468/12 of the Murdoch University Animal Ethics Committee and permit 2012/055 of the Murdoch University Human Research Ethics Committee.

4.2.2 Study Site

The study was conducted from October 2012 to May 2013 and September 2013 to April 2014 (southern hemisphere spring – autumn) in Perth, Western Australia. This city experiences a Mediterranean climate with hot, dry summers and cool, wet winters. The study was not conducted through winter, based on the assumption that many cats would not spend as much time outside or travel as far in cold, wet conditions (Goszczyński et al. 2009).

4.2.3 Selection of Cats, Trial Design and environmental variables

Thirty-five cats were involved in the study after their owners were recruited through personal contact with the authors or were suggested by another owner already recruited to the study. A cat was only accepted if the combined weight of the GPS collar and CatBib or BBS was less than 5% of its weight (i.e. the cat weighed over 3 kg).

All GPS collars, CatBibs and BBS were fitted during a home visit in which the importance of correct fit for safety was emphasised to owners. Twenty-nine cats were fitted with GPS collars for 10 consecutive days. Each cat alternated between five days wearing the GPS collar alone and five days wearing either a CatBib (15 cats) or BBS (14 cats) in addition to the GPS collar. The order was determined randomly for each cat. A further cat (Boo) in the CatBib group did not complete 10 days consecutively because he contracted an eye infection during the study and data collection was paused until after he recovered. Seven cats wore the CatBib first and nine wore it second, while the respective numbers for the BBS were seven and seven. This design ensured that all cats spent a period with and without the CatBib/BBS, as well as controlling for possible effects of the sequence of treatments.

A further five cats were withdrawn from the study before they had completed the trial because the owners felt the cats were unhappy. Four of these cats had completed part of the trial with the GPS collar only and these data were used for some of the analyses (see below). Data from one cat were excluded because she only completed four days with the GPS collar and BBS.

All cats were desexed prior to the study. Of the 16 cats that trialled the CatBib, 13 were male and three were female. The average age was seven and the range one to 18 years old. Of the 14 cats that completed the trial with the BBS, eight were male and six were female. The average age was six years and ranged from two to 12 years old. Of the four cats that were used for roaming predictor analysis only, all were male and the average age was two, ranging from one to four years old (Table 4.1). Based on owners' assessments, nine cats were defined as hunters (i.e. bring at least one prey item home per fortnight) and eighteen cats did not currently hunt regularly (but may have been good hunters when they were younger) or did not hunt at all. No information on hunting behaviour was provided for seven cats. Sixteen cats were kept inside each night (N=16). We also recorded the environmental variables of housing density, number of days of rain, total rainfall, and mean maximum temperature. Weather variables were determined from the records of the closest Bureau of Meteorology station to each cat's household.

4.2.4 GPS Collars

Five GPS collars (model G2C128A, Sirtrack Ltd., Havelock North, New Zealand) were used to track the movement patterns of cats. Each collar weighed approximately 140 g and was powered by a replaceable C123 lithium battery (Figure 4.1a). Each collar also included a VHF radio-transmitter for locating it if it was lost. The GPS attempted to record a location every 30 minutes. The manufacturer specified accuracy indicates that 50% of fixes are within 5 m of the true location and 90% are within 8 m.

At the end of each cat's 10-day study, the data were downloaded. The accuracy of each location was indicated by a horizontal dilution of precision (HDOP) value (observed range 1.0 - 12.7). Locations with HDOP values of 9 or above were not used in home range calculations to reduce outlier influence (Metsers et al. 2010).

Table 4.1: Characteristics of cats and environmental conditions during the trials.

Trial (n)	Age of cat (mean ± s.e.)	Mean maximum temperature (˚C) (mean ± s.e.)	Mean total rainfall (mm) (mean ± s.e.)	Mean no. of days with rain (mean ± s.e.)	Mean housing density (dwellings/ha) (mean ± s.e.)
CatBib					
Females with (3)	8.2 ± 3	24.1 ± 2.3	37 ± 9.4	1.7 ± 0.7	11.8 ± 5.7
Females without (3)		23.1 ± 1.4	30.5 ± 16	1.3 ± 0.9	
Males with (13)	7 ± 1.3	25.2 ± 1.3	12.9 ± 4.6	1.5 ± 0.4	18.1 ± 2.7
Males without (13)		25.2 ± 1.3	14.8 ± 5	1.3 ± 0.4	
All with (16)	7.2 ± 1.1	25.0 ± 1.1	17.5 ± 4.7	1.5 ± 0.4	16.9 ± 2.5
All without (16)		24.8 ± 1.1	17.7 ± 5	1.3 ± 0.3	
Birdsbesafe					
Females with (6)	3 ± 0.4	29.5 ± 2.4	4.2 ± 3.1	1 ± 0.7	22.1 ± 2.6
Females without (6)		29.4 ± 2	4.5 ± 4.5	0.7 ± 0.7	
Males with (8)	8.3 ± 1.3	30.8 ± 1.4	0.9 ± 0.9	0.3 ± 0.3	21.6 ± 4
Males without (8)		31.0 ± 1.7	1.8 ± 1.1	0.5 ± 0.3	
All with (14)	6 ± 1	30.2 ± 1.3	2.3 ± 1.4	0.6 ± 0.3	21.8 ± 2.5
All without (14)		30.3 ± 1.3	2.9 ± 2	0.6 ± 0.3	
All cats without a predation deterrent device					
Females (9)	4.7 ± 1.3	27.3 ± 1.7	13.2 ± 6.9	0.9 ± 0.5	18.7 ± 2.9
Males (25)	6.7 ± 0.9	27.3 ± 1.1	10.4 ± 3	1.3 ± 0.4	18 ± 2.2
All cats (34)	6.2 ± 0.7	27.3 ± 0.9	11.1 ± 2.8	1.2 ± 0.3	18.1 ± 1.7

Figure 4.1: Timba wearing (a) GPS collar only, (b) GPS collar with CatBib, (c) GPS collar with BBS.

4.2.5 Catbibs

CatBibs are made of neoprene and come in several colours. Turquoise CatBibs were used in this study (Figure 4.1b) for consistency and to minimise additional sources of variation in the experiment. CatBibs interfere with the capture of prey (Cat Goods Inc. 2011), while not impeding other cat activities such as eating, playing or grooming (Calver et al. 2007, Cat Goods Inc. 2011).

4.2.6 Birdsbesafe® (BBS)

The BBS is a 50 cm length of brightly coloured cloth formed into a tube. It slips over a standard cat safety collar to appear as a brightly coloured ‘ruff’ or flared-out encircling cloth ‘clown collar’ about 5 cm wide (Figure 4.1c). Multiple colourful prints are available; for consistency we selected the design with rainbow stripes of red, yellow, grey, white and fuchsia. The BBS provides a visual warning to prey of a stalking cat’s presence (Birdsbesafe LLC 2009). Birds and lizards have excellent colour vision and thus should see the BBS from a distance and escape more readily (Hall et al. 2015, Willson et al. 2015).

4.2.7 Estimation of Home Range and Data Analysis

Estimations of cat home range were calculated in Ranges Software version 8 (Kenward et al. 2009). We estimated the home range with 95% kernel density (95% KDE) and used the 50% kernel density (50% KDE) to represent the core home range/areas of high usage, calculating KDE by the fixed method with reference bandwidth (Metsers et al. 2010). We also provide the 100% minimum convex polygon (MCP) for comparison with other studies. We used incremental area analysis to determine whether the home ranges were fully revealed in the time frame. We did not distinguish diurnal and nocturnal fixes, because some cats were confined at night. Instead, we included night confinement as a predictor variable in the analysis.

Our study objectives were to determine if 95% and 50% KDE of domestic cat home range varied when cats wore a BBS or CatBib, and to determine the influence of individual- and environmental-based covariates on home range. To achieve this we employed an information theoretic approach (Burnham and Anderson 2002) whereby we evaluated *a priori* hypotheses and covariates using Akaike’s information criterion applied to linear mixed models. Analyses were conducted in two sets: first, we evaluated the dataset of 30 cats wearing anti-predation devices, and second we analysed data from 34 cats not wearing the devices to further identify important covariates of home range size. In all instances we followed the suggestions of Zuur et al. (2009) for data exploration, model fit and checking for violations of assumptions. Home range was LN-transformed in all analyses, but no covariates required transformation. All analyses were conducted in R 3.1.2 (R Core Team 2014) using packages lme4 (Bates et al. 2015), MuMIn (Bartoñ 2015) and ggplot2 (Wickham 2009). In all cases we report models with Akaike weights >5% and parameter estimates of the top-selected model.

To evaluate the effect of the BBS and CatBib on home range we had a sample of 30 cats with home range estimated for periods of the device being on or off; thus we obtained 60 observations of home range size. In addition to our experimental manipulations (device on-off, device type) we wanted to evaluate covariates associated with each animal (age, original sex, in-out at night, order of treatment) and the environment (housing density, total rain during measurement period, number of days of rain, mean maximum temperature). To account for two observations per cat, we used a mixed effects model where the identity of each cat was treated as random and other predictors as fixed. We then constructed a series of models where device on-off (the *a priori* question of the study) was included in every model and all other covariates were evaluated using all subsets regression. Because of the modest size of the dataset, we limited the maximum number of predictors per model to a maximum of three to avoid overfitting; we had no expectation of interactions among predictors and saw no evidence of interactions in plots of the data. Therefore we only considered additive models. Models were ranked using AICc (AIC corrected for small sample size) and models with weights greater than 5% retained. For our broader set of cats (N=34) without predation deterrents we only had one observation per cat and therefore applied a simple linear model. As before, we used an all subsets approach where we limited the maximum number of predictors to three to prevent overfitting.

4.3 RESULTS

4.3.1 Characteristics of Cats in the Study and Environmental conditions

The mean housing density for cats in the study was 18 dwellings/ha with the majority of cats (23) living in areas of 15-20 houses/ha, which is typical of general suburbia with detached housing in Perth. The lower average housing density for cats in trialling the CatBib is driven by three cats (two male and one female) that lived on rural properties (Table 4.1).

The mean maximum daily temperature during the study was 27.3 ˚C (Table 4.1). Although it was hotter during the BBS trial than the CatBib trial, 30.3 ˚C and 25 ˚C respectively, there was no substantial difference in temperature for cats with or without a BBS/CatBib in each trial. During the CatBib trial, the mean rainfall for all cats was 17 mm irrespective of whether or not cats were wearing the CatBib. Female cats experienced more rainfall on average, with a mean of 37 mm with the CatBib and 30 mm without over 1.7 and 1.3 days respectively. Male cats in the CatBib trial experienced much less rainfall overall and less variation in the amount of rain between treatments (12.9 mm with the CatBib and 14.8 mm without) over 1.5 and 1.3 days respectively. It was much drier for the cats trialling the BBS, with most cats (9) experiencing no rainfall at all. On average, cats in the BBS trial experienced 2.3 mm with the BBS and 2.9 mm without over 0.6 days each. Females experienced slightly more rain than males (Table 4.1).

Individual characteristics for each cat are provided in Appendix 3.

4.3.2 Influence of the CatBib and BBS on Home Range Size

Incremental area analysis showed that home range estimates for cats when wearing or not wearing a CatBib or BBS had plateaued, with the exception of two cats wearing the BBS. Thus the BBS home ranges reported are modest underestimates.

Home range sizes for 95% and 50% KDE of cats with and without a CatBib or BBS were similar (Table 4.2; Figure 4.2; see Appendix 4 for home ranges for each individual cat). The top models for both 95% KDE and 50% KDE included housing density but not the type of device (Table 4.3). Akaike weight of the top model for 95% KDE was 0.32 and 0.33 for 50% KDE (Table 4.3). Other top-ranked models (sequence identical across 95% and 50% KDE) included covariates of type of anti-predation device, order, sex, and in-out at night with Akaike weights spanning 0.17 to 0.06 (Table 4.3). Within the top model, the estimated effect of a CatBib or BBS being on was not significant (95% KDE: 0.02, SE=0.10, t=0.2, p=0.39; 50% KDE: 0.01, SE=0.08, t=0.1,p=0.39) (Figure 4.2) (thus the fact that two cats' home ranges had not plateaued when wearing the BBS could not have hindered a significant result). The effect of housing density was similar for 95% KDE (Figure 4.3; estimate -0.08, SE=0.02, t=4.1, p<0.001) and 50% KDE (estimate -0.07, SE=0.02, t=4.2, p<0.001).

Table 4.2: Home range, core areas, mean number of successful fixes and percentage of successful fixes and for cats with and without a CatBib, with and without a BBS, and for all cats without either predation deterrent fitted. Sample sizes are shown in parentheses

Trial (n)	Home range (ha) (mean ± s.e.)		Core range (ha) (mean ± s.e.)	Mean number of successful fixes[a] (mean ± s.e.)	Fixes as a % of all possible fixes[b] (mean ± s.e.)	% fixes successful[c] (mean ± s.e.)
	100% MCP	95% KDE	50% KDE			
CatBib						
Females with (3)	7.52 ± 6.52	6.36 ± 5.85	1.80 ± 1.00	118.3 ± 17.9	57.4 ± 8.3	86.0 ± 4.2
Females without (3)	8.84 ± 7.95	6.43 ± 6.05	2.03 ± 1.93	131.3 ± 17.0	60.6 ± 8.6	90.8 ± 2.5
Males with (13)	4.01 ± 1.39	1.97 ± 1.07	0.48± 0.25	94.6 ± 8.3	44.3 ± 4.1	89.8 ± 1.2
Males without (13)	3.14 ± 1.26	1.54 ± 0.72	0.41 ± 0.19	92.9 ± 7.7	45.1 ± 3.8	86.9 ± 2.4
All with (16)	4.69 ± 1.56	2.79 ± 1.34	0.72 ± 0.29	99.1 ± 7.7	46.7 ± 3.8	89.1 ±1.2
All without (16)	4.20 ± 1.72	2.46 ± 1.22	0.71 ± 0.38	100.1 ± 7.8	48.0 ± 3.7	87.6 ± 2.0
BBS						
Females with (6)	0.72 ± 0.12	0.43 ± 0.14	0.16 ± 0.07	79.5 ± 8.2	39.0 ± 4.0	85.2 ± 2.3
Females without (6)	0.75 ± 0.16	0.50 ± 0.18	0.16 ± 0.06	73.0 ± 7.9	34.8 ± 3.8	87.4 ± 0.8
Males with (8)	1.31 ± 0.71	0.69 ± 0.40	0.15 ± 0.06	93.2 ± 22.2	48.1 ± 9.8	77.6 ± 6.2
Males without (8)	1.25 ± 0.64	0.50 ± 0.23	0.13 ± 0.04	98.1 ± 14.4	47.3 ± 6.5	85.6 ± 1.3
All with (14)	1.06 ± 0.41	0.58 ± 0.23	0.15 ± 0.04	87.4 ± 12.1	44.2 ± 5.8	80.8 ± 3.7
All without (14)	1.04 ± 0.37	0.50 ± 0.14	0.14 ± 0.04	87.4 ± 8.7	42.0 ± 4.3	86.4 ± 0.8
All cats without a device						
Females (9)	3.45 ± 2.66	2.48 ± 2.01	0.78 ± 0.64	92.4 ± 12.0	43.4 ± 5.5	88.5 ± 1.0
Males (25)	3.41 ± 1.12	2.06 ± 0.87	0.69 ± 0.38	96.2 ± 6.0	46.1 ± 2.8	87.3 ± 1.4
All cats (34)	3.42 ± 1.06	2.17 ± 0.82	0.72 ± 0.32	95.2 ± 5.4	45.4 ± 2.5	87.6 ± 1.0

[a] Successful fixes are those with an HDOP value <9. See section 2.3 for further explanation
[b] number of fixes (irrespective of success)/ total number of fixes that could have been received in a 5-day period (i.e. 1 point every 30 mins = 240 points in 5 days)
[c] the number of successful fixes / the number of fixes received

Table 4.3: Model selection results for predictors of home range size (95 and 50 % kernels) of cats (N=30) wearing either a CatBib or BBS anti-predation device in Perth, Western Australia. Models with the lowest AICc and highest wi have the strongest support.

	Model†	k	AICc	ΔAICc	w_i
95 % KDE	DeviceOnOff + Housing Density	5	153.6	0	0.32
	DeviceOnOff + Housing Density + Device Type	6	154.9	1.3	0.17
	DeviceOnOff + Housing Density + Order	6	156.0	2.4	0.09
	DeviceOnOff + Housing Density + Sex	6	156.0	2.4	0.09
	DeviceOnOff + Housing Density + InOut at Night	6	156.1	2.5	0.09
50 % KDE	DeviceOnOff + Housing Density	5	138.6	0	0.33
	DeviceOnOff + Housing Density + Device Type	6	140.4	1.8	0.13
	DeviceOnOff + Housing Density + Order	6	141.0	2.4	0.10
	DeviceOnOff + Housing Density + Sex	6	141.1	2.5	0.10
	DeviceOnOff + Housing Density + InOut at Night	6	141.2	2.6	0.09
	DeviceOnOff + Housing Density + Age	6	142.1	3.5	0.06

†Full model for cats wearing a CatBib or BBS: ln(Kernel Size) ~ Intercept + collarOn-Off + Housing Density. Models presented are those with a minimum of 5% model weights given the model set.

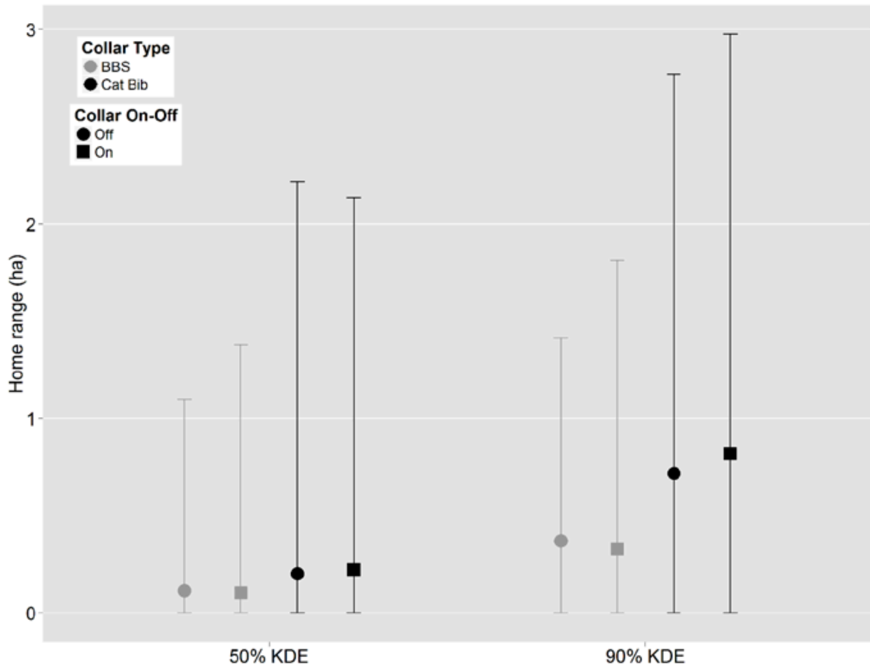


Figure 4.2: Home ranges (ha) of cats represented as 95% KDE (kernel density estimate) and 50% KDE when cats were wearing or not wearing a device (CatBib or a BBS). Error bars indicate 95% CL back transformed from the logarithmic data analysed.

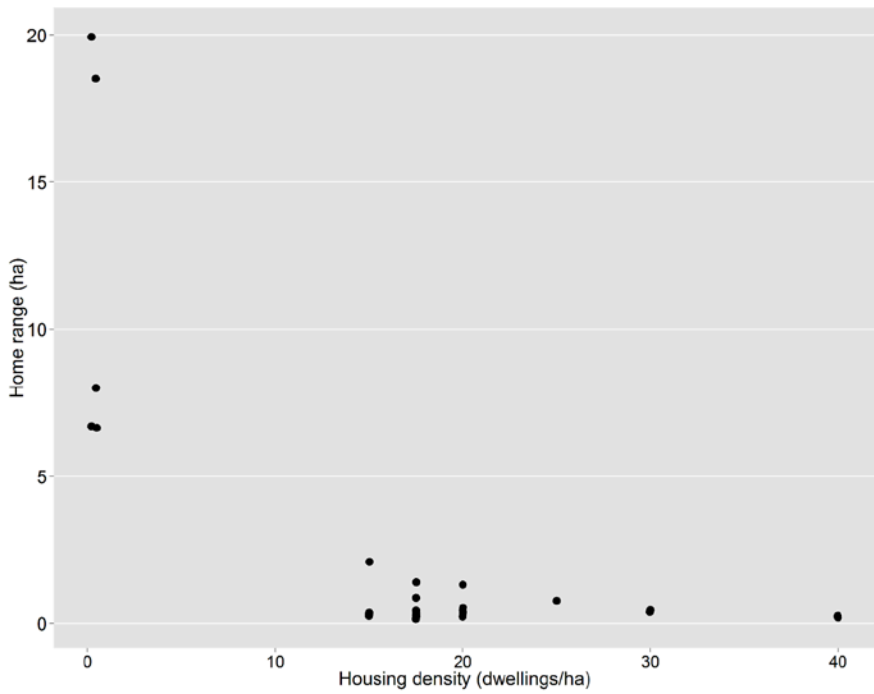


Figure 4.3: Home ranges (ha) of cats represented as 95% KDE (kernel density estimate) at different housing densities when cats (N=30 plus an additional 4 never fitted with CatBib/BBS) were not wearing either a CatBib or BBS.

4.3.3 Environmental Covariates

Using our dataset of 34 cats not wearing a CatBib or BBS, top models predicting 95% and 50% KDE of home range size were identical, including housing density and total rain during the measurement period (Table 4.4). Top models had weights of 0.28 and 0.29 for 95% and 50% KDE respectively (Table 4.4). The age covariate was present in both second-ranked models, both of which had higher weights, while other covariates (mean maximum temperature, number of days with rain, sex) had markedly lower support (Table 4.4). As with cats wearing a CatBib or BBS, housing density represented the largest effect with a negative estimate (Figure 4.4; 95% KDE: -0.09, SE=0.01, t=6.2, p<0.001; 50% KDE: -0.09, SE=0.01, t=6.4, p<0.001). Total rainfall during the measurement also had support in the data with a negative effect on home range size (95% KDE: -0.02, SE=0.01, t=2.6, p=0.02; 50% KDE: -0.03, SE=0.01, t=3.0, p=0.01). However, low rain occurred during the period of measurement of cats at the lowest housing densities, suggesting caution in inference (Figure 4.4).

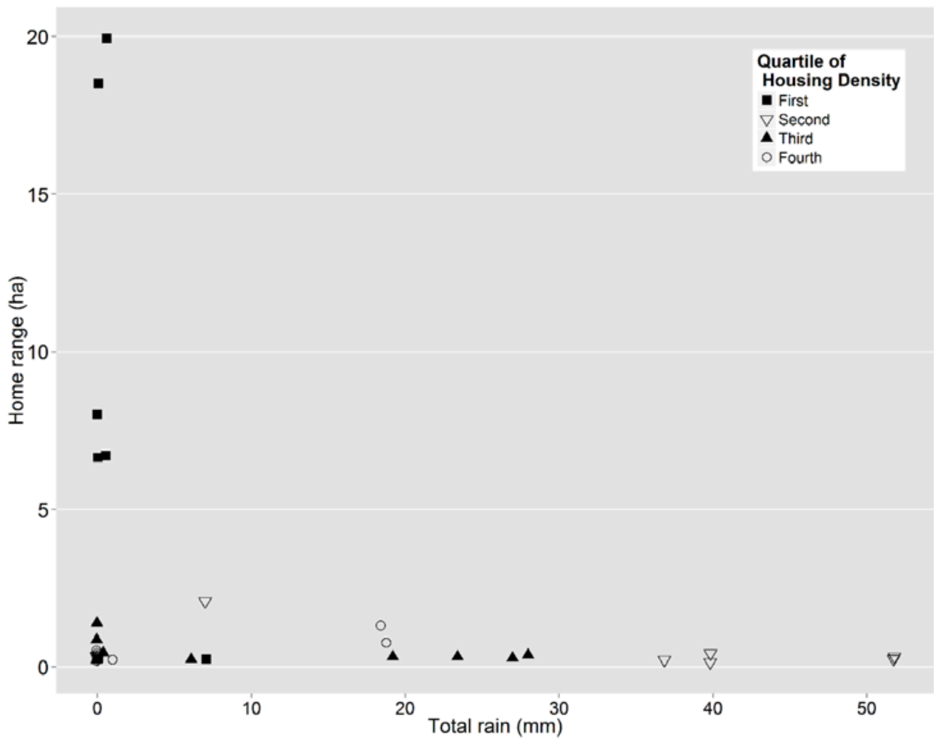


Figure 4.4: Home ranges (ha) of cats represented as 95% KDE (kernel density estimate) under different rainfall conditions when cats were not wearing either a CatBib or BBS. Shape indicates the quartile of housing density for each cat in the study; rainfall

Table 4.4: Model selection results for predictors of home range size (95 and 50 % kernels) of cats (N=34) not wearing a CatBib or BBS in Perth, Western Australia. Models with the lowest AICc and highest wi have the strongest support.

	Model†	k	AICc	ΔAICc	wi
95% KDE	Housing Density + Total Rain	4	93.8	0	0.28
	Housing Density + Total Rain + Age	5	94.2	0.5	0.22
	Housing Density + Total Rain + Mean Max Temp	5	96.1	2.4	0.08
	Housing Density + Total Rain + N days rain	5	96.2	2.4	0.08
	Housing Density + Total Rain + Sex	5	96.4	2.6	0.07
50% KDE	Housing Density + Total Rain	4	91.3	0.0	0.29
	Housing Density + Total Rain + Age	5	91.3	0.03	0.29
	Housing Density + Total Rain + Mean Max Temp	5	93.8	2.5	0.08
	Housing Density + Total Rain + Sex	5	93.9	2.6	0.08
	Housing Density + Total Rain + N days rain	5	94.0	2.6	0.08

†Full model: ln(Kernel Size) ~ Intercept + Housing Density + Total Rain. Models presented are those with a minimum of 5% model weights given the model set.

4.4 DISCUSSION

4.4.1 Influence of the CatBib and the BBS on Home Ranges

Despite indications from both Calver et al. (2007) and Hall et al. (2015) that the CatBib and BBS may reduce pet cats' roaming behaviour, this was not the case in this first experimental test of the hypothesis that these devices reduce pet cats' home ranges. Importantly, this indicates that lower prey capture rates are not caused by reduced roaming, further strengthening the inference of prior studies concluding that the CatBib interferes with prey capture and the BBS alerts prey with good colour vision. It also means that owners cannot use either device as a tool to reduce roaming.

Approximately 50% of cats hunt at some time in their lives (Paton 1991, Perry 1999, REARK 1994b), but this study included a large proportion of cats that were not hunting regularly (at least, were not bringing prey home for their owners to report). However, both Calver et al. (2007) and Hall et al. (2015) used cats known to bring home at least one prey a fortnight on average in their studies of the effectives of the CatBib and BBS in reducing predation on wildlife. Corroborative evidence of the devices reducing hunting success could include increased appetite because of lower prey capture or increased roaming time to compensate for lower success. In Hall et al. (2015) many of the cat owners who reported that their cats came home earlier or stayed closer to home also recounted that their cats ate more food during this time. Furthermore, two cats were reported as staying out more (Hall et al. 2015). If hunting success is a factor in the change of roaming behaviour for the cats reported in the Calver et al. (2007) and Hall et al. (2015) studies, it may not have been relevant to many of the cats in this study and therefore we would not see any effect overall.

4.4.2 Factors predicting home range

The home ranges we report are within the ranges of other studies in Australia and internationally (Appendix 5). Consistent with our results, other studies have reported that housing density is a strong limiting factor on home range, with cats living in rural areas or on the urban fringe having larger home ranges than cats in inner-city suburbs (Lilith et al. 2008, Metsers et al. 2010, Morgan et al. 2009, van Heezik et al. 2010). There are two principal explanations for this. One is that rural areas and urban fringes are closer to large areas of natural vegetation through which cats can move unimpeded. Morgan et al. (2009) found that cats living closer to a wetland in New Zealand had larger home ranges and travelled further into the wetland than cats living further away and van Heezik et al.

(2010) found that cats located next to any open green space had larger home ranges. In this study, cats in the CatBib trial had a higher mean home range because several of these cats lived in rural areas compared to the BBS trial where all of the cats lived in suburban settings with reduced access to green space.

The second factor is the density and distribution of cat-owning households. Domestic cats have a complex social structure. In cat colonies, female cats tend to have smaller home ranges and live in groups of related cats that are clumped around food sources. Male cats have larger home ranges based on the distribution of females, with subordinate male cats having smaller home ranges (Liberg 1984). Female cats often have completely overlapping home ranges with related females, but very little overlap with unrelated females except around food (Liberg 1984). The home ranges of male cats overlap more, presumably because their resource (females) is dispersed, unpredictable and harder to defend (Liberg 1984). Although this study and the others mentioned in Appendix 5 are predominantly concerned with pet cats, which entail different living conditions than colonies (e.g. many cats in multiple cat households are unrelated and most cats in the studies are desexed), cats still adhere to a social structure. Barratt (1997a) found that related cats in the same household had completely overlapping home ranges, in contrast to unrelated cats from the same residence that had overlapping core home ranges but tended to have non-overlapping outer home ranges. Barratt (1997a) also found that there was no overlap of home range between females from separate residences, but some overlap in the home ranges of males and males and females of separate homes. Males from separate homes also appeared to actively avoid each other's core areas (Barratt 1997a). Meek (2003) also found that cats from different households did not overlap in core areas. Thus, given strong evidence of cat density and distribution influencing roaming behaviour, it is reasonable to expect that in areas of higher housing density and therefore higher cat densities, home ranges will be reduced.

All cats in our study were desexed and there was no significant effect of sex on home range though, on average, male cats had slightly larger home ranges than females, which was consistent with previous studies (Hansen 2010, Lilith et al. 2008, Morgan et al. 2009). It is very unlikely that the home range of male desexed cats depends on the distribution of females. Barratt (1997a) suggests that the home ranges of male desexed cats are more likely to be based on food distribution (i.e. their home where food is provided). Guttilla and Stapp (2010) found no effect of desexing on the home ranges of unowned cats and Horn et al. (2011) found that the one desexed male cat in their study had a smaller home range to the unowned entire male cats, but that the one desexed female had an average home range comparable to the unowned entire female cats. However, it may be that once a cat has already established its home range, desexing may have no effect. It may have a much larger effect on pet cats that have not established their home range before being desexed. However, this would be difficult to test.

We found no strong evidence of an impact on home range of whether a cat was kept in at night or allowed to roam freely all the time. This was unexpected, because several other studies indicate that cats roam significantly further at night time than during the day (Barratt 1997a, Hansen 2010, Meek 2003, Metsers et al. 2010, Thomas et al. 2014). However, the particular timing of when owners decide to bring their cat in is variable. Many of the cats that are kept in at night may not actually be confined until after dark, or may be let out very early in the morning if they wake and annoy their owners.

We found some evidence of rain reducing roaming behaviour and thus home range estimates. These results are constrained by the fact that cats in the lowest housing density condition were tracked without devices during a dry period. Therefore, while we found no formal statistical issues (variance inflation, severe co-linearity of covariates), we are cautious in our inference. However, the negative impact of rain on roaming behaviour during a 5-day period does fit with general expectations. This effect might have been negated if cats had worn collars for longer periods, thereby exceeding the typical timeframe of weather fronts (~2-4 days) and reducing potential influence.

4.4.3 Validity of the Study Sample and Home Range Estimates

The sample of cats used in this study were recruited via personal contact with owners raising a potential bias in the sample. Despite this, the sample of animals represented a broad range of ages (Table 4.1) and housing densities (Figure 4.3). Further, the study was conducted across a range of weather conditions (Table 4.1, Figure 4.4). Therefore we feel that the sample of cats in the study offers strong inference in the context of assessing movement in relation to predation deterrent device, housing density, and weather conditions. Other, more subtle, socioeconomic details are beyond the scope of the present study.

After we completed our data collection, Coughlin and van Heezik (2014) found that heavy GPS collars (>3% of body mass) reduced home ranges by approximately 25% compared to the lightest collars. Given that our collars fall into the heavy range, our data may be underestimates of the true home range. The possible underestimate does not impact the inference of this study because all cats wore the same GPS collar type. There may be complex interactions between environmental conditions and collar weight in our assessment of the influence of environmental conditions on home range, but that would be speculation in the absence of evidence. The collar weight issue is relevant to all but the most recent studies of home range that have been able to take advantage of the latest lightweight collars.

4.4.4 Implications for Environmental Management, Cat Husbandry and Cat Welfare

The manufacturers of both the CatBib and the BBS claim that the devices do not curtail a range of normal behaviours of cats other than hunting (Birdsbesafe LLC 2009, Cat Goods Inc. 2011). Our results corroborate these claims, at least in relation to roaming. This may be important for owners considering using either device, but having reservations about whether or not the device may impede the free movement of their animals. Neither device is an option for owners wishing to restrict their cats' roaming.

Owners wishing to restrict their cats' roaming cannot resort to a CatBib or BBS and need to keep their cats confined to their property. However, this is unpopular with many owners (Dabritz et al. 2006, Grayson et al. 2002, Lilith 2007, Sims et al. 2008). Rochlitz (2005) suggests that the main concern with an indoor environment is that it can be impoverished, predictable and monotonous compared to outdoors. This stresses and bores the cat or contributes to type 2 diabetes (Slingerland et al. 2009). However, the environment of indoor cats can be enriched by companionship from humans, other cats and other pets; toys, climbing structures or food games; comfortable resting places; and sensory stimulation such as an outlook from a window (Ellis 2009). Cats can be successfully housed indoors or with access to outdoor enclosed cat runs provided they are used to these conditions from an early age (Rochlitz 2005), although cats used to outdoor access may have difficulty adapting to an entirely indoor existence (Hubrecht and Turner 1998).

4.5 CONCLUSION

The suggestions from earlier studies that the collar-mounted predation deterrents the CatBib and the BBS might reduce the roaming behaviour of pet cats were not supported by this experimental test. The most substantial influence on roaming behaviour was housing density, probably operating as a surrogate for the density of other cats in the vicinity. Owners who want to use either a CatBib or BBS to curtail their cat’s hunting behaviour but not restrict its roaming can do so with confidence, while owners wishing to curtail roaming behaviour need to find another solution. Confinement, although unpopular, remains the most effective option for reducing the environmental, social and animal welfare problems associated with roaming cats.

5 FACTORS DETERMINING THE HOME RANGES OF PET CATS: A META-ANALYSIS

Catherine M HALL, Kate A BRYANT, Kathy HASKARD, Taryn MAJOR, Sarah BRUCE, Michael C CALVER

This chapter is currently under review for publication in the journal Biological Conservation

ABSTRACT

Roaming pet cats *Felis catus* are a significant conservation issue because they may hunt, harass and compete with wildlife; spread disease, interbreed with feral populations, and hybridise with wild native felids. Studies of the roaming behaviour of pet cats are often hampered by modest sample sizes and variability between cats, limiting statistical significance of the findings and their usefulness in recommending measures to discourage roaming. We resolved these difficulties through meta-analyses of 25 studies from 10 countries involving 469 pet cats to assess the influence of sex, whether a cat was desexed or entire and housing density on roaming. A complementary linear mixed models approach used data on 311 individual animals from 22 studies and was also able to assess the influence of age and husbandry practices on roaming. This restricted sample gave greater statistical power than the meta-analyses.

Meta-analyses found that: male pet cats had larger home ranges than females, desexing did not influence home range, and cats had larger home ranges when housing densities were low. The linear mixed models supported those results. They also indicated that animals ≥ 8 years old had lesser home ranges than younger cats. Cats fed regularly, provided with veterinary care and socialised with humans had similar home ranges to cats living in association with households but not provided for in some of these ways. Short of confinement, there is no simple measure owners can adopt to reduce roaming by their cats and prevent the associated environmental problems.

Keywords: pet cats; *Felis catus*; wildlife protection; home range

Author Contributions

This chapter has five co-authors. M. Calver and K. Bryant assisted with survey design and analysis. K. Haskard, T. Major and S. Bruce provided detailed oversight and direction of the meta-analysis.

5.1 INTRODUCTION

"It is in the nature of cats to do a certain amount of unescorted roaming." – **Adlai Stevenson (1949)**

Wandering pet cats (*Felis catus*) (those living closely associated with a household providing food and other needs (Baker et al. 2010)) hunt wildlife (Baker et al. 2005), transmit diseases to people and wildlife, (Lepczyk et al. 2015), compete with other predators (George 1974), reduce the reproductive success of prey species by fear of predation (Beckerman et al. 2007) or by attracting other predators to prey defensive behaviour (Preisser et al. 2005), reduce the genetic integrity of wild felids by hybridising (Beaumont et al. 2001), and contribute to feral populations by interbreeding or abandonment of kittens (Jongman 2007). There are also concerns about unrestrained roaming because of risks to cat welfare (Egenvall et al. 2009, Loyd et al. 2013a).

Research on relationships between the home ranges of pet cats and their impacts on wildlife give ambivalent results. Hansen (2010) and van Heezik et al. (2010) concluded that home range did not influence the number of prey caught, but Meek (2003) and Morgan et al. (2009) found a greater diversity of prey in pet cats with larger home ranges. Nevertheless, concern about pet cats entering nature reserves or remnant native vegetation led Lilith et al. (2008) and Metsers et al. (2010) to use data on roaming behaviour to recommend buffer zones around sensitive habitat to protect against cat incursions. Concern amongst owners fuels interest in commercial deterrents for predatory behaviour (Calver et al. 2007, Hall et al. 2015, Nelson et al. 2005, Willson et al. 2015), which might act in part by curtailing roaming behaviour (Hall et al. 2016b). Reduced roaming should also restrict opportunities for other problems such as disease transmission or encounters that could change prey behaviour through fear of predation, but we are unaware of relevant data.

Despite the uncertainty about the relationship between roaming and impacts on wildlife, under the precautionary principle the plausibility that restricting roaming might protect wildlife justifies attempts to reduce roaming while the uncertainty is resolved (Calver et al. 2011). Surveys this century indicate that many owners are reluctant to confine their cats to protect wildlife (Grayson et al. 2002, Hall et al. 2016a, Lilith et al. 2006, MacDonald et al. 2015a, Thomas et al. 2012) but there might be other husbandry approaches such as desexing or confining only younger animals that might be more acceptable. A better understanding of the influence of factors such as age, desexing, sex, habitat variables such as housing density, and husbandry on roaming behaviour are important topics, because they might indicate practices owners could adopt or regulators could encourage to reduce roaming.

One of the primary difficulties in assessing influences on roaming behaviour is the substantial variation between individual cats (e.g. cats in Lilith et al. (2008) had home ranges (95% MCP) between 0.01 and 2.54 ha, while cats in Hall et al. (2016b) had home ranges (95% KDE) between 0.20 and 20.00 ha), causing difficulty in obtaining large enough sample sizes to reach statistically significant conclusions in the face of these variations. For example, several studies on pet cats report larger home ranges for males than females but no statistically significant difference between the two (Kays and DeWan 2004, Lilith et al. 2008, Morgan 2002, Thomas et al. 2014), while others do report a significant difference (Corbett 1979, Liberg 1980, Schär and Tschanz 1982). Sample sizes, husbandry of cats, whether the animals were desexed or entire, and possible interactions between these factors might all influence findings. In sum, Kays and DeWan (2004) observed that influences on cat roaming are not well understood, both at the level of individual cat's characteristics such as sex and at the level of environmental factors such as housing density, although better understanding could improve management of cats for wildlife protection.

We sought to overcome these difficulties through meta-analyses of the available data, concentrating on the influence of sex, age, desexing, husbandry practices and housing density on home range. Based on the results, we offer suggestions for managing the roaming of pet cats.

5.2 METHODS

5.2.1 Selection of Studies

We attempted to find every study that had analysed the home ranges of pet cats. In order to find studies we searched for key words (various combinations of pet, farm, domestic, cats, home range, roaming, wandering) in the Keywords + titles + abstracts in the journal database Scopus. All results were carefully checked for data on cat home range. Scopus does not claim to have complete data prior to 1996, so to locate earlier studies and grey literature such as theses we checked the reference lists of all the papers that either tested for cat home range or referred to studies that did. We continued to do this with any new papers until no new references were found. In the case of theses we attempted to contact the library of the relevant university if the thesis was unavailable online, but unfortunately some had been lost.

Estimates of home range are sensitive to variations in methods, especially the time periods involved and the density of location data. We included studies that used radio-tracking (17) or GPS collars (8) to determine home range. We excluded studies that used observational data only because cats could often not be seen, leading to underestimates of home range.

5.2.2 Study Variables

We attempted to find the home range, living conditions (husbandry), age, sex, and breeding status (desexed or entire) for each individual cat in each study. In some cases this was provided in text or in supplementary material, but for other studies we contacted the authors of the papers or found a relevant thesis that provided additional information.

We considered, but ultimately did not include, numerous other predictor variables including detailed descriptions of the habitat and more details on the study methods (e.g. GPS vs radio-tracking) because of considerable variation in the information reported and because including many predictor variables relative to sample size in statistical models risks overfitting (Anderson 2008). Instead, we included individual studies as a variable in analyses and regard habitat and methodological effects as part of the variability within studies.

Home Range

For some papers only figures of the home ranges were provided and these were analysed with Assess 2.0 image analysis software (Lamari 2015). Assess 2.0 was developed to determine the area of diseased tissue in plant leaves, so it is readily transferrable to measuring other irregular 2D shapes such as home range. In instances where multiple home ranges were provided for a single cat (e.g. nocturnal and diurnal home ranges or seasonal home ranges) the largest home range for each cat was chosen as a representation of the most extreme possible scenario. All home ranges, asymptotic or not, were included because authors were not always clear on this point (an important reason for including individual studies as a random factor in analysis).

The home range data provided by each study varied in how they were recorded because preferred methods of determining home range have changed over time. They included

100 % minimum convex polygons (100 % MCP), 95 % MCP and 95 % Kernel density estimates (95 % KDE). For analysis, a single measure of home range in hectares (HR in tables and equations) was defined which used the 95 % KDE where available, with the 95 % MCP or 100 % MCP used where 95 % KDE measurements were not given.

Living Conditions

These embraced two variables: the husbandry methods used by owners and the housing density where the cats were living. On the basis of husbandry, we distinguished between pet cats and farm cats. Refining the definition of Baker et al. (2010), pet cats were those that belonged to a household and were fed at least daily. They received veterinary treatment when required and had a close relationship with their owners. Farm cats lived on farms and were usually kept to catch rodents in farm buildings. They were fed regularly (at least daily), but were unlikely to receive veterinary treatment and lived in farm buildings rather than the house. We chose to include farm cats because we wanted to determine if there were any differences in home range based on husbandry practices and not just housing density. Farm cats were also much less likely to be desexed and therefore sex differences and the effect of desexing could be better analysed. We did not include studies that analysed the home range of stray or feral cats that lived on farms unless they also included data for pet or farm cats.

With regard to housing density, where possible cats were described qualitatively as rural (pet cats living in non-urban areas of low housing density), farm (rural cats not allowed access to human habitation but living on farm and regarded as owned) and urban (pet cats living in cities or their suburbs with higher housing density than rural). All classifications were based on the information provided by authors in text, which was mostly inadequate to quantify housing density more precisely. Housing density may actually function as a surrogate for cat density, but it can be measured more readily.

Age

It was decided that a categorical measure of age was sufficient for analysis purposes. Cats were classified as “young” if less than 2 years old, “adult” if at least 2 years old but less than 8 years old and “mature” if at least 8 years old. Although an age in years wasn’t provided for cats in either Macdonald and Apps (1978) (four cats) or Hansen (2010) (eight cats), both studies provided enough information to conclude that the cats were older than 2 years. These cats were included in the adult category.

Sex and Breeding Status

Cats were classed as male and female and as desexed or entire. If information on the sex of animals or desexed status was not given in the paper, this information was obtained directly from the authors where possible.

5.2.3 Statistical Analysis

Taking the natural logarithm of home range resulted in data that were approximately normal with stable variance. Exploratory data analysis of studies with results from more than one type of home range measure showed that ratios of group means (e.g. males/females, mature/adult/young) were reasonably consistent across measurement types. This gave more confidence to combine data with different measurement types in the one analysis, since only the ratio matters when modelling log-transformed home range data.

We first determined the effects of factors of interest (sex, desexed status, and housing density) using meta-analyses. We also fitted linear mixed models to the unit level home range data (on the log scale), taking advantage of the individual data available from 22 of 25 relevant studies identified. These totalled 311 of 469 cats. Given the high proportion of cats with unit level data this complementary analysis was worthwhile because of its greater statistical power. Linear mixed models also permitted analysis of the affects of age and husbandry on home range. All analyses were carried out in the statistical package R version 3.1.2 (R Core Team 2014).

Meta-Analyses

We examined the study level data for suitability for performing a separate meta-analysis for each of the factors of interest: sex, desexed status, husbandry and housing density (Table 5.1). A study could only contribute to a meta-analysis if we could estimate the effect size of interest from it.

Only one study included both farm and pet husbandry, so we were unable to perform a meta-analysis for husbandry. For the remaining three factors (sex, desexed status and housing density), we collapsed the data within each relevant study by each factor in turn, to estimate the effect size for that factor. Although housing density had three levels overall (urban, rural and farm), the three studies with complete housing density data and cats from more than one housing density factor only included urban and rural density, so only this difference could be tested in the meta-analysis. Barratt (1997a) included both farm and pet cats, but it was unknown whether the pet cats came from urban or rural dwellings. Hence, Barratt (1997a) was excluded from the housing density meta-analysis.

In cases where one factor level within a study had only one cat, the standard deviation for the other factor level within that study was used for both factor levels. Bradshaw (1992) was excluded from the analysis, because both rows had only one cat. Chipman (1990) was also excluded because no estimate of the home range standard deviation was available.

The treatment effect within each study was calculated using the weighted mean difference (WMD) method on the collapsed data. Random effects models were used, because data exploration showed evidence of heterogeneity between the studies. The DerSimonian and Laird method (Dersimonian and Laird 1986) was used to estimate this between-study variation and incorporate it into the calculation of the common effect. Heterogeneity was assessed using both the I^2 measure of heterogeneity and Cochran's Q, and a 10% significance level was used.

Reporting bias (publication bias, selective outcome reporting or selective analysis reporting) was qualitatively examined through funnel plots (Sterne et al. 2001, Sterne et al. 2011, Sutton et al. 2000). These are scatter plots of the effect estimates from each study against standard error (or some other measure of each study's precision). A solid line is plotted at the summary estimate of the effect of interest and dashed lines centred at this summary estimate show the triangular region within which 95 % of the studies would be expected to lie in the absence of both biases and heterogeneity. A statistical test for funnel plot asymmetry exists but is not recommended for meta-analyses with less than 10 studies because of its low power. Funnel plot asymmetry does not necessarily indicate reporting bias if heterogeneity is present. Such asymmetry can also be caused by other factors such as poor methods (especially in small studies) or chance (Sterne et al. 2011).

When effect estimates are related to standard errors (as indicated by funnel plot asymmetry), the random effects estimate will give more weight to smaller studies than the fixed effects estimate. Hence random effects models are not always conservative.

Sterne et al. (2011) recommend comparing fixed and random effects estimates when funnel plot asymmetry exists in a meta-analysis with between study heterogeneity.

Table 5.1: List of studies available for analysis, the number of cats included in the study and the factors that can be estimated from the study.

Study	Number of cats	Factor			
		Sex	Desexed status	Husbandry	Housing density
Barratt, 1997	17	yes	yes	yes	
Bradshaw, 1992	2	yes	yes		
Carss, 1995	1				
Chipman, 1990 in Bradshaw 1992	135	yes			
Corbett, 1979	16	yes			
Coughlin 2015	20	yes			
Das, 1993 in Barratt 1997	13	yes			
Catherine Hall	34	yes			yes
Hansen, 2010	8	yes			
Hervias, 2014	9	yes	yes		
Horn, 2011	11	yes			
Kays & DeWan, 2004	11	yes	yes		
Kitts-Morgan et al 2015	7	yes	yes		
Liberg 1980	10	yes			
Lilith, 2008	16	yes			yes
MacDonald, 1978	4	yes			
Meek, 2003	15	yes	yes		
Metsers, 2010	38	yes			yes
Morgan, 2002	21	yes			
Schar 1982	5	yes			
Thomas, 2014	20	yes			
Turner, 1986	11	yes	yes		
van Heezik, 2010	31	yes			
Warner,1985	11	yes			
Weber and Dailly, 1998	3	yes			
Total	**469**	**24**	**7**	**1**	**3**

Linear Mixed Models

Fixed effects were included in the initial model for study year, sex, desexed status, age, husbandry and housing density, as well as several two-way interactions with sex. Study year was included as a fixed effect because GPS monitoring tools were more commonly used in later studies and their readings are thought to be more accurate than those of VHF monitoring of cats. Study was included as a random effect to account for the likely correlation between observations on cats from the same study. Random effects were estimated using residual maximum likelihood (REML). There is no universally agreed way of calculating the denominator degrees of freedom (DDF) for small sample inference in mixed effects models using REML (Kenward and Roger 1997, Schaalje et al. 2002). The approach taken by R's nlme package, which was used for this analysis, "coincides with the classical decomposition of degrees of freedom in balanced, multilevel ANOVA designs and gives a reasonable approximation for more general mixed-effects models" (Pinheira et al. 2010).

No study tested all levels of all factors of interest, so the study design was unbalanced. With such unbalanced designs, the order in which factors are added to the model affects the results. This means that multiple models are needed in order to fully explore the significance of various terms in the model. Consequently, F test p-values need to be interpreted with care.

Backwards elimination was used to select the best set of fixed effects terms for inclusion in the final model. A significance level of 5 % was used. Once the model was selected, individual terms were tested by dropping each one in turn from the final model.

Predicted means and their standard errors were calculated for fixed effects significant at the 5 % level. For these predicted means, 95 % confidence intervals were calculated, with the means and confidence limits back-transformed to report them on the original measurement scale. In order to maximise the data available for model fitting, missing values for categorical age and housing density were coded as a separate category called "miss" and "UrbanRural", respectively.

Models were initially fitted including housing density (urban/rural/farm), which combined both rural/urban density types with pet/farm husbandry. The "full" model included the terms: sex, desexed, categorical age (agecat), housing density (density) and study year as well as the two-way interaction terms sex:desexed, sex:agecat and sex:density.

Using backwards elimination, all two-way interaction terms, study year and husbandry were removed because of lack of statistical significance. The resulting model included the main effects terms: sex, desexed, categorical age and housing density. However, within the housing density factor, urban cats were different to both rural and farm cats, while rural and farm cats were not significantly different. We could conclude that cats from rural or farm areas had larger home ranges than pet cats from urban areas, regardless of their husbandry. Therefore we collapsed the housing density factor from the three levels of urban/rural/farm to the two levels urban/rural. A new variable was created, hereafter designated UrbanRural (UR), that categorised all cats from the "farm" or "rural" categories of housing density as "rural" and all cats from the "UrbanRural" category as "miss."

For completeness, backwards elimination was performed starting from a “full” model that included the husbandry variable as well as the new urban/rural (UR) variable. The “full” model included the terms: sex, desexed, agecat, husbandry, UR and study year as well as the two-way interaction terms sex:desexed, sex:agecat, sex:husbandry and sex:UR.

Using backwards elimination, all two-way interaction terms, study year, desexed and husbandry were removed because of lack of statistical significance.

5.3 RESULTS

5.3.1 Studies Included and Cat Characteristics

We found 32 studies that had studied the home ranges of pet or farm cats and a summary of the main findings of these is provided in Appendix 6. Seven of these studies were excluded for various reasons, leaving 25 studies that were selected for analysis (Table 5.2). Subsets of these studies were used in specific analyses as described.

Pet cats ranged in age from 1.0 to 18.0 years old with a mean of 5.7 years (median 5) and 96 % were desexed. In the included studies, they often lived in single-cat households and very rarely did more than three cats live in one household. Cats from the same household were sometimes related (i.e. sibling or parent/offspring), but were often living with unrelated cats.

Farm cats do not live as long as pet cats. Their ages ranged from 1.0 to 10.0 years old with a mean of 2.9 years (median 2). Farm cats were less likely to be desexed with only one (1 %) desexed farm cat (Appendices 7 and 8). Consequently, they tend to live in groups of related cats. Studies were included if the farm cats were fed at least once per day although they primarily hunted for their food, often in the farm buildings. These cats are unlikely to receive veterinary treatment. Across the studies, farm cats vary in their affection to and treatment by humans, but in general they were wary of people and usually had to be trapped in order to be fitted with the radio or GPS collar.

Table 5.2: All studies found relating to the home range of pet or farm cats and whether they were included or excluded in analysis.

Study	Included/Excluded	Reason for Exclusion
(Barratt 1997a)	Included	
(Bradshaw 1992)	Included	
(Carss 1995)	Included	
(Chipman 1990) in (Bradshaw 1992)	Included	
(Corbett 1979)	Included	
(Coughlin and van Heezik 2014)	Included	
(Das 1993) in (Barratt 1997a)	Included	
(Ferreira et al. 2011)	Excluded	Food was provided too irregularly
(George 1978)	Excluded	Observation data only
(Hall et al. 2016b)	Included	
(Hansen 2010)	Included	
(Hervías et al. 2014)	Included	Semi-feral cats excluded
(Horn et al. 2011)	Included	
(Kays and DeWan 2004)	Included	
(Kitts-Morgan et al. 2015)	Included	
(Leyhausen and Wolff 1959)	Excluded	Observation data only
(Liberg 1980)	Included	
(Liberg 1984)	Excluded	Home range of male cats was divided by social class and not able to be included
(Lilith et al. 2008)	Included	
(Macdonald and Apps 1978)	Included	
(Meek 2003)	Included	
(Metsers et al. 2010)	Included	
(Morgan et al. 2009)	Included	
(Panaman 1981)	Excluded	Observation data only
(Schär and Tschanz 1982)	Included	
(Schmidt et al. 2007)	Excluded	Feral and pet cat data were merged in the paper and individual data for the cats could not be found through other means
(Thomas et al. 2014)	Included	
(Turner and Mertens 1986)	Included	
(van Heezik et al. 2010)	Included	
(Warner 1985)	Included	
(Weber and Dailly 1998)	Included	
(Wierzbowskaa et al. 2012)	Excluded	Food was provided too irregularly

5.3.2 Meta-analyses

Testing for a difference between male and female home ranges

Study level data from the 22 studies that tested for a difference in male and female cat home ranges were collapsed and a random effects meta-analysis was performed. Male cats had a home range around 1.88 times larger than female cats ($z = 4.92$, $p < 0.001$), with a 95% confidence interval 1.46 to 2.42 (Figure 5.1).

There was evidence of heterogeneity between studies: Cochran's Q had a p-value <0.001 ($Q_{21} = 56.41$) and the I^2 measure of heterogeneity indicated that around 63 % of the total variation across studies was caused by heterogeneity rather than chance. Therefore, modelling study as a random effect was the preferred choice for these data.

Examination of funnel plots (Borenstein et al. 2009) showed slight asymmetry, possibly indicating weak publication bias arising from three studies. A bias-corrected estimate of differences in male and female home ranges supported the conclusion of a sex difference ($z = 3.26$, $p = 0.001$), but with smaller magnitude (1.60 times larger, 95% CI 1.21 to 2.12).

Since we had heterogeneity between studies and asymmetry of the funnel plot, we also performed a meta-analysis with study as a fixed effect. The results were consistent with the random effects model, with an estimated effect size of 1.68 (95% CI 1.46 to 1.93).

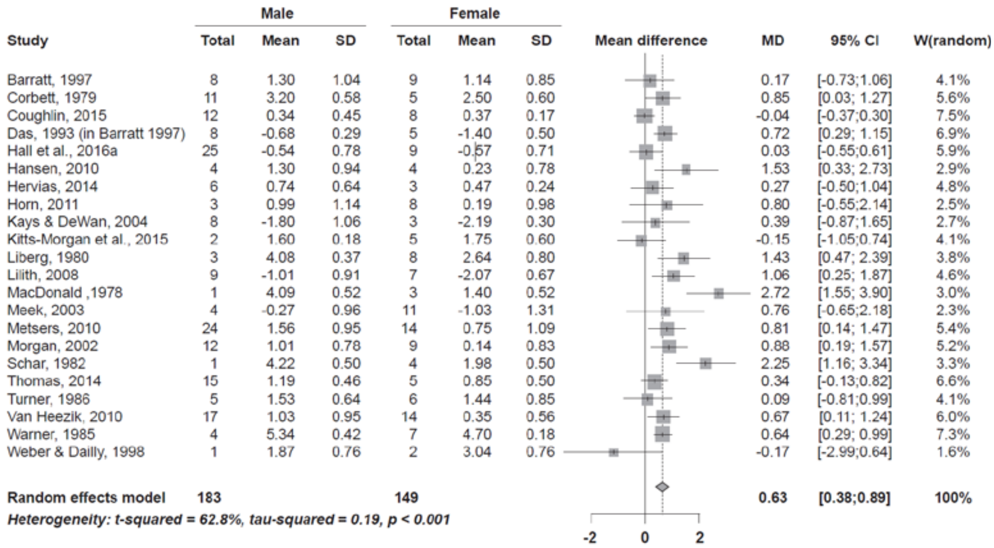


Figure 5.1: Forest plot of the random effects meta-analysis of studies measuring the difference in male and female cat home ranges (on the log scale). There is evidence that male cats have a larger home range than female cats.

Testing for a difference between entire and desexed cat home ranges

Study level data from the six studies that tested for a difference in desexed and entire cat home ranges were collapsed and a random effects meta-analysis was performed. There was no evidence that entire cats have a different home range than desexed cats ($z = 0.42$, $p = 0.68$) (Figure 5.2).

There was little evidence of heterogeneity between studies: Cochran's Q has a p-value of 0.19 ($Q_5 = 7.46$) and the I^2 measure of heterogeneity indicates that around 33 % of the total variation across studies is due to heterogeneity rather than chance. With only six studies included in this meta-analysis, it was not possible to assess symmetry with funnel plots.

We also performed a meta-analysis with study as a fixed effect. The results were consistent with the random effects model.

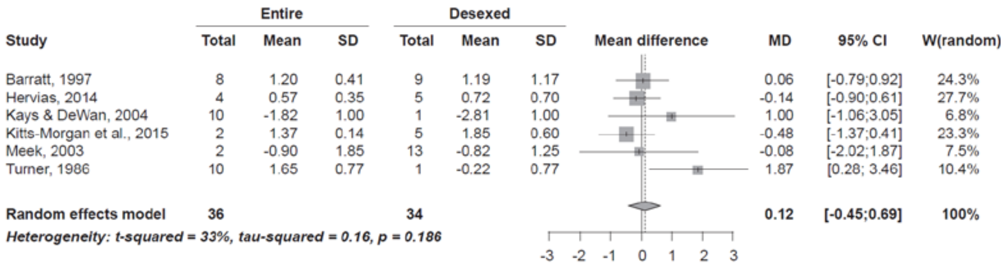


Figure 5.2: Forest plot of the random effects meta-analysis of studies measuring the difference in desexed and entire cat home ranges (on the log scale). There is no evidence that entire cats have a different home range than desexed cats.

Testing for a difference between urban and rural pet cat home ranges

Study level data from the three studies that tested for a difference in urban and rural housing density pet cat home ranges were collapsed and a random effects meta-analysis was performed. Pet cats from rural areas had a home range around 14.4 times as large as pet cats from urban areas ($z = 7.50$, $p < 0.001$), with a 95% confidence interval 7.2 to 28.8 (Figure 5.3).

There was evidence of heterogeneity between studies: Cochran's Q had a p-value of 0.07 ($Q_2 = 5.43$) and the I^2 measure of heterogeneity indicated that around 63 % of the total variation across studies was due to heterogeneity rather than chance. With only three studies included in the meta-analysis, it was not possible to assess symmetry with funnel plots.

We also performed a meta-analysis with study as a fixed effect. The results were consistent with the random effects model, with an estimated effect size of 14.5 (95% CI 9.5 to 22.0).

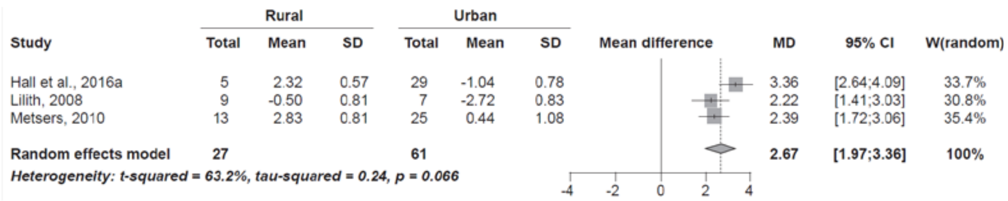


Figure 5.3: Forest plot of the random effects meta-analysis of studies measuring the difference in home ranges between pet cats from rural houses and pet cats from urban houses (on the log scale). There is evidence that pet cats from rural houses have a larger home range than pet cats from urban houses.

5.3.3 Linear mixed models

The final linear mixed model derived included the main effects terms: sex, agecat and UR (in which all non-urban cats were combined in the rural category). This was the model considered to best fit the data. Desexed status was excluded because it was not significant (Table 5.3).

With each term tested after allowing for the other three terms, male cats had significantly larger home ranges than females, ($F_{(1, 283)}$ = 20.31, p < 0.001), roaming up to twice as far (Table 2). Urban/rural housing density continued to be a significant predictor of log home range ($F_{(2, 283)}$ = 47.73, p < 0.001), with rural cats having home ranges over 10 times larger than urban cats (Table 2). Age was a significant predictor of log home range ($F_{(3, 283)}$ = 3.03, p = 0.030). Adult cats had significantly larger home ranges than mature cats, but not young cats. Mature cats and young cats had similar home ranges (Table 2). The scatterplot of standardised residuals vs fitted values for the selected model showed no obvious outliers, and residuals did not vary systematically with fitted values. Therefore the selected model appears reasonable.

Table 5.3: Summary of estimated effects from both the meta-analysis and mixed effects modelling approaches.

Factor	Meta-analysis		Mixed Effects Model	
	Estimated effect size (95% CI)	p-value	Estimated effect size (95% CI)	p-value
HR_{male}/HR_{female}	1.88 (1.46, 2.42)	<0.001	1.83 (1.40, 2.37)	<0.001
$HR_{rural\ and\ farm}/HR_{urban}$	Not tested		11.0 (6.66, 18.3)	<0.001
HR_{rural}/HR_{urban}	14.4 (7.16, 28.8)	<0.001	Not tested	
$HR_{entire}/HR_{desexed}$	1.13 (0.64, 2.00)	0.67	1.69 (0.90, 3.18)[1]	0.10
HR_{young}/HR_{adult}	Not tested		0.98 (0.65, 1.48)	0.91
HR_{young}/HR_{mature}	Not tested		1.56 (0.98, 2.51)	0.06
HR_{adult}/HR_{mature}	Not tested		1.60 (1.15, 2.22)	0.01

[1]The factor for desexed status was not included in the final mixed effects model due to a lack of significance. Its estimated effect size has been included in the table for comparison purposes only.

5.4 DISCUSSION

Many previous studies found that the mean home ranges of male pet cats were larger than those for females, but this was not statistically significant (Kays and DeWan 2004, Lilith et al. 2008, Morgan 2002, Thomas et al. 2014). However, combining the evidence from all known studies showed that male cats do have statistically larger home ranges than females, using both meta-analysis and linear mixed models.

Liberg et al. (2000) suggested that in entire cats, male home ranges are determined by the availability of females and female home ranges are clustered around food sources. This led to the conclusion that desexing female cats is unlikely to have an effect on home range but that desexing male cats should decrease their home range, because they should become more interested in food than females (Barratt 1997a). We found no evidence to support this hypothesis from the meta-analysis or the mixed-effects model. Guttilla and Stapp (2010) also found that desexing had no impact on the movements of feral cats, so this conclusion is equally applicable to pet and farm cats. It also has implications for the management of cat colonies by trap-neuter-release (TNR) (Longcore et al. 2009), because it is unlikely to reduce roaming by cats desexed and released. However, an unknown factor in the analyses is the age at which each cat was desexed. It is possible that if a cat is desexed as an adult once its home range has been established, desexing does not change its home range. This is suggested by Bradshaw (1992), citing data from Chipman (1990) who found that a male cat that had been desexed at age four had a similar home range to entire male cats as opposed to the other desexed male cats which had similar home ranges to females, which were smaller than entire male cats. It is possible that if a cat is desexed before it is sexually mature and its home range has not been fully established, desexing may reduce home range.

We found that categorical age had an impact on home range size, with adult cats (2-7 years) having significantly larger home ranges than mature (≥8 years) cats. There was no difference between adult cats and young cats (<2 years) or young cats and mature cats. This is supported by data collected by Chipman (1990) cited in Bradshaw (1992), that showed that adult cats had larger home ranges than younger and older cats. Hervías et al. (2014) found that home range size increased with age while Morgan et al. (2009) found that younger cats had larger home ranges than older cats. It is possible that complex social interactions associated with age impact home range with young cats, with low status cats either confined to small home ranges or in some cases forced to roam widely in order to avoid more dominant cats. When cats are adults they can establish a more permanent home range, but as they age they are less able to defend their territory and it begins to decrease again.

We found no effect of husbandry on cat roaming behaviour. Using linear mixed models, there is no evidence that pet cats have different home ranges to farm cats. Only one study tested both farm and pet husbandry, and so we were unable to perform a meta-analysis for husbandry. Leyhausen (1979) showed that feeding is independent of hunting behaviour and it also appears that how often a cat is fed and whether it is kept for the purpose of hunting, whether it receives veterinary treatment and the quality of its relationship with humans (i.e. whether it is a pet and part of the family or considered just another farm animal) do not affect roaming behaviour.

We found strong evidence that housing density is a major predictor of home range. While the meta-analysis tested cats from rural areas against urban areas and the mixed model tested cats from either rural or farm areas against urban areas, results were consistent across both modelling approaches. Cats living in lower density areas, whether they were farm cats or rural pets, had much larger home ranges than cats from urban areas. This was expected based on evidence from other studies (Lilith et al. 2008, Metsers et al. 2010, van Heezik et al. 2010).

At higher housing densities cats are more likely to encounter other cats, dogs or other deterrents to widespread roaming. Thus housing density can be considered a surrogate for cat density (Hall et al. 2016b), which may be the real factor underlying the effect of housing density on home range. In some environments, the presence of predators such as coyotes *Canis latrans* may be a confounding factor if they prey on cats roaming more widely from habitation (Crooks and Soulé 1999), or cats may be cautious venturing into habitat that may support predators (Kays and DeWan 2004). Thus housing density, cat density, predator activity and vegetation structure/remnant size may all interact to determine the observed home range of pet cats. While sample sizes and our wish to avoid overfitting in statistical models prevented assessments of many of these effects in meta-analysis or linear mixed models, we can make the robust generalisations that: male cats roam further than females, desexing is unlikely to change home range, and that roaming is most likely in cats aged 2-7 years.

In environmentally sensitive areas, some local governments are introducing buffer zones around nature reserves or remnant native vegetation to protect local wildlife from the potential impacts of pet cats (Baker 2001, Buttriss 2001, Lilith et al. 2008, Moore 2001). People living within these buffer zones are either prohibited from owning a pet cat or required to keep pet cats restricted to their property at all times. Lilith et al. (2008) and Metsers et al. (2010) quantified how wide these buffer zones should be, ranging from 360 m to 1.2-2.4 km respectively. The differences can be explained in terms of the great variability in individual cat roaming behaviour (Kays and DeWan 2004, Metsers et al. 2010, Morgan et al. 2009). There is no one rule that applies to all cats in all locations, so area-specific data will be required to recommend suitable buffer zones. In areas of lower housing density the problem will be more acute.

Given that the individual roaming behaviour of cats is highly variable, changes over time and is also influenced by environmental factors, the best way to ensure that pet cats do not negatively impact the environment or themselves through roaming is to confine them to their owners' properties. We have no evidence that popular husbandry techniques such as desexing or regular feeding, reduce home ranges, nor did Hall et al. (2016b) find that effective anti-predator devices act by reducing roaming behaviour. Our data show that mature cats roam less, so at best it is only younger animals that need to be confined.

However, confinement is unpopular for many owners (Lilith et al. 2006, McHarg et al. 1995, Perry 1999, REARK 1994a, 1994b, Rochlitz 2005, Sims et al. 2008). Therefore to encourage changes in cat husbandry, the attitudes towards cat confinement by cat owners and the general populace need to change. In a study of the community attitudes and practices towards pet cats in six countries Hall et al. (2016a) found that respondents in four of these (China, Japan, the UK and the USA) were unlikely to believe that pet cats negatively impacted wildlife and therefore using the impact on wildlife as a motivation to encourage responsible cat husbandry would not cause a change in behaviour. This is supported by MacDonald et al. (2015a), who found that the willingness of owners to bring their cats inside was prompted by the benefits to the cat or the positive impact on the owner, not wildlife protection. Therefore campaigns focusing on the benefits to cats and owners rather than the benefits to wildlife are more likely to elicit the desired change.

6 OVERVIEW OF PRINCIPAL FINDINGS AND THEIR IMPLICATIONS

In the introduction to this thesis I surmised that predation by pet cats could cause serious and irreversible environmental damage through loss of species and biodiversity in urban environments, including remnant bushland. Australian examples include reptiles such as the legless skink (*Delma impar*) from suburban Canberra (Osborne and Williams 1991) and the marsupial eastern barred bandicoot (*Perameles gunnii*) from Hamilton, Victoria (Dufty 1994). There are further examples from New Zealand (van Heezik et al. 2010), the UK (Thomas et al. 2012) and the USA (Balogh et al. 2011). Free roaming pet cats may also inter-breed with semi-feral or feral cats (Jongman 2007) and transmit disease (Eymann et al. 2006, Izawa et al. 2009, Torrey and Yolken 2003).

However, there are many causes of wildlife decline in urban areas, leading critics of legislation of cat ownership claim that cats are an easy scapegoat and shift attention from habitat destruction, road traffic and other causes of wildlife decline (Chaseling 2001, Nattrass 1992). Nevertheless, while there is scientific uncertainty about the true extent of the impact of pet cats in every situation, there are reasonable grounds to use strong precaution for this issue because reducing cats' impacts may prevent the loss of wildlife in urban areas or at least slow it down while the other issues can be addressed. Such actions given the lack of full scientific certainty are consistent with the precautionary principle (Calver et al. 2011, Deville and Harding 1997).

In order to apply the precautionary principle, careful consideration of all possible methods needs to be undertaken to choose those that will be suitable, cost-effective and adhered to by cat owners. Therefore the four specific objectives examined in this study were:

i) Assess the social attitudes in Australia, the USA, the UK, New Zealand, Japan and China towards pet cats and cat ownership and responsibilities

ii) Assess whether the new collar-mounted anti-predation BBS cat collar cover is effective at significantly reducing cat predation on birds but not other prey

iii) Assess how collar-mounted anti-predation devices such as the CatBib and BBS work (i.e. do they work predominantly by alerting prey and interfering with prey capture or do they cause a change in cat roaming behaviour or activity)

iv) Examine available information on the roaming behaviour of pet cats and assess factors that influence roaming behaviour.

I addressed the first aim by a detailed survey of citizens' attitudes toward wildlife and cats in six countries. In association with colleagues from Australia and overseas, I assessed the differences in attitudes and husbandry regarding restrictions and desexing of pet cats, as well as their interactions with wildlife of cat owners and non-owners in Australia, New Zealand, the UK, the USA, China and Japan. I found significantly different results between all countries, indicating that if any legislation was to be imposed regarding pet cats unique approaches would be required in each country. Given that one key finding was that many cat owners will not keep their cats inside, other methods to prevent wildlife capture and reduce pet cat roaming behaviour are appropriate. Therefore I addressed the uncertainty over the effectiveness of the BBS in reducing bird predation, what determines roaming, and whether or not roaming could be curtailed by using either a CatBib or BBS.

6.1 ATTITUDES AND PRACTICES OF CITIZENS REGARDING CATS AND WILDLIFE

Since results differed significantly between countries, unique approaches to cat legalisation are required. If one of the aims of cat legislation is to encourage wildlife friendly cat husbandry, the best chances for success are in Australia and New Zealand where concern for the impact of pet cats on wildlife is high. In Australia especially there is support for restrictions and therefore any legislation is likely to be adhered to, although support in New Zealand by cat owners is lower and legislative pressure may not be received as favourably.

In other countries legislation because of wildlife concerns is very unlikely to be successful because the population does not accept that there is a problem. In these countries a focus on cat welfare such as reducing the incidence of car accidents and unwanted kittens may be a better approach. However, welfare approaches may be less likely to be considered reasonable grounds for establishing legislation by government authorities and therefore a strong focus on education would be more suitable.

6.2 ASSESS WHETHER THE NEW COLLAR-MOUNTED ANTI-PREDATION BIRDSBESAFE CAT COLLAR COVER IS EFFECTIVE AT SIGNIFICANTLY REDUCING CAT PREDATION ON BIRDS BUT NOT OTHER PREY

The Birdsbesafe® (BBS) cat collar cover reduced the amount of prey with good colour vision (birds and herpetofauna) brought home by pet cats in the study by 54% in the first year and 47% in the second year, rates that are comparable with those for other anti-predator devices available (Calver et al. 2007, Calver and Thomas 2011, Nelson et al. 2005, Ruxton et al. 2002). Red and rainbow collar covers were more effective than yellow at reducing return rates of birds. This product is currently the only device that is known to cause a statistically significant reduction the amount of herpetofauna brought home by pet cats. The BBS provides an effective option for owners who wish to reduce the numbers of birds and/or herpetofauna that their cat brings home.

The BBS had no effect on the return rates of mammals. This has the positive effect of reducing populations of non-native mammal pests such as rats and mice while protecting bird and herpetofauna populations. However, the BBS is not suitable for cats living in areas with sensitive native mammal populations or cats that hunt small and medium native mammals such as bandicoots. Invertebrates were not considered in the study, so no comment can be made on whether they are protected by the BBS. As cats can still predate on mammals which may be intermediate hosts of the parasite *Toxoplasma gondii*, the BBS does not reduce the risk of infection to cats, as do other devices that reduce prey capture more generally.

Just prior to the publication of our study, Willson et al. (2015) published a study testing the effectiveness of the BBS in the USA. They tested only the effectiveness on reducing bird and mammal captures and found that cats caught 19 times more birds in the spring and 3.4 times more birds in autumn when not wearing the BBS. There was no difference in small mammal captures in the spring but half as many mammals were caught during autumn while wearing the BBS (Willson et al. 2015). This reduction in bird capture was much greater than ours and may be influenced by either the different BBS colour/pattern used or the different species and habitat for birds in New York as compared to Perth. In the US, bird feeding is popular and encouraged by government agencies (U.S. Fish & Wildlife Service 2001) and therefore many birds may be in open space and more vulnerable to cat predation. Willson et al. (2015) also described many of the bird species in their study as ground-dwelling, which was not true of most of the species caught in ours. As the birds in Willson et al. (2015) could have been in more open space, they may have seen cats wearing the BBS from further away, giving them a longer time to escape. Many of the birds in our study were nectar feeders. They often feed in low shrubs where their vision may have been obscured until the cats were closer, reducing the effectiveness of the BBS.

Willson et al. (2015) suggest that the difference in mammal predation between spring and autumn in their study was caused by changes in cat behaviour. Some owners in their study felt that their cats hunted less or stopped hunting altogether while wearing the BBS because they were no longer successful and this may explain the reason why mammal captures were reduced during the autumn after the cats had already participated in the spring trial (Willson et al. 2015). Although the numbers of mammals caught with and without the BBS were the same during spring, Willson et al. (2015) rejected the hypothesis that snow cover in the spring when small mammals tend to burrow in the snow resulted in fewer mammal captures to the point of negating the effectiveness of the BBS because mean capture rates of mammals were higher in spring than in autumn.

We found a difference in the effectiveness of different colours of BBS on the capture rate of birds but not herpetofauna, with the red and rainbow collar covers more effective than the yellow for birds. Further testing on different colours should be carried out to determine the most effective colours and/or colour combinations to warn potential bird and herpetofauna prey. Willson et al. (2015) also suggest that some colours may be more effective than others depending on the time of year because the red, orange and yellow in the BBS covers they tested closely matched the pattern of fallen leaves during autumn and may have contributed to them being less effective for protecting birds during this season. A weakness of the BBS approach is that colours and patterns are variable, so consistency is difficult to maintain.

Anecdotal evidence from owners in our study suggested that some cats may change their roaming behaviour while wearing the BBS either by staying closer to home or staying out longer. This was similar to results from a study on the effectiveness of a pounce protector, the CatBib, at reducing cat predation on wildlife (Calver et al. 2007) and prompted further testing on both of these devices.

6.3 DO COLLAR-MOUNTED ANTI-PREDATION DEVICES SUCH AS THE CATBIB AND BIRDSBESAFE CAUSE A CHANGE IN CAT ROAMING BEHAVIOUR?

I tested the hypothesis that pet cats change their roaming behaviour while wearing either a CatBib or BBS. Using GPS collars to determine the home range of pet cats with and without either a CatBib or BBS, I showed that neither device made a significant difference to cat home range. Cats in the BBS and CatBib studies were active hunters (Calver et al. 2007, Hall et al. 2015) and it is possible that their changes in roaming behaviour were caused by the reduction in their hunting success by either coming home earlier for food because they were hungry, or travelling further/staying out longer waiting for a successful capture. Many of the cats in this trial were not active hunters, so if hunting success were a reason for changes to roaming behaviour, it would not have been applicable. This study showed the CatBib and BBS cannot be used by owners to reduce roaming. However, it did demonstrate that neither device changes cat roaming behaviour and supports their manufacturers' claims that there is no ground for concern that these devices change this aspect of cats' behaviour.

Individual cat home ranges can be highly variable. Therefore we used the GPS data while cats were not wearing a BBS or CatBib to determine what factors have the greatest influence on home rage. Home range was predicted most strongly by housing density, which is presumably a surrogate for cat density. This is of particular concern for wildlife conservation because cats that live close to large areas of natural bushland such as national parks are likely to be roaming much further and have greater opportunity to come into contact with wildlife. Even if cats are not affecting native species through predation, they may have indirect effects on birds because of their fear of predation (Preisser et al. 2005) such as reduced food provisioning, breeding suppression and reduced fledgling survival (Bonnington et al. 2013, Dunn et al. 2012, Lima 1987, 1998, Martin et al. 2000, Schwagmeyer and Mock 2008). The presence of cats may also increase the chance of nest predation because warning calls made by birds when they see the cat may alert other predators such as corvids to the nest location (Bonnington et al. 2013). Cats may also introduce infectious oocysts for *Toxoplasma gondii* into bushland or reserves.

If owners wish to curtail roaming behaviour, the most effective method is to confine the cat indoors or to the property. This is especially important in outer-urban or rural areas where cats are likely to travel further and therefore more likely to come into contact with native wildlife, interact with feral cats, cross dark or busy roads where cars may be travelling at higher speeds and encounter poisoned food such as fox or rat baits.

6.4 EXAMINE AVAILABLE INFORMATION ON THE ROAMING BEHAVIOUR OF PET CATS AND ASSESS FACTORS THAT INFLUENCE ROAMING BEHAVIOUR

Although many studies have assessed the roaming behaviour of pet cats, individual studies are often hampered by modest sample sizes and high variability between individual cats. This often limits the statistical significance of the findings and makes it difficult to suggest recommendations to limit cat roaming behaviour or protect wildlife reserves from pet cats. I attempted to overcome these difficulties with a meta-analysis and a linear mixed models approach to analyse all suitable information collected on pet and farm cats' home ranges. I found a total of 25 studies involving 469 cats that could potentially be used for analysis. Data were only included if researchers used radio-telemetry or GPS to determine the cats' home ranges because this is more accurate than observational data. I assessed the influences of sex, whether a cat was desexed or entire, age, housing density and husbandry practices on roaming.

In many studies male cats had larger home ranges than females but this was not found to be statistically significant (Kays and DeWan 2004, Lilith et al. 2008, Morgan 2002, Thomas et al. 2014). However, the meta-analysis and mixed linear models did show that male cats have significantly larger home ranges than females. The results also indicated that older adults (over 8 years old) had smaller home ranges than younger adult cats (2-8 years old). With regard to husbandry, cats fed regularly, provided with veterinary care and socialised with humans had similar home ranges to cats living in association with households but not provided for in some of these ways. Desexing also had no influence over home range, but it is possible that the age at which the cat was desexed (which could not be determined from the data) may influence this factor. Cats that are desexed before they are fully mature and have not yet established their full home range may be influenced by desexing whereas desexing older cats that have already established their home range may not be influenced at all.

Apart from confining cats to their owner's property or house, there is no simple measure owners can adopt to reduce roaming by their cats and prevent the associated environmental problems. Feeding a cat well, interacting with it frequently, desexing it and providing veterinary care will not affect roaming.

6.5 RESULTS INTO ACTION

Pro-environmental behaviour can be difficult to initiate for many individuals in the general public (MacDonald and She 2015). Slater (2015) suggests that individuals who have strong beliefs on a topic are less likely to change their beliefs even in the face of new evidence. In addition there can be a large gap between what people believe and what they actually do (Slater 2015). MacDonald and She (2015) suggest seven cognitive concepts that influence pro-environmental behaviour and these are summarised below with examples specific to encouraging more responsible pet cat management by owners (Table 6.1).

Table 6.1: Cognitive concepts for encouraging pro-environmental behaviour specific to cat ownership (Adapted from MacDonald and She, 2015).

Cognitive Concept	Definition and Description	Examples
Responsibility	A sense of responsibility for current environmental problems can be divided into two groups: a sense of responsibility for causing the problems and a sense of responsibility for solving the problems (MacDonald and She 2015). Focusing on the latter and providing a sense of personal control over the solution can encourage responsible behaviour.	Encouraging owners to keep their cats inside in order to avoid disease transmission, traffic accidents and wildlife deaths.
Complex Decision Making Skills	Many people lack understanding of environmental problems and risks and often feel overwhelmed when it comes to decision making and choosing what option to pursue (Kaplan 2000, Levin 1993). Industry standards and regulations and incentives can help people make decisions and incorporate environmental considerations (MacDonald and She 2015).	Minimum safety standard for collars and simple information on how to correctly fit them. Create regulations requiring pet cats to be desexed with local government to provide a monetary incentive on receipt of veterinary certificate. Require breeders to microchip and desex kittens before selling. The requirements contained in the 2011 Western Australian Cat Bill provide a focus for required behaviour from cat owners (Government of Western Australia 2011).

Cognitive Concept	Definition and Description	Examples
Decision Heuristics	Decision heuristics are "shortcuts" in someone's mind that help to simplify judgments and decisions (Tversky and Kahneman, 1974) and aid in quick decision making (Gigerenzer et al., 2004). Generally, they lead to good decision outcomes, but they can also lead to irrational judgments and decisions. For environmental issues, the general public's concern is often not aligned with the actual risks (Slimak and Dietz, 2006) especially in regards to the potential impacts of pet cats on wildlife as previously established. It is important not to ignore popular concerns or just try to address them with education, even if the concerns are not accurate (MacDonald and She 2015). Altering products accompanied with appropriate education is required.	Require all collars to have either a break-away clip or elastic section to address owner concerns of cats getting caught in collars as well as providing information on the correct fitting of collars. Cat shelters sometimes offer two cats for the price of one so individual cats don't get lonely when kept solely inside.
Altruism-sacrifice link	Altruism often implies a message of self-sacrifice for the sake of others. Kaplan (2000) argue that focusing on altruism suggests that people need to live with less, resulting in an impoverished and joyless future. In addition, some people perceive a link between high levels of consumption and greater happiness (Geller et al. 2002). This means that even though people care about the impact of their behaviour, large sacrifices in personal benefit will hinder good intentions (MacDonald and She 2015). MacDonald and She (2015) suggest focusing on the potential benefits and downplaying altruism when trying to encourage pro-environmental behaviour.	Don't focus on the sacrifices owners have to make to keep their cat inside to protect wildlife. Focus education campaigns on the positives of protecting pets from traffic accidents and disease.

Cognitive Concept	Definition and Description	Examples
Trust	The general public has to overcome several trust issues when it comes to pro-environmental behaviour. In regards to cat husbandry, a person must trust the science that identifies the environmental problems and his or her ability to personally affect the problems with pro-environmental behaviour (MacDonald and She 2015). Guber (2003) suggests that the environmental movement has sacrificed its credibility by downplaying environmental progress and using exaggerated warnings to motivate public awareness and concern, so people are less likely to look towards environmental experts for advice.	The general public may be more likely to trust the advice of veterinarians or animal shelter staff. If these sources promote collar wearing and identification, desexing and keeping cats indoors, cat owners may be more likely to comply, especially if the reasoning promotes cat welfare.
Cognitive dissonance and guilt	When it comes to an individual's environmental behaviour, feelings of guilt may be a motivation for change (Festinger and Carlsmith, 1959). However, they may also result in a change of values, attitudes, or beliefs about the environment to a position of less concern (Immerwahr, 1999; Vining et al., 2002). This may result in people fundamentally decreasing the importance they place on environmental problems, or their belief that environmental problems exist. Inducing feelings of guilt should therefore be avoided (Levin, 1993).	Pets make up an important part of life for many people. Campaigns that cause people to feel guilty about their cats are unlikely to be effective and may cause owners to downplay the other impacts people have on the environment such as individual responsibility of water and energy consumption.

Cognitive Concept	Definition and Description	Examples
Motivation	Extrinsic motivation, in which a person derives satisfaction from a reward given when the behaviour is performed is the best motivator for pro-environmental behaviour when there is a tangible incentive and personal sacrifice is minimal (Guber 2003). Examples of extrinsic motivators include financial incentives as well as guilt. However, although the latter may give the reward of removing an unpleasant cognitive state, as previously discussed in the row on 'cognitive dissonance and guilt' it can lead to very undesirable consequences (MacDonald and She 2015).	Veterinarians and shelter workers could fit free collars on cats and show owners how to fit them correctly allowing cats to wear visible identification or anti-predation deterrents. Councils could offer financial incentives for desexing cats, especially for elderly and low-income earners. Shelters can offer two cats for the price of one so pets won't get lonely when left solely inside.

6.5.1 International Perspectives

In Australia and New Zealand where attitudes towards wildlife are favourable and people acknowledge that pet cats may be detrimental to wildlife populations, targeted education programs to encourage more confinement of cats in order to protect local wildlife could gain support. Cats are often kept as family pets for children (Lepczyk et al. 2004), so educating school children about the risks to local wildlife and their pets could encourage parents to keep cats indoors. Awasthy et al. (2012) demonstrated that children who participated in exercises with researchers in local green space demonstrated a greater level of nature awareness and retained this level three months after the program's completion. Schools could be encouraged to adopt a local bushland on the school property or very close by, monitor the wildlife and plants growing there and participate in rehabilitation if required. Children could be taught about the effect that cats can have in these bushland remnants directly through predation or indirectly by predating on native bird species required for plant pollination (Paton 1991). Follow-up discussion would include what methods the children can undertake to prevent this from happening, allowing them to conclude for themselves that keeping their cats inside or in their yard would help protect wildlife in their local area. This should be especially effective if they have an attachment to that area because they are directly involved in looking after it.

In the UK, cat confinement was very unpopular even amongst non-owners and respondents did not feel that pet cats had a significant effect on local wildlife. It is often felt that cat confinement is cruel because cats are natural wanderers and therefore prohibiting them from doing so will make them miserable (Rochlitz 2005). Although Thomas et al. (2014) indicated that collar-mounted anti-predation devices were the most acceptable option in the UK for preventing predation, only 52% of cat owners were supportive of this. Many owners who were not supportive were concerned that a collar may cause distress or injury (Thomas et al. 2014). Calver et al. (2013) found that collar injuries requiring veterinary treatment are very rare, occurring approximately once per 2.3 years of veterinary practice. Information distributed though veterinary practices on the benefits of collars for I.D. tags and mounting predation deterrents, together with directions on checking that collars are fitted correctly, could help dispel this fear. Cat owners may be encouraged to confine their cats inside or to their properties if provided with information on the incidence of cats killed in traffic accidents and the difficulty of returning cats without identification to their homes (Egenvall et al. 2009, Lord et al. 2007, Rochlitz 2004a, Rochlitz et al. 2001). When adopting new kittens, animal welfare agencies could provide information on how to create an appropriate environment for cats that are kept solely inside so that they do not become bored or distressed (American Bird Conservancy 2011d, Rochlitz 2005).

A further barrier to cat regulation in the UK is the lack of endorsement from conservation groups such as the Royal Society for the Protection of Birds (RSPB). The RSPB are a wildlife conservation group and therefore do not encourage indoor confinement of cats on the basis of cat welfare purposes. They state that they are "not able to urge the government to introduce such legislation, as we have no scientific evidence of the impact of cat predation on bird populations that is strong enough to support such a call" (RSPB 2015b). They do, however, encourage the use of bells to reduce prey capture (RSPB 2005a) and ultrasonic cat deterrents to deter cats from visiting gardens where they are not welcome (RSPB 2005b). They claim that most of the birds captured by pet cats would have died of other causes anyway by the next breeding season and that many bird species that are encountering serious decline do not often encounter cats, so cats cannot be the cause (RSPB 2015a). However, two of the species most commonly caught by pet cats in the UK (house sparrow and starling) have shown declines in breeding populations, and cat predation in scarce habitats such as heathland could contribute to decline in species that rely on these areas such as cirl buntings and Dartford warblers (RSPB 2015a). I believe that these present reasonable grounds to encourage cat confinement, because although cat predation may not be the sole cause of decline for many species, it is an additive pressure for bird species living in an increasingly urbanised and fragmented environment. Reducing predation may help slow declines and prevent some of the healthy individuals that would have survived to the next breeding season from being taken. Lobbying for conservation groups to adopt this attitude and to support the introduction of cat legislation could help to change the community attitude towards the impact of pet cats on wildlife and help enable legislation to be introduced.

Although in the survey over 80% of cats were desexed in all countries except China, a much lower proportion of respondents felt that it should be compulsory for all pet cats to be desexed, with the exception of cats owned by registered breeders. This survey targeted middle-class respondents, which may be the reason for higher desexing rates. Perhaps they do not want to impose the cost on others or believe that owners have a right to choose. Cech and Lloyd (undated) in Australia and Aguilar and Farnworth (2013) in

New Zealand found that in lower socio-economic areas, the rate of desexing was much lower than the average. Cech and Lloyd (undated) found that 100% of people in the areas surveyed would use a free desexing clinic and suggest that offering free monthly desexing clinics, in addition to providing information on the welfare of unwanted animals, would encourage high compliance and more responsible pet ownership. The response of veterinarians to the offer of subsidised or free desexing would have to be considered.

6.5.2 National Government Regulatory Approaches in Australia

In 2015, the Australian Commonwealth released a draft of the threat abatement plan for predation by feral cats including a specific objective to increase public support for feral cat management and promote responsible cat ownership (DoE 2015). The draft plan emphasises that because cats are valued as companion animals by many people in the community, ongoing education and support from the community for feral cat management are important and provides four actions to help achieve this objective (DoE 2015).

Action 1: "Quantify the proportion of the domestic and stray cat population that transitions to the feral cat population" (DoE 2015; pg. 18)

There is scientific uncertainty over the contribution of pet and stray cats to the feral population and whether this has a significant impact on the threat of predation on threatened species, particularly in remote communities or places where pet cats are actively encouraged to hunt for rodent control such as farms (DoE 2015). From my research on the roaming behaviour of cats, although pet cats in Australia are likely to be desexed, it is very unlikely that farm cats will be. Farm cats tend to live in family groups. Although often fed by farmers, they are usually kept for hunting rodents. Cats in rural areas have larger home ranges than their urban counterparts and sometimes wander far into bushland areas. Although it has not been quantified, because farm cats may wander and are unlikely to be desexed, there is a great potential for them to breed with feral cats, contribute significantly to feral populations and increase the effect of feral cats on wildlife populations.

Action 2: "Promote to the community: an understanding of the threat to biodiversity posed by cats and support for their management; an understanding of the transitions between domestic, stray and feral cats, and the need for responsible ownership; and support for the containment of domestic cats where their roaming may impact on identified conservation areas" (DoE 2015; pg. 18)

This action focuses on community support and understanding of the effects of feral cats but also how husbandry of pet cats may contribute to this issue. Entire cats may have opportunities to breed with feral cats and wandering pets may leave their homes and transition to become stray or feral cats, potentially bringing healthy breeding animals into these communities. In addition, wandering pet cats also negatively impact on wildlife through predation and disease transmission. As a result, the Commonwealth supports containment of pet cats, especially in high risk areas. However, since this option is still unpopular with many cat owners and the Commonwealth has no jurisdiction over the control of pet cats, this will require extensive education to gain community support, requiring funding and effort on the behalf of state and local governments. Education is especially important in regards to farm cats, because they are usually not desexed and the owners are rarely willing to provide veterinary treatment.

Action 3: "Promote the reduction of food and other resources to stray cats" (DoE 2015; pg. 19)

Stray cats still rely on humans for food provisioning at least part of the time, whether it is by deliberate feeding of stray cats by people or accidently by refuse from rubbish tips, food outlets and some small-holdings. Minimising food availability may slow population growth, reducing numbers of feral cats (DoE 2015). Keeping cats confined and encouraging desexing will decrease unwanted kittens and provide opportunities for animal shelters to rescue stray cats and rehome them if appropriate.

The Commonwealth does not advocate the trap-neuter-return (TNR) policy (involving trapping, sterilising (and sometimes vaccinating and worming) of stray cats before they are returned to the environment where they are fed by volunteers) because it is only effective under specific circumstances (DoE 2015, Lepczyk et al. 2010, Longcore et al. 2009). In Australia, feral cats are damaging to wildlife both on the continent and on islands and have resulted in the extinction of many species. At least 80 threatened species are listed under the EPBC Act as being affected by feral cat predation. Returning cats in better health than they were previously does not prevent predation on wildlife and may prolong damage if cats live longer after veterinary treatment and immunisation. In addition, TNR is ineffective at eliminating colonies in the long term unless at least 70% of the population is desexed annually, whereas removing >50% of the population annually achieves the same result with less resources (Andersen et al. 2004). Feral and stray cats are often in poor health and the survival rate of kittens is very low (Jessup 2004, Schmidt et al. 2007). Even though the survival rate is high enough that populations continue to grow, the quality of life for these animals is very poor and is not a humane existence considering that wanting them to have a full life and not be euthanised is the main reason why many people prefer this course of action (Lepczyk et al. 2010, Longcore et al. 2009).

Action 4: "Develop specific communication campaigns to accompany the release of new broad-scale cat control techniques, and other current/new cat control techniques" (DoE 2015; pg. 19)

Community support is important for effective feral cat management. Even with restrictions on availability and use, some members of the community may still be concerned and therefore education campaigns will be required to gain support (DoE 2015).

Since the Commonwealth government does not have jurisdiction over the husbandry practices for pet cats, it cannot create legislation to address many of these actions which are important for the success of the entire feral cat management plan. The Commonwealth requires local governments and communities to accept the importance of reducing the impact of feral cats on the environment and to take action with their pets to aid the process. Although established on the grounds of animal welfare, one such model that could be effective for solving the problem of transition between pet, stray and feral cats and significantly reducing the stray cat population would be Getting to Zero (G2Z 2015).

6.5.3 State, Local Government and NGO Initiatives in Australia

Getting to Zero (G2Z) is an initiative that aims to achieve zero euthanasia of all healthy and treatable cats and dogs in every community and municipality in Australia (G2Z 2015). The G2Z model encourages the community, pounds and shelters, breeders and the local government to work together to prevent abandonment and save existing lives, so that only animals with serious untreatable illness, severe behavioural issues or a poor prognosis for rehabilitation are euthanised (G2Z 2015). This model has the advantage of addressing many different levels of society so that everyone is working together towards the same goal.

G2Z encourages education campaigns in schools to develop awareness of the numbers of abandoned animals and commitment to responsible animal care through four key actions:

i. Desex: this reduces/prevents the incidence of unwanted litters
ii. Identify: by microchipping and tagging pets, lost animals can be returned to their homes and families
iii. Train: this is more applicable to dogs than cats and prevents them from becoming a nuisance to families as they grow older, which is a common reason for dog abandonment
iv. Keep safe: because cats can be difficult to train, the easiest way to keep cats safe and prevent them from taking risks such as crossing busy roads, entering small spaces and fighting with other animals is to keep them inside or provide limited access outside with a cat run or specialised fencing. Keeping cats safe would also include providing an appropriate indoor environment such as having another cat for companionship and providing toys and places to watch what goes on outside (American Bird Conservancy 2011d, Rochlitz 2005).

Veterinary clinics can aid this process by providing information to all pet owners on desexing and indoor husbandry, assisting owners in financial hardship by providing low cost or free desexing and microchipping services, and providing health checks and free/cheap microchipping and desexing to animal shelters. While veterinarians may respond reasonably that they run businesses, not charities, discounted services to the unemployed or pensioners would be equivalent to the pro bono work practised in other professions. In Australia in 2003, it was estimated that veterinary practices perform almost $30 million worth of pro bono work per year which is approximately $16,565 per veterinary practice (Anon 2003). The cost of offering further discounted services to pet owners may be financially difficult for many practices but could be ameliorated by having voluntary charitable funds or by transparently taxing all clients by advertising that a small percentage of the profit is used for charitable cases. This allows informed client choices when choosing one practice over another (Yeates 2012). Animal shelters should ensure that all pets are health checked, desexed, microchipped and dewormed before they are rehomed. Local governments can help to enforce compliance by creating legislation so that all cats and dogs must be microchipped and all must be desexed except for registered breeders. A permit system for breeders would ensure the well-being of animals and require all kittens and puppies to be desexed and microchipped prior to sale.

These concerns were addressed in Western Australia with the 2011 Cat Bill (Government of Western Australia 2011). The Cat Bill aims to "provide for the control and management of cats; and promote and encourage the responsible ownership of cats" and requires compulsory microchipping and desexing of all cats, except for those owned by registered breeders, and requires these to have occurred prior to sale. The Cat Bill also delegates authority to local councils to create local laws regarding cat ownership such as cats that create a nuisance, requiring premises in certain areas to provide suitable enclosed spaces for cats and limiting the number of cats kept on premises. Examples of other initiatives undertaken by local governments in other Australian states include requiring cats to wear predation-deterrent devices on their collars, banning cats in new housing sub-divisions, cat exclusion zones around sensitive wildlife habitat and curfews where cats must be confined between specified hours (Buttriss 2001, Lilith et al. 2010, Moore 2001, Pergl 1994).

According to G2Z, their 4-step model has been trialled successfully in Queensland, Australia (G2Z 2015). In 2009/10, 85% of the 7,000 stray and surrendered cats and dogs in Gold Coast City were either reclaimed or rehomed. All healthy dogs and cats were saved with only 8% of incoming dogs and 9% of incoming cats deemed untreatable because of illness or aggression. Only another 1% of treatable dogs and 15% of treatable cats had to be saved for there to be zero euthanasia of treatable animals for the city. Most other pounds and shelters euthanise 40% of dogs and 60% of cats on average, so the introduction of this model in Gold Coast City reduced these rates considerably. If surrounding areas introduce G2Z it is expected that Gold Coast City will achieve zero euthanasia of healthy animals and that surrounding areas will start to reduce their oversupply and soon also reach zero. It is estimated that at least 90% of stray and surrendered cats and dogs are either healthy or treatable and could be rehomed if models such as G2Z were in place (G2Z 2015).

6.5.4 Would Australian Initiatives Work Internationally?

Based on the results of the international survey, I expect that the 4-step G2Z model would also be effective in New Zealand, which showed some similar results to Australia, and also in the UK where cat welfare appears to be a major consideration by owners as opposed to impact on wildlife. While indoor confinement for cats is already common practice for Japan and mainland USA, this model may encourage further compliance and community support. In the USA, where TNR is a common method for trying to control stray cat populations (Willson et al. (2015) even advocated fitting BBS collars to colony cats), perhaps there could be a focus on desexing cats to reduce unwanted litters and then increasing adoptions from stray populations rather than returning them to the streets.

In China, desexing rates are very low (38%) and cat confinement either solely inside or to their owners' properties is only 55%, potentially leading to a significant issue with unwanted kittens. Eighty per cent of Chinese households have only one cat, leading to the conclusion that unwanted kittens are not kept by the household. If kittens are relinquished to animal shelters, overcrowding may lead to many cats needing to be euthanised and kittens left on the streets can lead to large feral cat populations that will hunt wildlife, spread disease, fight with pets and cause general nuisance. In some areas of China cat meat is a delicacy and many wandering cats are stolen from surrounding cities and sent to these areas (CAPN 2015). In China, animal welfare organisations are recent, with Animals Asia founded in 1998 and the Chinese Animal Protection Network (CAPN), commencing in 2004. Some of their activities include opposing the consumption of cat and dog meat and supporting trap-neuter-return programs to control cat population numbers (Animals Asia 2015, CAPN 2015). These organisations have community support and often use local celebrities to promote their views. These organisations would be ideally placed for education campaigns that could encourage desexing and confinement in order to prevent pets from being stolen for the meat trade and unwanted kittens from facing the same fate. It would also reduce the population of feral cats in cities. These organisations could also campaign for free desexing clinics, especially in lower socio-economic areas where the cost of the operation may be an issue for some cat owners.

6.6 CONCLUDING REMARKS

It has been a decade since Tantillo (2006) queried control of feral cats in the USA, arguing that the effect of feral cats is likely to be exaggerated and that it is immoral to assume that just because cats were brought to the USA by humans they are therefore of less worth than the species that existed already. Data since then show that his position should be reconsidered, at least with regard to his assessment that the effect of feral cats is greatly overstated (Fancourt and Jackson 2014, Medina et al. 2011, Woinarski et al. 2011). Managing pet cats is even more contentious. However, data have also accumulated, including evidence in this thesis, to give a convincing rationale for regulation of pet cats as part of conservation programs for urban wildlife. Although pet cats are only part of the reason for decline of some wildlife species in urban areas, they are an additive pressure these species face on top of increasing habitat destruction and fragmentation. In addition, the wandering nature of cats puts wildlife in bushland reserves at risk from predation and sub-lethal effects from the presence of cats, as well as potential breeding with feral cats, hybridisation with wildcats and the spread of disease in these areas. Keeping cats indoors is the most effective way to ameliorate these issues and with special attention to the suitable requirements of indoor living for cats it provides a safe and enjoyable lifestyle for them as well as allowing people to take pleasure in their company. The American Bird Conservancy (American Bird Conservancy 2011a, 2011b, 2011d) is a strong advocate of this approach and their public education materials are an excellent template for similar campaigns in other countries (Warner 1985).

7 REFERENCES

ACAC (2010). *Contribution of the Pet Care Industry to the Australian Economy - 7th Edition*. Australian Companion Animal Council.

Aguilar, G. D. and Farnworth, M. J. (2013). "Distribution characteristics of unmanaged cat colonies over a 20 year period in Auckland, New Zealand." *Applied Geography* **37**: 160–167.

Albert, A. and Bulcroft, K. (1988). "Pets, Families, and the Life Course." *Journal of Marriage and Family* **50**(2): 543-552.

Allendorf, F. W., Leary, R. F., Spruell, P. and K.Wenburg, J. (2001). "The problems with hybrids: setting conservation guidelines." *Trends in Ecology and Evolution* **16**(11): 613-622.

American Association of Feline Practitioners. (2007). "Confinement of owned indoor cats." Retrieved January 20, 2015, from http://www.catvets.com/guidelines/position-statements/confinement-indoor-cats.

American Bird Conservancy. (2011a). "City of Aurora, Colorado- a sample cat law." Retrieved December 28, 2014, from http://www.abcbirds.org/abcprograms/policy/cats/materials/aurora_law.pdf.

American Bird Conservancy. (2011b). "Domestic cat predation on birds and other wildlife." Retrieved December 28, 2014, from http://www.abcbirds.org/abcprograms/policy/cats/materials/predation.pdf.

American Bird Conservancy. (2011c). "Getting the facts about cat law." Retrieved December 28, 2014, from http://www.abcbirds.org/abcprograms/policy/cats/materials/cat_law.pdf.

American Bird Conservancy. (2011d). "Human attitudes and behavior regarding cats." Retrieved December 28, 2014, from http://www.abcbirds.org/abcprograms/policy/cats/materials/attitudes.pdf.

Ancillotto, L., Serangeli, M. T. and Russo, D. (2013). "Curiosity killed the bat: Domestic cats as bat predators." *Mammalian Biology* **78**: 369-373.

Andersen, M. C., Martin, B. J. and Roemer, G. W. (2004). "Use of matrix population models to estimate the efficacy of euthanasia versus trap-neuter-return for management of free-roaming cats." *Journal of the American Veterinary Medical Association* **225**(12): 1871-1876.

Anderson, D. R. (2008). *Model based inference in the life sciences*. New York, Springer Science + Business Media LLC.

Andrich, D., Sheridan, B. and Luo, G. (2013). *Interpreting RUMM2030*. Perth, RUMM Laboratory Pty. Ltd.

Angold, P. G., Sadler, J. P., Hill, M. O., Pullin, A., Rushton, S., Austin, K., Small, E., Wood, B., Wadsworth, R., Sanderson, R. and Thompson, K. (2006). "Biodiversity in urban habitat patches." *Science of the Total Environment* **360**: 196– 204.

Animals Asia. (2015). "Animals Asia." Retrieved 10/04/15, from http://www.animalsasia.org/au/.

Anon (2003). "Research puts a dollar figure on pro bono work." *Australian Veterinary Journal* **81**(5): 244-245.

Armstrong, J. S. and Overton, T. S. (1977). "Estimating Nonresponse Bias in Mail Surveys." *Journal of Marketing Research* **14**(3): 396-402.

Arnaud, G., Rodriguez, A., Ortega-Rubio, A. and Alvarez-Cardenas, S. (1993). "Predation by cats on the unique endemic lizard of Socorro Island (*Urosaurus auriculatus*), Revillagigedo, Mexico." *Ohio Journal of Science* **93**(4): 101-104.

Australian Wildlife Society. (2014). "Feeding native animals - information about feeding native Australian wildlife ", from http://www.australianwildlife.net.au/pdf/school/Feeding_native_animals.pdf.

AVMA - American Veterinary Medical Association. (2012). "U.S. Pet Ownership Statistics." from https://www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-pet-ownership.aspx.

Awasthy, M., Popovic, A. Z. and Linklater, W. L. (2012). "Experience in local urban wildlife research enhances a conservation education programme with school children." *Pacific Conservation Biology* **18**: 41–46.

Baker, D. (2001). Cat curfew - Casey City Council. *10th Urban Animal Management Conference*. Murray, D. Melbourne, Australian Veterinary Association.

Baker, P. J., Bentley, A. J., Ansell, R. J. and Harris, S. (2005). "Impact of predation by domestic cats *Felis catus* in an urban area." *Mammal Review* **35**: 302-312.

Baker, P. J., Molony, S. E., Stone, E., Cuthill, I. C. and Harris, S. (2008). "Cats about town: Is predation by free-ranging pet cats *Felis catus* likely to affect urban bird populations?" *Ibis* **150**: 86-99.

Baker, P. J., Soulsbury, C. D., Iossa, G. and Harris, S. (2010). Domestic cat (*Felis catus*) and domestic dog (*Canis familiaris*). *Urban carnivores: ecology, conflict and conservation*. Gehrt, S. D., Riley, S. P. D. and Cypher, B. L. Baltimore, The Johns Hopkins University Press**:** 157-172.

Baldock, F. C., Alexander, L. and More, S. J. (2003). "Estimated and predicted changes in the cat population of Australian households from 1979 to 2005." *Australian Veterinary Journal* **81**(5): 289-292.

Balogh, A. L., Ryder, T. B. and Marra, P. P. (2011). "Population demography of Gray Catbirds in the suburban matrix: sources, sinks and domestic cats." *Journal of Ornithology* **152**: 717-726.

Bamford, M. J. and Calver, M. C. (2012). "Cat Predation and Suburban Lizards: A 22 Year Study at a Suburban Australian Property." *The Open Conservation Biology Journal* **6**: 25-29.

Banks, P. B. (1999). "Predation by introduced foxes on native bush rats in Australia: do foxes take the doomed surplus?" *Journal of Applied Ecology* **36**: 1063-1071.

Barratt, D. G. (1997a). "Home range size, habitat utilisation and movement patterns of suburban and farm cats *Felis catus*." *Ecography* **20**: 271-280.

Barratt, D. G. (1997b). "Predation by house cats *Felis catus* (L) in Canberra, Australia. I. Prey composition and preference." *Wildlife Research* **24**: 263-277.

Barratt, D. G. (1998). "Predation by house cats *Felis catus* (L) in Canberra, Australia. II. Factors affecting the amount of prey caught and estimates of the impact on wildlife." *Wildlife Research* **25**: 475-487.

Bartoñ, K. (2015). "Package 'MuMIn.'." Retrieved 8th August 2015, from https://cran.r-project.org/web/packages/MuMIn/MuMIn.pdf.

Bates, D., Maechler, M., Bolker, B. and Walker, S. (2015). "lme4: Linear mixed-effectsmodels using Eigen and S4. R package version 1. 1–8." from http://CRAN.R-project.org/package=lme4.

Beauchamp, G. K., Maller, O. and Rogers Jr., J. G. (1977). "Flavor Preferences in Cats (*Felis catus* and *Panthera* sp.)." *Journal of Comparative and Physiological Psychology* **91**(5): 1118-1127.

Beaumont, M., Barratt, E. M., Gottelli, D., Kitchener, A. C., Daniels, M. J., Pritchards, J. K. and Bruford, M. W. (2001). "Genetic diversity and introgression in the Scottish wildcat." *Molecular Ecology* **10**: 319–336.

Beckerman, A. P., Boots, M. and Gaston, K. J. (2007). "Urban bird declines and the fear of cats." *Animal Conservation* **10**: 320-325.

Beidler, L. M., Fishman, I. Y., Hardiman, C. W. and 235–239., A. J. P. (1955). "Species differences in taste responses." *The American Journal of Physiology* **181**(2): 235-239.

Bender, D. J., Contreras, T. A. and Fahrig, L. (1998). "Habitat loss and population decline:a meta-analysis of the patch size effect." *Ecology* **79**(2): 517-533.

Berdoy, M., Webster, J. P. and Macdonald, D. W. (1995). "Parasite-altered behaviour: Is the effect of *Toxoplasma gondii* on *Rattus norvegicus* specific?" *Parasitology* **111**(4): 403-409.

Berdoy, M., Webster, J. P. and Macdonald, D. W. (2000). "Fatal attraction in rats infected with *Toxoplasma gondii*." *Proceedings of the Royal Society B: Biological Sciences* **267**(1452): 1591-1594.

Berger, S., Wikelski, M., Romero, L. M., Kalko, E. K. V. and Rödl, T. (2007). "Behavioral and physiological adjustments to new predators in an endemic island species, the Galápagos marine iguana." *Hormones and Behavior* **2007**: 653–663.

Birdsbesafe LLC. (2009). "Birdsbesafe cat collars: Keeping wild birds and cats apart " Retrieved 19.11.14, from http://www.birdsbesafe.com/.

Biró, Z. S., Szemethy, L., Heltai, M. and Randi, E. (2005). "Feeding habits of feral domestic cats (*Felis catus*), wild cats (*Felis silvestris*) and their hybrids: trophic niche overlap among cat groups in Hungary." *Journal of Zoology* **266**: 187-196.

Blancher, P. (2013). "Estimated number of birds killed by house cats (*Felis catus*) in Canada." *Avian Conservation and Ecology* **8**(2): 3.

Blumstein, D. T., Daniel, J. C., Griffin, A. S. and Evans, C. S. (2000). "Insular tamar wallabies (*Macropus eugenii*) respond to visual but not acoustic cues from predators." *Behavioral Ecology* **11**(5): 582-535.

Bond, T. G. and Fox, C. M. (2007). *Applying the Rasch model: fundamental measurement in the human sciences (second edition)*. Hillsdale, New Jersey., Lawrence Erbaum Associates.

Bonnaud, E., Medina, F. M., Vidal, E., Nogales, M., Tershy, B., Zavaleta, E., Donlan, C. J., Keitt, B., Le Corre, M. and Horwath, S. V. (2011). "The diet of feral cats on islands: a review and a call for more studies." *Biological Invasions* **13**: 581-603.

Bonnington, C., Gaston, K. J. and Evans, K. L. (2013). "Fearing the feline: domestic cats reduce avian fecundity through trait-mediated indirect effects that increase nest predation by other species." *Journal of Applied Ecology* **50**: 15–24.

Boone, W. J., Staver, J. R. and Yale, M. S. (2014). *Rasch analysis in the human sciences*. Dordrecht, Springer.

Borenstein, M., Hudges, L. V., Higgins, J. P. T. and Rothstein, H. R. (2009). *Introduction to Meta-Analysis*. West Sussex, United Kingdom, John Wiley and Sons, Ltd.

Bradshaw, J. (2013). "Are Britain's cats ready for cat cafés?" *Veterinary Record* **173**: 554-555.

Bradshaw, J. W. S. (1992). *The Behaviour of the Domestic Cat*. UK, CABI Publishing.

Bradshaw, J. W. S. (2006). "The Evolutionary Basis for the Feeding Behavior of Domestic Dogs (*Canis familiaris*) and Cats (*Felis catus*)." *The Journal of Nutrition* **136**: 206.

Bradshaw, J. W. S., Casey, R. A. and Brown, S. L. (2012). *The Behaviour of the Domestic Cat. 2nd Edition*. Oxfordshire, UK, CABI.

Bradshaw, J. W. S., Goodwin, D., Legrand-Defrétin, V. and Nott, H. M. R. (1996). "Food Selection by the Domestic Cat, an Obligate Carnivore." *Comparative Biochemistry and Physiology* **114A**(3): 205-209.

Bradshaw, J. W. S., Horsfield, G. F., Allen, J. A. and Robinson, I. H. (1999). "Feral cats: their role in the population dynamics of *Felis catus*." *Applied Animal Behaviour Science* **65**: 273–283.

Brickel, C. M. (1979). "The Therapeutic Roles of Cat Mascots with a Hospital-based Geriatric Population: A Staff Survey." *The Gerontologist* **19**(4): 368-372.

Brickner-Braun, I., Geffen, E. and Yom-Tov, Y. (2007). "The domestic cat as a predator of Israeli wildlife." *Israel Journal of Ecology and Evolution* **53**(2): 129-142.

Brinkley, C. H. (2007). "Successful closure of feline axillary wounds by reconstruction of the elbow skin fold." *Journal of Small Animal Practice* **48**: 111-115.

Burnham, K. P. and Anderson, D. R. (2002). *Model Selection and Multimodel Inference: A Practical Information-theoretic Approach, second ed.* Springer, New York.

Buttriss, R. (2001). No cat zone - City of Kingston. *10th Urban Animal Management Conference*. Murray, D. Melbourne, Australian Veterinary Association.

Calver, M., Thomas, S., Bradley, S. and McCutcheon, H. (2007). "Reducing the rate of predation on wildlife by pet cats: The efficacy and practicability of collar-mounted pounce protectors." *Biological Conservation* **137**: 341-348.

Calver, M. C., Adams, G., Clark, W. and Pollock, K. H. (2013). "Assessing the safety of collars used to attach predation deterrent devices and ID tags to pet cats." *Animal Welfare* **22**: 95-105.

Calver, M. C., Grayson, J., Lilith, M. and Dickman, C. R. (2011). "Applying the precautionary principle to the issue of impacts by pet cats on urban wildlife." *Biological Conservation* **144**: 1895–1901.

Calver, M. C. and Thomas, S. (2011). "Effectiveness of the *Liberator* ™ in reducing predation on wildlife by domestic cats." *Pacific Conservation Biology* **16**: 244-250.

CAPN. (2015). "Chinese Animal Protection Network." Retrieved 10/04/15, from http://www.capn-online.info/en.php.

Caro, T. M. (1980). "Effects of the Mother, Object Play, and Adult Experience on Predation in Cats." *Behavioral and Neural Biology* **29**: 29-51.

Carss, D. N. (1995). "Prey brought home by two domestic cats (*Felis catus*) in northern Scotland." *Journal of Zoology (London)* **237**: 678–686.

Cat Goods Inc. (2011). "CatBib." Retrieved 19.11.14, from http://www.catbib.com.au/.

Cech, V. and Lloyd, S. (undated). "Attitudes towards breeding and desexing of pets in rural communities." Unpublished manuscript available, from http://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CB4QFjAA&url=http%3A%2F%2Fwww.ndn.org.au%2Fassets%2Ffiles%2FCech%2520Veronica%2520and%2520Lloyd%2520Shan%2520Attitudes%2520Towards%2520Breeding%2520and%2520Desexing%2520of%2520Pets%2520in%2520Two%2520Rural%2520Australian%2520Communities.doc&ei=PRdQVYimGMK7mgXJooCgDg&usg=AFQjCNHZqma67i92WU6pPNIaWv1FhwVJ-A&sig2=c1qnoUKxNblLUQnrxgNZOA.

Chaseling, S. (2001). Pet populations in Australia. Dogs increasing and cats decreasing - why is it so? *10th Urban Animal Management*. Murray, D. Melbourne, Australian Veterinary Association.

Cheng, M., Cheng, C., Tian, Y. and Fan, X. (2015). "Student nurses' motivation to choose gerontological nursing as a career in China: A survey study." *Nurse Education Today*.

Chipman, P. (1990). *Influence on the home range size of domestic cats (Felis catus), in an urban environment*. MSc thesis, Manchester Polytechnic.

Chu, K., Anderson, W. M. and Rieser, M. Y. (2009). "Population characteristics and neuter status of cats living in households in the United States." *Journal of the American Veterinary Medical Association* **234**: 1023-1030.

Churcher, P. B. and Lawton, J. H. (1987). "Predation by domestic cats in an English village." *Journal of Zoology (London)* **212**: 439 - 455.

Coleman, J. S. and Stanley, A. (1993). "Rural Residents' Free-Ranging Domestic Cats: A Survey." *Wildlife Society Bulletin* **21**(4): 381-390.

Corbett, L. K. (1979). *Feeding ecology and social organization of wildcats (Felis silvestris) and domestic cats (Felis catus) in Scotland*, University of Aberdeen.

Coughlin, C. E. and van Heezik, Y. (2014). "Weighed down by science: do collar-mounted tags affect cat behaviour?" *Wildlife Research* **41**(7): 606–614.

Council of the Town of Coolee Dam. (1988). "Ordinance no. 359, Section 6.05.020." Retrieved December 28, 2014, from http://www.codepublishing.com/WA/couleedam/mobile/?pg=CouleeDam06/CouleeDam0605.html#6.05.

Courchamp, F., Langlais, M. and Sugihara, G. (1999). "Cats Protecting Birds: Modelling the Mesopredator Release Effect." *Journal of Animal Ecology* **68**(2): 282-292.

Courchamp, F., Langlais, M. and Sugihara, G. (2000). "Rabbits Killing Birds: Modelling the Hyperpredation Process." *Journal of Animal Ecology* **69**(1): 154-164.

Crew, G. (2008). *Cat on the island*. Australia, Harper Collins.

Crooks, K. R. and Soulé, M. E. (1999). "Mesopredator release and avifaunal extinctions in a fragmented ecosystem." *Nature* **400**: 563-566.

Cuthill, I. (2006). Color perception. *Bird coloration: mechanisms and measurements*. Hill, G. and McGraw, K. Cambridge, MA, Harvard University Press**:** 3-40.

Dabritz, H. A., Atwill, E. R., Gardner, I. A., Miller, M. A. and Conrad, P. A. (2006). "Outdoor fecal deposition by free-roaming cats and attitudes of cat owners and nonowners toward stray pets, wildlife and water pollution." *Journal of the American Veterinary Medical Association* **229**: 74-81.

Daniels, G. D. and Kirkpatrick, J. B. (2006). "Does variation in garden characteristics influence the conservation of birds in suburbia?" *Biological Conservation* **133**: 326-335.

Daniels, M. J., Balharry, D., Hirst, D., Kitchener, A. C. and Aspinall, R. J. (1998). "Morphological and pelage characteristics of wild living cats in Scotland: implications for defining the 'wildcat'." *Journal of Zoology* **244**: 231-247.

Das, A. (1993). *Noctumal carnivore (Felis catus and Vulpes vulpes) activity in an urban native park* Honours, University of Melbourne.

Davies, Z. G., Fuller, R. A., Loram, A., Irvine, K. N., Sims, V. and Gaston, K. J. (2009). "A national scale inventory of resource provision for biodiversity within domestic gardens." *Biological Conservation* **142**: 761-771.

de Vaus, D. A. (2002). *Surveys in Social Research*. Sydney, Allen & Unwin.

Denny, E., Yakovlevich, P., Eldridge, M. D. B. and Dickman, C. R. (2002). "Social and genetic analysis of a population of free-living cats (*Felis catus* L.) exploiting a resource-rich habitat." *Wildlife Research* **29**: 405-413.

Dersimonian, R. and Laird, N. (1986). "Meta-analysis of clinical trials." *Controlled Clinical Trials* **7**: 177-188.

Deville, A. and Harding, R. (1997). *Applying the Precautionary Principle*. Sydney, The Federation Press.

Dickman, C. R. (2009). "House cats as predators in the Australian environment: impacts and management." *Human-Wildlife Conflicts* **3**: 41-48.

Dickman, C. R. (2014). Measuring and managing the impacts of cats. *Carnivores of Australia: past, present and future*. Glen, A. S. and Dickman, C. R. Melbourne, CSIRO Publishing**:** 173-195.

Dickman, C. R. and Newsome, T. M. (2015). "Individual hunting behaviour and prey specialisation in the house cat Felis catus: implications for conservation and management." *Applied Animal Behaviour Science*.

DoE (2015). *Threat abatement plan for predation by feral cats*. Commonwealth of Australia. Canberra http://www.environment.gov.au/biodiversity/threatened/tap-approved.html

Driscoll, C. A., Clutton-Brock, J., Kitchener, A. C. and O'Brien, S. J. (2009a). "The taming of the cat." *Scienctific American* **300**: 68–75.

Driscoll, C. A., Macdonald, D. W. and O'Brien, S. J. (2009b). "From wild animals to domestic pets, an evolutionary view of domestication." *Proceedings of the National Academy of Sciences of the United States of America* **106**: 9971–9978.

DSEWPC (1992). *Intergovernmental Agreement on the Environment*. Department of Sustainability, Environment, Water, Population and Communites. http://www.environment.gov.au/about/esd/publications/igae/index.html

DSEWPC (2011). *The Feral Cat (Felis catus)*. Department of Sustainability, Environment, Water, Population and Communities. http://www.environment.gov.au/biodiversity/invasive/publications/pubs/cat.pdf

Duarte, M. H. L. and Young, R. J. (2011). "Sleeping Site Selection by Urban Marmosets (*Callithrix penicillata*) Under Conditions of Exceptionally High Predator Density." *International Journal of Primatology* **32**: 329–334.

Dubey and Lappin (2012). Toxoplasmosis and Neosporosis. *Infectious Diseases of the Dog and Cat. Fourth Edition*. Greene, C. E. USA, Elsevier**:** 806-827.

Dubey, J. P. (1973). "Feline toxoplasmosis and coccidiosis. A survey of domiciled and stray cats." *Journal of the American Veterinary Medical Association* **162**(10): 873-877.

Dufty, A. C. (1994). "Population demography of the eastern barred bandicoot (*Perameles gunnii*) at Hamilton, Victoria." *Wildlife Research* **21**: 445-457.

Dunn, J. C., Hamer, K. C. and Benton, T. G. (2012). "Fear for the family has negative consequences: indirect effects of nest predators on chick growth in a farmland bird." *Journal of Applied Ecology* **47**: 994–1002.

Ebeling, W., Natoli, R. C. and Hemmi, J. M. (2010). "Diversity of Color Vision: Not All Australian Marsupials Are Trichromatic." *PLoS ONE* **5**(12): e14231.

Edwards, D. L., Keogh, J. S. and Knowles, L. L. (2012). "Effects of vicariant barriers, habitat stability, population isolation and environmental features on species divergence in the south-western Australian coastal reptile community." *Molecular Ecology* **21**: 3809–3822.

Egenvall, A., Nødtvedt, A., Hägström, J., Ström Holst, B., Möller, L. and Bonnett, B. N. (2009). "Mortality of life-insured Swedish cats during 1999-2006: age, breed, sex and diagnosis." *Journal of Veterinary Internal Medicine* **23**: 1175-1183.

Ellis, S. (2009). "Environmental Enrichment: Practical Strategies for Improving Feline Welfare." *Journal of Feline Medicine and Surgery* **11**: 901-912.

Erickson, W. P., Johnson, G. D. and Young, J., D.P. (2005). "A summary and comparison of bird mortality from anthropogenic causes with an emphasis on collisions." *USDA Forest Service General Technical Report PSW-GTR* **191**: 1029-1042.

Errington, P. L. (1946a). "Predation and Vertebrate Populations." *The Quarterly Review of Biology* **21**(2): 144-177.

Errington, P. L. (1946b). "Predation and Vertebrate Populations (Concluded)." *The Quarterly Review of Biology* **21**(3): 221-245.

Euromonitor International. (2004). "China: Changing Attitudes to Pet Ownership Drive Pet Food Sales." from http://www.marketresearchworld.net/content/view/281/77.

Evans, A. R., Wilson, G. P., Fortelius, M. and Jernvall, J. (2007). "High-level similarity of dentitions in carnivorans and rodents." *Nature* **445**.

Eymann, J., Herbert, C. A., Cooper, D. W. and Dubey, J. P. (2006). "Serologic survey for *Toxoplasma gondii* and *Neospora caninum* in the common brushtail possum (*Trichosurus vulpecula*) from urban Sydney, Australia." *Journal of Parasitology* **92**: 267-272.

Fan, M., Kuang, Y. and Feng, Z. (2005). "Cats protecting birds revisited." *Bulletin of Mathematical Biology* **67**: 1081–1106.

Fancourt, B. A. and Jackson, R. B. (2014). "Regional seroprevalence of *Toxoplasma gondii* antibodies in feral and stray cats (*Felis catus*) from Tasmania." *Australian Journal of Zoology*.

Farnworth, M. J., Campbell, J. and Adams, N. J. (2010). "Public awareness in New Zealand of animal welfare legislation relating to cats." *New Zealand Veterinary Journal* **58**(4): 213-217.

Farnworth, M. J., Campbell, J. and Adams, N. J. (2011). "What's in a Name? Perceptions of Stray and Feral Cat Welfare and Control in Aotearoa, New Zealand." *Journal of Applied Animal Welfare Science* **14**(1): 59-74.

Faure, E. and Kitchener, A. C. (2009). "An archaeological and historical review of the relationships between felids and people." *Anthrozoös* **22**(3): 221-238.

Ferreira, J. P., Leitão, I., Santos-Reis, M. and Revilla, E. (2011). "Human-Related Factors Regulate the Spatial Ecology of Domestic Cats in Sensitive Areas for Conservation." *PLoS ONE* **6**(10): e25970.

Fitzgerald, B. M. (1990). "Is cat control needed to protect urban wildlife?" *Environmental Conservation* **17**: 168-169.

Fitzgerald, B. M. and Karl, B. J. (1979). "Foods of feral house cats (*Felis catus* L.) in forest of the Orongorongo Valley, Wellington." *New Zealand Journal of Zoology* **6**: 107-126.

Fitzgerald, B. M. and Turner, D. C. (2000). Hunting behaviour of domestic cats and their impact on prey populations. *The domestic cat: the biology of its behaviour*. Turner, D. C. and Bateson, P. Cambridge, U.K., Cambridge University Press**:** 151-175.

Flux, J. E. C. (2007). "Seventeen years of predation by one suburban cat in New Zealand." *New Zealand Journal of Zoology* **34**(4): 289-296.

Fonberg, E. (1982). "Neural mechanisms involved in the predatory behaviour of cats." *Aggressive Behavior* **8**(2): 217-219.

Foster-Bey, J. (2008). *Do race, ethnicity, citizenship and socio-economic status determine civic-engagement? CIRCLE Working Paper# 62*. Center for Information and Research on Civic Learning and Engagement (CIRCLE).

G2Z. (2015). "Getting to Zero."   Retrieved 08/05/15, from http://www.g2z.org.au.

Galbreath, R. and Brown, D. (2004). "The tale of the lighthouse-keeper's cat: Discovery and extinction of the Stephens Island wren (*Traversia lyalli*) " *Notornis* **51**(4): 193-200.

Gaston, K. J., Smith, R. M., Thompson, K. and Warren, P. H. (2005a). "Urban domestic gardens (II): experimental tests of methods for increasing biodiversity." *Biodiversity and Conservation* **14**: 395–413.

Gaston, K. J., Warren, P. H., Thompson, K. and Smith, R. M. (2005b). "Urban domestic gardens (IV): The extent of the resource and its associated features." *Biodiversity and Conservation* **14**: 3327-3349.

Geller, E. S., Bechtel, R. B. and Churchman, A. (2002). The Challenge of increasing proenvironmental behavior. *Handbook of Environmental Psychology*. Bechtel, R. B. and Churchman, A. New York, John Wiley & Sons, Inc.**:** 525-540.

George, W. G. (1974). "Domestic Cats as Predators and Factors in Winter Shortages of Raptor Prey." *The Wilson Bulletin* **86**(4): 384-396.

George, W. G. (1978). "Domestic cats as density independent hunters and "surplus killers"." *Carnivore Genetics Newsletter* **3**(8): 282-287.

Glen, A. S. and Dickman, C. R. (2005). "Complex interactions among mammalian carnivores in Australia, and their implications for wildlife management." *Biological Reviews of the Cambridge Philosophical Society* **80**(3): 387-401.

Glen, A. S. and Dickman, C. R. (2008). "Niche overlap between marsupial and eutherian carnivores: Does competition threaten the endangered spotted-tailed quoll?" *Journal of Applied Ecology* **45**(2): 700-707.

Gonyea, W. J. (1978). "Functional implications of felid forelimb anatomy." *Acta Anatomica* **102**(2): 111-121.

Gonzalez, L. E., Rojnik, B., Urrea, F., Urdaneta, H., Petrosino, P., Colasante, C., Pino, S. and Hernandez, L. (2007). "*Toxoplasma gondii* infection lower anxiety as measured in the plus-maze and social interaction tests in rats A behavioral analysis." *Behavioural Brain Research* **117**: 70–79.

Gordon, J. K., Matthaei, C. and Van Heezik, Y. (2010). "Belled collars reduce catch of domestic cats in New Zealand by half." *Wildlife Research* **37**: 372-378.

Goszczyński, J., Krauze, D. and Gryz, J. (2009). "Activity and exploration range of house cats in rural areas of central Poland." *Folia Zoologica* **58**(4): 363–371.

Government of Western Australia (2011). Cat Bill.

Goyder, J., Warriner, K. and Miller, S. (2002). "Evlauating socio-economic status (SES) bias in survey nonresponse." *Journal of Official Statistics* **18**: 1-11.

Grayson, J., Calver, M. and Lymbery, A. (2007). Species richness and community composition of passerine birds in suburban Perth: is predation by pet cats the most important factor? *Pest or guest: the zoology of over abundance*. Lunney, D. and Hutchings, P. Mosman, New South Wales, Royal Zoological Society of New South Wales**:** 195 – 207.

Grayson, J. and Calver, M. C. (2004). Regulation of domestic cat ownership to protect urban wildlife: a justification based on the precautionary principle. *Urban wildlife: more than meets the eye*. Lunney, D. and Burgin, S. Mosman, New South Wales, Royal Zoological Society of New South Wales**:** 169 – 178.

Grayson, J., Calver, M. C. and Styles, I. (2002). "Attitudes of suburban Western Australians to proposed cat control legislation." *Australian Veterinary Journal* **80**: 536-543.

Griffin, A. S., Evans, C. S. and Blumstein, D. T. (2002). "Selective Learning in a Marsupial." *Ethology* **108**: 1103—1114.

Guber, D. L. (2003). *The Grassroots of a Green Revolution: Polling America on the Environment*. Cambridge, Mass, MIT Press.

Guerrero, O. M., Chinchilla, M. and Abrahams, E. (1997). "Increasing of *Toxoplasma gondii* (Coccidia, Sarcocystidae) infections by *Trypanosoma lewisi* (Kinetoplastida, Trypanosomatidae) in white rats " *Revista de Biologia Tropical* **45**(2): 877-882.

Gunaseelan, S., Coleman, G. and Toukhsati, S. (2013). "Attitudes towards responsible pet ownership behaviors in Singaporean cat owners." *Anthrozoös* **26**(2): 198-211.

Guttilla, D. A. and Stapp, P. (2010). "Effects of sterilization on movements of feral cats at a wildland-urban interface." *Journal of Mammalogy* **91**: 482-489.

Hall, C. M., Adams, N. A., Bradley, J. S., Bryant, K. A., Davis, A. A., Dickman, C. R., Fujita, T., Kobayashi, S., Lepczyk, C. A., McBride, E. A., Pollock, K. H., Styles, I. M., Heezik, Y. v., Wang, F. and Calver, M. C. (2016a). "Community attitudes and practices of urban residents regarding predation by pet cats on wildlife: An International comparison." *PLoS ONE* **11**(4): e0151962.

Hall, C. M., Bryant, K. A., Fontaine, J. B. and Calver, M. C. (2016b). "Do collar-mounted predation deterrents restrict wandering in pet domestic cats?" *Applied Animal Behaviour Science* **176**: 96–104.

Hall, C. M., Fontaine, J. B., Bryant, K. A. and Calver, M. C. (2015). "Assessing the effectiveness of the Birdsbesafe® anti-predation collar cover in reducing predation by pet cats on wildlife in Western Australia." *Applied Animal Behaviour Science* **173**: 40–51.

Hansen, C. M. (2010). *Movements and Predation Activity of Feral and Domestic Cats (Felis catus) on Banks Peninsula*. Master of Science, Lincoln University, New Zealand.

Harris, R. B. (1996). "Approaches to conserving vulnerable wildlife in China: Does the colour of cat matter - If it catches mice?" *Environmental Values* **5**: 303-334.

Hart, B. L. and Leedy, M. G. (1987). "Stimulus and hormonal determinants of flehmen behavior in cats." *Hormones and Behavior* **21**(1): 44-52.

Hart, N. S. (2001). "Variations in cone photoreceptor abundance and the visual ecology of birds." *Journal of Comparative and Physiological A* **187**: 685-698.

Harzing, A.-W., Brown, M., Köster, K. and Zhao, S. (2012). "Response style differences in cross-national research: dispositional and situational determinants." *Management International Review* **52**: 341-363.

Headey, B. (1999). "Health Benefits and Health Cost Savings Due to Pets: Preliminary Estimates from an Australian National Survey." *Social Indicators Research* **47**(2): 233-243.

Heffner, R. S. and Heffner, H. E. (1985). "Hearing range of the domestic cat." *Hearing Research* **19**(1): 85-88.

Hervías, S., Oppel, S., Medina, F. M., Pipa, T., Díez, A., Ramos, J. A., Ybáñez, R. R. d. and Nogales, M. (2014). "Assessing the impact of introduced cats on island biodiversity by combining dietary and movement analysis." *Journal of Zoology* **292**: 39-47.

Hill, D. and Dubey, J. P. (2001). "*Toxoplasma gondii*: transmission, diagnosis and prevention." *Clinical Microbiology and Infection* **8**: 634-640.

Horn, J. A., Mateus-Pinilla, N., Warner, R. E. and Heske, E. J. (2011). "Home range, habitat use, and activity patterns of free-roaming domestic cats." *The Journal of Wildlife Management* **75**(5): 1177–1185.

Hu, Y. (2014). "Early evidence of commensal relationships between people and cats." *PNAS* **111**(1): 116-120.

Hubbard, A. L., McOris, S., Jones, T. W., Boid, R., Scott, R. and Easterbee, N. (1992). "Is survival of European wildcats *Felis silvestris* in Britain threatened by interbreeding with domestic cats?" *Biological Conservation* **63**(3): 203-208.

Hubrecht, R. C. and Turner, D. C. (1998). Companion animal welfare in private and institutional settings. *Companion Animals in Human Health*. Wilson, C. C. and Turner, D. C. Thousand Oaks, CA, Sage Publications Inc.**:** 267–289.

Humane Society of the United States. (2011). "HSUS Pet Overpopulation Estimates." from http://www.humanesociety.org/issues/petoverpopulation/facts/overpopulationestimates.html.

Hunter, L. (2012). "Challenging the reported disadvantages of e-questionnaires and addressing methodological issues of online data collection." *Nurse Researcher* **20**: 11-20.

Izawa, M., Doi, T., Nakanishi, N. and Teranishi, A. (2009). "Ecology and conservation of two endangered subspecies of the leopard cat (*Prionailurus bengalensis*) on Japanese islands." *Biological Conservation* **142**: 1884-1890.

Jehl, J. R., Jr., and Parkes, K. C. (1983). ""Replacements" of Landbird Species on Socorro Island, Mexico." *The Auk* **100**(3): 551-559.

Jessup, D. A. (2004). "The welfare of feral cats and wildlife." *Journal of the American Veterinary Medical Association* **225**(9).

Johnson, J. and Calver, M. C. (2014). "Prevalence of desexed cats in relation to age in a convenience sample of Western Australian cats." *Australian Veterinary Journal* **92**(6).

Jongman, E. C. (2007). "Adaptation of domestic cats to confinement." *Journal of Veterinary Behavior: Clinical Applications and Research* **2**: 193-196.

Kaplan, S. (2000). "Human nature and environmentally responsible behavior." *Journal of Social Issues* **56**(3): 491-508.

Kays, R. W. and DeWan, A. A. (2004). "Ecological impact of inside/outside house cats around a suburban nature preserve." *Animal Conservation* **7**: 273-283.

Kenward, M. G. and Roger, J. H. (1997). "Small sample inference for fixed effects from restricted maximum likelihood." *Biometrics* **53**: 983-997.

Kenward, R. E., Casey, N. M. and Walls, S. S. (2009). *Ranges 8. For the analysis of tracking and location data.* Wareham, UK, Anatrack Ltd.,

Keverne, E. B., Murphy, C. L., Silver, W. L., Wysocki, C. J. and Meredith, M. (1986). "Non-olfactory chemoreceptors of the nose: recent advances in understanding the vomeronasal and trigeminal systems." *Chemical Senses* **11**(1): 119-133.

Kienzle, E. (1994). "Effect of Carbohydrates on Digestion in the Cat." *Journal of Nutrition* **124**: 2568S-2571S.

Kinnear, J. E., Sumner, N. R. and Onus, M. L. (2002). "The red fox in Australia - An exotic predator turned biocontrol agent." *Biological Conservation* **108**: 335-359.

Kitts-Morgan, S. E., Caires, K. C., Bohannon, L. A., Parsons, E. I. and Hilburn, K. A. (2015). "Free-Ranging Farm Cats: Home Range Size and Predation on a Livestock Unit in Northwest Georgia." *PLoS ONE* **10**(4): e0120513.

Kokko, H. and Ruxton, G. D. (2000). "Breeding Suppression and Predator-Prey Dynamics." *Ecology* **81**(1): 253-260.

Konarzewski, M. and Starck, J. M. (2000). "Effects of Food Shortage and Oversupply on Energy Utilization, Histology, and Function of the Gut in Nestling Song Thrushes (*Turdus philomelos*)." *Physiological and Biochemical Zoology* **73**(4): 416-427.

Lamari, L. (2015). *Assess 2.0. Image analysis software for plant disease quantificantion.* APS Press http://www.apsnet.org/apsstore/shopapspress/Pages/43696m5.aspx. Accessed August 26th, 2015,

Lampila, P., Mönkkönen, M. and Desrochers, A. (2005). "Demographic Responses by Birds to Forest Fragmentation." *Conservation Biology* **19**(5): 1537–1546.

Le Corre, M. (2008). "Cats, rats and seabirds." *Nature* **451**: 134-135.

Lecis, R., Pierpaoli, M., Birò, Z. S., Szemethy, L., Ragni, B., Vercillo, F. and Randi, E. (2006). "Bayesian analyses of admixture in wild and domestic cats (*Felis silvestris*) using linked microsatellite loci." *Molecular Ecology* **15**: 119–131.

Lepczyk, C. A., Dauphine, N., Bird, D. M., Conant, S., Cooper, R. J., Duffy, D. C., Hatley, P. J., Marra, P. P., Stone, E. and Temple, S. A. (2010). "What conservation biologists can do to counter trap-neuter-return: response to Longcore *et al*." *Conservation Biology* **24**: 627-629.

Lepczyk, C. A., Lohr, C. A. and Duffy, D. C. (2015). "A review of cat behavior in relation to disease risk and management options." *Applied Animal Behaviour Science* **173**: 29-39.

Lepczyk, C. A., Mertig, A. G. and Liu, J. (2004). "Landowners and cat predation across rural-to-urban landscapes." *Biological Conservation* **115**: 191-201.

Levin, G. (1993). "Too Green for Their Own Good." *Advertising Age*: 29.

Lévy, F., Keller, M. and Poindron, P. (2004). "Olfactory regulation of maternal behavior in mammals." *Hormones and Behavior* **46**: 284– 302.

Leyhausen and Wolff (1959). "Zeitschrift fur Tierpsychologie." *Journal of Comparative Ethology* **16**: 666-670.

Leyhausen, P. (1979). *Cat Behaviour: The Predatory and Social Behaviour of Domestic and Wild Cats*. New York & London, Garland STPM Press.

Li, X., Li, W., Wang, H., Bayley, D. L., Cao, J., Reed, D. R., Bachmanov, A. A., Huang, L., Legrand-Defretin, V., Beauchamp, G. K. and Brand, J. G. (2006). "Cats lack a sweet taste receptor." *Journal of Nutrition* **136**(7): 1932S-1934S.

Liberg, O. (1980). "Spacing patterns in a population of rural free roaming domestic cats." *Oikos* **35**(3): 336-349.

Liberg, O. (1984). "Home range and territoriality in free ranging house cats." *Acta Zoologica Fennica* **171**: 283-285.

Liberg, O., Sandell, M., Pontier, D. and Natoli, E. (2000). Density, spatial organization and reproductive tactics in the domestic cat and other felids. *The domestic cat: the biology of its behaviour*. D.C., T. and Batson, P. Cambridge, United Kingdom, Cambridge University Press**:** 120-147.

Lilith, M. (2007). *Do pet cats (Felis catus) have an impact on species richness and abundance of native mammals in low-density Western Australian suburbia?* PhD thesis, Murdoch University.

Lilith, M., Calver, M. and Garkaklis, M. (2008). Roaming habits of pet cats on the suburban fringe in Perth, Western Australia: What size buffer zone is needed to protect wildlife in reserves? *Too close for comfort: contentious issues in human-wildlife encounters*. Lunney, D., Munn, A. and Meikle, W. Sydney, Australia, Royal Zoological Society of New South Wales**:** 65-72.

Lilith, M., Calver, M. and Garkaklis, M. (2010). "Do cat restrictions lead to increased species diversity or abundance of small and medium-sized mammals in remnant urban bushland?" *Pacific Conservation Biology* **16**: 162-172.

Lilith, M., Calver, M., Styles, I. and Garkaklis, M. (2006). "Protecting wildlife from predation by owned domestic cats: Application of a precautionary approach to the acceptability of proposed cat regulations." *Austral Ecology* **31**: 176-189.

Lima, S. L. (1987). "Clutch Size in Birds: A Predation Perspective." *Ecology* **68**(4): 1062-1070.

Lima, S. L. (1998). "Stress and behaviour stress and decision making under the risk of predation: Recent develeopments from behavioral, reproductive, and ecological perspectives." *Advances in the Study of Behavior* **27**: 215-290.

Linseele, V., Neer, W. V. and Hendrickx, S. (2007). "Evidence for early cat taming in Egypt." *Journal of Archaeological Science* **34**: 2081-2090.

Lohr, C. A. and Lepczyk, C. A. (2013). "Desires and Management Preferences of Stakeholders Regarding Feral Cats in the Hawaiian Islands." *Conservation Biology* **28**(2): 392–403.

Lohr, C. A., Lepczyk, C. A. and Cox, L. J. (2014). "Identifying people’s most preferred management technique for feral cats in Hawaii." *Human–Wildlife Interactions* **8**(1): 56–66.

Longcore, T., Rich, C. and Sullivan, L. M. (2009). "Critical assessment of claims regarding management of feral cats by trap-neuter-return." *Conservation Biology* **23**: 887-894.

Lord, L. K., Griffin, B., Slater, M. R. and Levy, J. K. (2010). "Evaluation of collars and microchips for visual and permanent identification of pet cats." *Journal of the American Veterinary Medical Association* **237**(4): 387-394.

Lord, L. K., Wittum, T. E., Ferketich, A. K., Funk, J. A. and Rajala-Schultz, P. J. (2007). "Search and identification methods that owners use to find a lost cat." *Journal of the American Veterinary Medical Association* **230**(2): 217-220.

Loss, S. R., Will, T. and Marra, P. P. (2012). "Direct human-caused mortality of birds: improving quantification of magnitude and assessment of population impact." *Frontiers in Ecology and the Environment* **10**(7): 357-364.

Loss, S. R., Will, T. and Marra, P. P. (2013a). "Estimates of bird collision mortality at wind facilities in the contiguous United States." *Biological Conservation* **168**: 201-209.

Loss, S. R., Will, T. and Marra, P. P. (2013b). "The impact of free-ranging domestic cats on wildlife of the United States." *Nature Communications* **4**(1396): 1-7.

Loss, S. R., Will, T. and Marra, P. P. (2014a). "Estimation of bird-vehicle collision mortality on U.S. roads." *Journal of Wildlife Management* **78**: 763-771.

Loss, S. R., Will, T. and Marra, P. P. (2014b). "Refining estimates of bird collision and electrocution mortality at power lines in the United States." *PLoS ONE* **9**: e101565.

Loyd, K. A. T., Hernandez, S. M., Abernathy, K. J., Shock, B. C. and Marshall, G. J. (2013a). "Risk behaviours exhibited by free-roaming cats in a suburban US town." *Veterinary Record*: 1-6.

Loyd, K. A. T., Hernandez, S. M., Carroll, J. P., Abernathy, K. J. and Marshall, G. J. (2013b). "Quantifying free-roaming domestic cat predation using animal-borne video cameras." *Biological Conservation* **160**: 183–189.

Macdonald, D. (1981). The behaviour and ecology of farm cats. *The Ecology and Control of Feral Cats*. Universities Federation for Animal Welfare, Universities Federation for Animal Welfare,.

Macdonald, D. W. and Apps, P. J. (1978). "The social behaviour of a group of semi-dependent farm cats, *Felis catus*: A progress report." *Carnivore Genetics Newsletter* **3**(7): 256-269.

MacDonald, D. W., Yamaguchi, N. and Kerby, G. (2000). Group-living in the domestic cat: its sociobiology and epidemiology. *The domestic cat: the biology of its behaviour*. Turner, D. C. and Bateson, P. Cambridge, United Kingdom, Cambridge University Press.

MacDonald, E., Milfont, T. and Gavin, M. (2015a). "What drives cat-owner behaviour? First steps towards limiting domestic-cat impacts on native wildlife." *Wildlife Research* **42**: 257–265.

Macdonald, E. A., Burnham, D., Hinks, A., Dickman, A., Malhi, Y. and Macdonald, D. W. (2015b). "Conservation inequality and the charismatic cat: *Felis felicis*." *Global Ecology and Conservation* **3**: 851-866.

MacDonald, E. F. and She, J. (2015). "Seven cognitive concepts for successful eco-design." *Journal of Cleaner Production* **92**: 23-36.

MacDonald, M. L., Rogers, Q. R. and Morris, J. G. (1984). "Nutrition of the domestic cat, a mammalian carnivore." *Annual Review of Nutrition* **4**: 521-562.

MacGregor-Fors, I. and Schondube, J. E. (2011). "Gray vs. green urbanization: Relative importance of urban features for urban bird communities." *Basic and Applied Ecology* **12**: 372–381.

Machado, J. C. and Genaro, G. (2014). "Influence of olfactory enrichment on the exploratory behaviour of captive-housed domestic cats." *Australian Veterinary Journal* **192**: 492-498.

Martin, T. E., Martin, P. R., Olson, C. R., Heidinger, B. J. and Fontaine, J. J. (2000). "Parental Care and Clutch Sizes in North and South American Birds." *Science* **287**(5457): 1482-1485.

Matsui, S. and Takagi, M. (2012). "Predation risk of eggs and nestlings relative to nest-site characteristics of the bull-headed shrike *lanius bucephalus*." *Ibis* **154**: 621-625.

McBeath, J. and McBeath, J. H. (2006). "Biodiversity conservation in China: Policies and practice." *Journal of International Wildlife Law and Policy* **9**: 293-317.

McChesney, G. J. and Tershy, B. R. (1998). "History and Status of Introduced Mammals and Impacts to Breeding Seabirds on the California Channel and Northwestern Baja California Islands." *Colonial Waterbirds* **21**(3): 335-347.

McDonald, J. L., Maclean, M., M.R., E. and Hodgson, D. J. (2015). "Reconciling actual and perceived rates of predation by domestic cats." *Ecology and Evolution*.

McEvoy, J., Sinn, D. L. and Wapstra, E. (2008). "Know thy enemy: Behavioural response of a native mammal (*Rattus lutreolus velutinus*) to predators of different coexistence histories." *Austral Ecology* **33**: 922–931.

McGeachin, R. L. and Akin, J. R. (1979). "Amylase levels in the tissues and body fluids of the domestic cat (*Felis catus*)." *Comparative Biochemistry and Physiology* **63B**: 437-439.

McHarg, M., Baldock, C., Headey, B. and Robinson, A. (1995). *National people and pets survey*. Urban Animal Management Coalition.

Meachen-Samuels, J. and Van Valkenburgh, B. (2009a). "Craniodental indicators of prey size preference in the Felidae." *Biological Journal of the Linnean Society* **96**: 784–799.

Meachen-Samuels, J. and Van Valkenburgh, B. (2009b). "Forelimb Indicators of Prey-Size Preference in the Felidae." *Journal of Morphology* **270**: 729–744.

Medina, F. M., Bonnaud, E., Vidal, E., Tershy, B., Zavaleta, E., Donlan, C. J., Keitt, B., Le Corre, M., Horwath, S. V. and Nogales, M. (2011). "A global review of the impacts of invasive cats on island endangered vertebrates." *Global Change Biology* **17**: 3503–3510.

Medina, F. M. and Nogales, M. (2009). "A review on the impacts of feral cats (*Felis silvestris catus*) in the Canary Islands: Implications for the conservation of its endangered fauna." *Biodiversity and Conservation* **18**: 829-846.

Meek, P. D. (2003). "Home range of house cats *Felis catus* living within a National Park." *Australian Mammalogy* **25**: 51-60.

Mella, V. S. A., Cooper, C. E. and Davies, S. J. J. F. (2010). "Ventilatory frequency as a measure of the response of tammar wallabies (*Macropus eugenii*) to the odour of potential predators." *Australian Journal of Zoology* **58**: 16–23.

Melson, G. F. (2003). "Child development and the human-companion animal bond." *American Behavioral Scientist* **47**(1): 31-39.

Mermet, N., Coureaud, G., McGrane, S. and Schaal, B. (2008). "Odour-guided social behaviour in newborn and young cats: an analytical survey." *Chemoecology* **17**: 187–199.

Mesago Messe Frankfurt Corp. (2014). Japanese Pet Market Information. *Interpets 2014: International Fair for a Better Life with Pets, A Happy & Healthy Life with Pets*, Japan Pet Food Association, Messe Frankfurt.

Metsers, E. M., Seddon, P. J. and Van Heezik, Y. M. (2010). "Cat-exclusion zones in rural and urban-fringe landscapes: How large would they have to be?" *Wildlife Research* **37**(1): 47-56.

Miller, P. S., Boone, J. D., Briggs, J. R., Lawler, D. F., Levy, J. K., Nutter, F. B., Slater, M. and Zawistowski, S. (2014). "Simulating free-roaming cat population management options in open demographic environments." *PLoS ONE* **9**.

Møller, A. P. (2011). "Song Post Height in Relation to Predator Diversity and Urbanization." *Ethology* **117**: 529–538.

Møller, A. P. and Erritzøe, J. (2000). "Predation against birds with low immunocompetence." *Oecologia* **122**: 500–504.

Møller, A. P. and Ibáñez-Álamo, J. D. (2012). "Escape behaviour of birds provides evidence of predation being involved in urbanization." *Animal Behaviour* **83**(2): 341-348.

Moore, S. (2001). Cat confinement - does it work? *10th Urban Animal Management Conference*. Murray, D. Melbourne, Australian Veterinary Association.

Morgan, S. A. (2002). *Movements and hunting activity of house cats (Felis catus) living around Travis Wetland, Christchurch, New Zealand* M.Sc. Thesis, Lincoln University.

Morgan, S. A., Hansen, C. M., Ross, J. G., Hickling, G. J., Ogilvie, S. C. and Paterson, A. M. (2009). "Urban cat (*Felis catus*) movement and predation activity associated with a wetland reserve in New Zealand." *Wildlife Research* **36**: 574-580.

Murray, J. K., Browne, W. J., Roberts, M. A., Whitmarsh, A. and Gruffydd-Jones, T. J. (2010). "Number and ownership profiles of cats and dogs in the UK." *Veterinary Record* **166**: 163-168.

Nattrass, R. (1992). Wildlife conservation in the urban environment: are pets a threat? *Proceedings of the First National Conference on Urban Animal Management in Australia*. Murray, R. W. Mackay, Brisbane, Chiron Media.

Nelson, S. H., Evans, A. D. and Bradbury, R. B. (2005). "The efficacy of collar-mounted devices in reducing the rate of predation of wildlife by domestic cats." *Applied Animal Behaviour Science* **94**: 273-285.

New, J. C., Kelch, W. J., Hutchison, J. M., Salman, M. D., King, M., Scarlett, J. M. and Kass, P. H. (2004). "Birth and death rate estimates of cats and dogs in U.S. households and related factors." *Journal of Applied Animal Welfare Science* **7**(4): 229-241.

Norbury, G. (2001). "Conserving dryland lizards by reducing predator-mediated apparent competition and direct competition with introduced rabbits." *Journal of Applied Ecology* **38**: 1350–1361.

Norbury, G. and Heyward, R. (2008). "Predictors of clutch predation of a globally significant avifauna in New Zealand’s braided river ecosystems." *Animal Conservation* **11**: 17–25.

Norris, J. M., Bell, E. T., Hales, L., Toribio, J.-A. L. M. L., White, J. D., Wigney, D. I., Baral, R. M. and Malik, R. (2007). "Prevalence of feline immunodeficiency virus infection in domesticated and feral cats in eastern Australia." *Journal of Feline Medicine and Surgery* **9**(4): 300-308.

NSW Government, Environment & Heritage (2014). *Keep wildlife wild: please don't feed the animals*. NSW Government, Environment & Heritage. http://www.environment.nsw.gov.au/animals/KeepingWildlifeWild.htm

O’Haire, M. (2010). "Companion animals and human health: Benefits, challenges, and the road ahead." *Journal of Veterinary Behavior* **5**: 226-234.

O’Haire, M. (2013). "Animal-assisted intervention for autism spectrum disorder: A systematic literature review." *Journal of Autism and Developmental Disorders* **43**(7): 1606-1622.

Obendorf, D. L., Statham, P. and Driessen, M. (1996). "Detection of agglutinating antibodies to *Toxoplasma gondii* in sera from free-ranging eastern barred bandicoots (*Perameles gunnii*)." *Journal of Wildlife Diseases* **32**(4): 623-626.

Ödeen, A. and Håstad, O. (2010). "Pollinating birds differ in spectral sensitivity." *Journal of Comparative and Physiological A* **196**: 91–96.

Oliveira, R., Godinho, R., Randi, E. and Alves, P. C. (2008a). "Hybridization versus conservation: are domestic cats threatening the genetic integrity of wildcats (*Felis silvestris silvestris*) in Iberian Peninsula?" *Philosophical Transactions of the Royal Society B* **363**: 2953-2961.

Oliveira, R., Godinho, R., Randi, E., Ferrand, N. and Alves, P. C. (2008b). "Molecular analysis of hybridisation between wild and domestic cats (*Felis silvestris*) in Portugal: implications for conservation." *Conservation Genetics* **9**: 1–11.

Olsson, M., Stuart-Fox, D. and Ballen, C. (2013). "Genetics and evolution of colour patterns in reptiles." *Seminars in Cell & Developmental Biology* **24**: 529– 541.

Osborne, W. and Williams, K. (1991). Conservation problems with cats in the Australian Capital Territory. *Proceedings of a workshop on the impact of cats on native wildlife*. Potter, C. Canberra, Australian National Parks and Wildlife Service**:** 14-17.

Panaman, R. (1981). "Behaviour and ecology of freeranging female farm cats (*Felis catus*)." *Zeitschrift fur Tierpsychologie* **56**: 59-73.

Parameswaran, N., O'Handley, R. M., Grigg, M. E., Fenwick, S. G. and Thompson, R. C. A. (2009a). "Seroprevalence of *Toxoplasma gondii* in wild kangaroos using an ELISA." *Parasitology International* **58**: 161–165.

Parameswaran, N., O'Handley, R. M., Grigg, M. E. and Thompson, R. C. A. (2009b). "Vertical transmission of *Toxoplasma gondii* in Australian marsupials." *Parasitology* **136**: 939-944.

Parameswaran, N., Thompson, R. C. A., Sundar, N., Pan, S., Johnson, M., Smith, N. C. and Grigg, M. E. (2010). "Non-archetypal Type II-like and atypical strains of *Toxoplasma gondii* infecting marsupials of Australia." *International Journal for Parasitology* **40**: 635–640.

Parslow, R. A., Jorm, A. F., Christensen, H., Rodgers, B. and Jacomb, P. (2005). "Pet ownership and health in older adults: Findings from a survey of 2,551 community-based Australians aged 60-64." *Gerontology* **51**: 40-47.

Paton, D. C. (1990). "Domestic cats and wildlife." *Bird Observer* **696**: 34-35.

Paton, D. C. (1991). Loss of wildlife to domestic cats. *Proceedings of a workshop on the impact of cats on native wildlife*. Potter, C. Canberra, Australian National Parks and Wildlife Service**:** 64-69.

Patronek, G. J., Beck, A. M. and Glickman, L. T. (1997). "Dynamics of dog and cat populations in a community." *JAVMA* **210**: 637–642.

Peck, D. R., Faulquier, L., Pinet, P., Jaquemet, S. and Le Corre, M. (2008). "Feral cat diet and impact on sooty terns at Juan de Nova Island, Mozambique Channel." *Animal Conservation* **11**: 65–74.

Pergl, G. (1994). The Sherbrooke experience. *Proceedings of the Third National Conference on Urban Animal Management in Australia*. Paxton, D. W., Australian Veterinary Association.

Perry, G. (1999). Cats - perceptions and misconceptions: two recent studies about cats and how people see them. *Proceedings of the 8th National Conference on Urban Animal Management in Australia*. Murray, D., Australian Veterinary Association.

Peterson, M. N., Hartis, B., Rodriguez, S., Green, M. and Lepczyk, C. A. (2012). "Opinions from the front lines of cat colony management conflict." *PLoS ONE* **7**(9): e44616.

Pfaffmann, C. (1955). "Gustatory nerve impulses in rat, cat and rabbit." *Journal of Neurophysiology* **18**(5): 429-440.

Pierpaoli, M., Birò, Z. S., Herrmann, M., Hupe, K., Fernandes, M., Ragni, B., Szemethy, L. and Randi, E. (2003). "Genetic distinction of wildcat (*Felis silvestris*) populations in Europe, and hybridization with domestic cats in Hungary." *Molecular Ecology* **12**: 2585–2598.

Pinheira, J., Bates, D. and Hardle, W. (2010). *Mixed-effects models in S and S-PLUS, e-book*. New York, Springer.

Plourde, L. (2014). "Cat Cafés, Affective labor, and the healing boom in Japan." *Japanese Studies* **34**: 115-133.

Pontes, A. R. M. and Soares, M. L. (2005). "Sleeping sites of common marmosets (*Callithrix jacchus*) in defaunated urban forest fragments: a strategy to maximize food intake." *Journal of Zoology (London)* **266**: 55–63.

Preisser, E. L., Bolnick, D. I. and Bernard, M. F. (2005). "Scared to death? The effects of intimidation and consumption in predator-prey interactions." *Ecology* **86**(2): 501–509.

Pulliam, H. R. (1988). "Sources, Sinks, and Population Regulation." *The American Naturalist* **132**(5): 652-661.

R Core Team (2014). *R: A language and environment for statistical computing. R Foundation for Statistical Computing.* Vienna, Austria, http://www.R-project.org

Randi, E. (2008). "Detecting hybridization between wild species and their domesticated relatives." *Molecular Ecology* **17**: 285–293.

Randi, E., Pierpaoli, M., Beaumont, M., Ragni, B. and Sforzi, A. (2001). "Genetic identification of wild and domestic cats (*Felis silvestris*) and their hybrids using bayesian clustering methods." *Molecular Biology and Evolution* **18**(9): 1679–1693.

Randi, E. and Ragni, B. (1991). "Genetic Variability and Biochemical Systematics of Domestic and Wild Cat Populations (*Felis silvestris*: Felidae)." *Journal of Mammalogy* **72**(1): 79-88.

Rayner, M. J., Hauber, M. E., Imber, M. J., Stamp, R. K. and Clout, M. N. (2007). "Spatial heterogeneity of mesopredator release within an oceanic island system." *PNAS* **104**(52): 20862–20865.

REARK (1994a). *The Cat in The Suburbs Survey in Sydney and Melbourne*. Petcare Information and Advisory Services, South Yarra, Victoria.

REARK (1994b). *The Metropolitan Domestic Cat. A Survey of the Population Characteristics and Hunting Behaviour of the Domestic Cat in Australia*. Petcare Information and Advisory Services, South Yarra, Victoria.

Rhymer, J. M. and Simberloff, D. (1996). "Extinction by hybridization and introgression." *Annual Review of Ecology and Systematics* **27**: 83–109.

Risbey, D. A., Calver, M. C., Short, J., Bradley, J. S. and Wright, I. W. (2000). "The impact of cats and foxes on the small vertebrate fauna of Heirisson Prong, Western Australia: II. A field experiment." *Wildlife Research* **27**: 223-235.

Rochlitz, I. (2004a). "Clinical study of cats injured and killed in road traffic accidents in Cambridgeshire." *Journal of Small Animal Practice* **45**: 390-394.

Rochlitz, I. (2004b). "The effects of road traffic accidents on domestic cats and their owners." *Animal Welfare* **13**: 51-55.

Rochlitz, I. (2005). "A review of the housing requirements of domestic cats (*Felis silvestris catus*) kept in the home." *Applied Animal Behaviour Science* **93**: 97-109.

Rochlitz, I., de Wit, T. and Broom, D. M. (2001). A pilot study on the longevity and causes of death of cats in Britain. *BSAVA Congress Clinical Research Abstracts*, British Small Animal Veterinary Association, Gloucester, p.528.

Rödl, T., Berger, S., Romero, L. M. and Wikelski, M. (2007). "Tameness and stress physiology in a predator-naive island species confronted with novel predation threat." *Proceedings of the Royal Society of Biological Sciences* **274**: 577-582.

Rothwell, T. (2004). "Evidence for Taming of Cats." *Science* **305**(5691): 1714.

RSPB. (2005a). "The RSPB: Advice: Collar that cat to save wildlife!" Retrieved 14/05/15, from http://www.rspb.org.uk/makeahomeforwildlife/advice/gardening/unwantedvisitors/cats/collarthatcat.aspx.

RSPB. (2005b). "The RSPB: Advice: RSPB endorses ultrasonic cat deterrent." Retrieved 14/05/15, from http://www.rspb.org.uk/makeahomeforwildlife/advice/gardening/unwantedvisitors/cats/catdeterrent.aspx.

RSPB. (2014). "Are cats causing bird declines?", from http://www.rspb.org.uk/makeahomeforwildlife/advice/gardening/unwantedvisitors/cats/birddeclines.aspx.

RSPB. (2015a). "The RSPB: Advice: Are cats causing bird declines?" Retrieved 14/05/15, from http://www.rspb.org.uk/makeahomeforwildlife/advice/gardening/unwantedvisitors/cats/birddeclines.aspx.

RSPB. (2015b). "The RSPB: Advice: Cats and the Law." Retrieved 14/05/15, from http://www.rspb.org.uk/makeahomeforwildlife/advice/gardening/unwantedvisitors/cats/catsandthelaw.aspx.

Russell, J. C., Lecomte, V., Dumont, Y. and Corre, M. L. (2009). "Intraguild predation and mesopredator release effect on long-lived prey." *Ecological Modelling* **220**: 1098–1104.

Ruxton, G. D. and Lima, S. L. (1997). "Predator-Induced Breeding Suppression and Its Consequences for Predator-Prey Population." *Proceedings: Biological Sciences* **264**(1380): 409-415.

Ruxton, G. D., Thomas, S. and Wright, J. W. (2002). "Bells reduce predation of wildlife by domestic cats (*Felis catus*)." *Journal of Zoology (London)* **256**: 81-83.

Sakurai, R. and Jacobson, S. K. (2010). "Assessing the effectiveness of the tailored design method for increasing response rates of mail surveys in Japan." *Sociological Theory and Methods* **25**: 267-274.

Salazar, I. and Sánchez-Quinteiro, P. (2011). "A Detailed Morphological Study of the Vomeronasal Organ and the Accessory Olfactory Bulb of Cats." *Microscopy Research and Technique* **74**: 1109–1120.

Salo, P., Banks, P. B., Dickman, C. R. and Korpimäki, E. (2010). "Predator manipulation experiments: impacts on populations of terrestrial vertebrate prey." *Ecological Monographs* **80**(4): 531-546.

Salo, P., Korpimäki, E., Banks, P. B., Nordström, M. and Dickman, C. R. (2007). "Alien predators are more dangerous than native predators to prey populations." *Proceedings of the Royal Society Biological Sciences* **274**: 1237-1243.

Saunders, G. R., Gentle, M. N. and Dickman, C. R. (2010). "The impacts and management of foxes *Vulpes vulpes* in Australia." *Mammal Review* **40**(3): 181-211.

Schaalje, G. B., McBride, J. B. and Fellingham, G. W. (2002). "Adequacy of approximations to distributions of test statistics in complex mixed linear models." *Journal of Agricultural, Biological, and Environmental Statistics* **7**: 512-524.

Schär, R. and Tschanz, B. (1982). *Social behaviour and space utilization of farm cats using biotelemetry.* Proceedings of 7th International Symposium of Biotelemetry, Stanford.

Schmidt, P. M., Lopez, R. R. and Collier, B. A. (2007). "Survival, fecundity, and movements of free-roaming cats." *Journal of Wildlife Management* **71**(3): 915–919.

Schwagmeyer, P. L. and Mock, D. W. (2008). "Parental provisioning and offspring fitness: size matters." *Animal Behaviour* **75**: 291-298.

Scott, W. J. and Acock, A. C. (1979). "Socioeconomic status, unemployment experience, and political participation: A disentangling of main and interaction effects." *Political Behavior* **1**: 361-381.

Seewagen, C. L. and Slayton, E. J. (2008). "Mass Changes of Migratory Landbirds during Stopovers in a New York City Park." *The Wilson Journal of Ornithology* **120**(2): 296-303.

Selby, L. A. and Rhoades, H. D. (1981). "Attitudes of the public towards dogs and cats as companion animals." *Journal of Small Animal Practice* **22**: 129-137.

Serpell, J. A. (2000). Domestication and history of the cat. *The Domestic Cat: The Biology of its Behaviour*. Turner, D. and Bateson, P. Cambridge, UK, Cambridge University Press.

Shevelev, I. A. and Polovets, S. S. (1973). "Features of the neuronal apparatus of the night and day vision of the cat and hypotheses concerning their evolutionary-ecological origin." *Journal of Evolutionary Biochemistry and Physiology* **9**(4): 370-377.

Shochat, E., Lerman, S. B., Anderies, J. M., Warren, P. S., Faeth, S. H. and Nilon, C. H. (2010). "Invasion, Competition, and Biodiversity Loss in Urban Ecosystems." *BioScience* **60**(3): 199-208.

Siegel, J. M. (1990). "Stressful life events and use of physician services among the elderly: The moderating role of pet ownership." *Journal of Personality and Social Psychology* **58**(6): 1081-1086.

Simons, L. A., Simons, J., McCallum, J. and Friedlander, Y. (2000). "Pet Ownership is Not Associated with Future Health: a Nine Year Prospective Study in Older Australians." *Australasian Journal on Ageing* **19**(3): 139-142.

Sims, V., Evans, K. L., Newson, S. E., Tratalos, J. A. and Gaston, K. J. (2008). "Avian assemblage structure and domestic cat densities in urban environments." *Diversity and Distributions* **14**: 387-399.

Siracusa, A. M. (2012). "Relationships between the bird community and density of domestic cat *Felis silvestris catus* in a Sicilian urban area." *Avocetta* **34**(1): 57-61.

Slater, M. R. (2015). Chapter 5: Behavioural ecology of free-roaming/community cats. *Animal behaviour for shelter veterinarians and staff*. Weiss, E., Mohan-Gibbons, H. and Zawistowski, S., Wiley-Blackwell**:** 102-128.

Slater, M. R., Di Nardo, A., Pediconi, O., Villa, P. D., Candeloro, L., Alessandrini, B. and Del Papa, S. (2008). "Cat and dog ownership and management patterns in central Italy." *Preventive Veterinary Medicine* **85**: 267-294.

Slingerland, L. I., Fazilova, V. V., Plantinga, E. A., Kooistra, H. S. and Beynen, A. C. (2009). "Indoor confinement and physical inactivity rather than the proportion of dry food are risk factors in the development of feline type 2 diabetes mellitus." *Veterinary Journal* **179**: 247-253.

Smith, A., Clark, P., Aaveris, S., Lymbery, A. J., Wayne, A. F., Morris, K. D. and Thompson, R. C. A. (2008). "Trypanosomes in a declining species of threatened Australian marsupial, the brushtailed bettong *Bettongia penicillata* (Marsupialia: Potoroidae)." *Parasitology* **135**: 1329-1335.

Smith, A. P. and Quin, D. G. (1996). "Patterns and causes of extinction and decline in Australian conilurine rodents." *Biological Conservation* **77**: 243-267.

Soulé, M. E., Bolger, D. T., Alberts, A. C., Wright, J., Sorice, M. and Hill, S. (1988). "Reconstructed Dynamics of Rapid Extinctions of Chaparral-Requiring Birds in Urban Habitat." *Conservation Biology* **2**(1): 75-92.

Statsoft Inc. (2013). *STATISTICA (data analysis software system), version 12.* www.statsoft.com

Sterne, J. A., Egger, M. and Davey Smith, G. (2001). "Investigating and dealing with publication and other biases in meta-analysis." *BMJ* **323**: 101-105.

Sterne, J. A. C., Sutton, A. J., Ioannidis, J. P. A., Terrin, N., Jones, D. R., Lau, J., Carpenter, J., Rücker, G., Harbord, R. M., Schmid, C. H., Tetzlaff, J., Deeks, J. J., Peters, J., Macaskill, P., Schwarzer, G., Duval, S., Altman, D. G., Moher, D. and Higgins, J. P. T. (2011). "Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials." *BMJ* **43:**: d4002.

Stevenson, A. (1949). "Reproduced in Respectfully Quoted: A Dictionary of Quotations." Retrieved 28/8/2015, from http://www.bartleby.com/73/163.html.

Stieger, S., U-D, R. and Voracek, M. (2007). "Forced-response in online surveys: bias from reactance and an increase in sex-specifc dropout." *Journal of the American Society for Information Science and Technology* **58**: 1653-1660.

Straede, C. M. and Gates, G. R. (1993). "Psychological Health in A Population Of Australian Cat Owners." *Anthrozoös* **6**(1): 30-41.

Sunvold, G. D., G. C. Fahey, J., Merchen, N. R., Bourquin, L. D., Titgemeyer, E. C., Bauer, L. L. and Reinhart, G. A. (1995). "Dietary fiber for cats: in vitro fermentation of selected fiber sources by cat fecal inoculum and in vivo utilization of diets containing selected fiber sources and their blends." *Journal of Animal Science* **73**: 2329-2339.

Sutton, A. J., Duval, S. J., Tweedie, R. L., Abrams, K. R. and Jones, D. R. (2000). "Empirical assessment of effect of publication bias on meta-analysis." *BMJ* **320**: 1574-1577.

Tabachnick, B. G. and Fidell, L. S. (2001). *Using Multivariate Statistics. 5th edition*. Boston, Allyn and Bacon.

Tantillo, J. A. (2006). Killing cats and killing birds: philosophical issues pertaining to feral cats. *Consultations in feline internal medicine*. August, J. R. Missouri, Elsevier Saunders, St. Louis**:** 701-708.

Tenter, A. M. (2009). "*Toxoplasma gondii* in animals used for human consumption." *Memorias do Instituto Oswaldo Cruz* **104**(2): 364-369.

Tenter, A. M., Heckeroth, A. R. and Weiss, L. M. (2000). "*Toxoplasma gondii*: from animals to humans." *International Journal for Parasitology* **30**: 1217-1258.

The Cat Site.com. (2015). "Cat welfare: collars and bells." from http://optimail.com.au/berrime/collbell.htm.

Thomas, R. L., Baker, P. J. and Fellowes, M. D. E. (2014). "Ranging characteristics of the domestic cat (*Felis catus*) in an urban environment." *Urban Ecosystems* **17**: 911-921.

Thomas, R. L., Fellowes, M. D. E. and Baker, P. J. (2012). "Spatio-temporal variation in predation by urban domestic cats (*Felis catus*) and the acceptability of possible management actions in the UK." *PLoS ONE* **7**(11): e49369.

Tokyo International Communication Committee. (2006). "Comprehensive living guide for foreign residents in Japan." Retrieved 8th April 2015, from http://www.tokyo-icc.jp/guide_eng/info/10.html.

Torrey, E. F., Bartko, J. J., Lun, Z.-R. and Yolken, R. H. (2007). "Antibodies to *Toxoplasma gondii* in Patients With Schizophrenia: A Meta-Analysis." *Schizophrenia Bulletin* **33**(3): 729-736.

Torrey, E. F. and Yolken, R. H. (2003). "*Toxoplasma gondii* and schizophrenia." *Emerging Infectious Diseases* **9**(11): 1375-1380.

Toukhsati, S. R., Young, E., Bennett, P. C. and Coleman, G. J. (2012). "Wandering cats: attitudes and behaviors towards cat containment in Australia." *Anthrozoös* **25**(1): 61-74.

Turner, D. and Mertens, C. (1986). "Homerange size, overlap and exploitation in domestic farm cats (*Felis catus*)." *Behaviour* **99**: 22–45.

U.S. Fish & Wildlife Service (2001). *For the Birds*. U.S. Fish & Wildlife Service. http://publications.usa.gov/epublications/forbirds/forbird.htm

Uetake, K., Yamada, S., Yano, M. and Tanaka, T. (2014). "A Survey of Attitudes of Local Citizens of a Residential Area Toward Urban Stray Cats in Japan." *Journal of Applied Animal Welfare Science* **17**: 172-177.

van Heezik, Y., Smyth, A., Adams, A. and Gordon, J. (2010). "Do domestic cats impose an unsustainable harvest on urban bird populations?" *Biological Conservation* **143**: 121-130.

van Heezik, Y., Smyth, A. and Mathieu, R. (2008). "Diversity of native and exotic birds across an urban gradient in a New Zealand city." *Landscape and Urban Planning* **87**: 223-232.

Vázquez-Domínguez, E., Ceballos, G. and Cruzado, J. (2004). "Extirpation of an insular subspecies by a single introduced cat: the case of the endemic deer mouse *Peromyscus guardia* on Estanque Island, Mexico." *Oryx* **38**(3): 347-350.

Veitch, C. R. (2001). "The eradication of feral cats (*Felis catus*) from Little Barrier Island, New Zealand." *New Zealand Journal of Zoology* **28**(1): 1-12.

Verberne, G. (1976). "Chemocommunication among domestic cats, mediated by the olfactory and vomeronasal senses. II. The relation between the function of Jacobson's organ (vomeronasal organ) and Flehmen behaviour)." *Zeitschrift fur Tierpsychologie* **42**(2): 113-128.

Verberne, G. and de Boer, J. (1976). "Chemocommunication among domestic cats, mediated by the olfactory and vomeronasal senses. I. Chemocommunication." *Zeitschrift fur Tierpsychologie* **42**(1): 86-109.

Verbrugghe, A., Hesta, M., Daminet, S. and Janssens, G. P. J. (2012). "Nutritional Modulation of Insulin Resistance in the True Carnivorous Cat: A Review." *Critical Reviews in Food Science and Nutrition* **52**(2): 172-182.

Vigne, J.-D. and Guilaine, J. (2004). "Evidence for Taming of Cats." *Science* **305**(5691): 1714-1715.

Vigne, J.-D., Guilaine, J., Debue, K., Haye, L. and Gérard, P. (2004). "Early Taming of the Cat in Cyprus." *Science* **304**(5668): 259.

Vorobyev, M. (2004). "Ecology and evolution of primate colour vision." *Clinical and Experimental Optometry* **87**: 230-238.

Wandesforde-Smith, G., Denninger Snyder, K. and Hart, L. A. (2014). "Biodiversity Conservation and Protected Areas in China: Science, Law, and the Obdurate Party-State." *Journal of International Wildlife Law and Policy* **17**: 85-101.

Warner, R. E. (1985). "Demography and Movements of Free-Ranging Domestic Cats in Rural Illinois." *The Journal of Wildlife Management* **49**(2): 340-346.

Watts, C. and Thornburrow, D. (2009). "Where have all the weta gone? Results after two decades of transferring a threatened New Zealand giant weta, *Deinacrida mahoenui*." *Journal of Insect Conservation* **13**: 287-295.

Watts, C. H., Armstrong, D. P., Innes, J. and Thornburrow, D. (2011). "Dramatic increases in weta (Orthoptera) following mammal eradication on Maungatautari – evidence from pitfalls and tracking tunnels." *New Zealand Journal of Ecology* **35**(3): 261-272.

Weber, J.-M. and Dailly, L. (1998). "Food habits and ranging behaviour of a group of farm cats (*Felis catus*) in a Swiss mountainous area." *Journal of Zoology (London)* **245**: 234-237.

Webster, J. P., Brunton, C. F. A. and Macdonald, D. W. (1994). "Effect of *Toxoplasma gondii* upon neophobic behaviour in wild brown rats, *Rattus norvegicus*." *Parasitology* **109**(1): 37-43.

Wehi, P. M., Nakagawa, S., Trewick, S. A. and Morgan-Richards, M. (2011). "Does predation result in adult sex ratio skew in a sexually dimorphic insect genus?" *Journal of Evoluntionary Biology* **24**: 2321–2328.

Wei, X., Zhang, Z., Song, X., Xu, Y., Wu, W., Lao, X. and Ma, W. (2014). "Household smoking restrictions related to secondhand smoke exposure in Guangdong, China: A population representative survey." *Nicotine and Tobacco Research* **16**: 390-396.

Wells, Y. and Rodi, H. (2000). "Effects of Pet Ownership on the Health and Well-being of Older People." *Australasian Journal on Ageing* **19**(3): 143-148.

Wheeler, R. and Priddel, D. (2009). "The impact of introduced predators on two threatened prey species: A case study from western New South Wales." *Ecological Management and Restoration* **10**: S117-S123.

White, G. (2013). "Cats."   Retrieved 6th July 2015, from http://sayit.co.nz/blog/cats.

White, J. G., Antos, M. J., Fitzsimons, J. A. and Palmer, G. C. (2005). "Non-uniform bird assemblages in urban environments: the influence of streetscape vegetation." *Landscape and Urban Planning* **71**: 123–135.

Wickham, H. (2009). *ggplot2: Elegant Graphics for Data Analysis*. NewYork, Springer.

Wierzbowskaa, I. A., Olkoa, J., Hedrzakb, M. and Crooksc, K. R. (2012). "Free-ranging domestic cats reduce the effective protected area of a Polish national park." *Mammalian Biology* **77**: 204–210.

Wildlife Society (2006). "Final position statement: Feral and free-ranging domestic cats."

Williams, C. M. and Kramer, E. M. (2012). "The Advantages of a Tapered Whisker." *PLoS ONE* **5**(1): e8806.

Willson, S. K., Okunlola, I. A. and Novak, J. A. (2015). "Birds be safe: Can a novel cat collar reduce avian mortality by domestic cats (*Felis catus*)?" *Global Ecology and Conservation* **3**: 359–366.

Winefield, H. R., Black, A. and Chur-Hansen, A. (2008). "Health effects of ownership of and attachment to companion animals in an older population." *International Journal of Behavioral Medicine* **15**: 303-310.

Woinarski, J. C. Z., Burbidge, A. A. and Harrison, P. L. (2014). *The action plan for Australian mammals 2012*. Collingwood, Victoria, CSIRO Publishing.

Woinarski, J. C. Z., Ward, S., Mahney, T., Bradley, J., Brennan, Ziembicki, M. and Fisher, A. (2011). "The mammal fauna of the Sir Edward Pellew island group, Northern Territory, Australia: refuge and death-trap." *Wildlife Research* **38**: 307–322.

Wood, L. J., Giles-Corti, B., Bulsara, M. K. and Bosch, D. A. (2007). "More than a furry companion: The ripple effect of companion animals on neighborhood interactions and sense of community." *Society and Animals* **15**: 43-56.

Woods, M., McDonald, R. A. and Harris, S. (2003). "Predation of wildlife by domestic cats *Felis catus* in Great Britain." *Mammal Review* **33**(2): 174–188.

Yeates, J. (2012). "Economics and animal welfare in small animal veterinary practice: the case of genetic welfare problems." *Animal Welfare* **21(S1)**: 155-160.

Yeh, E. T. (2013). "The politics of conservation in contemporary rural China." *Journal of Peasant Studies* **40**: 1165-1188.

Zar, J. H. (2010). *Biostatistical Analysis. Fifth Edition*, Prentice Hall.

Zhang, J., Fan, M. and Kuang, Y. (2006). "Rabbits killing birds revisited." *Mathematical Biosciences* **203**: 100–123.

Zoran, D. L. (2002). "The carnivore connection to nutrition in cats." *Journal of the American Veterinary Medical Association* **221**(11): 1559-1567.

Zufall, F. and Leinders-Zufall, T. (2007). "Mammalian pheromone sensing." *Current Opinion in Neurobiology* **17**: 483–489.

Zuur, A., Ieno, E. N., Walker, N., Saveliev, A. A. and Smith, G. M. (2009). *Mixed Effects Models and Extensions in Ecology with R*. New York, Springer.

APPENDIX 1 CAT QUESTIONNAIRE AUSTRALIA

1. Instructions

a) At the beginning of each section, a brief explanation has been provided as to the reasons behind each heading

b)When answering the questions below, please give YOUR INITIAL REACTION and circle the most appropriate answer.

c) Please use "I don't know" ONLY when you have no opinion on the issue.

d) At the end of each section, a space has been provided should you wish to make any comments.

2. Restrictions Towards Cats

Some people feel that restrictions should be placed on cat ownership to prevent cats being a nuisance to neighbours and wildlife. The restrictions may also help to protect cats from fighting or being run over. Other people feel that such restrictions are inhumane, unnecessary and difficult to enforce. Please give us ***your opinion*** by answering the questions below.

1. There is a need for cat legislation. Strongly agree, agree, disagree, strongly disagree, I don’t know.

2. Are you aware of any areas within Australia where cats must be registered? Yes, no, I don’t know

3. Cats CAN be kept within the boundaries of their owner’s property. Strongly agree, agree, disagree, strongly disagree, I don’t know

4. All cats should be kept in at night time (curfewed). Strongly agree, agree, disagree, I don’t know.

5. Cats should be kept on their owner's property at all times. Strongly agree, agree, disagree, strongly disagree, I don’t know.

6. All cats should be registered with the council in the same way dogs are. Strongly agree, agree, disagree, strongly disagree, I don’t know.

7. People that breed and sell cats should be registered. Strongly agree, agree, disagree, strongly disagree, I don’t know.

8. Local governments should be responsible for enforcing cat control laws. Strongly agree, agree, disagree, strongly disagree, I don't know.

9. The increased costs for cat control should be covered by increasing council rates/taxes. Strongly agree, agree, disagree, strongly disagree, I don't know.

10. Authorised enforcement officers (rangers) should have the power to impound nuisance cats. Strongly agree, agree, disagree, I don't know.

11. Rangers should have the authority to pick up and impound ANY cats seen roaming on the streets. Strongly agree, agree, disagree, strongly disagree, I don't know.

12. Rangers should have the power to put to sleep (euthanase) impounded cats that are not claimed within two weeks. Strongly agree, agree, disagree, strongly disagree, I don't know.

13. Local governments should have the power to limit the number of cats per household. Strongly agree, agree, disagree, strongly disagree, I don't know.

14. The maximum number of cats per household should be: unlimited, one to two cats, three to five cats, no cats, I don't know.

15. Local governments should have the power to establish cat free zones in new subdivisions. Strongly agree, agree, disagree, strongly disagree, I don't know.

16. Owners of pet cats have: a higher risk of heart attack compared to the general population, a moderate risk of heart attack compared to the general population, just as much risk of a heart attack compared to the general population, less risk of a heart attack compared to the general population, much reduced risk of heart attack compared to the general population.

17. How do you feel about pet cats? Cats are a wonderful animal, cats are okay, I don't like cats, cats should be prohibited as pets, no strong opinion.

18. Do you have any comments about this section?

3. Wildlife

Many people believe cats are one of the major contributors to the decline of wildlife (i.e. animals such as mice/rats, birds, lizards, frogs, etc.) in cities and rural areas. Others feel that the real problems are elsewhere and that cats are being used as a scapegoat. Please tell us ***your views*** by answering the following questions.

1. It is important to have wildlife in cities and towns and in rural areas. Strongly agree, agree, disagree, strongly disagree, I don't know.

2. Pet cats killing wildlife in cities and towns and in rural areas is a serious problem. Strongly agree, agree, disagree, strongly disagree, I don't know.

3. Pet cats on farms are harmful to wildlife. Strongly agree, agree, disagree, strongly disagree, I don't know.

4. Pet cats in nature reserves are harmful to wildlife. Strongly agree, agree, disagree, strongly disagree, I don't know.

5. Do you think that cats hunt more in the daytime or nighttime? Daytime, nighttime, the same in each, I don't know.

6. Pet cats hunt less if they are well fed. Strongly agree, agree, disagree, strongly disagree, I don't know.

7. A desexed cat is less likely to hunt than a cat that is not neutered. Strongly agree, agree, disagree, strongly disagree, I don't know.

8. Pet cats protect native wildlife by controlling vermin such as rats and mice. Strongly agree, agree, disagree, strongly disagree, I don't know.

9. Pet cats living outdoors make the neighbourhood safer for wildlife by chasing away stray cats. Strongly agree, agree, disagree, strongly disagree, I don't know.

10. Do you believe that it should be illegal to keep a cat as a pet in Australia? Strongly agree, agree, disagree, strongly disagree, I don't know.

11. Wearing a bell is effective at reducing the number of prey caught. Strongly agree, agree, disagree, strongly disagree, I don't know.

12. In Australia, do you believe that diseases are transmitted from cats to people and animals? Strongly agree, agree, disagree, strongly disagree, I don't know.

13. All pet cats should be declawed (have their claws removed). Strongly agree, agree, disagree, strongly disagree, I don't know.

14. Do you have any comments about this section?

4. Sterilisation

Some believe that by sterilising all pet cats, the impact on wildlife will be lessened, there will be fewer unwanted cats/kittens and pet cats will be less of a nuisance to neighbours. Others feel that unwanted sterilisation may be inhumane and could change the value of cats as pets. Please indicate how ***you feel*** about this issue by answering the questions below.

1. Except for a cat owned by a breeder, all cats should be desexed. Strongly agree, agree, disagree, strongly disagree, I don't know.

2. All cats should be desexed. Strongly agree, agree, disagree, strongly disagree, I don't know.

3. ONLY male cats should be desexed. Strongly agree, agree, disagree, strongly disagree, I don't know.

4. ONLY female cats should be desexed. Strongly agree, agree, disagree, strongly disagree, I don't know.

5. Female cats should be allowed to have a litter of kittens before they are desexed. Strongly agree, agree, disagree, strongly disagree, I don't know.

6. At what age can female cats first reproduce: 0 – 3 months of age, 4 – 7 months of age, 8 – 10 months of age, 11 months and over, I don't know.

7. The cost of desexing a female cat is: $20 - $40, $41 - $60, $61 - $90, $91 or more, I don't know.

8. The cost of desexing a male cat is: $20 - $40, $41 - $60, $61 - $90, $91 or more, I don't know.

9. The cost of having a cat desexed is: Extremely reasonable, very reasonable, reasonable, unreasonable, extremely unreasonable, unsure.

10. Only a registered veterinarian should desex cats. Strongly agree, agree, disagree, strongly disagree, I don't know.

11. Desexed cats fight less. Strongly agree, agree, disagree, strongly disagree, I don't know.

12. Desexed cats are less likely to wail. Strongly agree, agree, disagree, strongly disagree, I don't know.

13. Desexed cats are less likely to roam. Strongly agree, agree, disagree, strongly disagree, I don't know.

14. Desexed male cats are less likely to spray (territory marking). Strongly agree, agree, disagree, strongly disagree, I don't know.

15. Do you have any comments about this section?

16. Do you currently own a cat? Yes No

5. About YOUR cats

If you do own a cat/s, please complete the rest of the survey.

If you own more than one cat, please answer the following questions for each cat. If you have more than four cats, please choose to answer the questions with reference to the four cats you have owned for longest. CAT ONE

1. Cat's name

2. Has this cat been desexed? Yes, no.

3. If not, what was the reason?

you don't think it is necessary]

you want to, or do breed from this cat

you haven't gotten around to it

it is too expensive

you are worried the cat's personality may change and it may get fat

Other (please specify)

4.At about what age was this cat when it was desexed?

Less than 6 months old

6 to 10 months

11 to 15 months

more than 15 months

my cat/s was/were already neutered when I got it/them

I don't know

5. If it became compulsory to have pet cats desexed, would you have your cat/s desexed? Yes, no, unsure. If no, why?

6. Does this cat live:

solely inside

solely outside

solely inside during the night, but free roaming during the day

inside and outside, but restricted to my property

inside and outside, but free roaming

7. I would be happy to keep this cat on my property from sunset to sunrise. Yes, no, I don't know

8. I would be happy to keep this cat on my property at all times. Yes, no. I don't know

9. Would you keep this cat in at nighttime if it was legally required? Yes, no, I don't know

10. Would you license this cat if it became compulsory? Yes, no, I don't know

11. Does this cat wear any identification on its collar? Yes, no, sometimes

12. Has this cat had its yearly vaccinations? Yes, no, I don't know

13. Does this cat wear a bell on its collar? Yes, no, sometimes

14. Do you use any method of flea control on this cat (i.e. flea collar, flea powder, herbal flea repellent etc.)? Yes, no, sometimes

15. When you last went away on holiday, what arrangements did you make for this cat?

a friend or neighbour comes in to feed this cat

I leave food out for this cat

the situation has never arisen

I take this cat with me on holiday

this cat goes to a cattery (boarding kennel for cats)

I had someone stay in the house to look after this cat/s and the house

Other (please specify)

16. Has this cat ever caught any: (you may select more than one choice)

mice or rats

other furred animals

birds

frogs or toads or newts

lizards or snakes

none

17. Please list the type and number of animals caught by this cat caught in the last two weeks.

18. What type of food do you mainly feed this cat?

fresh food (i.e. fish, chicken)

tinned/canned cat food

scraps

dried food

Other (please specify)

Automatic RETURN to top for next cat

19. Last month, approximately how much did you spend on food for your cat/s?

20. In the last 12 months, approximately how much did you spend on veterinary bills for your cats?

21. Do you have any comments about this section?

6. And Now Some Questions About You.

People's experience and attitudes towards cats vary with their upbringing, occupation, age and other factors within their lives. Please answer the following questions by circling the appropriate answer.

1. How old were you when you or your family first owned a cat (if you or your family have never owned a cat, please write "never")

2 .In what year were you born?

3. Does your current occupation involve working with animals (e.g. farming, vet,

breeding, training, handling / warden, etc.)? Yes, no.

4. What is your current occupation?

clerical worker

crafts-worker

farmer, farm manager or farm labourer

home-maker

machine operator or labourer

manager or administrator

military/armed forces

professional or technical

retired

service worker or private household worker

sales worker

student

unemployed/looking for work

Other (please specify)

5. Have you ever taken, or are currently undertaking, any classes that involve topics such as

environmental issues, animal studies? Yes, no.

6. Which of the following best describes your highest education level?

completed Year 10 at high school

completed Year 12 at high school

completed/completing diploma at TAFE

completed/completing degree at university

post graduate studies at university

Other (please specify)

7. Has your opinion towards cats altered in any way in the last 10 years? (If yes, how)

8. Are you: Male, female

9. What is your postcode?

10. What suburb do you live in?

11. Do you live in a:

separate house

terrace or semi-detached house

flat or apartment

home unit or townhouse

Other (please specify)

12. How many people live in your household?

13. How many cats do you have? please give number or 0 if none.

14. Do you have any comments about this section?

Thank you very much for your invaluable assistance. The time you have taken is most appreciated.

APPENDIX 2: OWNER QUESTIONNAIRES. (A) INITIAL QUESTIONNAIRE. (B) FINAL QUESTIONNAIRE

(a)

About you:

1. Your name:
2. Your address:
3. Your telephone number:
4. Would you like to receive a copy of the final report?

About your cat:

1. Your cat's name:
2. Which of the following statements best describes your cat's freedom of movement:
   i. always outside
   ii. freedom to move inside/outside at will
   iii. kept inside at night
   iv. other (please give details)
3. How old is your cat?
4. Is your cat male or female?
5. Has your cat been neutered?

(b)

1. Why did you volunteer for this study?
2. Were there any problems with the Birdsbesafe?
3. How well did your cat adjust to wearing the Birdsbesafe?
4. Did you notice any changes in the cat's behaviour while wearing the Birdsbesafe?
5. Did the Birdsbesafe get snagged, chewed or removed whilst your cat was wearing it?
6. Do you believe the Birdsbesafe worked?
7. The Birdsbesafe retails for c. $15. Do you consider this price reasonable?
8. Will you continue to use the Birdsbesafe? Why or why not?

APPENDIX 3: INDIVIDUAL CHARACTERISTICS AND ENVIRONMENTAL CONDITIONS FOR EACH CAT

Cat	Collar Type	Order	Hunter (Yes/No/Unknown)	Sex	Desexed (Yes/No)	Age (Years)	Inside/Outside at night	Housing Density (houses/ha)	With Device			Without Device		
									Mean max temp (˚C)	Total Rain (mm)	No. Days of Rain	Mean max temp (˚C)	Total Rain (mm)	No. Days of Rain
Angel	CatBib	With	N	M	Y	10	Outside	17.5	23.26	51.8	1	20.6	39.8	3
Blueberry	CatBib	Without	N	F	Y	8	Outside	17.5	20.6	39.8	3	23.26	51.8	1
Boo	CatBib	Without	N	M	Y	18	Inside	20	21.42	9	2	22.44	19.2	1
Bruno	CatBib	Without	N	M	Y	5	Outside	0.44	33.5	1.2	1	30.48	0	0
Comet	CatBib	With	U	M	Y	1	Inside	20	20.2	23.4	5	20.2	18.4	4
Elliot	CatBib	Without	U	M	Y	5	Inside	17.5	29.58	0	0	26.96	36.8	2
Hazelnut	CatBib	Without	N	M	Y	8	Outside	17.5	20.6	39.8	3	23.26	51.8	1
Jay	CatBib	Without	Y	M	Y	8	Outside	20	32.88	0	0	36.38	0	0
Misty	CatBib	With	Y	F	Y	3	Outside	0.44	28.5	19.5	1	25.42	0	0
Rex	CatBib	Without	N	M	Y	10	inside	20	24.72	18.8	2	25.13	6.1	1
Scaboo	CatBib	Without	N	M	Y	7	Inside	25	21.28	5	2	20.38	18.8	3
Sparkles	CatBib	With	N	F	Y	13.5	Outside	17.5	23.26	51.8	1	20.6	39.8	3
Timba	CatBib	Without	Y	M	Y	1	Inside	20	25.04	3.8	0	23.64	0.4	0
Toby	CatBib	With	U	M	Y	3	Inside	0.49	29.78	0	0	25.45	0	0
Widget	CatBib	With	N	M	Y	10	Outside	40	20.7	15.4	3	22.94	1	2
Zimba	CatBib	With	Y	M	Y	5	Outside	17.5	24.64	0	0	29.46	0	0
BobbySocks	BBS	With	N	M	Y	12	Inside	15	33.3	0	0	35.42	0	0
Casa	BBS	With	Y	F	Y	2	Outside	15	24.66	7	2	27.16	0	0
Hugo	BBS	Without	N	M	Y	5	Inside	40	34.98	0	0	35.72	0	0
Indigo	BBS	Without	U	F	Y	3	Outside	17.5	35.46	0	0	34.3	0	0
Jasmine	BBS	With	Y	F	Y	3	Outside	20	33.6	0	0	31.12	0	0
Licca	BBS	Without	Y	M	Y	8	Outside	15	27.16	0	0	24.66	7	2
Lilly	BBS	With	U	F	Y	2	Inside	20	20.2	18.4	4	20.76	27	4
Rina	BBS	Without	N	M	Y	2	Outside	15	27.16	0	0	24.66	7	2
Sammy	BBS	Without	N	F	Y	3	Inside	30	32.22	0	0	31.1	0	0
Skye	BBS	With	N	F	Y	5	Inside	30	31.1	0	0	32.22	0	0
Squiggles	BBS	Without	N	M	Y	6	Inside	40	29.92	0	0	31.64	0	0
Taz	BBS	With	N	M	Y	10	Outside	15	24.66	7	2	27.16	0	0
Thomas	BBS	With	N	M	Y	12	Inside	15	33.3	0	0	35.42	0	0

Appendix 3

Cat	Collar Type	Order	Hunter (Yes/No/Unknown)	Sex	Desexed (Yes/No)	Age (Years)	Inside/Outside at night	Housing Density (houses/ha)	With Device			Without Device		
									Mean max temp (˚C)	Total Rain (mm)	No. Days of Rain	Mean max temp (˚C)	Total Rain (mm)	No. Days of Rain
Tobey	BBS	Without	N	M	Y	11	Inside	17.5	35.54	0	0	32.92	0	0
Bacon	Neither	N/A	U	M	Y	1	Inside	20	N/A	N/A	N/A	20.33	28	7
Billy	Neither	N/A	Y	M	Y	4	Outside	0.22	N/A	N/A	N/A	32.9	0.6	0
Max	Neither	N/A	Y	M	Y	4	Outside	0.22	N/A	N/A	N/A	32.9	0.6	0
TC	Neither	N/A	U	M	Y	1	Outside	20	N/A	N/A	N/A	20.4	23.4	5

APPENDIX 4: HOME RANGE (HA) FOR EACH CAT

Cat	Collar Type	100% MCP With	100% MCP Without	95% KDE With	95% KDE Without	50% KDE With	50% KDE Without	Proportion of Good Fixes With	Proportion of Good Fixes Without
Angel	CatBib	0.17	0.28	0.13	0.15	0.03	0.04	0.90	0.81
Blueberry	CatBib	0.90	0.86	0.46	0.33	0.13	0.10	0.78	0.88
Boo	CatBib	4.65	1.42	0.44	0.33	0.11	0.09	0.89	0.90
Bruno	CatBib	16.48	16.50	14.35	8.00	3.30	2.42	1.00	1.00
Comet	CatBib	10.86	2.80	3.21	1.31	0.85	0.33	0.87	0.90
Elliot	CatBib	0.29	0.38	0.18	0.23	0.05	0.07	0.93	0.94
Hazelnut	CatBib	0.60	0.98	0.27	0.26	0.09	0.08	0.85	0.83
Jay	CatBib	1.68	1.68	0.61	0.53	0.13	0.15	0.88	0.92
Misty	CatBib	20.56	24.74	18.06	18.52	3.60	5.88	0.93	0.96
Rex	CatBib	0.38	0.44	0.29	0.24	0.10	0.09	0.91	0.88
Scaboo	CatBib	2.98	1.46	1.02	0.77	0.22	0.21	0.95	0.89
Sparkles	CatBib	1.10	0.93	0.57	0.43	0.17	0.10	0.87	0.89
Timba	CatBib	1.09	1.40	0.32	0.45	0.12	0.14	0.88	0.86
Toby	CatBib	7.87	7.62	2.86	6.65	0.67	1.39	0.88	0.63
Widget	CatBib	0.40	0.54	0.27	0.24	0.10	0.07	0.84	0.85
Zimba	CatBib	5.03	5.27	1.60	0.87	0.43	0.24	0.89	0.89
BobbySocks	BBS	1.49	1.08	0.67	0.36	0.13	0.09	0.85	0.89
Casa	BBS	0.70	0.41	0.48	0.28	0.15	0.12	0.80	0.88
Hugo	BBS	0.59	0.85	0.28	0.25	0.09	0.08	0.91	0.88
Indigo	BBS	1.12	1.69	1.08	1.40	0.49	0.47	0.81	0.84
Jasmine	BBS	0.50	0.78	0.16	0.22	0.04	0.06	0.83	0.87
Licca	BBS	6.16	5.64	3.42	2.09	0.52	0.43	0.85	0.87
Lilly	BBS	0.29	0.48	0.15	0.29	0.05	0.07	0.83	0.90
Rina	BBS	0.69	0.40	0.34	0.25	0.12	0.10	0.39	0.87
Sammy	BBS	0.97	0.55	0.41	0.39	0.11	0.13	0.90	0.87
Skye	BBS	0.75	0.61	0.32	0.45	0.12	0.12	0.94	0.88
Squiggles	BBS	0.08	0.27	0.09	0.19	0.03	0.06	0.71	0.84
Taz	BBS	0.49	0.41	0.28	0.25	0.11	0.10	0.89	0.88
Thomas	BBS	0.04	0.90	0.05	0.35	0.02	0.11	0.71	0.84

Cat	Collar Type	100% MCP With	100% MCP Without	95% KDE With	95% KDE Without	50% KDE With	50% KDE Without	Proportion of Good Fixes With	Proportion of Good Fixes Without
Tobey	BBS	0.99	0.42	0.40	0.27	0.14	0.11	0.88	0.77
Bacon	Neither	N/A	0.75	N/A	0.39	N/A	0.10	N/A	0.90
Billy	Neither	N/A	10.48	N/A	6.70	N/A	1.33	N/A	0.95
Max	Neither	N/A	22.69	N/A	19.93	N/A	9.47	N/A	0.94
TC	Neither	N/A	0.58	N/A	0.32	N/A	0.10	N/A	0.90

APPENDIX 5: COMPARATIVE HOME RANGE ESTIMATES OF PET CATS IN DIFFERENT STUDIES

100% MCP (ha) Mean (range)	95% MCP (ha) Mean (range)	95% KDE (ha) Mean (range)	Location	Reference
3.4 (0.3 – 24.7)	**2.4 (0.2 – 19.5)**	**2.2 (0.1 – 19.9)**	**Australia**	**This study**
5.6 (0.02 – 39.9)[a] 11.6 (0.1 – 43.6)[b]	2.7 (0.02 – 17.2)[a] 7.9 (0.02 – 27.9)[b]		Australia	(Barratt 1997a)
2.9 (0.1 – 14.7)	0.9 (0.02 – 6.5)		Australia	(Meek 2003)
0.7 (0.1 – 3)	0.24 (0.1 – 1.3)		USA	(Kays and DeWan 2004)
	0.6 (0.01 – 2.9)		Australia	(Lilith et al. 2008)
2.8 (0.1 – 10)			New Zealand	(Morgan et al. 2009)
4.8 (0.7 – 13.4)			New Zealand	(Hansen 2010)
26 (1 – 206)		10.1 (0.2 – 69)	New Zealand	(Metsers et al. 2010)
3.2 (0.5 – 21.8)			New Zealand	(van Heezik et al. 2010)
	1.9 (0.2 – 9)	2.8 (0.2 – 14.9)	USA	(Horn et al. 2011)
9.3 (0.8 – 37.9)		3.9 (0.6 – 13.6)	Corvo Island, Portugal	(Hervías et al. 2014)
14.3 (2.6 – 26.9)	3.4 (1.3 – 7.6)		UK	(Thomas et al. 2014)
		1.51[c] 1.26[d] 1.10[e]	New Zealand	(Coughlin and van Heezik 2014)

[a] Diurnal home range

[b] Nocturnal home range

[c] Light collar treatment (36 g)

[d] Medium collar treatment (86 g)

[e] Heavy collar treatment (136 g)

APPENDIX 6: SUMMARY OF MAIN FINDINGS OF HOME RANGE STUDIES ON PET AND FARM CATS

Study	Location	Farm/House Cat	Cats living close to forest edge have larger home ranges	Forest fragment size influences home range	Nocturnal home range larger than diurnal home range	Male cats have significantly larger home range than females	Male cats have larger home ranges than females but not statistically significant	Relationship and social structure influence	Farm cats have larger home range than house cats	Desexing has an effect on home range	House cats in rural areas/urban edge have larger home ranges than suburban cats	Age effects home range size	Season effects home range size	Cats with larger home ranges catch a wider variety/different groups of prey than cats with smaller home ranges	Cats with larger home ranges bring home more prey	Cat size influences home range	No. of neighbouring cats influences home range	No. of cats in household effects home range	Feeding frequency	House/Farm cats have smaller home range than feral cats	Cat size	Weather	Notes
(Barratt 1997a)	Australia	House & Farm			✓	X	✓	✓	✓														
(Bradshaw 1992)[a]	UK	House																					
(Carss 1995)[b]	Scotland	House																					
(Chipman 1990) in (Bradshaw 1992)	UK	House								✓		✓											Desexed males had similar home ranges to females except for one male that had not been desexed until he was four possibly suggesting that his home range was already established and not changed by deseing
(Corbett 1979)	Scotland	Farm				✓		✓				✓	✓										
(Coughlin and van Heezik 2014)	New Zealand	House				X	✓					X										X	Weight of collar makes significant difference to home range size with heavier collars decreasing home range Cats that had previously worn a collar had a significantly smaller home range
(George 1978)	USA	House						✓															
(Hall et al. 2016b)	Australia	House				X	✓				✓												
(Hansen 2010)	New Zealand	House	X		✓*	X	✓	✓				X	X		X	X	X	X	X	✓			*male cats had significantly larger nocturnal home ranges than diurnal but females showed no significant difference
(Hervías et al. 2014)	Corvo Island	House				X	✓			X		✓											
(Horn et al. 2011)	USA	House				X	X						X							✓	X		Crepuscular activity for house cats but

Appendix 6

Study	Location	Farm/House Cat	Cats living close to forest edge have larger home ranges	Forest fragment size influences home range	Nocturnal home range larger than diurnal home range	Male cats have significantly larger home range than females	Male cats have larger home ranges than females but not statistically significant	Relationship and social structure influence	Farm cats have larger home range than house cats	Desexing has an effect on home range	House cats in rural areas/urban edge have larger home ranges than suburban cats	Age effects home range size	Season effects home range size	Cats with larger home ranges catch a wider variety/different groups of prey than cats with smaller home ranges	Cats with larger home ranges bring home more prey	Cat size influences home range	No. of neighbouring cats influences home range	No. of cats in household effects home range	Feeding frequency	House/Farm cats have smaller home range than feral cats	Cat size	Weather	Notes
																							not for feral cats
(Kays and DeWan 2004)	USA	House	X	X			✓																Forest fragment size did not influence cat presence but smaller fragments had more individual cats
(Kitts-Morgan et al. 2015)	USA	Farm			✓	X	✓			✓*			X										Although the paper reports that entire cats have significantly larger home ranges, there appears to be a discrepancy with the raw data provided which appears to show that most desexed cats had larger home ranges than entire cats
(Liberg 1980)	Sweden	Farm				✓		✓												✓			
(Liberg 1984)	Sweden	Farm				✓		✓												✓			
(Lilith et al. 2008)	Australia	House				X	✓				✓	X	X										
(Macdonald and Apps 1978)	England	Farm					✓	✓															
(Meek 2003)	Australia	House				X	✓			X				✓									
(Metsers et al. 2010)	New Zealand	House			X/✓*	X	X/✓*				✓												*Cats from three locations were tested. These tests were significant in some places but not others
(Morgan 2002, Morgan et al. 2009)	New Zealand	House	X			X	✓					✓	X	✓									Cats living closer to the edge of the wetland did not have significantly larger home ranges but did travel significantly further into the wetland compared to cats living further away
(Schär and Tschanz 1982)	Switzerland	Farm				✓		✓															
(Schmidt et al. 2007)	USA	House & Feral				X	✓													✓			

Appendix 6

Study	Location	Farm/House Cat	Cats living close to forest edge have larger home ranges	Forest fragment size influences home range	Nocturnal home range larger than diurnal home range	Male cats have significantly larger home range than females	Male cats have larger home ranges than females but not statistically significant	Relationship and social structure influence	Farm cats have larger home range than house cats	Desexing has an effect on home range	House cats in rural areas/urban edge have larger home ranges than suburban cats	Age effects home range size	Season effects home range size	Cats with larger home ranges catch a wider variety/different groups of prey than cats with smaller home ranges	Cats with larger home ranges bring home more prey	Cat size influences home range	No. of neighbouring cats influences home range	No. of cats in household effects home range	Feeding frequency	House/Farm cats have smaller home range than feral cats	Cat size	Weather	Notes
(Thomas et al. 2014)	UK	House			✓	X	✓						X										Cats preferred gardens and green space to urban habitat
(Turner and Mertens 1986)	Switzerland	Farm					✓	✓															Males had large exclusive home ranges but large female home ranges were shared
(van Heezik et al. 2010)	New Zealand	House	X		X	X	✓				✓				X								Cats had larger home ranges on urban edge next to larger green spaces
(Warner 1985)	USA	Farm				✓																	
(Weber and Dailly 1998)	Switzerland	Farm					X						✓										Smaller home range in winter

[A] Cat data provided in book and used in this analysis, but author drew no conclusions about patterns in cat behaviour.

[B] Study included only single cat. Data used in this analysis but conclusions could not be drawn about cat behaviour

APPENDIX 7: DATA ON INDIVIDUAL CAT HOME RANGES FROM ALL AVAILABLE AND APPLICABLE STUDIES

Reference	Location	Farm/Rural/House	Husbandry (Farm/Pet)	Cat Reference	Age	Sex	Desexed	Home Range (ha)		
								100% MCP	95% MCP	95% KDE
Barratt 1997a	Australia	Farm	Farm	Female A	1	F	N	23.4	3.7	
Barratt 1997a	Australia	Farm	Farm	Female B	3	F	N	9.7	3.2	
Barratt 1997a	Australia	Farm	Farm	Female C	1	F	N	4.4	1.8	
Barratt 1997a	Australia	Farm	Farm	Female D	1	F	N	5.5	3.3	
Barratt 1997a	Australia	Farm	Farm	Female E	1	F	N	3.2	1.4	
Barratt 1997a	Australia	Farm	Farm	Male A	1	M	N	7.5	4.5	
Barratt 1997a	Australia	Farm	Farm	Male B	1	M	N	7.4	1.8	
Barratt 1997a	Australia		Pet	Blossom	5	F	Y	0.1	0.04	
Barratt 1997a	Australia		Pet	Gismette	1	F	Y	0.8	0.5	
Barratt 1997a	Australia		Pet	Gismo	1	M	Y	8.2	6.7	
Barratt 1997a	Australia		Pet	Horse	10	M	Y	0.4	0.2	
Barratt 1997a	Australia		Pet	Jasper	3	M	N	43.6	20.5	
Barratt 1997a	Australia		Pet	Merry	2	F	Y	0.9	0.3	
Barratt 1997a	Australia		Pet	Mitzie	6	M	Y	0.1	0.1	
Barratt 1997a	Australia		Pet	Pippin	2	M	Y	1.4	0.9	
Barratt 1997a	Australia		Pet	Simba	1	M	Y	33.1	22.2	
Barratt 1997a	Australia		Pet	Tiddles	7	F	Y	28.1	27.9	
Bradshaw 1992	England		Pet	Bradshaw F	1	F	Y	0.9	0.5	
Bradshaw 1992	England		Pet	Bradshaw M	1	M	Y	0.9	0.3	
Carss 1995	Scotland	Rural	Pet	Torphins	2	M	Y	53		
Corbett 1979	Hosta, Scotland	Farm	Farm	Mum		F	N	30.3		
Corbett 1979	Hosta, Scotland	Farm	Farm	Slim		F	N	14.7		
Corbett 1979	Hosta, Scotland	Farm	Farm	Fishpond		F	N	4.9		
Corbett 1979	Hosta, Scotland	Farm	Farm	Mosaic		F	N	15.4		
Corbett 1979	Hosta, Scotland	Farm	Farm	Juliet		F	N	8.2		
Corbett 1979	Hosta, Scotland	Farm	Farm	Topcat		M	N	63.2		
Corbett 1979	Hosta, Scotland	Farm	Farm	Blackie		M	N	41		
Corbett 1979	Hosta, Scotland	Farm	Farm	4-Star		M	N	7		

Reference	Location	Farm/Rural/House	Husbandry (Farm/Pet)	Cat Reference	Age	Sex	Desexed	Home Range (ha)		
								100% MCP	95% MCP	95% KDE
Corbett 1979	Hosta, Scotland	Farm	Farm	Whitefoot		M	N	23.4		
Corbett 1979	Hosta, Scotland	Farm	Farm	Dad		M	N	18.4		
Corbett 1979	Hosta, Scotland	Farm	Farm	Dave		M	N	39.2		
Corbett 1979	Hosta, Scotland	Farm	Farm	Pug		M	N	41.9		
Corbett 1979	Hosta, Scotland	Farm	Farm	Saddles		M	N	33.2		
Corbett 1979	Hosta, Scotland	Farm	Farm	Grub		M	N	15.4		
Corbett 1979	Hosta, Scotland	Farm	Farm	Pastie-Face		M	N	18.2		
Corbett 1979	Hosta, Scotland	Farm	Farm	Sarong		M	N	4.4		
Coughlin and van Heezik 2015	New Zealand		pet	Ace	3	M	Y	3.6		0.9
Coughlin and van Heezik 2015	New Zealand		pet	Angus	4	M	Y	7.2		1.9
Coughlin and van Heezik 2015	New Zealand		pet	Bowie	6	F	Y	2.8		1.5
Coughlin and van Heezik 2015	New Zealand		pet	Buffy	2	F	Y	5.4		1.6
Coughlin and van Heezik 2015	New Zealand		pet	Cas	2	M	Y	6.1		3.6
Coughlin and van Heezik 2015	New Zealand		pet	Cosmo	1	F	Y	3.9		1.6
Coughlin and van Heezik 2015	New Zealand		pet	Gilben	9	M	Y	3.1		1.6
Coughlin and van Heezik 2015	New Zealand		pet	Koko	7	F	Y	3.4		1.6
Coughlin and van Heezik 2015	New Zealand		pet	Loki	3	M	Y	2.2		1.5
Coughlin and van Heezik 2015	New Zealand		pet	Mo	7	M	Y	3.8		1.6
Coughlin and van Heezik 2015	New Zealand		pet	Mort	1	M	Y	1.8		0.7
Coughlin and van Heezik 2015	New Zealand		pet	Munta	3	M	Y	6.6		1.5
Coughlin and van Heezik 2015	New Zealand		pet	Nala	1	F	Y	2.1		1.3
Coughlin and van Heezik 2015	New Zealand		pet	Orion	4	M	Y	2.2		1.7
Coughlin and van Heezik 2015	New Zealand		pet	Otto	3	M	Y	3.1		1
Coughlin and van Heezik 2015	New Zealand		pet	Poppy	10	F	Y	3.8		1.9
Coughlin and van Heezik 2015	New Zealand		pet	Soco	5	F	Y	4		1
Coughlin and van Heezik 2015	New Zealand		pet	Titan	1	M	Y	7.3		1.3
Coughlin and van Heezik 2015	New Zealand		pet	Vex	5	M	Y	3.3		1.3
Coughlin and van Heezik 2015	New Zealand		pet	Yuki	3	F	Y	2.6		1.2
Hall et al. in review-b	Australia	House	Pet	Angel	10	M	Y	0.3	0.2	0.1
Hall et al. in review-b	Australia	House	Pet	Blueberry	8	F	Y	0.9	0.7	0.3
Hall et al. in review-b	Australia	House	Pet	Boo	18	M	Y	1.4	0.4	0.3

Reference	Location	Farm/Rural/House	Husbandry (Farm/Pet)	Cat Reference	Age	Sex	Desexed	Home Range (ha)		
								100% MCP	95% MCP	95% KDE
Hall et al. in review-b	Australia	Rural	Pet	Bruno	5	M	Y	16.5	10.6	8
Hall et al. in review-b	Australia	House	Pet	Comet	1	M	Y	2.8	1.6	1.3
Hall et al. in review-b	Australia	House	Pet	Elliot	5	M	Y	0.4	0.2	0.2
Hall et al. in review-b	Australia	House	Pet	Hazelnut	8	M	Y	1	0.3	0.3
Hall et al. in review-b	Australia	House	Pet	Jay	8	M	Y	1.7	0.8	0.5
Hall et al. in review-b	Australia	Rural	Pet	Misty	3	F	Y	24.7	19.1	18.5
Hall et al. in review-b	Australia	House	Pet	Rex	10	M	Y	0.4	0.3	0.2
Hall et al. in review-b	Australia	House	Pet	Scaboo	7	M	Y	1.5	1.1	0.8
Hall et al. in review-b	Australia	House	Pet	Sparkles	13.5	F	Y	0.9	0.4	0.4
Hall et al. in review-b	Australia	House	Pet	Timba	1	M	Y	1.4	0.6	0.4
Hall et al. in review-b	Australia	Rural	Pet	Toby	3	M	Y	7.6	6.4	6.6
Hall et al. in review-b	Australia	House	Pet	Widget	10	M	Y	0.5	0.3	0.2
Hall et al. in review-b	Australia	House	Pet	Zimba	5	M	Y	5.3	1.3	0.9
Hall et al. in review-b	Australia	House	Pet	BobbySocks	12	M	Y	1.1	0.6	0.4
Hall et al. in review-b	Australia	House	Pet	Casa	2	F	Y	0.4	0.2	0.3
Hall et al. in review-b	Australia	House	Pet	Hugo	5	M	Y	0.9	0.3	0.3
Hall et al. in review-b	Australia	House	Pet	Indigo	3	F	Y	1.7	1.3	1.4
Hall et al. in review-b	Australia	House	Pet	Jasmine	3	F	Y	0.8	0.3	0.2
Hall et al. in review-b	Australia	House	Pet	Licca	8	M	Y	5.6	4.6	2.1
Hall et al. in review-b	Australia	House	Pet	Lilly	2	F	Y	0.5	0.3	0.2
Hall et al. in review-b	Australia	House	Pet	Rina	2	M	Y	0.4	0.3	0.3
Hall et al. in review-b	Australia	House	Pet	Sammy	3	F	Y	0.6	0.3	0.4
Hall et al. in review-b	Australia	House	Pet	Skye	5	F	Y	0.6	0.4	0.4
Hall et al. in review-b	Australia	House	Pet	Squiggles	6	M	Y	0.3	0.2	0.2
Hall et al. in review-b	Australia	House	Pet	Taz	10	M	Y	0.4	0.2	0.3
Hall et al. in review-b	Australia	House	Pet	Thomas	12	M	Y	0.9	0.4	0.3
Hall et al. in review-b	Australia	House	Pet	Tobey	11	M	Y	0.4	0.2	0.3
Hall et al. in review-b	Australia	House	Pet	TC	1	M	Y	0.6	0.4	0.3
Hall et al. in review-b	Australia	House	Pet	Bacon	1	M	Y	0.8	0.5	0.4
Hall et al. in review-b	Australia	Rural	Pet	Max	4	M	Y	22.7	19.5	19.9
Hall et al. in review-b	Australia	Rural	Pet	Billy	4	M	Y	10.5	8.4	6.7

Reference	Location	Farm/Rural/House	Husbandry (Farm/Pet)	Cat Reference	Age	Sex	Desexed	Home Range (ha)		
								100% MCP	95% MCP	95% KDE
Hansen 2010	New Zealand		Pet	Lucy	adult	F	Y	2.2		1
Hansen 2010	New Zealand		Pet	Flossy	adult	F	Y	6.3		2.5
Hansen 2010	New Zealand		Pet	Zoe	adult	F	Y	1.2		0.5
Hansen 2010	New Zealand		Pet	Queenie	adult	F	Y	0.7		0.3
Hansen 2010	New Zealand		Pet	Pisco	adult	M	Y	2.6		0.6
Hansen 2010	New Zealand		Pet	Einstein	adult	M	Y	2.2		0.6
Hansen 2010	New Zealand		Pet	Couscous	adult	M	Y	13.4		15.1
Hansen 2010	New Zealand		Pet	Tigger	adult	M	Y	9.6		6.6
Hervías et al. 2014	Corvo Island		Pet	Corvo 1	6*	M	Y	0.8		1.2
Hervías et al. 2014	Corvo Island		Pet	Corvo 2	7	M	Y	1.7		1.2
Hervías et al. 2014	Corvo Island		Pet	Corvo 3	0.5	M	N	2		2.7
Hervías et al. 2014	Corvo Island		Pet	Corvo 5	3	F	N	3.9		2
Hervías et al. 2014	Corvo Island		Pet	Corvo 10	11	M	N	7.9		1.4
Hervías et al. 2014	Corvo Island		Pet	Corvo 11	9	F	Y	6.2		1.5
Hervías et al. 2014	Corvo Island		Pet	Corvo 15	4	M	Y	10.7		3
Hervías et al. 2014	Corvo Island		Pet	Corvo 19	3	M	Y	6.8		5.9
Hervías et al. 2014	Corvo Island		Pet	Corvo 20	9	F	N	2.6		1.4
Horn et al. 2011	USA		Pet	F2		F	Y		0.4	1.3
Horn et al. 2011	USA		Pet	F3		F	Y		0.4	0.4
Horn et al. 2011	USA		Pet	F22		F	Y		9	7.6
Horn et al. 2011	USA		Pet	F5		F	Y		1	2.4
Horn et al. 2011	USA		Pet	F6		F	Y		0.4	1.3
Horn et al. 2011	USA		Pet	F7		F	Y		3.8	2.3
Horn et al. 2011	USA		Pet	F8		F	Y		0.3	0.2
Horn et al. 2011	USA		Pet	F9		F	Y		0.1	0.2
Horn et al. 2011	USA		Pet	M1		M	Y		0.2	0.4
Horn et al. 2011	USA		Pet	M10		M	Y		0.7	0.2
Horn et al. 2011	USA		Pet	M6		M	Y		4.7	14.9
Kays and DeWan 2004	USA		Pet	Billy	4	M	Y	1.1	0.3	
Kays and DeWan 2004	USA		Pet	Charlie	4	M	Y	0.4	0.3	
Kays and DeWan 2004	USA		Pet	Dog	6*	F	N	0.3	0.2	

Reference	Location	Farm/Rural/House	Husbandry (Farm/Pet)	Cat Reference	Age	Sex	Desexed	Home Range (ha)		
								100% MCP	95% MCP	95% KDE
Kays and DeWan 2004	USA		Pet	Fred	15	M	Y	0.2	0.03	
Kays and DeWan 2004	USA		Pet	Junior	8	M	Y	0.2	0.1	
Kays and DeWan 2004	USA		Pet	Mookie	4	F	Y	0.1	0.1	
Kays and DeWan 2004	USA		Pet	Orion	1	M	Y	3	1.3	
Kays and DeWan 2004	USA		Pet	Quinton	6	M	Y	0.3	0.1	
Kays and DeWan 2004	USA		Pet	Rusty	7	M	Y	0.4	0.1	
Kays and DeWan 2004	USA		Pet	Smokey	6*	F	N	0.1	0.1	
Kays and DeWan 2004	USA		Pet	Willie	4	M	Y	1	0.1	
Kitts-Morgan et al 2015	USA	Farm	Farm	Missy	6	F	N			3.6
Kitts-Morgan et al 2015	USA	Farm	Farm	Arena Kitty	10	F	Y			9.4
Kitts-Morgan et al 2015	USA	Farm	Farm	Oscar	6	F	Y			4.4
Kitts-Morgan et al 2015	USA	Farm	Farm	Hook	4	F	Y			14.4
Kitts-Morgan et al 2015	USA	Farm	Farm	Preggo	7	F	Y			3
Kitts-Morgan et al 2015	USA	Farm	Farm	Little Deb	3	M	N			4.4
Kitts-Morgan et al 2015	USA	Farm	Farm	Psycho	13	M	Y			5.6
Liberg 1980	Sweden	Farm	Farm	F41	5*	F	N	23.8		
Liberg 1980	Sweden	Farm	Farm	F61	5*	F	N	23.3		
Liberg 1980	Sweden	Farm	Farm	M303	1	M	N	36.7		
Liberg 1980	Sweden	Farm	Farm	M302	1	M	N	68.3		
Liberg 1980	Sweden	Farm	Farm	M229	2*	M	N	84.7		
Liberg 1980	Sweden	Farm	Farm	F113	2	F	N	56.5		
Liberg 1980	Sweden	Farm	Farm	F301	1	F	N	28.7		
Liberg 1980	Sweden	Farm	Farm	F2	10	F	N	2.5		
Liberg 1980	Sweden	Farm	Farm	F30	6	F	N	2.4		
Liberg 1980	Sweden	Farm	Farm	F112	1	F	N	7.5		
Liberg 1980	Sweden	Farm	Farm	F111	1	F	N	9.7		
Lilith et al. 2008	Australia	House	Pet	Billy	5	M	Y		0.01	
Lilith et al. 2008	Australia	House	Pet	Cindy	12	F	Y		0.03	
Lilith et al. 2008	Australia	House	Pet	Cali	1	F	Y		0.02	
Lilith et al. 2008	Australia	House	Pet	Rogue	2	F	Y		0.03	
Lilith et al. 2008	Australia	House	Pet	Bob	7	M	Y		0.1	

Reference	Location	Farm/Rural/House	Husbandry (Farm/Pet)	Cat Reference	Age	Sex	Desexed	Home Range (ha)		
								100% MCP	95% MCP	95% KDE
Lilith et al. 2008	Australia	House	Pet	Dustpan	5	M	Y		0.6	
Lilith et al. 2008	Australia	House	Pet	Ziggy	4	M	Y		0.1	
Lilith et al. 2008	Australia	Rural	Pet	Stripes	8	F	Y		1.1	
Lilith et al. 2008	Australia	Rural	Pet	Melba	4	F	Y		0.9	
Lilith et al. 2008	Australia	Rural	Pet	Pepper	5	F	Y		0.1	
Lilith et al. 2008	Australia	Rural	Pet	Tigger	2	M	Y		0.8	
Lilith et al. 2008	Australia	Rural	Pet	Charlie	7	M	Y		0.3	
Lilith et al. 2008	Australia	Rural	Pet	Max	3	M	Y		2.9	
Lilith et al. 2008	Australia	Rural	Pet	DJ	7	M	Y		1.9	
Lilith et al. 2008	Australia	Rural	Pet	Puttaton	2	F	Y		0.1	
Lilith et al. 2008	Australia	Rural	Pet	Scooter	10	M	Y		0.2	
Macdonald and Apps 1978	England	Farm	Farm	Smudge	adult	F	N	7		
Macdonald and Apps 1978	England	Farm	Farm	Pickles	adult	F	N	2		
Macdonald and Apps 1978	England	Farm	Farm	Domino	adult	F	N	4.5		
Macdonald and Apps 1978	England	Farm	Farm	Tom	adult	M	N	60		
Meek 2003	Australia		Pet	Fluff	5	F	Y	14.7	6.5	
Meek 2003	Australia		Pet	Orange Boy	10	M	Y	12	2.3	
Meek 2003	Australia		Pet	Tinkerbell	2	F	Y	3.7	0.2	
Meek 2003	Australia		Pet	Sarg	1	M	Y	2.5	0.02	
Meek 2003	Australia		Pet	Cassie	6	F	Y	1.6	0.1	
Meek 2003	Australia		Pet	Candy	5	F	Y	2	0.5	
Meek 2003	Australia		Pet	Poncho	1	M	N	1.5	1.5	
Meek 2003	Australia		Pet	Sampson	8	M	Y	0.9	0.6	
Meek 2003	Australia		Pet	Emma	5	F	Y	0.6	0.1	
Meek 2003	Australia		Pet	Tiffiny	5	F	Y	0.6	0.1	
Meek 2003	Australia		Pet	Chloe	10	F	N	0.4	0.1	
Meek 2003	Australia		Pet	Katie	4	F	Y	0.2	0.2	
Meek 2003	Australia		Pet	Peggy	2	F	Y	0.2	0.2	
Meek 2003	Australia		Pet	Puss	9	F	Y	0.04	0.04	
Meek 2003	Australia		Pet	Sadie	3	F	Y	3.2	1.5	
Metsers et al. 2010	New Zealand	Rural	Pet	Bella	4	F	Y	10		5

Reference	Location	Farm/Rural/House	Husbandry (Farm/Pet)	Cat Reference	Age	Sex	Desexed	Home Range (ha)		
								100% MCP	95% MCP	95% KDE
Metsers et al. 2010	New Zealand	Rural	Pet	Fizz	4	F	Y	103		64
Metsers et al. 2010	New Zealand	Rural	Pet	Millie	6	F	Y	32		13
Metsers et al. 2010	New Zealand	Rural	Pet	Panini	9	F	Y	1		0.3
Metsers et al. 2010	New Zealand	Rural	Pet	Dexter	12	M	Y	2		0.5
Metsers et al. 2010	New Zealand	Rural	Pet	Jaffa	7	M	Y	14		7
Metsers et al. 2010	New Zealand	Rural	Pet	Mr Hyde	4	M	Y	141		69
Metsers et al. 2010	New Zealand	Rural	Pet	Muffy	5	M	Y	30		18
Metsers et al. 2010	New Zealand	Rural	Pet	Mumtu	2	M	Y	206		34
Metsers et al. 2010	New Zealand	Rural	Pet	Patch	9	M	Y	58		16
Metsers et al. 2010	New Zealand	Rural	Pet	Roly	3	M	Y	108		39
Metsers et al. 2010	New Zealand	Rural	Pet	Stan	12	M	Y	53		23
Metsers et al. 2010	New Zealand	Rural	Pet	Wild Cat	10	M	Y	39		23
Metsers et al. 2010	New Zealand	House	Pet	Evo	4	F	Y	2		1
Metsers et al. 2010	New Zealand	House	Pet	Leo (F)	12	F	Y	1		0.4
Metsers et al. 2010	New Zealand	House	Pet	Meiwe	3	F	Y	5		1
Metsers et al. 2010	New Zealand	House	Pet	Biscuits	10	M	Y	28		11
Metsers et al. 2010	New Zealand	House	Pet	Colin	10	M	Y	2		1
Metsers et al. 2010	New Zealand	House	Pet	Goldberg	8	M	Y	7		1
Metsers et al. 2010	New Zealand	House	Pet	Iwe	3	M	Y	32		19
Metsers et al. 2010	New Zealand	House	Pet	Leo (M)	6	M	Y	2		1
Metsers et al. 2010	New Zealand	House	Pet	Roger	8	M	Y	1		1
Metsers et al. 2010	New Zealand	House	Pet	Schmeizee	8	M	Y	4		2
Metsers et al. 2010	New Zealand	House	Pet	Whitebait	4	M	Y	4		3
Metsers et al. 2010	New Zealand	House	Pet	Flossy	10	F	Y	1		0.3
Metsers et al. 2010	New Zealand	House	Pet	Gracie	4	F	Y	9		6
Metsers et al. 2010	New Zealand	House	Pet	Kitty	9	F	Y	40		9
Metsers et al. 2010	New Zealand	House	Pet	Lilly	2	F	Y	1		0.2
Metsers et al. 2010	New Zealand	House	Pet	Mouse	3	F	Y	6		1
Metsers et al. 2010	New Zealand	House	Pet	Sputnik	6	F	Y	1		0.4
Metsers et al. 2010	New Zealand	House	Pet	Tinkerbelle	11	F	Y	1		0.4
Metsers et al. 2010	New Zealand	House	Pet	Ball	13	M	Y	3		1

Reference	Location	Farm/Rural/House	Husbandry (Farm/Pet)	Cat Reference	Age	Sex	Desexed	Home Range (ha)		
								100% MCP	95% MCP	95% KDE
Metsers et al. 2010	New Zealand	House	Pet	Bandit	7*	M	Y	10		1
Metsers et al. 2010	New Zealand	House	Pet	Bat	10	M	Y	9		1
Metsers et al. 2010	New Zealand	House	Pet	Bob	5	M	Y	2		1
Metsers et al. 2010	New Zealand	House	Pet	Olly	10	M	Y	1		0.4
Metsers et al. 2010	New Zealand	House	Pet	Otis	15	M	Y	15		8
Metsers et al. 2010	New Zealand	House	Pet	Rastus	8	M	Y	4		2
Morgan 2002	New Zealand		Pet	Alfy	3	M	Y	10		
Morgan 2002	New Zealand		Pet	Ally	1	F	Y	0.6		
Morgan 2002	New Zealand		Pet	Angel	16	F	Y	1.6		
Morgan 2002	New Zealand		Pet	Ant	13	F	Y	1.8		
Morgan 2002	New Zealand		Pet	Asha	13	F	Y	1.1		
Morgan 2002	New Zealand		Pet	Big Puss	8	M	Y	3.4		
Morgan 2002	New Zealand		Pet	Churchill	8	M	Y	0.2		
Morgan 2002	New Zealand		Pet	Cuddles	2	M	Y	6.6		
Morgan 2002	New Zealand		Pet	Gatino	4	M	Y	4		
Morgan 2002	New Zealand		Pet	Hercules	11	M	Y	0.6		
Morgan 2002	New Zealand		Pet	Jems	12	F	Y	0.3		
Morgan 2002	New Zealand		Pet	Little Puss	6	M	Y	3.5		
Morgan 2002	New Zealand		Pet	Misty	8	F	Y	0.5		
Morgan 2002	New Zealand		Pet	Monty	2	M	Y	9.4		
Morgan 2002	New Zealand		Pet	Paws	8	M	Y	0.4		
Morgan 2002	New Zealand		Pet	Rosy	7	F	Y	0.1		
Morgan 2002	New Zealand		Pet	Sally	4	F	Y	4.3		
Morgan 2002	New Zealand		Pet	Snoopy	12	M	Y	2.6		
Morgan 2002	New Zealand		Pet	Tammy	2	F	Y	4.3		
Morgan 2002	New Zealand		Pet	Wiskas	8	M	Y	3.8		
Morgan 2002	New Zealand		Pet	Zeus	5	M	Y	0.2		
Schär and Tschanz 1982	Switzerland	Farm	Farm	Male		M	N	68.3		
Schär and Tschanz 1982	Switzerland	Farm	Farm	Y Female		F	N	10.6		
Schär and Tschanz 1982	Switzerland	Farm	Farm	G Female		F	N	5.3		
Schär and Tschanz 1982	Switzerland	Farm	Farm	R Female		F	N	13		

Reference	Location	Farm/Rural/House	Husbandry (Farm/Pet)	Cat Reference	Age	Sex	Desexed	Home Range (ha)		
								100% MCP	95% MCP	95% KDE
Schär and Tschanz 1982	Switzerland	Farm	Farm	P Female		F	N	3.79		
Thomas et al. 2014	UK		Pet	Thomas 1	1	M	Y	16.2	6.2	
Thomas et al. 2014	UK		Pet	Thomas 2	8	F	Y	17.5	4.7	
Thomas et al. 2014	UK		Pet	Thomas 3	9	M	Y	11.7	2.1	
Thomas et al. 2014	UK		Pet	Thomas 4	1	F	Y	7.8	2.4	
Thomas et al. 2014	UK		Pet	Thomas 5	8	M	Y	33.8	3.3	
Thomas et al. 2014	UK		Pet	Thomas 6	1	F	Y	16.7	3.3	
Thomas et al. 2014	UK		Pet	Thomas 7	3	M	Y	23	7.6	
Thomas et al. 2014	UK		Pet	Thomas 8	12	F	Y	5.7	1.3	
Thomas et al. 2014	UK		Pet	Thomas 9	6	M	Y	15.6	2.1	
Thomas et al. 2014	UK		Pet	Thomas 10	9	M	Y	2.6	1.5	
Thomas et al. 2014	UK		Pet	Thomas 11	1	M	Y	21.7	5.5	
Thomas et al. 2014	UK		Pet	Thomas 12	3	M	Y	26.9	3.2	
Thomas et al. 2014	UK		Pet	Thomas 13	16	M	Y	8.4	2.6	
Thomas et al. 2014	UK		Pet	Thomas 14	4	M	Y	22.7	4.6	
Thomas et al. 2014	UK		Pet	Thomas 15	10	M	Y	5.9	2	
Thomas et al. 2014	UK		Pet	Thomas 16	7	F	Y	3.7	1.4	
Thomas et al. 2014	UK		Pet	Thomas 17	8	M	Y	13.8	5.4	
Thomas et al. 2014	UK		Pet	Thomas 18	7	M	Y	10.1	3.4	
Thomas et al. 2014	UK		Pet	Thomas 19	9	M	Y	11	2.6	
Thomas et al. 2014	UK		Pet	Thomas 20	5	M	Y	10.8	3	
Turner and Mertens 1986	Switzerland	Farm	Farm	Max	1	M	N	25		9.8
Turner and Mertens 1986	Switzerland	Farm	Farm	Mietze	1	F	N	26.5		9
Turner and Mertens 1986	Switzerland	Farm	Farm	Schrurrli	2	F	N	11		4
Turner and Mertens 1986	Switzerland	Farm	Farm	Mohrli	4	F	N	10		3.2
Turner and Mertens 1986	Switzerland	Farm	Farm	Pfaffli	1	F	N	4.8		1.2
Turner and Mertens 1986	Switzerland	Farm	Farm	Fritz	2	M	N	4		1
Turner and Mertens 1986	Switzerland	Farm	Farm	Lumpi	4	M	N	49.2		16
Turner and Mertens 1986	Switzerland	Farm	Farm	Sebastian	2	M	N	22		8.2
Turner and Mertens 1986	Switzerland	Farm	Farm	Ramona	6	F	N	39		17.2
Turner and Mertens 1986	Switzerland	Farm	Farm	Muger	4	F	N	5.5		1.5

Reference	Location	Farm/Rural/House	Husbandry (Farm/Pet)	Cat Reference	Age	Sex	Desexed	Home Range (ha)		
								100% MCP	95% MCP	95% KDE
Turner and Mertens 1986	Switzerland	Farm	Farm	Nicki	2	M	Y	3.8		0.8
van Heezik et al. 2010	New Zealand		Pet	Ash	2	F	Y	1.2		
van Heezik et al. 2010	New Zealand		Pet	Alice	3	F	Y	0.7		
van Heezik et al. 2010	New Zealand		Pet	Choccie	6	F	Y	2.6		
van Heezik et al. 2010	New Zealand		Pet	Ruby	6	F	Y	1.3		
van Heezik et al. 2010	New Zealand		Pet	Ellie	1	F	Y	2.5		
van Heezik et al. 2010	New Zealand		Pet	Lexie	4	F	Y	0.5		
van Heezik et al. 2010	New Zealand		Pet	Muffin	1	F	Y	1.3		
van Heezik et al. 2010	New Zealand		Pet	Petra	2	F	Y	2.1		
van Heezik et al. 2010	New Zealand		Pet	Pfiffer	5	F	Y	1.1		
van Heezik et al. 2010	New Zealand		Pet	Oakley	5	F	Y	1.4		
van Heezik et al. 2010	New Zealand		Pet	Smithies	2	F	Y	2		
van Heezik et al. 2010	New Zealand		Pet	Lily	7	F	Y	2.3		
van Heezik et al. 2010	New Zealand		Pet	Cami	2	F	Y	4.1		
van Heezik et al. 2010	New Zealand		Pet	Mushka	2	F	Y	0.2		
van Heezik et al. 2010	New Zealand		Pet	Bandit	5	M	Y	14.9		
van Heezik et al. 2010	New Zealand		Pet	Twiggy	1	M	Y	1.6		
van Heezik et al. 2010	New Zealand		Pet	Dylan	3	M	Y	21.8		
van Heezik et al. 2010	New Zealand		Pet	Fingers	5	M	Y	3.4		
van Heezik et al. 2010	New Zealand		Pet	Marlowe	2	M	Y	1.1		
van Heezik et al. 2010	New Zealand		Pet	Misty	5	M	Y	5.3		
van Heezik et al. 2010	New Zealand		Pet	Mittens	9	M	Y	3.2		
van Heezik et al. 2010	New Zealand		Pet	Spencer	5	M	Y	4.5		
van Heezik et al. 2010	New Zealand		Pet	Theseus	10	M	Y	2.6		
van Heezik et al. 2010	New Zealand		Pet	Barney	9	M	Y	2.1		
van Heezik et al. 2010	New Zealand		Pet	Beer	1	M	Y	2.4		
van Heezik et al. 2010	New Zealand		Pet	Big Puddy	6	M	Y	0.5		
van Heezik et al. 2010	New Zealand		Pet	Majik	7	M	Y	3.4		
van Heezik et al. 2010	New Zealand		Pet	Pushkin	10	M	Y	2		
van Heezik et al. 2010	New Zealand		Pet	Latte	3	M	Y	4.3		
van Heezik et al. 2010	New Zealand		Pet	Zebedee	11	M	Y	2.6		

Reference	Location	Farm/Rural/House	Husbandry (Farm/Pet)	Cat Reference	Age	Sex	Desexed	Home Range (ha)		
								100% MCP	95% MCP	95% KDE
van Heezik et al. 2010	New Zealand		Pet	Louie	2	M	Y	0.4		
Weber and Dailly 1998	Switzerland	Farm	Farm	M1	3	M	N	6.5		
Weber and Dailly 1998	Switzerland	Farm	Farm	F1	7	F	N	45.3		
Weber and Dailly 1998	Switzerland	Farm	Farm	F2	7	F	N	10.6		

*Age estimated from mean age of other cats in that study

APPENDIX 8: SUMMARY DATA ON CAT HOME RANGES FROM ALL AVAILABLE AND APPLICABLE STUDIES

Reference	Location	Husbandry	House/ Rural/ Farm	Sex	Desexed	n	Home Range 100% MCP (ha)			Home Range 95% MCP (ha)			Home Range 95% KDE (ha)		
							Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Barratt 1997a	Australia	Farm	Farm	M	N	2	7.4	0.6	7.4-7.5	2.7	1.9	1.8-4.5			
Barratt 1997a	Australia	Farm	Farm	F	N	5	9.2	8.3	3.2-23.4	3.1	1	1.4-3.7			
Barratt 1997a	Australia	Pet		M	Y	5	8.6	14.1	0.1-33.1	6	9.4	0.1-22.2			
Barratt 1997a	Australia	Pet		M	N	1	43.6			20.5					
Barratt 1997a	Australia	Pet		F	Y	4	7.5	13.8	0.1-28.4	7.2	13.8	0.04-27.9			
Bradshaw 1992	England	Pet		F	Y	1	0.9			0.5					
Bradshaw 1992	England	Pet		M	Y	1	0.9			0.3					
Carss 1995	Scotland	Pet	Rural	M	Y	1	53								
Chipman 1990 in Bradshaw 1992	UK	Pet		M	N	17	0.9*								
Chipman 1990 in Bradshaw 1992	UK	Pet		M	Y	52	0.1*								
Chipman 1990 in Bradshaw 1992	UK	Pet		F	64N /66Y	66	0.1*								
Corbett 1979	Hosta, Scotland	Farm	Farm	M	N	11	27.8	17.7	4.4-63.2						
Corbett 1979	Hosta, Scotland	Farm	Farm	F	N	5	14.7	9.8	4.9-30.3						
Coughlin and van Heezik 2015	New Zealand	Pet		F	Y	8	3.5	1	2.1-5.4				1.5	0.3	1.1-1.9
Coughlin and van Heezik 2015	New Zealand	Pet		M	Y	12	4.2	2	2.2-7.2				1.6	0.7	0.7-1.9
Das 1993 in Barratt 1997a	Australia	Pet		F		5	0.3	0.2							
Das 1993 in Barratt 1997a	Australia	Pet		M		8	0.5	0.2							
Hall et al. in review-b	Australia	Pet	House	F	Y	8	0.8	0.4	0.4-1.7	0.5	0.4	0.2-1.3	0.5	0.4	0.2-1.4
Hall et al. in review-b	Australia	Pet	House	M	Y	21	1.3	1.5	0.3-5.6	0.7	1	0.2-4.6	0.5	0.5	0.2-2.1
Hall et al. in review-b	Australia	Pet	Rural	F	Y	1	24.7			19.1			18.5		
Hall et al. in review-b	Australia	Pet	Rural	M	Y	4	14.3	6.7	7.6-22.7	11.2	5.8	6.4-19.5	10.3	6.4	6.6-19.9
Hansen 2010	New Zealand	Pet		F	Y	4	2.6	2.5	0.7-6.3				1.1	1	0.3-2.5
Hansen 2010	New Zealand	Pet		M	Y	4	7	5.5	2.2-13.4				5.7	6.9	0.6-15.1

Reference	Location	Husbandry	House/ Rural/ Farm	Sex	Desexed	n	Home Range 100% MCP (ha)			Home Range 95% MCP (ha)			Home Range 95% KDE (ha)		
							Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Hervías et al. 2014	Corvo Island	Pet		F	Y	1	6.2						1.5		
Hervías et al. 2014	Corvo Island	Pet		F	N	2	3.2	1	2.6-3.9				1.7	0.4	1.4-2
Hervías et al. 2014	Corvo Island	Pet		M	Y	4	5	4.7	0.8-10.7				2.8	2.2	1.2-5.9
Hervías et al. 2014	Corvo Island	Pet		M	N	2	5	4.2	2-7.9				2.1	0.9	1.4-2.7
Horn et al. 2011	USA	Pet		F	Y	8				1.9	3.1	0.1-9	2	2.5	0.2-7.6
Horn et al. 2011	USA	Pet		M	Y	3				1.8	2.5	0.2-4.7	5.2	8.5	0.2-14.9
Kays and DeWan 2004	USA	Pet		F	Y	2	0.2	0.1	0.1-0.3	0.2	0.1	0.1-0.2			
Kays and DeWan 2004	USA	Pet		F	N	1	0.1			0.1					
Kays and DeWan 2004	USA	Pet		M	N	8	0.8	0.9	0.2-3	0.3	0.4	0.1-1.3			
Kitts-Morgan et al 2015	USA	Farm	Farm	F	N	1							3.6		
Kitts-Morgan et al 2015	USA	Farm	Farm	F	Y	4							7.8	5.2	3-14.4
Kitts-Morgan et al 2015	USA	Farm	Farm	M	N	1							4.4		
Kitts-Morgan et al 2015	USA	Farm	Farm	M	Y	1							5.6		
Liberg 1980	Sweden	Farm	Farm	F	N	7	19.3	18.1	2.4-56.5						
Liberg 1980	Sweden	Farm	Farm	M	N	3	63.2	24.4	36.7-84.7						
Lilith et al. 2008	Australia	Pet	House	F	Y	3				0.03	0.01	0.02-0.03			
Lilith et al. 2008	Australia	Pet	House	M	Y	4				0.2	0.3	0.01-0.6			
Lilith et al. 2008	Australia	Pet	Rural	F	Y	4				0.5	0.5	0.1-1.1			
Lilith et al. 2008	Australia	Pet	Rural	M	Y	5				1.2	1.2	0.2-2.9			
Macdonald and Apps 1978	England	Farm	Farm	M	N	3	4.5	2.5	2-7						
Macdonald and Apps 1978	England	Farm	Farm	F	N	1	60								
Meek 2003	Australia	Pet		F	Y	10	2.7	4.4	0.04-14.7	0.9	2	0.04-6.5			
Meek 2003	Australia	Pet		F	N	1	0.4			0.1					
Meek 2003	Australia	Pet		M	Y	3	5.1	6	0.9-12	1	1.2	0.02-2.3			
Meek 2003	Australia	Pet		M	N	1	1.5			1.5					
Metsers et al. 2010	New Zealand	Pet	House	F	Y	10	6.7	12	1-40				2	3	0.2-9
Metsers et al. 2010	New Zealand	Pet	House	M	Y	15	8.3	9.7	1-32				3.6	5.2	0.4-19
Metsers et al. 2010	New Zealand	Pet	Rural	F	Y	4	36.5	46.2	1-103				20.6	29.4	0.3-64
Metsers et al. 2010	New Zealand	Pet	Rural	M	Y	9	72.3	66.8	2-206				25.5	20.2	0.5-69
Morgan 2002	New Zealand	Pet		F	Y	9	1.6	1.6	0.3-4.3						

Reference	Location	Husbandry	House/ Rural/ Farm	Sex	Desexed	n	Home Range 100% MCP (ha)			Home Range 95% MCP (ha)			Home Range 95% KDE (ha)		
							Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Morgan 2002	New Zealand	Pet		M	Y	12	3.7	3.4	0.2-10						
Schär and Tschanz 1982	Switzerland	Farm	Farm	M	N	1	68.3								
Schär and Tschanz 1982	Switzerland	Farm	Farm	F	N	4	8.2	4.3	3.8-13						
Thomas et al. 2014	UK	Pet		F	Y	5	10.3	6.4	3.7-17.5	2.7	1.4	1.3-4.7			
Thomas et al. 2014	UK	Pet		M	Y	15	15.6	8.5	2.6-22.7	3.7	1.8	1.5-6.2			
Turner and Mertens 1986	Switzerland	Farm	Farm	M	N	4	25.1	18.6	4-49.2				8.8	6.2	1-9.8
Turner and Mertens 1986	Switzerland	Farm	Farm	M	Y	1	3.8						0.8		
Turner and Mertens 1986	Switzerland	Farm	Farm	F	N	6	16.1	13.7	5.5-39				6	6.2	1.2-17.2
van Heezik et al. 2010	New Zealand	Pet		F	Y	14	1.7	1	0.2-4.3						
van Heezik et al. 2010	New Zealand	Pet		M	Y	17	4.4	5.4	0.4-21.8						
Warner 1985	USA	Farm	Farm	F	N	7	112	21	48-185						
Warner 1985	USA	Farm	Farm	M	N	4	228	100	109-528						
Weber and Dailly 1998	Switzerland	Farm	Farm	M	N	1	6.5								
Weber and Dailly 1998	Switzerland	Farm	Farm	F	N	2	28	24.5	10.6-45.3						

*median not mean