Invasive Animals Cooperative Research Centre

Review of cat ecology and management strategies in Australia

Dr Elizabeth A Denny and
Professor Christopher R Dickman

THE UNIVERSITY OF SYDNEY

Invasive Animals CRC

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A report for the Invasive Animals Cooperative Research Centre

Dedicated to Emma Georgina Denny

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and Professor Christopher R Dickman

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Executive summary

Felis catus, the domestic cat, occurs throughout the Australian mainland as well as on more than 40 islands off the Australian coast. Cats exploit diverse habitats, including deserts, forests, woodlands, grasslands, towns and cities, and occur from sea level to altitudes above 2000 m. The classification of cats as domestic, stray or feral (Moodie 1995) reflects the varied ecology of cats and their dichotomous status in Australia — as both a valued pet species and an introduced feral predator.

Impacts

Feral cats are carnivorous hunters that depredate animals up to 2 kg, but more often take prey under 200 g. The feral cat is linked to the early continental extinctions of up to seven species of mammals. They are also linked to island and regional extinctions of native mammals and birds and have caused the failure of reintroduction attempts aimed at re-establishing threatened species. Today, 35 vulnerable and endangered bird species, 36 mammal species, seven reptile species and three amphibian species are thought to be adversely affected by feral cats. Other species are potentially affected by infectious diseases transmitted by cats. The true environmental and economic impact of feral cats has not been calculated.

Legislation

In most Australian states and territories, legislation has been introduced to restrict the reproductive and predation potential of owned domestic cats. Many local government areas have introduced cat-specific legislation, with restrictions including the banning of cats as pets in some communities, compulsory neutering, individual identification, and containment of pet cats.

Predation by feral cats was listed as a Key Threatening Process under the Federal *Endangered Species Protection Act 1992* (now incorporated in the *Environment Protection and Biodiversity Conservation Act 1999*). *A Threat Abatement Plan for Predation by Feral Cats* was produced in 1999 and amended in 2008 to promote the recovery of vulnerable and endangered native species and threatened ecological communities (Environment Australia 1999 and DEWHA 2008).

Estimating abundance

The three most common techniques for estimating cat abundance in Australia are spotlighting, counting tracks, and bait uptake estimates. The accuracy of spotlighting is dependent upon the density of vegetative cover and cat behaviour; the accuracy of track counts depends upon where track pads are set and the competence of the operative in recognising tracks; and most bait uptake studies provide data on cat activity rather than relative abundance or densities.

All three techniques are best suited to open, dry habitats with low vegetative cover. In wetter, more closed and productive habitats with high vegetative cover, techniques such as remote photography and the analysis of DNA extracted from scats or hairs provide alternatives for estimating abundance or density. Such estimates are a necessary prerequisite for the implementation of control or eradication programs to avoid over- or under-commitment of labour, time and money, and are also necessary to measure the efficacy of management programs.

Techniques for control or eradication

A nationally co-ordinated program of feral cat control across Australia is not feasible, as it is with other introduced species, and control efforts are best targeted at protecting threatened species or habitats. All successful cat eradication programs in Australia have been conducted on islands or within areas bounded by predator-proof fencing, and most have required the use of more than one control method. Successful techniques for the control or eradication of cats on islands have proved largely impractical on the mainland. Hunting, trapping and shooting are time and labour intensive and not economically viable over large areas. Trap-neuter-return is unsuccessful in open populations and not practical over large areas. The introduction of disease (eg panleucopaenia) is restricted by the probable impact on owned domestic cats and the low transmission rate amongst widely dispersed feral cats. Toxins presently registered for cat baiting may have unacceptable environmental impacts on many habitats.

Research into more felid-specific toxins, cat attracting baits and lures and cat-specific toxin delivery systems may lead to the adoption of poisoning as the most widely used technique for the control or eradication of feral cats.

Management at the regional and local level

Management of feral cats requires reliable data on the density or relative abundance of cats in targeted areas, and analysis of the cost effectiveness and efficacy of the various control measures that may be implemented. At the regional and local level, eradication of cat colonies and the management of resource-rich artificial habitats to discourage colonisation by cats should be an adjunct to any feral cat control program. Implementation of companion animal legislation that requires firmer controls on the owned, domestic cat population is also an important consideration for the longer-term reduction of the feral cat population in Australia.

Factors limiting effective management

Although adequate legislation is in place in some jurisdictions, the problems associated with cat control programs in Australia include: the time, cost and social impacts associated with enforcing companion animal legislation; the acceptance in some states of cats as pest control agents; variable cat densities between habitats; relatively low bait acceptance by feral cats; a lack of programs aimed specifically at stray cat colonies exploiting highly modified habitats; little data on the impact of cat removal on populations of introduced rodents and rabbits; and few accurate estimates of the density or relative abundance of feral cats.

Research is needed to define the most successful methods for gaining public acceptance of the importance of maintaining effective companion animal legislation; estimating densities of cats in various habitats; the cost effectiveness of control techniques including broadscale baiting; assessing the impact of the removal of colony-forming cats in resource-rich artificial habitats on the broader feral cat population; and assessing the impact of cat removal on both native and introduced small mammal populations and the further indirect effects of removal on other components of the biota.

1. Introduction

One of two major mammalian predators introduced to this continent over the last two hundred years or more, the house or domestic cat, *Felis catus* L., unlike the fox (*Vulpes vulpes* L.), holds a dichotomous status in Australian society. Throughout history, cats have been either greatly persecuted or greatly admired (Turner 2000). This dichotomy continues today throughout Australia, where cats are viewed as either valued pets and encouraged in rural areas as biological control agents for introduced rodents and the rabbit, or as an exotic pest impacting on native species. The history of the evolution, domestication and dispersal of cats throughout the world is central to an understanding of cats and their impacts in Australia.

Until recently, the precise origin of the domestic cat was uncertain, however the subspecies *Felis silvestris lybica* (the African wild cat), as opposed to *F. silvestris silvestris* (the European wild cat), is now considered the most likely ancestor (Serpell 1994). As there are only minor differences in the morphology of the domestic cat compared to their wild ancestors (Yamaguchi et al 2004a, b), the evidence for *lybica* being the most likely ancestor is based largely on behavioural characteristics (Bradshaw 1992) and on circumstantial evidence that domestication began 8000 years ago (le Brun et al 1987), or earlier, in the eastern Mediterranean region where *F. s. lybica* is extant (Vigne et al 2004). Attempts at taming *F. s. silvestris* in modern times have proven difficult, with adult cats retaining exceptional shyness and intractability (Kitchener 1998). In contrast, *F. s. lybica* is known to live and forage near human settlements and displays a more docile temperament (Serpell 1994).

Recent genetic analysis indicates that *F. silvestris* is comprised of five subspecies: *F. silvestris silvestris* (European wildcat), *F. s. lybica* (Near Eastern wildcat), *F. s. ornata* (Central Asian wildcat), *F. s. cafra* (Southern African wildcat), and *F. s. bieti* (Chinese desert cat) (Driscoll et al 2007). Analysis of mitochondrial DNA indicates the age of ancestral *F. silvestris* to be in the order of 230 000 years, while the estimated age of *F. s. lybica*, and hence domestic cats, is some 131 000 years. Figure 1 represents a phylogenetic tree of 176 haplotypes from 742 cat samples across a range of small cats, and shows clustering of samples from the domestic cat, European wildcat, Near Eastern wildcat, Central Asian wildcat, Southern African wildcat, Chinese desert cat and sand cat (Driscoll et al 2007) (see Figure 1).

1.1 Worldwide distribution of the domestic cat

Cats occur throughout the world — on every continent except the Poles. Records from the Eighteenth Dynasty of ancient Egypt indicate that the cat was fully domesticated over 3500 years ago (Morris 1996) and suggest that the domestication process began even earlier than this. Indeed, early evidence suggests that domestication began as long ago as 8000 BP (Zeuner 1958), but more recent discoveries indicate that cats may have been domesticated as long as 9500 years ago (Vigne et al 2004). The most recent genetic analysis reveals that cats were most likely domesticated in the near east and probably began their association with humans commensally with the development of agricultural villages (Driscoll et al 2007). The domestic cats of ancient Egypt, depicted in the art of the time, were viewed in several capacities: as a household companion, hunting companion, humorous figure, serpent-slayer and goddess (Morris 1996).

From these times, the domestic cat spread slowly across Europe. It is believed that the Romans were responsible for introducing domestic cats into much of northern Europe, but cats arrived in Britain prior to this, as evidenced by their presence in Iron Age sites (Harcourt 1979; Smith and Hodgson 1994). The domestic cat appears to have been widespread, if not common, throughout Europe and Asia by the tenth century (Serpell 1994). In the last 2000 years, cats have been actively transported to most parts of the world (Lever 1994).

An important aspect of the spread of the cat worldwide was its use as a biological control agent for pest species (Turner 2000). The cat became an asset to man when rodents exploited stored grain, and cats were encouraged as a natural predator. The cat maintained close associations with humans and, with the discovery and settlement of new continents by Europeans, the distribution of the cat widened to include most of the world's land masses and many islands. Turner and Bateson (2000) calculated the pet or owned cat populations in several countries in 1996-98. The following list records the owned cat population and the human population (in brackets): Australia 2.65 million (20.3 million); Italy 6.53 million (58.1 million); Japan 7.24 million (127.4 million); United Kingdom 7.76 million (60.4 million); France 8.4 million (60.6 million); and USA 56.09 million (295.7 million). Pimentel et al (2001) estimated that there are approximately 18 million feral cats in Australia, although the accuracy of this estimation is unknown. Jessup (2004) puts the United States population at 60 to 100 million feral and abandoned cats. Another estimate for the British Isles suggested that the feral population comprised 20 per cent of the total population (Tabor 1981).

1.2 Brief history of cats in Australia

As a geographically isolated island continent, Australia remained free from introduced mammalian species (with the exception of the Dingo *Canis lupus dingo*, Johnson 1999) until the arrival of European settlers at the end of the eighteenth century. Many European mammals were introduced as the early settlers attempted to reproduce the European experience in the Australian context. Olsen (1998) listed 22 introduced mammalian species that have established free-living populations in Australia. Included in this list are three rodents: the Black Rat (*Rattus rattus*), Brown Rat (*Rattus norvegicus*), and House Mouse (*Mus musculus*); two lagomorphs: the European Rabbit (*Oryctolagus cuniculus*) and Brown Hare (*Lepus capensis*); and two predators: the fox and the cat. The histories (and impact) of these species in Australia have been largely those of predator (fox and cat) and prey (rodents and rabbits).

Mice and rats have always been viewed as problematic because of their exploitation of human food resources and the risks they pose to human health; rabbits and foxes were declared pest species by the mid to late nineteenth century because of their impact on the agricultural and pastoral industries (Rolls 1969). The cat, by contrast, was still accepted as a pet and as an agent for biological control well into the twentieth century. In the last decades of the twentieth century, however, the cat was officially recognised as a predator, impacting on many native species, and listed in both Commonwealth and state legislation as a threatening process (Olsen 1998).

Cats arrived in Australia fairly late in their history as domestic animals. It is believed they were brought here as pets by the first European settlers in the last decades of the eighteenth century (Dickman 1996), although it has been suggested that cats appeared in Australia even before European settlers and were traded by Malays to coastal Aboriginal people in the north of the continent (Rolls 1969). However, both Gaynor (2000), in a report on the history of the arrival of cats in Western Australia, and Abbott (2002), in an extensive search of historical sources for early references to cats in Australia, concluded that cats arrived with European settlement and spread from a number of introductions along the coastline between 1824 and 1886. Today the cat is known to exploit such diverse habitats in Australia as open plains, tropical rainforests, sub-Antarctic islands, alpine and sub-alpine regions, the central deserts, and rural and urban landscapes. The distribution of cats in Australia is nationwide, including Tasmania and many offshore islands, with densities varying markedly between habitats (Dickman 1996).

1.3 Cats as pest control agents

By the 1890s, the European rabbit was widespread in southern Australia and was already considered a major pest on agricultural lands (Rolls 1969). Apart from spreading to rural settlements as pets (Abbott 2008), cats were also purposely established on rural properties in an attempt to control rabbits and mice (Rolls 1969; Abbott 2008). In 1886, four hundred cats were transported to Bourke in western New South Wales and sent to Togo Station on the Paroo River, 130 miles further west (Rolls 1969). In 1899, two hundred cats were released between Eyre Sand Patch and Mount Ragged in Western Australia wherever traces of rabbits were seen, and in 1936 it was reported that the WA Department of Agriculture in Perth purchased cats for release at Eucla (Abbott 2008).

Advertisements appeared in the press of cats for sale to rural property owners for control of rabbits, and in the 1880s the price of cats ranged from one shilling to two shillings and sixpence (Rolls 1969). On some properties, huts were erected to provide shelter for cats; this fact is commemorated by the name Cat House Mountain in Victoria (McKeown 1922). With only the dingo (*Canis lupus dingo*), the red fox (*Vulpes vulpes*), the Tasmanian devil (*Sarcophilus harrisii*), the Thylacine (*Thylacinus cynocephalus*) and the wedge-tailed eagle (*Aquila audax*) as possible predators of the cat in restricted areas, and widely available prey species such as birds, small mammals, reptiles and young rabbits, cats were soon established throughout the continent (Wilson et al 1992). In some areas, cats are still encouraged as pest control agents, particularly around rural homesteads. Using information on the transportation of cats by people during the late nineteenth and early twentieth centuries, Abbott (2008) concluded that the spread of cats into the countryside was associated largely with human settlement.

1.4 Cats as pests

Although initially encouraged as a pest control agent and a valued pet, in the nineteenth and early twentieth centuries some naturalists expressed concern about the impact of cats on the native species of Australia. Gould (1863) was perhaps the first to comment on the predatory effects of domestic cats, noting their role in procuring specimens for him of native mammals. Later expressions of concern were more strident.

In 1914, W W Froggatt wrote:

> *''The next was the advent of the common domestic cats, which not only hunted through the parks and gardens, but also spread in the bush lands, where they grew larger and fiercer as they reverted to wild conditions and levied a heavy toll on our feathered friends.''*

Likewise, in 1922 McKeown wrote:

> *''The Cats do not appear to have been effective in the control of Rabbits, but they, and also the Fox – another unfortunate instance of man's interference with Nature – have proved the greatest enemies of our indigenous bird life. The Fox has almost exterminated our ground-frequenting birds; while the Cat wages havoc among the other species, and before their combined attack many species are rapidly becoming scarce.''*

And Wood Jones, in 1925:

> *''Apart altogether from questions of economic utility, these feral cats are a terrible scourge, when we consider the vast numbers of the more rare, interesting, and beautiful members of our native fauna that are annually destroyed by them.''*

Despite the concerns of such astute observers, little attention was paid generally to the possible impact of cats on native Australian species throughout the early twentieth century. Apart from the occasional mention of the depredation of native fauna, particularly of birds, the cat retained a favoured role as pet and pest controller in the Australian landscape. In 1969, Eric Rolls published his seminal book 'They All Ran Wild', a collation of facts, anecdotes and observations on the introduction, spread and establishment of introduced fauna in Australia. Although acknowledged by Rolls as a predator of native fauna (particularly small mammals), scant attention is paid in his work to the role of the cat as a pest controller, except as an unsuccessful rabbit control agent.

There was a small commercial industry for cats during the 1980s when cat skins were graded by colour and exported to Austria, Germany and the United Kingdom and used to line gloves, jackets and collars (Ramsay 1994). The largest number of skins exported was 9161 in 1989. Since that year, however, no exports of cat skins have been recorded by the Australian Bureau of Statistics (Ramsay 1994). No longer commercially viable, more pressing reasons for hunting or controlling cats were beginning to arise.

In the 1980s, as the national consciousness of environmental issues increased and public awareness campaigns were instigated by various conservation groups, greater attention was paid to the impact of the cat on native species (eg Jones and Coman 1981; Dickman 1993; Anderson 1994; Collis 1999). The fox, by contrast, because of its impact on sheep breeding, had been the subject of research and control since the nineteenth century (Rolls 1969). Although the cat was still viewed as a companion animal, and was useful in the control of rodents, public perceptions were changing. This was due in part to emerging research suggesting that domestic cats kill large numbers of native mammals, birds and reptiles each year (Paton 1990, 1991), and partly due to active educational campaigns and a series of workshops on the likely effects of cats on wildlife (eg Australian National Parks and Wildlife Service 1991; Queensland Department of Environment and Heritage 1993; Australian Nature Conservation Agency 1994). The Commonwealth Government listed predation by feral cats as a Key Threatening Process in 1992.

1.5 Cat control programs

Cat control programs in Australia are in their infancy. Cats have no economic value, pose no acknowledged threat to agricultural activities (except, potentially, disease transmission) and were not, until relatively recently, classified as a pest species. Reddiex (2004) reviewed existing pest control in Australia and mapped the sites of cat control programs operating in 2003, reporting that few control operations specifically targeted cats, despite their continent-wide distribution. Reddiex et al (2006) determined that the area where cat control was carried out in 2002-2003 was <0.3 million ha, as opposed to 10.5 million ha for foxes. While fox control programs involved broadscale baiting on agricultural land and in reserved areas, the authors reported that most ongoing cat control programs represented actions aimed at the conservation of threatened species, involved use of exclusion fencing, and were confined to an average area of 35 km^2.

The absence of a nationwide cat management plan, despite the existence of a national *Threat Abatement Plan*, to some extent reflects the dearth of effective measures to assess the relative abundance and management of cats in various habitats; the paucity of data on the population dynamics of cats in the Australian context; the lack of resources for cat control, and the positioning of cat control as a social phenomenon because of the dual status of cats in Australian society.

1.6 Cat impacts on native fauna

Reported impacts of cats on native fauna in Australia include, most frequently, direct predation on mammals, birds, reptiles, amphibians and some invertebrates. Dickman (1996) proposed a ranking system to evaluate the susceptibility of native species to predation by feral cats, suggesting that species up to 3 kg, but most frequently those below 220 g (mammals) and 200 g (birds), are most susceptible to predation by feral cats. The *Threat Abatement Plan for Predation by Feral Cats* (2008) lists 35 threatened and three unlisted bird species, 36 mammals, seven threatened and two unlisted reptiles, and three amphibian species likely to be impacted adversely by feral cats. The specific species are listed in DEWHA 2008.

There is also evidence of potential threats from cats to native species through the dissemination of diseases and parasites. The cat is the only definitive host for the protozoan parasite *Toxoplasma gondii* that causes toxoplasmosis, a condition recorded in several species of native birds and mammals (Moodie 1995). Although there is a lack of data on competition between cats and native species, larger dasyurids, varanids and large raptors are the most likely to suffer a reduction in available resources through competition with cats (Glen and Dickman 2005, 2008). The impacts of cats on native fauna may be exacerbated when the prey species are also negatively impacted by habitat modification, by climatic events such as droughts, fires and floods, and by disease and changes in food distribution and abundance. The impact of cats on native fauna is discussed more thoroughly in Section 4.1.

1.7 Cat status and management

To separate the various populations of cats in Australia, Moodie (1995) categorised cats as domestic, feral or stray. The domestic cat lives with humans, with its ecological requirements being intentionally provided by humans. The feral cat is one that lives with little or no reliance on humans, and survives and reproduces in self-perpetuating populations. The stray cat relies only partly on humans for its ecological requirements, and lives in urban fringe situations such as rubbish tips.

Although Moodie (1995) qualified this classification by stating that individual cats may move between these categories within a lifetime, the concept of feral cats, as opposed to domestic or stray cats, is well embedded in the literature. In terms of legislation and cat control programs, most attention currently is paid to owned domestic and feral cats, with little information on colonies of cats exploiting highly modified habitats in urban fringe or rural areas. Legislation has been introduced in most states and territories to address the control, via sterilisation, marking (tattooing or micro-chipping), and confinement of owned, domestic cats. Stray cats, however, living in self-perpetuating populations in urban, peri-urban or highly modified rural habitats and, constituting possibly the largest sub-group of cats in Australia, remain largely unrecognised.

1.8 Cat abundance

The question of where cats are most successful and where they have the most impact in Australia was broadly answered by Wilson et al (1992) in *Pest Animals in Australia* and by Dickman (1996) in his *Overview of the Impacts of Feral Cats on Australian Native Fauna.* Wilson et al (1992) provided a map of cat densities throughout Australia that was based largely on unquantified impressions from various observers, while Dickman (1996) plotted the distribution of species at high risk from cat impact against densities of cats, to identify high-risk areas. Dickman (1996) also separated feral from stray and domestic cats based on Moodie's (1995) definition, and noted that only a small number of studies had provided evidence of either minor or major impacts on populations of native species from domestic or stray cats.

Dickman (1996) suggested that although there are few absolute density estimates, there are several estimates of relative cat density in Australia. He concluded that the abundance of cats in Australia is usually highest on offshore islands, and also higher in open inland environments than in temperate or tropical closed forest or wet heath. In southern Europe, Lozano et al (2003) determined that to preserve the habitat of European Wildcats (*Felis silvestris*) there was a need to retain scrub-pastureland mosaics, a habitat similar to many that occur in the open, inland environments of Australia.

An important conclusion from Dickman's 1996 overview is that the potential impacts of feral cats on susceptible native species may be increased by a subsidy effect where introduced or native prey species reach high densities. This subsidy effect is the result of a relatively stable resource base (ie high densities of prey species) maintaining a cat population that can then prey incidentally upon any endangered and vulnerable native species occurring in low densities in the same location (Smith and Quin 1996).

1.9 Cat colonies

Throughout the Australian mainland, highly modified habitats provide resource rich 'islands of opportunity' for feral or stray cats. Such sites include rubbish tips, large and small townships, homesteads, mining sites and tourist resorts, which provide food, resting and nesting sites and breeding opportunities for cats. In such habitats, cats have been recorded forming localised but dense colonies, based on matrilines, where females defend the resources and recruit their own kittens to the colony (Denny et al 2002).

1.10 Formulating cat control programs

The *Threat Abatement Plan for Predation by Feral Cats*, published by Environment Australia in 1999, focused primarily on the actions required to reduce the threat of feral cats to endangered or vulnerable species or ecological communities. There was also reference in this plan to programs for the management of both domestic and stray cats in urban and semi-urban areas. However, control programs to date have concentrated almost exclusively on feral cats, although density estimates suggest that stray cats exploiting habitat hotspots may constitute the largest sub-group of non-domestic cats in Australia, and likely contribute to feral populations in the surrounding environment.

Olsen (1998) posited five major steps in the formulation of successful pest control programs:

1. Define the problem
2. Determine objectives
3. Identify and evaluate management options
4. Implement a management plan
5. Monitor and evaluate the outcome of the plan (including, if necessary, redefining the problem)

The *Threat Abatement Plan for Predation by Feral Cats* (DEWHA 2008) covered each of these five steps, providing a framework for cat control in Australia through the following five objectives:

- prevent feral cats occupying new areas in Australia and eradicate feral cats from high conservation value 'islands'
- promote the maintenance and recovery of native species and ecological communities that are affected by feral cat predation
- improve knowledge and understanding of feral cat impacts and interactions with other species and other ecological processes
- improve effectiveness, target specificity, humaneness and integration of control options for feral cats, and
- increase awareness of all stakeholders of the objectives and actions of the TAP, and of the need to control and manage feral cats.

1.11 Scope of review

This review presents details of the current legislative framework that exists for cat control in Australia; describes the ecology of feral and stray cats exploiting various habitats; assesses the efficacy of the methods used to estimate relative abundance of cats; describes currently used cat control methodologies; and discusses possible future directions for the control of cats in Australia.

2. Legislative status of cats

The status and management of cats in Australia is covered by legislation at the Commonwealth, state and local government levels. In 1992 the feral cat in Australia was listed as a Key Threatening Process under the *Endangered Species Protection Act 1992*, now incorporated in the *Environment Protection and Biodiversity Conservation Act 1999.* In 1994 the Australian Nature Conservation Agency held a workshop to forge a national approach to cat control, and a *Threat Abatement Plan for Predation by Feral Cats* was produced in 1999 to promote the recovery of vulnerable and endangered native species.

The aims of the 1999 *Threat Abatement Plan* were to ''promote the recovery of endangered or vulnerable native species and communities, and to prevent further species becoming endangered by reducing predation by feral cats to non-threatening levels". There were seven key objectives of the Plan, including: the eradication of cats from islands where they pose a threat to endangered or vulnerable native animals; prevention of the colonisation by cats of new islands in Australia; improvements in the effectiveness and humaneness of cat control methods; improvements in the knowledge and understanding of the impacts of cats and the interactions of cats with other pest species; communication of the outcomes of the abatement plan actions to the wider community including management agencies, landholders and the public; and, effectively coordinate feral cat control activities.

The 1999 *Threat Abatement Plan* concluded that eradication of feral cats on the Australian mainland was not feasible at that time, and suggested that the methods available for cat control could be effective only in limited areas. In 2005, the Commonwealth Bureau of Rural Sciences reviewed the Plan and outlined difficulties in accurately determining the effectiveness of the cat TAP in reducing the impacts of cats on biodiversity (Hart 2005). Although this review recommended little change to the original objectives of the TAP, suggestions were made to improve its implementation. The *Threat Abatement Plan for Predation by Feral Cats* (2008) replaced the 1999 TAP, and incorporated knowledge gained in the intervening years. The 2008 TAP outlined the need for closer co-operation by stakeholders, including local, state and territory government departments, landholders, community groups, pest management agencies and the Commonwealth Government and its agencies.

The 2008 TAP listed five main objectives and sets of actions to achieve these objectives. The five objectives are: the prevention of the spread of feral cats into new areas in Australia; the recovery of native species and ecological communities affected by predation by feral cats; improvement in the understanding of the impact of feral cats on native species; improvement in the control options for feral cats; and increasing the awareness of all stakeholders of the need to control and manage feral cats. Key actions described in the 2008 TAP for each objective provide a framework with performance indicators and the priority and timeframe of actions, to achieve an integrated approach to the control and/or eradication of cats on the Australian mainland and offshore islands.

Australian states and territories have formulated their own legislation in relation to feral, stray and domestic cats, and some local councils have implemented cat management programs that primarily target owned cats (Brown 1993; Hinchcliffe 1993; Staindl 1993). Although not all states and territories have passed legislation that refers specifically to cats, all states and territories are governed by Commonwealth legislation, and most states have enacted legislation that directly or indirectly provides a basis for the control or eradication of domestic, stray and feral cats.

2.1 Australian Capital Territory

Most pest species in the ACT are listed under the *Pest Plants and Animals Act 2005*; however, cats are not. The *Domestic Animal Act 2000* covers domestic cats and, under this Act, identification of domestic cats by collar or microchip is preferred but not mandatory and cats born after June 2001 must be de-sexed. The *Domestic Animal (Cat Containment) Act 2005* provides the legislative basis for the containment of domestic cats in suburbs that are adjacent to the Mulligans Flat and Goorooyarroo Nature Reserves. Other relevant legislation includes the *Animal Welfare (Amendment) Act 1997* and the *ACT Nature Conservation Plan 1997.* The *Animal Welfare (Welfare of Cats in the ACT) Code of Practice 2007* specifically refers to the welfare of cats used for pest control, suggesting that there is still scope for the use of cats for combating mice and rats.

2.2 New South Wales

Predation by feral cats is listed as a Key Threatening Process under Schedule 3 of the NSW *Threatened Species Conservation Act 1995,* amended 2002*.* Nine threat abatement strategies were formulated to deal with feral cat predation, seven of which received high priority. Included in the strategies were: research (develop and trial) a cat-specific bait that ensures that non target species are not impacted, and the development of cost effective methods for broadscale control of feral cats. Also rated highly in the threat abatement strategies was a review of the evidence of the impacts of cats and the undertaking of control actions.

Under the *Companion Animal Act 1998*, owned domestic cats must be identified by either a collar and tag or a microchip and cats are prohibited from wildlife protection areas.

2.3 Northern Territory

The *Territory Parks and Wildlife Conservation Act 2000* is the main legislative instrument for control of cats in the Northern Territory. Other legislation relevant to cat control in the Northern Territory includes the *Animal Welfare Act 2005*, which contains obligations and offences associated with the welfare of all animals.

2.4 Queensland

The feral cat is declared a Class 2 species under the *Land Protection (Pest and Stock Route Management) Act 2002*. Declared species represent ‘‘a threat to primary industries and natural resources, and have a social impact on other human activities’. This legislation describes a feral cat as one that is not fed and kept by someone. The word ‘kept’ specifically means that the cat is housed in a domestic situation. Under the *Animal Care and Protection Act 2001* there are offence exemptions for the killing of feral or pest animals, including feral cats.

2.5 South Australia

The *Dog and Cat Management Act 1995,* which repealed the *Dog and Cat Management Act 1979*, refers to the status and control of cats in South Australia. Under this Act cats are classified as either ‘owned’ or ‘unowned’, with ‘owned cats identified by a collar or a tattoo on the ear indicating the presence of a microchip. The objects of this Act are: to encourage responsible dog and cat ownership; to reduce public and environmental nuisance caused by dogs and cats; and to promote the effective management of dogs and cats (including through encouragement of the de-sexing of dogs and cats). Councils in South Australia are responsible for the administration and enforcement of provisions under this Act.

The *Natural Resources Management Act 2004* provides for the prevention or control of impacts caused by pest species of animals and plants that may have an adverse effect on the environment, primary production, or the community. Under this Act it is illegal to release a feral animal in the wild. The Act covers cats in remote or fragile areas. A warden under the *National Parks and Wildlife Act 1972* may lawfully ‘seize, detain, destroy or otherwise dispose of any cat found within a reserve within the meaning of that Act’. Also, in wilderness protection areas or zones constituted under that Act: ‘A person may lawfully seize, detain, destroy or otherwise dispose of any cat found in a place that is more than one kilometre from any place genuinely used as a place of residence.' A major objective of the *National Parks and Wildlife Act 1972* is the control of vermin and exotic animals.

2.6 Tasmania

The *Nature Conservation Act 2002* is the legislative instrument for the control of animal pest species in Tasmania. Of 60 introduced vertebrate species in Tasmania, 32 are recognised as environmental pests. Of the recognised environmental pests, only two (both fish species) have been formally declared as pests. The *Animal Health Act 1995* allows for the taking and destruction of animals deemed to present a threat to the health of domestic stock.

In 2005 the Greens (the political party) introduced a *Draft Cat Control Bill* in the Tasmanian Parliament that would provide for statewide uniform cat de-sexing and cat registration, as well as establishing mechanisms for state funded cat control measures. The Tasmanian *State of the Environment Report* (2004) described predation on native species and economic loss of livestock to disease as examples of the impact of feral cats.

2.7 Victoria

The *Domestic (Feral and Nuisance) Animals Act 1994* forms a legal distinction between owned and unowned cats and provides a basis for local councils to mount an effective response to nuisance, straying, unowned and feral cats (Penson 1995). Also, under the *Wildlife Act 1975*, an authorised officer may seize a dog or cat found in a State Wildlife Reserve or Nature Reserve and the animal may be destroyed within eight days if ownership is not claimed. The *Prevention of Cruelty to Animals Act 1986* contains the obligations and offences associated with all animals in Victoria. The first cat curfew and registration legislation at a local level in Australia that pertained to owned domestic cats was introduced in Sherbrooke, Victoria.

2.8 Western Australia

The *Wildlife Conservation Act 1950* and the *Conservation and Land Management Act 1984 and Conservation and Land Management Regulations 2002* are the two main legislative instruments covering the protection of biodiversity in Western Australia. Cats are not listed under the *Agriculture and Related Resources (Declared Animal) Regulations 1985.* Under the *Animal Welfare Act 1992* pest animals (including cats) may be killed in a manner that is usual and reasonable for killing pests.

Summary

- The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* is the overarching legislation for the control of feral pest animals in Australia.
- The *Threat Abatement Plan for Predation by Feral Cats* (2008) provides a blueprint for actions required to eradicate feral cat populations on Australian islands and control feral cat populations on the mainland.
- The control of stray and domestic cat populations is most commonly covered by legislation at the state and local government levels.

3. Population dynamics and morphometrics

3.1 Density

The spatial organisation of cats has been shown to vary in response to food abundance and breeding opportunities. The densities and home ranges of cats vary between studies, from descriptions of cats being solitary animals (eg Jones 1977, Jones and Coman 1982a, Harper 2001), to congregating in groups of varying sizes (Macdonald 1983). Liberg et al (2000) reviewed the results of 28 studies of cats from throughout the world. They found that densities of cats vary from <1 to more than 2000 cats/km^2 and that these densities are related to general characteristics of the food supply, such as food abundance, quality and dispersion.

Macdonald (1983) proposed the Resource Dispersion Hypothesis (RDH) to explain how species of carnivores, in which independent adults are not usually associated spatially, may congregate together and form groups. The RDH suggests that '…the smallest territory that will provide adequate security for the primary social unit may also support additional group members'. Under the RDH, additional members would be expected to recruit into the group territory when resource density was high, and all would be likely to share a degree of kin relationship with the primary social unit. For females, territory security is based on food and shelter, and for males it is comprised of access to receptive females.

The highest densities of cats have been recorded from areas associated with humans, where the animals exploit resource-rich habitats such as food dumps (Izawa et al 1982; Izawa 1983; Mirmovitch 1995) and farms (Macdonald and Apps 1978; Liberg 1980; Liberg 1984a and b), or are intentionally provided with food by humans (Dards 1978, 1983; Natoli and de Vito 1988, 1991). Densities reported in these studies range from the equivalent of 200 cats km^2 to 2800 cats km^2.

High cat densities have been recorded in Australia by Wilson et al (1994) at three rubbish dumps (Mac's Reef Road, Mugga Lane and Belconnen) on the outskirts of Canberra. The cat densities were assessed as equivalent to 90 cats km^2, 19 cats km^2 and 38 cats km^2 respectively. Hutchings (2003) estimated that 30-50 cats were exploiting a tip site in Victoria and Hale (2003) reported 51 cats exploiting the central holding sheds on a 12 ha pig farm in Menangle, NSW. Denny (2005) reported densities at tip sites at Oberon and Tibooburra in NSW higher than those found by Wilson et al (1994) and equivalent to those of Hutchings (2003) and Hale (2003). Newsome (1995) reported a population of 200 cats shot at the Uluru rubbish tip in Central Australia during drought conditions in the mid-1970s. The high densities of cats at this site may have represented an influx of animals due to low prey numbers away from the tip site during the drought, rather than representing long-term resident cats at the tip.

Cats can also achieve high densities on small islands. Copley (1991), for example, reported densities of 20-30 cats km^2 on Althorpe Island, South Australia, while Hayde (1992) estimated a density of 56.9 cats km^2 on Great Dog Island, Tasmania. An even higher density cat population probably resided on North West Island, Queensland, prior to an eradication program, with 105 individuals being removed from the 105 ha island over the course of a year (Domm and Messersmith 1990). Larger offshore islands tend to support relatively fewer cats, with densities commonly remaining <1 km^2 (Paton 1993). As with waste disposal sites elsewhere, the most inflated densities of cats on islands are almost certainly due to the presence of food subsidies. These may be human derived or, more commonly, from allochthonous inputs of seabirds, fish, or other marine prey that wash onto the island beaches.

Markedly lower densities of cats have been reported (<1-7 km^2) where cats rely on hunting with very little or no food subsidy (Liberg et al 2000). For example, Ridpath (1990) described cat densities of 0.03 km^2 in the Northern Territory, while Burrows and Christensen (1994) found equivalent densities in the Gibson Desert of Western Australia during drought, with an increase to 0.13 km^2 in non-drought periods. Similar densities were reported by Short and Turner (2005) from Heirisson Prong in Western Australia, with numbers increasing to 2.8 cats km^2 during exceptional periods. Read and Bowen (2001) reported densities of 0.7 cats km^2 at Roxby Downs in South Australia; similar densities were found by Mahon et al (1998) in the Simpson Desert of western Queensland. More-temperate habitats support higher densities of cats. Jones and Coman (1982b) estimated densities of 0.7 cats km^2 during winter and up to 2.4 km^2 in summer at Hattah-Kulkyne in Victoria. At Yathong, New South Wales, Newsome (1991) reported cat densities of <1 km^2 during drought and 4.7 km^2 during non-drought periods, while Dickman (1996) listed densities of 0.1 to 6.3 cats km^2 from a variety of mainland habitats. There has been only one Australian report of cats living in high densities on the mainland away from artificial food sources. In 1992, high densities of cats were reported, but not quantified, in the Diamantina region of western Queensland, apparently in response to three summer seasons of good rainfall and a marked increase in the abundance of the long-haired rat, *Rattus villosissimus* (Pettigrew 1993).

In one study in north eastern New South Wales, Barnett et al (1976) reported the abundance of cats in various habitats. Cat signs were scarce in open forest, woodland, pine plantation, grassland and creek associations; they were found more commonly in tall open forest. Newsome (1994) reported cats as present on either side of the border between New South Wales and Queensland, although no status could be assigned because of lack of data. Dickman (1996) suggested that cat abundance is usually higher in open habitats than in closed forest or wet heath. The densities of cats reported from relatively unmodified habitats and pastoral areas on the mainland, from offshore islands and from highly modified habitats, such as rubbish tips and farms, are shown in Table 1.

Table 1. Densities of cats from relatively unmodified habitats, highly modified habitats and islands

Site	Density(cats/km^2)	Reference
Relatively unmodified and pastoral habitats		
Hattah-Kulkyne, Vic	0.74 (winter)	Jones & Coman 1982a
Hattah-Kulkyne, Vic	2.4 (summer)	Jones & Coman 1982a
Victoria	>0.9	Coman 1991
Brindabellas, ACT	0.2	Dickman (unpublished)
Yathong, NSW	<1.0 (drought)	Newsome 1991
Yathong, NSW	4.7 (non-drought)	Newsome 1991
Royal Nat Park NSW	1	Mahood 1980
Gnalta, NSW	2	Mahood 1980
Gibson Desert, WA	.03 (drought)	Burrows & Christensen 1994
Gibson Desert, WA	0.13 (non-drought)	Burrows & Christensen 1994
Roxby Downs, SA	0.7±0.11	Read & Bowen 2001
Roxby Downs, SA	0.6±0.13	Read & Bowen 2002
Kapalga, NT	0.03	Ridpath 1990
Shark Bay, WA	1.5	Short & Turner 2005
Highly modified habitats		
Oberon NSW	700-750	Denny et al 2002
Tibooburra NSW	500-800	Denny 2005
Canberra ACT	90	Wilson et al 1994
Canberra ACT	19	Wilson et al 1994
Canberra ACT	38	Wilson et al 1994
Camden NSW	425	Hale 2003

Site	Density(cats/km²)	Reference
Islands		
Cousin Is	220	Veitch 1985
Tasman Is	40	Brothers 1982
Macquarie Is	4.34	Brothers et al 1985
Althorpe Is, SA	20-30	Copley 1991
Kangaroo Is, SA	0.7	Paton 1993
Great Dog Is, Tas	56.9	Hayde 1992
North West Is, Qld	100	Domm & Messersmith 1990
Gabo Is Vic	20	Twyford et al 2000

3.2 Movement patterns

Liberg and Sandell (1994) outlined the differences in home range sizes of cats between sexes and between populations utilising various habitats. The sizes of male home ranges are on average 3.5 times larger than those of females (Liberg and Sandell 1994). The authors related the size of male home ranges to access to females, and suggested that the home ranges of non-breeding males are smaller than those of breeding males. There is also some evidence that the home range of males increases during the breeding season as breeding males seek access to receptive females (Liberg and Sandell 1994).

Several Australian studies have assessed cat home ranges in areas where cats are dependent upon live prey. In arid western Victoria, Jones and Coman (1982a) reported mean home ranges of 6.2 km^2 (male) and 1.7 km^2 (female). Brothers (1982) found much smaller male home ranges, of just 0.41 km^2, on Macquarie Island. In heavily dissected highland closed forest, Wright (1993) reported home ranges of 0.75 – 6.7 km^2, while Schwarz (1995) reported range sizes of 1.54 km^2 for males and 0.29 km^2 for a single female in open forest in Tasmania. Molsher et al (2005) calculated home ranges of 4.23 km^2 for males and 2.38 km^2 for females in a mixed agricultural-open forest landscape in central eastern New South Wales. Reflecting the lower productivity of central Australian habitats, two studies have indicated that male ranges may exceed 20 km^2 during dry periods (Mahon 1999; Edwards et al 2001). Reviewing the results of a number of studies of solitary cats living on islands and in New Zealand and Australia, Liberg and Sandell (1994) suggested that there is overlap in the home ranges of both males and females. Turner and Meister (1994) suggested that home range shape and size and the distribution and abundance of prey, which is in turn related to characteristics of the habitat, affect the distances travelled by cats during hunting excursions.

3.3 Morphometrics

3.3.1 Weight

The body weight of cats is influential in terms of the size of prey they are capable of exploiting, and is important also in predicting the quantity of food that individual cats can be expected to consume to maintain their body weight (Dickman 1996). Body weight may also be significant in terms of reproductive success (Natoli and De Vito 1991).

Despite anecdotal evidence of free-living cats of unusually large size in Australia, only one study has documented very heavy cats. In that study, at Gnalta in western New South Wales, Mahood (1980) estimated the mean weight of 79 cats at 8.8 kg, with the heaviest weighing 16.1 kg. These weights are well outside the range of weights of cats reported in all other Australian studies, and follow up work has failed to locate cats of equivalent weights at the original study site (P Wagner, pers. comm). Because Mahood's (1980) records appear so extreme and have not been approached in any subsequent studies, and the author is deceased, they are considered here to have been erroneous and are not subject to further discussion.

The lowest mean male weights (2.43 ± 0.23 kg) in an Australian study were reported by Risbey et al (2000) for cats scavenging at rubbish tips at Heirisson Prong in Western Australia, while the largest mean male weights (4.73 ± 1.27 kg) were reported by Jones and Horton (1982) in the semi-arid mallee region of Victoria. The mean body weights of male cats recorded from Oberon and Tibooburra, both in New South Wales (4.04 ± 0.12 and 4.37 ± 0.15 kg respectively), fall within this range (Denny 2005).

Likewise, the lowest mean pregnant and/or non-pregnant female weights (2.47 ± 0.17 kg) were reported by Risby et al (2000) for tip cats at Heirisson Prong in Western Australia and the highest (3.47 ± 0.103 kg) were recorded by Jones and Horton (1982) from western New South Wales. The heaviest mean weights for non-pregnant (3.607 ± 1.09 kg) and pregnant females (3.87 ± 1.69) were recorded by Brothers et al (1985) on Macquarie Island. The mean weights and range of weights recorded from cats throughout Australia are shown in Table 2.

Table 2. Mean weights and range of weights of adult feral and stray cats

Site	Mean ± SE	Range (sample size)	Reference
Male			
Oberon, NSW	4.152±0.466	3.3 – 5 (n = 16)	Denny et al 2002
Tibooburra, NSW	4.21±0.671	3.3 – 5.5 (n = 22)	Denny 2005
Macquarie Is	4.4518±0.516	-	Jones 1977
Macquarie Is	4.295±0.65	? – 5.5	Brothers et al 1985
Lake Burrendong, NSW	4.37±0.14	? – 5.68	Molsher 2001
Roxby Downs, SA	3.9±0.1	? – 7.3	Read & Bowen 2001
Western NSW	4.535±0.126	-	Jones & Horton 1982
Hattah-Kulkyne, Vic	4.734±0.127	-	Jones & Horton 1982
Mallee farmland	4.631±0.135	-	Jones & Horton 1982
Settled rural	4.197±0.97	-	Jones & Horton 1982
Eastern Highlands	4.41±0.58	-	Jones & Horton 1982
Macquarie Island	4.459±0.87	-	Jones & Horton 1982
Canberra, ACT	-	3.89 – 4.2	Kunihira 1995
Heirisson Prong, WA Feral	3.68±0.17(65)	- (n = 65)	Risbey et al 1999
Semi-feral	2.43±0.23(35)	- (n = 35)	Risbey et al 1999
Female			
Oberon, NSW	3.171±0.119	2.3 – 3.75 (n = 7)	Denny 2005
Tibooburra, NSW	3.007±0.09	2.25 – 4.1 (n = 28)	Denny 2005
Lake Burrendong, NSW	3.34±0.06	-	Molsher 2001
Roxby Downs, SA	2.8±0.07	5 (Preg)	Read & Bowen 2001
Western NSW	3.469±0.103	-	Jones & Horton 1982
Hattah-Kulkyne, Vic	3.197±0.91	-	Jones & Horton 1982
Mallee farmland	3.059±0.8	-	Jones & Horton 1982
Settled rural	2.946±0.93	-	Jones & Horton 1982
Eastern Highlands	3.235±0.96	-	Jones & Horton 1982
Macquarie Island	2.946±0.93	-	Jones & Horton 1982
Macquarie Island	3.675±0.93	? – 5.8 (n = 54)	Brothers et al 1985
Non-preg	3.607±1.09	-	Brothers et al 1985
Preg	3.870±1.69	-	Brothers et al 1985

Weight is the most common parameter recorded for cats in Australian studies. However, weight is dependent upon both nutritional and breeding status (Short and Turner 2005), and without qualification, weight alone gives little indication of the comparative sizes of cats from within or between areas. Variability in weight between individual domestic cats increases with age and is more pronounced amongst males (Rosenstein and Berman 1973). With the exception of birth weight, females generally weigh more through to approximately 10 weeks of age, at which point males become heavier with increasing age. Nutritional status and general condition also contribute to variations in the weight of individuals. Jones and Coman (1982a) proposed weight for age categories for feral cats in Australia and, together with observational data on tooth wear and general condition, the classifications can be used to roughly assess the age structure of cat populations. However, variability in the weight of individual cats suggests that data on weight should not be used alone to investigate differences in the body size or age distribution of populations of cats, and that some calibration with less variable measures, such as skull and limb length, should be included.

3.3.2 Body measurements

Although size and sexual dimorphism in cats are often expressed as functions of body weight alone (eg Jones 1977), size differentiation is probably best expressed by linear body measurements or linear measures combined with body weight. Some studies have reported the head/body lengths or the body lengths of free-living cats. In the early 1800s a soldier-naturalist, Captain Best, recorded a cat on Lord Howe Island that was 32 ins (81.28 cm) long and 13 ins (33.02 cm) tall (Iredale and Whitley 1967-68). Hall and Pelton (1979) reported mean head/body lengths of cats in Tennessee of 56 cm for males and 52 cm for females. Jones (1977) documented mean head/body lengths of cats on Macquarie Island of 52.2 $\pm$ 2.0 cm, and Muir (1982) reported a mean head/body/tail length of 63 cm (for cats from national parks in Western Australia). Spencer (1991) reported one cat with a head/body length of 63 cm from Black Rock in Queensland. At Lake Burrendong in New South Wales, Molsher (1999) reported body lengths of 49.2 $\pm$ 0.7 cm (male) and 46.5 $\pm$ 0.75 cm (female) while at Heirisson Prong, Risbey et al (2000) reported body lengths for males of 49.4 $\pm$ 0.7 cm (feral) and 48.9 $\pm$ 0.7 cm (semi-feral) and for females of 44.8 $\pm$ 0.9 cm (feral) and 46.8 $\pm$ 1.5 cm (semi-feral). In the Western Australian wheatbelt, Dickman (unpublished) recorded the head/body lengths of male cats as 55.2 $\pm$ 9.7 cm, and those of females as 51.0 $\pm$ 7.2 cm.

Denny (2005) recorded the head width, head length, head/body length, tail length and femur length of cats captured at and away from tip sites in north western New South Wales and in the state's central highlands. The measuring of head/body length as well as femur length in this study provided a clearer picture of the relative size of the cats than weight alone, and suggested that these measures were related linearly to weight. As cats' hunting behaviour focuses on prey species small enough to be killed by a solitary cat, the range of available prey may increase as the size of the cat (in terms of head/body and femur length) increases. Although there are few empirical data to support this expectation in cats, positive prey size/body size relationships have been found in other mammalian predators (Kiltie 1984; Dickman 1988; Fisher and Dickman 1993) and are supported by predator-prey theory (eg Wilson 1975; Stephens and Krebs 1986).

Although estimates of body condition of cats can be made subjectively, recorded by order or rank (eg poor, fair, good, very good), subjective measures are difficult to compare between studies. Short and Turner (2005) used head length versus weight to compare relative condition between sexes and ages of cats from Shark Bay, Western Australia. Although the correlation was strong between weight and all body measurements, including head length from cats from two sites in New South Wales (Table 3), it was suggested that the best body measurement for estimating expected weight is femur length (Denny 2005). The femur, as a rigid bone with readily palpable ends (Reighard and Jennings 1966), can be most easily and accurately measured in the field.

Table 3. Linear regressions of the weight and body measurements of male and female cats. Estimates are shown ± s.e.

Variables	Sex	n	r	Constant	Slope	s.e.	P
Weight v head length	F	48	0.861	-4.09±0.56	0.738±0.062	0.421	<0.001
	M	57	0.825	-5.44±0.79	0.923±0.082	0.739	<0.001
Weight v head width	F	44	0.826	-4.0±0.657	1.086±0.108	0.454	<0.001
	M	55	0.886	-4.914±0.57	1.243±0.086	0.886	<0.001
Weight v head/body	F	54	0.817	-2.021±0.45	0.093±0.009	0.668	<0.001
	M	65	0.876	-3.065± 0.45	0.119±0.008	0.625	<0.001
Weight v tail length	F	52	0.718	-1.386±0.53	0.152±0.021	0.567	<0.001
	M	59	0.854	-3.853±0.57	0.264±0.021	0.854	<0.001
Weight v femur length	F	54	0.853	-1.57±0.353	0.359±0.031	0.430	<0.001
	M	65	0.895	-4.226±0.48	0.614±0.039	0.579	<0.001

3.4 Sex ratios

The sex ratios of cats appear to vary markedly between populations. On Macquarie Island, Brothers et al (1985) found an overall ratio of males to females of 1:0.80, which was a marked, but not statistically significant, departure from equality. Within age classes, the sex ratios M:F were adult 1:0.73, subadult 1:0.54, and juvenile 1:1.13, and the departure from unity in these ratios bordered on significance (Brothers et al 1985). In north eastern Tennessee, USA, Hall and Pelton (1979) found a M:F sex ratio among cats of 1:2.29, indicating a marked female bias. In contrast, Pascal (1980) found disequilibrium in the sex ratios of cats in the Kerguelen Archipelago, with a distinct male bias. He suggested that hunting pressure either induced or revealed this disequilibrium and that the higher number of males led to early maturation of primiparous cats and then their high perinatal mortality. Rauzon (1985), in work on Jarvis Island, found a M:F sex ratio of 1:0.92, which was not significantly different from equality. On Herekopare Island, New Zealand, Fitzgerald and Veitch (1985) found a M:F sex ratio of 1:0.61, which they suggested did not differ significantly from equality. This was evidently because the sample size was small.

Australian studies report moderate variation in cat sex ratios between habitats. In their study of cats on North West Island in the Great Barrier Reef, Domm and Messersmith (1990) found, from a total of 105 cats, that 57.5 per cent were males and 42.5 per cent were females, translating to an M:F ratio of 1:0.73. Jones and Horton (1982) also found an excess of males in an overall sample from five Australian localities and Macquarie Island. However, when cats from the Eastern Highlands were excluded, there was no significant difference in the sex ratio. The authors proposed that, because cats from the Eastern Highlands were the only ones captured by leghold traps, the sample was biased due to a greater susceptibility of males to capture by this method. At Heirisson Prong, Western Australia, Short and Turner (2005) reported an overall sex ratio of 1.23:1 from a sample of 290 cats. Male bias was stronger in juveniles and subadults (1.59:1), with adult females being represented relatively more strongly. From these and other studies it appears that the sex ratio of free-living adult cats may usually be equal, but also that variations in the sex ratio can be attributed to trapping bias or sex-based differences in activity or survival.

3.5 Breeding periods

Female cats in Australia reach sexual maturity at 10-12 months and have an average of two litters per year (Jones and Coman 1982a). Most studies indicate a non-breeding period over the winter months. On subantarctic Macquarie Island, Jones (1977) found a non-breeding period between March and November, while on the same island, Brothers et al (1985) later suggested a non-breeding period between March and October. In temperate south eastern Australia, Jones and Coman (1982a) found that most kitten births occurred between September and March. At warm, temperate Lake Burrendong in central New South Wales, Molsher (2001) found a non-breeding period from March to September, and at arid Roxby Downs in northern South Australia, Read and Bowen (2001) found a non-breeding period between March and June. Denny (2005) reported a shorter non-breeding period in the warmer, semi-arid Tibooburra area of north western New South Wales (May-July) than in the cooler Oberon area in the central highlands (March-August). Overall, the non-breeding period for feral and stray cats in Australia is shorter in warm, semi-arid regions than in cooler, more temperate regions. Thus in warmer climates, the breeding period may be as long as nine months (Read and Bowen 2001), while in cooler regions the breeding period may be as short as four months (Jones 1977).

3.6 Litter size

Deag et al (2000) reported that the average litter size from 71 litters of laboratory or domestic cats was 4.4 (range 2-8), and related the number of kittens to the number of nipples (8) on the cat. Again from laboratory studies, Hall and Pierce (1934) found the mean litter size of domestic cats to be 3.88 kittens, with larger cats tending to have more kittens in the litter.

There have been few studies of the litter size or kitten survival rates for feral or stray cats in Australia. A mean number of 4.4 embryos was recorded by Say et al (2002) for feral cats on the subantarctic Kerguelen peninsula, and on Marion Island van Aarde (1983) reported the mean number of corpora lutea in free-living cats as 5.88 $\pm$ 1.12, indicating a relatively high reproductive potential. Brothers et al (1985), in their study on Macquarie Island, found that the mean number of embryos per female was 4.7; Mahood (1980), in far western New South Wales, found five litters each with four kittens. In south eastern Australia, Jones and Coman (1982*a*) found a mean prenatal litter number of 4.35 $\pm$ 1.27 (range 2 – 7), while Read and Bowen (2001), found the mean number of embryos to be 4.1 $\pm$ 0.3 from 17 pregnant females at Roxby Downs, South Australia. However, the potential birth rate may overestimate the real birth and survival rates of juvenile free-living cats. Short and Turner (2005) also reported marked differences in kitten production between seasons, with 1.2 kittens per female being produced when prey resources are scarce and 5.4 during times of plenty.

At a tip site at Oberon in the central highlands of New South Wales, the mean litter size of juveniles >1 month old was 2.25; 1.93 kittens were recorded at sites at Tibooburra in the state's far north west (Denny 2005). In a study of farm cats near Sydney, Hale (2003) autopsied four pregnant females and found one female with three embryos and the remaining three females carrying only one embryo each. The author suggested that such low breeding rates might have been a function of poor nutrition or disease, although the sample size was too small for definite conclusions. The low embryo numbers reported by Hale (2003) were from a population of cats living in high densities, similar to the tip cats at Oberon and Tibooburra.

3.7 Kitten survival rate

Coman (1991) noted low recruitment rates to feral cat populations despite high reproductive potential. He attributed this phenomenon to low kitten or subadult survival rates that were related, in turn, to the younger cats' poor ability to capture prey. Coman's (1991) study did not indicate whether there were differential survival rates between sexes. A study by Mirmovitch (1995) on urban feral cats in Jerusalem found that kittens younger than six months suffered high mortality, with only seven of 43 kittens (16 per cent) surviving to six months of age. Izawa and Ono (1986) also found low survival rates (9.5 per cent) of juveniles at ten months in a high-density population. Brothers et al (1995) noted that kitten mortality increased with age, and kittens growing to weights >1.8 kg usually occurred in litters of two or less. Denny (2005) reported kitten survival rates of 60 per cent at tip sites in New South Wales, which were high in comparison to those reported by Mirmovitch (1995) and Izawa and Ono (1986). The mortality rate amongst juveniles may be linked to the ability of juveniles to capture prey, as suggested by Coman (1991), although at rural tip sites and other high resource habitats, a relatively stable food resource may compensate for poor hunting ability in juveniles. Undisturbed nesting and resting sites that provide a relatively secure environment may assist in the achievement of higher survival rates of the offspring of cats exploiting resource-rich habitats.

3.8 Reproductive potential

The cat is a long-lived, multi-parous species, and the reproductive potential for such species is high. There have been few estimates of the lifespan of feral or stray cats, although Warner (1985) reported that survival beyond three to five years is rare in free-ranging farm cats, with only one per cent surviving beyond seven years. In contrast, the expected lifespan of owned, domestic cats has been reported as nine to 15 years, with the longest documented lifespan being 31 years (Comfort 1956). Owned, domestic male cats have been known to produce offspring up to 16 years of age, whilst females up to 12 years of age have been reported bearing kittens (Morris 1996). However, reproduction usually ceases in both sexes before these ages are attained.

Because of exposure to predation, disease and injury, the potential for feral or stray cats to reproduce to the same age as owned, domestic cats is extremely low. The reported life-span of males and females, the litter sizes and the kitten survival rates all suggest that the reproductive potential of feral and stray cats is considerably lower than that of owned domestic cats. However, despite a relatively short life expectancy and relatively low kitten survival rates, the reproductive potential of feral and stray cats is still considerable and greater than replacement. At one site, Heirisson Prong in Western Australia, Short and Turner (2005) estimated a population doubling time of just 8.5 months.

3.9 Cat colonies and highly modified habitats

Liberg and Sandell (1994) suggested that female cats near abundant food resources form groups that are stable over time, and that membership of the groups is based on kinship. Thus, rather than being ad hoc collections of animals exploiting resource-rich sites, these groups are structured and functional subpopulations of cats. The groups are defined by the females through matrilineal lines and are maintained by recruiting female kittens and excluding non-related females (Kerby and Macdonald 1994). Izawa and Ono (1986) suggested that weaned kittens gradually develop a home range that overlaps that of the mother and littermates, with all using a common feeding site, and it is the repetition of this process that appears to generate the feeding groups.

In the Australian context, high densities of cats have been identified exploiting rural rubbish tips (Wilson et al 1994; Denny et al 2002; Hutchings 2003; Denny 2005). In a study of cats exploiting tip sites in the Australian Capital Territory, Wilson et al (1994) suggested that the apparently high turnover of cats at one tip site could be explained partly by the dispersal of cats from the tip area; however, there was no concrete evidence of such dispersal.

In a study based on observations and genetic analyses, by contrast, Denny (2005) confirmed that cats living away from a rural tip in relatively unmodified habitat were more closely related to the tip cats than cats from a nearby township. The data indicated that rather than comprising loose collections of 'dumped' suburban cats, the tip populations were made up of self-perpetuating, closely related animals, from which individuals could disperse into the surrounding habitats.

Although weak, the dispersal patterns revealed by migration analysis indicate that cats moving away from tip sites relocated to areas where they would be dependent solely on predation. From the same study, Denny (2005) recorded non-members of the resident tip populations at two tip sites and both males and females initially captured at the tips were observed or captured away from the tip sites. Although both tip colonies comprised long-term resident cats, there was movement both into and away from each site. Frequently located at sites near or adjacent to farmland, remnant vegetation and conservation areas, rural tips provide a potential source of feral cats near habitats known to support vulnerable, rare or endangered native species. The tip habitats provide supplementary food sources, secure resting and nesting sites and breeding opportunities for cats. These sites also provide a source of cats that may move out and exploit surrounding habitats, as well as sinks providing supplementary food to which cats may retreat in times of climatic stress.

Wilson et al (1994) found that cats recolonised tip sites after removal, and suggested that control in perpetuity would be needed to prevent the re-establishment of high density colonies. Wilson et al (1994) also proposed the control of introduced rodents at tip sites to keep cat numbers at lower levels. Further investigations are needed to determine whether rodent control would substantially reduce cat numbers; whether tip cats would be able to survive without the rodent component of their diet; or whether rodent removal would encourage the cats to move away from the tip sites to become established in surrounding habitats.

Summary

- The densities of cats in Australia are highest on islands and in highly modified habitats.
- Open habitats usually support higher densities of cats than closed or dense, wet habitats.
- Male home ranges are larger than those of females; range size in both sexes also scales inversely with habitat productivity.
- Males are larger than females, but there is little evidence of geographical or habitat-based differences in size or dimorphism between cat populations.
- The breeding period for cats is longer in drier, warmer, semi-arid and arid zones than in cooler, wetter climates.
- Plasticity in the structure of cat society suggests that cat densities increase and decrease in response to shifts in food abundance and distribution.
- Differences in the ecology of cat populations among habitats and climatic regions suggest that cat control will need to be flexible and responsive to the prevailing conditions.

4. Cat impacts on native fauna

4.1 Predation

Studies throughout the world have reported predation by cats on native species (eg Hawai'i – Hodges et al 2001, Smucker et al 2000, Hess et al 2007; Mexico – Keitt et al 2002; the Galapagos Islands – Konecny 1987; Mona Island in the Caribbean – Garcia et al 2001; Japan – Jogahara et al 2003; Medina et al 2008; Canary Islands – Medina and Nogales 2009). Predation by cats on native Australian species has been well documented. Numerous studies have identified and classified the variety of species preyed upon by feral, stray and domestic cats. The Commonwealth *Threat Abatement Plan for Predation by Feral Cats* (2008) lists 36 mammal, 35 bird, seven reptile and three amphibian native species that are threatened and are known or perceived to be under threat from cats. The TAP (DEWHA 2008) also identifies four unlisted bird species, two unlisted reptile species and two listed critical habitats that may be adversely affected by feral cats.

The difficulty in assessing the impact of cats on populations of native species, as opposed to predation on prey individuals, is the teasing out of the relative contributions of all the variables that can lead to reductions in the abundance, distribution and densities of species. These variables include climatic events (drought, fire, flood, etc), habitat modification, disease, and food resource distribution and density. It is not sufficient to simply document the diet of cats and assume that this equates to impact at the population level, although several studies have attempted to do this. Such extrapolations are inappropriate for several reasons. First, cats may prey most readily upon the 'doomed surplus'; that is, the individuals in a prey population that are too young, old, or weak to reproduce (Banks 1999). Their removal clearly makes no difference to a population's rate of increase. Second, remaining prey individuals may respond to the removal of conspecifics by showing improved survival and increased reproductive output, thereby compensating for individual losses at the population level. Third, cats may eat individuals of a particular prey species but have positive effects on prey population growth and size if they depress other species that would otherwise impact on the prey species more strongly. Such indirect interactions are pervasive in natural systems, and are likely to have particularly strong effects in predator-prey systems (Glen and Dickman 2005; Dickman 2007).

Although there is no unambiguous evidence to implicate *F. catus* as the sole agent for extinction of any native species in Australia, there is considerable evidence of the impact of cats at a local level on populations of native species (Copley 1991; Dickman 1994; Dowling et al 1994; Coutts-Smith et al 2007; Dickman 2009). Risbey et al (2000) presented experimental evidence of cats impacting negatively on small mammal populations at Heirisson Prong, Western Australia, and this remains the only study in Australia to date to present such evidence.

Dickman (1996) reported that cats, together with habitat modification associated with agricultural development, can be implicated in the demise of up to 16 species of native mammals in western New South Wales prior to 1857. Abbott (2006) proposed that epizootic disease, together with predation by cats and climatic factors such as drought, led to the decline from 1875 of native species in the western third of Australia. Smith and Quin (1996) reported further that the abundance of cats was the best predictor of the decline of small conilurine rodents (<35g), and of conilurines of all sizes where foxes and rabbits were scarce or absent.

Declines in some isolated populations of native species can be attributed directly to cats. Spencer (1991) commented on the predatory effects of a feral cat on an isolated colony of the Allied Rock-wallaby, *Petrogale assimilis*, at Black Rock in tropical Queensland, an area where rabbits and other small mammals were present in low numbers. Gibson et al (1994) reported the impact of *F. catus* on captive-bred Rufous Hare-wallabies (*Lagorchestes hirsutus*) released in the Tanami Desert, Northern Territory. Horsup and Evans (1993) described predation by cats on the endangered Bridled Nailtail Wallaby (*Onychogalea fraenata*) in Queensland, and

Seebeck et al (1991) reported predation by cats on the endangered Eastern Barred Bandicoot (*Perameles gunnii*) in Victoria. Friend (1993) suspected that cats could be implicated in problems encountered in re-establishing the Numbat (*Myrmecobius fasciatus*) at a site in Western Australian. Burbidge and Manly (2002), in a study of the extinction of native species on landbridge islands of Australia, found that extinctions of ground-dwelling native prey species were positively correlated with the presence of cats, particularly on more arid islands with an absence of rock-pile habitat. Dickman (1992) summarised evidence of cat impacts that had probably caused mammalian extinctions on five islands around the Australian coast.

4.1.1 Characteristics of prey species

Dickman (1996) scored a number of biological attributes of both cats and prey species to develop a rank-scoring system to predict the susceptibility of populations of native species to cat predation. From these rankings it was concluded that mammals that are most vulnerable to predation from cats are species weighing less than 220 g, that are nocturnal and scansorial or terrestrial, and that occupy open vegetation such as woodland, grassland or gibber plains. Birds and reptiles showed similar patterns of vulnerability but differed in the body weights that cats prefer. In addition, species that gather in groups for feeding or reproduction, species that are usually sedentary within small areas, or species that congregate seasonally for feeding, breeding or hibernation are susceptible to predation by cats. Also susceptible to predation are species whose breeding rate is less than one young per female per year (Dickman 1996). The greater the number of the listed attributes possessed by a prey species, the more vulnerable such a species is to cat predation.

Analyses from many studies of the stomach contents and scats of feral cats indicate that most prey species fall into the susceptible categories as outlined by Dickman (1996). From these studies, 36 native mammal, 26 bird, 40 reptile, four insect, two fish and one amphibian species have been conclusively identified as prey of free-living cats in Australia (Dickman 1996).

Paton (1991) in Adelaide and Barratt (1997) in Canberra assessed the prey taken by domestic or owned cats. The study by Paton (1991) did not identify the prey to species level, but Barratt (1997) identified nine mammal species, 47 bird species, five reptile species, two amphibian species and one fish species as falling prey to owned domestic cats. Kunihira (1995) found differences in the diets of cats from urban and fringe areas of Canberra and related the prey taken to their abundance and vulnerability.

4.2 Disease

There is evidence of the potential threat from cats to native species through the dissemination of diseases and parasites. Moodie (1995) surveyed the incidence of disease and parasites in Australian cats and found that, of more than 100 pathogens recognised in *F. catus*, at least 30 have been recorded in native species. Most research into the impacts of cat transmitted diseases has been concerned with parasites (Akucewich et al 2002), with those pathogens that impact on domestic livestock (Coman 1972; Hartley and Munday 1974; Gregory and Munday 1976; Ryan 1976; Collins and Charlston 1979; Cross 1990), or with cat specific pathogens such as feline calici virus and feline herpes virus (Coman et al 1981 a and b; Wilson et al 1994; Hale 2003), feline panleukopaenia (van Rensberg et al 1987) and feline immunodeficiency virus (Fromont et al 1998; Courchamp et al 2000).

There are few data to suggest that pathogens recorded in cats impact on native species in Australia. However, the protozoan parasite *Toxoplasma gondii*, which causes toxoplasmosis, and for which the cat is the definitive host, has been discovered in the Eastern Barred Bandicoot (*Perameles gunnii*) in Tasmania (Obendorf and Munday 1990) and in many other native mammal and bird species (Moodie 1995). The pseudophyllidean tapeworm *Spirometra erinacei* also uses the cat as a definitive host and has been recorded in a wide range of native mammals, snakes and frogs (Reddacliff and Spielman 1990; Whittington 1992; Vogelnest and Woods 2008). Despite these observations, and the documentation of many pathogens in free-living *F. catus* in Australia, there remains a dearth of information on pathogens in native species (Dickman 1996; Vogelnest and Woods 2008) and the possible impact of disease from cats on native species remains unknown.

4.3 Competition

As with parasites and disease, there is a lack of information on the effects on native predators of competition from cats. The larger dasyurids and large raptors are the most likely species to suffer reduction in available resources through competition with free-living cats (Dickman 1996). Glen and Dickman (2008) showed that there was much overlap in diet and use of space between quolls and eutherian predators, including cats, and suggested that there was strong potential for competition to occur. At the same time, however, there is also evidence of raptors preying or attempting to prey on cats (Jeans 1993) and cat remains have been recorded on occasion in the scats or stomach contents of quolls, Tasmanian Devils (Guiler 1970) and wild dogs (Mitchell and Banks 2005). Recent studies confirm that cats can kill quolls (Glen et al 2009), and suggest that the relative effects of competition and intraguild killing and predation between cats and native carnivores remain to be disentangled.

4.4 Diet

Bradshaw (2006) outlined the evolutionary basis for the feeding behaviour of *F. catus* with reference to dentition, sense of taste and meal patterning. The author concluded that the domestic cat is a physiologically and morphologically highly specialised carnivore, preferring several small meals each day, and with limited sensitivity to both salt and sugars. Despite the ready availability of food, domestic cats still show much interest in hunting small prey.

Fitzgerald and Turner (2000) reviewed dietary studies of cats from the northern hemisphere (Europe and North America) and continental Australia and found the mean frequency of occurrence of mammals in the diet to be 69.6 per cent and 69.1 per cent, respectively; birds comprised 20.8 per cent and 20.7 per cent, respectively; and reptiles 1.6 per cent and 32.7 per cent, respectively. The major geographical variation in diet was in the frequency of occurrence of reptiles, which were more prominent in the diet of cats from the drier, warmer Australian continent.

4.4.1 Mammals

Although native species are well represented in the diet of cats in Australia, most studies of cat predation indicate that introduced species form the bulk of the diet. In a semi-arid environment, for example, Catling (1988) found that the introduced rabbit (*Oryctolagus cuniculus*) formed the greatest prey component in cat stomachs by both occurrence and weight. Similarly, Bayly (1978) found that rabbits formed the bulk of the diet of cats in an arid environment. Rabbits also formed the bulk of the diet of cats at Lake Burrendong in central eastern New South Wales, although house mice (*Mus musculus*) increased in importance after rabbit numbers were reduced by the appearance of rabbit haemorrhagic disease (RHD) (Molsher et al 1999).

Several studies in Australia have reported high frequencies of occurrence of rabbit in the diet of cats in arid and semi-arid zones (eg Bayly 1978; Jones and Coman 1981; Catling 1988; Martin et al 1996; Risbey et al 1999; Read and Bowen 2001) as well as in more temperate regions (eg Coman and Brunner 1972; Jones and Coman 1981; Barratt 1997; Molsher et al 1999; Kirkwood et al 2005). Catling (1988) reported the frequency of occurrence of rabbit in the diet of cats in western New South Wales as varying from 72 per cent to 90 per cent. Read and Bowen (2001) recorded a similar frequency of occurrence of rabbits (>60 per cent) in the diet of cats in arid South Australia, while Risbey et al (2000) found that the frequency of occurrence of rabbit varied from 19.4 per cent in the diet of semi-feral cats, to 66.6 per cent in the diet of feral cats in Western Australia. Jones and Horton (1982) found that rabbits constituted the bulk of cats' diets on Macquarie Island, and Jones and Coman (1981) found that rabbits and house mice contributed most to the diet of free-living cats in Victorian mallee areas.

Holden and Mutze (2002) reported a substantial reduction in the population of cats in the Flinders Rangers, South Australia, following a rapid decline in rabbit numbers following the release of RHD.

Several species of native dasyurids and murids, as well as species of possums, gliders, bandicoots and small wallabies have all been recorded in the diet of feral cats (Dickman 1996, 2009). Native mammal species identified in the gut or scats of feral cats range from small mammals (eg *Rattus fuscipes* (Bush Rat), *Sminthopsis crassicaudata* (Fat-tailed Dunnart), *Sminthopsis macroura* (Stripe-faced Dunnart), *Pseudomys hermannsburgensis* (Sandy Inland Mouse) and *Leggadina forresti* (Forrest's Mouse)) (Paltridge et al 1997; Paltridge 2002; Denny 2005; Pavey et al 2008) through medium sized (eg *Perameles gunnii* (Eastern Barred Bandicoot), *Trichosurus vulpecula* (Common Brushtail Possum), *Lagorchestes hirsutus* (Mala), *Lagostrophus fasciatus* (Banded Hare-wallaby) *Bettongia penicillata* (Woylie), *Bettongia lesueur* (Burrowing Bettong), *Myrmecobius fasciatus* (Numbat), *Petauroides volans* (Greater Glider) (Kinnear 1991; Gibson et al 1994; Christensen and Burrows 1995; Molsher et al 1999; Priddell and Wheeler 2004; Morris et al 2004; Denny 2005) to larger species such as *Onychogalea fraenata* (Bridled Nailtail Wallaby) and *Petrogale assimilis* (Allied Rock-wallaby (Spencer 1991; Horsup and Evans 1993).

4.4.2 Birds

Fitzgerald and Turner (2000) ranked birds as the second most important component by occurrence in the diet of cats from mainland areas around the world. Cat diet studies throughout Australia have indicated wide variations in the contribution of birds between areas. Occurrences of less than ten per cent were recorded by Coman and Brunner (1972) in Victoria, Bayly (1976) in South Australia, Jones and Coman (1981) in the Victorian mallee, Martin et al (1996) in rural Western Australia, and Paltridge et al (1997) in the semi-arid Northern Territory. The lowest occurrence was 7.1 per cent, recorded by Bayly (1976). Occurrences greater than 20 per cent were recorded by Bayly (1978) in South Australia, Catling (1988) in semi-arid western New South Wales, Jones and Coman (1981) in both semi-arid Kinchega in western New South Wales and the temperate eastern highlands of Victoria, and Martin et al (1996) in pastoral Western Australia. The highest occurrence, of 45 per cent, was recorded at Kinchega (Jones and Coman 1981). Denny (2005) recorded bird remains in 58.3 per cent of cat scats from semi-arid New South Wales. Dietary studies suggest that there is no correlation between climate and the degree of bird predation by cats, and the relative abundance and the behaviour of the available bird species probably play an important part in the degree of predation by cats, as suggested by Dickman (1996).

4.4.3 Reptiles

Occurrences of reptiles of more than 25 per cent have been reported in cat diets from studies in arid and semi-arid environments (eg Bayly 1976, 1978; Jones and Coman 1981; Catling 1988; Martin et al 1996; Arnaud et al 1993). Lower occurrences have been recorded in cooler, more temperate areas (eg Coman and Brunner 1972; Jones and Coman 1981; Triggs et al 1984; Fitzgerald and Veitch 1985; Dickman 2009), possibly reflecting differences in the relative abundance of reptiles between regions.

4.4.4 Other species

Other items eaten by cats include amphibians, invertebrates and vegetation, although most studies suggest that these comprise minor components of the diet. There have been reports, however, of relatively high occurrences of insects in the diet of cats. Bayly (1976) reported the frequency of occurrence for insects in the scats of cats in semi-arid areas of the Northern Territory as 100 per cent, while Hutchings (2003) reported the frequency of occurrence for insects as ≈ 40 per cent in the scats of tip cats in Victoria. Denny (2005) reported 51 per cent insect occurrence in cat scats collected at and away from a tip site in semi-arid New South Wales, with the insect component comprised almost exclusively of plague locusts during one season of the study.

4.4.5 Scavenging

Dietary studies have shown that cats also scavenge. Scavenged items, including human food scraps, have been identified in the scats of cats considered to be mainly dependent upon live prey. Jones and Coman (1981) found both human food scraps and carrion in the diet of cats from three areas in New South Wales and Victoria. Catling (1988) similarly found carrion in the diet of cats from semi-arid New South Wales. Paltridge et al (1997) reported carrion in the stomachs of cats from central Australia during dry winters when live prey was scarce, while in a study in central New South Wales, Molsher et al (1999) found that cattle and pig carcasses were scavenged by cats, albeit infrequently. Dickman (2009) described the diet of cats exploiting suburban and temperate habitats in the Sydney basin in New South Wales, and reported that the volumetric occurrence of scavenged items in scats (both organic and inorganic) ranged from zero to 57 per cent.

4.5 Assessing vulnerability of native species to cat predation

Dickman (1996) proposed a rank-scoring system for assessing the vulnerability of native species to predation by cats. Dickman's rank-scoring system based the vulnerability of vertebrate species to cat predation on scores assigned to the body weight, habitat use, behaviour, mobility and fecundity of the prey species, as well as on the abundance of cats. A modification of Dickman's rank-scoring provides a method for rapid assessment of the vulnerability of species to predation by cats in the absence of indices of the relative abundance of cats. The scoring is based on adult animals only; subadults and juveniles of many species may be more vulnerable to cat predation than indicated by this rank-score index. Scores are awarded for body size, habitat and behaviour, and an assessment is made on this basis of the vulnerability of each species to predation by cats.

Table 4. Rank-scoring system for assessing the vulnerability of native species to predation by cats

Attribute	Criteria and scores			
Size:	>2000 g **	0 or	>45 cm***	0
	1001 – 2000 g	1 or	30-35 cm	1
	220 – 1000 g	2 or	25-34 cm	2
	<220 g	3 or	<25 cm	3
Habitat:*	Very dense ground cover/heath			0
	Closed forest, mangroves, swamps, caves			1
	Open forest, moderate ground cover			2
	Woodland, grassland, cultivated land, urban			3
Behaviour:*	Diurnal			0
	Nocturnal or crepuscular			1
	Oceanic, aquatic, arboreal, fossorial, volant			0
	Terrestrial, scansorial			1
	Defences such as teeth, claws, aggression			0
	No defences			1

*The scores within the Habitat and Behaviour categories are cumulative. **Mammals. ***Birds and reptiles.

Cumulative scores across categories: >5 = high; 3 – 5 = low; < 3 = negligible.

An example of the application of this rapid assessment rank-scoring system is shown in Appendix 1. It is based on species known/expected from the Southern Ark Project area in the East Gippsland district of Victoria.

4.6 Discussion

Dickman (1996) concluded that although cats may have a competitive impact on native predators, and an amensal impact in terms of the spread of disease organisms such as *Toxoplasma gondii* to native species, the greatest impact from cats in Australia is through direct predation on native species. Although there is little evidence to suggest that cats have been the sole instruments in the extinction of any native species, there is evidence of the population level impacts of cats on threatened fauna, most graphically illustrated by reports of cat predation on captive-bred animals released into the wild. Mammals form the bulk of the diet of feral cats and many studies report that introduced rodents (*Mus musculus, Rattus rattus* and *Rattus norvegicus*) and rabbits (*Oryctolagus cuniculus*) are the main component of the diet. These exotic prey species are distributed throughout the continent, with some local areas supporting all four. They provide, together with scavenged items from highly modified habitats, a relatively stable food source that helps to maintain the cat population continent wide.

Summary

- Small mammals constitute the largest component of the cat’s diet both in Australia and overseas, but prey up to several kilograms in weight may be taken on occasion.
- Birds represent the second most important component in the diet of cats.
- In arid Australia, reptiles have been recorded in up to 25 per cent or more of cat scats.
- Introduced rodents and the rabbit are a major component of the diet of cats in Australia.
- Cats are suspected to have caused extinctions of native species in Australia, but confirmed impacts have been documented only on local populations of prey species.
- Direct predation probably has the strongest impact on prey, but competition, transmission of parasites and diseases, and indirect interactions may also occur.
- The vulnerability of native species to predation by cats may be quickly assessed using a modified Dickman rank-scoring system based on characteristics of individual prey species.

5. Monitoring cat abundance

Witmer (2005) discussed the factors that influence the preferred detection method of mammals in the field. The author suggested that initial considerations should include the likelihood of seeing or capturing the animal or locating its signs (eg scats, hair), the portion of the entire study area that could be sampled, and how the samples would be best distributed. In a comprehensive review for the Federal Department of the Environment and Heritage, of methods used to estimate the abundance of feral cats in Australia, Forsyth et al (2005) reported that from published research, only three methods have been used, either alone or in combination, to estimate cat abundance: spotlighting, track counts and bait-take. The authors concluded that these methods provide indices of abundance, but also that there are no techniques available to estimate absolute abundance of cats, and that protocols need to be developed for estimating absolute abundance and for determining kill rates obtained in control programs. The following assessment of field techniques for establishing the presence/absence or relative abundance of cats includes those techniques reported by Forsyth et al (2005) as well as techniques reported elsewhere.

5.1 Track counts

Track counts are an established method for estimating the relative abundance or activity of cats (Mahon et al 1998; Edwards et al 2000). In areas with a dry, sandy or dusty substrate, predator footprints can be counted along walking or driving transects and are easily discernible and usually recognisable as either fox, dog or cat (Brunner and Coman 1974). In areas with rocky surfaces and/or dense forb, grass or litter cover, paved roadways, and permanent creeks and water courses, footprints are difficult to discern or identify, and artificial track plates then need to be used. A comparison of carbon soot, photocopy toner and talcum powder as tracking media in forest areas showed carbon soot and toner to be the most effective, with the toner easier to transport and handle than soot (Belant 2003). To increase visitation to track plates, scent or auditory attractants can be added; however, Allen and Sparkes (2001) reported that track plates without attractants provided a more reliable index of relative abundance.

Although track counts may indicate the presence/absence of cats, preferential use of specific features of the landscape (eg roads, creek lines) may lead to biases in the data (Mahon et al 1998; Helon et al 2002). The same animals using the same track but in opposite directions during the same tracking period may also lead to biases (Denny 2005). Track counts are relatively inexpensive and are best suited to estimates of relative abundance of a species in fixed locations over several years (Wilson and Delahay 2001). In forested areas, track plates located on transects along the sides of road ways and tracks, without lures or attractants, can be used to assess the presence/absence of cats and to provide an index of relative abundance. A commonly used alternative to track plates is the use of sand pads, with strips of sand placed across tracks or other accessible sites in the sampling area.

5.2 Tree scratches

Scratches on smooth barked trees (eg *Eucalyptus camaldulensis)* can indicate the presence of cats in areas where there are no arboreal mammals (Denny 2005). This method is not valid in forest or woodland areas that support arboreal mammals such as koalas (*Phascolarctos cinereus*), gliders or possums. However, tree scratches in some habitats may provide an indication of cat presence and may be some indication of relative abundance between habitats supporting the same varieties of trees.

5.3 Kills

The identification of carcasses as cat kills can indicate the presence/absence of cats. Identifiable cat kills are usually birds, where the wings, and occasionally the feet and head, remain (Triggs 1996; Denny 2005). Forensic DNA techniques have also recently been used to confirm the killing of a quoll (*Dasyurus geoffroii*) by a cat, and may be used more generally for identifying the role of cats and other predators in the killing of prey (Glen et al 2009). However, such techniques rely on the presence of a carcase, preferably a fresh one, or at least the partial remains of prey for examination. Small mammalian and reptilian prey is usually consumed entirely, leaving no evidence of predation. The persistence of prey remains depends upon climatic conditions and scavenging by other species and, because kills are often moved to concealed sites for consumption, the probability of finding kills is low (Denny 2005). Aside from opportunistic finds, prey remains therefore provide a poor indication of cat presence and no indication of relative abundance.

5.4 Spotlighting

Spotlighting transects are frequently used for detecting and assessing the abundance of nocturnal mammals, and are carried out either by foot or from a moving vehicle. Factors that may affect the results of spotlighting surveys include weather (eg rain, cloud cover), time and season of the survey, the complexity or structure of the surrounding habitat, and variations in the behaviour and population structure of the target species (Wilson and Delahay 2001). Obtaining a reliable estimate of the relative abundance of cats from spotlighting has proven difficult. Mahon et al (1998) found spotlighting underestimated the abundance of cats compared to another index based on track counts. Edwards et al (2000) also found that spotlighting was not a reliable indicator of the relative abundance of cats, but concluded that it was a quicker and easier method to undertake than tracking and other alternatives. Both studies were conducted in arid areas. In forested environments, the viewing distance is lower than in more open habitats and thus the detection rate from spotlighting is lower. Denny (2005) suggested that when cat numbers are clumped near townships, homesteads, tips, or other attraction points, mean densities along spotlight transects may overestimate the densities of cats over the entire study area.

Although a common tool for providing simple indices of abundance, spotlighting can either overestimate cat abundance in areas surrounding townships and farms, or underestimate it because of the habitat structure and the cryptic nature of cats (Denny 2005). Increased confidence may be placed in the results of spotlighting following improvements in distance sampling methods (eg Ruette et al 2003; Buckland et al 2004), but spotlighting is likely to remain at best a rough guide to cat abundance.

5.5 Faecal accumulation rates or scat counts

Bateson and Turner (2000) posited that free-living cats do not bury their scats and deposit many scats on grass tussocks. Liberg (1980) stated that domestic cats close to home tend to bury scats, but leave them exposed when further away. Thus scat counts along transects, or faecal accumulation rates, may be used as the basis for indices of the relative abundance of cats, especially if additional information is available on movements or range areas. However, in an analysis of dog, fox and cat scats in Port Stephens, New South Wales, Lees et al (1997) found only three cat scats in searches of 193 km of tracks. The authors concluded that cat scats were least likely to be found where roads were constructed of road base and fringed by leaf litter and bushland. Likewise, Denny (2005) found cat scats to be more easily detectable in an open, semi-arid environment than in temperate, forested areas. Wilson and Delahay (2001) suggested that when monitoring the abundance of an animal through faecal surveys, the surveys should be standardised by location and time of year, and comparisons between sites should be based on sites of similar habitat.

5.6 Remote photography

Remote-trip cameras activated by a trip line or plate, photic cells or infrared beams can be used for individual recognition of cats and, when used in grids or transects, may form the basis for estimates of population densities (Wilson and Delahay 2001). Glen and Dickman (2003) found remote photography to be more accurate than the identification of tracks on sand plots in a study of bait uptake in forested areas. Wilson and Delahey (2001) suggested that the pattern of placement of photo-traps should take into consideration the movement pattern and behaviour of the target species to avoid biasing the data when estimating abundance. Difficulties associated with the use of remote-trip cameras include frequent malfunction of triggering systems, triggering of cameras by non target species, and difficulty in ascertaining the accurate identification of individuals (eg Towerton et al 2008).

Despite such problems, Claridge et al (2004) reported the use of Digicam DC110 infrared cameras (Faunatech/Ausbat Pty Ltd, Bairnsdale, Australia) at two latrine sites used by the solitary Spotted-tail Quoll (*Dasyurus maculatus*) in Kosciuszko National Park in southern New South Wales. This is a fully automated digital photographic system designed for remote field recording. It incorporates a modified Olympus digital camera, an infrared flash, camera controller, sensor processor and power supply, all contained in a compact environmental housing. The authors found the cameras were compact and easy to set up in remote field situations, and that they could be left for relatively long periods without checking (Claridge et al 2004). The cameras allowed discrimination between individual quolls, suggesting that they could also serve to identify cats with different coat patterns. From this study, fixed cameras would appear to provide a reliable method of detecting cats in forested areas.

In a study of marked, radio-collared coyotes, however, Larrucea et al (2007) concluded that remote cameras do not always provide unbiased samples of the target population, and that the behaviour of the target species is a major consideration when using remote cameras for estimates of abundance. In a forested state park and a forested urban reserve in New York, Gompper et al (2006) reported that camera traps and track plates were approximately equivalent in detection efficiency, and suggested that animals may be wary of stepping on tracking surfaces. Likewise, Foresman and Pearson (1998) ranked both cameras and track plates for five performance categories, including detection, latency to detection, species identification, implementation effort and cost, and found that the remote cameras ranked higher than track plates for detection, species identification and implementation effort.

A further camera-based field technique, video surveillance, is used most frequently in behavioural studies, but it may be used also to estimate abundance if individuals are recognisable. As with remote-trip cameras, however, malfunction in the field often presents a problem. Wilson and Delahay (2001) suggested that video surveillance might be more suited to group-living carnivores, especially if cameras could be trained on communal dens.

Robley et al (2008) evaluated detection methods and sampling designs for determining the abundance of feral cats at a study site at Anglesea, Victoria. This study comprised multiple detection devices, including cage traps, leghold traps, VHF/GPS collars, heat-in-motion cameras and DNA samplers. However, the detection rate in the selected study site was low, suggesting low cat densities, while other study sites also proved unsuitable because of low cat densities and/or topographical or climatic difficulties in using the several different detection methods. The authors used simulation modeling to propose a protocol to detect cats, of 49 cameras arranged in a 6 x 6 km grid for 20 days, but still suggested caution in applying this methodology because of the small sample size on which the results were based (Robley et al 2008). However, it should be noted that the TrailMAC Digital cameras, with a minimum one-minute time delay between photos, that were used in this exercise are relatively insensitive (S. Lapidge, pers. comm). Much more sensitive cameras, with no time delays and that are specifically built for wildlife researchers are now available (ie Reconyx Inc), which substantially enhance animal detection.

5.7 DNA analysis

There are numerous examples of the use of microsatellite loci analysis in Australian research, including paternity determination in the Koala (*P. cinereus*) (Houlden et al 1995) and studies of relatedness and pedigree reconstruction in the Northern Hairy-nosed Wombat (*Lasiorhinus krefftii*) (Taylor et al 1997). Wilton et al (2000) used microsatellite variation to distinguish the dingo from the domestic dog (*Canis lupus dingo*), Robinson and Marks (2001) investigated the dispersal of red foxes (*Vulpes vulpes*) in urban Melbourne using five canine microsatellites, while Eldridge et al (2001) investigated the dispersal of rock-wallabies between patches of habitat using 11 microsatellite loci. Rollins et al (2006) used the expansion of the European starling (*Sturnus vulgaris*) into Western Australia as an example of how genetic analysis can be used to provide information that is vital for pest-management strategies. Such information includes identifying the origin of invasive individuals, and can be used to identify the source of invading populations for more efficient management (Rollins et al 2006).

Recent advances in genetic analysis provide techniques for retrieving genetic material from both hair and faeces (Wilson and Delahay 2001; Berry et al 2007), allowing for the genotyping of individuals from a study population. This technique can be applied to investigations of relative abundance by estimating the number of individuals exploiting a given area. The technique relies, however, on acquiring either fresh scats or hair samples. The remote collection of hair for genetic analysis presents the problem of determining whether the hair is from one or more individuals. However, Bremner-Harrison et al (2006) reported a hair snare that prevents multiple sampling, that is cost effective and easy to construct, and is safe for target and non target species.

In forested areas where cat scats are difficult to locate (Lees et al 1997; Denny 2005) and capture rates are low, genetic analysis may not provide any more information on relative abundance of cats than any other technique. However, used together with a variety of techniques, microsatellite loci analysis is a valuable tool for investigations into the population dynamics of cats (Denny 2005).

5.8 Bait uptake

The removal of toxic or non-toxic baits by target animals may be used as an index of relative abundance. The removal of baits by cats is assumed to be negatively related to the abundance of cats (Forsyth et al 2005), however, bait uptake assessments require the identification of species taking the baits, so such studies should include track plates and/or photography to increase the likelihood of identifying what species are attracted to, investigate, and/or take the baits. On Heirisson Prong on the Western Australian coast, baits (mouse carcasses containing a single oat with 4.5 mg of 1080) were placed at sites 100 m apart and the sandy substrate surrounding the baits was swept to provide a clear area for identifying tracks. The program included radio-collared cats, all of which died during, or shortly after, the baiting period. Spotlighting, together with bait uptake and the death rate of radio-collared cats, was used to estimate the relative abundance of cats in the area and the success rate of the baiting program (Short et al 1997).

Bait uptake was again used at Heirisson Prong in 1993-95 (Short and Turner 2005) to estimate the densities of cats using the index-manipulation-index method developed by Caughley (1977). Spotlighting before and after baiting was used to calculate indices of abundance, and baiting with cyanide capsules removed a known number of cats (Short and Turner 2005).

5.9 Discussion

Witmer (2005) noted that it is difficult, and time and resource–intensive, to obtain accurate estimates of population density for most wildlife species. The author suggested further that, although population indices are easier to obtain, many unknown factors are implicated and it is difficult to assess the relationship between population indices and actual population densities. In their review of field methods for estimating the abundance of terrestrial carnivores, Wilson and Delahay (2001) concluded that the field techniques employed should be based upon the ecology of the target species, and that the use of more than one method may be preferable. The authors also suggested that the chosen field methods should be validated by comparing the results, where possible, with an accurately known population estimate (Wilson and Delahay 2001).

Forsyth et al (2005) reported that most monitoring of feral animal control in Australia is based on indices of relative abundance. Estimates of absolute abundance by mark-recapture of removal estimators are difficult to obtain for animals with low abundance and/or low detection probability. This is particularly the case for feral cats throughout much of Australia.

Most field techniques that provide direct or indirect estimates of the relative abundance of cats are best suited to open, dry habitats with low vegetation cover, rather than more temperate forested areas. A review of the recorded densities of cats in Australia suggests that the abundance of cats is relatively low in most habitats, with the exception of highly modified habitats such as townships, farms and rubbish tips, and on some offshore islands.

Estimates of the relative abundance of cats are essential when assessing the impacts that cat predation may have on vulnerable or endangered native species. The greater the abundance of cats in an area, the more likely the native species will be under threat (Dickman 1996). However, when indices of relative abundance are not available, attributes of prey species may be used to infer the vulnerability of each species to cat predation.

Summary

- The three most common techniques for estimating cat abundance in Australia are spotlighting, track counts and bait uptake estimates.
- These three techniques are most suited to open, dry habitats with low vegetative cover.
- The accuracy of track counts is dependent upon the competence of individual operatives in recognising tracks.
- Bait uptake estimates are usually dependent upon track recognition.
- In wetter, more closed habitats with high vegetative cover, techniques such as remote photography and DNA analysis from scats or hairs provide alternative techniques for estimating cat abundance.
- The relationships between estimates of abundance and absolute population densities are difficult to assess.
- An understanding of the population dynamics of cats and the way in which they exploit the Australian landscape is a necessary adjunct to estimates of abundance.
- The most accurate estimates of abundance of cats can be obtained from identification of individuals through remote photography or DNA analysis.
- No detection technique on its own is reliable and a suite of techniques should be used to provide data robustness.

6. Cat management strategies

Successful cat control programs in Australia are comprised of the eradication of cats on several islands and within fenced reserves and sanctuaries on the mainland, with few control programs having yet been implemented throughout the broader landscape. Newsome (1991) outlined several possible control methods for stray and feral (free-living) cats in Australia, including shooting, trapping, poisoning or biological control (disease). Olsen (1998) added habitat manipulation and physical exclusion (by fences and other barriers) to the list of vertebrate pest management strategies. Legislative strategies, community and incentive schemes such as bounties may be included as part of the overall management structure that is needed, although successful reduction of cat numbers or impact will clearly still depend on methods of control in the field.

Control strategies that have been adopted on mainland Australia and offshore islands are shooting, trapping, poisoning and the introduction of feline panleucopaenia (Brothers 1982; Muir 1982; Brothers et al 1985; Domm and Messersmith 1990; Short et al 1997; Algar and Burrows 2004). Successful cat eradication measures have all involved the use of more than one approach.

On Marion Island, the introduction of feline panleucopaenia, hunting and trapping were the preferred methods (Howell 1984; Bloomer and Bester 1992). Domm and Messersmith (1990) reported that eradication of the cat population of North West Island on the Queensland coast was achieved by shooting, trapping and poisoning with 1080 (sodium monofluoracetate), while Clapperton et al (1992) described a probable cat eradication on Matakohe (Limestone) Island in Whangarei Harbour, New Zealand, during July/August 1991, using 1080 and gin trapping. In 1982, Brothers reported an eradication program on Tasman Island using baiting with 1080; after five years, the author anticipated that virtually all the cats on the island had been eradicated and that a further two visits would eradicate them totally (Brothers 1982).

Veitch (2001) described a cat eradication program in New Zealand that commenced in 1977 and concluded in 1980 using cage traps, leghold traps, dogs and 1080 poison. The author found that leghold traps and 1080 poison were the only effective methods. In semi-arid Western Australia, Short et al (1997) substantially reduced a free-living cat population by poisoning with 1080, which was introduced in the carcasses of laboratory mice. Assessment of the effectiveness of this method was made directly by monitoring radio-collared animals, all of which were killed, and spotlighting transects, which showed a 74 per cent reduction in sightings. In contrast to these studies, however, Muir (1982) suggested that control of cats by poisoning was not very successful, and that on-going shooting programs provided the most effective method of control.

In 2002, Algar et al reported the successful eradication of feral cats from Hermite Island (Montebello Islands) off Western Australia using trapping and poisoning. Algar et al (2003) also reported the removal of approximately 90 per cent of the feral/stray cats from the Cocos (Keeling) Islands using sterilisation of owned domestic animals to prevent young animals entering the cat population, as well as trapping, shooting and poisoning. Read and Bowen (2001) used shooting and trapping effectively to remove cats from a 14 square kilometre fenced enclosure at Roxby Downs in South Australia, while Twyford *et al*(2000) reported the eradication of cats from Gabo Island, Victoria, by poisoning, trapping and shooting. Broad scale baiting was employed in the Gibson Desert, Western Australia, in a trial by Burrows et al (2003) of control strategies for introduced predators.

Control of cats in almost all of these studies required the implementation of two or more strategies. It was not feasible for a single control method to eradicate cats from an island situation. On the mainland, the problem is further complicated by the movements of cats immigrating to and emigrating from a target area. Reddiex et al (2006) reviewed existing pest control in Australia and mapped the sites of cat control programs in 2003, and reported that few pest control operations specifically targeted cats, despite their continent-wide distribution. Reddiex et al (2006) estimated that the area where cat control was carried out in 2002/3 was >0.4 million ha as opposed to 10.5 million ha for foxes. While fox control programs included broadscale baiting on agricultural land and in reserved areas, the authors reported that most ongoing cat control programs were carried out as part of conservation plans for threatened species, involved exclusion fencing, and were confined to an average area of 35 km^2.

Three major considerations for the implementation of any pest control program are humaneness, environmental impacts including impacts on non target species, and feasibility in terms of time and labour costs (DEFRA 2005). A model code of practice and standard operating procedures for the humane capture, handling and destruction of feral animals in Australia was produced by the NSW Department of Primary Industries (Sharp and Saunders 2004, 2005). Concerns, inconsistencies and gaps in knowledge listed in the report included lack of uniformity in the approach to pest animal control across states and territories, a lack of a centralised reporting of non target impacts of poisoning incidents, and inconsistent requirements for animal welfare. Sharp and Saunders (2005) described the ideal vertebrate pest control method as '…Humane, target specific, efficient, cost effective and safe for humans to use'.' The authors evaluated the following strategies in use in Australia for the control of feral cats in terms of humaneness, efficacy, cost effectiveness and target-specificity.

6.1 Exclusion fencing

The only successful way of eradicating cats from any specific area on the mainland has been to create an 'island' situation by installing exclusion fencing and eradicating the cats inside the fenced area. This approach has been used in Western Australia on Heirisson Prong, Shark Bay (Risbey et al 1997), in the Tanami Desert in the Northern Territory (D. Gibson, pers comm), at Currawinya in south western Queensland (P. McRae, pers comm), at Scotia in western New South Wales (G. Finlayson, pers comm), in programs to re-establish captive-bred native species in the wild at the 17 ha waterbird enclosure at Tidbinbilla Nature Reserve in the Australian Capital Territory (Osborne and Williams 1991), and surrounding the town of Roxby Downs in South Australia (Read and Bowen 2001; Moseby et al 2009). Long and Robley (2004) reported the types of fences available for cat exclusion, such as floppy-top, overhang, electric wire overhang, mesh electric wire composite and capped. The authors reported various degrees of success with these fence types, but concluded that not all types had been rigorously tested.

A comprehensive report on cost effective feral animal exclusion fencing for areas of high conservation value in Australia was prepared for the Federal Department of the Environment and Heritage (now the Department of Environment, Water, Heritage and the Arts) by Long and Robley (2004). The authors reported that feral cats could jump a 1.5 m barrier and readily climb solid structures such as wooden fence posts. Floppy-top fences that are difficult for cats to climb are the only cat exclusion fences that have been experimentally tested in Australia (Long and Robley 2004). The construction of one successful type of fence used a wire netting base with a floppy top of 60 cm with electric wires at 120 and 150 cm from the ground (Long and Robley 2004).

Moseby and Read (2006) used pen and field trials to test the effectiveness and cost-efficiency of wire netting and electric fences for rabbit and feral predator exclusion, and concluded that a low fence (115 cm) with a 60 cm floppy overhang was as effective at excluding both cats and foxes as taller fences (180 cm). Sharp and Saunders (2005) concluded that exclusion fencing was acceptable in terms of humaneness, but had limited application and was expensive and impractical for broad scale cat control. However, in the absence of any other long-term eradication programs for cats on the mainland, exclusion fencing has proved to be effective for the protection of many vulnerable and endangered species.

6.2 Shooting

Shooting is widely used in wildlife management. The humaneness and effectiveness of shooting is dependent upon the competence of the shooter (DEFRA 2005). In Australia, shooting of cats has been employed for both research (Coman 1991; Read and Bowen 2001) and cat control on islands and on the mainland (Brothers 1982; Domm and Messersmith 1990; Read and Bowen 2001). Most frequently, shooting has been combined with trapping and poisoning to remove remnant cat populations from islands (Brothers 1982; Domm and Messersmith 1990; Bester et al 2000). Shooting is target-specific and relatively humane, but is also time and labour intensive, and is most suited to cat control in isolated areas such as islands (Sharp and Saunders 2005). Van Rensberg and Bester (1988) suggested that sustained hunting by a sufficient number of experienced hunters would eradicate feral cats from Marion Island, as all areas of the island were accessible. The authors reported that when cat densities were low and the growth rate zero on the island, shooting was highly successful in eradicating the last remaining cats.

6.3 Trapping

A variety of traps, including cage traps, soft jaw (padded jaw) traps, net traps and treadle-snare traps, have been employed for cat control in Australia. Trap response may be influenced by a number of factors, including weather conditions, activity of the target species, hunger, social status, sex or reproductive condition (King and Edgar 1977). However, the viability of the trapping apparatus used is central to the success of any trapping project, and attempts to trap free-living cats have led to much research into suitable trap types as well as into successful baits and lures.

Trapping over 1000 nights, Meek et al (1995) found the Victor Soft Catch™ No. 3 trap was the most effective trap type, catching more animals with fewer escapes and fewer injuries than the treadle-snare. Lee (1995) tested both cage and soft-jawed traps and found that the soft-jawed traps were more effective than cage traps (10.6 per cent and 1.8 per cent capture success respectively). There were, however, many non target species captured by the soft-jawed traps.

Short et al (2002) compared the success rate of various trapping methods for free-living cats in a study at Shark Bay, Western Australia. Both cage traps and concealed foothold traps were used, together with various baits and lures. The results from 31 703 trap-nights indicated that no particular trap type or combination of trap and lure type was more efficient than any other, but that trapping was most successful when the dominant prey of cats (rabbits) was declining or low. The authors found that cats scavenging at rubbish tips or around human settlement were more easily trapped. The trap rate from near rubbish tips was 9.4 per cent, compared to an overall trap rate for the study of 0.83 per cent (Short et al 2002). Likewise, Denny (2005) reported trap rates around rubbish tips in temperate and semi-arid bioregions of 13.21 per cent and 28.57 per cent, respectively. Molsher (2001) reported a capture rate of 1.3 per cent over 6027 trap-nights at Lake Burrendong in central New South Wales. Again, the author found no significant difference in the relative efficiency of cage traps and leghold traps.

Bloomer and Bester (1992) reported that non target species were captured by jaw traps, which was not a problem with cage traps. This study revealed that each cat captured required 1473 trap hours of trap effort. Domm and Messersmith (1990), in their report on a feral cat eradication program on an island of the Barrier Reef, abandoned trapping as a technique for cat control because of the time and manpower required.

6.3.1 Cage traps

The most commonly used cage trap consists of a commercially supplied wire box (60 x 30 x 30 cm) with a spring door operated by either a treadle or hook mechanism. The NSW Department of Primary Industries, in its Standard Operating Procedure CAT002, recommends the use of a treadle system only, as the hook system can cause injury to captured animals. Cage traps are either solid or collapsible for easy transport. These traps have proved to be successful in highly modified habitats such as rubbish tips, with capture rates of ~ 30 per cent (Denny et al 2002; Short et al 2002; Denny 2005), while in less modified habitats, capture rates of less than two per cent have been reported (Molsher 2001; Short et al 2002; Denny 2005). Cage traps are relatively humane, and although non target species may be caught, they are usually released unharmed. Cage trapping is, however, time and labour intensive and unsuitable for broad scale control on the mainland.

6.3.2 Leghold traps

Unmodified steel-jaw traps are prohibited in most states (Saunders and McLeod 2007). However, soft-jaw (padded jaw) leghold traps are used in Australia for cat research and/or control programs (Molsher 2001; Read and Bowen 2001; Algar et al 2003). Leghold traps are buried, and baits or lures are used to attract cats to the traps. Algar et al (2003) described a technique for setting leghold traps comprised of a channel slightly wider than the width of the trap that was cleared into a bush, forming a blind trap set. It was then suggested that baits and lures were placed strategically to attract cats into the channel and onto the leghold trap. Although relatively humane, soft-jaw leghold traps can cause injury to non target species, including mammals, birds and reptiles. Sharp and Saunders (2005) graded soft-jaw traps as only conditionally acceptable for humaneness. As with cage trapping, soft-jaw trapping is both time and labour intensive and not suited to broad scale cat control. Sharp and Saunders (2005) recommended that trapping with soft-jaw traps should be restricted in non-urban areas to late autumn and winter, when the capture of non target species is reduced. The authors suggested that the impact on non target species might be further reduced by avoiding the setting of traps near sites such as waterholes that are frequented by non target species.

6.3.3 Soft net traps

Ecotrap P/L, a Victorian company, released a humane net trap, the Ecotrap™, in 1992. The trap consists of a flexible metal frame and netting that collapses onto the target animal. The trap requires a cleared area of about one m diameter to trigger successfully. The Ecotrap™ is triggered by string snares and has been used to capture cats, dogs, birds, rabbits, bandicoots, wallabies and possums (Ecotrap™ 2007). The trap has been successfully used to capture cats in the Tibooburra area (Dan Hough, pers comm), but no other independent assessment of the relative trap rates of this device is available. Although humane, soft net traps appear to be relatively ineffective, expensive, and time and labour intensive, and are not suited to broad scale cat control (Sharp and Saunders 2005).

6.4 Immunocontraception

The development of viral-vectored immunocontraception (VVIC) for controlling pest species requires the development of both a suitable vaccine and efficacious and safe delivery systems (Miller et al 1998). Hood et al (2000) suggested that hosts with low birth rates and moderate mortality rates are the best targets for VVIC. Courchamp and Cornell (2000) modelled the relative efficiency of immunocontraception using three disseminating techniques for cat control on oceanic islands: baits; genetically modified viral vectors; and a combination of both. The authors concluded that VVIC was a more efficient disseminating technique than baits.

Gorman et al (2002) reported a study of immunocontraception in cats, using a vaccine to prevent fertilization of the ovum. However, although high antibody titres were present in individual cats, there was no reduction in fecundity or suppression of oestrus. Seamark (2001) reported progress in the development of control of pest species through immunocontraception using a vaccine delivered by a recombinant virus. This research centred on the rabbit (*Oryctolagus cuniculus*), the fox (*Vulpes vulpes*) and the house mouse (*Mus musculus*). Hardy et al (2006) reported that high levels of infertility could be induced in mice and rabbits infected with viruses expressing reproductive antigens. However, Cooper and Herbert (2001) suggested that the use of immunocontraception is incompatible with the function of protection against disease, and that selection for failure to respond to immunocontraceptives would occur, changing the immune function of individuals in general. The authors expressed doubt that immunocontraception would be effective and that, if it were used on a broadscale, it would would result in undesirable ecological consequences (Cooper and Herbert 2001).

In 2007, McLeod et al concluded that there are technological and social barriers to the development of virally vectored immunocontraception as a control method for vertebrate pest species. Without a naturally transmitted vector, delivery of contraception would have to rely on baiting. The authors suggest that lethal control should be favoured over immunocontraception when delivery of fertility control is dependent upon baits.

6.5 Trap-neuter-return

Increasingly trap-neuter-return or release (TNR) programs are being adopted in the United States to manage peri-urban populations of stray and feral cats. Advocates of such programs (Scott et al 2002; Levy et al 2003; Levy et al 2004) are adamant that TNR, combined with an adoption component, can be successful at reducing cat populations if sufficient resources and time are allowed. However, such results have rarely been demonstrated, irrespective of resources (Foley et al 2005). Furthermore, modeling of such programs reports that TNR will result in a similar reduction to euthanasia, and a half combination of both, in closed populations (Schmidt et al 2009), but euthanasia is far more effective in open cat populations (Andersen et al 2004; Schmidt et al 2009).

The TNR practise however is not without its detractors. Winter (2004) argues that TNR should not be practiced where cat management is occurring to help protect threatened species, particularly birds, and that a trap and removal program is the only option. Barrows (2004) and Jessup (2004) are far more damning of the technique and question the ethical behaviour of veterinarians that trap-neuter-‘re-abandon’ stray and feral cats, which go on to depredate wildlife. Jessup (2004) suggests that the practice potentially violates the *Endangered Species Act*, and is not supported by groups such as People for the Ethical Treatment of Animals (PETA).

The one thing that all researchers in the area of TNR agree on is that the technique is unlikely to be effective in widely dispersed, open cat populations, as occurs throughout much of the Australian mainland.

6.6 Disease

Disease introduced into a wild population has been investigated as a method of control or eradication of pest species. Howell (1984) discussed the complex interactions between the physical and biological aspects of a biological control agent and the host species, including prevailing environmental conditions. The disease feline panleucopaenia (FPL) was introduced in the 1970s as a primary control mechanism for cats on Marion Island in the Indian Ocean. Over a five year period, the cat population reduced by 29 per cent per annum on average (van Rensberg et al 1987). After five years, however, the disease no longer spread effectively as cat density decreased and the age structure of the population changed (van Rensberg et al 1987); alternative eradication methods were then introduced to remove the remaining cats from the island. Courchamp and Sugihara (1999) provided mathematical models to describe the impacts on both cats and their prey of introducing two viruses, feline leukaemia virus (FLV) and feline immunodeficiency virus (FIV) into a feral cat population. The authors reported that eradication with FLV was possible if there was low natural immunity in the cat population, while FIV would not eradicate, but could control, a population of feral cats. Courchamp et al (2000) investigated the spread of FIV in an urban population of stray cats and reported that socially dominant males were most likely to be infected by the virus, which is spread by bites. Because of their social ranking, the at risk individuals had a high probability of retransmitting the virus. Although disease has been used successfully as a control mechanism for cats on islands, it is not under consideration for cats on mainland Australia. Low cat densities in most habitats suggest that there would be a low transmission rate amongst feral populations of any feline specific diseases.

6.7 Baiting

Scavenging behaviour is central to the acceptance of bait by any target species, and dietary studies do indicate that cats will scavenge, albeit not frequently and often only if other sources of food — especially live prey — are not available. The acceptance of commercial cat food and food scraps by domestic cats is a form of scavenging (Fitzgerald and Turner 2000). Studies of cats exploiting highly modified habitats (eg refuse sites, farmlands) suggest that scavenged items make up a high proportion of the diet (Denny 2005). Several studies have described cats in urban and semi rural habitats consistently exploiting a variety of food resources, such as rubbish bins and refuse sites (Errington 1936; McMurry and Sperry 1941; Jackson 1951; Calhoon and Haspel 1989; Mirmovitch 1995; Hutchings 2003; Dickman 2009), village fish dumps (Izawa et al 1982; Izawa 1983), farm foods (Laundré 1977; Macdonald and Apps 1978; Panaman 1981; Kerby and Macdonald 1994; Genovesi et al 1995; Hale 2003), as well as food scraps or commercial cat food deliberately supplied by humans (Dards 1978; Liberg 1984a; Natoli 1985; Natoli and de Vito 1988, 1991; Jogahara et al 2003).

Scavenged items, as well as human food scraps, have also been identified in the scats of cats considered to be mainly dependent upon live prey. Jones and Coman (1981) found both human food scraps and carrion in the diet of cats from three areas in New South Wales and Victoria. Catling (1988) similarly found carrion in the diet of cats from semi-arid New South Wales, Paltridge et al (1997) found carrion in the stomachs of cats from central Australia during dry winters when prey was scarce, and in studies in central New South Wales, Molsher (1999) and Molsher et al (1999) found cattle and pig carcasses to be scavenged occasionally by cats. However, the contribution of scavenged items to the diet of cats in relatively unmodified habitats is usually low. Consequently, many attractants have been tested to increase the probability of cats investigating and consuming baits.

6.7.1 Lures

Visual, olfactory and auditory lures have been tested with varying degrees of success to attract cats to traps or baits. Visual lures include ribbons, blinking lights, feathers, tinsel, imitation mice/rats and imitation reptiles. Olfactory lures include food-based odours, social odours and plant material, while auditory lures comprise cat, bird or rabbit vocalisation devices. A study of cat attractants conducted in the Northern Territory by Edwards (1997) concluded that the most successful lures were sun-rendered prawns and anal gland preparations from male and female cats. In 1994, Clapperton et al tested a number of cat attractants, using both pen and field trials, and found both catnip and matatabi to be successful candidates for cat lures. In contrast, Clapperton et al (1992) tested catnip in a field situation on Matakohe Island and found that it did not increase bait take. The authors concluded that this result might reflect the fact that there is a genetic basis to the response to catnip, with cats in some populations showing much stronger responses than in others. Risbey et al (1997) reported that neither a visual lure (tape on a stake) nor an olfactory lure (Canine Call, a commercial product) significantly altered bait uptake, while Wark (2004) arrived at similar conclusions using auditory and visual lures. Algar et al (2002) tested three visual and two auditory lures and reported that bait uptake could be enhanced by the use of visual lures, while Moseby et al (1994) recommended the use of auditory over olfactory lures.

6.7.2 Baits

Risbey et al (1997) tested four baiting methods for feral cats: dried meat baits, baited rabbit carcasses, a fishmeal-based bait and bait coated in the flavour enhancer Digest. The authors reported that none of these four baiting methods was successful. Short et al (1997) used the carcasses of laboratory mice impregnated with 1080 and reported a 74 per cent reduction in spotlight counts after baiting. The authors suggested, however, that when rabbit densities were high, the likelihood of bait uptake by cats was reduced. Algar et al (2002) tested the acceptability of three bait types: a kangaroo and chicken fat chipolata-sized sausage, a sausage composed entirely of chicken meat, and a day-old cockerel carcass. The authors also tested three visual and two auditory lures and reported that there was a measurable preference for the kangaroo sausage, and bait uptake could be enhanced by the use of visual lures (Algar et al 2002). The results of this study suggested that bait uptake appeared to be related to a number of environmental factors, and was likely to be highly variable in the short term.

Burrows et al (2003) reported on broad scale baiting from aircraft in the Gibson Desert in Western Australia using 40-60 g dried meat baits impregnated with the poison 1080. Although successful in virtually eradicating both dingoes and foxes, the abundance of cats increased after the initial bait drops, indicating that cats were not attracted to the dried meat baits and could in fact have benefited from the baits, as the baits had removed the two species of canids.

In a trial of bait uptake by cats on French Island, Victoria, Johnston et al (2007) used Rhodamine B as a marker to discover whether cats were taking moist meat baits. Trapping and analysis of the presence of Rhodamine B in the cats' whiskers showed that half of the study's 71 cats had consumed at least one bait.

The most successful bait used to date appears to be the chipolata-sized sausage discussed above. Developed by the Department of Conservation and Land Management (now the Department of Environment and Conservation) in Western Australia, this bait appears to satisfy all criteria for a successful bait medium. The bait consists of a chipolata-sized sausage containing 70 per cent kangaroo mince, 20 per cent chicken fat and some unspecified flavour enhancers (Patent No.AU13682/01) (Algar et al 2002). The sausage bait weighs 20 g, is injected with 1080 at the rate of 3.0 mg/bait and is treated with an ant deterrent. The bait has been successfully deployed from aircraft in the Gibson Desert in Western Australia at rates of 10 and 22 km^{-2} (Algar and Burrows 2004). Although this sausage bait injected with 1080 can be deployed freely in the western regions of Australia, above ground baiting with 1080 is not permitted in the continent's south east.

Algar et al (2007) conducted bait uptake trials for feral cats over a number of seasons at Peron Peninsula in Western Australia, and found again that the most successful bait was the ERADICAT® sausage developed in the west. The authors reported that bait uptake by cats varied both temporally and spatially, but became more frequent and consistent in late summer/early autumn, with a significant relationship being found between bait uptake and rabbit abundance — the greater the abundance of rabbits, the less frequent and consistent the bait uptake. Algar et al (2007) also reported significant bait uptake by non target species, in particular corvids and varanids, and noted that this non target uptake reduced the bait availability to feral cats.

In contrast, Algar and Brazell (2008) reduced the non target uptake of ERADICAT® baits to ≈ one per cent by employing a bait-suspension device in a cat control program on Christmas Island in the Indian Ocean. The device proved successful for delivering baits to male and female cats of varying ages, and for excluding non target species from the baits.

6.7.3 Toxins

Toxic baits need to be target-specific with a relatively humane mode of action; they need to constitute an acceptable environmental risk, and be efficacious in the field (Fisher et al 2005). There is only one bait (sodium monofluoroacetate, or 1080) that is registered presently for use in cat control programs in Australia, although cyanide may be used under licence for research purposes only.

6.7.3.1 Sodium monofluoroacetate (1080)

Sodium monofluoroacetate (1080) is an odourless and tasteless white compound first used in Australia as a rabbit poison. 1080 is a highly effective but Restricted Schedule 7 poison, and is used extensively in Australia for the control of vertebrate pests such as wild dogs, foxes, pigs, rabbits, possums and two species of wallaby (Belcher 1998). The compound degrades rapidly in the field and the dosage, bait medium, and method of delivery can be varied to target specific pest species.

The LD_{50} oral dose for cats is 0.4 mg/kg; Eason et al (1992) reported that 100 per cent mortality is achieved with a dose rate of >0.4 mg/kg. 1080 is readily absorbed from the gastrointestinal tract, the respiratory tract, abraded skin and mucous membranes. It is not absorbed through intact skin and is not known to accumulate in any one tissue (Peterson and Talcott 2006). Biochemically, 1080 poison disrupts the Krebs cycle, and clinical signs of toxicosis include vomiting, salivation, urination, defecation and hyperesthesia, with convulsions often occurring between periods of frenzied and normal behaviour, followed by coma; death occurs from two to 12 hours after the appearance of clinical signs, dependent upon species (Peterson and Talcott 2006).

Sodium monofluoroacetate is not species-specific. In a review of the literature on the use of 1080, Denny (2001) calculated that from experiments in both enclosures and in the field, at least 61 native vertebrate species were known to have taken 1080 poison baits, and 24 of these native species were known to have been killed by 1080 baits. Included in the list are two species (Tiger Quoll and Long-nosed Potoroo) that are listed as Vulnerable in the *Environment Protection and Biodiversity Conservation Act 1999*. In contrast to this, Körtner and Watson (2005), Claridge and Mills (2007) and Körtner (2007) have reported that wild quolls rarely, if ever, die during 1080 aerial baiting campaigns, and that the practice is likely to benefit quolls due to the reduced competition from wild dogs, foxes and cats (Körtner and Watson 2005). In one study conducted in southern New South Wales, Claridge and Mills (2007) reported that none of 16 radio-collared quolls and two of three radio-collared feral cats died during an aerial baiting campaign.

Denny (2001) also noted that nine invertebrate orders are prone to 1080 poisoning, and poisoned invertebrates may provide a means of secondary poisoning for insectivores. However, Eason et al (2007) assessed such risks and found residues in insects to be rapidly eliminated, and the risk of transfer of 1080 to insectivores to be short lived.

Because of concerns over poisoning of non target species, animal welfare, environmental persistence, and the effectiveness of 1080 in biodiversity conservation programs, the Australian Pesticides and Veterinary Medicines Authority reviewed the use of 1080 as a toxin for vertebrate pest species. They concluded that with certain improvements, the APVMA could be satisfied that the continued use of *sodium fluoroacetate* is safe for the environment. However, Sherley (2007) reported that 1080 does not meet the criteria for humane poisoning and suggested that research into alternative control methods or the improvement of the humaneness of 1080 baits should be a priority. Research on the effects of adding anxiolytic and, especially, analgesic drugs to 1080 baits is a current suggestion that shows much promise (Marks et al 2000, 2009), although there may be complications with the field use of such compounds. Other research into new toxicants is discussed below.

6.7.3.2 Para-aminopropiophenone (PAPP)

In 1983, when it appeared that 1080 would be deregistered in the United States of America, Savarie et al initiated acute oral toxicity tests with coyotes and 14 other mammal and bird species, including cats, using para-aminopropiophenone (PAPP). These tests showed that species within the *Canidae* and *Felidae* families were highly susceptible to the effects of orally administered PAPP. The effect of PAPP is to induce methaemoglobinaemia, whereby the haemoglobin in the blood is oxidised, with symptoms progressing from cyanosis through lethargy to death. The authors reported an LD_{50} for cats with a weight range of 1.8 to 4.1 kg of 5.6 mg/kg (range 3.5–8.9 mg/kg) (Savarie et al 1983). After ingesting a lethal dose of PAPP, cats become lethargic within 16-204 minutes and die within 37-246 minutes (Murphy et al 2007). PAPP is currently being examined in Australia for use on feral cats (Algar and Burrows 2004), red foxes and wild dogs (Marks et al 2004; Fleming et al 2006).

Murphy et al (2005) suggested that mammalian carnivores appear to be more susceptible to PAPP than either rodents or birds; however, certain species of birds and reptiles may be vulnerable. The authors reported investigations into the delivery of PAPP via a pellet implanted in meat baits. For cat pellets, the dosage of PAPP was 100 mg/pellet. At this dosage, it was suggested that 24 native species might eat the pellet and of these, there could be some mortality for 16 species, mostly birds (Murphy et al 2005). The authors also suggested that reptiles might be vulnerable to PAPP as this toxin induces methaemoglobin, as does the compound acetaminophen that is used for the control of brown tree-snakes (*Boiga irregularis*) on Guam (Murphy et al 2005).

In a study of the induction of methaemoglobin in dogs, Bright and Marrs (1983) administered four aminophenones, and reported that orally administered PAPP was the most effective. In a later study, Bright et al (1987) reported sex differences in response to PAPP by beagle dogs, with females producing more methaemoglobin for a given dose than males.

In an investigation into the oral toxicity of PAPP to ferrets, Fisher and O'Connor (2007) recorded the mean time to death for ferrets, receiving dosages of 14–25 mg/kg by gavage, as ranging from 103 $\pm$ 28.2 to 108 $\pm$ 41.9 minutes. In a study of the acute oral toxicity of PAPP in the hydrochloride form to stoats, Fisher et al (2005) reported an LD_{50} of 9.3 mg/kg, with rapid onset of symptoms and death occurring generally within an hour. Marks et al (2004) reported that PAPP produced a mean time to death in foxes 7.7 times faster than 1080, with the onset of symptoms occurring 15 times faster, with much less activity occurring prior to death, and with the absence of the convulsions, paddling and spasms associated with 1080 poisoning. Fisher et al (2008) reported the results of pen trials of gavaged PAPP on Common Brushtail Possums (*Trichosurus vulpecula*), Tammar Wallabies (*Macropus eugenii*) and Mallards (*Anas platyrhynchos*). The authors suggested that the hazard to the possums and wallabies from predator control operations using PAPP baits would be low, but noted that ducks were susceptible, with an estimated LD_{50} of 38 mg kg^{-1}. Fisher et al (2008) provided a table of the reported oral lethal dose values of PAPP for a number of species. This table has been modified for Australian and New Zealand conditions, and Table 5 presents the values for introduced and native species from Australia and New Zealand, as well as for exotic species of the same order as native Australian and New Zealand species (Table 5).

Table 5. Oral toxicity of para-aminopropiophenone to some mammal and bird species

Species	LD_{50} (mg kg^{-1})	Reference
Dog (*Canis familiaris*)	26-43	Murphy *et al* 2007
Kit fox (*Vulpes velox*)	14.1	Savarie *et al* 1983
Cat (*Felis catus*)	5.6	Savarie *et al* 1983
	20-34	Murphy *et al* 2007
Stoat (*Mustela erminea*)	9.3	Fisher *et al* 2005
	37-95	Murphy *et al* 2007
Ferret (*Mustela furo*)	15.5	Fisher & O'Connor 2007
Mouse (*Mus musculus*)	233	Savarie *et al* 1983
Rat (*Rattus norvegicus*)	177	Savarie *et al* 1983
Coturnix quail (*Coturnix coturnix*)	233	Savarie *et al* 1983
Starling (*Sturnus vulgaris*)	>316	Savarie *et al* 1983
Red-winged Blackbird (*Agelaius phoeniceus*)	178	Savarie *et al* 1983
Black-billed Magpie (*Pica hudsonia*)	178	Savarie *et al* 1983
Common Crow (*Corvus brachyrhynchos*)	178	Savarie *et al* 1983
Mallard (*Anas platyrhyncos*)	38	Fisher *et al* 2008
Brushtail Possum (*Trichosurus vulpecula*)	>500	Fisher *et al* 2008
Tammar (Dama) Wallaby (*Macropus eugenii*)	89	Fisher *et al* 2008

Absent from the list of susceptible species are reptiles and amphibians, as well as many birds and marsupials, suggesting that further research is needed to ensure pest predator control using PAPP has minimal impact on non target species. To overcome some potential non target hazards Marks et al (2006) have proposed to deliver PAPP using a 4.7 mm Hard Shell Delivery Vehicle (hard coated pill), which feral cats readily consume but many non target species eat around or spit out. This is discussed further below.

6.7.3.3 Cyanide (HCN)

For most mammalian species the minimum toxic dose of hydrogen cyanide (prussic acid; HCN) is 2 mg/kg. The action of cyanide is to disrupt the ability of cells to use oxygen in oxidative phosphorylation, the net result being histotoxic tissue hypoxia, with the blockage of cellular respiration and respiratory arrest occurring within a few minutes (Peterson and Talcott 2006). Clinical signs include vomiting, hypernea, tachycardia and cardiac arhythmias, seizures, coma and apnea (Peterson and Talcott 2006).

Cyanide bait is commonly used in New Zealand to control possums (*Trichosurus vulpecula*). The use of cyanide for pest control in Australia is permitted only for research. In New Zealand, an encapsulated cyanide pellet (Feratox®) containing 96 mg of potassium cyanide is used extensively for possum control, and provides a cost effective alternative to trapping in areas with low to medium possum densities (Thomas et al 2003). The application of Feratox® requires licensed personnel, safety equipment, protective clothing and a 'Cyanide First Aid Kit'.

Campbell and Chapman (2000) and Peterson and Tallcott (2006) reported a number of further agents that are toxic to cats, including ethylene glycol and acetaminophen, but none of these satisfy one or more of the criteria of humaneness, minimal environmental impact or efficacy in the field. In a review of badger toxins, DEFRA (2005) concluded that all poisons carry significant risks of poisoning non target species, although the design of baits could improve their specificity and risks to non target species.

Whilst cyanide may offer animal welfare advantages over 1080, it is also not species specific, and its field delivery to feral cats would be problematic.

6.7.4 Toxin delivery

The specificity of baits may be increased through modified delivery methods. A number of methods have been trialed to present toxins to cats and prevent bait uptake by non target species. Marks et al (2006) tested coated pellets that could be used to carry toxins in baits, and reported that cats would ingest larger pellets than would native rats (*Rattus fuscipes*, *Rattus lutreolus*), although both Northern Quolls (*Dasyurus hallucatus*) and Eastern Barred Bandicoots (*Perameles gunnii*) could crush the pellets. The authors suggested that the target specificity of cat baiting could be increased if toxins were delivered in 4.7 mm-diameter pellets, with the pellets ensuring a more reliable lethal dose and a greater persistence of the toxin (Marks et al 2006).

Strategies for limiting exposure of non target species include: modifying bait characteristics such as size, colour and material; timing baiting campaigns to avoid periods when food sources for most non targets are scarce; pre-feeding to increase bait uptake by target species; removal of carcasses of poisoned animals to reduce the likelihood of secondary poisoning of non targets; and bait placement to discourage discovery or uptake of baits by non targets (Sherley 2007). In the south eastern states of Australia, 1080 can be delivered only through baits buried ~ten cm deep in most areas because of non target impact concerns. Although this is a successful toxin delivery method for canids, cats are likely to consume only surface laid baits.

Alternative delivery routes for some toxins are through broken skin or by placement on fur, to be licked off during subsequent grooming. Ongoing studies in New Zealand are investigating the utility of bait delivery devices that include sensors that discriminate between species based on morphometrics, such as weight, head/body length, height and leg length. The enclosed devices can contain traps, baits or include a system for squirting toxin onto the targeted animal. The research is continuing at present (Paul Jansen, pers comm). As no currently available toxins are cat specific, and the likelihood of baiting programs impacting on non target species is relatively high, the development of methods of delivery that are cat specific may prove to be the most feasible way of conducting broad scale cat control programs using toxins.

6.8 Targeting subgroups

The management strategies discussed above all target feral cats in rural and remote areas. However, because of the unique status of cats in Australia (pet and pest) management strategies need to address not only feral cats, but also stray and domestic animals. Most jurisdictions have implemented legislation related to the identification, desexing and confinement of domestic cats. The control of stray cats exploiting highly modified habitats, such as tip sites, has been largely ignored.

Genetic analyses combined with observational data suggest that the tip habitat provides a source from which dispersing cats can move into new habitats, and a sink into which cats move for feeding or breeding opportunities (Newsome 1995; Denny et al 2002; Denny 2005).

In a study of cats exploiting tip sites in the Australian Capital Territory, Wilson et al (1994) suggested that the apparently high turnover of cats at one tip site could be explained partly by the dispersal of cats from the tip area. The stable food source at tip sites provides supplementary food which may be exploited by visiting cats during times of climatic stress when prey abundance in the surrounding environment is low, thus ensuring a greater survival rate than would otherwise be possible. Cat colonies exploiting such habitat hotspots occur in relatively high densities, display high breeding potential and are relatively easily trapped (Denny 2005). The removal of cat colonies from such sites would considerably reduce the unowned cat population of peri-urban Australia and potentially slow the recruitment to feral populations.

In a study of population reduction on predator home range size and spatial overlap, Frey and Conover (2007) reported that the home range sizes of mammalian predators were not constrained by population density, and that predator control may provide only temporary reductions in predator density. The authors suggested that more permanent reduction in predator density would be achieved by modifying the habitat by reducing food and shelter resources (Frey and Conover 2007). Habitat modification would be most feasible in accessible and artificial habitats.

6.9 Discussion

The eradication of cats is sometimes considered to be a desirable goal for the protection and management of native wildlife, but will usually be impossible to achieve except in small, isolated areas such as islands or fenced mainland enclosures where reinvasion cannot occur. Even in such situations, a combination of methods is required to achieve effective eradication, with increasing effort needed to capture or kill the last remaining individuals in the population. In most situations the only realistic and cost effective option for cat management is to reduce cat activity or abundance to levels below an acceptable damage threshold. Introductions of diseases and virally vectored immunocontraceptive agents have been suggested as possible means of broad scale population control, but both methods would likely face significant community opposition. In addition, many of the disease organisms posited for introduction to cat populations are already prevalent in the wild and so would have little additional effect on cat numbers; and technical problems and the need to obtain approval from regulatory bodies for the introduction of genetically engineered organisms suggest that immunocontraceptive solutions also are a long way off.

In the absence of broad scale solutions to cat management, shooting, trapping and baiting are sometimes carried out in small areas to protect threatened species (eg Pettigrew 1993). Shooting is effective and, with the operation of trained personnel, is a humane means of culling cats, but it remains highly labour intensive and costly. The trap response of cats largely reflects the relative abundance of cats, and perhaps also the proximity of cats to humans, their familiarity with carrion or other scavenged foods, and their degree of hunger. In areas of relatively high density, trap rates are high (Denny et al 2002; Short et al 2002; Hale 2003; Denny 2005). Cage trapping of cats is most productive near sites of human habitation or influence, such as townships, rubbish tips, rural homesteads and sheds. The trap rates for cats away from human habitation are generally low, with little difference in the capture rate between cage traps and leghold traps. Trap response also varies in response to food availability, with a lower trap response expected when live prey is abundant, and higher capture rates at times of food shortage during late summer, autumn and early winter (Jones and Coman 1982; Newsome 1991; Molsher 1999; Short et al 2002). Even at the right times and in high density situations, however, trapping remains a time consuming and costly method of management for cats. It is probably best used as a means of capturing animals for intensive studies involving tracking or where tissue samples, disease or parasite screening are needed for population studies.

Baiting, using a suitable toxin and delivery system, remains the most attractive and cost effective possibility for broad scale cat management, but this option is also problematic with the current state of knowledge. In a comprehensive review of bait uptake in feral cats in Western Australia, Algar et al (2003) suggested that the abundance of prey species was critical to bait uptake by cats. Results of the Western Australian studies indicate that bait uptake is most successful when prey species abundance is low ('baiting-window'), and is unlikely to be effective outside this period (Algar et al 2003). These authors also found that, at the time of study, on-track baiting regimes with bait placement of 100 m intervals provided a contact rate of 62 per cent (Algar et al 2003).

Any medium for delivering toxins to target pest species must have operational utility, including a capacity to carry a toxin; it must be relatively simple and inexpensive to manufacture, and be easily and safely handled and transported (DEFRA 2005). Bait mediums also should be based on the feeding ecology and taste preferences of the target species. Prior to the deployment of baits, it is essential that sufficient testing is carried out to ensure that bait delivery for the target species is effective and risks for non target species are minimised. It is important also to take a broad strategic view of any baiting program so that the indirect or second order effects of removing or reducing the numbers of the target species can be predicted. Such predictions require some ecological understanding of the system in which the target species operates (eg Hickling et al 1999; Innes and Barker 1999). In particular, for predators such as cats, it is important to know whether removal is likely to 'release' smaller (meso) predators or prey species such as rabbits or introduced rodents. The consequences of unintended, and unexpected, ecological releases can be detrimental to other species in the system (Dickman 2007, 2009). Ecological releases may have dramatic effects on the broader environment. Bergstrom et al (2009a) suggested that feral cats on sub-Antarctic Macquarie Island were exerting top-down control on the feral rabbit population, and that the eradication of the cats led to a substantial increase in rabbit numbers. However, Dowding et al (2009) proposed that the primary reason for the increased rabbit abundance coincided with a reduction in the application of the rabbit control agent, Myxoma virus. The issue continues to be debated (Bergstrom et al 2009b)

Summary

- Most successful cat eradication programs require more than one control method, and are usually accomplished on islands or in protected areas behind exclusion fencing.
- Exclusion fencing, shooting and trapping are not practicable for broad scale control of cats.
- The introduction of diseases and/or immunocontraceptive agents to cat populations would be very challenging and of questionable efficacy for cat management.
- Ground set baits offer some potential for broadscale control, in certain habitats and at particular times.
- Cats are unlikely to discover and consume buried baits.
- The development of cat specific delivery methods is required to increase bait uptake by cats and decrease bait uptake by non target native species.
- Control programs for introduced rodents and rabbits should be integrated into cat control programs to avoid population explosions after cat removal.
- Control programs should also consider native species that may suffer adverse indirect effects of cat removal or management.
- Control programs should incorporate the eradication of colonies of stray cats exploiting highly modified habitats within or close to feral cat control sites.

7. General discussion

Although *Felis catus*, a feral predator, was first established on the Australian mainland with the arrival of Europeans in the last decades of the eighteenth century (Abbott 2002), it was not until 1992 that predation by feral cats was embedded in federal legislation as a Key Threatening Process in the Australian environment. During the interim, the distribution of cats increased dramatically, with records now being made regularly throughout the Australian landscape, including such diverse habitats as sandy and stony deserts, semi-arid and temperate agricultural lands, open and closed forests, woodlands, shrublands, grasslands and urban and peri-urban areas. Despite their arid origins in the near east/north African region, free-living cats also occur widely in the Australian snow country (Watson 2006).

The late recognition of predation by cats in Australia as a threatening process meant that for almost two centuries cats freely invaded almost all parts of the continent, with their dispersal assisted frequently by human agency. Cats were actively encouraged as pest control agents for rabbits, rats and mice (and to some degree still are) and consequently the distribution and abundance of cats spread from a number of introduction sites around the Australian coast. Since the European settlement of Australia, cats have also been valued as companion animals, with the national pet cat population in 1996/98 estimated at 2.65 million (Turner and Bateson 2000).

The dichotomy of the cat as pet/pest control agent versus feral pest has provided challenges for land managers attempting to control or eradicate feral cats. The implementation of control methods such as the spread of disease, broad scale dissemination of toxic baits, viral vectored immunocontraception or even trapping and shooting programs have all been inhibited not only by time, labour and economic costs, but also by the weight of community expectations and the difficulties associated with targeting one subgroup of cats (ferals) while avoiding any impact on another (owned domestics).

Over the past few decades, with increased public education on the problem of predation by cats on native species, the federal government, most state governments, and many local government bodies have introduced legislation requiring or encouraging stricter control of pet cats. Such legislation most usually requires the neutering, marking and confinement of pet cats, thus requiring greater responsibility by owners for the protection of their companion animals (eg Department of Local Government 1994; DNRE 1998). There is considerable community support for such initiatives (Grayson et al 2002; Lilith et al 2006). The control of owned, domestic cats is an important aspect for the control of all cats on the Australian mainland.

Another subgroup of cats requiring urgent attention is the colony forming subgroup of cats that exploit resource rich, manmade habitats in rural and suburban fringe areas. These cats possibly constitute the largest subgroup of cats in Australia. They not only exploit manmade habitats, but are able to move out into surrounding habitats to exploit native species. As they live in groups in relatively small, defined habitats, ongoing removal programs would significantly reduce their abundance, and hence remove an important and ongoing source of cat reinvasion into the Australian landscape.

While research continues into the feasibility of successful broad scale cat control programs on mainland Australia, several factors currently inhibit the implementation and/or success of such programs. These factors include:

- The distribution of cats encompasses most habitats across the continent.
- The relatively low reported densities of feral cats throughout much of their range.
- The excessively high time and labour costs of hunting, trapping and shooting cats.
- The absence of a registered felid specific toxin.
- The restrictions placed on available toxins such as 1080 and strychnine because of adverse environmental impacts.
- The relatively low level of bait uptake by cats, except during periods of low prey availability.

The only successful cat eradication programs in Australia have been conducted on islands or within areas surrounded by predator proof fencing on the mainland. Current research programs include investigations into:

- Developing more species specific toxins that have less environmental and non target impacts than the toxins currently approved for use in Australia
- Baits and/or lures that are consistently attractive to cats
- Delivery systems that are more species specific than baits injected with toxins
- Bait densities that are sufficient to control cats and have minimal environmental impacts
- Population dynamics of cats in forested areas
- Impacts of cats in specific areas, such as the east coast of Tasmania.

Cat control through broad scale baiting is likely to be only temporarily successful unless conducted in perpetuity, as domestic and stray cat populations provide ongoing sources for the rescue or re-establishment of feral cat populations. The dependence of cats in Australia on introduced prey species such as rabbits, house mice and rats suggests that control of these prey species should be considered a necessary adjunct in integrated cat control programs.

Parkes (1993) argued that pest management that is not inclusive of pests, resources, people, and their interactions, usually fails. The author considered three questions in relation to pest control:

- How the biology of pests determines the nature of their impacts
- How management solutions require strategic organization before they are implemented
- How the biological and strategic factors limit the kind of policy adopted for the effective management of the pest species.

These three aspects of feral pest control are particularly pertinent to the control of feral cats on the Australian mainland and should provide the basis for any proposed cat control programs.

8. Recommendations

One of the key aims of the *Threat Abatement Plan for Predation by Feral Cats* (2008) is to 'establish a national framework to guide and coordinate Australia's response to the impacts of feral cats on biodiversity.' (DEWHA 2008). Major considerations for the implementation of control programs for feral cats on mainland Australia include: the status of the cat as both a pet and a pest species, the cryptic nature of the cat, the flexibility of its social structure, the cat's preference for hunting live prey, and the dependence of the cat on introduced prey species.

1. There are few reliable data quantifying the impact of cats on threatened and endangered native animals at the species level, although cats have been implicated in reducing some species populations and shifting species status. However, predation by cats on numerous native species has been well documented and the promotion of the recovery of endangered or vulnerable native species and communities requires alternative approaches to those required to prevent further species becoming threatened through predation by feral cats.

2. Central to the management of feral cats in Australia is the control of the owned and stray cat populations that constitute a source of cats capable of moving away from the influence of humans into relatively unmodified habitats. The distribution of cats throughout the continent, the flexibility of their social structures, and the likelihood of interactions and gene flow between owned, stray and feral cats suggest that the control and reduction of both owned and stray populations should ultimately reduce populations of feral cats.

3. Feral cats currently cannot be controlled effectively in large remote areas, so management should aim to prioritise sites, areas and regions that would be most likely to benefit from intensive cat control. Such sites may include areas containing important populations of native species, threatened species, ecological communities or processes that are known or likely to be at risk of cat predation. Determination of priority areas and regions should use risk-assessment protocols (eg Dickman 1996) and adaptive management strategies at the site level (eg Hess et al 2009) to maximise the cost effectiveness of control measures.

4. Management of remote populations of feral cats will continue to be very expensive in the absence of biological control, immunocontraceptive or broadscale baiting programs. As baiting is the only foreseeable control method over the next several years, at least, continued effort should be made to develop felid-specific toxins that kill cats humanely but have few or no non target and environmental effects. As part of this research, cat lures, bait delivery systems, bait density, distribution and setting should also be investigated.

5. Without reliable indices of activity, density or relative abundance of cats in various habitats, it is difficult to assess the level of input of time, labour and money required to reduce the feral cat population on the mainland. Future research should address field based and analytical methodologies for improving indices of cat density rather than cat activity.

6. As cat control becomes more target specific, measurable and effective, it will be important to measure the responses of not just the target species or systems that are the intended beneficiaries of cat management, but also the responses of other species with which cats may interact. Populations of rabbits and introduced rodents will be the most obvious targets for monitoring in most situations.

7. The effectiveness of cat control programs will be best measured by the responses of native species populations to cat removal over the long term, as short term responses may reflect the 'boom and bust' nature of resource pulsing over much of the Australian landscape.

8. Ongoing public education and implementation of companion animal legislation requirements, such as neutering, micro-chipping and containment of pet cats, should be encouraged nationally to reduce the breeding and predation potential of the owned cat population. Programs for the control in perpetuity of cat colonies exploiting resource rich, artificial habitats, such as rubbish tips, should be a management requirement. Cat eradication should be conducted regularly at such sites at six-12 month intervals.

9. Community consultation efforts should be directed at landowners in rural areas to stress the desirability of eradicating stray or feral cats from their properties.

10. The survival of many highly threatened species is dependent upon the re-introduction of captive-bred specimens into suitable habitat. Protection of these species is best maintained by release on cat free islands, or into predator proof reserves.

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On-line Resources

Bureau of Rural Sciences – National Feral Animal Control Program website:
www.brs.gov.au/feral

Department of Environment, Water, Heritage and the Arts – Invasive animals website:
www.environment.gov.au/biodiversity/invasive/index.html

Invasive Animals Cooperative Research Centre website
www.invasiveanimals.com

Feral.org – Invasive animals database
www.feral.org.au Online Resources

Appendix 1

Vulnerability to cat predation of listed species from the East Gippsland region, Victoria

Legend:

EPBC *Environmental Protection and Biodiversity Conservation Act 1999*

E	endangered
V	vulnerable
CD	conservation dependent

FFG *Victorian Flora and Fauna Guarantee Act 1988*

L	listed as threatened
I	ineligible (nominated but rejected)

LTV *Advisory List of Threatened Vertebrate Fauna in Victoria 2007*

(non-statutory)

CE	critically endangered
E	endangered
V	vulnerable
NT	near threatened
DD	data deficient

MAMMALS

Family	Common Name	Scientific Name	EPBA	FFG	LTV	Weight (g)	Score	Habitat	Behaviour	Risk
Burramyidae	Eastern Pygmy Possum	*Cercartetus nanus*	-	I	NT	15-45	3	2	3	High
Dasyuridae	Brush-tailed Phascogale	*Phascogale tapoatafa*	V	L	V	110-310	3	2	3	High
Dasyuridae	Spot-tailed Quoll	*Dasyurus maculatus*	E	L	E	2-7 kg	0	2	1	Low
Dasyuridae	White-footed Dunnart	*Sminthopsis leucopus*	-	L	NT	7-14	3	3	3	High
Emballonuridae	Yellow-bellied Sheathtail Bat	*Saccolaimus flaviventris*	-	L	-	30-60	3	0	2	Low
Macropodidae	Brush-tailed Rock-wallaby	*Petrogale penicillata*	V	L	CR	5-11 kg	0	0	1	Neg
Macropodidae	Eastern Wallaroo	*Macropus robustus robustus*	-	L	E	25-55 kg	0	1	1	Neg
Muridae	Smoky Mouse	*Pseudomys fumeus*	E	L	CR	45-90	3	2	3	High
Peramelidae	Southern Brown Bandicoot	*Isoodon obesulus*	E	I	NT	.4-1.6 kg	1	3	3	High
Potoroidae	Long-footed Potoroo	*Potorous longipes*	E	L	E	1.7-2.1 kg	1	2	3	High
Potoroidae	Long-nosed Potoroo	*Potorous tridactylus*	V	L	E	660-1600	2	2	3	High
Pteropodidae	Grey-headed Flying Fox	*Pteropus poliocephalus*	V	L	V	.46-1.05 kg	2	2	1	Low
Rhinolophidae	Eastern Horseshoe Bat	*Rhinolophus megaphylus*	-	L	V	7-14	3	0	2	Low
Vespertilionidae	Common Bentwing Bat	*Minopteris schreibersii*	CD	L	E	10.5-19.5	3	0	2	Low
BIRDS										
Phasianidae	King Quail	*Coturnix chinensis*	-	L	E	13	3	3	2	High
Phasianidae	Brown Quail	*Coturnix ypsilophora*	-	-	NT	18-20	3	3	2	High
Diomedeidae	Shy Albatross	*Diomedea cauta*	-	L	V	95-1000	0	0	0	Neg
Diomedeidae	Wandering Albatross	*Diomedea exulans*	V	L	E	80-135	0	0	0	Neg
Diomedeidae	Yellow-nosed Albatross	*Thalassarche chlororhynchos*	V	Listed	V	75	0	0	0	Neg
Diomedeidae	Black-browed Albatross	*Thalassarche melanophris*	V	-	E	85	0	0	0	Neg
Procellariidae	Southern Giant-Petrel	*Macronectes giganteus*	E	L	V	85-90	0	0	0	Neg
Oceanitidae	White-faced Storm-Petrel	*Pelagodroma marina*	-	-	NT	20	3	0	0	Neg
Phalacrocoracidae	Black-faced Cormorant	*Phalacrocorax fuscescens*	-	-	NT	65	0	0	0	Neg
Phalacrocoracidae	Pied Cormorant	*Phalacrocorax varius*	-	-	NT	70-75	0	0	0	Neg
Anseranatidae	Magpie Goose	*Anseranas semipalmata*	-	L	V	71-92	0	0	0	Neg
Anatidae	Australasian Shoveler	*Anas rhynchotis*	-	-	V	46-53	0	0	0	Neg
Anatidae	Hardhead	*Aythya australis*	-	-	V	42-49	0	0	0	Neg

Birds cont'd

Family	Common Name	Scientific Name	EPBA	FFG	LTV	Weight (g)	Score	Habitat	Behaviour	Risk
Anatidae	Musk Duck	*Biziura lobata*	-	-	V	47-73	0	0	0	Neg
Anatidae	Blue-billed Duck	*Oxyura australis*	-	L	E	35-44	1	0	0	Neg
Anatidae	Freckled Duck	*Stictonetta naevosa*	-	L	E	48-59	0	0	0	Neg
Rallidae	Lewin's Rail	*Rallus pectoralis*	-	L	V	21-23.5	2	0	2	Low
Ardeidae	Great Egret	*Ardea alba*	-	L	V	90-103	0	0	0	Neg
Ardeidae	Intermediate Egret	*Ardea intermedia*	-	L	CR	56-70	0	1	0	Neg
Ardeidae	Australasian Bittern	*Botaurus poiciloptilus*	-	L	E	72	0	0	0	Neg
Ardeidae	Little Egret	*Egretta garzetta*	-	L	E	55-65	0	0	0	Neg
Ardeidae	Black Bittern	*Ixobrychus flavicollis australis*	-	L	V	66	0	0	0	Neg
Ardeidae	Nankeen Night Heron	*Nycticorax caledonicus*	-	-	NT	59	0	0	0	Neg
Plataleidae	Royal Spoonbill	*Platalea regia*	-	-	V	70-76	0	0	0	Neg
Scolopacidae	Common Sandpiper	*Actitis hypoleucos*	-	-	V	20	3	0	0	Low
Scolopacidae	Sanderling	*Calidris alba*	-	-	NT	20	3	0	0	Neg
Scolopacidae	Red Knot	*Calidris canutus*	-	-	NT	25	2	0	0	Neg
Scolopacidae	Great Knot	*Calidris tenuirostris*	-	L	E	28	2	0	0	Neg
Scolopacidae	Latham's Snipe	*Gallinago hardwickii*	-	-	NT	24-26	2	0	0	Neg
Scolopacidae	Grey-tailed Tattler	*Heteroscelus brevipes*	-	L	CR	26	3	1	0	Low
Scolopacidae	Black-tailed Godwit	*Limosa limosa*	-	L	V	50-56	0	0	0	Neg
Scolopacidae	Eastern Curlew	*Numenius madagascariensis*	-	-	NT	55-61	0	0	0	Neg
Scolopacidae	Whimbrel	*Numenius phaeopus*	-	L	V	38-43	1	0	0	Neg
Scolopacidae	Wood Sandpiper	*Tringa glareola*	-	-	V	20-23	2	0	0	Neg
Rostratulidae	Australian Painted Snipe	*Rostratula benghalensis*	V	L	CR	22-25	3	1	1	Low
Haematopodidae	Sooty Oystercatcher	*Haematopus fuliginosus*	-	-	NT	48	0	0	0	Neg
Charadriidae	Greater Sand Plover	*Charadrius leschenaultii*	-	L	V	20-23	3	1	1	Low
Charadriidae	Lesser Sand Plover	*Charadrius mongolus*	-	L	V	19-20	3	1	1	Low
Charadriidae	Pacific Golden Plover	*Pluvialis fulva*	M	M	NT	24-26	2	2	1	Low
Charadriidae	Grey Plover	*Pluvialis squatarola*	-	-	NT	19-21	3	0	1	Low

Birds cont'd

Family	Common Name	Scientific Name	EPBA	FFG	LTV	Weight (g)	Score	Habitat	Behaviour	Risk
Charadriidae	Hooded Plover	*Thinornis rubricollis*	-	L	V	19-20	3	1	0	Low
Laridae	Whiskered Tern	*Chlidonias hybridus*	-	-	NT	25.5-27	2	0	0	Neg
Laridae	White-winged Black Tern	*Chlidonias leucopterus*	-	-	NT	22-24	2	0	0	Neg
Laridae	Pacific Gull	*Larus pacificus*	-	I	NT	63	0	0	0	Neg
Laridae	Little Tern	*Sterna albifrons*	-	L	V	20-23	3	2	2	High
Laridae	Caspian Tern	*Sterna caspia*	-	L	NT	50-56	0	0	0	Neg
Laridae	Fairy Tern	*Sterna nereis*	-	L	E	22-24	1	0	0	Neg
Laridae	Gull-billed Tern	*Sterna nilotica*	-	L	E	35-43	1	0	0	Neg
Laridae	White-fronted Tern	*Sterna striata*	-	-	NT	39	1	0	0	Neg
Accipitridae	Grey Goshawk	*Accipiter novaehollandiae*	-	L	V	38-55	0	2	0	Neg
Accipitridae	Spotted Harrier	*Circus assimilis*	-	-	NT	50-61	0	0	0	Neg
Accipitridae	White-bellied Sea-Eagle	*Haliaeetus leucogaster*	-	L	V	75-85	0	0	0	Neg
Accipitridae	Square-tailed Kite	*Lophoictinia isura*	-	L	V	50-56	0	0	0	Neg
Columbidae	Diamond Dove	*Geopelia cuneata*	-	L	NT	19-20	3	3	0	High
Cacatuidae	Glossy Black-Cockatoo	*Calyptorhynchus lathami*	E	L	V	48	0	3	0	Neg
Platycercinae	Swift Parrot	*Lathamus discolor*	E	L	E	24	3	2	1	High
Platycercinae	Elegant Parrot	*Neophema elegans*	-	-	V	22	3	3	1	High
Platycercinae	Turquoise Parrot	*Neophema pulchella*	-	L	NT	20	3	3	1	High
Platycercinae	Fairy Prion	*Pachyptila turtur*	V	L	V	24-28	2	0	0	Neg
Platycercinae	Ground Parrot	*Pezoporus wallicus*	-	L	E	30	3	3	3	High
Strigidae	Barking Owl	*Ninox connivens*	-	L	E	40	1	2	1	Low
Strigidae	Powerful Owl	*Ninox strenua*	-	L	V	55	0	2	1	Neg
Tytonidae	Masked Owl	*Tyto novaehollandiae*	-	L	E	37-47	0	2	1	Neg
Tytonidae	Sooty Owl	*Tyto tenebricosa*	-	L	V	40-48	1	2	1	Low
Alcedinidae	Azure Kingfisher	*Alcedo azurea*	-	-	NT	18	3	2	0	Neg
Climacteridae	Brown Treecreeper	*Climacteris picumnus*	-	-	NT	16-18	3	2	1	High
Pardalotidae	Speckled Warbler	*Chthonicola sagittata*	-	L	V	11-12.5	3	3	2	High

Birds cont'd

Family	Common Name	Scientific Name	EPBA	FFG	LTV	Weight (g)	Score	Habitat	Behaviour	Risk
Pardalotidae	Eastern Bristlebird	*Dasyornis brachypterus*	E	L	E	20-22	3	1	2	High
Pardalotidae	Chestnut-rumped Heathwren	*Hylacola pyrrhopygia*	E	L	V	13-14	3	3	2	High
Meliphagidae	Yellow-tufted Honeyeater	*Lichenostomus melanops*	E	L	CR	17-23	3	3	1	High
Meliphagidae	Regent Honeyeater	*Xanthomyza phrygia*	E	L	CR	20-23	3	3	1	High
Cinclosomatidae	Spotted Quail-thrush	*Cinclosoma punctatum*	-	-	NT	25-28	2	3	2	High
Petroicidae	Hooded Robin	*Melanodryas cucullata*	-	L	NT	16	3	3	1	High
Ploceidae	Diamond Firetail	*Stagonopleura guttata*	-	L	V	12	3	3	1	High

REPTILES

Family	Common Name	Scientific Name	EPBC	FFG	LTV	Size	Score	Habitat	Behaviour	Risk
Boidae	Diamond Python	*Morelia spilota spilota*	-	L	E	2 m	0	2	0	Neg
Dermochelydiae	Leathery Turtle	*Dermochelys coriacea*	V	L	CR	3 m	0	0	0	Neg
Scinidae	Alpine Bog Skink	*Pseudemoia cryodroma*	-	L	E	5	3	3	2	High
Scinidae	Alpine Water Skink	*Eulamprus kosciuskoi*	-	L	CR	8	3	2	2	High
Scinidae	Delicate Skink	*Lampropholis delicata*	-	L	DD	4	3	3	2	High
Scinidae	Eastern She-oak Skink	*Cyclodomorphus michaeli*	-	L	NT	13	3	3	2	High
Scinidae	Glossy Grass Skink	*Pseudemoia rawlinsoni*	-	-	NT	5	3	1	2	High
Scinidae	Swamp Skink	*Egernia coventryi*	-	L	V	15	3	1	2	High
Varanidae	Lace Monitor	*Varanus varius*	-	-	V	1.5 m	0	3	1	Low

FROGS

Family	Common Name	Scientific Name	EPBC	FFG	LTV	Size	Score	Habitat	Behaviour	Risk
Hylidae	Alpine Tree Frog	*Litoria verreauxii alpina*	V	L	CR	3	3	3	2	High
Hylidae	Giant Burrowing Frog	*Heleioporus australiacus*	V	L	V	9.5	3	1	1	Low
Hylidae	Green and Golden Bell Frog	*Litoria aurea*	V	L	I	8.5	3	1	1	Low
Hylidae	Growling Grass Frog	*Litoria raniformis*	V	L	E	8	3	1	2	High
Hylidae	Large Brown Tree Frog	*Litoria littlejohni*	V	L	DD	5.5-6	3	3	3	High
Myobachtridae	Southern Barred Frog	*Mixophyes balbus*	V	L	CR	8	3	1	1	Low
Myobachtridae	Southern Toadlet	*Pseudophryne semimarmorata*	-	-	V	3	3	1	3	High

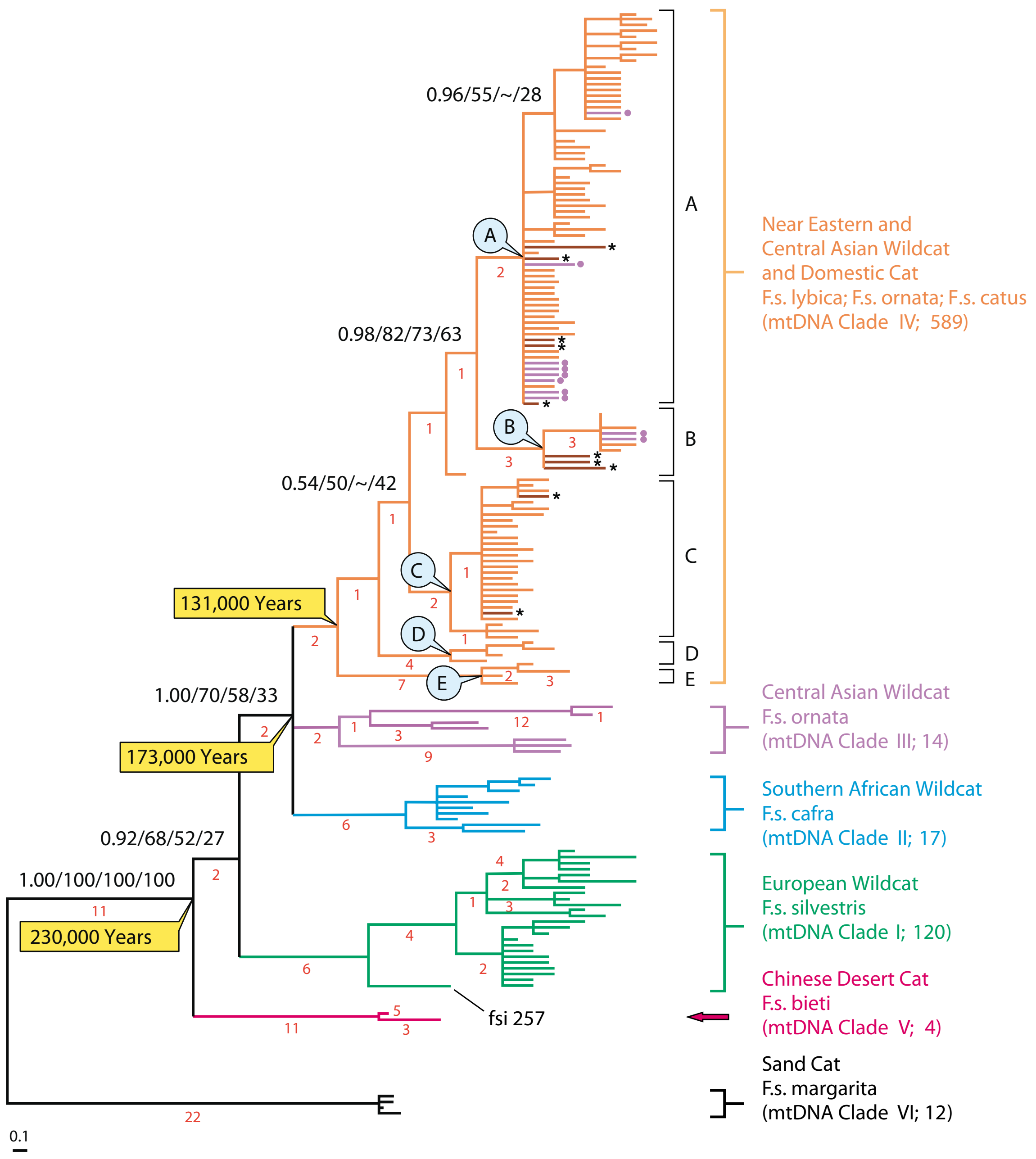

Figure 1. Phylogenetic tree of 176 haplotypes from 742 cats sampled across domestic cat, European wildcat, Near Eastern wildcat, Central Asian wildcat, Southern African wildcat, Chinese desert cat and sand cat (Driscoll et al 2007).

Images


Cat tracks in mud, Elizabeth Denny


Poor tracking/scat collection habitat (arid zone), Elizabeth Denny


Cat scats on litter (arid), Elizabeth Denny


Poor tracking/scat collection habitat (forest), Elizabeth Denny


Good tracking/scat collection habitat (arid zone), Elizabeth Denny


Food resource (tip site), Elizabeth Denny

Images (continued)

Resting/nesting area (arid tip site), Elizabeth Denny

Cat captured in cage trap, Dan Hough

Cat captured in net trap, Dan Hough

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