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How does cat behaviour influence the development and implementation of monitoring techniques and lethal control methods for feral cats?

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ABSTRACT

The need for lethal control of feral cats will remain in some contexts and potentially increase in others, alongside an obligation to develop and apply methods that are as cost-effective, humane and target-specific as possible. Drawing on practices particularly used in Australia, New Zealand and on offshore islands we review current lethal techniques applied for feral cat removal, such as shooting, trapping and poison baiting, and how our understanding of feral cat behaviour has influenced their development and application.

1. Introduction

The International Union for Conservation of Nature (IUCN) lists cats (*Felis catus*) among 100 of the world's worst invasive species (Lowe et al., 2000). Feral cats utilize the 'wild' end of a highly adaptive behavioural spectrum that equips them as destructive predators and disease vectors, with more subtle ecological impacts now becoming apparent (e.g. Medina et al., 2014). The ability of cats to survive either with or without dependency on humans seems intrinsic to their historical value as commensal or companion animals but is also a serious downside to their introduction, intentional or not, to naive ecosystems. The global distribution and abundance of cats currently sit in stark contrast to the precarious conservation status of the many species of endemic mammals, birds, herpetofauna and invertebrates on which cats prey. Among various published definitions, here we focus on feral cats as those in populations that are geographically isolated from human habitation and are self-sustaining in remote areas, including offshore islands. They have no dependence on humans and many such cats may never have encountered people. In such situations managing feral cats through non-lethal approaches – such as capture–rehoming, deterrence, exclusion or reducing fertility or recruitment (e.g. Trap–Neuter–Return (TNR) programmes) – is impractical within constraints of geographical scale, resourcing and the urgent need to prevent extirpation of some species of endemic wildlife threatened by feral cat predation. Some authors have clearly articulated the shortcomings of TNR

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in terms of the overall welfare of cats (Jessup, 2004) while others have noted dubious efficacy of TNR in protecting biodiversity values from the impacts of feral cats (Longcore et al., 2009; Lepczyk et al., 2010). For these reasons we do not further discuss non-lethal approaches. Here we review feral cat management practices mostly from Australia, New Zealand and offshore islands, as examples that have wider application in how considerations of cat behaviour must be incorporated into the development of lethal techniques and their operational implementation against criteria of efficacy, economy over broad-scale areas, target specificity and minimization of welfare impacts.

2. Why lethal techniques for feral cats?

The view of feral cats as an introduced species with harmful impacts on ecosystems has been described as a 'normative judgement' (Robertson, 2008) in some contexts. However, in Australia and New Zealand at least, the impacts of feral cats on native biodiversity values are judged severe enough to merit regulatory acknowledgement in legislation and corresponding management directives which include lethal control. Historical accounts of the European colonization of Australia and New Zealand and subsequent ecological research have provided ample evidence of ongoing adverse impacts following the arrival and spread of cats, alongside a suite of other invasive predators (e.g. Woinarski et al., 2014).

Cats were brought to New Zealand from 1769 onwards and are implicated in the extinction of at least six endemic species and some 70 local extinctions (King, 1984). They continue to contribute to the ongoing decline of a number of threatened species (Dowding and Murphy, 2001; Gillies and Fitzgerald, 2005). National conservation and biosecurity legislation and regional pest management strategies across New Zealand provide for the management of feral cats as a pest, using lethal techniques (Farnworth et al., 2010a). Defined as an animal in a 'wild state', feral cats are therefore not covered by New Zealand animal welfare legislation to the same extent as domestic cats (Farnworth et al., 2010b).

Introduction of cats to Australia possibly occurred during trade between Malay and Aboriginal people (Rolls, 1969) but was certainly accelerated with arrival of Europeans around 1800 (Dickman, 1996). Abbott (2002) suggests multiple point sources of cat arrival in Western Australia during 1824–1886. Feral cats have been linked to continental extinctions of seven species of Australian native mammals and to island and regional extinctions of native mammals and birds, and have caused the failure of reintroduction attempts aimed at re-establishing threatened species (e.g. Denny and Dickman, 2010). Feral cat management is recognized as one of the most important fauna conservation issues in Australia today, under the auspices of a national 'Threat Abatement Plan for Predation by Feral Cats' (Environment Australia, 2008). However policies across Australian states are inconsistent. Some state legislature and regulations define and regulate feral cats as a pest (Denny and Dickman, 2010) while others do not. Victorian state legislation, for example, declares it an offence for cats to attack, bite, worry or chase wildlife but currently provides no definition of feral cats which could then be used to classify these animals as pests, as occurs with domestic and wild dogs (State of Victoria, 1975, 1994). This situation limits the tools and techniques that may be used to manage feral cat populations where they exist in Victoria on land managed for biodiversity conservation.

There is also extensive evidence that the introduction of cats to oceanic islands has been disastrous for many species of island endemics. Feral cats have contributed to at least 14% of 238 vertebrate extinctions recorded globally by the IUCN and currently threaten 8% of the 464 species listed as critically endangered (e.g. Medina et al., 2011; Nogales et al., 2013). On remote islands without human habitation, lethal methods for removing feral cats are the most feasible for urgent biodiversity protection, with affordable operational implementation and no risk of unwanted impacts on owned cats that are allowed to roam. In recent years, eradication of cats from relatively large islands (Algar et al., 2010; Campbell et al., 2011; Parkes et al., 2014) has been achieved using a combination of lethal methods.

3. How does a feral cat behave?

Some phenotypes selected in artificial breeding of pedigree domestic cats (e.g. brachycephaly, very long coats) are probably maladaptive in truly feral populations (Bradshaw et al., 1999). While coat colours in a feral population are influenced by founder genetics, they are commonly tabby, black, grey, tortoiseshell or ginger (Brothers et al., 1985; Gillies and Fitzgerald, 2005). The metabolic inability of cats to synthesize certain nutrients is overcome by their being obligatorily carnivorous (Bradshaw, 2006), and feral cats are physiologically the same as other classes of *Felis catus* in these stringent nutritional requirements and also in how they are affected by and susceptible to toxic substances. Feral cats can meet their nutritional requirements completely through predation, including survival for times without fresh water, which has allowed them to colonize and persist in arid habitats where other invasive mammals cannot. Behavioural repertoires are also considered similar across the species as a whole (e.g. all classes of cats are predatory); however, feral cats are characterized by behaviours that represent the 'wild' end of the spectrum.

3.1. Responses of feral cats to humans

Avoidance of and fear reactions to humans are highly characteristic of feral cats; described by Gosling et al. (2013) as '...unapproachable in its free-roaming environment, when trapped will display aggressive defence behaviour or cower and try to hide, when released into a confined space will not be possible to handle the cat'. Such reactions have genetic and developmental components, for example kittens with little or no contact with humans until they are two months old are likely to remain fearful of people unless remedially socialized (Bradshaw et al., 1999). In feral cat populations that rarely if ever encounter people, their innate or learned avoidance of some control methods is attributed to fearful responses to the sight, sound or smell of people, and neophobia towards artificial devices such as traps.

3.2. Predation and food selection in feral cats

Cats locate, stalk and capture live prey primarily using visual and auditory cues presented by potential prey (Bradshaw, 1992); movements of small animals will stimulate hunting behaviour even in well-fed domesticated cats. Additional to the stalk–pounce–bite approach commonly observed in cats hunting in urban environments, feral cats adapt hunting tactics to available prey. They have been observed to 'fish' using their front claws to hook rabbits from underground refuges (McTier, 2000), and to focus on highly localized and temporally abundant small prey that are incapable of avoiding them (e.g. emerging turtle hatchlings on beaches; Hilmer et al., 2010).

Domestic cats are primarily opportunistic hunters and 'choosey' only secondarily (Barratt, 1997), and similarly diet selection by feral cats appears driven primarily by what to hunt rather than what to eat (Bradshaw, 2006). Domestic cats respond more strongly to stimuli triggering predation than to gustatory stimuli, but consumption following successful capture will depend on the palatability of the food (Adamec, 1976). This suggests feral cats are inclined to kill first and then determine whether the kill is worth eating. Adamec (1976) further states: 'the precedence of preying over eating may have the functional value of increasing food input if the opportunity arises.' Thus feral cats may kill more immediately available prey than they can eat at once; for example an estimated population of 50 cats on Tasman Island killed an estimated >50,000 seabirds annually (Bryant and Shaw, 2006). Compared with the longer-range visual and auditory cues presented by prey, odour cues are considered more a proximal stimulus to predation once a potential prey item is close, or to palatability and subsequent feeding once prey has been caught. Mugford (1977) suggested that food odour can both initiate and sustain feeding in cats, influence selection of food, and also mediate recognition of food that is aversive. Preferential consumption of certain parts and discarding the remainder of captured prey suggests that taste or texture also influences what feral cats eat, at least when they are not nutritionally stressed. Field observations often record evidence of feral cat kills in open areas, perhaps indicating they prefer to process their prey in such places, or at least that evidence of kills are more readily observed in open areas. Typical signs of a feral cat kill include 'pinioning' of avian prey, where the primary flight feathers are discarded. Field observations of birds killed by feral cats typically indicate a bite to the back of the head and consumption of the brain or whole head (Veitch, 1985). Feral cat predation of Hutton's shearwaters (*Puffinus huttoni*) was characterized by a bite to the back of the neck or head, peeling away of intact skin and feathers from the body and initial feeding on the larger pectoral muscles (Cuthbert, 2003). Cats may specialize in particular prey species, influenced by training from their mother (Bradshaw, 1992) or through seasonal and local prey availability (Johnston et al., 2011). One feral cat trapped in the Mackenzie Basin, New Zealand, had at least 34 lizards in its stomach (Murphy et al., 2004).

A preference in domestic cats for several small meals each day (Bradshaw, 2006) probably reflects multiple daily kills by feral cats when food is continuously available. When food is limited cats will as readily gorge on infrequent large meals (Thorne, 1982). Prey size influences the impacts of feral cat predation; on the Australian mainland this impact falls most heavily on species weighing less than c. 200 g (Dickman, 1996). Prey availability, comprising local abundance, density, naivety, body size and species composition of prey, is inextricably linked to diet selection by feral cats. Such information is used to determine which particular species are most vulnerable to feral cat predation–which directs management decisions around timing feral cat control efforts to optimize relief from predation pressure. In New Zealand, protection of kiwi species and endangered lizards requires year-round feral cat control (Gillies et al., 2003; Reardon et al., 2012), but for some shorebirds, cat control targets the spring–summer breeding season (Dowding and Davis, 2007; Moore, 2009). In Australia, the timing of control programmes is governed more by optimizing the reduction of feral cat populations over large areas within a short period (e.g. baiting when the prey resources are lowest).

Numerous studies provide static descriptions of what some feral cats eat (e.g. Jones and Coman, 1981; Paltridge et al., 1997; Read and Bowen, 2001; Gillies and Fitzgerald, 2005), but the majority of scientific literature addressing food selection and relative preference describes studies of domesticated cats, or at least cats with some artificial diet rather than live prey. Such studies consistently demonstrate a strong influence of food availability in what and how much cats choose to eat. Feral cats will eat carrion in some situations (Jones and Coman, 1981; Paltridge et al., 1997) and the general assumption that they prefer live prey to carrion remains untested by field studies. In New Zealand, rabbits and rodents are the primary prey of feral cats (Gillies and Fitzgerald, 2005), but if these resources are reduced, feral cats will switch to other prey such as birds and lizards (Murphy et al., 2004). Feral cat populations may also increase following an irruption of a prey species, followed by prey switching when the dominant prey population falls (Rich et al., 2014).

The distinction between what prey cats kill and what proportion of that kill is actually eaten highlights a key issue about impacts. Feral cats rely entirely on the prey that happen to be in their habitat; for some endangered wildlife populations this is a constant drain on viability and for others the excesses of feral cats' appetites can, and have, proved to be the last straw. This has been evident in some Australian conservation programmes involving reintroduction of wildlife species susceptible to feral cat predation (Moseby et al., 2011). Understanding when predation effects are most detrimental can only help to target feral cat control such that lethal control of feral cats results in a tangible benefit for valued wildlife (e.g. Littin, 2010).

3.3. Density and movements, social and reproductive behaviour in feral cats

Reproductive success is driven by resource abundance – feral cats generally have litters of up to five kittens and can breed several times a year when resources are not limiting (Jones and Coman, 1982; Read and Bowen, 2001; Gillies and Fitzgerald, 2005). Habitat use by feral cats varies with local conditions and resources-important information for optimizing control programmes (Bengsen et al., 2012). As summarized by Recio and Seddon (2013) feral cats structure their home ranges to optimize access to prey resources, so where these resources are sparse or widely distributed, cat populations are dispersed as solitary individuals that defend non-overlapping home ranges or show limited mutual tolerance. Spatial movements of males are typically larger and influenced by those of females to ensure mating success, whereas movements of female feral cats are more influenced by food abundance and shelter to rear kittens. Feral cat home-ranges have been recorded as 0.46–20.83 km^2 (Gillies and Fitzgerald, 2005; Johnston et al., 2011, 2012). In New Zealand, density estimates range from 0.19 to 0.27 cats/km^2 on Stewart Island when prey was scarce (Harper, 2004) to 33 cats being caught on a 28-ha island (118 cats/km^2) when prey was abundant (Fitzgerald and Veitch, 1985). Where prey is abundant and localized, relatively high densities of feral cats with reduced and overlapping home ranges could be supported through space sharing, aggregation and mutual tolerance (Recio and Seddon, 2013).

The role of scent glands and odour marking in territorial, social and mating behaviour in Felidae is well-described in general terms (Bradshaw, 1992; Mellen, 1993). Vocalization and auditory communication of cats has been researched in the context of how domestic cats relate to conspecifics or to people (e.g. Bradshaw and Cameron-Beaumont, 2000; Yeon et al., 2011). While the use of odour and auditory cues has been investigated in feral cat management (e.g. in attracting them to control devices), this appears to have been largely based on extrapolation of what we know about domesticated cats rather than an understanding of how such stimuli influence the behaviour of low density populations of feral cats in remote habitats.

4. Lethal methods for feral cat removal

4.1. Shooting

Shooting of free-ranging feral cats is a humane method when undertaken by skilled personnel using firearms of appropriate calibre and where shot placement can be made accurately on an animal that can be seen clearly and is within range. Shooting is most effective at night using artificial light sources (spotlight or night vision equipment) to create eyeshine from cats under illumination, which allows accurate targeting. Auditory lures may assist with attracting cats closer to a shooter's vantage point. Shooting is most likely to be successful when feral cats are unaware of a shooter's presence, or perceive the presence of a shooter or spotlight as a new object to be watched rather than as an imminent danger. However, feral cats can become spotlight-shy if previous attempts at shooting have been unsuccessful, showing behavioural adaptability in learning to avoid threats. The success of shooting in removing feral cats from a population also depends on openness of the habitat and the use of cover by feral cats in their movements. Practical experience to date shows that shooting is relatively expensive, labour intensive and as a sole removal method requires continual application to be effective at controlling feral cats even over small areas (Bloomer and Bester, 1991). Shooting can have useful application in removing small remnant numbers of feral cats which show behavioural avoidance of other trapping or baiting (Parkes et al., 2014). In remote field situations especially, a single rifle shot to the brain is the optimal means of killing feral cats captured in restraining traps (Sharp and Saunders, 2012).

4.2. Trapping

Trapping is most effective over relatively small scales or as an adjunct to other control methods (e.g. Algar et al., 2013) and for research procedures such as radio-collaring and release. Traps can be broadly categorized as live-restraining traps or kill traps; in Australia only live traps are used whereas New Zealand agencies may also use kill traps (Table 1). Use of steel-jawed, serrated-tooth 'gin' traps (e.g. Veitch, 1985) has been phased out in favour of more humane padded leg-hold traps (Meek et al., 1995) that reduce injury to restrained animals compared with unpadded jawed traps or wire snares. Regulating the frequency of checking live restraining traps is another measure to minimize injury and stress to trapped cats. Live traps require daily checking, making large-scale trapping operations very labour intensive. The New Zealand National Animal Welfare Advisory Committee (NAWAC) developed guidelines for assessing the welfare performance of restraining and kill traps (National Animal Welfare Advisory Committee, 2011) which, along with other regulation of leg-hold traps, have been used to identify specific trap types and sets for best-practice feral cat control in New Zealand (Table 1). Kill traps that have passed the NAWAC guideline will reliably render cats irreversibly unconscious within three minutes. In both Australia and New Zealand, 'raised sets' – where traps are set above ground on a platform, or at the top of a leaning board – are used to exploit cats' ability to jump and climb, while preventing ground-dwelling non-target wildlife from interacting with the trap (e.g. elevated 'bucket traps' were used on Christmas Island to prevent interference by land crabs; Algar and Brazell, 2008; Johnston et al., 2010).

Live-trapped feral cats will generally respond to human approach with flight/escape attempts and defensive aggression, particularly if any attempt is made to handle them. Where live trapping is used to gain close proximity to a feral cat in order to apply a killing method, shooting is the most practicable, rapid and humane method. Sedation of trapped cats followed by lethal injection is less suitable, partly due to the constraints of administering the required drugs in remote field settings. More importantly, the transport and handling required to affect sedation or anaesthesia before lethal injection will also prolong experiences of fear and other negative affective states for a trapped feral cat before it is rendered unconscious, increasing the risk of injury to both cat and handler. Cats that escape from poorly-set traps or through

Table 1
Trap types used in control of feral cats in Australia and New Zealand.

	Australia	New Zealand
Live restraining traps	Padded leg-hold traps in some states under permit (e.g. Victor soft catch traps) Treadle- or bait-hook-operated cage traps	Victor 1½ soft catch (padded leg-hold) traps only Treadle- or bait-hook-operated cage traps
Kill traps	Not used	Steve Allan raised Conibear trap system (with leaning board) Belisle Super X220 (in a cubby or 'chimney' station) Timm's trap (raised set) Set-n-Forget trap system (with leaning board).

human error in handling are unlikely to be trapped again, especially with the same type of trap and set – presumably having learnt from the aversive experience. Where feral cats are trapped and released after undergoing procedures for field research (e.g. fitting of tracking collars) this ideally entails the use of drugs that induce amnesia, to optimize the chance of recapture.

For effective reduction of feral cat populations there should be at least one trap within each home range, set in locations where cats are most likely to encounter them. Typically traps are located along linear landscape features that cats regularly traverse, such as fence lines, vegetation boundaries, waterways, tracks and intersections. Where feral cats are abundant, an extensive trap layout is required – in New Zealand traps are generally laid 100–200 m apart; and for localized threatened species protection more intensive layouts are used with traps about 50 m apart (Moore, 2009). In Australia, larger-scale programmes use 500-m trap spacing. Individual feral cats often follow particular routes around their home ranges and the areas they hunt can be very specific (Recio and Seddon, 2013); this behaviour can be used to optimize trap location.

While cage traps may seem optimal for minimizing welfare impacts they can be inefficient for feral cats (Short et al., 2002), possibly due to feral cats' wary or neophobic responses to artificial devices or their reluctance to enter a confined space. Cage traps secured in an open position with 'free feed' bait inside can familiarize the cat population to entering the traps over time before they are set. This is not practical in remote areas, on a very large simultaneous scale or where there are non-target species present that may 'familiarize' more readily to cage traps than feral cats. Concealed leg-hold traps are often more successful (Short et al., 2002), presumably because they are not perceived as a new object if perceived at all, but are triggered consequent to a cat simply walking over them. Paired padded leg-hold traps are usually set in configurations that encourage cats to tread where they will trigger the traps (Short et al., 2002; Algar et al., 2013).

4.3. Lures and baits

Lures are intended to influence feral cats to move in from the wider environment so they at least encounter a monitoring device, trap or toxic bait. Lures can present odour/scent, auditory or visual cues that stimulate investigation by cats as either potential prey or through responses to potential conspecific competitors or mates. Cats' hunting instincts rely principally on auditory and visual stimuli rather than olfaction so lures must be sufficiently long-range and attractive to induce close inspection by cats; but should be of limited or ideally no interest to other species. Hence food lures are less commonly used in favour of those invoking social or territorial investigative behaviour in cats. Food-based lures can also be less effective if feral cats are not hungry and therefore less inclined to investigate potential prey, or if the lure decays over time and is less attractive as food. Cats are very inquisitive about other cats in their area, and a range of scents, including social and plant-based (e.g. catnip *Nepeta cataria*) odours, have been trialled as lures for feral cats (Clapperton et al., 1994; Edwards et al., 1997). Current Australian feral cat control programmes use sound lures ('Feline Attracting Phonic', Westcare Industries, Western Australia), scent lures made of scats and urine from domestic cats, or visual mobile lures such as feathers or tinsel.

As distinct from a lure, bait is food-based and needs to be sufficiently attractive and palatable for a feral cat to eat upon encounter. This could be for the delivery of a poison (see below) or to encourage a cat that has encountered a baited trap to enter or interact with the trap sufficiently to be caught. Where possible, baits should simulate local prey for feral cats so the most effective baits often differ with location. In New Zealand typical baits are fresh, frozen or salted meat from rabbits, hares or possums, or fish. In Australia, various types of fresh or preserved meat or fish bait or tinned commercial cat food are commonly used (e.g. Short et al., 2002). Domestic cats are influenced by moisture content in diet selection (Mugford, 1977) and field experience indicates that acceptability of fresh meat baits to feral cats declines over time, presumably through dessication, invertebrate interference and bacterial decay. Low efficacy of poison baiting programmes in Australia before 1990 was attributed to the hard, dried meat baits used having a low uptake by feral cats. This seems to have reinforced the misconception that feral cats will not consume carrion or bait but only live-caught prey. While inanimate baits are assumed to be less preferred food items relative to normal live prey, feral cats are adaptable enough to scavenge, so where possible baiting and trapping is timed to coincide with low availability of natural food resources. The higher acceptance of fresh meat baits by feral cats confers a requirement to regularly refresh baits as they degrade, posing a major operational constraint for control programmes conducted on a large scale in areas with harsh climates and difficult terrain. Thus the development of long-life baits and lures for feral cats could offer substantial improvements to current techniques. To date, extensive research has been undertaken in Western Australia to develop an effective bait more durable to field

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Table 2
Toxic formulations currently registered or under field evaluation for feral cat control in New Zealand and Australia.

Australia	New Zealand
Eradicat® 1080 bait, manufactured by and for use by the Western Australian government. Each bait weighs approximately 15 g when dried and contains 4.5 mg of 1080.	PredaStop for Feral Cats (Connovation, Auckland), paste formulation containing PAPP, only for use in bait stations
Under field trials towards registration: Curiosity® bait containing PAPP	0.10% 1080 Feral Cat Bait (Animal Control Products, Whanganui), fish-meal-based polymer bait. For use only by the Department of Conservation, either hand-laid or in weather-proof bait stations

conditions and resistant to interference by invertebrates (Algar and Burrows, 2004); culminating in the development of a proprietary semi-dried meat sausage-bait formulation (Eradicat®), composed of kangaroo meat mince, chicken fat, digest and flavour enhancers and before application is sprayed with an ant deterrent compound.

4.4. Poison baiting

Secondary poisoning can occur when cats ingest poison through taking prey (typically rodents) that have ingested toxic bait and contain residual concentrations in their bodies. While this is an unwanted outcome for domestic cats where anticoagulant rodenticides are used (Berny et al., 2010), secondary poisoning of feral cats has been exploited during ongoing management of other invasive pests (e.g. Alterio, 1996; Gillies and Pierce, 1999) and in some eradication attempts on large offshore islands (Parkes et al., 2014). Poison baiting that directly targets feral cats is currently the most cost effective method for large-scale control on mainland Australia (e.g. Short et al., 1997; Algar and Burrows, 2004; Algar et al., 2013). While poison baiting for feral cats is not used over such large areas in New Zealand, it is also considered more cost-effective than trapping or shooting. Two poisons are currently available for feral cat control: sodium fluoroacetate (1080) and para-aminopropiophenone (PAPP).

Developed for rodent control in the 1940s (Atzert, 1971), most of the current worldwide use of 1080 is in New Zealand and to a lesser extent in Australia for the control a range of introduced mammals. In both countries 1080 is registered in bait formulations for feral cats (Table 2). Advantages of 1080 include its biodegradability (Eason et al., 2011), but the lack of an effective treatment for accidental poisoning and ongoing uncertainty about its humaneness (e.g. Sherley, 2007; Twigg and Parker, 2010) remain problematic in its use. PAPP is a more recent development (Murphy et al., 2011), being recently registered in New Zealand as a bait formulation for feral cat control (Table 2) and currently undergoing development and field-testing towards registration for feral cat and wild canid control in Australia (Eason et al., 2014). PAPP is more selectively toxic than 1080, with relatively higher toxicity to eutherian carnivores than to other mammals and birds; however, reptiles seem to have relatively high susceptibility (Eason et al., 2014; Johnston et al., 2014). Advantages of PAPP include a relatively humane mode of action and the availability of effective antidotal treatment for accidental PAPP poisoning (Eason et al., 2014).

An in-development bait formulation (Curiosity®) incorporates technologies to improve target specificity in delivering a lethal exposure of PAPP to feral cats. It has similar basic constituents and sausage format as Eradicat® but incorporates an encapsulated pellet formulation of PAPP within the bait matrix (Johnston et al., 2014). This presentation exploits the dentition and feeding behaviour of cats, where they shear off chunks of meat with their carnassial teeth and swallow larger particles in food with minimal mastication (Marks et al., 2006). Field studies have shown that a range of Australian wildlife, particularly smaller species, will eat the Curiosity® bait but reliably reject the toxic pellet and therefore avoid exposure to PAPP (Hetherington et al., 2007; Forster, 2009). While the Eradicat® and Curiosity® bait formulations are more resistant to dessication and degradation in field conditions than fresh meat baits, the currently registered New Zealand formulation of PAPP is limited to use in fresh meat baits.

Beyond improving the attractiveness, palatability or field life of baits and lures, other developments in toxin delivery include self-resetting mechanized systems that target feral cats to attach a small quantity of an adherent toxic formulation to their fur. This aims to exploit the grooming behaviour of cats, whereby a lethal amount of the toxin is ingested as a cat removes the sticky substance from itself by licking. This approach may overcome some of the variables inherent in voluntary ingestion of food-based bait and provide target specific toxin delivery to feral cats, and systems based on this principle for small-scale testing are being developed both in Australia and New Zealand (Read, 2010; Blackie et al., 2013).

4.5. Monitoring

As with many wild mammalian carnivores, the monitoring of feral cat abundance is difficult because they are cryptic and often have low densities and large home ranges (Witmer, 2005; Long et al., 2007). Capture–recapture studies are usually impractical because of trap aversion, so most monitoring relies on derived indices of abundance – such as trap-catch effort, spotlight surveys, scent station counts and track counts (e.g. Edwards et al., 2000; Algar and Burrows, 2004; Algar et al., 2013). Such indices can be influenced by feral cat behaviour (e.g. where males move more widely and frequently than females) and potentially confound animal activity with abundance because they are generally unable to identify individual animals (Anderson, 2001). Monitoring and detection techniques that identify individual feral cats are more useful in achieving robust estimates of abundance and in measuring the efficacy of lethal control. Such techniques include the use of camera ‘traps’, hair snares and detector dogs (see below).

Camera 'traps' are increasingly popular for field monitoring of wildlife, including feral cats (Robley et al., 2010) because they can partly overcome the interacting constraints of remote areas, challenging climates, low population density and cryptic behaviour. Camera traps eliminate many of the 'human interaction' elements – overcoming fear, neophobic or learned aversion responses to human presence – that probably reduce the accuracy of current methods for monitoring feral cats; allowing for better understanding of feral cat behaviour. Recent technological advances in portability, ruggedness, battery and memory capacity have increased the practical viability of field cameras for monitoring of feral cats in remote areas over large spatial scales. This can facilitate improved detection probability estimates and estimates of abundance, and the subsequent targeting of lethal control methods that are optimally cost-effective, humane and target specific. Current experience with field cameras for monitoring feral cats suggests that the noise and flash light emitted by triggered cameras can elicit both investigative and flight responses (Glen et al., 2013; Johnston, personal observation). Hair snares are another potential index; a study in arid Australia found feral cats were attracted to, and left hairs on, roughened wooden stakes sprayed with cat urine (Hanke and Dickman, 2013). While cat hair can be differentiated from that of other species by microscopic examination of cuticle and scale patterns (Triggs and Brunner, 2002), there is a further possibility of extracting DNA from hair samples to identify individual cats or related individuals.

Trained dogs are increasingly being used to detect the presence of a targeted species for invasive animal management. It needs to be emphasized that such dogs are used as highly sensitive detectors, not to hunt and kill. In New Zealand, there is an accreditation scheme for working detector dogs that provides a measurable standard of a dog's ability to detect and indicate the proximity and presence of cats to their handler but to ignore non-target species (Cheyne, 2011). Detector dogs were instrumental in the final stages of a recent eradication of feral cats from subantarctic Macquarie Island (Robinson and Copson, 2013). The purpose of detector dogs in feral cat control is to allow targeted removal of feral cats, typically in situations where they are at very low population densities or show avoidance of lethal control methods, and to independently validate the success of eradication programmes (Algar et al., 2011).

5. Conclusion

Most published literature addressing predatory, food selection and social behaviour in *Felis catus* describes studies of domesticated cats, or at least those that live in some association with people and thus are more amenable to observational or quantitative study. Such research is widely extrapolated to predict the behaviour of feral cats, backed by comparatively few actual studies of feral cat behaviour *per se* (rather than studies of feral cat responses to lethal control). Subsequently, managers of feral cats are largely working on assumptions based on an understanding of cat behaviour relative to human influence. True feral cat behaviour is difficult to study due to the remote areas and wide areas they inhabit, but what we do know indicates that effective feral cat control is very much linked to their prey resources. Because such predator–prey relationships are localized, using the knowledge of people involved at the coalface of wildlife management with respect to feral cat control programmes is critical.

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