Abstract

Over the past 20 years conservation efforts in New Zealand have moved from being concentrated in rural and isolated island locations, where exotic mammalian predators are often controlled, to begin to bring native fauna back to major cities. However, human-wildlife conflicts arise when conservation occurs in close proximity to cities, which, by definition, are vastly altered habitats from the natural form in both structure and species composition. These conflicts are particularly intense when companion animals are involved either as potential predators or prey of high-value conservation animals. Within New Zealand this conflict is particularly fraught around domestic cats (*Felis catus*) in the urban environment, where both owned and unowned individuals live at high densities. Cats in New Zealand are recognised as major introduced predators of native fauna, but they also prey upon small introduced predatory mammals. This dynamic causes much conflict between people with different attitudes towards animals, but as yet few studies have explored the role(s), either negative or positive, of urban cats in New Zealand. Here, we review current knowledge on domestic cats in urban New Zealand, identify gaps in knowledge, and make suggestions for future research – which include citizen science-based research programmes investigating urban cat ecology, further social research regarding motivators for behaviour change in cat owners, investigation into international cat management legislation, market research of cat containment systems, and more in depth research into cat diseases and zoonoses. This information is vital for informing the public and improving the management of the urban cat populations, including mitigating any potential conservation impacts. Urban ecologists will need to be versatile in the way that they design and conduct experiments in this unique situation.

Key Words

Invasive species; wildlife conservation; cat; domestic; stray; feral; human-wildlife conflict; Citizen Science; owned; unowned

Introduction

Worldwide, over 50% of the human population lives in urban environments (World Health Organization (WHO) 2014), and over 85% of New Zealanders live in cities (Statistics New Zealand 2014). Globally, habitat loss is an ongoing threat to biodiversity (Townsend 2008). As such, urban and semi-urban environments are increasingly performing essential environmental roles as wildlife refuges (Aronson *et al.* 2014), contributing to the increase in research on urban ecology - the interdisciplinary study of ecosystems in human-dominated environments (Marzluff *et al.* 2008). Wildlife in close proximity to cities often leads to human-wildlife conflicts (Conover 2001). These conflicts can be especially fraught where companion animals are predators, or prey, of wildlife of high-conservation value (Baker *et al.* 2008; Gehrt *et al.* 2013). One such conflict reported is that of domestic cats (*Felis catus*), which are major predators of small mammals, reptiles, and invertebrates (Loss *et al.* 2013), as well as birds (Loyd *et al.* 2013) and fish (Woods *et al.* 2003). While direct predation of wildlife by cats is often emphasized in research and popular press, other documented impacts of cats include competition for resources, alteration of ecological processes, behavioural changes (e.g. induction of stress or changes in breeding behaviour), and disease transmission (Medina *et al.* 2014). In New Zealand, cats pose a particularly complex problem as: 1) native species have evolved in the absence of predatory mammals and face current challenges of vastly altered ecosystems (Towns *et al.* 2001), 2) conservation efforts are increasingly focusing on cities (Innes *et al.* 2012), 3) cats are the most common companion animal in New Zealand (NAWAC 2007), and are predators of both native and exotic species (King 2005;

Fitzgerald and Karl 1979; Tocher 2006), 4) evidence of predator-prey dynamics of cats in urban locations is in its infancy (but see Gillies and Clout 2003; Morgan *et al.* 2009; Flux 2010; Metsers *et al.* 2010; van Heezik *et al.* 2010), and 5) amongst New Zealanders, vastly different attitudes towards animals can be found (Farnworth *et al.* 2013b).

Almost 50 years ago, the New Zealand Wildlife Service produced and distributed a pamphlet, *Problem Cats*, to all New Zealand households outlining their threat to native wildlife within forested areas (Swarbrick 2013). Since that time, several studies in non-urban areas have added evidence of the threat of cats to native wildlife (e.g., Fitzgerald and Karl 1979; King 2005; Tocher 2006). For example, cats are in part responsible for the extinction of the Stephens Island wren, *Traversia lyalli*, (Galbreath and Brown 2004) and the decline of many reptile populations (Daugherty and Towns 1991; Hitchmough *et al.* 2016). However, evidence that cats may have some beneficial effects (e.g. suppressing smaller predatory mammals) has led to disparate views among people with different attitudes towards animals (Loyd and Hernandez 2012; Farnworth *et al.* 2013b; van Heezik 2010). Only in the past 13 years have investigations of cats within New Zealand's urban environment, and their potential effects, been published (Table 1). The resurgence in public debate is primarily due to Dr. Gareth Morgan's "Cats to Go" campaign (Morgan Foundation 2013). As a result, public conflict concerning cats in New Zealand has received substantial media coverage, both locally and overseas (Cowlishaw 2013; Berwick 2014; Shuttleworth 2013).

Here, we review the current knowledge of ecology of urban cats in New Zealand to help identify areas of research needed to better understand their ecological and social impacts. This includes information on: ecology of urban cats, for example population size; home range/territory size; predator-prey dynamics; potential for predator-release should cats be controlled; behavioural syndromes (e.g., hunting ability); antipredator devices (e.g., bells on collars), zoonoses (e.g., toxoplasmosis); and investigation into the public perceptions and

attitudes towards cats and their management. This information is necessary to enable the public to make informed decisions regarding how they manage their pet cats, for government (local and central) to improve cat management, and to aid in mitigating conservation impacts within urban environments. We also include a table of current cat restriction bylaws in New Zealand (Table 2).

Cats in New Zealand

No national body for the management of owned cats currently exists in New Zealand. However, in November 2014, several organisations came together to form the "National Cat Management Strategy Group" (NCMSG). Member organisations include the New Zealand Veterinary Association (NZVA), the New Zealand Companion Animal Council, the Royal New Zealand Society for the Prevention of Cruelty to Animals, the Morgan Foundation, and Local Government New Zealand. Technical advisors to the group include the Department of Conservation and the Ministry for Primary Industries. This group's primary objective is to promote responsible cat ownership, environmental protection, and humane cat management (Smallman 2016). However, legislation regarding the management of cats is, at present, left to the local government.

In September 2016, the NCMSG launched a draft cat management strategy implementation document and requested feedback on the proposal (cite NZVA: http://www.nzva.org.nz/newsstory/vision-responsible-cat-ownership-and-humane-cat-management). The consultation period runs through October 2016 and the NCMSG plans to submit the proposal to central government by the end of 2016. Consistent national legislation regarding cat management will be a huge step forward, making it easier for local councils to

96 establish bylaws which will both benefit cat welfare and help protect vulnerable native
97 wildlife.

98 At present, regulations and bylaws pertaining to the management of owned cats in
99 New Zealand are piecemeal amongst individual councils (Table 2). The local government
100 sectors in New Zealand are comprised of 11 Regional Councils, 61 territorial authorities (50
101 District Councils and 11 City Councils), and 6 Unitary Councils (territorial authorities with
102 regional council responsibilities) (LGNZ 2016). While cats are not specifically mentioned in
103 the bylaws of many councils, it is possible for management issues regarding pet cats to be
104 addressed under a council's Nuisance Laws or within the Health Act, however these are
105 limited in their ability to reduce impacts on wildlife. While some councils do limit the
106 number of cats per household (Table 2), the Wellington City Council reviewed its Animal
107 bylaw in August 2016 and voted that all cats over 12 weeks of age must be microchipped and
108 registered with the New Zealand Companion Register by early 2018 – the first such cat
109 management legislation of any council in New Zealand.

110 In New Zealand, the public perception of cats (in general) ranges from valued
111 household companion animal to introduced pests (Kikillus, unpublished data); in part this
112 perception is likely due to both the perceived emotional value provided by cats in conjunction
113 with the perceived environmental costs imposed by their presence (Farnworth *et al.* 2011).
114 These underlying social perceptions of cats have driven the development of their three
115 categories found in the Animal Welfare (Companion Cats) Code of Welfare (NAWAC 2007,
116 hereinafter called 'the code'): companion, stray and feral cats. Likewise, variations in public
117 considerations concerning the control of these three categories of cat are associated with
118 value-based judgements (Farnworth *et al.* 2011). The definitions are primarily driven by
119 anthropocentric principles; companion cats are those fully provided for within an ownership
120 model, stray cats are provided for either directly or indirectly by human populations (e.g. *ad*

121 *hoc* provision of food and shelter) whilst feral cats receive no human support. These
122 definitions may easily be misconstrued by those who do not have a working knowledge of the
123 code (Farnworth *et al.* 2010). The definitions do, however, indicate that unowned urban cats
124 are stray as opposed to feral. Stray cats, as per the code, are considered within the purview of
125 animal welfare charities whereas feral cats are 'in a wild state' and therefore able to be
126 controlled and managed (Anonymous 1987; NAWAC 2007). As such, for simplicity, here
127 we refer to cats as 'owned' or 'unowned' to enable their management to be addressed
128 appropriately.

129 Despite the afore-mentioned definitions of cats, it is reasonable to suggest that the cat
130 population is in reality a single fluid contiguous group where individuals may transition from
131 one group to another, dependent upon their location and the human population that it lives
132 within or besides. Unowned urban cats are more prevalent in areas with higher human
133 population density (Aguilar and Farnworth 2013; Aguilar and Farnworth 2012, Aguilar *et al.*
134 2015) and live at far higher densities than unowned cats in rural environs (Langham and
135 Porter, 1991). Proximity to human environments and anthropogenic food sources likely
136 provide unowned urban cats with the necessary resources to reproduce and survive in
137 significant numbers.

138 In 2013, the New Zealand Veterinary Association (NZVA) commissioned a
139 systematic literature review of peer-reviewed cat publications from New Zealand and
140 overseas (Farnworth *et al.* 2013a). The key findings from the report included that cats in
141 New Zealand likely prey upon millions of small animals (both native and non-native)
142 annually; Trap-Neuter-Return (TNR) is unlikely to provide a long term solution to cat
143 population management in New Zealand; formal mechanisms to establish cat ownership
144 should be investigated (e.g. compulsory registration and microchipping); more research is
145 needed on cat population management; and the promotion of responsible pet ownership must

be a focus of any strategy for cat management (Farnworth *et al.* 2013a). In all cases, more research is needed to better understand the impact of cats on the environment.

Despite much research in New Zealand on the impacts of unowned cats in rural locations, the impact of owned cats on wildlife in urban locations is a matter of vigorous public debate; one that may be hard to resolve given that conservationists and those involved with (companion) animal welfare organisations can have diametrically opposed viewpoints (Farnworth *et al.* 2013b). Studies on other impacts of cats, such as disease transmission and the emotional value of pet cats in New Zealand to their owners, are also limited (but see Farnworth *et al.* 2011; Roe *et al.* 2013). There is scope for much more research on cats in New Zealand.

Suggestions for future research on cats in urban environments in New Zealand

We have identified several areas which warrant further research in regards to cats in New Zealand (See Figure 1).

Social studies

Being such an emotive topic, any research and / or management of urban cats is going to raise debate amongst the public. Therefore, social research in order to understand the public perception of cats in New Zealand is vital. Some research has begun, from investigating the use and perception of cat collars (Harrod *et al.* 2016) to the acceptability of unowned cat control (Farnworth *et al.* 2013a). A survey designed to better understand the attitudes of Western Australians towards cat control legislation (Grayson *et al.* 2002) has been adapted for use in other countries, including New Zealand. Results showed that the vast majority of New Zealand respondents agreed that pet cats in nature reserves are harmful to wildlife.

Despite this, responses suggested that New Zealanders that did not own cats were much more likely to support the idea of cat legislation than those who did own cats (Hall *et al.* 2016).

In the UK, cat owners are often unwilling to admit that their pets may be a threat to wildlife (McDonald *et al.* 2015). Recent research has suggested that advocacy campaigns for cat containment that focus on the benefits to cat welfare, rather than wildlife conservation, may be more successful (MacDonald *et al.* 2015) (cite Hall 2016) and that a better understanding by cat owners of the risks encountered by free-ranging cats may result in behaviour change (Gramza *et al.* 2016). Include Farnworth papers here.

Ecology and Environment

Citizen Science

In much of traditional ecology, experiments involving control and treatment groups are used (Karban and Huntzinger, 2006). However, in the case of urban cats and the public, it is difficult to obtain such a broad-scale level of cooperation (e.g., by comparing one neighbourhood with free-roaming owned cats to a similar neighbourhood where residents have agreed to keep their cats indoors for a specified period of time). Therefore, other research options are needed in place of traditional ecological methods - such as Citizen Science, where scientists partner with the public to answer scientific questions. Citizen Science provides scientists with increased potential for data collection and analyses, and the public with important science education; not only do they gain a better understanding of science, but also increased engagement in environmental issues (Roetman and Daniels 2011). Studies involving Citizen Science are becoming more popular in New Zealand, and by using this methodology, extensive research on urban cats is possible and can provide much

193 needed data for their management and the conservation of native species. Large-scale Citizen
194 Science projects involving cats could include investigating cat movements, behaviour
195 (especially via collar-mounted cameras – as per Loyd *et al*. 2013), owner's attitudes towards
196 cat management, and building a large database of prey brought home by owned cats.

197 *How many cats are there?*

198 As no registration regulations exist for cats in New Zealand (as there are with dogs),
199 no reliable population census of cat numbers exists, however according to the New Zealand
200 Companion Animal Council, New Zealand has the highest recorded rate of cat ownership in
201 the developed world (MacKay 2011). Two studies focused on the South Island cities of
202 Dunedin and Christchurch estimated the percentages of households owning cats as 35% and
203 33%, respectively (van Heezik *et al.* 2010, Morgan *et al.* 2009). It is unknown if the cat
204 ownership estimates in these cities are representative of all of New Zealand urban areas,
205 especially those in the North Island, which has a higher human population than the South
206 Island as well as New Zealand's most populated city (Auckland) and the capital (Wellington).

207 Due to maintenance provided by humans, high densities of cats can exist in urban
208 spaces (Lepczyk *et al.* 2004, Sims *et al.* 2008, Aguilar and Farnworth, 2013). Knowing the
209 percentage of households owning one or more cats is vital for local government agencies
210 considering implementing legislation changes, and hence, how many rate payers may be
211 affected by these changes (M. Emeny, Wellington City Council, pers. comm.). Similarly, the
212 proportion of cats that are owned (companion) vs. unowned (stray), and how these interact
213 with free-living (feral) cats, is unclear. Within Auckland, unowned stray and owned pet cats
214 are geographically indistinguishable, and the cat population density is positively correlated
215 with human population density (Aguilar and Farnworth 2012; Aguilar and Farnworth 2013).

Where does kitty wander?

A home range is defined as the area an animal uses to find food and resources, whereas a territory is a portion of the home range that is defended (Spotte, 2014). Several studies of cat home ranges overseas (encompassing both owned and unowned cats) show that cats can vary dramatically in this regard - from less than 1 hectare for urban strays in Japan (cite Yamane 1994) to over 2000 hectares for rural ferals in Australia's Northern Territory (cite Edwards 2001) - although in general, larger cats tend to have larger home range sizes (Spotte 2014; Molsher *et al.* 2005). In New Zealand, studies have shown that pet cats living near natural areas (e.g. wetlands, reserves, etc.) or in rural areas tend to have larger home ranges than strictly urban cats (Morgan *et al.* 2009; Metsers *et al.* 2010) (Table 1). Preliminary results from a Citizen Science-based cat tracking project in Wellington, New Zealand (www.cattracker.nz) are consistent with these findings (Kikillus, unpublished data). Additional studies in other New Zealand cities will help to clarify patterns that may predict home range sizes for urban cats, or whether home range is related to habitat-specific traits of a city (for example, do urban cats venture further in areas with more open space, such as reserves, compared to areas where they may be constrained by buildings and motorways?). Further, continuing to use GPS techniques will help identify how often owned cats are entering areas of high conservation value, and thus whether more controls are needed, or suggest sizes of cat "buffer zones" that may be appropriate and the feasibility of implementing them – both in the practicality of having enough space and in the public support for them (Metsers *et al.* 2010).

What does the cat drag in?

The type of environment in which cats are located will impact the type(s) of prey captured. For example, in one study in Auckland, prey captured by cats in more "natural" forested neighbourhoods consisted mostly of rodents, and was dramatically different from

241 prey caught in purely urban areas (primarily invertebrates) (Gillies and Clout 2003) (Table 1).
242 Therefore, within urban environments, ecologists must take into account the differences
243 among various available habitats.

244 Cats have no natural predators in New Zealand, yet prey upon a wide variety of
245 smaller animals (King 2005) and may have impacts on native fauna. However, they may also
246 be indirectly helping native wildlife by keeping other introduced pests, such as rodents and
247 rabbits, in check. Further research into the impacts of owned cats on prey populations (both
248 introduced mammals and native wildlife) is warranted and a large database of prey captured
249 by cats could be easily conducted via a Citizen Science smartphone app. Meso-predator
250 release (when a top predator is removed and another predator – for example, rodents - fills
251 the void) can occur in some situations when an apex predator is eradicated (Oppel *et al.*
252 2014). Research into meso-predator release scenarios in areas where cats are removed is
253 needed within the urban environment in New Zealand (ideally via field comparisons between
254 similar areas where cats, but no other predators, have and have not been eradicated, but also
255 possibly through modelling scenarios). It has been suggested that the potential of meso-
256 predator release involving the eradication of cats should be considered on a case-by-case
257 basis in areas in New Zealand (Jones 2008).

258 Consistent differences in behavioural syndromes have been well-documented in
259 numerous species of animals (Sih *et al.* 2004) and among cats it has been observed that not
260 all cats are avid predators (Loyd *et al.* 2013) (add van Heezik). Why are some cats ardent
261 hunters whereas others are not? Research into what factors influence predatory behaviour
262 and prey specialisation (e.g. some target certain prey species, such as birds or rodents), could
263 investigate factors such as the prey available in a given environment or genetic components
264 of behavioural syndromes. For example, urban cats in the USA avoided larger-sized rats and
265 focussed their hunting efforts on smaller (under 300 gram) specimens – these may have been

easier to catch than larger rats, but the predation had no real impact on the rat population size as larger, sexually-mature rats were not controlled by cats and were left to breed (Glass *et al.* 2009). In Australia, studies found that cats often specialise in a particular type of prey and may continue to hunt their preferred prey, even if numbers are low – this may contribute another challenge to the conservation of rare native species (cite Dickman 2015). The studies outlined in Table 1 provide further support, in that: 1) not all owned cats in New Zealand bring prey home, and 2) rodents, followed by birds, generally appear to be the most popular prey items.

Anti-predation devices

Cats are likely to remain as a fixture in the urban environment of New Zealand. Therefore, research on effective anti-predation methods is vital. In Dunedin, New Zealand, Gordon and coworkers (2010) found that bells attached to domestic cat collars can reduce prey catch by half. Overseas, trials of various anti-predation products, such as the CatBib™, sonic devices, and the Birdsbesafe® collar cover have successfully shown reduced prey catch by owned cats compared to control groups (Calver *et al.* 2007; Hall *et al.* 2015). (cite Nelson 2005 and Willson 2015). Similar trials are urgently needed in New Zealand to test the effectiveness of these products and investigate if they are more effective than bells on collars. Of special interest are New Zealand-based studies of the Birdsbesafe® collar cover, which have been shown overseas to decrease bird and herpetofauna predation but not significantly reduce the predation of small mammals (cite Hall 2015). This is of great relevance to New Zealand, where native birds and herpetofauna are vulnerable to free-roaming cats but where small mammals (i.e. rodents) are introduced pests. It is important to note that while anti-predation devices may assist to mitigate the impacts of cats on native wildlife, they are not an ultimate solution as they do nothing to address the issue of wandering cats (which may spread diseases and cause a nuisance to neighbours). Additionally, the mere presence of cats may also have

sub-lethal effects on birds, by instigating fear of a presence of predators which can result in reduced nesting success (Bonnington *et al.* 2013; Beckerman *et al.* 2007).

Law and Governance

Areas in several overseas countries, such as Australia and Canada, have implemented legislation regarding the management of pet cats – specifically restricting the number of cats permitted at a residential premises, mandatory identification and registration, and / or requiring cats to be confined to their owners' property (cite WA: https://www.slp.wa.gov.au/pco/prod/FileStore.nsf/Documents/MRDocument:28995P/$FILE/Cat%20Act%202011%20-%20[00-d0-00].pdf?OpenElement and CA: http://documents.ottawa.ca/sites/documents.ottawa.ca/files/2003_77_en.pdf). Research questions could include: Why does cat management legislation move forward in some areas but not others? How successful are these measures in regulating cats? And are they contributing to the protection of native wildlife? Would similar regulations be accepted and supported by cat owners in New Zealand? And why do some cat owners baulk at the idea of regulating pet cats? A better understanding of what sorts of laws work and where they are (or are not) successful would be helpful in guiding decisions of the newly-formed National Cat Management Strategy Group in New Zealand.

Business and Marketing

Containment / indoor cat keeping is a common practice overseas, not only to prevent predation of wildlife, but also for the welfare of the cats themselves (which may have their own predators – e.g. coyotes) (American Bird Conservancy, 2013). In Tasmania, Australia, a survey of cat owners found that the most commonly- reported barrier to containing pet cats was the belief that "it is natural behaviour for cats to wander so they should be allowed to do so" (cite McLeod). How does this compare with the beliefs of New Zealand cat owners? A

survey of 151 cat owners in New Zealand indicated that 95% of companion cats had free access to the outdoors (Farnworth *et al.* 2010) *whilst* a recent survey found that New Zealand cat owners had low support for 24 hour containment of cats (18.6% of respondents) (cite Hall 2016). Further research into identify the drivers and barriers of pet cat containment is warranted.

A Google search of the term "catio" (a combination of the words "cat" and "patio", which is an enclosed outdoor area in which to contain cats) turns up multiple websites and businesses providing cat containment equipment. However, if search results are filtered to only pages from New Zealand, the results are relatively limited, with only one distributor selling cat containment equipment in the country, and only offering installation of the equipment in the city of Auckland (cite Oscillot, http://catfence.nz/) . Why do cat containment systems appear to be unpopular in New Zealand when compared to other countries? What factors are preventing their widespread use and acceptance here? Are there business opportunities for overseas companies to provide cat containment solutions to the New Zealand public? Market research may help to provide answers to these questions.

Cats and zoonoses

Cats are capable of carrying a wide variety of diseases, some of which can be transferred to humans (Lepczyk *et al.* 2015). Cats are the definitive host for *Toxoplasma gondii*, a protozoan parasite that can be transferred to other mammals, including humans (Centers for Disease Control and Prevention (CDC) 2014). In humans, Toxoplasmosis is associated with schizophrenia, memory impairment, and birth defects (Gajewski *et al.* 2014; Wong *et al.* 2013). Toxoplasmosis is also a concern for wildlife that has not evolved with cats (Hollings *et al.* 2013). For example, it is present in native birds in New Zealand (Stewart 2014) and has been linked to local marine mammal deaths (Roe *et al.* 2013). Investigation of the prevalence rates of *T. gondii* in urban cats in relation to the prevalence detected in their owners and

wider community would aid better understanding of this parasite, its means of transmission, and effects on both humans and wildlife. Free-roaming pet cats are also more susceptible to contracting viruses such as Feline Leukaemia Virus and Feline Immunodeficiency Virus (FIV) from unowned cats encountered on their wanderings (Lee *et al.* 2002). Other infections reported in cats in New Zealand include numerous bacterial infections, including *Mycobacterium* spp. and *Salmonella* spp., Rickettsial diseases, and fungal and ectoparasite diseases (Thompson 2009). The extent to which these and other diseases may be transmitted to other companion animals, humans and / or wildlife is unknown.

Conclusions

In order to explore the need for, and subsequent effective management of urban cats in New Zealand, we need a clear understanding of their ecology, behaviour, and impact on the local environment within these environments. Many of the ideas suggested above cannot be achieved without the full cooperation of cat owners themselves – therefore many of these research projects have the ability to become large scale Citizen Science programmes. From surveying cat owners about their cats' habits and hunting behaviour to cooperatively compiling a database of prey items brought home from pet cats would allow for a large amount of both social and ecological information to be gathered and analysed. We need to remember that cats are an important part of many families and refrain from accusing cat owners of being irresponsible and contributing to the decline of wildlife. This will make co-operative research programmes such as these more likely to succeed by gathering data which may be to the benefit of both ecologists and cat owners. Finding ways to increase public awareness about cat management options and their ability to improve cat welfare and help mitigate cat impacts in New Zealand is also warranted.

Currently we are unable to effectively establish the number of cats, their ownership status, and the extent of their impact on wildlife. It has been suggested that a "Precautionary Principle" be implemented in New Zealand, which "provides a rationale for immediate intervention to protect wildlife from pet cats while we await definitive studies" (Calver *et al.* 2011; Jones, 2008). In New Zealand this principle has often been taken to mean imposing a complete ban or at least a moratorium until the subject has been proved beyond, not just reasonable, but any, doubt to be 100% safe. In wider practice the concept more generally urges caution, but captures a balance between costs and benefits; i.e. in the sense that precautions should remain in place until advantages outweigh disadvantages, both real and imagined (Cameron 2006). In this case we should continue to encourage responsible pet ownership and cat containment amongst New Zealanders - until pet cats' value as companions and pest removers from human living spaces is deemed to be of greater value than the loss of individuals from native species and the chance that our domestic pets will convert to become stray or feral (unowned) animals. Urban ecologists will need to be versatile in the way that they design and conduct urban ecology experiments in this unique situation.

References

AGUILAR, G. D. & FARNWORTH, M. J. 2012. Stray cats in Auckland, New Zealand: Discovering geographic information for exploratory spatial analysis. Applied Geography, 34, 230-238.

AGUILAR, G. D. & FARNWORTH, M. J. 2013. Distribution characteristics of unmanaged cat colonies over a 20 year period in Auckland, New Zealand. Applied Geography, 37, 160-167.

AGUILAR, G. D., FARNWORTH, M. J. & WINDER, L. 2015. Mapping the stray domestic cat (*Felis catus*) population in New Zealand: Species distribution modelling with a climate change scenario and implications for protected areas. *Applied Geography,* 63**,** 146-154.

AMERICAN BIRD CONSERVANCY. 2013. *Cats Indoors* [Online]. Available: http://www.abcbirds.org/abcprograms/policy/cats/index.html [Accessed 12 September. 2013.

ANONYMOUS 1987. The Conservation Act. *In:* GOVERNMENT, N. Z. (ed.). Wellington, New Zealand.

ARONSON, M. F., LA SORTE, F. A., NILON, C., KATTI, M., GODDARD, M., LEPCZYK, C. A., WARREN, P. S., WILLIAMS, N. S. G., CILLIERS, S., CLARKSON, B., DOBBS, C., DOLAN, R., HEDBLOM, M., KLOTZ, S., KOOIJMANS, J. L., KÜHN, I., MACGREGOR-FORS, I., MCDONNELL, M., MÖRTBERG, U., PYSEK, P., SIEBERT, S., SUSHINSKY, J., WERNER, P. & WINTER, M. 2014. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceedings of the Royal Society B,* 281**,** 20133330.

BAKER, P. J., MOLONY, S. E., STONE, E., CUTHILL, I. C. & 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.

BECKERMAN, A. P., BOOTS, M. & GASTON, K. J. 2007. Urban bird declines and the fear of cats. *Animal Conservation,* 10**,** 320-325.

BERWICK, L. 2014. Cat campaigner Morgan happy to stroke council's cause *The Southland Times* [Online]. Available: http://www.stuff.co.nz/southland-times/news/9846642/Cat-campaigner-Morgan-happy-to-stroke-councils-cause.

BONNINGTON, C., GASTON, K. J. & 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.

CALVER, M., THOMAS, S., BRADLEY, S. & 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., GRAYSON, J., LILITH, M. & DICKMAN, C. R. 2011. Applying the precautionary principle to the issue of impacts by pet cats on urban wildlife. *Biological Conservation* 144**,** 1895-1901.

CAMERON, L. 2006. Environmental risk management in New Zealand - Is there scope to apply a more generic framework? *In:* TREASURY, N. Z. (ed.). Wellington, New Zealand: New Zealand Treasury

CENTERS FOR DISEASE CONTROL AND PREVENTION (CDC). 2014. *Parasites - Toxoplasmosis (Toxoplasma infection)* [Online]. Available: http://www.cdc.gov/parasites/toxoplasmosis/ [Accessed 14 April, 2014.

CONOVER, M. 2001. *Resolving human-wildlife conflicts: the science of wildlife damage management,* Boca Raton, Florida, USA, CRC Press LLC.

COWLISHAW, S. 2013. Morgan's attack on cats extends to SPCA staff *Stuff.co.nz* [Online]. Available: http://www.stuff.co.nz/environment/8331526/Morgans-attack-on-cats-extends-to-SPCA-staff.

DAUGHERTY, C. H. & TOWNS, D. R. 1991. The Cat's Breakfast. *New Zealand Science Monthly.*

FARNWORTH, M. J., CAMPBELL, J. & ADAMS, N. J. 2010. Public awareness in New Zealand of animal welfare legislation relating to cats. *New Zealand Veterinary Journal,* 58**,** 213-217.

FARNWORTH, M. J., CAMPBELL, J. & 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**,** 59-74.

FARNWORTH, M. J., MUELLNER, P. & BENSCHOP, J. 2013a. A systematic review of the impacts of feral, stray and companion cats (*Felis catus*) on wildlife in New Zealand and options for their management. New Zealand Veterinary Association.

FARNWORTH, M. J., WATSON, H. & ADAMS, N. J. 2013b. Understanding attitudes toward the control of nonnative wild and feral mammals: Similarities and differences in the opinions of the general public, animal protectionists, and conservationists in New Zealand (Aotearoa). *Journal of Applied Animal Welfare Science,* 17**,** 1-17.

FITZGERALD, A. M. & 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.

GAJEWSKI, P. D., FALKENSTEIN, M., HENGSTLER, J. G. & GOLKA, K. 2014. *Toxoplasma gondii* impairs memory in infected seniors. *Brain, Behavior, and Immunity,* 36**,** 193-199.

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

GEHRT, S. D., WILSON, E. C., BROWN, J. L. & ANCHOR, C. 2013. Population ecology of free-roaming cats and interference competition by coyotes in urban parks. *PLoS ONE,* 8**,** 1-11.

GILLIES, C. & CLOUT, M. 2003. The prey of domestic cats (*Felis catus*) in two suburbs of Auckland City, New Zealand. *Journal of Zoology,* 259**,** 309-315.

GLASS, G. E., GARDNER-SANTANA, L. C., HOLT, R. D., CHEN, J., SHIELDS, T. M., ROY, M., SCHACHTERLE, S. & KLEIN, S. L. 2009. Trophic garnishes: Cat-rat interactions in an urban environment. *PLoS ONE,* 4**,** 1-7.

GORDON, J. K., MATTHAEI, C. & VAN HEEZIK, Y. 2010. Belled collars reduce catch of domestic cats in New Zealand by half. *Wildlife Research,* 37**,** 372-378.

GRAMZA, A., TEEL, T., VANDEWOUDE, S. & CROOKS, K. 2016. Understanding public perceptions of risk regarding outdoor pet cats to inform conservation action. *Conservation Biology,* 30**,** 276-286.

GRAYSON, J., CALVER, M. C. & SYTLES, I. 2002. Attitudes of suburban Western Australians to proposed cat control. *Australian Veterinary Journal,* 80**,** 536-543.

HALL, C., FONTAINE, J., BRYANT, K. & CALVER, M. 2015. Assessing the effectiveness of of the Birdsbesafe® anti-predation collar cover in reducing predation of wildlife by pet cats in Western Australia. *Applied Animal Behaviour Science,* 173**,** 40-51.

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., VAN HEEZIK, Y., 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,* DOI:10.1371/journal.pone.0151962

HARROD, M., KEOWN, A. J. & FARNWORTH, M. J. 2016. Use and perception of collars for companion cats in New Zealand. *New Zealand Veterinary Journal,* 64**,** 121-124.

HITCHMOUGH, R. A., ADAMS, L. K., REARDON, J. T. & MONKS, J. M. 2016. Current challenges and future directions in lizard conservation in New Zealand. *Journal of the Royal Society of New Zealand,* 46**,** 29-39.

HOLLINGS, T., JONES, M., MOONEY, N. & MCCALLUM, H. 2013. Wildlife disease ecology in changing landscapes: Mesopredator release and toxoplasmosis. *International Journal for Parasitology: Parasites and Wildlife,* 2**,** 110-118.

INNES, J., LEE, W. G., BURNS, B., CAMPBELL-HUNT, C., WATTS, C., PHIPPS, H. & STEPHENS, T. 2012. Role of predator-proof fences in restoring New Zealand's biodiversity: a response to Scofield *et al*. (2011). *New Zealand Journal of Ecology,* 36**,** 232-238.

JONES, C. 2008. An assessment of the potential threats to indigenous biodiversity posed by cats (*Felis catus*) in urban environments. Landcare Research.

KARBAN, R. & HUNTZINGER, M. 2006. *How to do ecology: a concise handbook,* New Jersey, USA, Princeton University Press.

KING, C. (ed.) 2005. *The Handbook of New Zealand Mammals,* Melbourne, Australia: Oxford University Press.

LANGHAM, N. P. E. & PORTER, R. E. R. 1991. Feral cats (*Felis catus* L.) on New Zealand farmland. I. Home range. *Wildlife Research,* 18**,** 741-760.

LEE, I. T., LEVY, J. K., GORMAN, S. P., CRAWFORD, P. C. & SLATER, M. R. 2002. Prevalence of feline leukemia virus infection and serum antibodies against feline immunodeficiency virus in unowned free-roaming cats. *Journal of the American Veterinary Medical Association,* 220**,** 620-622.

LEPCZYK, C., MERTIG, A. & LIU, J. 2004. Landowners and cat predation across rural-to-urban landscapes. *Biological Conservation,* 115**,** 191-201.

LEPCZYK, C. A., LOHR, C. A. & DUFFY, D. C. 2015. A review of cat behaviour in relation to disease risk and management options. *Applied Animal Behaviour Science,* 173**,** 29-39.

LGNZ, L. G. N. Z. 2016. *LGNZ, Local Government New Zealand,* [Online]. [Accessed 15 February, 2016.

LOSS, S. R., WILL, T. & MARRA, P. P. 2013. The impact of free-ranging domestic cats on wildlife of the United States. *Nature Communications,* 4**,** 1-7.

LOYD, K., HERNANDEZ, S., CARROL, J., ABERNATHY, K. & MARSHALL, G. 2013. Quantifying free-roaming domestic cat predation using animal-borne video cameras. *Biological Conservation,* 160**,** 183-189.

LOYD, K. A. T. & HERNANDEZ, S. M. 2012. Public perceptions of domestic cats and preferences for feral cat management in the Southeastern United States. *Anthrozoös,* 25**,** 337-351.

MACDONALD, E., MILFONT, T. & GAVIN, M. 2015. What drives cat-owner behaviour? First steps towards limiting domestic-cat impacts on native wildlife. *Wildlife Research,* 42**,** 257-265.

MACKAY, J. 2011. Companion animals in New Zealand. Auckland, New Zealand: New Zealand Companion Animal Council.

MARZLUFF, J. M., SHULENBERGER, E., ENDLICHER, W., ALBERTI, M., BRADLEY, G., RYAN, C., SIMON, U. & ZUMBRUNNEN, C. (eds.) 2008. *Urban Ecology: An international perspective on the interaction between humans and nature,* New York, USA: Springer Science + Business LLC.

MCDONALD, J. L., MACLEAN, M., EVANS, M. R. & HODGSON, D. J. 2015. Reconciling actual and perceived rates of predation by domestic cats. *Ecology and Evolution,* 5**,** 2745-2753.

MEDINA, F. M., BONNAUD, E., VIDAL, E. & NOGALES, M. 2014. Underlying impacts of invasive cats on islands: not only a question of predation *Biodiversity Conservation,* 23**,** 327-342.

METSERS, E. M., SEDDON, P. J. & VAN HEEZIK, Y. 2010. Cat-exclusion zones in rural and urban-fringe landscapes: how large would they have to be? *Wildlife Research,* 37**,** 47-56.

MOLSHER, R., DICKMAN, C. R., NEWSOME, A. & MÜLLER, W. 2005. Home ranges of feral cats (*Felis catus*) in central-western New South Wales, Australia. *Wildlife Research,* 32**,** 587-595.

MORGAN FOUNDATION. 2013. *Cats to Go* [Online]. Available: http://garethsworld.com/catstogo/ [Accessed January 13, 2013.

MORGAN, S. A., HANSEN, C. M., ROSS, J. G., HICKLING, J. G., OGILVIE, S. C. & 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.

NAWAC 2007. Animal Welfare (Companion Cats) Code of Welfare. *In:* MINISTRY FOR PRIMARY INDUSTRIES (ed.). Wellington, New Zealand.

OPPEL, S., BURNS, F., VICKERY, J., GEORGE, K., ELLICK, G., LEO, D. & HILLMAN, J. C. 2014. Habitat-specific effectiveness of feral cat control for the conservation of an endemic ground-nesting bird species. *Journal of Applied Ecology,* 51**,** 1246-1254.

ROE, W. D., HOWE, L., BAKER, E. J., BURROWS, L. & HUNTER, S. A. 2013. An atypical genotype of *Toxoplasma gondii* as a cause of mortality in Hector's dolphins (*Cephalorhynchus hectori*). *Veterinary Parasitology,* 192**,** 67-74.

ROETMAN, P. E. J. & DANIELS, C. B. (eds.) 2011. *Creating Sustainable Communities in a Changing World,* Adelaide, Australia: Crawford House Publishing.

SHUTTLEWORTH, K. 2013. Cat meeting goes feral. *The New Zealand Herald* [Online]. Available: http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10866685 [Accessed February 20, 2013].

SIH, A., BALL, A. M., JOHNSON, J. C. & ZIEMBA, R. E. 2004. Beahavioral Syndromes: An integrative overview. *The Quarterly Review of Biology,* 79**,** 241-277.

SIMS, V., EVANS, K. L., NEWSON, S. E., TRATALOS, J. A. & GASTON, K. J. 2008. Avian assemblage structure and domestic cat densities in urban environments. *Diversity and Distributions,* 14**,** 387-399.

SMALLMAN, E. R. 2016. Cats in crosshairs as new group targets numbers. *Dominion Post,* 24 February, 2016.

SPOTTE, S. 2014. *Free-ranging cats: Behavior, Ecology, Management,* West Sussex, UK, John Wiley & Sons, Ltd.

STATISTICS NEW ZEALAND. 2014. Available: http://www.stats.govt.nz/browse_for_stats/population/Migration/internal-migration/urban-rural-migration.aspx [Accessed 26 March, 2014.

STEWART, M. 2014. Cat disease found in native birds. *The Dominion Post* [Online]. Available: http://www.stuff.co.nz/dominion-post/news/10483663/Cat-disease-found-in-native-birds [Accessed 11 September, 2014].

SWARBRICK, N. 2013. *Creature Comforts: New Zealanders and their pets,* Dunedin, New Zealand, Otago University Press.

THOMPSON, J. 2009. Important infectious diseases of cats in New Zealand. *Surveillance,* 26**,** 3-5.

582 TOCHER, M. D. 2006. Survival of grand and Otago skinks following predator control.
583 *Journal of Wildlife Management,* 70**,** 31-42.
584 TOWNS, D. R., DAUGHERTY, C. H. & CREE, A. 2001. Raising the prospects for a
585 forgotten fauna: a review of 10 years of conservation effort for New Zealand reptiles.
586 *Biological Conservation,* 99**,** 3-16.
587 TOWNSEND, C. 2008. *Ecological applications: toward a sustainable world,* Singapore,
588 Blackwell Publishing.
589 VAN HEEZIK, Y. 2010. Pussyfooting around the issue of cat predation in urban areas. *Oryx,*
590 44**,** 153-154.
591 VAN HEEZIK, Y., SMYTH, A., ADAMS, A. & GORDON, J. 2010. Do domestic cats
592 impose an unsustainable harvest on urban bird populations? . *Biological*
593 *Conservation,* 143**,** 121-130.
594 WONG, W. K., UPTON, A. & THOMAS, M. G. 2013. Neuropsychiatric symptoms are
595 common in immunocompetent adult patients with *Toxoplasma gondii* acute
596 lymphadenitis. *Scandinavian Journal of Infectious Diseases,* 45**,** 357-361.
597 WOODS, M., MCDONALD, R. A. & HARRIS, S. 2003. Predation of wildlife by domestic
598 cats *Felis catus* in Great Britain. *Mammal Review,* 33**,** 174-188.
599 WORLD HEALTH ORGANIZATION (WHO). 2014. *Urban Population Growth* [Online].
600 Available:
601 http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text
602 /en/ [Accessed 14 April, 2014.

603

604

605

606 **Table 1.** Ecologically-based studies of urban domestic cats (*Felis catus*) conducted in New Zealand.

Type of study	Location	N (cats)	Recorded	Outcome	Citation
Prey type	Auckland City	46	Prey brought in by owned cats over 12 months	73% invertebrates; ~14% birds; ~5% lizards	Gillies & Clout 2003
	Auckland (Urban-rural fringe)	34	Prey brought in by owned cats over 12 months	66% rodents; ~15% birds; 11% lizards	Gillies & Clout 2003
	Christchurch	88	Prey brought in by owned cats over 12 months	38% rodents; 20% birds; 18% lizards; 22% invertebrates; 2% other (frogs, goldfish, mustelids)	Morgan et al 2009
	Dunedin	144	Prey brought in by owned cats over 12 months	37% birds; ~34% rodents; ~20% invertebrates; ~8% lizards; 0.65% other mammals (lagomorphs and mustelids)	van Heezik et al 2010
	Wellington	1	Prey brought in by a single cat over 17 years	~51% rodents; ~40% birds; ~6% rabbits; ~2% lizards	Flux 2007
	Dunedin	45	Prey capture over 6 weeks (control group in belled collar trial)	~57% rodents; ~32% birds; ~5% invertebrates; ~4% lizards, ~2% rabbits	Gordon et al 2010
	Stewart Island	11	Prey capture over 6 months	Only 4 cats brought home prey. 67% rodents; 33% birds	Wood et al 2015
Spatial movement	Auckland	Numerous	1 year of stray cat location data (2010-2011) analysed via GIS	Aggregated stray cat density: Manurewa = 50.41/km^2 ; Papakura = 35.29/km^2; Mangere = 32.64/km^2	Farnworth & Aguilar 2012

Auckland	Numerous	20 years of colony cat data analysed via GIS	Colonies were located close to urbanised areas and reports of colonies increased over time	Farnworth & Aguilar 2013
New Zealand	Numerous	Data from Farnworth & Aguilar (2012, 2013) analysed via species distribution modelling	Projections to a climate change-based scenario showed a consistent increase in the area and intensity of areas suitable for un-owned cats, especially in the North Island	Aguilar, Farnworth, & Winder 2015
Christchurch	21	Tracking owned cats via radio telemetry over 12 months	Median home range (100% MCP) = 1.8 ha; Range = 0.1-10.0 ha	Morgan et al 2009
Dunedin	32	Tracking owned cats via GPS collars over 6 days	Median home range (100% MCP) = 2.2 ha; Range = 0.48 – 21.75 ha	van Heezik et al 2010
Dunedin	20	Tracking owned cats via differently-weighted GPS collars for 1 week at a time	Cats travelled slightly further whilst wearing tracking units that were ~1% of their body weight than when wearing heavier tracking collars	Coughlin and van Heezik 2014
Oban, Stewart Island	15	Radio-tracking of pet cats over a one month period (minimum of 30 fixes)	Median home range (100% MCP) = 0.05; Range = 0.05 – 16.58 ha	Wood et al 2015
Canterbury (urban fringe)	11	Tracking owned cats via GPS collars over 10 days	Median home range (95% MCP) = 4 ha.	Metsers et al 2010
Otago (urban fringe)	14	Tracking owned cats via GPS collars over 10 days	Median home range (95% MCP) = 3.5 ha.	Metsers et al 2010

Behaviour	Wellington	10	~80 hours of video footage captured using collar-mounted video cameras	Cats spent the majority of their time "investigating" (~40%) or indoors (~32%)	Kikillus & Gaby (unpublished data)
Anti-predation device	Dunedin	45	Prey capture over 6 weeks for cats wearing a collar with a bell attached	Bells on cat collars reduced hunting by half, but did not affect prey species composition in comparison to control group (see above under prey type)	Gordon et al 2010

607 This table was constructed by using the search term "cat*" in conjunction with other terms: "urban", "predation", "New Zealand", and "ecology"
608 in the online database 'Web of Science' and "urban cats New Zealand" in the search engine 'Google Scholar'. References within articles were
609 also sought.

610
611
612
613
614
615
616
617
618

619 **Table 2:** Existing owned cat legislation by Local Authority in New Zealand (as of May 2016). Documents available upon request.

North Island	Authority	Maximum number of pet cats permitted	Document	Relevant section number
	Far North District Council	5	Keeping of Animals, Poultry and Bees 2007	1306
	Kaipara District Council	5	General Bylaws 2008	807
	South Waikato District Council	5	South Waikato District Keeping of Animals, Poultry and Bees Bylaw 2011	7.2.2
	New Plymouth District Council	5	New Plymouth District Council Bylaw 2008: Animals	7.1
	Hastings District Council	4	Bylaws Part 03: Animals	9
	Rangitikei District Council	3	Animal Control Bylaw 2013	7
	Manawatu District Council	3	Manawatu District Bylaw 2008	5.4.2
	Palmerston North City Council	3	Palmerston North Animals and Bees Bylaw 2011 (incorporating amendments as at 9 September 2013)	8
	Ruapehu District Council	4	Animal Control Bylaw 2012	10

	Masterton District Council	3	The Masterton and South Wairarapa District Councils' Consolidated Bylaw 2012	5
	South Wairarapa District Council	3	The Masterton and South Wairarapa District Councils' Consolidated Bylaw 2012	5
	Wellington City Council	-	All domestic cats over the age of 12 weeks must be microchipped by early 2018 and the cat's microchip registered with New Zealand Companion Animal Register.	4
South Island	Marlborough District Council	4	Marlborough District Council Bylaw 2010: Keeping of Animals, Poultry and Bees	705
	Buller District Council	3	Amendment to the Buller District Council general bylaw NZS 9201 Part 13 The Keeping of Animals	1306
	Invercargill City Council	3	Bylaw 2013/2 – Keeping of Animals, Poultry and Bees	3

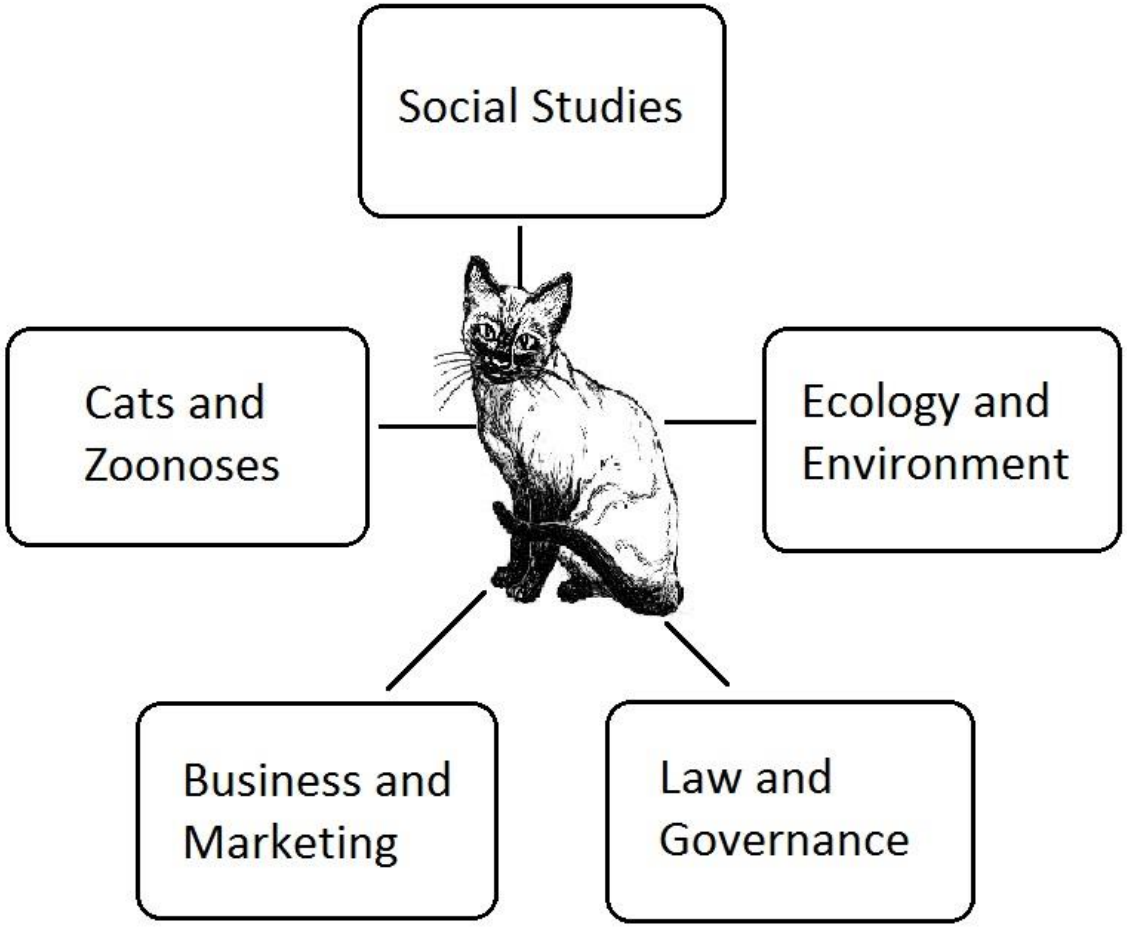
620

621 This table was constructed by searching local government websites for information regarding regulations of owned cats in each local authority.
622 If no information was available, then Councils were contacted individually for clarification.

623

624 Figure 1: Insert caption.

625


Social Studies
Cats and Zoonoses
Ecology and Environment
Business and Marketing
Law and Governance

626