A systematic review of the impacts of feral, stray and companion domestic cats (*Felis catus*) on wildlife in New Zealand and options for their management

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Prepared by Mark Farnworth BSc (Hons) MSc
Senior Lecturer in Animal Behaviour and Welfare
Department of Natural Sciences
Unitec Institute of Technology
Private Bag 92025
Victoria Street West
Auckland 1142
Phone: +64 9 815 4321 ext 7071
Facsimile: +64 9 815 4346
Email: m.farnworth@unitec.ac.nz

Co-authored by Dr Petra Muellner (New Zealand Veterinary Association) and Dr Jackie Benschop (Massey University)
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1 Summary

Stray and companion (pet) cats are common in New Zealand and present a substantial threat to both native and non-native wildlife, especially in areas close to stands of mature trees or native bush. Conservative estimates created within this review suggest that the pet and stray cat populations in New Zealand may prey upon between 19-44 and 15-33 million animals per year respectively. The stray cat population albeit substantially smaller (~196,000) may have a comparable predation impact to the significantly larger companion cat population (~1.4 million). This is driven by the increased likelihood that a stray cat will be compelled to hunt to survive whilst the impact of companion cats is reduced by regular feeding.

Currently there is no national strategy for cat management in New Zealand. After reviewing the evidence it is clear that any management approach should address two distinct aspects of the problem: 1) identify appropriate management methods for New Zealand to reduce stray cat numbers and prevent predation; and 2) identify methods for improving ownership practices and social value as they relate to companion cats in New Zealand.

The stray cat population appears to be growing both internationally and in New Zealand. Although some stray cats are cared for directly in colonies, most are unlikely to receive appropriate or timely veterinary care, protection from harm, or regular feeding, and so have shortened lives and reduced welfare associated with injury, disease and malnutrition. Continued survival also necessitates that animals hunt, which implies a likely greater impact on wildlife for stray than pet cats. The literature
evaluated suggests that a Trap-Neuter-Return (TNR) strategy would not be judicious for the majority of stray cats as it is costly, does not stop predation of wildlife by cats and has little effect on the spread of diseases amongst cats. There is also little evidence that clearly shows TNR improves cat welfare overall or results in population decline on a broad scale. Although TNR is already used informally for small groups of stray cats (colonies), it is highly unlikely that it is applicable to stray cat populations on a large geographical scale. Therefore, any long-term strategy to manage stray cats should consider a suite of available methods including adoption and euthanasia, both of which are already employed within New Zealand. Any strategy should be collaboratively developed, formalised and rigorously monitored by all stakeholders if it is to have a clear effect. To protect stray cats that have identified carers (i.e. people who feed them but do not consider the cat to be ‘theirs’) a strong promotion of the benefits of transitioning stray cats into an ownership model may be useful. An option to minimise any negative emotional impacts of population management on carers may be that managers and carers of existing stray cat colonies in ecologically appropriate areas should perhaps be required to formally register. Managers and carers should also be required to adhere to procedures and processes (e.g. routine sterilisation, removal of newcomers) which will result in the eventual extinction of that colony.

Effective management of stray cats will require that they can be definitively identified. Visible identification for companion cats may allow this and may also reduce predation rates if collars with bells are used. Consideration of other methods of companion cat management should perhaps address formal mechanisms by which ownership can be established and improved. This may include registration of pet cats,
restriction of ownership in areas of environmental value and promoting a partial or complete indoor-cat lifestyle. Contrary to popular belief, cats can live indoor lifestyles.

Questions as to how society should manage a growing cat population to protect other species, but also to improve cat welfare, are problematic. Cats are loved by many New Zealanders and are an important component of New Zealand families/whanau. This report in no way seeks to suggest this importance be ignored, in fact this dynamic is of great significance to many stakeholders including the New Zealand Veterinary Association.
2 Introduction

Human habitation is strongly linked to the decline of many species not adapted to urban environments (Radeloff et al. 2005). Alongside fundamental changes in habitat, and inability to adapt, myriad anthropogenic factors place significant pressure on natural or native populations of animals within the human landscape (Purvis et al. 2000). One such factor is the introduction of mammalian predators closely linked to human social systems. Domestic cats are an important part of society providing, for many, a sense of attachment and emotional support (Zasloff and Kidd 1994) even if not directly owned (Centonze and Levy 2002). However, they are also cited as having a potentially negative impact upon local ecologies (e.g. van Heezik et al. 2010). Currently estimates of the worldwide population of the domestic cat (Felis catus) suggest that it now exceeds 600 million (Peterson et al. 2012) and is showing signs of increasing (Dabritz and Conrad 2010) as the urban human population grows. In the United Kingdom (UK) this growth now outstrips the available financial resources for managing the un-owned population (Stavisky et al. 2012). In light of this population growth and limited resource, the welfare, environmental impact and population management of cats have gained significant attention in recent years. This review aims to assess both the wildlife predation risk posed by cats in New Zealand and the potential effects of any predation on wildlife populations. It will also explore available methods for cat population management.

For the purposes of this review cats are defined as three distinct groups as per the Animal Welfare (Companion Cats) Code of Welfare (2007), those being: companion, stray and feral. ‘Semi-owned’ cats, those that have their basic needs met by people but are not regarded as ‘owned’ are considered to be a subset of the stray cat population.
2.1 Cats in New Zealand

New Zealand’s cat population is likely no exception to this growth trend. New Zealand has an estimated companion cat population of 1.4 million and a household cat ownership level reported to be approximately 48% (MacKay 2011). These statistics suggest a substantial and dense population of cats in urban areas showing potential signs of growth (Aguilar and Farnworth 2013) despite a sterilisation rate of approximately 87% for companion cats in some regions (Farnworth et al. 2010a). These numbers also indicate that almost half of all New Zealanders can be considered to be supportive of keeping cats as companion animals. This is in contrast to the fact that New Zealand’s mammal-naïve ecology is vulnerable to introduced mammalian predators and it is likely this that has led to a schism in public opinion as it relates to cats and their management (Farnworth et al. 2011).

2.2 Cat populations

It is important to note that the domestic cat population of New Zealand is not limited to the 1.4 million companion cats estimated by MacKay (2011). There are no absolute or estimated statistics on New Zealand’s total cat population which include not only companion but also un-owned stray and feral cats. Within the scientific literature very few studies attempt to quantify the total population, including un-owned cats, and any proposed value ranges are therefore large, representing high levels of uncertainty. For example, in the United States of America (USA) it is estimated that the un-owned cat population accounts for 10-50 million individuals and therefore, at the very least, un-owned cats attribute an additional 14% to the owned population (~75 million) but this contribution could be as high as 67% (Mahlow and Slater 1996). If this situation applied more widely, the New Zealand cat population could be conservatively
estimated at 1.5 million, but might be significantly more. Indeed, in one year in Auckland alone, 8,573 stray cats were collected by a single welfare charity (Aguilar and Farnworth 2012). Despite the seemingly high rate of desexing for companion cats in Auckland (McKay et al. 2009) it is not known what proportion of uplifted stray cats are desexed. It is plausible, assuming that the population of cats continues to grow in New Zealand, that the stray population may be a significant source of kittens in urban areas. In Australia, where desexing rates are also high for companion cats (>90%), researchers identified that 96% of 15,206 strays entering a shelter in Melbourne were entire, almost half of which were mature adults (Marston and Bennett 2009).

2.3 Defining cat populations

Within the literature free-roaming cat populations are described using myriad terms. In general, free-roaming cats are defined as those “not currently under direct control or [is] not currently restricted by a physical barrier” (Anonymous undated). As such, free-roaming may include both owned and un-owned individuals. Free-roaming cats may be a significant issue in New Zealand. By way of illustration, in Auckland and Kaitaia, a survey sample indicated that 95% of owned cats have free outside access (Farnworth et al. 2010a).

More specific to New Zealand are the definitions provided in the Animal Welfare (Companion Cats) Code of Welfare (hereinafter referred to as the Cat Code) (Anonymous 2007). The Cat Code provides definitions for stray, feral, companion and colony cats (Anonymous 2007) which are broadly delineated using anthropocentric principles as follows:
Companion Cat: *Common domestic cat* (including a kitten unless otherwise stated) that lives with humans as a companion and is dependent on humans for its welfare.

Stray Cat: means a companion cat which is lost or abandoned and which is living as an individual or in a group (colony). Stray cats have many of their needs indirectly supplied by humans, and live around centres of human habitation. Stray cats are likely to interbreed with the unneutered companion cat population.

Feral Cat: means a cat which is not a stray cat and which has none of its needs provided by humans. Feral cats generally do not live around centres of human habitation. Feral cat population size fluctuates largely independently of humans, is self-sustaining and is not dependent on input from the companion cat population.

Colony: *A group of stray cats living together*

These definitions are the ones upon which this report is based, however they are not broadly understood by the general public (Farnworth *et al.* 2010a) and do not necessarily align with terminology used outside New Zealand or within the peer-reviewed literature (Farnworth *et al.* 2010b).
The objectives of this review were firstly to assess the wildlife predation risk posed by cats in New Zealand and the potential effects of any predation on wildlife populations and secondly to explore available methods for cat population management.

3 Methodology

A systematic review of the literature was conducted using a defined protocol to retrieve, appraise and summarize available evidence relevant to the research objectives and to minimise the effect of the reviewers’ own biases (Stroup et al. 2000). Systematic reviews also create a rigorous framework against which management actions for companion animals may be assessed (Trotz-Williams and Trees 2003). For this document the literature search was conducted by the primary author of this report, a master’s-degree-qualified animal welfare research scientist with seven years of research experience. The protocol used was co-developed and reviewed by the two co-authors (PM; JB) both of whom are veterinary epidemiologists with doctorate qualifications and experience in the use of systematic reviews and meta-analyses.

3.1 Retrieval of publications

Peer-reviewed publications were retrieved by interrogating selected electronic databases subscribed to by Massey University. This included Web of Science (www.webofknowledge.com), Scopus (www.scopus.com) and The Knowledge Basket a New Zealand news and information archive (www.knowledge-basket.co.nz). Retrieved articles from each of these databases were crosschecked and combined in EndNote X5 to ensure maximal inclusion of publications. For all searches done using
electronic databases, accuracy was recorded based on the number of retrieved articles that were considered potentially relevant.

Once compiled, the literature was cross-referenced against resources that had been compiled by the New Zealand Department of Conservation\(^1\) to identify additional articles of specific relevance to this review and to explore the rigour and consensus of the search process. On reading of included articles any seminal references not previously identified were subsequently added to the resources for this work in the interests of completeness.

In addition to peer-reviewed resources ‘grey literature’ was included as it came to the attention of the authors. This approach was considered appropriate to ensure as broad a coverage of the literature as possible.

### 3.2 Search terms

The searches were conducted using keyword algorithms to maximise search specificity and sensitivity. The literature searches were conducted in consultation with Massey University library services and an eResearch librarian with extensive experience in database information retrieval. Once compiled, the following algorithms were used to search titles, abstracts and keywords:

For predation:

(cat OR cats) AND (predat* OR threat* OR risk* OR kill* OR prey*) AND (wildlife OR bird* OR “small mammal*” OR reptile* OR lizard*)

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\(^1\) Supplied by K M’Innes, Department of Conservation, 18-32 Manners Street, Wellington, New Zealand.
For population management:

(cat OR cats) AND (stray OR feral) AND (population* OR colony OR colonies) AND (control* OR manage*)

3.3 Inclusion criteria

Studies which addressed cat predation upon wildlife were included as were those that addressed cat ownership and cat welfare as they pertained to population management. All cat types (stray, companion, feral and colony) were included as it was considered important to have as broad a perspective as possible. However, papers which focussed solely on feral cats (as defined in section 2.3) were noted but did not comprise a major component of this review beyond simple presentation of over-arching themes. Papers which included assessment of companion, stray or colony cats or a comparison of any of these three groups with feral cats were retained for further exploration. As this report spans an array of disciplines and study types no constraints were placed on the types of studies included, or designs thereof. This is for four reasons. First, at the moment there is significant debate around the most suitable strategies to manage owned cats in New Zealand. Second, cat owners and cats may vary less between countries than do ecologies and conservation imperatives. Third, the predation impact of cats in different environments and with varying degrees of human management is still being debated. Finally, because cat management is a potentially emotive topic as broad a perspective as possible may help avoid bias brought about by the relative dearth, and potential topic bias, of regional information. Given the relative lack of information and the burgeoning nature of research in this area, no exclusion was implemented based on time of publication. For this study topic it is unlikely that older
literature is less accurate or relevant and therefore the same weight was given to studies from different years. Studies from outside New Zealand were included if they were considered relevant to the objectives of the review (see section 3.4 for details) but articles had to have at least an abstract available in English.

3.4 Evaluation of relevance

Information on all retrieved articles was recorded in an Excel database and included key information such as: author(s), country of study site, year published and source type (e.g. Journal, Report). Beyond the general inclusion criteria (see 3.1) further evaluation of the relevance of the materials was made based on pre-set criteria such as relevance to the research objective.

3.4.1 Relevance to research objectives

The literature surrounding the impacts of cats on wildlife was explored and its relevance was assessed based upon the objectives of this review. As there were a number of stated objectives those were bundled into two objectives groups (i.e. Objective 1: predation risk and Objective 2: population control). Papers were able to be placed against either one or both objectives.

Objective 1: Assessment of wildlife predation risk posed by cats in New Zealand and the effects of any predation on wildlife populations

Objective 2: Assessment of available methods for cat population control.
Objective 2 was sub-divided into whether or not population control was assessed with regards to its effect on:

i) Predation levels
ii) Animal welfare
iii) Animal health including zoonotic risk
iv) Effectiveness and applicability in a New Zealand context
v) Stray population growth
vi) Populations of other predators and integrated pest management strategies.

3.4.2 Assessment of relative value of retrieved documents
To assess the relative value of retrieved articles a number of criteria were implemented. These did not necessarily lead to exclusion of articles but allowed the body of work to be broadly assessed (e.g. calculation of the proportion of management projects that included longitudinal studies).

The first criterion included in the assessment sheet was the group of cats on which the work was conducted. These were placed into one of four categories: companion (pet); stray; feral; and colony. These categories were defined as per the Cat Code (Anonymous, 2007). Where the term ‘feral’ was used in the retrieved literature to describe urban cat populations dependent upon human social structures, which is common practice in studies based in the USA, these were re-categorised as ‘stray’ or ‘colony’ dependent upon the given context. In addition, the number of cats for which information was provided was recorded because studies with larger sample sizes are less likely to be affected by chance. Similarly, the location in which the study was conducted was identified and was placed into one of five categories: 1) studies
conducted in New Zealand; 2) studies in countries or on islands other than New Zealand but without significant native mammalian fauna (e.g. Hawai’i); 3) studies outside New Zealand where the country has native mammals but also a felid-naïve fauna, with cats having been introduced recently (e.g. Australia); 4) studies in countries with mammalian predators and where domestic cats are historically present (e.g. USA); and 5) studies in countries with mammalian predators, small native felids and a long historic presence of domestic cats (e.g. UK). The final criterion that was included was the duration of the study (in years) because longer studies are potentially more likely to show a credible link between interventions and effects on cat population, cat welfare and native animal populations.

4 Results

4.1 Results of retrieval of publications

4.1.1 Objective 1: Predation impact

Using the search algorithm for predation identified in section 3.2 Scopus returned 799 publications, Web of Science 623 and New Zealand Science (The Knowledge Basket) 184. Web of Science and Scopus had 277 duplicated resources bringing the combined total of articles from the three databases included in the first reading to 1329. Where duplication was identified, the Scopus citation was retained.

All abstracts were screened by the first author of this report (MF); articles that were not relevant to the objectives of the work were omitted. Where needed the decision to include or exclude an individual article was backed by one of the co-authors. Omitted articles generally included publications concerning species other than the domestic cat, veterinary case reports, and reports on diseases and parasites. Following this
process a total of 243 articles were retained for further analysis, comprising 56 articles from Web of Science, 138 from Scopus and 45 from The Knowledge Basket.

Of the retained 243 publications, 175 concerned the predation impacts of feral cats only and were therefore not retained for in-depth exploration, but are briefly summarised in this report. Comparison with a database supplied by The Department of Conservation identified an additional 15 papers which were concerned with companion, stray, or colony cat predation and were therefore included.

4.1.2 Objective 2: Population management

Using the search algorithm for management identified in section 3.2 Scopus returned 329 publications, Web of Science 247 and The Knowledge Basket 183. Web of Science and Scopus had 132 duplicated resources bringing the combined total of articles from the three databases included in the first reading to 759. Where duplication was identified the Scopus citation was retained. As for Objective 1 the definition of the cats of interest was addressed relative to the definitions in The Cat Code. This was especially so for management literature from the USA where ‘feral’ is often used to indicate ‘stray’ as per the Cat Code definition.

As for Objective 1 all abstracts were screened by the first author of this report (MF) and, articles that were not relevant to the objectives of the work were omitted. Where needed, the decision to include or exclude an individual article was backed by one of the co-authors. Omitted articles generally included publications concerning species other than the domestic cat, veterinary case reports, and reports on diseases and parasites that were not related to specific population management or control practices.
Following this process a total of 188 articles were retained for further analysis, this included 20 articles from Web of Science, 158 from Scopus and 10 from The Knowledge Basket.

Of the retained 188 publications, 85 concerned the management of feral cats (as defined by the Cat Code) and were therefore not retained for in-depth exploration, but are summarised in this report. Comparison with a database supplied by The Department of Conservation identified an additional five papers which were concerned with companion, stray, or colony cat management and were therefore included.

4.2 Analysis of retrieved sources

4.2.1 Relevance to cat group

There is a substantial skew in the distribution of cat groups represented within the articles which address predation, with the majority addressing feral and companion cats and relatively few concerned with the impacts of stray or colony cats (Figure 1). However, there has recently been a substantial increase in literature around the management of stray and colony cats (Figure 2).
4.2.2 Year of publication

There has been a clear increase in the attention received by domestic cats in recent decades, with the evidence suggesting that cat predation impact received earlier attention than cat management.
4.2.3 Origin of study

There is a clear difference in the origins of studies with predation studies primarily originating from countries with relatively naïve ecologies and recent cat introductions, (see Figure 3 for definitions of categories 1-5), whereas cat population management studies primarily originate from countries with a long historical association with domestic cats and ecologies which are now potentially robust to small mammalian predators.
Figure 3: Distribution of retrieved and retained articles for objective 1 (predation assessment; n=256) and objective 2 (population management; n=199) relative to the country of origin of each study. Origins are defined as follows: 1) studies conducted in New Zealand; 2) studies in countries or on islands other than New Zealand but without substantial native mammalian fauna (e.g. Hawai‘i); 3) studies outside New Zealand where the country has native mammals but also a felid-naïve fauna, with cats having been introduced recently (e.g. Australia); 4) studies in countries with mammalian predators and where domestic cats are historically present (e.g. USA); and 5) studies in countries with mammalian predators, small native felids and a long historic presence of domestic cats (e.g. UK). The category “other” includes reviews, theoretical experiments (e.g. ex situ exploration of immunocontraceptives), and population modelling.

4.3 Objective one: Assessment of predation risk

4.3.1 Feral domestic cats

The earliest exploration of the impacts of feral domestic cats on wildlife in New Zealand was written in the mid-20th century (Wodziki 1950). Since this date there has been significant international exploration of these impacts including a number of reviews. With the exception of only a handful of publications, the impact of feral
domestic cats has been negative, leading to population declines, local extirpation, or extinction of vulnerable species (Nogales et al. 2004). For those studies where such declines are not evident, the lack of population declines appear to have resulted from limitation of cat population growth due to seasonal prey availability (Catry et al. 2007), unsuitable habitat for cats (Robertson et al. 2005), or the cats preying on other species (e.g. rats) which were themselves impacting upon populations of vulnerable species (Matias and Catry 2008). Population modelling has suggested that, in uncontrolled environments, feral cats may reduce extinction rates for island-based native mammal populations through predation of black rats (Rattus rattus) if they are also present (Hanna and Cardillo 2013). In this latter example, as in others (Fitzgerald et al. 1991; Medina and Nogales 2009), this results in a call for the simultaneous extermination of cats and other mammalian meso-predators. Meso-predator release was not presented as an argument against feral cat control. Broad-scale invasive species control is intended to prevent meso-predator release, a phenomenon whereby smaller predators (e.g. rats) or competitors for resources (e.g. rabbits for nest burrows), released from the predation impact of a controlled predator (e.g. cat) increase in number and therefore exert greater pressure upon another species (e.g. a seabird). The potential for meso-predator release has been further documented both in the field (Bergstrom et al. 2009) and through modelling (Courchamp et al. 1999), although it is not conclusively supported (Hughes et al. 2008). Notwithstanding this effect a number of studies indicate that concomitant removal of feral cats and other meso-predators from environments in which they are non-native has resulted in population recovery or reestablishment of native populations (Wanless et al. 2002; Rauzon et al. 2008; Moseby et al. 2009; Ratcliffe et al. 2010).
The significantly negative impacts of feral cats are particularly evident in environments where native fauna are mammal-/felid-naïve. As a result of a lack of selective pressure brought about through predation by cats (or other mammals) the innate behavioural and hormonal responses of native fauna to predation threats are less rapid, exposing them to greater than normal risks (Rödl et al. 2007). Much of the research into feral cats has taken place in felid-naïve communities, which often arise as a result of geographic isolation. It is therefore intuitive that many studies occur on islands onto which a range of invasive mammalian species have been introduced. Of those papers retained that considered the impact of feral cats, 50 addressed their impact on the endemic species found on small oceanic islands. Comprehensive reviews of these and other studies have already been conducted and reinforce the assertion that feral cats present a significant threat to wildlife, especially seabirds (Nogales et al. 2004; Bonnaud et al. 2011; Medina et al. 2011). Of the remainder 29 manuscripts specifically explored feral cats in either New Zealand or its islands and 22 considered Australia.

Largely the evidence indicates that feral domestic cats are generalist predators. Many studies, both in New Zealand (Langham 1990; Alterio and Moller 1997) and elsewhere (Molsher et al. 1999; Millán 2010), indicate a dietary preference for lagomorphs and rodents. However feral cats have been shown through observation, scat sampling, and gut content analysis, to prey upon other small native mammals (Mifsud and Woolley 2012), reptiles (Arnaud et al. 1993; Harlow et al. 2007), insects, birds (Harper 2010), and amphibians (Bonnaud et al. 2011). In studies which did not address a single species of concern, scat and gut samples were found to frequently
include all of the taxa noted above (Catling 1988; Paltridge et al. 1997; Molsher et al. 1999; Paltridge 2002; Medina et al. 2006; Kutt 2011; 2012).

In the absence of substantial populations of rabbits, rats, or mice, often as a result of seasonal variations in abundance (Oppel et al. 2011), studies indicate increases in predation of other animals, including native species (Catling 1988) which may, theoretically, have a significant impact on population persistence (Khan and Al-Lawatia 2008). Only very few articles indicated a greater likelihood that feral cats will disperse rather than switch to consumption of non-preferred prey species (Harper 2005). Modelling of the impact of feral cats suggests that increases in preferred prey populations may function to support feral cat population growth. In turn, this increases the likelihood that less preferred vulnerable species, often existing in low numbers, will come under increased predation pressure simply by virtue of increased rates of encounter (Smith and Quin 1996). This is known as the hyper-predation effect (Courchamp et al. 2000).

Studies of feral cats in New Zealand and its associated islands identify them as significant predators of mammals (Murphy et al. 2004), mainly introduced mammals but also native bats (Scrimgeour et al. 2012). Likewise, they have been linked to predation of both introduced and native birds including kiwi (Gillies et al. 2003), kakapo (Powlesland et al. 1995; Clout and Merton 1998), variable oyster catchers (Rowe 2008), New Zealand Dotterel (Dowding and Murphy 1993), silvereyes (Flux 2007), bellbird (van Heezik et al. 2010) and many species of seabird (Ratz et al. 1999; Dowding and Murphy 2001; Medway 2004) (see Table 2. for full list). Although cats are seen as predators of native birds they will, and do, prey upon native reptiles
(Veitch 2001; Tocher 2006) and insects (Alterio and Moller 1997). Predation by cats, although clearly not the only significant factor, has resulted in regional declines in a number of species and, in a few notable cases, extinction (Galbreath and Brown 2004). However, generally there is strong evidence that feral cats show a dietary preference for introduced mammals, especially in areas where extirpation of native species may already have occurred (Fitzgerald and Gibb 2001) or the ecosystem is severely degraded (Langham 1990). On the basis that cats are generalist predators capable of having a significant effect on native species, the feral cat is recognised as a pest in New Zealand and identified for lethal control in most of New Zealand’s native species recovery plans. As an animal in a wild state, feral cats are not specifically covered by the Animal Welfare Act 1999 or The Cat Code and can legally be lethally controlled (Farnworth et al. 2010b).

4.3.2 Stray, colony and companion cats

Broad estimates within the USA suggest free-ranging cats account for between 1.4-3.7 billion bird and 6.9-20.7 billion mammal predations annually (Loss et al. 2013) although most of these can be attributed to un-owned (i.e. feral, stray) or semi-owned (i.e. those that are provided with care but not considered to be owned (Toukhsati et al. 2007)) cats. Of the literature that addresses free-roaming cats, and where the term free-roaming is further elucidated (i.e. ownership status is included), by far the largest amount of information concerns companion cats (see table 1) and estimates annual catch per companion cat at between 2.8 and 128 individual prey. The upper estimate in this case is based upon cat-borne camera observations which indicate that predation based upon returned prey may account for just one in four actual kills (Loyd et al. 2013). Other studies which have used multiple assessment methods support the notion
that owner-reports of prey items likely underestimate total take (Barratt 1998; Krauze-Gryz et al. 2012). In broad terms the data support the assertion that cats in human environments remain generalist predators with a preference for rodents (Flux 2007) but will also scavenge substantially from human refuse (Hutchings 2003) and consume carrion (Langham 1990).

The urban environment is generally low quality and highly fragmented and is therefore already degraded and less able to support many species (Sims et al. 2008; Valcarcel and Fernandez-Juricic 2009). Although the diversity of predatory species is also reduced, urban environments do not represent safe-zones for adaptable bird species (Jokimäki et al. 2005). High densities of single-species introduced predators, including domestic cats, likely exacerbate local species decline (Baker et al. 2003). Species diversity will also be governed by habitat availability and types, as well as predator abundance (Lilith et al. 2010).

Studies which used bird density at the individual garden level rather than a wider population census found no effect of cat presence on bird abundance in Australia (Parsons et al. 2006). However, broader-scale studies in the UK indicate that the ratio of cats to 21 bird species were significantly different between urban and rural environments, suggesting that there are more cats and fewer birds in urban environments (Sims et al. 2008). Despite significant impacts upon bird populations, certain species (e.g. black redstarts, *Phoenicurus ochruros* in Germany) appear to be robust to cat predation pressure (Weggler and Leu 2001) whilst others are not (e.g. blackbirds (*Turdus merula*) in New Zealand; (van Heezik et al. 2010).
Companion cats are not all active hunters (Robertson 1998; Baker et al. 2005; Loyd et al. 2013). However, outdoor access for companion cats has been shown to increase the likelihood of predation of wildlife (Robertson 1998). There is also substantial variation amongst hunting patterns of individual cats. In some studies a small percentage of individuals may account for the majority of prey samples (Gillies and Clout 2003; Tschanz et al. 2011) whilst in others large percentages of included cats return relatively few prey (Barratt 1997). Cats also appear to show inter-individual preferences for prey species (Ancilatto et al. 2013) with prolific hunters appearing to prefer rodents (van Heezik et al. 2010).

Unlike feral cats, stray and companion cats exist in environments where anthropogenic food sources are either intentionally or unintentionally readily available (Finkler et al. 2011b). As a result, proximity to people (Ferreira et al. 2011) and human population density (Aguilar and Farnworth 2012) have both been strongly correlated with cat and stray cat densities. Anthropogenic food sources reduce, but by no means remove, the likelihood that cats in the urban environment will hunt (Silva-Rodriguez and Sieving 2011). The prey intake of feral cats is approximately four times that of a companion cat (Liberg 1984) but within the companion cat population the degree to which cats were fed by people also impacted upon the likelihood that they caught and consumed prey. Poorly-fed cats are 4.7 times more likely than well fed cats to have wild animal remains in their faeces (Silva-Rodriguez and Sieving 2011) and an early study indicates that cats not fed meat may also hunt more frequently (Robertson 1998). Stray cats are typically provided with less food and care than companion cats and, although this is not yet substantiated, may therefore be more likely to exert significant predation pressure on populations of prey species. Stray cats
also live longer and breed more successfully than their feral counterparts (Schmidt et al. 2007).

A survey of free-roaming companion cat owners indicated that bird predation levels did not significantly differ between cats living in urban, suburban and rural areas (Lepczyk et al. 2004), however the species of birds taken in each area was not provided and this has been shown to differ between urban and suburban environments (Gillies and Clout 2003). Domestic cats show strong seasonal variation in prey types and quantities, often correlating with peak reproduction in their prey (Ancillotto et al. 2013). Within the companion population this also extends to the proportion of wild animals in the diet; in one study approximately 50% of scat samples by weight derived from pet food in summer but this rose to 85% in winter, the remainder being non-anthropogenically-derived (Liberg 1984). By far the greatest increase in predation is observed during the summer months (Baker et al. 2005). Domestic cats also show age-related changes in predation rates, with younger cats (those under 7 years of age) generally returning more birds and lizards (but not mammals) than older individuals (Woods et al. 2003). A longitudinal study of a single cat supports this hypothesis, indicating an overall decline in the number of prey taken annually beyond the age of 11 years (Flux 2007).

Within New Zealand specifically, companion cats have been shown to prey on a wide range of both native and non-native species (see Table 2) and the diversity of prey species appears closely linked to the environment in which the cat resides, with more native species being preyed upon by cats living adjacent to native bush (Gillies and Clout 2003) or large gardens with mature trees (van Heezik et al. 2010). Studies of
companion cats within New Zealand are relatively few compared to those on feral cats and there appear to be no studies that specifically assess the impacts of either stray or colony cats on wildlife. However, in studies where predation levels have been quantified (see Table 2) there is evidence that those companion cats which do hunt do so opportunistically. Although companion cats in these studies kill rodents in larger numbers they also take significant numbers of birds, reptiles and invertebrates. The species taken most appear to be those which are most common. In one Dunedin-based study (van Heezik et al. 2010), cat predation was at a high-enough level to threaten the persistence of six urban bird species suggesting that the city population may persist only as a result of immigration from reproductively viable city fringe populations. Gillies and Clout (2003) showed significant variation in species caught depending upon the location of an Auckland suburb (i.e. urban or semi-urban). Most prey caught were rodents, especially those caught in the forest fringe; however native birds, insects and reptiles were also more likely to be caught in the forest-fringe as compared to more urban areas. In urban areas insects were the predominant prey and birds were caught in equal numbers between the two suburbs but tended to be non-native species in urban areas. In Hamilton the domestic cat was found to be the only major predator regularly identified within the city itself (Morgan et al. 2009a). The city of Hamilton also had a relatively high nesting success rate for four bird species, two native (fantails and silveryeyes) and two non-native (blackbirds and song thrushes) (Morgan et al. 2011), possibly due to low rat numbers outside gullies. However, this study also suggested that the impact of cats may be more significant at fledging making nest success a potentially less robust measure of the impact of cats.
4.3.3 Free-roaming cat density

Studies in New Zealand indicate that the vast majority of companion cats are free-roaming (Farnworth et al. 2010a). Outside urban environments the density of cats is curtailed to some degree by the availability of prey; this is why cat density is typically low in areas without dense human habitation. For example, Hawke’s Bay farmland has approximately 2-3 cats/km² (Langham 1990), estimated densities on Kangaroo Island, Australia were 0.7 cats/km² (Bengsen et al. 2011), and rural areas in the Mediterranean report densities of 0.26 cats/km² (Ferreira et al. 2011). In human-mediated environments this pressure is removed and predation pressure may not decline as prey species abundance declines (Shochat 2004) especially since urban cats may not be subject to optimal foraging requirements (i.e. efficiency based on capture rates and energy returns) (Maclean et al. 2008). As a result, companion domestic cats (excluding stray and colony cats) are able to live at extremely high densities within urban environments with estimates for Dunedin being 223 cats/km² (van Heezik et al. 2010).

Beyond companion cats, large populations of stray cats can be supported through provision of food by semi-owners (Toukhsati et al. 2007) or colony carers. Evidence suggests that this increases the local stray cat population and concomitantly reduces the diversity of other species (Hawkins et al. 1999). In countries where stray and colony cats are either protected or are an accepted part of the urban environment (e.g. Israel) total cat density can exceed 2300 cats/km² (Mirmovitch 1995). Based on stray cats numbers collected by a single charity in one year in Auckland, stray cat density may, at the very least, range from 15-50 cats/km² depending on location (Aguilar and Farnworth 2012). As the data used by Aguilar and Farnworth (2012) only accounted
for cats that were reported and removed, and 44% of the data on stray cats could not be used, the actual density is likely to be substantially higher. However, stray cat numbers will differ across New Zealand, and a report on a single Wellington shelter reported a much lower annual intake (Rinzin et al. 2008). Reasons for such variation are not evident within the research.

4.3.4 Home-ranges of cats

Feral cats have been shown to have large home-ranges which often coincide with areas of significant prey abundance (Fitzgerald and Karl 1986). Urban cats have smaller home ranges than those found either in the suburbs or in rural areas (Lilith et al. 2008; Loyd and Hernandez 2012). Companion cats are also found to have significantly smaller ranges than stray cats (Schmidt et al. 2007) with stray cats spending 14% of their time highly active (i.e. hunting) as compared to 3% in companion cats (Horn et al. 2011). Stray cats also have higher survival rates than feral cats and likewise higher fecundity (Schmidt et al. 2007). Despite high mortality rates in the first six months of life, stray cat populations have a high reproductive capacity (Nutter et al. 2004b). When tracked, companion cats showed preference for areas in which hunting success is improved (Loyd and Hernandez 2012). Prey that live at high density in patchy and fragmented habitat may be particularly vulnerable in this regard (Larsen and Henshaw 2001). Despite having a contracted home range there is strong evidence that urban or suburban domestic cats will incur upon surrounding rural, semi-rural, or national park landscapes (Lilith et al. 2008; Marks and Duncan 2009; Fandos et al. 2012) where prey may include remnant native species (Meek 1998). Dispersal of domestic cats is aided by sparse human settlements which act both as
outposts for free-roaming stray cats and smaller centres of aggregation (Ferreira et al. 2011; Young et al. 2013).

4.3.5 Estimated predation impact of companion and stray cats

4.3.5.1 Companion cats

The total predation impact of cats on fauna in New Zealand has not yet been estimated but, in other nations, is estimated to be billions (Loss et al. 2013) or hundreds of millions (Woods et al. 2003) dependent upon the size of the cat population. It seems pertinent to attempt a rudimentary and conservative calculation based upon the data provided by three recent studies to address predation by companion cats in New Zealand (Gillies and Clout 2003; Flux 2007; van Heezik et al. 2010). Using the broad (and highly conservative) assumption that 35% of companion cats are active hunters this would indicate that approximately 490,000 of the 1.4 million companion cats (MacKay 2011) routinely return prey to New Zealand households. Using the mean annual return rate across the three studies (22.3 prey items per annum) this would indicate a total population annual return of some 10,927,000 individual animals. We may postulate that somewhere between 1 in 4 (Loyd et al. 2013) and 1 in 1.7 (Barratt 1998) prey are returned making the number of animals killed somewhere between 18.58 - 43.71 million. The breakdown by taxa, based upon mean values from Gillies and Clout (2003) and van Heezik et al. (2010) would be as follows: mammals 6.23-14.64 million; birds 4.7-11.06 million; reptiles and amphibians 1.45-3.41 million; invertebrates 6.21-14.6 million.
4.3.5.2 Stray cats

It is more difficult to estimate the impact of stray cats and, in this regard, this section should be considered highly speculative. Using a conservative estimate of the stray cat population, that being an additional 14% of the companion population (Mahlow and Slater 1996), stray cat numbers may be at the lower estimate of 196,000 across New Zealand. Little information exists on individual impacts of stray cats. Stray cats, or those living around anthropogenic food sources (Hutchings 2003), are likely to exploit available food, but also to supplement these with prey. One may reasonably assume that a stray cat is unlikely to be provided with its complete daily dietary needs. Include evidence that poorly fed cats are 4.7 times more likely to consume vertebrate prey than well fed cats (Silva-Rodriguez and Sieving 2011) and one may conclude that the proportion of stray cats that hunt, even infrequently, is likely 100%. Using an assumption that an individual stray cat may consume twice as many prey items as a companion cat (i.e. (22.3*2)*4 or 1.7) the annual take would be between 75.82 and 178.4 prey items per cat. Based upon total population estimates this would indicate a total take of approximately 14.86 – 32.97 million prey items. A further breakdown of the taxa is perhaps not helpful given the speculative nature of this estimate and a lack of data as to where stray cats are found but, conservatively, could be considered to be proportionally similar to that for companion cats.

4.3.6 Non-predatory impacts of domestic cats

More recently the sub-lethal impacts of urban cat populations are being explored. At high densities they are being shown to have indirect impacts upon other species. The response of birds to the presence of a cat in the locale has been directly related to an increased likelihood of nest predation by animals other than cats (Bonnin
gton et al.
2013). It is indicated that this is probably due to exposure of the location of the nest as the bird responds to cat presence. Models of the sub-lethal impact of urban domestic cat populations suggest that a reduction in provisioning by nesting birds equal to one fewer fledglings per nest per year may be enough to significantly reduce urban bird abundance (Beckerman et al. 2007). Such reductions in provisioning may result from increased vigilance, reduced foraging time, and increased predator evasion and even well-adapted bird species are more vigilant in urban environments as compared to rural ones (Valcarcel and Fernandez-Juricic 2009).
Table 1: Summary of studies retained which contained data concerning predation by urban populations of companion and stray cats

<table>
<thead>
<tr>
<th>Study</th>
<th>Country</th>
<th>Study length</th>
<th>Cat type (n)</th>
<th>% Active hunters</th>
<th>Sampling method (n)</th>
<th>Mean composition/number of prey taken during study</th>
<th>Estimated annual take per cat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mammals</td>
<td>Birds</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Returned (1961)</td>
<td>65%</td>
<td>27%</td>
</tr>
<tr>
<td>Barratt (1997)</td>
<td>Australia</td>
<td>12 months</td>
<td>Companion (214)</td>
<td>-</td>
<td>Returned (1961)</td>
<td>65%</td>
<td>27%</td>
</tr>
<tr>
<td>Barratt (1998)</td>
<td>Australia</td>
<td>12 months</td>
<td>Companion (135)</td>
<td>~80%</td>
<td>Returned (-)</td>
<td>6.9 ± 2.3</td>
<td>2.6 ± 0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Returned (-)</td>
<td>6.9 ± 2.3</td>
<td>2.6 ± 0.7</td>
</tr>
<tr>
<td>Barratt (1998)</td>
<td>Australia</td>
<td>12 months</td>
<td>Companion (135)</td>
<td>~80%</td>
<td>Returned (-)</td>
<td>6.9 ± 2.3</td>
<td>2.6 ± 0.7</td>
</tr>
<tr>
<td>Baker et al. (2005)</td>
<td>UK</td>
<td>144 days</td>
<td>Companion (131)</td>
<td>26-49%</td>
<td>Returned (358)</td>
<td>75%</td>
<td>24%</td>
</tr>
<tr>
<td>Baker et al. (2008)</td>
<td>UK</td>
<td>12 months</td>
<td>Companion (275)</td>
<td>~39%</td>
<td>Returned (495)</td>
<td>66%</td>
<td>24%</td>
</tr>
<tr>
<td>Borkenhagen (1979)</td>
<td>Germany</td>
<td>-</td>
<td>Companion (54)</td>
<td>-</td>
<td>Returned (309)</td>
<td>62%</td>
<td>22.1%</td>
</tr>
<tr>
<td>Brickner-Braun et al. (2007)</td>
<td>Israel</td>
<td>-</td>
<td>Urban stray (43) Village stray (59)</td>
<td>-</td>
<td>Gut contents (102)</td>
<td>0%</td>
<td>22%</td>
</tr>
<tr>
<td>Calver and Thomas (2011)</td>
<td>Australia</td>
<td>3 weeks a</td>
<td>Companion (15)</td>
<td>100%</td>
<td>Returned (60)</td>
<td>52%</td>
<td>38%</td>
</tr>
<tr>
<td>Campos et al. (2007)</td>
<td>Brazil</td>
<td>2 months (July; Jan)</td>
<td>Free-ranging suburban/rural (-)</td>
<td>-</td>
<td>Scat (97)</td>
<td>20.51%</td>
<td>12.82%</td>
</tr>
<tr>
<td>Flux (2007)</td>
<td>NZ</td>
<td>17 years</td>
<td>Companion (1)</td>
<td>100%</td>
<td>Returned (558)</td>
<td>58.2%</td>
<td>40%</td>
</tr>
<tr>
<td>Gillies and Clout (2003)</td>
<td>NZ</td>
<td>1 year</td>
<td>Companion (80)</td>
<td>-</td>
<td>Returned (1674)</td>
<td>32%</td>
<td>13.5%</td>
</tr>
<tr>
<td>Gordon et al. (1998)</td>
<td>NZ</td>
<td>6 weeks a</td>
<td>Companion (45)</td>
<td>~80%</td>
<td>Returned (257)</td>
<td>63%</td>
<td>32%</td>
</tr>
<tr>
<td>Study (Year)</td>
<td>Location</td>
<td>Duration</td>
<td>Method(s)</td>
<td>Returned</td>
<td>Prey Items</td>
<td></td>
<td></td>
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<tr>
<td>-------------</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Kays and DeWan (2004)</td>
<td>USA</td>
<td>3 months</td>
<td>Companion (12)</td>
<td>100%</td>
<td>Returned (60)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2013)</td>
<td></td>
<td></td>
<td>(159)</td>
<td></td>
<td>86% 14%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Krauze-Gryz et al. (2012)</td>
<td>Poland</td>
<td>30 months</td>
<td>Companion (34)</td>
<td>100%</td>
<td>Returned (1545)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(55)</td>
<td></td>
<td>69.8% 13.1% 8% 8.2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Langham (1990)</td>
<td>NZ</td>
<td>44 months</td>
<td>Rural stray</td>
<td>(-)</td>
<td>(321)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74% 24% 2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loyd et al. (2013)</td>
<td>USA</td>
<td>7-10 days</td>
<td>Companion (55)</td>
<td>44%</td>
<td>Camera observation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>26% 13% 41% 21%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nelson et al. (2005)</td>
<td>UK</td>
<td>1 month</td>
<td>Companion (89)</td>
<td>100%</td>
<td>Returned (309)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>58.6% 37.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thomas et al. (2012)</td>
<td>UK</td>
<td>8*6 weeks</td>
<td>Companion (348)</td>
<td>~75%</td>
<td>Returned (1150)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>65% 30%</td>
<td></td>
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</tr>
<tr>
<td>Tschanz et al. (2011)</td>
<td>Switzerland</td>
<td>48 days</td>
<td>Companion (32)</td>
<td>65.6%</td>
<td>Returned (71)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>76.1% 11.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>van Heezik et al. (2010)</td>
<td>NZ</td>
<td>12 months</td>
<td>Companion (144)</td>
<td>75%</td>
<td>Returned (1887)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35% 37% 8.1% 19.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woods et al. (2003)</td>
<td>UK</td>
<td>5 months</td>
<td>Companion (696)</td>
<td>91%</td>
<td>Returned (11537)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>68% 24.3% 4.8% &lt;3%</td>
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</tr>
</tbody>
</table>

*Period excludes one or more identical period during which a predation deterrent was tested*  
*Cats recruited in these studies were known hunters*  
*Cats recruited in these studies were known hunters*  
*Actual number 1.67/month in Summer; observed kills = 5.54/month (66.48/year by same calculation)*  
*Cats in this study are described as ‘feral’ however they live and scavenge around human habitation meaning they are potentially ‘stray’ under code of welfare definition*  
*Actual number 2.4 items per week, mean of successful hunters only*  
*Percentage of cats having returned prey after eight seasons*
Table 2: Prey species identified following return to owner by companion cats in New Zealand. Where numbers of returns are not available, species are presented in order of most to least frequent.

<table>
<thead>
<tr>
<th>Study</th>
<th>Birds (n)</th>
<th>Mammals (n)</th>
<th>Reptiles/Amphibia</th>
<th>Invertebrates (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cats n=1</td>
<td><em>Silveryeyes Zosterops lateralis</em> (43)</td>
<td>Rat <em>Rattus rattus</em> (63)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Greenfinch <em>Carduelis chloris</em> (30)</td>
<td>Rabbit <em>Oryctolagus cuniculus</em> (35)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Goldfinch <em>Carduelis carduelis</em> (22)</td>
<td>Hare <em>Lepus europaeus</em> (4)</td>
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<tr>
<td></td>
<td>Chaffinch <em>Fringilla coelebs</em> (17)</td>
<td>Weasel <em>Mustela nivalis</em> (2)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>House sparrow <em>Passer domesticus</em> (16)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Blackbird <em>Turdus merula</em> (13)</td>
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<tr>
<td></td>
<td>Song thrush <em>Turdus philomelos</em> (7)</td>
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<tr>
<td></td>
<td>European starling <em>Sturnus vulgaris</em> (6)</td>
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<tr>
<td></td>
<td>*Fantail <em>Rhipidura fuliginosa</em> (5)</td>
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</tr>
<tr>
<td></td>
<td>*Grey Warbler <em>Gerygone igata</em> (4)</td>
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</tr>
<tr>
<td></td>
<td>*Kingfisher <em>Halcyon sancta</em> (1)</td>
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<tr>
<td></td>
<td>*Shining cuckoo <em>Chrysococcyx lucidus</em> (1)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Redpoll <em>Carduelis cabaret</em> (1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gillies and</td>
<td>House sparrow <em>Passer domesticus</em> (1)</td>
<td>Rat spp. <em>Rattus rattus/norvegicus</em> (313)</td>
<td>(*) Skink <em>Cyclodina</em> spp. (117)</td>
<td></td>
</tr>
<tr>
<td>Cats n=80</td>
<td>Blackbird <em>Turdus merula</em></td>
<td>Stoot <em>Mustela erminea</em> (4)</td>
<td>*Auckland green gecko</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Song thrush <em>Turdus philomelos</em></td>
<td>Rabbit <em>Oryctolagus cuniculus</em> (2)</td>
<td><em>Nautilinus elegans elegans</em> (2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>European starling <em>Sturnus vulgaris</em></td>
<td>Hedgehog <em>Erinaceus europaeus</em> (1)</td>
<td>Frog <em>Litoria</em> spp. (2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>*Kereru <em>Hemiphaga novaeseelandiae</em> (1)</td>
<td></td>
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<td></td>
<td>*Tui <em>Prosthemadera novaeseelandiae</em> (2)</td>
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<td>*Grey Warbler <em>Gerygone igata</em> (2)</td>
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<td>*Fantail <em>Rhipidura fuliginosa</em> (1)</td>
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<td></td>
<td>*Kingfisher <em>Halcyon sancta</em> (1)</td>
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| van Heezik et al. (2010) cats n=144 | *Silverseyes Zosterops lateralis (182)  
House sparrow Passer domesticus (78)  
Song thrush Turdus philomelos (69)  
Blackbird Turdus merula (42)  
*Fantail Rhipidura fuliginosa (32)  
*Bellbird Anthornis melanura (11)  
European starling Sturnus vulgaris  
Greenfinch Carduelis chloris  
Goldfinch Carduelis carduelis  
Chaffinch Fringilla coelebs  
Redpoll Carduelis cabaret  
Yellowhammer Emberiza citrinella (7)  
Mallard Anas platyrhynchos  
*Kereru Hemiphaga novaeseelandiae  
*Tui Prosthemadera novaeseelandiae | House mouse *Mus musculus (386)  
Rat *Rattus rattus (241)  
Stoat *Mustela erminea; Rabbit Orectolagus cuniculus (12)  
Rat *Rattus norvegicus (2) | Common skink *Oligosoma nigriplantare polychrome (149)  
Frog *Litoria spp. (4) | (**) Invertebrates (362) |

(*) Native to New Zealand  
(asterisk) May include native species  
(asterisk) 22 species of which six were native
4.4 Objective two: Management of the cat population

4.4.1 Management of feral cat populations

Without exception current control and management of feral cats involves lethal means including trapping (Short et al. 2002), shooting (Phillips et al. 2005), poisoning (Eason and Frampton 1991; Burrows et al. 2003; Hetherington et al. 2007) introduction of disease (Bester et al. 2002), and hunting (Rauzon et al. 2008). The goal of any such management is the total eradication of cats from the area and often requires a combination of control measures (e.g. Bester et al. 2002). However, total eradication is generally only possible within confined geographical areas such as islands (e.g. Veitch 2001). Within mainland populations control is primarily intended to reduce numbers of feral cats and therefore limit population growth (Gillies et al. 2003). Lethal management of feral cats is generally supported by the New Zealand public and is considered more acceptable than lethal control of stray cats (Farnworth et al. 2011).

Within the literature there has been some practical (Gorman et al. 2002) and theoretical (Courchamp and Cornell 2000) consideration of immunocontraception for remote populations of feral cats. To date immunocontraception remains under investigation. Currently the value of long-acting contraception is also being explored for controlling stray cat populations (Levy 2011) but is not commonly used as it remains under development (Levy et al. 2011). The ability of any non-lethal population control method to mitigate cat predation rates and improve welfare requires consideration.
4.4.2 Stray cat management techniques

While much of the information around management focuses on stray cat colonies, the information available for management of the wider stray cat population (i.e. those that are not closely associated with carers) is limited. The number of stray cats able to be supported in any given environment will have upper limits (McCarthy et al. 2013). As this is normally resource-driven the presence of anthropogenic food sources indicates that the population carrying capacity of human environments is large. Wilful provision of food in the absence of other population management processes supports significant and growing numbers of stray cats (Tennent and Downs 2008). It is perhaps then self-evident that any strategy to control cat populations requires strong consideration of the human origins of the issue (Lohr et al. 2013). Outside New Zealand, a significant body of literature suggests that, overall, public attitudes towards stray cat management favour non-lethal methods (Ash and Adams 2003; Tennent et al. 2010; Loyd and Hernandez 2012). In New Zealand, although there is some public support for non-lethal cat control (Farnworth et al. 2013a), this is not unequivocal (Farnworth et al. 2011) and, as elsewhere (Loyd and Miller 2010b), preferences may be related to perceptions of the value of wildlife.

4.4.2.1 Trap, Neuter, Return (TNR) and Trap-Euthanise (TE)

For the purposes of this review TNR is also considered to encompass other techniques of sterilisation and return including those with additional schedules of vaccination and health care (e.g. trap-test-vaccinate-alter-return-monitor (TTVARM) Hughes and Slater 2002). In general TNR is the process by which individual stray cats, or those living in colonies, are live-trapped, sterilised, potentially vaccinated, and then returned to the location from which they were taken (Robertson 2008). The degree of
diagnosis and care provided by individual TNR providers will differ (e.g. Wallace and Levy 2006). It is considered to be a more ethical approach to stray cat population management in that it does not result in the death of otherwise healthy cats. Reportedly it also prevents incursion into areas left vacant by cat removal (Mahlow and Slater 1996), however observations do not support this assertion given that sexually entire cats were in some instances able to exclude and outcompete gonadectomised cats (Gunther et al. 2011). Recently an alternative method has been modelled that uses trap-vasectomy-hysterectomy-release (TVHR) (McCarthy et al. 2013). Such methods remove a cat’s reproductive capability whilst leaving sexual behaviour unaltered (Mendes-de-Almeida et al. 2011). This may prevent incursion by other individuals. Compared to other models (see later), TVHR may only require 35% of the population to be captured and treated annually to cause population decline over 11 years, assuming four annual capture efforts with high capture probability. This model indicated that TNR was unable to outperform either TE or TVHR in any simulation. However, this model did not appear to include the potential for population maintenance through abandonment of cats by owners.

TNR and its variants are particularly espoused for semi-owned cats which continue to receive *ad hoc* care on an on-going basis. In general, managed colonies could be considered those which are provided food, water, shelter and veterinary care on an irregular basis. The literature is equivocal concerning decline and extinction of colonies. In one 11-year study a colony was reduced from 68 to 23 individuals. However, of 155 cats removed or lost from the colony over 11 years, 47% of the cats were adopted and 21% either disappeared or migrated away (Levy *et al.* 2003). Another study focused on university campuses with a combined estimate of 186
colony cats across five locations. A TNR rate of 57% did not appear to reduce the colony sizes, although they were stable (Jones and Downs 2011) and a later paper indicated a need for removal of animals to reduce the population (and its impact) before maintenance through TNR (Tennent et al. 2009). Where TNR is actively employed, colony extinction may require 5-10 years of on-going management and so is not advised in areas where significant problems require rapid solutions (e.g. colonies in the vicinity to endangered species) (Stoskopf and Nutter 2004). Stoskopf and Nutter (2004) used six colonies of cats where an experimental management protocol, which included TNR, was implemented. This resulted in relatively large colony declines (36%) over short periods of time (2 years), three control colonies concomitantly showed a 47% increase in population size. Early modelling suggested TNR would require 75% of any given population to be consistently sterilised before population stability and decline was achieved. If TE was modelled this percentage dropped to 50% (Andersen et al. 2004) suggesting TE was more effective. Other models of TNR and non-surgical contraception suggest that in any given year 51% and 60% of the population would need to be sterile or have a contraceptive implant respectively (Budke and Slater 2009). When TNR and TE procedures were modelled in Hawai‘i, TNR was identified as being significantly more expensive, an issue which has previously been cited as an impediment to broad-scale use (Levy 2011). TNR was shown to require 30 years to extirpate any population assuming a 0% abandonment rate. In contrast, TE required 2 years for extirpation (Lohr et al. 2013). However 0% influx via abandonment is unrealistic in any open system and in one Italian study this was estimated to be as high as 21% (Natoli et al. 2006). As a result, any TE programme would need to be repeated on a regular basis to suppress a growing population whilst TNR failed to significantly reduce the population (Lohr et al. 2013)
and was described as ‘a waste of time’ (Natoli et al. 2006) until cat abandonment by owners was effectively addressed. The suggestion that neither TNR nor TE can effectively manage populations with significant influx from abandonment is supported in other models (Schmidt et al. 2009).

Modelling of population interventions is problematic in that models do not incorporate public acceptance which will vary relative to local perception (Robertson 2008). In one study a TE campaign to reduce an unowned free-roaming cat population was routinely disrupted by those opposing it whereas TNR increased compliance (Levy et al. 2003) and in another there was strong opposition to eradication of the stray cat population (Tennent et al. 2010). Without regular trapping and hysterectomy of females approximately every 6 months (Mendes-de-Almeida et al. 2011) the population growth rate of colonies cannot be effectively curbed.

Broadly speaking the literature around TNR tends towards discussion of small groups of cats and small numbers of colonies in localised geographical areas with dedicated carers, often in or around universities (Hughes and Slater 2002; Levy et al. 2003; Nutter et al. 2004a; Jones and Downs 2011). In examples where large longitudinal samples are explored there appears little evidence of population decline (Foley et al. 2005) or only moderate decline (Natoli et al. 2006), and where decline is evident it is of questionable validity as it is drawn from surveys which rely on carers’ recollections rather than observation (Centonze and Levy 2002). In the latter study of 103 colonies surveyed only one had become extinct during a 10-year TNR intervention. Likewise, another large study (Hughes et al. 2002) was unable to specifically identify a direct cat population reduction as a result of a county-wide TNR effort. Other papers which
discuss TNR provide no clear assessment of the size of source populations of cats or the ultimate impacts of the TNR event. Some of these papers discuss small populations (Gibson et al. 2002) but others consider TNR on a large scale (n=103,643 Wallace and Levy 2006). Studies on colonies of cats that have undergone TNR suggest that there is no reduction in home-range or in the propensity of cats to enter areas of native forest (Guttilla and Stapp 2010) although this is a single study on a small population. There is some evidence that the provision of localised food sources, often in excessive amounts (Natoli et al. 1999), may act as both an attractant for additional stray cats and increase fecundity of any cats which remain unneutered. The tendency of colony carers to have strong emotional attachments to the cat group (Centonze and Levy 2002) may also reduce the likelihood that new cats entering the group will be removed and seems to encourage belief-based rather than evidence-based objectives and systems of care (Peterson et al. 2012). Reproductive output is directly attributable, in some cases, to the management style and resources available to the carers (Finkler et al. 2011b).

Cat management and predation of wildlife by cats are often addressed in isolation, especially in relation to the direct predation effect of stray cats and cat colonies. No papers were found in this systematic review that directly addressed conservational concerns (e.g. predation rates) alongside active colony management using TNR.

4.4.2.2 Removal and rehoming

One of the most common processes by which stray cats can be permanently removed from environments where they are potentially at risk, and are a potential risk to wildlife, is through removal and adoption (Robertson 2008). Removal and adoption
has proved useful in reducing the size of stray cat colonies (Levy et al. 2003) but has not always discussed in detail (Natoli et al. 2006; Jones and Downs 2011). In other campaigns kittens as young as six weeks were returned to colonies following sterilisation with no clear articulation of an intent to re-home any individuals (Gibson et al. 2002). Data on the number of cats arriving at adoption centres and outcomes for those cats are not promising (Rinzin et al. 2008; Marston and Bennett 2009; Alberthsen et al. 2013). Adoption as a strategy can only generally apply to well socialised adults or kittens (Levy et al. 2003).

There has been some discussion around cat sanctuaries which would be organised spaces where large numbers of cats can be allowed to live. Within some areas in the USA there appears to be significant support for this idea (Loyd and Hernandez 2012). However, evidence suggests that where these do exist they fill rapidly, are inefficient, and are unable to meet service demand (Levy and Crawford 2004). Dense populations of cats are also likely to require significant health care to prevent outbreaks of infectious diseases such as upper respiratory tract disease (Dinnage et al. 2009). This is especially important for individuals not intended to be adopted.

4.5 Companion cat management techniques

Modelling of TNR and TE for stray cat population management suggests that abandonment of companion cats places significant financial and temporal impairment on either strategy (Castillo and Clarke 2003; Natoli et al. 2006; Lohr et al. 2013) and therefore strategies to improve the cat-owner bond are vital. In Israel persistent negative ownership behaviours such as allowing uncontrolled breeding and wilful
abandonment have been shown to contribute to stray cat over-population (Finkler and Terkel 2012).

Preventing companion cats from contributing to the stray cat population requires two main problems to be addressed. First, suitable levels of gonadectomy must be achieved. Current evidence is that, within New Zealand, gonadectomy rates for owned cats are close to 90% (McKay et al. 2009; Farnworth et al. 2010a) and comparable to those in Australia (Marston and Bennett 2009). Furthermore, early gonadectomy (prior to puberty) appears to be the norm within New Zealand’s veterinary practices (Farnworth et al. 2013b). However, internationally, poor companion cat care and management has been linked to variations in the socio-economic characteristics of carers and locations (Finkler et al. 2011a; Gunther et al. 2011). Within Auckland, the prevalence of stray cats in areas with high deprivation scores suggests that similar problems may be present (Aguilar and Farnworth 2012).

Beyond minimising the reproductive potential of the companion cat population there is a need to minimise abandonment. Anthropologically, identifiable colonies of cats may increase the likelihood that additional cats will be abandoned in that locale (Castillo and Clarke 2003; Natoli et al. 2006). Public perception of cats as independent animals may lead to individuals abandoning cats in an attempt to ‘give them a chance’ rather than relinquishment at a welfare centre where they may be euthanased (Levy and Crawford 2004). Acceptance that cats should be free-roaming also increases the likelihood of semi-ownership (Toukhsati et al. 2007). There is a strong need to minimise abandonment rates by improving the owner-cat bond.
Minimising the predation impact of companion cats would appear to be best served by use of collars with attached bells or sonic devices. In instances where this has been directly assessed it appears to cause a significant reduction in predation (Ruxton et al. 2002; Woods et al. 2003; Nelson et al. 2005; Gordon et al. 2010; Calver and Thomas 2011), although this effect has not been observed in all studies (Barratt 1998; Morgan et al. 2009b) and some devices can be unreliable (Nelson et al. 2006). Alongside prevention of predation, collars also allow ready identification of owned cats and hence the owner. This increases likelihood that companion animals will be reunited with owners (Weiss et al. 2011). Current research suggests that cats in New Zealand are unlikely to be provided with a collar and even less so one with an attached bell (Farnworth et al. 2010a). A survey in Australia suggests that this may result from a generally unfounded fear of injuries being caused by collars (Calver et al. 2013).

Within Australia, confinement of cats or curfews have been implemented to minimise owned cats’ opportunities to hunt, a measure which has received support within the State of Victoria (Toukhsati et al. 2012). Many espouse keeping cats in at night, something which has been identified as reducing predation rates (Woods et al. 2003), or restricting ownership (Lilith et al. 2006). However, cat restrictions have not clearly been linked to changes in prey density or type (Lilith et al. 2010). In countries such as the USA where cats are themselves prey for larger predators, indoor cats are more common and are less likely to receive injuries from other cats (Clancy et al. 2003). Evidence suggests that exclusively indoor cats, if provided for appropriately (e.g. with opportunities to display normal behaviour patterns), are unlikely to experience poor welfare (Jongman 2007). Other strategies that would allow companion cats, and by
association stray cats, to be identified include compulsory registration, an intervention which has been proposed in Australia (Calver et al. 2011).


5 Discussion

5.1 Literature included

As with any systematic review of the literature inclusion of information is potentially limited by the terms and search engines used. We have, however, gone to considerable effort to engage with the peer-reviewed literature at the broadest possible level. In terms of literature prevalence there is clear evidence that studies of both cat predation and population management have gained significant attention of late with a particular increase in the last 20 years. However, this may be associated with a general increase in peer-reviewed publication and not solely a result of increased concern about cat populations.

Much of the predation literature focuses on feral cats (see section 4.1.2) and companion cats. There is little information concerning predation by stray or colony cats, possibly as a result of an inability to easily sample these groups. The predation literature, in particular, addresses the problem in countries and island chains that fall into categories 1-3, but relatively few papers address predation in countries which fall into categories 4-5. In part this may be due to a more obvious impact upon naïve fauna caused by recent cat introductions and also a stronger drive towards conservation imperatives in countries such as New Zealand (category 1), Australia (category 3) and islands with sea bird colonies and unique fauna (category 2). Likewise, these studies tend to originate from areas of sparse human population where conflict between feral cats and wildlife is most common. In countries such as those in North America (category 4) and Europe (category 5) the historic presence of the domestic cat, high human density and the likely historic extirpation of vulnerable
species may reduce the perceived urgency of research to quantify and mitigate predation impact.

In contrast, the literature around the management of cat groups, whilst also focussed on removal of feral cats, has a significant body of research which addresses stray and companion cats. Much of this literature arises directly from category 4 and 5 countries where discussion of cat management likely does not have the same conservational imperative for action. In this regard it also focuses primarily on non-lethal control methods for stray and feral cats. Literature from Australia and New Zealand which addresses population management for stray and companion cats tends to address mechanisms by which ownership and shelter practices can be addressed to minimise impacts.

5.2 Defining cat populations

Wherever possible the literature discussed in this document has been attributed to one of The Cat Code definitions. This was particularly problematic when reviewing the American literature where little clear distinction is made between ‘stray’ and ‘feral’ populations. In addition to Farnworth et al. (2010b) this research raises further questions about defining cat groups on a primarily anthropocentric basis. For example, some papers indicate that cats feeding at refuse sites (Hutchings 2003) or on the margins of farms (Langham 1990) are ‘feral’, but within the definitions of The Cat Code these could be argued to be stray in that they, at least in part, derive food from human sources, habitats and activities and may, at some point, have been abandoned. Additionally, an unneutered companion cat in a rural or semi-rural environment, where its home range is larger (Lilith et al. 2008), is arguably more likely to
encounter, and contribute directly to, the feral cat population than a similar individual in an urban centre. This is despite the supposition within The Cat Code that the companion cat population and feral cat population are largely independent of one another. In fact there is little evidence within the scientific literature that this is, or is not, the case. Future research should consider genetic flow between the three cat groupings as well as the origins of New Zealand’s companion cats.

If New Zealand’s major cities are similar to Melbourne, Victoria (Australia) it may be that the stray population acts to maintain the companion population (Marston and Bennett 2009). This is especially so as the companion population, within Auckland and Kaitaia at least, seemingly exceeds a sterilisation rate of 87% (McKay et al. 2009; Farnworth et al. 2010a). A rate around 76-88% has been identified as being able to prevent population increases (Burns et al. 2013). These statistics suggest that the unneutered stray and semi-owned populations may be the primary source of companion cats (Toukhsati et al. 2007), either through casual acquisition or through adoption at shelters (Marston and Bennett 2009). In essence, the companion and stray cat populations overlap significantly. Likewise, so too do the feral and stray populations, despite The Cat Code stating that stray cats will likely breed with unneutered companion cats (but with no mention of feral cats). The inability to clearly extricate one cat grouping from another presents significant problems in terms of population and welfare management. The definitions within The Cat Code may also lead to misunderstandings and miscommunication between interested parties with different foci (e.g. cat control agencies and cat protection agencies).
5.3 Impact of cats

The estimated numbers of animals killed by cats proposed within the literature reviewed in this document suggest that cats have a substantial impact upon other species. At an individual level, companion cats will likely have a reduced predation impact when compared to stray, feral, or colony cats by virtue of the ready availability of food which is shown to reduce prey take (Silva-Rodriguez and Sieving 2011). However, there are a number of reasons why these rudimentary calculations should be treated with caution. Firstly, beyond companion cat data, little or no evidence could be found for the prey take of stray cats and we would recommend work similar to that of Loyd et al. (2013) be undertaken. The lack of evidence meant that the estimated take of stray cats was created using highly conservative values, and stray cats may well kill far more than twice the mean annual number of prey taken by companion cats. Secondly, stray cat number estimates were based upon the lower population estimate of an American study (Mahlow and Slater 1996) and may be inaccurate within the New Zealand context so again further study is recommended to provide a clear estimate of the stray cat population. Thirdly, the three studies used to generate the companion cat estimate were not conducted in comparable areas on comparable populations and some included invertebrates explicitly in the prey take (Gillies and Clout 2003; van Heezik et al. 2010) whilst others did not (Flux 2007). Finally these calculations are extrapolated from urban and semi-urban cat populations and cannot take into account local and regional variations in cat territory and prey availability. However, these limitations noted, the total prey take parameters provided are more likely to underestimate impact than overestimate it.
5.3.1 Feral cats

Notwithstanding the information provided in 5.1, the evidence shows that the impact of the feral domestic cat is substantial, despite generally living at low densities (Fitzgerald and Gibb 2001). This is particularly so: 1) in environments where anthropogenic food is neither directly nor indirectly available; 2) where the ecology has evolved in the absence of mammalian predators; and 3) where introduced predator populations can be either sustained or grow unchecked. Therefore, the feral cat within New Zealand is legitimately identified as a pest and has had, and continues to have, significant impacts upon native fauna since its introduction. Some of these impacts, even those of single individuals (Scrimgeour et al. 2012), are extremely relevant to the conservation of critically endangered or vulnerable fauna (Clout and Merton 1998). This is despite evidence of a preference for other introduced mammals such as rodents and lagomorphs and assertions that cats may function to reduce the populations of other predators and meso-predators (Fitzgerald and Gibb 2001). Research into the impact of feral cats outside islands and particularly in protected or pristine mainland areas should be encouraged, especially as related to populations of other predators.

5.3.2 Companion cats

Tables 1 and 2 demonstrate the wide variation found in both the nature of studies concerning companion cats and the impacts of companion cats. With the exception of studies which recruited known hunters (e.g. Calver and Thomas 2011), all studies of companion cats indicate a significant proportion that do not actively hunt or do so only rarely. Precisely why this is the case is difficult to establish but it is likely a result of a range of factors including age (Woods et al. 2003), home-range, food
intake (Silva-Rodriguez and Sieving 2011), prey availability (Sims et al. 2008) and food type. Research comparing specific samples of cats that hunt with those that do not may provide further insight. Despite this, at high densities (e.g. 223/km2: van Heezik et al. 2010), even the lowest estimate of the number of hunters (26%: Baker et al. 2005) would indicate a density of actively hunting cats far in excess of that found in uninhabited environments (Ferreira et al. 2011). As a result, the cumulative impact of companion cats upon prey species is likely to be substantial. Further, the number of prey taken is often significantly underestimated, with prey numbers potentially being more than four times what owner report (Loyd et al. 2013). Of interest is that there was no significant difference in the likelihood that any particular group of species (e.g. birds) would be left at the site of the predation event, consumed, or brought home. This suggests that the proportion and diversity at the level of taxa, notwithstanding rare items, is likely accurate. There may, however, be some bias based upon the palatability of individual species (Krauze-Gryz et al. 2012). How aspects of prey return rate and palatability relate to New Zealand’s native vertebrate and invertebrate species are not currently known.

There is clear evidence that, in general, companion cats kill substantial numbers of other animals (Table 1). Within New Zealand this is predominantly non-native species (e.g. Gillies and Clout 2003) but does include significant numbers of native birds, reptiles and invertebrates (Table 2). Our calculations indicate that this impact may be quite large, but note that this is a rudimentary calculation only, hence it used assumptions that lie at the lower end of any ranges provided in the literature. Which species are killed, and how often, will depend on availability of prey which, in turn, is dependent upon the environment in which the cat is kept. Urban companion cats, for
example, are more likely to prey upon small mammals, birds and insects, and likely
those species which are introduced and commonly adapted to urban environments
(van Heezik et al. 2010). In this regard urban studies in New Zealand are similar to
those elsewhere (e.g. UK: Woods et al. 2003) in that urban biodiversity often
comprises a number of ubiquitous species which are well represented in recorded kills
(e.g. house sparrows, house mice and rats). New Zealand’s urban fauna is already
depauperate, lacking in native species diversity. However, cats living close to
fragments of native forest, stands of mature trees or open park land may have
increased access to a wider diversity of prey species including those that are native
(Gillies and Clout 2003). Studies suggest that cats show a preference for nearby edge
habitats and areas of cover (Kays and DeWan 2004; Lilith et al. 2008) and will enter
them regularly (Fandos et al. 2012). Although anecdotally, this likelihood declines as
distance from the fragment increases (Gillies 2007). This means that in these areas
prey species that exploit edge habitats may be particularly vulnerable (Barratt 1998;
Marks and Duncan 2009). In one New Zealand study native birds were more likely to
be preyed upon, albeit still in low numbers, in less urbanised suburbs (Gillies and
Clout 2003) or larger gardens with mature trees (van Heezik et al. 2010). The most
commonly caught native bird in New Zealand is the silvereye (Gillies and Clout 2003;
Flux 2007; van Heezik et al. 2010), perhaps reflecting its adaptability to living in
urban and semi-urban environments. Of concern may be the indication that these are
predominantly adults of breeding age whilst other non-native species are more likely
to be preyed on shortly after fledgling (Flux 2007). Cat-free exclusion zones have
been proposed to restrict ownership in areas with vulnerable populations of native
species, however research suggests that this is an unpopular measure (Grayson et al.
2002). To date implementation of these strategies has not been explored in a New Zealand setting.

Large densities of companion cats should also be considered beyond their immediate and direct predation impacts. The hyper-predation hypothesis (see Courchamp et al. 2000) suggests that prey populations at low numbers may be particularly at risk in urban or semi-urban environments. Likewise, a high density of predators potentially acts to suppress normal population growth through sub-lethal (e.g. reduced foraging rates and nest provisioning rates) as well as lethal effects (e.g. direct predation) and, if this is the case, the hunting status of the cat is ostensibly irrelevant. These effects may also reduce the likelihood that vulnerable prey species will either persist or re-establish themselves in areas of high cat density. In a number of papers it is asserted that cats may have a quantifiably positive effect on native species populations (especially birds) by controlling rodent numbers (e.g. Flux 2007). This may be true in areas where no pest control is currently implemented. However, most urban environments do implement targeted rodent control and targeted pest control may be preferable to the use of cats which also prey upon non-pest species.

Little is known about the predation habits of companion cats outside major urban centres in New Zealand. Studies elsewhere suggest that their predation rate may not be increased (Lepczyk et al. 2004), however home-ranges do increase (Loyd and Hernandez 2012) as does access to different habitat and vegetation types which support higher biodiversity (Baker et al. 2003). Therefore the predation impact of rural companion cats may be substantially different to that of companion cats in urban environments. For example, rural studies indicate a strong preference for lagomorphs
(Liberg 1984; Langham 1990) which are rare or absent in urban studies and,
conversely, urban studies indicate a significant increase in the proportion of
invertebrate prey (Gillies and Clout 2003; van Heezik et al. 2010). Further research is
required to explore this issue.

Ultimately, the direct conservation impact of companion cats may be limited by the
species available for predation. Unlike other countries in which predation studies have
been conducted (Woods et al. 2003; Baker et al. 2005; Lilith et al. 2006), New
Zealand has no vulnerable species of ground-dwelling endemic mammals, often
favoured by cats, and urban and suburban birds are predominantly introduced
European species (van Heezik et al. 2010). The question as to how important non-
native bird species are for urban cats is one that requires further exploration. Little is
known about the impact of cats upon urban populations of native reptiles and
arthropods despite evidence that they are also directly affected (Gillies and Clout
2003). A tendency to focus on cats as bird predators may therefore mask other
significant issues.

Future research should explore a wider range of companion cat density including a
comparison of the impacts of companion cats in New Zealand’s rural, semi-rural and
urban environments. The persistence of native and non-native species in areas of high
companion cat density also requires further consideration. Currently there are few
New Zealand studies and all are limited either by the sample size or by the geographic
region under consideration. Single cat studies such as that by Flux (2007) may be of
limited value as they function at a small scale. As indicated previously, population
assessments at the individual garden scale are unable to accurately reflect species
abundance (Parsons et al. 2006), possibly because gardens act as sinks for birds in adjacent properties. Further research should include overlaying aspects of density, population size and breeding success of prey species with cat density and be similar to the work of van Heezik et al. (2010) but on a national scale, including more robust estimates of both avian and non-avian prey populations.

5.3.3 Stray cats

Most stray cats are unlikely to exist in managed colonies and many unmanaged colonies have been identified (Aguilar and Farnworth 2013). However, stray cats, including those in colonies, may have a substantially larger predation rate than companion cats in that, by definition, they are less likely to be fed regularly or to have their nutrient needs met than companion cats. They are therefore more likely to hunt systematically and have larger home ranges (Horn et al. 2011). A much smaller population of cats can thus have a disproportionate impact upon local fauna. Stray cats are also more likely to aggregate at sources of food and shelter (Natioli 1985; Denny et al. 2002) but as these may be ephemeral there is significant opportunity for migration. Given that they are more likely to survive longer than feral cats and have higher fecundity than either companion or feral cats (Schmidt et al. 2007), the stray cat population is likely self-sustaining and it can therefore be proposed they have a marked potential to impact negatively on urban bird, insect and reptile populations.

As for companion cats, the location in which a stray cat is resident will directly affect which species it preys on and any impact it has. To date this has not been effectively quantified. Given the propensity for stray and unowned cats to have larger home-ranges (Horn et al. 2011) and be more active, it is probable that they will aggregate
either around provided food sources or around suitable hunting habitat. If the latter results in populations which attract the former there is potential for stray cats to become a major concern.

There is a need to further consider the direct impacts of stray cats in New Zealand and specifically to explore the dispersal of stray cats, especially in semi-rural and rural areas where stray and feral cats may be difficult to distinguish as per The Cat Code definitions. It is reasonable to suggest that stray cats may have the greatest predation impact simply by virtue of both numbers and necessity. They also likely bolster both the companion and feral populations, compounding this effect.

5.4 Management techniques

5.4.1 Managing the stray cat population

Managing stray cats is difficult given the understandable emotional attachment that many people have to them. This report demonstrates that there is no simple answer and control of stray cats is likely going to require multiple strategies which can be efficiently and judiciously applied. In line with current recommendations, management techniques should be considered that meet the needs of the cats themselves, minimise suffering, mitigate poor welfare, allow populations to be controlled such that re-incursion opportunities are minimised (Sparkes et al. 2013) and to be fully integrated with management strategies for other pests to minimise the potential effects of prey-switching. However, these methods need to take into consideration New Zealand’s unique fauna and ecology. Methods such as immunocontraception would, if sufficiently developed, allow non-lethal management of populations but are difficult to apply to free-roaming populations (Jewgenow et al.
2006). This is because such methods are indiscriminate and would affect feral and owned cats. Immunoc contraception is likely only of potential in isolated areas and would not prevent on-going issues of direct predation by individual cats.

No strategy will be without its financial costs and research from the UK suggests that the economic burden of managing un-owned cats and dogs may already outstrip the capacity of charitable organisations (Stavisky et al. 2012). Serious consideration needs to be given, and research undertaken, to explore cat population management further. Some discourse must also occur around where the fiscal burden lies for any such initiative. All other discussion aside, there appears strong international, inter-disciplinary, and temporal consensus that preventing cats from becoming stray by reducing abandonment and promoting responsible ownership must be the major focus of any management strategy (Feldmann and Carding 1973; Clarke and Pacin 2002; Natoli et al. 2006; Finkler et al. 2011b; Lohr et al. 2013). In terms of mitigation of predation, it appears from the evidence available for this review, that TNR can only have an impact in the longer term if it effectively prevents population growth or initiates population decline. In the short term there is, therefore, no likely reduction in predation impact.

Few actual studies have been done on the wider implications of broad scale TNR campaigns. One major issue is a general lack of accurate assessments of the stray cat population size and hence an inability to draw a full understanding of the financial, conservational, and social implications of any such strategy. It is precisely this absence of information which causes wide divisions around TNR and a demand for
greater evidence within conservation and animal welfare sciences (Longcore et al. 2009; Lepczyk et al. 2010; Calver et al. 2011).

If utilised, techniques such as TNR and TVHR are likely only of significant value in specific circumstances. The population of cats would require regular human care, including routine capture, vaccination and treatment to prevent transmission of both feline specific and zoonotic diseases (Nutter et al. 2004a). A named person should be required to act as a *de facto* owner of the cats. It would also likely be preferable that the group of cats be limited in number with no new cats being added (an immigration rate of zero). Given that TNR can in no way mitigate the predation impacts of individuals, cats should, perhaps, not be returned within the proximity of areas of ecological value, fragments of bush or even areas with mature trees. It would be valuable to conduct more research around New Zealanders’ attitudes towards, and interactions with, stray cats including the intentions of colony carers and semi-owners during such provision.

On a wider scale TNR is unlikely to be a viable broad scale response to a large stray cat population and, as a sole strategy, TNR is unlikely to result in the extinction of colonies where cat immigration and abandonment continues without removal. Much of the current research comes from countries where the ecology of the cat is substantially different. Extrapolation from these studies is therefore problematic. For example, modelling in Australia indicates that cat populations may be partially suppressed, and their impacts reduced, by the presence of other larger native and non-native carnivores (Hanna and Cardillo 2013). In New Zealand there is no such dynamic. Similarly, feline diseases may be more or less prevalent in New Zealand as
compared to other countries. Hence specific research is needed regarding the size, health and reproductive viability of New Zealand’s stray cat population. Given estimates from Australia that indicate between 92% (Alberthsen et al. 2013) and 96% (Marston and Bennett 2009) of stray cats entering shelters are not de-sexed the ability to have a meaningful impact upon the stray population through TNR primarily is questionable, especially if decline requires 71-81% (Budke and Slater 2009) or 75% (Andersen et al. 2004) of the population to be sterilised. In countries where stray cats are a common feature of the urban landscape cat density is high and no clear population decline, or stabilisation, can be discerned outside small sub-population samples (i.e. known colonies). In studies where TNR resulted in significant and rapid declines it was implemented alongside other rigid protocols and selection criteria for inclusion of colonies in the study (Stoskopf and Nutter 2004). This means TNR is only likely to be wholly effective in small isolated areas where intensive management is long-term and on-going and where the goal of any such management is extirpation of the colony. TNR is also unable, on a broad scale, to mitigate the potential for reduced welfare in the stray population. Stray cats are likely to continue to have poorer condition, higher parasite and disease burdens (Spada et al. 2012; Spada et al. 2013) and increased rates of injury compared with companion cats. In addition stray cats are also more likely to have shorter lives than companion cats, and in some models urban ‘feral’ lifespan is estimated at just 3 years (Budke and Slater 2009). Likewise, in the USA colony born kittens generally experience very low survival rates with 75% dying before 6 months of age (Nutter et al. 2004b). Kitten survival in New Zealand requires further exploration as survival pressure is likely to differ from that reported in other countries.
From the perspective of the welfare of the cats TNR can only be considered to be positive if it improves outcomes for the cats themselves. How this is measured is not clear but should consider the health of the animal, longevity, condition and injury status, many of which are suboptimal (Jessup 2004). All of these aspects will also be impacted upon by the nature of any ad hoc care given to the cat or colony. Understanding how exactly carers provide for stray cats and cat colonies requires future research. There is some evidence that under intense management protocols such as TTVAR colonies of cats may have a comparable disease status to companion cats (Nutter et al. 2004c), but this level of care is likely rare. TNR may also improve kitten and adult survival rates (Gunther et al. 2011) by reducing sexual aggression and resource competition. Body-condition score has also been noted to improve following TNR (Scott et al. 2002) although this was ascertained using only 14 of 105 individual cats assessed one year after sterilisation. Other authors suggest that colonies maintained by TNR represent significant populations of cats that act as a reservoir for zoonotic infections such as Toxoplasma gondii (Gerhold and Jessup 2013) and that, in general, cat colonies experience significant levels of disease (Borji et al. 2011; Spada et al. 2013). Higher rates of disease transmission (Mendes-de-Almeida et al. 2011) and shorter lifespans may be associated with TVHR, as compared to TNR (McCarthy et al. 2013), due to continued aggression and copulation (Mendes-de-Almeida et al. 2007b). It is likely therefore that the collateral costs in terms of cat welfare are potentially too great.

The value of current research into TNR is unclear given that it often focuses on well managed colonies outside New Zealand where cats are socialised to human presence and regularly trapped. This socialisation means they are potentially easier to catch and
manage on a routine basis (Nutter et al. 2004a). Little information exists as to how TNR would apply to a wider scale management process in environments where cats are not well socialised and are avoidant of people or traps. More exploration of TNR as a management tool and its economic costs and benefits in a New Zealand setting is required.

Most of the literature addresses groups of cats in urban centres or industrial areas and there is little information concerning semi-rural or rural application of TNR. Broader application of TNR must consider the impacts of cats in different geographical locations especially as it relates to variable predation impacts (see section 4.2.2). TE has also been demonstrated to be unable to be effectively applied to reduce stray cat populations in environments where abandonment of cats continues (Andersen et al. 2004; Schmidt et al. 2009) and whether or not it is economically preferable is unclear. However, given the on-going commitment required to manage populations of stray cats it is probable that short-term costs of TE are lower (Lohr et al. 2013). Beyond the practical implications of TNR it already receives significant public support globally. Public education and research around alternatives is important (Clarke and Pacin 2002) if indeed TNR is considered inappropriate for New Zealand.

Removal and adoption is, currently, the major strategy utilised within New Zealand. However, wit is likely that the number of homes willing to adopt cats may be declining given the numbers of potential stray cats and kittens that are available as compared to the estimated 48% household ownership of cats in New Zealand (MacKay 2011). Literature from New Zealand (Rinzin et al. 2008) and Australia (Marston and Bennett 2009; Alberthsen et al. 2013) suggest that a substantial
proportion of cats and kittens held in shelters and welfare centres are euthanased. Given the number of cats available it is possible that this may lead to a perception that they represent ‘disposable’ commodities which, in turn, increases re-abandonment. Thus removal and re-homing can only be considered as an addendum to any wider management strategy to curb source populations.

Given that cat ownership in New Zealand at a household level is high and ownership significantly affects attitudes towards cats (Farnworth et al. 2011), public perception is likely of significance here as elsewhere (Finkler et al. 2011a). Ownership also impacts upon beliefs around predation impact. Cat-owners were more likely to agree or be unsure when compared to bird-watchers, when presented with the statement “free-roaming cats do not harm wildlife” (Loyd and Hernandez 2012). Awareness of feral cat issues and support of TNR (Loyd and Miller 2010a) may also vary between rural and urban populations. Community approaches to issues around stray overpopulation will require a wider community engagement of stakeholders than simply those considered to be ‘pro-cat’ or ‘anti-cat’ (Hamilton 2010); a distinction which is, in and of itself, divisive.

It may be reasonable to say that any predation effect that an individual cat has is unlikely to be mitigated by sterilisation unless a concomitant change occurs in the cat’s immediate opportunity or need to be a predator. To date this is only likely to be achieved by removal and adoption, a strategy which is often utilised alongside TNR (Levy et al. 2003). Few observations exist concerning predation by colonies following TNR and these are, at best, anecdotal (Levy and Crawford 2004).
5.4.2 Managing companion cats

In terms of predation it is likely that companion cats present the least pressing concern compared with feral and stray cats and their impact on native species could be substantially reduced through promotion of collars with bells attached. Of greater concern is the current lack of ownership models for companion cats. In order to minimise increases in stray cat populations and predation by companion cats it appears that significant steps need to be taken to alter the public perception about cats within New Zealand. This should start with identifying what ‘responsible ownership’ is construed to be; this call for research not new (Selby et al. 1979).

Currently in New Zealand there is no legal requirement for companion cats to be identified either through micro-chipping or the use of collars. There is also no formal process of registration for cats. As a result, distinguishing between stray cats and free-roaming owned cats is problematic. Discussion of responsible ownership of cats should therefore consider several aspects, some of which are progressing well in New Zealand while, for others, dialogue is yet to occur. A major focus should be on education of the wider public about appropriate care of cats. Evidence suggests that New Zealand’s companion cat population is already reproductively curtailed, although broader studies of sterilisation rates should be conducted nationwide. The goal to increase sterilisation rates may benefit from more campaigns and funding focussed in areas of low socio-economic status (Aguilar and Farnworth 2012) similar to those which already function to provide cut-price or free desexing services. Identification of cats is also paramount to ensure that effective strategies for control of un-owned cats, whatever they may be, can progress. These strategies could include simple promotion of collars or other visible tagging devices through to registration
and compulsory micro-chipping in a similar manner to dog ownership. The addition of a bell to a collar has been shown to be an effective method by which predation impact can also be reduced (e.g. Gordon et al. 2010). Strategies should also consider promotion of indoor lifestyles for cats, including dismissing misconceptions around their unsuitability. From a welfare and health perspective strategies that curtail free-roaming may also reduce the opportunities for cats to acquire diseases, fight, or be injured.

If it is accepted that companion cats often originate as strays which are subsequently either informally or formally adopted. Measures should thus also be taken to promote a transition away from semi-ownership towards full-ownership. This can take a number of forms but may require a promotion of full-ownership models through community and governmental action whilst semi-ownership practices which perpetuate stray cat populations (e.g. ad hoc food provision without additional care) could be discouraged.

6 Future research

There are a number of areas where information concerning cats, cat management and attitudes towards cats in New Zealand is absent. Research to provide potential answers would be judicious and could include exploration of the following:

- The ecology of the cat across New Zealand, especially rural and urban ecologies of companion and stray cats and their predation impacts. This should include impacts upon desirable (e.g. bird) and undesirable (e.g. rodent) groups.
• The gene flow between the three cat groupings in New Zealand, especially stray cats and their contribution to the wider population.

• Predation rates of un-owned and stray urban cats in New Zealand.

• Public attitudes towards cat population management techniques including the potential for consensus amongst interested parties.

• Cost-benefit analyses of cat population management strategies.

• Understanding the companion cat population, its size, its origins (i.e. where and how people acquire their cats) and end-points (i.e. what happens to cats).

• Public perceptions of responsible ownership practices and barriers to the adoption of such practices.

• Current use of TNR within New Zealand and cat colony management practices.

7 Conclusions

Exactly how cats impact upon New Zealand depends upon the environment in which they live as well as human attitudes towards their well-being and management. Overall there is a substantial need for a greater understanding of cat ecologies within New Zealand. That aside, there is strong evidence that, although feral cats provide the greatest risk to native species, the domestic cat has a significant and potentially harmful impact upon New Zealand’s wildlife. It is likely, however, that the negative impacts of domestic cats can, in the large part, be mitigated through effective and responsible ownership policies for companion cats and effective population management for stray cats. Taking a precautionary approach to reducing predation effect such as that proposed by Calver et al. (2011), while maximising the welfare of
free-roaming cats, would suggest that active management to reduce the numbers of free-roaming cats, and especially un-owned cats, is required in the short to medium-term. Delays in implementing effective strategies will likely have a quantifiable impact on both cat welfare and wildlife persistence. Given our limited understanding of cat ecologies in New Zealand and elsewhere any management processes should be responsive to new information as it arises to ensure best practice. Furthermore, there is a need for the stray cat (including colonies) and companion cat populations to be more clearly delineated, for example through a formal identification of owned cats and active promotion of change in how cats are perceived and owned in New Zealand. This would allow more effective management to occur.

In general the stray cat population is likely to grow without clear management and it is already likely a self-sustained population which, rather than being supported by the companion cat population, is the primary source of companion cats. Methods of control such as TNR, whilst possibly effective for small isolated groups of cats which are consistently managed, are not likely to reduce the impact of cats on wildlife, nor can they mitigate welfare issues experienced by un-owned and unmanaged cats. They are also likely to be prohibitively expensive when extrapolated to the wider stray population. In this regard TNR, although potentially useful in very specific circumstances, is unlikely to present a viable option for long-term cat population management at a regional or national level. In instances where colonies are extant their impact can be minimised by ensuring they are not adjacent to areas of ecological value and that they are routinely de-sexed every 6 months (Mendes-de-Almeida et al. 2011). Cats in colonies should also be vaccinated and health-checked annually by a veterinary professional and have a person who is legally responsible for their welfare.
and care. To prevent growth and promote gradual disestablishment of colonies all new adults and kittens should be routinely removed and re-homed. Where re-homing is not possible and would compromise the welfare of the individual euthanasia may be the preferable option. Returning cats to areas where they are un-managed is not in the interests of cat welfare.

Formation of a national working party, which includes welfare, governmental, academic and conservation stakeholders would be of benefit. Such a group could collaboratively address how a framework of legislation, education and research may allow more effective management of cats, especially stray cats, to occur within New Zealand.

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