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Review of methods used to estimate the abundance of feral cats.

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Executive Summary

Project and client
Feral cats are believed to be responsible for the extinction or decline of native marsupials and birds in Australia and are listed as a known or perceived threatening process for 58 native species under the *Environmental Protection and Biodiversity Conservation (EPBC) Act 1999*. Although many agencies and organisations commit significant resources to managing feral cats, there is little reliable information on the impacts of feral cats, or on the benefits of controlling feral cats: this situation is at least partly due to uncertainly about our ability to accurately and precisely estimate the relative or absolute abundance of feral cats, or the kill rates of control operations. The Department of the Environment and Heritage (DEH) commissioned the Arthur Rylah Institute for Environmental Research to review and evaluate the methods used to estimate the abundance of feral cats.

Objectives
The objectives of this study were:
1. Review and evaluate the methods used (in Australia and overseas) to determine the abundance of feral cats.
2. Provide a clear description of the methods used, the advantages and disadvantages of each method, and relative costs.
3. Discuss how animal welfare issues influence the use of these methods.
4. Provide a bibliography of the reference material reviewed.
5. Identify and prioritise the gaps in existing knowledge.
6. Provide recommendations as to areas of future research activity that will address those gaps identified in existing knowledge.

Methods
- The general requirements for estimators of feral cat abundance were identified.
- A recent survey of feral cat control in Australia was used to identify the methods used to monitor feral cats in control operations.
- The national and international published and unpublished literature was reviewed to identify, 1) the various methods used to estimate feral cat abundance, and 2) new methods that could potentially be used to estimate feral cat abundance.

Results
- Two methods have been widely used to estimate feral cat abundance in Australia: track counts and spotlight counts. The costs of the two methods are similar, but data suggest that track counts are a more useful estimator of feral cat abundance than spotlight counts. Neither of these methods has any animal welfare issues.
- Although both cage and leg-hold traps have been widely used to capture feral cats in eradication and sustained control operations, they have not been used to estimate absolute abundance in a trapping grid or web. The major animal welfare issue is the capture of non-target animals in leg-hold traps.
- DNA capture-mark-recapture has been used to estimate the abundance of several carnivore species in North America and may be useful for estimating the abundance of feral cats in some Australian habitats.

Discussion
- Although the track count is the most useful estimator of feral cat abundance currently used, a random sampling design should be employed. This may require substantial changes to the resourcing of this monitoring method.
- The best way to estimate the kill rate of a feral cat control operation is by attaching mortality-sensing radio-collars to a random sample of the population immediately prior to control. This approach needs to be adopted by management agencies.

- There are no techniques for estimating the absolute abundance of feral cats, but these are required for studies of population dynamics and predator-prey interactions.
- An important pre-cursor to developing methods for estimating both the absolute and relative abundance of feral cats is to estimate the probability of detecting feral cats with various detection devices.
- Potential methods for estimating the absolute abundance of feral cats are grid- and web-based capture-mark-recapture techniques using either leg-hold traps or traps that collect hair from which DNA can be extracted and used to identify individuals.
- Because feral cats may occur at very low densities in some habitats and a significant proportion of the population may be averse to detection, there may never be techniques available for estimating the absolute abundance of feral cats that are considered 'affordable' by managers.

Summary of Key Recommendations

1. Although the track count is the most useful estimator of feral cat abundance currently used, a random sampling design should be employed.

2. Protocols need to be developed for estimating the absolute and relative abundance of feral cats, and the kill rates of feral cats in control operations. Further work is required to develop protocols for estimating the absolute and relative abundance of feral cats, but a protocol for estimating the kill rate in feral cat control operations could be written with available information.

3. At least one study should be funded to (i) estimate the probability of detecting feral cats with track counts, cage traps and leg-hold traps, and (ii) evaluate the potential of these detection devices in various sampling designs for estimating the absolute and relative abundance of feral cats. The optimal designs should be field tested and then, if they prove to be reasonable estimators, translated into monitoring protocols.

4. Capture-mark-recapture techniques based on grid- or web-based detection devices should be investigated as a method for estimating the absolute abundance of feral cats.

5. Methods for identifying individual feral cats from DNA in hair and faeces need to be tested/developed.

1. Introduction

The Department of the Environment and Heritage (DEH) commissioned the Arthur Rylah Institute for Environmental Research (Department of Sustainability and Environment, Victoria) to review and evaluate the methods used to estimate the abundance of feral cats. The key aims of the project were to review: (1) the methods used (in Australia and overseas) to determine the abundance of feral cats; (2) describe the methods used, the advantages and disadvantages of each method, and relative costs; (3) discuss how animal welfare issues influence the use of these methods; (4) identify and prioritise the gaps in existing knowledge; (5) provide recommendations as to areas of future research activity that will address those gaps identified in existing knowledge.

2. Background

Feral cats (*Felis catus*) probably became established in Australia soon after the arrival of the first Europeans. Feral populations now occupy most parts of the mainland, Tasmania and some offshore islands (Abbott 2002). Cats eat a wide range of native wildlife (reviewed in Robley et al. 2004), and for this reason are thought to reduce the distribution and abundance of many native species, especially on islands.

Feral cats are listed as a known or perceived threatening process for 58 native species under the *Environmental Protection and Biodiversity Conservation (EPBC) Act 1999*. Although many agencies and organisations commit resources to managing feral cats (Reddiex et al. 2004), there is little reliable information on the impacts of feral cats (e.g., Abbott 2002), or on the benefits of controlling feral cats (Dickman 1996; Reddiex et al. 2004; Robley et al. 2004). This lack of information is at least partly due to uncertainty about our ability to accurately and precisely estimate the relative or absolute abundance of feral cats, or the kill rates obtained in control operations. The Department of the Environment and Heritage (DEH) commissioned the Arthur Rylah Institute for Environmental Research to review and evaluate the methods used to estimate the abundance of feral cats.

3. Objectives

The objectives of this study were to:
1. Review and evaluate the methods used (in Australia and overseas) to determine the abundance of feral cats.
2. Provide a clear description of the methods used, the advantages and disadvantages of each method, and relative costs.
3. Discuss how animal welfare issues influence the use of these methods.
4. Provide a bibliography of the reference material reviewed.
5. Identify and prioritise the gaps in existing knowledge.
6. Provide recommendations as to areas of future research activity that will address those gaps identified in existing knowledge.

4. Requirements for monitoring the abundance of feral cats

4.1 Absolute abundance, relative abundance and kill rate

The most useful estimate of abundance is *absolute* abundance. Absolute abundance is the number of animals estimated to be present, and is often expressed as a density (i.e., the number of animals per unit area). Absolute abundance is usually estimated using either mark-recapture or removal estimators; these techniques can potentially incorporate many additional covariates affecting abundance, and hence are generally considered to be the most accurate method of estimating abundance. Reviews of these techniques are given in Seber (1982), Borchers et al. (2002), Parmenter (2003), and Efford (2004). However, it is important to recognise that these methods may not perform well in all circumstances, in particular when the abundance of animals is very low (as may occur following a control operation), or when the detection probability of a species is very low. Estimates of absolute abundance are required in studies of feral cat population dynamics, and would also be useful for estimating the effectiveness of feral cat control activities (i.e., the kill rate). However, they are relatively expensive to obtain and may be unnecessary for many decisions in the management of feral cats.

Most monitoring of feral animal control in Australasia relies on indices of relative abundance (Warburton 2000; Reddiex et al. 2004). Caughley (1977) defined an index as “any measurable correlative of density”, and the most well-known index for monitoring feral cats is the track count (see below). Indices of abundance provide estimates of *relative* abundance rather than absolute abundance, and are more popular because they are cheaper to obtain and computationally simpler than most methods for estimating absolute abundance. However, indices have been criticised (e.g., Garshelis et al. 1990; Anderson 2001) for two general reasons. First, there is an underlying assumption that the relationship between the index and absolute abundance is positive and linear, with a slope that is constant across habitats, seasons and years. Nonlinear relationships between indices of abundance and true abundance occur if the index becomes “saturated” at high absolute abundance (Caughley 1977; Gibbs 2000; Forsyth et al. in press). These biases may invalidate the use of the index for some management purposes (Thompson et al. 1998, Gibbs 2000). MacKenzie and Kendall (2002) provided a worked example of how failing to incorporate detection probability (p) leads to potentially different inferences about changes in the abundance of Nuttall’s cottontail rabbit (*Sylvilagus nuttallii*). We believe that indices will often provide useful management information provided that either their accuracy (i.e., relationship with absolute abundance) is known and/or detection probability is estimated and incorporated into estimates of abundance (MacKenzie and Kendall 2002). Second, monitoring programs involving indices of abundance seldom demonstrate that they have sufficient power to detect the desired changes in population abundance, if they actually occur (e.g., Steidl et al. 1997; Thompson et al. 1998). Addressing this second point is beyond the objectives of this review.

A specific requirement for monitoring feral cats in Australia is the ability to estimate the proportional reduction in the abundance of feral cats achieved by a control operation (e.g., posion baiting, trapping, shooting). Managers need to know whether control operations have been successful at achieving the required population reductions so that the benefits of control for native species can be evaluated.

4.2 Sampling design

The sampling design used for the abundance estimation technique is critical for interpreting information on animal numbers and distribution (e.g., Thompson et al. 1998). In the context of feral cat monitoring, we suggest that the ideal design will be either simple or stratified random sampling. In random sampling, each site in the area of interest has the same probability of being sampled such that inferences from the sampling apply to the entire area of interest. Although systematic sampling can provide relatively unbiased estimates of abundance (see Thompson et al. 1998), we believe (on philosophical grounds) that either simple or stratified random sampling should be used. Methods that sample subsets of the area of interest (e.g., roads) can still have a simple random design, but the resulting inferences apply only to that subset. We thus consider the most desirable sampling design to be one that can be randomly employed across the entire area of interest.

5. Methods

As part of a recent national review of feral animal control, Reddiex et al. (2004) recorded information on 55 feral cat control operations. For each operation, the type of monitoring used for feral cats was recorded. We therefore used these data as a starting point for identifying the methods used to estimate feral cat abundance in Australia. As part of that review, any existing protocols for estimating feral cat abundance were identified and obtained. We then searched the national and international literature, and contacted colleagues who have conducted research on feral cats, for information on any additional methods used to estimate the abundance of feral cats. Finally, we searched the international literature for methods that have not yet been used to estimate the abundance of feral cats in Australia, but offer promise for doing so.

We estimated the costs of the methods currently used to estimate the abundance of feral cats in Australia. It was not possible to estimate the costs of potential methods for estimating the abundance of feral cats in Australia. We also evaluated the compliance of each method with current relevant Federal animal welfare legislation.

6. Results

6.1 Current methods for estimating the abundance of feral cats

Of the 55 control operations reviewed by Reddiex et al. (2004) that targeted feral cats, only 14 monitored feral cat abundance. Of those that did monitor feral cat abundance and for which information was provided, 2 solely used spotlighting, 6 solely used track counts (including sand plots), 3 solely used bait-take, and a further 3 used some combination of these three methods. We address these three methods in turn.

6.1.1 Spotlight counts

Spotlight counts are widely used to monitor the abundance of rabbits (*Oryctolagus cuniculus*) and foxes (*Vulpes vulpes*) in Australia (Reddiex et al. 2004), and there is obviously little cost in recording feral cats observed during this work. Spotlight counts have also been used specifically to monitor changes in the abundance of feral cats (Read and Bowen 2001). Spotlight counts involve counting animals at night from a vehicle driven at a constant speed (typically 10–15 km h^{-1}) along a fixed route (‘transect’) using either a hand-held or vehicle-mounted spotlight (typically 100-W). Feral cats can be distinguished from other species by the colour of their eyeshine, and part or all of the body may also be seen. The estimate is the number of feral cats sighted per km^{-1}. Transects should be at least 20km long, and counts should be made on at least 3 consecutive nights. The date, name and location of the transect, and any conditions that might be important (e.g., weather, presence of livestock) should be recorded. Because not all cats are likely to be observed with this method (and detection probability cannot be routinely estimated), spotlight counts are an index of relative rather than absolute abundance.

The advantages of spotlighting are that it can be conducted very quickly and with minimal equipment (a vehicle, a minimum of two people and a spotlight). The disadvantages are that an unknown proportion of cats are observed, and this proportion is likely to vary with habitat and possibly with time. For example, if shooting with the aid of a spotlight is used to control feral cats or other pest animal species then most survivors would likely avoid the spotlight. The distance from the transect line that the light penetrates will vary with habitat (e.g., long vs. short grass). In many habitats the vehicle cannot access all of the study area (often just roads) and hence the sampling design is non-random. Another disadvantage is that the spotlight search strategy (i.e., distance from the vehicle at which animals are searched for) is different for rabbits and predators.

Spotlight counts have been used to assess the responses of feral cat populations to fox control, measure the success of control programs and to monitor the dynamics of cat populations. Molsher et al. (1999) estimated the relative abundance of feral cats (and rabbits) from vehicle spotlight counts conducted monthly from 1994–1997. Transect lengths varied from 9–44 km in the first year but thereafter were always 30 km. Counts were repeated over three consecutive nights, and the vehicle travelled at 10 km h^{-1}. Read and Bowen (2001) conducted spotlighting along two 20-km transects every two months from 1989–1999. Feral cat density was estimated assuming that all animals within 100m of the vehicle were observed, and ranged from c. 0.25 km^{-2} to c. 3.0 km^{-2}. The highest cat densities were estimated when rabbits were most abundant and foxes least abundant, which is biologically sensible, suggesting that the technique at least detected changes in relative abundance. Edwards et al. (2000) observed that spotlight counts had very high coefficients of variation (the CV ranged from 93–224% in 10 surveys) and were relatively less ‘time-efficient’ than track surveys (CV ranged from 28–117%). A comparison of spotlight and track counts was undertaken by Mahon et al. (1998) and is summarised below (section 6.1.2).

Spotlight counts of carnivores may be affected by temporal shifts in activity. Seasonal variation in activity patterns has been reported for foxes (e.g., Phillips and Catling 1991) but not, to our knowledge, for feral cats. Ralls and Eberhardt (1997) showed how small sample sizes and lack of replication in spotlight surveys of San Joaquin kit foxes (*Vulpes macrotis mutica*) meant that the method was unlikely to detect anything but very large changes in abundance, and this criticism is likely to apply to spotlight counts in Australia.

There are no animal welfare issues associated with spotlight counts. There may be an unacceptable health and safety risk from one or more people standing on the tray of a utility vehicle operating the spotlight and/or counting animals. Observation cages can be built, but these are expensive and it may be difficult to obtain an engineers certificate of approval for these structures (M. Johnston, Department of Primary Industry Victoria, personal communication). Spotlighting from a vehicle cabin is far less practical than from a vehicle tray.

6.1.2 Track counts (sand plots)

Feral cats, and many other wildlife species in Australia, can often be identified from their tracks (Triggs 2002). Track counts have thus been widely used in Australia to monitor changes in the abundance of both native and feral animals. Track counts can either be ‘passive’ or ‘active’, the difference being that the latter uses a lure to attract cats to the tracking device. Although there have been many studies of active track stations for carnivores in North America (review in Wilson and Delahay 2001), we are not aware of any studies of feral cats involving active track counts.

A protocol for passive track counts (termed the ‘Allen Index’ or ‘Passive Activity Index’; ‘PAI’), has been developed by the Queensland Department of Natural Resources and Mines (undated). The tracks of animal species on sand plots constructed at fixed intervals in the landscape are counted over a short period of time. The underlying assumption is that the number of tracks counted is linearly proportional to the true abundance of animals. The method is intended to monitor both temporal and spatial differences in abundance. The PAI should not be used to estimate the absolute abundance (or density) of animals in an area.

Sand plots are a c. 1-m swathe across a travel-way used by animals (e.g., roads, creek crossings, cattle pads; Figure 1a). The sand plots are placed at regular intervals along a route called a transect. The transects are usually linear and follow established roads, tracks or trails. They should have as little foot or vehicular traffic as possible to avoid tracks being erased. Transects should be 50 km long, but a minimum of 30 km, with sand plots placed every 1 km. Sand plots should be established as early as possible in the morning. The vehicle odometer is used to measure 1 km between each plot, and the location of each sand plot is recorded with a GPS and marked on a map. Each sand plot is prepared by raking the surface flat, removing sticks, rocks and any other debris. The plot is 1m wide and stretches between the road shoulders. Sieved soil is spread over the surface until there is a coating of relatively fine material. Each sand plot is marked with brightly coloured surveying tape at eye level a few metres before the plot. The first and last plots can be marked with two strands of tape. When the last sand plot has been created, the area is exited by an alternative route to avoid driving over the new sand plots.

The sand plots are checked in the morning. A sheet for recording data on is provided in Queensland Department of Natural Resources and Mines (undated). The date, name and location of the transect, and any conditions that might be important (e.g., overnight and current weather) are recorded. The numbers of animals that cross each sand plot are recorded. If an animal has crossed the plot, turned and crossed again then this animal should be recorded once. Tracks are counted for all species or types of animals (e.g., ‘macropod’ if the species of macropod cannot be identified). Photographs or sketches of tracks can be made for subsequent identification. Cat tracks are shown in Figure 1b.

If a sand plot is washed out, damaged by wind or otherwise unreadable, this should be recorded differently from a zero count. Each sand plot is resurfaced when finished, except on the last day. Counts are made on two consecutive days; the third is optional. Counting for more than three mornings does not significantly increase the accuracy of the index but increases the likelihood that rare species are detected (Queensland Department of Natural Resources and Mines, undated).

A separate PAI is calculated for each species. For each day, the total number of tracks recorded for each species is divided by the number of readable sand plots. These values are then averaged for the two or three days. Engeman et al. (1998) provided a method for calculating the variance for the PAI.

Robley et al. (unpublished manuscript) compared predator abundances estimated using the Allen Index with randomization tests (Manly 1997). The null hypothesis was that there was no difference in the activity of foxes and wild dogs between the treatment and non-treatment sites. The observed difference, D_O, is the actual observed difference between the mean number of daily incursions for each of the treatment and non-treatment sites. The random difference, D_R, is the difference between the mean number of daily incursions for each of the treatment and non-treatment sites once the observations have been randomised. If $D_O > D_R$, then it is concluded that fox control is having an impact. Randomisation tests were also used to evaluate the variability of activity indices between sampling occasions for the treatment and non-treatment sites.

Mahon et al. (1998) compared spotlight counts and track counts along roads with track counts placed randomly in four 12-km^2 sites in the Simpson Desert, south-west

Queensland. These techniques were compared over eight sampling intervals between May 1995 and October 1996. The road track counts were made on 3×5-m plots established at 500-m intervals along 12 km of roadway, and two indices of relative abundance were estimated. First, plots were scored as either having (1) or not having (0) tracks (i.e., presence/absence). Second, the number of individual tracks were counted (defined on the basis of a pilot study as tracks occurring not less than 500 m since the last occurrence of that species on the road). Spotlight counts were performed with two 100-W Lightforce spotlights from a vehicle travelling at c. 15 km h^{-1}, between 2 and 5 h after sunset. Three nights of spotlighting were performed at each site per sampling period, with 15 km surveyed per night. At each site 28 randomly located 40×0.75-m sand plots were

(a)

(b)

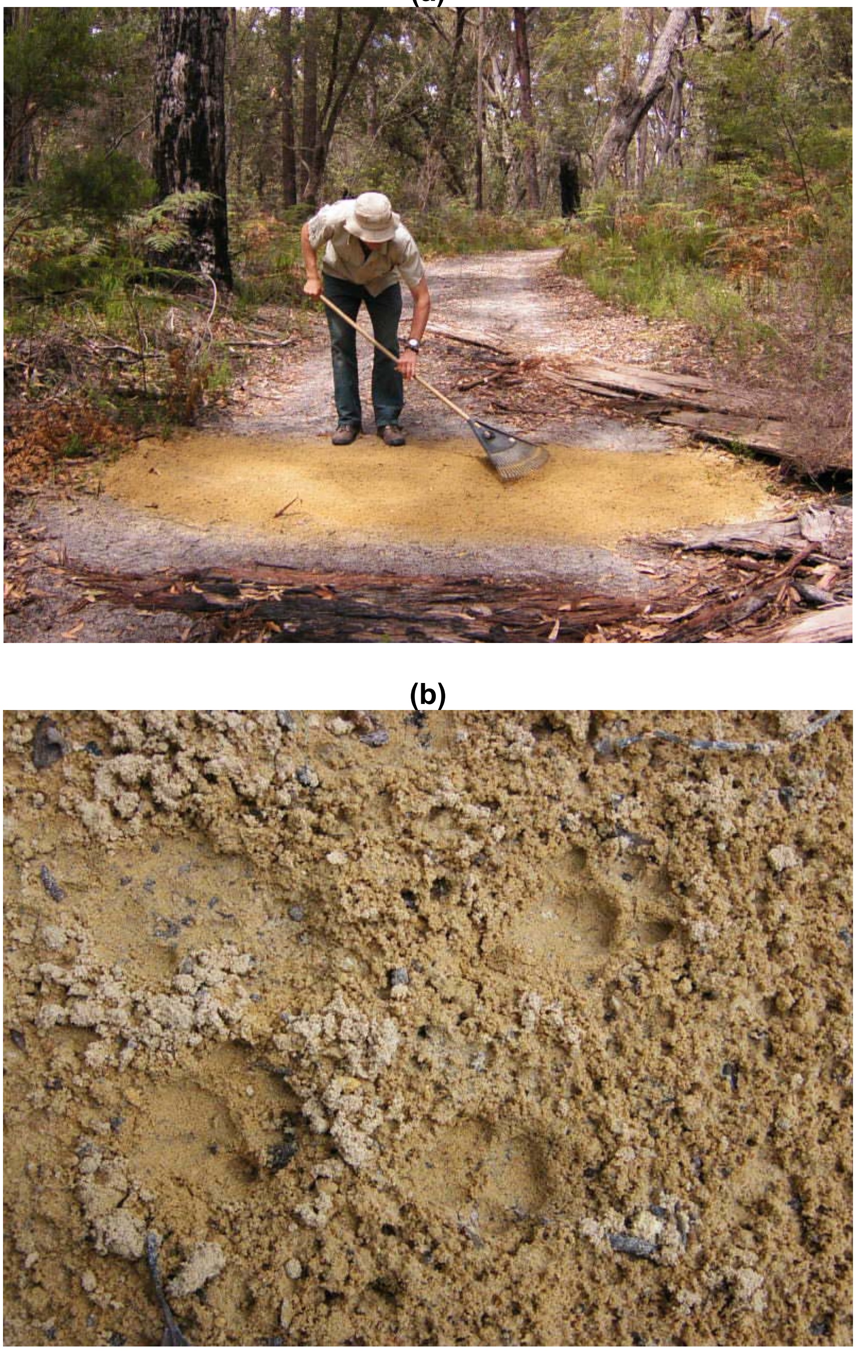

Figure 1. Sand plots. (a) Sweeping a sand plot. (b) Feral cat tracks in a sand plot. (Photos: A. J. Robley, Arthur Rylah Institute for Environmental Research.)

established with a hessian sack and were checked for the presence of footprints on three consecutive mornings during each sampling period.

For feral cats, the road counts and the random sand plot counts based on individual track counts were strongly positively correlated (r = 0.86), but those based on presence/absence were only weakly positively correlated (r = 0.37). However, these correlations are based on a small sample size (n = 7). Under the assumption that the random sand plots are more accurate than the road counts, both of the latter overestimated the abundance of foxes; the effect for cats was not presented (Mahon et al. 1998).

The correlation between spotlight counts and random spotlight counts varied greatly between the four sites (r = –0.28, 0.67, 0.24, and 0.34). Cats were detected on sand plots but not when spotlighting on 20 of 32 sampling occasions, but were detected by spotlighting but not sand plots on only two occasions (Mahon et al. 1998).

Edwards et al. (2000) used track counts estimated from continuous lengths of track. They established 10 km transects along dirt roads in central Australia. Dirt roads were chosen because they had a sandy surface substrate useful for recording tracks and signs of other animals. The transects were ≥5 km apart. Twenty-four hours prior to the start of a survey, each transect was cleared by dragging a 1.8-m steel bar behind a vehicle to erase all tracks and signs. Track counts were conducted the following morning by one observer driving a quad bike at 5–8 km h^{-1}. When carnivore tracks were observed the bike was stopped and the tracks identified to species. The quad bike dragged the steel bar behind it on each of either two or three consecutive survey days. The estimate was the mean of the total number of tracks recorded along each track over the survey period and expressed as the number of tracks per km. CVs for the estimates of relative cat abundance ranged from 28–117%. Burrows et al. (2003) also used track counts based on continuous sections of road (30–60 km inspected each night) to estimate changes in the relative abundance of feral cats (and also foxes and dingoes) in the Gibson Desert, Western Australia, before and after baiting operations.

Several studies have investigated the relationship between true abundance and track counts. Diefenbach et al. (1994) observed a positive correlation between the proportion of scent stations visited by bobcats (*Lynx rufus*) and true abundance, but concluded that only large differences in abundance were detectable. Like spotlight counts, track counts located along roads have poor spatial resolution, and the small number of transects sampled means that they have low statistical power. For example, Allen et al. (1996) used 2×50 km transects to estimate the PAI for wild dogs (*Canis lupus*) in Queensland. Sargeant et al. (1998), working with a statewide road network of scent station transects for carnivores in Minnesota, USA, observed that visits to scent-stations separated by <2 km were correlated for all carnivore species, apparently because individual carnivores sometimes visited several successive stations. Sargeant et al. (1998) overcame the problem of spatial autocorrelation by using a presence-absence technique for lines of 10 stations. Spatial correlation can thus be overcome by using randomly located lines of detection devices, where each line is the unit of replication (e.g., Sargeant et al. 1998; Warburton 2000; National Possum Control Agencies 2002). Stander (1998) evaluated the relationship between the true density of leopards (*Panthera pardus*), lions (*Panthera leo*) and wild dogs (*Lycaon pictus*) and track counts along roads in southern Namibia. The track density was positively correlated with density, but sample sizes were too small to reliably determine whether the index was linear or non-linear.

There are no animal welfare issues associated with any of the track count methods.

6.1.3 Bait-take

Bait-take involves monitoring the amount of either toxic or non-toxic bait removed in the study area and assuming that this is negatively related to the abundance of feral cats. Bait-take is thus an index of relative abundance. Changes in bait-take after a control operation can be used as an estimate of kill rate (see Hone 1994). However, because vertebrates can have either innate or learnt behavioural aversions to control methods we do not advocate using the same method to monitor changes in abundance as was used to control the pest, and we do not advocate its use for feral cats. It is considered here only for completeness.

There are no protocols for estimating the abundance of feral cats using bait-take. Burrows et al. (2003) attempted to use 'cyanide transects' to estimate the relative abundance of feral cats in the Gibson Desert, Western Australia. A small dose of cyanide paste is lethal to cats. However, the technique was 'not reliable' for estimating feral cat abundance because the uptake of cyanide baits by cats varied seasonally and with the availability of live prey. Cyanide is potentially lethal to humans.

The relationship between bait-take and absolute abundance has not been investigated for feral cats. Moreover, detection probability cannot be routinely estimated for bait-take and to our knowledge no study has attempted to estimate detection probability for bait-take.

A random sampling design could be adopted for bait-take. However, it is more likely to be systematic (i.e., a grid of bait stations) or non-random (laid along roads). Inferences based on bait-take monitoring along roads relate only to roads (i.e., in many situations only a small proportion of the area of interest).

One potentially large problem is that other species (e.g., varanids, crows, raptors, foxes, dingoes, quolls, and ants) may consume an unknown proportion of bait. Another problem is that unknown proportions of the population do not eat bait or eat bait but do not die. The caching of baits by predators also reduces the reliability of bait-take as an estimate of relative abundance (van Polanen Petel et al. 2001).

Animal welfare issues for bait-take centre on the nature of toxicosis and potential for exposure of non-target species when using toxic baits (M. Johnston, Department of Primary Industries Victoria, personal communication).

6.1.4 Relative costs of spotlight counts and track counts

The relative costs of spotlight counts and track counts outlined in Table 1 are largely based on resource requirements outlined by Parks Victoria (2004). Labour costs are assumed to be \$320 day^{-1}. The distance travelled by vehicle is similar for the two methods, but in some organisations staff may charge overtime for working at night (i.e., spotlight counts). Some staff conducting spotlight counts may also need a GPS. Sand required to construct sand plots will not be required in all localities.

Table 1 indicates that the approximate costs of spotlight counts and track counts, following the methods outlined above, are similar.

6.2 New methods for estimating the abundance of feral cats

This section outlines methods that could potentially be useful for estimating the absolute or relative abundance of feral cats in Australia. The list is not exhaustive: rather, we focus on methods that we consider the most promising.

Table 1. Summary of major resource requirements and costs for the two methods currently used to estimate the abundance of feral cats in Australia (after Parks Victoria 2004).

Method	Resource requirements	Costs
Spotlight counts	• 2 persons	
	• 4WD vehicle with safety frame (at least 150 km/night)	$ 338
	• at least 2 spotlights ($180 each)	$ 360
	• 3 nights (2 staff) and 1 day set-up (1 staff), 1 day entering and summarising data (i.e., 9 days)	$2560
		TOTAL $3258
Track counts (Sand plots)	• 2 persons	
	• 4WD vehicle (at least 150 km/day)	$ 338
	• 2 days and 1 day set-up for 2 staff, 1 day entering and summarising data (i.e., 7 days)	$2240
	• sand ($300/day if unavailable on site)	$ 600
	• 2 rakes ($40 each)	$ 80
	• 2 GPS units ($220 each)	$ 440
		TOTAL $3698

6.2.1 Trap-based estimates of abundance

Trap-based estimates have not been used to estimate the abundance of feral cats in Australia. However, there are a wide array of methods available for estimating abundance based on individual traps, including trapping webs and grids (Parmenter et al. 2003; Efford 2004), other capture-mark-recapture (CMR) techniques (Amstrup et al. in press), and removal estimators (Seber 1982; Forsyth et al. in press). In this section we outline the techniques used to trap feral cats with a view to understanding how these might be used as methods for estimating the absolute abundance of feral cats.

Veitch (1985: 133) showed how to set two types of cage traps for feral cats, but (although no data was provided) stated that they have a "relatively low capture rate". The preferred cage trap had a higher door opening (38cm), did not have hinges and had a separate access door for rebaiting. It was suggested that the lower capture rate of cage traps relative to leg-hold traps was due to the reluctance of cats to enter enclosed spaces. Human scent was deemed to reduce capture rates, and it was suggested that gloves be worn when setting traps or that bait be rubbed on the hands prior to setting traps (Veitch 1985).

As the name suggests, leg-hold traps are designed to capture the cat by the lower leg. Veitch (1985: 133) considered these to be 'clearly the most efficient method of trapping cats'. Veitch thought that cats can lift their feet faster than the jaws of some traps can close, but to our knowledge this has not been tested (B. Warburton, Landcare Research, personal communication).

Veitch (1985) also outlined protocols for setting leg-hold traps as either 'baited' or 'walk-through'. For a baited set, a tree (or other object) to which a bait can be attached is selected. The end of the trap chain is stapled to the tree or pegged into the ground so that the trap can be a handspan from the bait. The trap is finely set and placed firmly so that there is no movement and so that the upper side is level with the ground surface. A ‘fence’ of sticks and/or stones is then extended from the tree to the outer edge of both sides of the trap jaws to ensure that the only way that the cat can access the bait is by walking over the trap. The fence may also exclude non-target animals from being caught. Finally, the trap is covered with a fine layer of soil and leaves, taking care that this does not stop the trap from closing properly. A walk-through set attempts to capture cats as they walk through a gap between two obstacles. The traps are set finely, placed firmly in the ground with the top level with the surface, and lightly camouflaged. Fences of sticks may be built to guide the cat on to the trap.

P. Caley (CSIRO, personal communication) has trapped feral cats in farmland in New Zealand. Cats were captured in Victor No. 1.5 Soft-Catch® leg-hold traps (Figure 2) set for ferrets (*Mustelo furo*). (Soft-catch traps have rubber-coated jaws intended to reduce injuries to trapped animals relative to steel-jawed traps.) Traps were baited with fresh rabbit, European hare (*Lepus europaeus occidentalis*) or domestic chicken meat. Traps were set at approximately 200-m intervals, usually over 5–10 nights. Traps were set preferentially at rabbit holes but otherwise at the base of fence-posts or trees), with traps attached to a wooden stake (or tree) by a long-chain. Suffering of animals was minimised by using rubber jawed (c.f. steel jawed) traps, and checking traps as soon as practically possible each morning following setting. The use of leg-hold traps increases the efficiency of trapping, and enables traps to be set down burrows out of the way of livestock. Only 1–2% of feral cats broke legs, and this typically occurred when the swivel was prevented from swivelling by wire or vines (P. Caley, CSIRO, personal communication).

Short et al. (2002) compared the capture rate of feral cats in several types of cage and leg-hold traps at Shark Bay, Western Australia, from 1991–2001. Because it was a retrospective analysis of sustained control activities rather than a planned study to test hypotheses about the effectiveness of different trap/set/lure combinations, the conclusions should be treated cautiously. Semi-domestic cats (i.e., those living at rubbish tips and around human settlements) were easier to catch in cage traps than wild cats (i.e., those living away from settlements). It was suggested that the main reason for between-year differences in the capture rates of traps was the abundance of rabbits, and in particular the abundance of young rabbits (as estimated by spotlight counts). Trap success was highest when rabbits were least abundant, and lowest when rabbits were most abundant. The Victor Soft-Catch® leg-hold trap was deemed to be more effective than cage-traps for

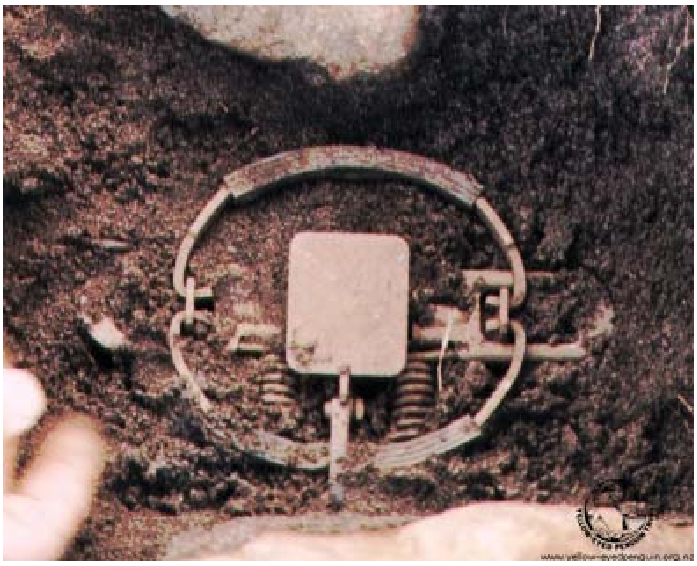

Figure 2. A Victor Soft-Catch® 1.5 trap being set.

general trapping, but cage-traps were used where domestic cats may have been caught and when capture of non-target native species may have occurred. Relative to the Victor Soft-Catch® leg-hold trap, treadle snares were considered expensive, bulky to transport, and time-consuming to set: they also had a lower capture rate. During the breeding season, young cats (kittens and sub-adults) were more easily trapped in leg-hold traps than adults.

Molsher (2001) found little difference in the capture efficiency of treadle-operated wire mesh cage traps (40×40×60cm) and Victor Soft-Catch® rubber-jawed leg-hold traps at Lake Burrendong, New South Wales. Cage traps were set as described above by Veitch (1985). Leg-hold traps were set just below ground level and tethered to a stake, and were most commonly set at entrances to fallen logs (to provide cover for the trapped animal and to hide the bait from non-target bird species). The bait was tethered on wire and placed 10–15cm behind the trap plate. Traps were approximately 200-m apart. Traps were checked in both the morning and the afternoon. Although several types of bait were tested in the first year of the study, only freshly killed rabbit was used in the second year. Captures averaged 1.3 cats per 100 trap-nights, with little difference between the cage and leg-hold traps. Most traps were captured in late autumn and early winter (see also Short et al. 2002). Non-target capture rate exceeded that of feral cats (2.2 animals per 100 trap nights), with lace monitors (*Varanus varius*) the most common non-target species. Brushtail possums (*Trichosurus vulpecula*), foxes, rabbits (*Oryctolagus cuniculus*), rats (*Rattus rattus*) and birds (not described but 'mostly corvids') were also caught.

The current retail price of Victor Soft-Catch® No. 1 and No. 1.5 traps are A$14 and A$17, respectively. The current retail price of the 'Havahart' No. 1089 cage trap (collapsible wire, single entry and treadle-operated) is A$110. Cage traps are thus more expensive than the Victor Soft-Catch® leg-hold trap, because of their bulk are difficult to transport, and are considered difficult to bait. However, when there is a potential for non-target native species to be captured the cage trap has a great advantage over leg-hold traps because the non-target species captured in cage traps can be released unharmed whereas those captured in leg-hold traps may be injured.

It has been suggested that the detection probability of traps and track counts may be substantially increased by the use of lures. Lures may be visual, olfactory and/or aural. Fresh or canned fish appears to be the lure most often used for attracting feral cats, at least in control operations (Veitch 1985). However, fish or fish-based lures performed poorly relative to other attractants in trials by Clapperton et al. (1994) in New Zealand and Edwards et al. (1997) in Australia. Of an array of lures evaluated in pen and field trials by Clapperton et al. (1994), the most promising were two lactones found in high concentrations in catnip (*Nepeta cataria*) and silver vine matatabi (*Actinidia polygama*). Urine and fish oil performed relatively poorly as attractants. Of the 10 food-based lures field-tested by Edwards et al. (1997) in central Australia, only sun-rendered prawn attracted feral cats. Two scent-based lures (anal-gland extracts from male and from female cats) attracted cats. A visual lure composed of bird feathers did not attract cats. In Western Australia, Victor Soft-Catch® leg-hold traps have been used with an audio cat-calling system and a scent lure (a blend of cat faeces and urine) to trap feral cats (Algar and Smith 1998).

Trap success is likely to be affected by the skill of the trapper (e.g., selection of trapping sites, how the trap is set and placement of attractants). These effects must be standardised if multiple trappers are used to generate estimates of abundance that are to be compared in time and space. A protocol that standardises as many of these factors as possible is required. The protocol used for estimating the relative abundance of brushtail possums in New Zealand (National Possum Control Agencies 2002) is a good example of an attempt to minimise the effects of operator variation on a trap-based index of abundance.

6.2.2 Animal welfare issues

Animal welfare in Australia is governed by State Acts and their Associated Regulations. Western Australia has the Animal Welfare Act 2002, Tasmania has the Animal Welfare Act 1993, Queensland has the Animal Care and Protection Act 2001, New South Wales has the Prevention of Cruelty to Animals Act 1979, Victoria has the Prevention of Cruelty to Animals Act 1986, and South Australia has the Prevention of Cruelty to Animals Act 2000.

The welfare of animals (both feral cats and non-target animals) caught in cage traps is governed by general provisions in each Act relating to the treatment of animals: all reasonable steps should be taken to prevent the suffering of animals caught in cage traps. Practically, these would involve checking traps as frequently as possible after sunrise and providing shade/water during hot months. Conversely, traps should not be set in exposed areas in cold months.

All Acts except the Western Australian Animal Welfare Act have specific provisions relating to the use of leg-hold traps. Leg-hold traps work by leaf springs or coils that are compressed when the trap is set. The jaws are opened and the trap latch is set under the trigger plate. When the animal steps on the plate the springs or coils are released and the jaws close quickly on the animal. The aim of the trap is to hold the animal by a limb until the trapper returns. In New South Wales and the Northern Territory, only soft-catch traps can be used. There are no restrictions on the types of traps that can be used in Western Australia. In Tasmania, an exemption must be obtained from the Minister to set a leg-hold trap suitable for feral cats. Queensland has a Schedule of prohibited traps, but none of the traps suitable for feral cats are listed on that Schedule. In Victoria, all leg-hold traps are legally permitted but the State Government policy is that only soft-catch traps be used (M. Rosier, Department of Sustainability and Environment, personal communication). In South Australia, only soft-catch traps are permitted, but these can only be set under a research program approved by an animal ethics committee.

The key concerns about the humaneness of leg-hold traps are: (i) exhaustion and dehydration if animals are held in the trap for a long time; (ii) injury and distress associated with being trapped; and (iii) escape while possibly injured (B. Warburton, Landcare Research, personal communication). In New Zealand, all traps must be checked within 8 h of sunrise, but there are no similar regulations in Australia. There has been some work in Australia to evaluate the second concern. Meek et al. (1995) evaluated the injuries received by seven feral cats caught in Victor Soft-Catch® No. 3 leg-hold traps. All seven cats suffered 'category 1' injuries: slight foot/leg oedema with no lacerations or broken bones. The four non-target species caught in this trap type were Australian ravens (*Corvus coronoides*; *n* = 4), magpie (*Gymnorhina tibices*; *n* = 1), swamp wallaby (*Wallabia bicolor*; *n* = 1), and brushtail possum (*n* = 1). Molsher (2001) reported that the 64 feral cats caught in cage traps received "generally minor" injuries (mostly abrasions to the face), but that of the 12 caught in Victor Soft-Catch® No. 1.5 leg-hold traps, one cat that was caught six times in one month (and 10 times in total) had a swollen front leg that forced it to limp; this cat was found dead two months later. The third concern is difficult to quantify, but the data collected for the second point suggest that few cats escape from traps with injuries. Field and pen trials could be conducted to better quantify all of these concerns (e.g., see Warburton 1998 for similar work on brushtail possums in New Zealand).

Suggested standard operating procedures (SOP) for trapping feral cats using padded-jaw leg-hold traps and cage traps have been developed by Sharp and Saunders (2004a,b). These SOPs should only be used subject to the applicable State/Territory legal requirements.

6.2.3 DNA Capture-Mark-Recapture (CMR)

Numerous studies have attempted to estimate the absolute abundance of carnivores using CMR techniques in which individuals are identified from the DNA in hair follicles left on detection devices . The detection devices are usually either a sticky pad or a circle of barbed wire with an attractant (e.g., blood or meat). The technique is potentially useful for estimating the abundance of feral cats because feral cats share several features in common with the carnivores to which this method has been applied: feral cats can have large home ranges (Jones and Coman 1982; Edwards et al. 2001; Molsher 2001), occur at low densities, at least in semi-arid regions (Jones and Coman 1982), and can be attracted to a device using a bait and/or lure (see above). The method involves setting up a grid or web of detection devices to which cats are attracted by bait/lure. The cat investigates the bait/lure and leaves hair on the detection device from which DNA is extracted. The unique DNA fingerprints identify individuals 'captured' at each device in space and time, and these are used as a sequence of capture events in CMR analyses (Amstrup et al. in press).

Possible detection devices for feral cats would include sticky pads and barbed wire. The technique seems intuitively useful for cats because at least some individuals that may not enter a cage-trap or leg-hold trap might be 'captured' by a sticky pad. However, we point out that not *all* cats are likely to be sampled in this manner, and emphasise the need to estimate detection probability for any technique. The disadvantages of the technique include the presence of hair from multiple cats and also from other species. Other species may also remove the bait/lure. There is also a level of uncertainty attached to identifying individuals from DNA, particularly when there may be follicles present from >1 individual (A. Byrom and D. Gleeson, Landcare Research, personal communication). Preliminary work with feral cats in New Zealand indicates that they can be sexed and individually typed from DNA collected from baited sticky traps (A. Byrom and D. Gleeson, Landcare Research, personal communication). Mills et al. (2000) discuss the problem (unique to DNA CMR) of some animals that have not previously been captured are believed to be recaptures because of their DNA profile being an indistinguishable shadow of previously captured animals.

It may be possible to identify individual cats from DNA on faeces. O. Berry and S. Sarre (Canberra University, personal communication) have developed a DNA test to discriminate fox faeces from other carnivore faeces. Piggott (2004) could identify individual foxes from DNA on the surface of their faeces, but amplification rates decreased and genotyping error rates increased with faecal age, particularly after one week. There was also a seasonal effect, with lower amplification rates and higher genotyping error rates in winter than in summer. These error rates meant that up to eight samples may be required from fox faeces collected in winter. Furthermore, trials indicated that it was difficult to determine the age of fox faeces in the field (Piggott 2004). Identifying individual cats from faeces is likely to be more difficult due to the presence of prey DNA and enzymes that break down the cat's own DNA (A. Byrom and D. Gleeson, Landcare Research, personal communication). Another problem in the use of DNA as a monitoring technique is the search effort required to collect reasonable numbers of cat faeces from the area of interest. It may well be more cost-effective to use DNA in hair follicles from cats attracted to detection devices than to search for faeces. However, faeces may be deposited at detection devices with or without hair follicles, and may well provide useful ancillary data for CMR estimates of feral cat abundance.

A major limitation of identifying individuals (and perhaps their gender) from hair and faeces is the low quantity and quality of recovered DNA (review in Piggott and Taylor 2003). Hence, extraction procedures are more costly than required for tissue/blood samples, and there is a greater probability of contamination and incorrect genotyping.

The CMR models used to estimate abundance have other key assumptions that may be violated, and the estimates of abundance may be inaccurate and have poor precision. Perhaps the most important is that of population closure, which can be separated into demographic and geographic closure. Demographic closure is equated to no births or deaths or permanent emigration or immigration during the study: this assumption may be met in studies of short duration (i.e., weeks). Geographic closure is violated if individuals move on and off the study area between sampling periods: the potential bias from violation of this assumption can be minimised by having a large study area compared to the size of the average home range. For examples of the application of DNA CMR techniques to the estimation of carnivore abundance see Mowat and Stobeck (2000; grizzly bear *Ursus arctos*) and Mowat and Paetkau (2002; marten *Martes americana*).

Boulanger et al. (2002) evaluated how well seven projects using grizzly bear DNA from bait stations with hair snags conducted in British Columbia (Canada) met the assumptions of CMR, and the accuracy and precision of those estimates. Unsurprisingly, recapture rate declined as sampling intensity decreased (and cell area increased). The assumption of demographic closure (required for estimating parameters using one of the CMR models) was more likely to be violated in smaller grids compared to large grids. Hence, there is a trade off in the design of DNA CMR studies: intensive sampling using smaller cells is needed to detect and model individual heterogeneity, yet smaller grids are more likely to violate the assumption of closure.

6.2.4 Photographic rates

It has been suggested that the number of camera-days per photograph is a useful index of abundance for cryptic carnivores (e.g., see Carbone et al. 2001 for tigers *Panthera tigris*). However, the method has not been applied to feral cats. The cameras used in this method are expensive and require routine maintenance, including replacement of film and batteries. Theft may also be a problem. Given the apparently low densities of feral cats in most Australian habitats, it is likely that the photographic rates estimated from randomly-placed cameras would have very low precision. Coupling cameras with attractants could be more cost-effective. It may also be possible to individually identify at least some cats from photographs (i.e., those with distinctive markings), which could be used to estimate abundance using CMR (e.g., Karanth and Nichols 1998 for tigers).

7. Discussion

7.1 Current methods used to estimate feral cat abundance

7.1.1 Relative abundance

Two methods are widely used to estimate the relative abundance of feral cats in Australia. Passive track counts have been used in all States and Territories, and a protocol has been published for use in Queensland (Queensland Department of Natural Resources and Mines, undated), and another is being developed by Parks Victoria (C. Miller, Parks Victoria, personal communication). Spotlight counts have been as widely used as track counts, but the only protocol specifically for cats that we are aware of is being developed by Parks Victoria (C. Miller, Parks Victoria, personal communication). It should be noted that feral cats are routinely counted during spotlight counts conducted primarily for detecting changes in the abundance of wild rabbits. Although spotlight counts may be a useful index of rabbit abundance (Caley and Morley 2001, 2002; c.f. Fletcher et al. 1999), they have had poor precision relative to track counts when used to estimate the relative abundance of feral cats in Australia (Mahon et al. 1998). Spotlight counts are only suitable for relatively open habitats that are accessible by vehicle. We therefore agree with Parks Victoria (2004) that track counts (or PAI or Allen Index) are likely to be the most efficient method for estimating the relative abundance of feral cats. However, one problem with the present protocols (Queensland Department of Natural Resources and Mines, undated; Parks Victoria 2004) is that sampling is restricted to roads. Sampling along roads means that inferences about the abundance of cats in the area of interest are restricted to roads, which will usually be only a small proportion of the total area of interest. We recommend that simple or stratified random sampling be employed: this may require both more labour and the use of different modes of transport (e.g., helicopters) but we believe that it is important that all points in the area of interest have the same probability of being sampled (see, for example, National Possum Control Agencies 2002).

The detection probability of track counts has not been estimated for any habitat. If the detection probability of track counts was known, then the efficiency (in terms of precision and cost) of various sampling designs could be explored through simulation modelling (Ramsey et al. in press). We therefore recommend that the detection probability of several devices be estimated using the methods of Ball et al. (in press).

7.1.2 Absolute abundance

Although some authors (e.g., Read and Bowen 2001) have assumed that spotlight counts within 100 m of the vehicle equate to absolute abundance, we believe that this is unrealistic because some cats will not be observed due to vegetation/topography and/or deliberate avoidance of the spotlight. Thus, despite the importance of these data for understanding population dynamics and predation (Robley et al. 2004), there are no methods available for estimating the absolute abundance of feral cats.

7.1.3 Kill rates

It is important for managers to estimate the kill rates obtained in their control operations, but only Risbey et al. (1997) has examined this. Unfortunately, only between seven and nine feral cats were monitored in the trial. Warburton et al. (2004) assessed the utility of two indices of relative brushtail possum abundance (trap-catch removal and bite marks on wax blocks) against the kill rate among radio-collared possums in each of seven operations. Between 48–50 possums were collared with a mortality-sensing radio-collar and checked one week before and one week after the control operations. The kill rate and its 95% confidence interval can be estimated using the binomial distribution (see Warburton et al. 2004). The correlation between the kill rates estimated by the pre- and post-trap-catch index and the radio-collars (the latter assumed to be least biased) was strongly positive (R^2=0.91) whereas the correlation between the kill rates estimates by pre- and post-control bite marks were less strongly positively correlated (R^2=0.66). We thus recommend that mortality-sensing radio-collars be placed on a sample of feral cats ($n \geq 20$) to estimate kill rates. The cats should be trapped using traps randomly located throughout the area of interest.

7.1.4 Animal welfare issues for current monitoring methods

There are no animal welfare issues for spotlight counts and track counts.

7.2 New methods for estimating feral cat abundance

Estimates of absolute abundance are required if progress is to be made in understanding the population dynamics and predator-prey dynamics of feral cats in Australia (Robley et al. 2004). Similarly, the dearth of techniques for estimating the absolute abundance of feral cats has been identified as a major limitation in understanding the benefits of feral cat control for native species and ecological communities (Reddiex et al. 2004; Reddiex and Forsyth 2004).

We believe that the most promising methods for estimating the abundance of feral cats in Australia are CMR techniques based on grid- or web-based detection devices. We also believe that the most useful detection devices are likely to be Victor No. 1 (or No. 1.5) Soft-Catch® leg-hold traps (that capture individuals that can be marked and released) or sticky-pads (that capture hair enabling individuals to be identified by their DNA). Leg-hold traps have been widely used for capturing feral cats in both Australia and New Zealand as part of eradication or control activities: a wide variety of methods exist for estimating abundance (and survival and reproductive rates) from trapping webs and grids (Parmenter 2003; Efford 2004; Amstrup et al. in press, and references therein).

Although DNA-CMR techniques hold much promise for estimating the abundance of low-density carnivores, there are methodological difficulties with identifying individuals from both hair follicles and faeces and these increase uncertainty in estimates of abundance (Mills et al. 2000). Violations of closure assumptions also reduce the accuracy and precision of estimates from both DNA- and trap-based estimates of abundance (Boulanger et al. 2002; Amstrup et al. in press). Similarly, there are methodological problems identifying the area around grids or webs from which density is estimated (i.e., absolute abundance/area; Efford 2004).

Removal estimators (Seber 1982; Forsyth et al. in press) may be useful for estimating the abundance of feral cats in some situations. The work by P. Caley (CSIRO) in New Zealand suggests that such estimators may be most useful in high-density populations. However, because removal estimators are based on animals being removed from the study area they are best suited to control operations involving trapping, and we do not recommend them as a standard technique for estimating the abundance of feral cats in Australia.

Detection devices for feral cats require baits and/or lures. Although it is desirable to have a bait/lure that is attractive to all cats for an eradication or control programme, for the purposes of monitoring it is more important that the detection probability of the device (with the bait/lure) is known. Recent work in New Zealand has estimated the probability of detecting a brushtail possum with a leg-hold trap placed in the centre of its home range to be c. 0.05 $night^{-1}$ (Ball et al. in press). Such low daily detection probabilities should be expected for available devices (sand plots, cage traps and leg-hold traps) placed in the centre of a feral cat's home range. We believe that it is critical to determine the detection probability of devices for feral cats, and to use that information to determine optimal sampling designs for monitoring methods using spatial simulation modelling (Ramsey et al. in press).

There are some legal and animal welfare issues associated with the use of leg-hold traps in a monitoring protocol. Soft-catch traps can be used in any Australian State or Territory, but require a research permit in South Australia and the Minister's approval in Tasmania. Provided soft-catch traps are used, any injuries suffered by trapped cats should be at the lower end of the scale (i.e., Category I; see Meek et al. 1995 for Victor Soft-Catch® No. 3 leg-hold trap injuries). Any concerns about injuries suffered by feral cats in Victor Soft-Catch® No. 1 or 1.5 leg-hold traps (which are likely to be more suitable for feral cats than the larger No. 3 trap) can be addressed in pen and field trials (e.g., Warburton 1998). We believe that non-target captures in leg-hold traps are a potentially more important welfare issue than injuries to trapped feral cats. For example, Molsher (2001) observed that the non-target capture rate was double that of feral cats, and both Meek et al. (1995) and Molsher (2001) captured native species in these traps. Because no studies have evaluated the injuries sustained by non-target species in leg-hold traps in Australia, the welfare implications of leg-hold traps for non-target species cannot be evaluated.

Relative to the other new methods outlined above, we believe that photographic rates offer little promise for estimating changes in the abundance of feral cats. Jennell et al. (2002) outline some problems with the interpretation of changes in photographic rates. Although those criticisms apply to many other indices of abundance, the cameras required for this method are expensive and require regular maintenance to ensure that they function. Given the low densities of feral cats in many Australian habitats, we do not believe that photographic rates will be a cost-effective method for estimating changes in the abundance of feral cats. However, cameras may be useful for identifying some individuals (e.g., tagged or otherwise distinctive) in research projects evaluating detection probabilities of various devices (see Ball et al. in press).

7.3 Concluding remarks

The issues that we have highlighted in this report apply to monitoring of many other species, both native and introduced. Anderson (2001) implored wildlife ecologists and managers to examine the basic tools of their trade. Abundance and density can be estimated by a wide variety of methods, and the few studies that have attempted to evaluate the accuracy of these methods against known numbers of small mammals (e.g., in fenced areas) have often performed poorly (Parmenter et al. 2003 and references therein). It is likely to be more difficult to estimate the abundance of feral cats than many other small mammals because some older individuals appear to be averse to detection and most individuals appear to have large home ranges: Jones and Coman (1982) estimated a mean home range size of 620 ha for four males and 170 ha for two females living in semi-arid Victoria, and Molsher (1999) estimated a mean home range size of 423 ha for 11 males and 238 ha for 4 females living in open forest in New South Wales. Thus, there is a possibility that there may never be techniques for estimating the abundance of feral cats that are considered 'affordable' by managers. However, the 'affordability' of a monitoring technique depends on how much weighting is attached to the information. We believe that it is very likely that the costs of reliably estimating the abundance of feral cats and the kill rate of feral cat control operations will be substantially higher than the current protocols for track counts and spotlight counts.

8. Key information gaps and recommended solutions

Below we outline key information gaps in methods for monitoring feral cat abundance. We also recommend solutions for filling those gaps. These gaps are listed in descending order of priority.

8.1 Detection probabilities for detection devices

Issue

The probability of detecting a feral cat, given that it is present, is defined as p. However, p has not been evaluated for any detection device. Such information is critical to identifying optimal designs for estimating the abundance of feral cats (Ball et al. in press; Ramsey et al. in press). Given that we recommend track counts rather than spotlight counts, we strongly suggest that the detection probability of the former is estimated. Since the detection probabilities of a number of devices can be estimated in a single study, we strongly recommend that the opportunity be taken to estimate p for cage-traps, leg-hold traps and some devices that capture hair. These data should then be used to evaluate the performance (accuracy, precision and cost) of a range of sampling designs for each technique for estimating feral cat abundance.

Recommended solution
We recommend a study that consists of two parts. The first part should estimate the probabilities of track counts, cage-traps and leg-hold traps detecting feral cats in at least one Australian habitat. The second part should use the detection probabilities to explore the potential (in terms of accuracy, precision and cost) of various sampling designs for estimating feral cat abundance. These sampling designs should be field-tested and, if they are found to be reasonable, then they should be adopted as protocols.

8.2 Universal protocols for estimating abundance and kill rate
Issue
Currently, organisations and even staff within the same organisation use different methods for estimating the abundance of feral cats. Because the estimates from the different methods cannot sensibly be compared (e.g., spotlight counts and track counts), this situation has been a major barrier to improving our understanding of feral cat population dynamics, interactions with other species, and the efficacy of control operations (e.g., Reddiex et al. 2004; Robley et al. 2004).

Recommended solutions
The work recommended in 8.1 should lead to standardised protocols for estimating the absolute and relative abundance of feral cats. DEH should only fund work related to feral cats that use these protocols, and a condition of the contract should be that the monitoring data is lodged with DEH.

There is a method available for estimating the kill rate of feral cat control operations (Risbey et al. 1997; *sensu* Warburton et al. 2004) and this should be adopted as a protocol.

Track counts provide a method of estimating relative abundance, but current protocols do not address the issues of random sampling. Future monitoring programs should, where possible, use random placement of track count transects.

8.3 Investigation of new techniques for estimating abundance
Issue
There are no methods available for estimating the absolute abundance of feral cats in any Australian habitat. We believe that capture-mark-recapture techniques based on grid- or web-based detection devices offer the greatest potential for estimating the abundance of feral cats in Australian habitats.

Recommended solution
The usefulness of grid- or web-based detection devices for estimating the absolute abundance of feral cats should be investigated in field studies in habitats suspected to have relatively low and high densities of feral cats (i.e., semi-arid rangelands and wetter areas with high densities of rabbits, respectively).

8.4 Identifying individual cats from hair and faeces
Issue
The use of DNA from hair follicles and faeces to identify individual feral cats has not been investigated, but offer much potential as a tool for estimating absolute abundance of feral cats, as well as for identifying the presence of cats in control operations or new immigrants in formerly cat-free areas (e.g., islands). Constraints on the accuracy of identification are likely to include the time since the hair or faece was deposited, and the method of storing the sample.

Recommended solution
Fund work to evaluate the conditions under which individual cats can and cannot be identified from hair follicles and faeces in both laboratory and field conditions. The best method(s) for storing the hair and faecal samples, and the primers used in analyses, should be described in a protocol.

9. Summary of Key Recommendations

1. Although the track count is the most useful estimator of feral cat abundance currently available, a random sampling design should be employed.

2. Protocols need to be developed for estimating the absolute and relative abundance of feral cats, and the kill rates of feral cats in control operations. Further work is required to develop protocols for estimating the absolute and relative abundance of feral cats, but a protocol for estimating the kill rate in feral cat control operations could be written with available information.

3. Studies should be funded to (i) estimate the probability of detecting feral cats with sand plots, cage traps and leg-hold traps, and (ii) evaluate the potential of these detection devices in various sampling designs for estimating the absolute and relative abundance of feral cats. These studies need to be in different habitats. The optimal designs should be field tested and then, if they prove to be reasonable estimators, translated into monitoring protocols.

4. Capture-mark-recapture techniques based on grid- or web-based detection devices should be investigated as a method for estimating the absolute abundance of feral cats.

5. Methods for identifying individual feral cats from DNA in hair and faeces need to be tested/developed.

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