Feral cat control research: *Western Shield* review—February 2003

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SUMMARY

Background

The feral cat (*Felis catus*) is recognised as a significant threat to fauna conservation in Western Australia, particularly in arid and semi arid regions of the State. Not only do feral cats prey on native fauna and have the potential to spread diseases, but they have proven to be an obstacle to fauna reintroduction programs. *Western Shield* fox baiting strategies have been ineffective against feral cats largely because the standard fox/dog baits are not attractive to feral cats. Until the commencement of the research described in this review paper, there was no broad area control technique available for feral cats.

Feral cat control research objectives and broad strategies

The principal objective of the feral cat control research program, commenced by scientists of the Western Australian Department of Conservation and Land Management (CALM) in December 1993, is to design and develop an operationally feasible bait, and baiting regimes to provide effective and cost-efficient broadscale control of feral cats. Essentially, three strategies are being employed to achieve this.

First, a comprehensive and carefully designed series of both cafeteria pen trials with stray cats and subsequent field trials with feral cats were conducted in an endeavour to develop a bait medium that was attractive to feral cats. The medium also had to have operational utility including a capacity to carry a toxin, be relatively simple and inexpensive to manufacture, be easily and safely handled and transported and applicable to aerial deployment over large areas. Initially, a number of bait media, representing a broad range in physical form and type, were examined for acceptability by cats. A variety of flavour enhancers was then added to the most preferred bait medium to assess whether acceptability could be further improved.

Second, field-based research and operational trials focussed on field testing and further development of effective broadscale aerial baiting strategies for feral cats. This initially involved examination of bait uptake in relation to the time of year (season) to enable baiting programs to be conducted when bait uptake is at its peak and therefore maximise efficiency. A key factor affecting bait uptake is the availability of live prey, the nature and abundance of which varies geographically and temporally. While a number of trials have been undertaken in a range of ecosystems, current and future investigations aim to examine the effects of season, baiting intensity (number of baits laid km^{-2}) and baiting frequency (interval between baiting operations) needed to optimise sustained control. These baiting research and development programs are ahead of schedules outlined in the *Western Shield* Proposal and the Western Shield Strategic Plan 1999-2004.

Finally, in addition to optimising the various parameters of baiting strategies, it will be essential that a comprehensive risk assessment of the potential impact of feral cat baiting programs on populations of non-target species be undertaken, and where necessary, methods devised to reduce this risk. This risk assessment is in part required to gain National Registration Authority registration of the new bait as well as assuring the protection of native fauna. While reliable techniques have been developed to assess the relative abundance of feral cats, it is also necessary to further develop techniques to efficiently and reliably census feral cat populations. This, together with an effective baiting strategy, will enable experimental determination of the level of feral cat control necessary to protect either extant fauna or reintroduced fauna across the State's semi-arid and arid bioregions.

Achievements

Investigations thus far have culminated in the development and patenting of a novel feral cat bait that is proving highly effective in experimental and operational baiting programs in arid and semi-arid regions of WA, as described in detail in this review. For example, the most recent large scale aerial baiting trial implemented under dry winter conditions in the Gibson Desert resulted in about a 95% reduction in the relative abundance of feral cats. The feral cat bait, which is also effective against foxes, has been used successfully in the eradication of feral cats from two islands off the Western Australian coast.

Research into the relationships between season, live prey abundance and bait uptake are well advanced in a number of bioregions. Results to hand show temporal (seasonal) variability in live prey abundance and bait consumption. In areas that experience a Mediterranean-type climate and particularly where rabbits are abundant, the optimum baiting period occurs in the drier autumn/early winter months when young, predator-vulnerable prey are not present but before the onset of winter rains. As predator-vulnerable young prey become more abundant, which is a function of long-term weather conditions (season/rainfall), bait uptake is likely to decline. In the arid zone, where rainfall is unreliable, the time and intensity of rainfall events and season determines the overall abundance of prey. Research in the interior arid zone has suggested that the optimum time to conduct baiting programs and maximise their effectiveness is under cool dry conditions in winter. At this time, the abundance and activity of all prey types, in particular small mammals, reptiles and birds, is at its lowest and bait degradation due to ants and to hot, dry weather, is significantly reduced.

The current series of trials is designed to investigate baiting efficacy at differing bait distribution rates (number of baits per unit area) to provide a cost-efficient control strategy. To-date, this series has demonstrated that a baiting density half that used in island eradications is equally efficacious in the control of feral cats in the arid interior. A highly effective toxic baiting of feral cats on the Gibson Desert Nature Reserve and Peron Peninsula this year has supported this evidence. The high level of bio-marking and good control of feral cats during these exercises suggests that further reductions in bait distribution may not reduce baiting efficacy.

Difficulties

There have been no extraordinary difficulties with a research project of this complexity and magnitude. Scientists commenced the project with little or no available background scientific information. There were commercial-in-confidence issues in accessing literature on cat food and the ramifications of patenting various aspects of the research. Other difficulties are associated with the temporal and spatial practical aspects of working on feral cats at an operational or large scale, and in remote areas. However, the main difficulty in such a project, and one which is universal to most research, that is gaining sufficient funding to enable the research to be carried out to a high standard and be completed within an acceptable time frame. To a large extent, this problem has been overcome with sponsorship being provided over a five-year period. The only other significant difficulty has arisen during the course of the collaborative research into the felid-specific toxin where development of the encapsulation system for the toxicant is taking a longer period of time than originally anticipated.

Potential economies

The step-wise approach to developing an optimal broadscale, aerial feral cat control strategy is being pursued to provide for effective and cost-efficient wildlife recovery. The focus is on optimising feral cat predation control through aerial baiting and providing a comprehensive evaluation of any impact on non-target species populations. The program is structured to enable analysis of the cost-benefit of various baiting regimes on both feral cats and non-target species and provide information essential to gaining registration of the feral cat bait.

The development of a readily manufactured sausage-type bait will result in considerable savings in production, handling and delivery of the bait. The cost of feral cat baits is currently about 30^c per bait at today's level of production. One third of this cost is for materials, and the remainder is associated with labour and production equipment. The future costs of baits will depend on economies of scale (level of production), degree of automation and the cost and depreciation rate of the manufacturing equipment, but it is anticipated that costs can be reduced when manufacture extends to an operational scale.

Potential improvements

Future research will focus on refinements to the bait medium, the development of a felid specific toxin, refinements to bait production and handling and designing bioregionally appropriate baiting regimes with respect to season, intensity and frequency of baiting. Further research on non-target issues is a high priority.

INTRODUCTION

The Department of Conservation and Land Management's (CALM) '*Western Shield*' project has been operational for 6 years and it is timely that the Corporate Executive has initiated a review of the project. The review is in four parts, including the preparation of a series of review papers on various topics relevant to operational and research activities aligned with *Western Shield*. This includes a review of feral cat control research. The terms of reference given to the authors were as follows:

- An overview of the rationale for feral cat control.
- An overview of all research aimed at developing a broadscale control technology for feral cats including results of cat control experiments across various climatic/habitat types.
- Address issues of non-target bait take.
- An overview of what is known of the interaction between feral cats, foxes and dingoes/dingo-dog hybrids.
- Provide an overview of the criteria for determining where and why feral cat control is required.

- Discuss any current obstacles to broadscale implementation and research needs and timelines for overcoming them.
- Discuss how and when bait registration can be achieved and the likely cost of feral cat baits.
- Discuss the future of the Felid Specific Toxin including whether non-target issues have been addressed.

(note: we have re-ordered the original terms of reference in to what we consider to be a more logical sequence)

While a number of papers have been written as internal reports and are now in various stages of preparation for publication or in press, few papers covering the above terms of reference in entirety have been published in scientific journals. To assist the reviewers, we therefore present detail about the objectives, methods and results of feral cat control research.

RATIONALE FOR FERAL CAT CONTROL

The Australian arid zone has experienced a high rate of native mammal decline following European settlement. Since the 1920s, about 33% of all mammals and about 90% of medium size mammals (35–5500 g adult body weight range) have either suffered dramatic range contractions or are extinct (Burbidge and McKenzie 1989). Many of these species are now restricted to several offshore islands and due to small population sizes and restricted geographic ranges, are vulnerable to total extinction. Large tracts of the arid interior of Western Australia are relatively pristine and have not experienced disturbances usually associated with European settlement such as pastoralism and clearing for agriculture and urbanisation. A number of causes have been proposed to explain this decline. These include changed fire regimes, competition from introduced herbivores, disease, extreme variability in weather and site fertility and predation by introduced predators, specifically the fox (*Vulpes vulpes*) and the feral cat (*Felis catus*) (Burbidge and McKenzie 1989; Johnson *et al.* 1989; Morton 1990; Dickman 1996; Environment Australia 1999; Abbott 2002). Predation by feral cats also threatens the continued survival of many other native species persisting at low population densities (e.g. Smith and Quin 1996; Risbey *et al.* 2000) and has been identified as one of the major obstacles to the reconstruction of faunal communities as it has prevented the successful re-introduction of species to parts of their former range (Christensen and Burrows 1995; Gibson *et al.* 1995; Dickman 1996; Environment Australia 1999).

Management of introduced predators is now generally viewed as a critical component of successful reintroduction, recovery or maintenance of small to medium-sized native fauna populations (Christensen and Burrows 1995; Fischer and Lindenmayer 2000). It has also been suggested that competition by feral cats with native carnivorous species (eg. some dasyurids, predatory birds and larger reptiles) may reduce their population viability (Cross 1990). However, compelling evidence for competition has not been obtained (Dickman 1996). Cats are also the hosts and reservoirs for a number of diseases such as *Toxoplasmosis* that can affect wildlife (Cross 1990; Dickman 1996; Environment Australia 1999).

As a consequence of these impacts, control of feral cats is recognised as one of the most important fauna conservation issues in Australia today. The impact of feral cats on native fauna is acknowledged by Commonwealth legislation, as outlined in Schedule 3 of the *Environment Protection and Biodiversity Conservation Act 1999*. The national *Threat Abatement Plan for Predation by Feral Cats* (Environment Australia 1999) lists 38 species on Schedule 1 of the above Act for which there is a known or inferred threat from feral cat populations. That is, 38 endangered species have been identified as potentially benefiting from effective feral cat control, as part of their management/recovery programs.

OVERVIEW OF RESEARCH AND SUMMARY OF KEY RESULTS

Historically, a range of techniques has been used in attempts to control feral cats, including shooting, trapping, poison baiting, biological control, hunting and exclusion fencing. The *Threat Abatement Plan for Predation by Feral Cats* (TAP) identifies these control techniques at the time as generally expensive, labour intensive and requiring continual application to be effective at controlling feral cats even over small areas (Environment Australia 1999). These existing methods, in their current form, are not suitable for broadscale control of feral cats over most of Australia.

Outlined in the TAP are a number of potential techniques which might offer effective feral cat control including various means of reducing reproductive success, biological control and development of new bait types with improved target-specificity. Reducing reproductive success through development of an immunocontraceptive agent was dismissed as a viable control option because the concept has not been successfully applied to a free ranging population of any species (Environment Australia 1999). The use of chemical sterilants was considered inappropriate, as there are no effective compounds that produce permanent sterility in cats (Moodie 1995, cited in Environment Australia 1999). In addition, fertility control does not address the immediate problem of predation by feral cats being at levels that are detrimental to the continued survival of a threatened species population. No benefit was expected from the release of endemic pathogens as lethal, self-disseminating biological agents (Moodie 1995, cited in Environment Australia 1999). The possibility of creating a new felid pathogen is likely to be unacceptable because of issues of target specificity in relation to domestic cats, and possibly to *Felidae* outside Australia (Fisher *et al.* 2001).

Development of an effective broadscale baiting technique, and the incorporation of a suitable toxin for feral cats, was cited as a high priority in the TAP as it was most likely to yield an operational and cost-effective method to control feral cat numbers in strategic areas (Environment Australia 1999). Under the Threat Abatement objectives and actions, 'Objective 4: Improve the effectiveness of feral cat control methods: delivery systems', the actions required were listed as:

- Identify the most attractive bait materials for use with feral cats and the conditions under which different baits will be most effective by reviewing the results of previous studies on a range of potential baits.
- Assess existing delivery systems for their effectiveness in delivering control substances to feral cats and minimising the risk of non-target impacts.
- Identify and develop the most attractive bait(s) for use in combination with the cat-specific toxin to provide a feral cat control system suitable for broadscale use.

Bait development

Commencing in December 1993 CALM scientists conducted a comprehensive and carefully designed series of cafeteria pen trials with stray cats and subsequent field trials with feral cats in an endeavour to develop a bait medium that was attractive to feral cats, capable of carrying a toxin, relatively easily and cheaply manufactured and could be deployed aerially over broadscale areas (Friend and Algar 1993; 1994a and b; 1995; Algar and Sinagra 1995; 1996 a, b and c). Initially, a number of bait media, representing a broad choice in physical form and type, were examined for acceptability. A range of flavour enhancers was then added to the most preferred bait medium to assess whether acceptability could be further improved. These initial trials indicated the suitability of kangaroo meat as a bait medium and early trials conducted in the Gibson Desert (see Section 'Baiting trials') using a prototype bait consisting of a 30-40 g, fresh kangaroo meat chunk confirmed bait acceptance by feral cats. Using kangaroo meat chunks as baits however presented a number of problems in bait manufacture and field application:

a) Provision of standard sized kangaroo meat chunks precluded automation of bait production as the baits could only be cut manually.
b) Manual production of baits was labour intensive and resulted in considerable wastage of meat.
c) Dosing the baits with the toxin had to be performed manually.
d) It was difficult to provide a uniform coating of the surface of baits with flavour enhancers and in the presence of rain the coating would wash off.
e) The coating made it extremely difficult to avoid baits clumping together when deploying them in the field.
f) Finally, the lean kangaroo meat would dry quickly in the sun, even during the cooler months, and become too hard within a short time to be acceptable to feral cats.

To overcome these problems, the use of a kangaroo meat sausage was assessed as a suitable alternative to the kangaroo meat chunk. These investigations have recently culminated in the development and patenting of a novel feral cat bait that is proving highly effective in experimental and operational baiting programs (see below, results of feral cat control experiments across various climatic/habitat types) to control feral cats. Paralleling this has been the development of an automated bait manufacturing process including the incorporation of a toxin (1080) (Armstrong, 2004). These baits are now routinely manufactured at the CALM Bait Factory in Harvey. The bait, hereafter referred to as the feral cat bait, is similar to a chipolata sausage in appearance, approximately 20 g wet-weight, dried to 15 g, blanched (that is, placed in boiling water for one minute) and then frozen. This bait is composed of 70% kangaroo meat mince, 20% chicken fat and 10% digest and flavour enhancers (Patent No. AU13682/01). Toxic feral cat baits are dosed at 4.5 mg of sodium monofluoroacetate (compound 1080) per bait. Prior to laying, feral cat baits are generally thawed and placed in direct sunlight. This process, termed 'sweating', causes the oils and lipid-soluble digest material to exude from the surface of the bait. All feral cat baits are sprayed, during the sweating process, with an ant deterrent compound (Coopex®) at a concentration of 12.5 $g\ l^{-1}$ Coopex as per the manufacturer's instructions. This process is aimed at preventing bait degradation by ant attack and the deterrent to bait acceptance from the physical presence of ants on and around the bait medium.

Feral cat bait design and development was essentially completed in 1999; certain refinements to the manufacturing process have occurred since this time to enable streamlining of bait production to produce a product of consistent standard and quality. These refinements have not affected feral cat bait acceptability (Algar and Brazell unpublished data). There are several factors in the bait production process and storage yet to be resolved, these include:

- Incorporation of the ant deterrent compound in the bait, rather than surface spraying
- Longevity of baits in storage.

Bait uptake in relation to time of year

Following development of the feral cat bait, a number of trials has been conducted examining bait uptake of this bait by feral cats in relation to the time of year. Examination of whether bait uptake is influenced by the time of year and if so, when bait uptake is at its peak, will determine the optimum period or periods to conduct control programs to maximise efficiency. To date, this research has been focused in semi-arid and arid areas.

The bait uptake trials were conducted by placing baits by hand along roads and tracks at dusk and measuring bait removal the following morning. We have observed that the uptake of baits recorded using this methodology is often significantly lower than that observed by the broadscale application of biomarked baits and therefore likely to be an underestimate of bait acceptance (Algar *et al.* in press, a).

Research into bait uptake by feral cats has indicated a temporal variability in bait consumption in areas influenced by Mediterranean climatic regimes (Algar and Angus 2000a; Algar *et al.* in press, a). This variability is correlated with the availability of prey (particularly where rabbits are the primary prey), which is a function of season/rainfall. In these areas, the optimum baiting period occurs in the drier autumn/early winter before the onset of winter rains when young, predator-vulnerable prey are not present. As predator-vulnerable young prey become more abundant, which is a function of long-term weather conditions (season/rainfall), bait uptake is likely to decline.

In the arid zone, where rainfall is unreliable, it has been observed that the time and intensity of rainfall events determines the abundance of many prey species, particularly mammals and birds (e.g., see Morton 1990). Research conducted in the arid zone has suggested that the optimum time to conduct baiting programs and maximise their effectiveness is under cool, dry conditions in late autumn/winter (Algar *et al.* 2002a). At this time rainfall, which will cause degradation of feral cat baits is less likely to occur than during the summer months, and the abundance and activity of all prey types, in particular predator-vulnerable young mammalian prey and reptiles, is at its lowest and bait degradation due to rainfall, ants and to hot, dry weather, is significantly reduced.

Baiting trials

Since completing development of the feral cat bait, a number of broadscale experimental and operational baiting programs have been conducted across various climatic/habitat types (Table 1). These baiting programs have commenced ahead of schedules outlined in the Western Shield Proposal (Burbidge *et al.* 1996) and the Western Shield Strategic Plan 1999–2004 (CALM 1999). The baiting campaigns conducted as part of the research program involved the examination of the level of control achieved under different baiting intensities (number of baits laid km^{-2}). These programs commenced following research examining bait uptake in relation to the time of year to enable baiting programs to be conducted when bait uptake is at its peak and therefore maximise efficiency. Other baiting campaigns have been conducted in the Gibson Desert Nature Reserve, initially with the prototype bait, and more recently using the feral cat bait. We present the key results of the various field trials relevant to feral cat control research carried out by CALM. These results are summarised in Table 1 and then the trials are documented in some detail by Bioregion (after Thackway and Cresswell 1995) apart from those on the Cocos (Keeling) Islands, which is an external territory and not described by Bioregion.

The Gibson Desert Bioregion – Gibson Desert Nature Reserve

The 18 900 km^2 Gibson Desert Nature Reserve (GDNR) is located in the interior of Western Australia, some 900 km from the west coast, at about 24.5° S to 25.5° S, 124.7° E to 126.3° E. The region has an arid climate (Beard 1969) with an annual average rainfall of about 217 mm. Typical of the arid zone, rainfall is erratic and undependable. Summers are hot with daily maximum temperatures often exceeding 45° C and winters are cool with overnight temperatures often falling below zero. The bioregion is characterised by gently undulating laterite plains, sand dunes, sand plains, stony mesaform hills and relict drainages. Various spinifex (*Triodia*) species form the dominant vegetation cover in association with scattered low shrubs and trees (see Thackway and Creswell 1995). Introduced vertebrate fauna in the region include

TABLE 1

Summary of recent broadscale feral cat baiting programs. Baiting efficacy is the per cent reduction in the relative abundance of the feral cat population following the baiting operation, or where non-toxic biomarker baits were used, the per cent of trapped feral cats that had taken a feral cat bait.

DATE	LOCATION & BIOREGION		BAITING INTENSITY (BAITS KM^{-2})	BAITING EFFICACY (%)
June 1999	Hermite Is., Montebellos, Pilbara Bioregion	Toxic operational baiting	100	80
March 2001	Faure Is., Carnarvon Bioregion	Toxic operational baiting	100	>90
July 2001	Gibson Desert Nature Reserve, Gibson Desert Bioregion	Biomarked non-toxic baits - cats trapped	100 50	82 100
March 2002	Pimbee Station, Carnarvon Bioregion	Biomarked non-toxic baits - cats trapped	50	100
March 2002	Peron Peninsula , Carnarvon Bioregion	Biomarked non-toxic baits - cats trapped	50	50
April 2002	Peron Peninsula , Carnarvon Bioregion	Toxic operational baiting	50	80
May 2002	Wanjarri Nature Reserve, Murchison Bioregion	Biomarked non-toxic baits - cats trapped	50 25	83 78
June 2002	Gibson Desert Nature Reserve, Gibson Desert Bioregion	Toxic operational baiting	50	96
August 2002	West Is., Cocos (Keeling) Islands	Toxic on-track baiting (baits suspended)	Baits at 100 m intervals	89

dingoes (*Canis lupus dingo*), foxes, feral cats, house mouse (*Mus domesticus*) and camels (*Camelus dromedarius*), which are widespread, and rabbits (*Oryctolagus cuniculus*) which are largely restricted to fossil drainage lines and are only relatively abundant after good rains.

The Gibson Desert project compromises a series of trials that commenced in 1989 (Christensen and Burrows 1995), is a BACI design (Before, After Control, Impact; Stewart-Oaten *et al.* 1986) with a baited (Impact) area and an unbaited reference (Control) area (see below). Surveys (described below) have been undertaken at regular intervals over the period 1989–2002 (Figure 1a–c) to determine the impact of various toxic baiting trials on the relative abundance of foxes, dingoes and feral cats.

There is no known efficient technique for reliably estimating the actual population of dingoes, foxes and feral cats in this environment (Jones 1977, Mahood 1980). The animals are difficult to capture and spotlighting was attempted but was unsuccessful due to the combined effects of relatively low animal density, thick spinifex cover and the cautious behaviour of the animals. Initially, introduced predator abundance surveys were carried out using two techniques; cyanide transects (Algar and Kinnear 1992) and track (paw print) count transects described below. The cyanide technique enables the calculation of the 'catch per unit effort index' (CPUEI) for each predator species (Algar and Kinnear 1992) but is very labour intensive, time consuming and potentially dangerous. Also, the cyanide technique was not reliable for estimating feral cat abundance because the uptake of cyanide baits by feral cats varied considerably from season to season depending on the availability of live prey. After initial trials, the cyanide technique was abandoned in favour of the track count transect technique.

Wilson and Delahay (2001) provide a summary of the strengths and weaknesses of using track counts along transects in their review of methods to estimate the abundance of terrestrial carnivores using field signs and observation. They cite work by Stander (1998) who was able to validate track counts against populations of lion (*Panthera leo*), leopard (*Panthera pardus*) and hunting dog (*Lycaon pictus*) of known size. They also cited work by Servin *et al.* (1987) and O'Donoghue *et al.* (1997) who demonstrated a relationship between track counts and actual abundance for fox and coyote (*Canis latrans*) respectively. Edwards *et al.* (2000) evaluated the efficacy of spotlight surveys and track surveys for assessing relative abundance of feral cats and dingoes in semi-arid rangelands in central Australia and reported that the track count method was more efficient and precise than spotlight surveys. On the other hand Stephenson and Karczmarczyk (1989) reported a poor correlation between snow-track count index and actual numbers of lynx but this involved a small number of surveys (Wilson and Delahay 2001). In an operational trial in Shark Bay, a semi-arid region of Western Australia, the mortality rate of radio collared feral cats following toxic baiting was closely correlated with the reduction in the track count index which was measured before and after baiting (K. Morris, CALM, pers. comm.).

The track count transect technique adopted in this and other trials involved scraping roads each day using 2 m long sections of steel railway line dragged behind a 4WD vehicle and then inspecting the roads just after sunrise each morning for fox, feral cat and dingo paw prints (tracks), which were readily discernible in the red sandy loam soils. Each survey involved inspecting 30-60 km of transect (along roads) each night over 3-4 nights. Experienced observers were securely positioned on a seat mounted on the front of a 4WD vehicle, which was driven along the road at 15-20 kmh^{-1}. The observers were skilled at track identification and were able to recognise (and record) the paw prints of foxes, feral cats and dingoes and of individual animals based on the size, shape and location of the prints along the transects. While animals usually followed the scraped roads for some distance, some individuals would meander on and off the roads. To reduce the possibility of double counting, individual sets of tracks that were physically indistinguishable (same species, same size, same shape, travelling in the same direction) but were less than 2 km apart on the transect, were assumed to be the same animal. Using this rule, and the same skilled observers, this technique provided a reliable and repeatable estimate of relative abundance with the standard error of the mean count over 3-4 nights being in the range 5-11% of the mean. As the transect distances were variable over the 13 years of the trial, the track counts were standardised to the number of tracks per 100 km and the resulting figure termed the track density index (TDI). Two and sometimes three introduced predator surveys were carried out each year in the impact area (treatment) and in the reference area (control) over the period 1989–2002 (Figure 1a–c).

Fundamentally, the Gibson Desert project aimed to determine whether applying toxic baits (the impact) significantly altered (decreased) the abundance of foxes, feral cats and dingoes in the impact area. In addition to tabulating and graphing the results of the individual trials described below, the overall impact of toxic baiting over the period of the project (1989–2002) was assessed by comparing the relative abundance of introduced predators at the site before and after baiting commenced, even though baiting was carried out irregularly (Table 2). As described above, the project was conducted over a relatively long period and at a large scale consistent with the natural density and activity patterns of these predators in this environment. Optimal experimental design that incorporates random assignment of treatments and controls appropriately replicated in space was not practical. First, reasonable spatial replication that assumes coverage of natural variation was not possible at the scale of this project. Second, the remoteness of the site, the limited access and resource limitations, made spatial replication unfeasible. Instead, the design is one that is spatially unreplicated (single-site) that requires a number of samples to be taken over time from two reasonably well defined populations in a treatment (impact) area and reference (control) area.

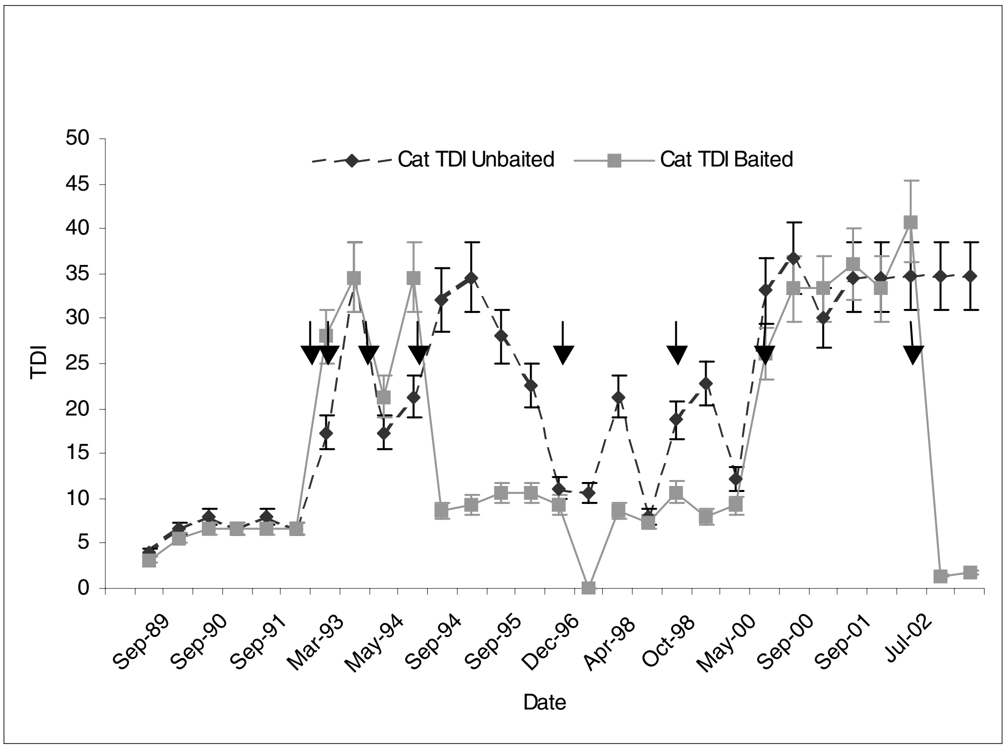

Figure 1a. Relative abundance of feral cats in the Gibson Desert study sites estimated using the track density index (TDI). Toxic bating is shown by the arrows. Various cat baits were used in May 1994, Sep. 1996, Sep. 1998 and Jun. 2002 (see Table 2).

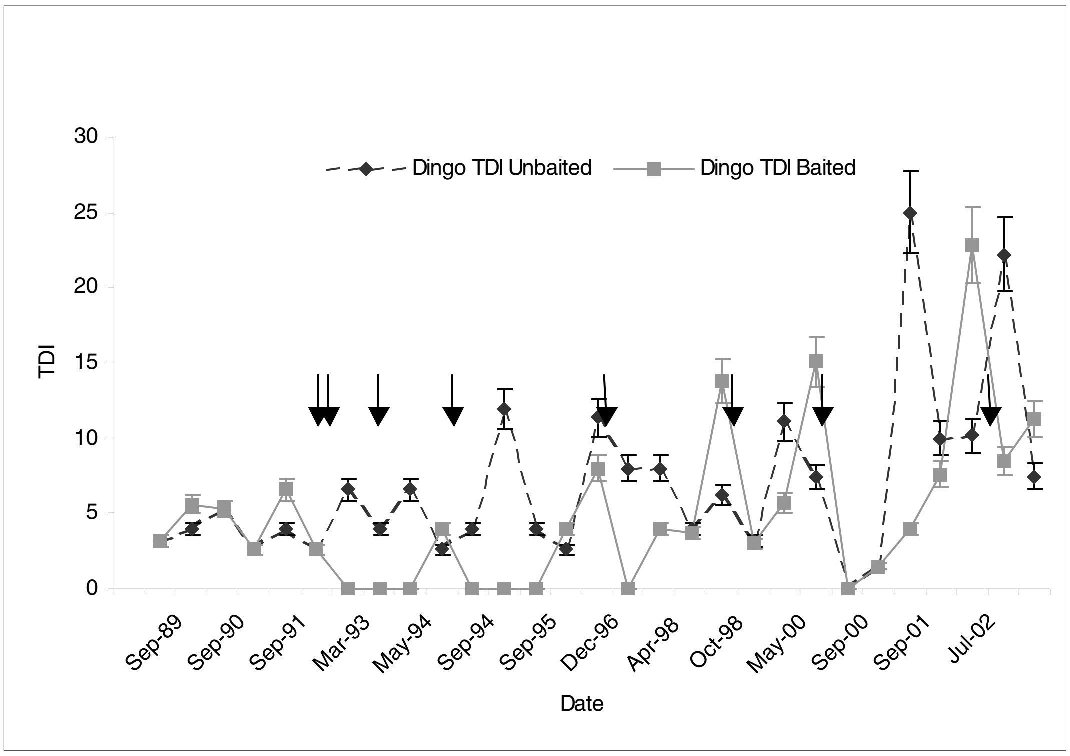

Figure 1b. Relative abundance of dingoes in the Gibson Desert study site estimated using the track density index (TDI). Toxic baiting is shown by arrows; Apr. 1992, Aug. 1992, Mar. 1993, May 1994, Sep. 1996, Sep. 1998, May 2000, Jun. 2002.

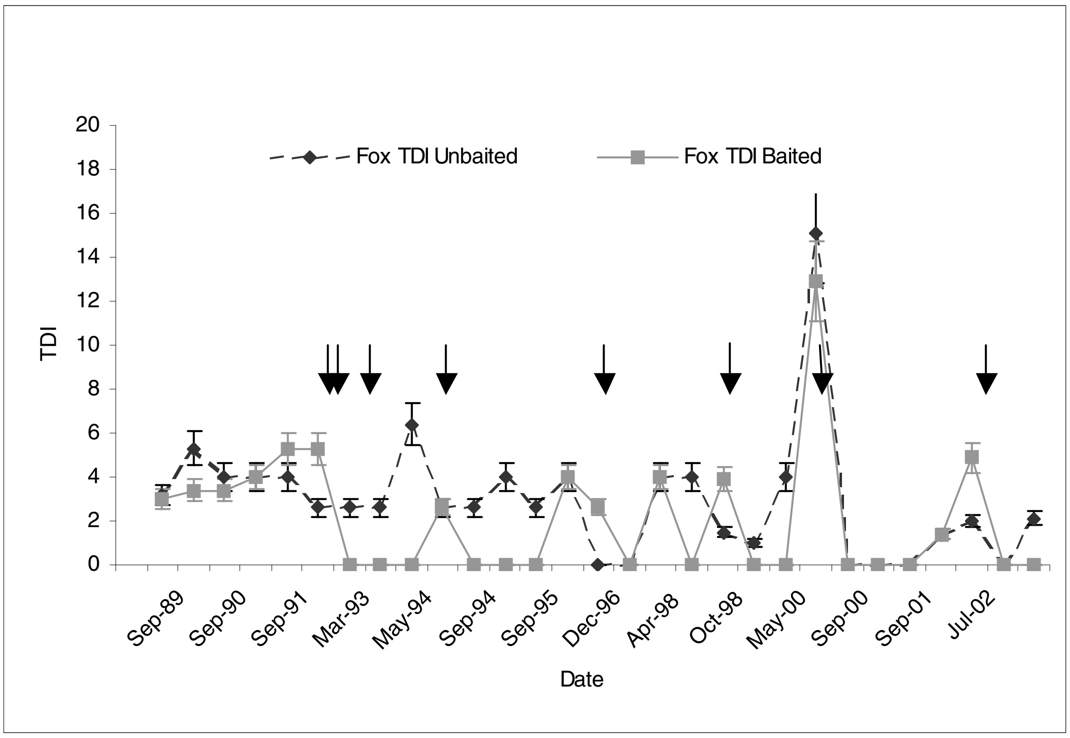

Figure 1c. Relative abundance of foxes in the Gibson Desert study sites estimated using the track density index (TDI). Toxic baiting is shown by the arrows; Apr. 1992, Aug. 1992, Mar. 1993, May 1994, Sep. 1996, Sep. 1998, May 2000, Jun. 2002.

Eberhardt (1976), in supporting the case for a role for non-traditional experimental designs in field ecology argues that two areas not widely separated in space, that are subject to the same climatic factors, are similar in landform, geology, soils and vegetation, have populations of (subject) animals with a similar make-up, would be expected to follow much the same population abundance trend over time, in the absence of human intervention. Stewart-Oaten *et al.* (1986) developed the BACI (Before, After, Control, Impact) sample design to deal with single-site environmental problems such as assessing the impacts of the discharge of effluents into aquatic ecosystems at a single point, where replicated experimental design is not possible. Because of the scale of this project, it was appropriate to adopt the BACI sample design of Stewart-Oaten *et al.* (1986). An impact (baited) and a control (unbaited reference) area were established and the relative abundance of introduced predators was sampled simultaneously at both places at various times before and after baiting with the objective of determining whether the differences between the impact and the control abundances had changed as a result of the baiting. Sampling times were used as 'replicates' and observations taken at the same time were averaged with one observation (the mean) used to represent the sample at each of the various time periods (Stewart-Oaten *et al.* 1986). The before and after mean differences in abundance (control and impact sites) were compared by a 't' test ($\alpha = 0.05$). The 't' test assumes that the observed differences, calculated at different times, are independent and that any differences are due to the impact (baiting in this case) (Stewart-Oaten *et al.* 1986). Similarly, we calculated and compared (using a 't' test) the mean ratios of introduced predator abundance; the Control-to-Impact abundance ratio for sample periods before and after baiting.

The results of the Gibson Desert Bioregion trials are presented at two levels. Firstly, we summarise the overall impacts of baiting on introduced predators and discuss long term trends in relative abundance in the Impact (baited) and Control (unbaited reference) areas, before and after baiting commenced in the study area, and then we summarise the results of the individual baiting trials shown in Table 2.

Over the thirteen year duration of the project, there has been a significant change in the difference in relative abundance (TDI) of introduced predators between the Impact (baited) area and the Control (unbaited reference) areas after baiting commenced, even though baiting over this period has been irregular (Table 3). The data presented below for individual trials using initially a prototype version and more recently the manufactured feral cat bait for feral cats over the period 1994–2002, show that the results of baiting operations were variable, as was the bait density and the time (season) of bait delivery. Notwithstanding this, the mean difference in relative abundance of feral cats between the Impact and the Control areas in the period prior to the commencement of baiting was 2.18 compared with a mean difference during the period after baiting commenced of 11.8 (Table 3). Similarly, there is a

TABLE 2

Summary of broadscale baiting operations associated with various research trials to develop techniques for controlling introduced predators in the Gibson Desert, Western Australia. Fox baits were 40–50 g dried meat. The bait type used for feral cats was initially the prototype version (fresh, small kangaroo meat chunks) and later the finalised manufactured (sausage product) feral cat bait. Baits were delivered at various densities by aircraft. Rainfall is from Carnegie Station.

DATE	RAINFALL 3 MONTHS PRIOR TO BAITING (MM)	BAITING TRIAL	AREA BAITED (KM^2)	BAIT TYPE	MEAN BAIT DENSITY (BAITS KM^2)
Apr. 1992	170	# 1	1 600	Fox bait toxic	6
Aug. 1992	90	# 1	1 600	Fox bait toxic	5
Mar. 1993	70	# 1	1 600	Fox bait toxic	5
May 1994	2	# 2	400	Prototype cat bait toxic	10
Sep. 1996	78	# 3	400	Prototype cat bait toxic	22
Sep. 1998	130	# 3	400	Prototype cat bait toxic	11
May 2000	214	# 4	1 600	Fox bait toxic	5
Jul. 2001	21	# 5	700	Feral cat bait non-toxic biomarker	50 and 100
Jun. 2002	10	# 6	625	Feral cat bait – toxic	50

TABLE 3

Changes in a) the mean difference in introduced predator relative abundance (TDI) between the Impact (baited) area and the Control (unbaited reference) area and b) in the mean ratio of introduced predator abundance; the Impact:Control ratio, before and after the commencement of baiting. Significant differences are shown as (**) a=0.05 and using a two-tailed t test.

VARIABLE	TIME PERIOD	MEAN (S.E.)		
		FERAL CAT	FOX	DINGO
a) Difference in relative abundance	Pre-baiting	2.18 (1.54)	0.00 (0.46)	0.47 (0.19)
	Post-baiting	11.81 (2.49)	2.74 (0.93)	5.34 (1.00)
	d.f.=24,t=3.28**	*d.f.*=21,t=2.30**	d.f.=21,t=4.71**	
b) Relative abundance ratio	Pre-baiting	1.12 (0.26)	1.21 (0.11)	0.88 (0.45)
	Post-baiting	0.49 (0.30)	0.37 (0.17)	0.54 (0.17)
		d.f.=24,t=5.49**	*d.f.*=21,t=4.07**	*d.f.*=21,t=1.92

statistically significant difference (a=0.05) between the mean relative abundance ratios for the Impact and Control areas before and after baiting commenced, with the mean before Impact:Control TDI ratio being 1.12 and the mean after Impact : Control TDI ratio being 0.49 (Table 3). Together with the individual trial data below, this suggests that the (significant) difference is due to baiting. Similar results apply to fox and dingo relative abundance, although the before and after abundance ratios for dingoes were not significantly different. This is probably due to the scale and frequency of baiting and the relatively rapid re-invasion by dingoes, especially in the smaller scale baiting operations.

A linear regression procedure PROC REG (SAS Corporation 1995) was used to develop a model to predict baiting effectiveness (per cent reduction in relative abundance of feral cats following baiting) using a linear combination of a number variables including baiting density, 12 months precedent rainfall, 3 months precedent rainfall, minimum temperature and maximum temperature. With only 5 degrees of freedom, the power of the regression analysis is low, but the procedure helped to statistically determine which variables acting alone or in combination explained most variation in baiting effectiveness. Based on a small number of feral cat baiting operations in the Gibson Desert (Table 2), bait density, precedent 3 months rainfall and minimum temperature during the baiting operation explained most of the variation in baiting effectiveness, with the first two variables accounting for most variation in the model;

$$BE = BD(0.41) - RN3(0.35) - MINT(0.25) + 83.4 \ldots\ldots\ldots\ldots (R^2 \text{ adjusted} = 0.46,\ P>F = 0.305)$$

where:
BE = baiting effectiveness (% reduction in TDI)
BD = baiting intensity (baits km^{-2})
RN3 = total rainfall in the previous 3 months (mm)
MINT = minimum temperature (^{o}C)

Because of the small number of samples upon which the model is based, and as reflected in the high intercept value, the model has limited application. However, it further supports the suggestion that baiting effectiveness is directly related to baiting intensity and inversely related to both rainfall prior to baiting and minimum daily temperature. Increasing baiting intensity, to a point, increases the chances of feral cats finding and consuming a bait. Prey availability is probably lower under cool, dry conditions, further enhancing the likelihood of hungry feral cats consuming a bait. This is discussed further below.

The track density index (TDI) survey data for the period 1989–2002 are presented in Figures 1a–c. These show that in the absence of control measures (baiting) canid abundance was variable but relatively low with the TDIs mostly less than 5 for foxes and 10 for dingoes. The highest canid densities were recorded during the year 2000 when the TDI reached 15.1 for both species. Fox abundance over the monitoring period was lower than what has been reported for other more productive natural environments in Western Australia. For example, over the period 1989 to 1991 when the CPUEI was measured together with TDI (prior to baiting), the CPUEI varied from 0.9 to 2.0 compared with CPUE indices of about 11 for Banksia woodlands (Algar and Kinnear 1992) and 17 for Acacia shrublands (Algar and Smith 1998) in near-coastal environments further to the south and west. In the unbaited areas of the Gibson Desert, the fox TDI varied from 0.0 to 15.1 but was commonly less than 5 (Figure 1b). By comparison, the fox TDI for the Peron Peninsula (mid-west coast of Western Australia) prior to control measures was in the vicinity of 85 (Neil Burrows, unpublished data). Following fox control on the Peron Peninsula, and in the absence of effective feral cat control, the cat TDI increased to about 60, which is almost double the highest level recorded in the Gibson Desert. In environments of high fox or feral cat abundance, such as parts of the mid-west coast of Western Australia, rabbits are usually also abundant and are an important dietary item (e.g. Jones 1977, Catling 1988, Short *et al.* 1997, Molsher *et al.* 1999). In the Gibson Desert where rabbits are normally scarce, none of the sampled fox scats or stomachs contained rabbit (Burrows *et al.* 2003).

In the absence of control measures, the feral cat TDIs were usually two to three times higher than that of the canids. As with the canids, the feral cat TDI was lowest during the late 1980s and peaked at about 35 during the early 1990s and again in the early 2000s. The feral cat TDI varied across a larger range than the canid TDI suggesting that feral cats may be more responsive to changing seasonal conditions than the canids; they showed a greater capacity to increase in abundance following seasons of average or above average rainfall. Feral cats are able to breed two to three times a year if conditions are suitable (Jones and Coman 1982), whereas the canids only breed once each year (Coman 1995, Corbett 1995). The impact of baiting events on the relative abundance of canids is clearly evident in Figures 1a–c. Baiting is followed by a significant reduction in the TDI. A similar pattern is evident for feral cats, but only following baiting with a feral cat bait type, either the prototype version (fresh, small kangaroo meat chunk) or the finalised manufactured (sausage product) feral cat bait. The magnitude of the reduction in feral cat relative abundance following baiting is quite variable and appears to be related to the density of baits, the season of baiting and the precedent rainfall.

Trends in the relative abundance (TDI) of feral cats in the unbaited reference area were associated with variation in the amount of rainfall (Figure 2), which in turn affects resource availability in these arid ecosystems (Morton 1990). The long term average annual rainfall for the region is about 217 mm. Rainfall records for the region (Figure 3), based on the mean rainfall for Carnegie, Glen Ayle and Warburton, meteorological stations within 250 km radius of the study site, show a period of below average rainfall during the 1980s, when the mean annual rainfall over the period 1981–1991 was 152 mm, followed by a period of well above average rainfall during the 1990s when the average annual rainfall over the period 1991–2001 was about 340 mm. This coincides with periods of low and high introduced predator densities (especially cat and dingo) respectively (Figure 1a–c).

GDNR Baiting Trial 1 (1989–93)

Aim

To control the abundance of introduced predators, especially the fox, by broad area aerial baiting so that founder populations of reintroduced mammals could establish. Research in the south-west of WA had shown that foxes were a serious threat to medium size mammals so baiting was largely aimed at controlling foxes. Because

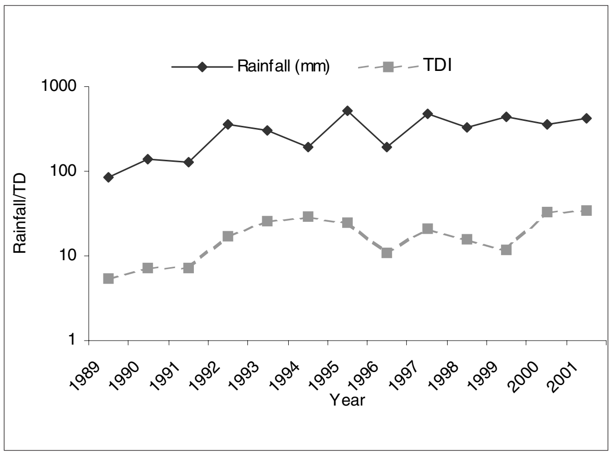

Figure 2. Mean annual rainfall (Carnegie Stn.) with mean track density index (TDI) for feral cats in an unbaited reference area in the Gibson Desert. Y axis is logarithmic.

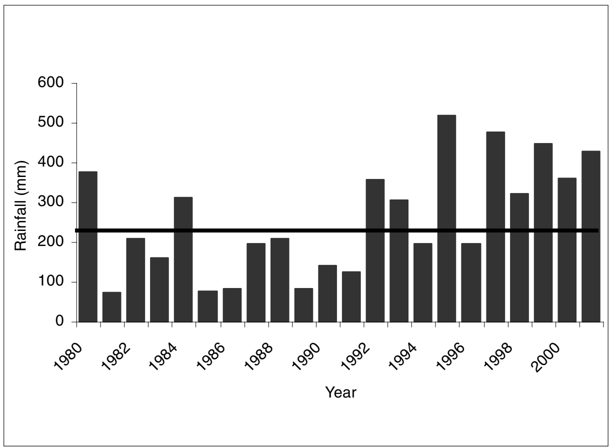

Figure 3. Average annual rainfall from three locations in the vicinity of the Gibson Desert Study area. The dark line is the long term average.

of their low density (at the commencement of this trial), smaller size and lack of evidence to the contrary, feral cats were thought not to be a serious threat.

Methods

Surveys to determine the relative abundance of foxes, feral cats and dingoes commenced in the area in May 1989 (Figure 1a–c), several years prior to the first (fox) baiting operation, which occurred in April 1992 (Table 2). At this time, and prior to mammal reintroductions, an area of approximately 1 600 km^2 (40 km x 40 km) was baited to provide protection for the reintroduced animals, which were released virtually in the centre of the baited area (Christensen and Burrows 1995). Heavy rain fell soon after baiting so the planned reintroduction was delayed and the area re-baited in August 1992. An aircraft was used to deliver standard 'fox' baits, which are 40-50 g dried meat injected with the 4.5 mg of the poison sodium monofluoroacetate (1080) (Table 2). This bait is routinely used to control foxes in the south-west of WA because of the known high resistance of native fauna to 1080 (King 1990). In August 1992, a total of 7800 fox baits was delivered at an average density of about 5 baits km^{-2}. Prior to and about one month after baiting, both an unbaited reference (control) area and the baited area were re-surveyed using the track count transect method described above to assess introduced predator densities. The 1600 km^2 area was baited again in March 1993 (Table 2) using standard fox baits and surveys of introduced predator densities were carried out before and about five months after baiting in both the baited and the unbaited areas.

Results and discussion

Aerial baiting using the standard fox bait (Table 2) was highly effective at reducing the abundance of canids as measured by the TDI (Table 4 and Figures 1b and c). Fox and dingo TDIs in the baited and unbaited reference areas were low prior to baiting, but fell to zero in the baited area three months after baiting and remained at zero for at least 12 months, suggesting local eradication or near eradication over this time (Burrows *et al.* 2003). Precisely when foxes and dingoes re-established following baiting is unknown because of the interval between post-baiting surveys. Figures 1b-c show that foxes and dingoes were not detected until May 1994 following baiting operations in August 1992 and March 1993. Even then, the TDIs were low at 2.6 and 4.0 for foxes and dingoes respectively. These data suggest that dingoes re-established more rapidly than foxes, which is to be expected. Dingoes occupy large home ranges and young animals are capable of dispersing over long distances. Home ranges of up to 77 km^2 and dispersal distances of 250 km have been recorded for parts of arid Australia (Corbett 1995).

Foxes in the semi-arid and arid zones of Western Australia appear to be highly susceptible to 1080 baiting. Virtual eradication of foxes was achieved following a single baiting on Peron Peninsula in the Shark Bay Region (Algar and Smith 1998) and in the Gascoyne region (Thomson *et al.* 2000). It is highly likely that in the arid environment of the Gibson Desert, the dried meat fox baits remain toxic in the field for some considerable time after delivery. This, combined with the low natural abundance of foxes and dingoes in this environment, especially during drought periods, probably explains the relatively long interval before re-invasion of the site.

The 1992 fox baiting operation appears to have had a positive impact on the feral cat population (Figure 1a and Table 4). Feral cat TDI in the baited area increased from 6.6 to 28.0 and in the unbaited area, from 6.6 to 17.3 (Table 4), suggesting that there was little if any ingestion of the fox baits by feral cats. The 10.7 units of increase in the feral cat TDI in the unbaited reference area is probably due to the above average rainfall (therefore higher prey availability and favourable breeding conditions) over the period (Burrows *et al.* 2003). This could also explain 10.7 of the 21.4 units of increase in the baited area. Dingoes have been shown to influence the abundance of feral cats in other ecosystems (Williams *et al.* 1995; Pettigrew 1993), so the removal of canids from the baited area may explain the balance of the feral cat TDI increase in the baited area (a further 10.7 units). However, with the removal of foxes and dingoes, it might be expected that feral cat activity on the roads and tracks would increase, giving the appearance that feral cat abundance had increased. A rapid and significant increase in feral cat abundance following removal of foxes was also observed in the Shark Bay area of Western Australia (Algar and Smith 1998).

TABLE 4

Baiting trial 1: Mean relative abundance of introduced predators (foxes, dingoes and feral cats) as determined by the track density index (TDI) before and after baiting using standard fox baits at a density of about 5 baits km^{-2}. TDI standard errors are in parentheses. Post-bait surveys were carried out 1–3 months after baiting.

DATE	FOX TDI				DINGO TDI				FERAL CAT TDI			
BAITED	BAITED		NOT BAITED		BAITED		NOT BAITED		BAITED		NOT BAITED	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
August 1992	5.3 (0.3)	0.0	2.6 (0.2)	2.6 (0.2)	2.6 (0.2)	0.0	4.0 (0.3)	6.6 (0.4)	6.6 (0.4)	28.0 (2.1)	6.6 (0.5)	17.3 (1.3)
March 1993	0.0	0.0	2.6 (0.2)	6.6 (0.5)	0.0	0.0	4.0 (0.3)	6.6 (0.4)	34.6 (2.8)	21.3 (1.7)	34.6 (2.4)	17.3 (1.4)

While the March 1993 baiting maintained the canid TDI at zero until at least September 1993, the feral cat TDI in both the baited and unbaited areas inexplicably fell by 39% and 50% respectively (Figure 1a and Table 4).

GDNR Baiting Trial 2 (1994–98)

Aim

To develop effective and efficient operational baiting techniques to control introduced predators, particularly the feral cat (Burrows *et al.* 2003). Baiting trial 1 (above) showed that standard fox baits had no direct impact on the feral cat population.

Methods

With the loss of the reintroduced mammals to predation by feral cats (see Christensen and Burrows 1995) the bait trial area was reduced to about 400 km^2 (20 km x 20 km) within the initial 1 600 km^2 impact area described above. The unbaited (control) area was also reduced in size (to 400 km^2) and located closer to the baited area (within 5 km). The same transects were used in the baited area to assess the relative abundance of introduced predators. Aerial baiting was carried out in May 1994, September 1996 and September 1998 using a prototype of the feral cat bait (Algar and Smith 1998) dispensed at different densities for each trial (Table 2). The prototype bait used in these trials was a small (30–40 g), fresh (rather than dried) kangaroo meat bait coated in digest, and dosed at 4.5 mg of 1080 per bait. The bait is also ingested by, and is lethal to, foxes and dingoes. Introduced predator track count surveys (as described above) were carried out over 3–4 consecutive nights in the baited and unbaited areas using about 30 km transects in each area before and after each baiting operation.

Results and discussion

The smaller scale baiting trial (400 km^2) conducted in May 1994 at a density of 10 baits km^{-2} using the prototype feral cat bait (Table 2) virtually eradicated canids from the baited area for at least 12 months after baiting with the TDI for foxes and dingoes falling to 0.0 (Table 5 and Figures 1b and c). Following the baiting, foxes and dingoes were first recorded in the baited area in September 1995. The feral cat TDI in the baited area fell from 34.6 measured just prior to baiting, to 8.6 measured about 3 months after baiting, representing a reduction in cat abundance of about 75%. Over the same period, feral cat TDI in the unbaited reference area increased from 21.3 to 34.6 (Table 5), representing a 62% increase in abundance (Burrows *et al.* 2003). In the absence of further baiting, feral cat TDI in the baited area increased slightly over the two years following the 1994 baiting, but declined in the unbaited area after an initial increase (Figure 1a). This may have been in response to an increase in dingo abundance over this period (Figure 1c) causing a real or apparent reduction in feral cat density.

The second small scale baiting conducted in September 1996 at a density of 22 baits km^{-2} also virtually eradicated canids (TDI = 0.0) when their abundance was assessed some three months after baiting (Table 5). There was also a 30% reduction in dingo abundance in the unbaited reference area suggesting that they may have been affected by the baiting. Dingoes are capable of travelling long distances and some animals may have ventured into the baited area, about 5 km from the unbaited area. The baiting did not appear to impact on feral cats or foxes in the unbaited reference area, suggesting that the buffer (distance) between the two areas was adequate for these species at least. In the baited area, feral cat TDI fell from 9.3 to 0.0 (measured 3 months after baiting), but remained about the same in the unbaited reference area (Table 5). This represents a 100% reduction in abundance based on the TDI survey technique. It is unlikely that eradication was achieved, but feral cat abundance was reduced to an undetectable level using the track count technique. Feral cat abundance was very low prior to baiting (TDI = 9.3), so these results need to be interpreted cautiously. The next survey was conducted in September 1997, some 12 months after the baiting operation. The

TABLE 5

Baiting trial 2: Mean relative abundance of introduced predators (foxes, dingoes and feral cats) as determined by the track density index (TDI) before and after baiting using the prototype feral cat bait at a density of a) 10 baits km^{-2} (1994), b) 22 baits km^{-2} (1996) and c) 11 baits km^{-2} (1998). TDI standard errors are shown in parentheses. Post-bait surveys carried out 1–3 months after baiting.

DATE BAITED	FOX TDI				DINGO TDI				FERAL CAT TDI			
	BAITED		NOT BAITED		BAITED		NOT BAITED		BAITED		NOT BAITED	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
May 1994	2.6 (0.2)	0.0	2.6 (0.2)	2.6 (0.2)	4.0 (0.3)	0.0	2.6 (0.2)	12.0 (0.9)	34.6 (2.9)	8.6 (0.6)	21.3 (1.8)	4.6 (2.6)
September 1996	2.6 (0.2)	0.0	0.0	0.0	8.0 (0.6)	0.0	11.4 (0.8)	8.4 (0.6)	9.3 (0.6)	0.0	11.1 (0.7)	10.6 (0.8)
September 1998	3.9 (0.3)	0.0	1.5 (0.1)	1.0 (0.1)	13.8 (1.2)	0.0	6.2 (0.5)	1.0 (0.1)	10.7 (1.0)	8.0 (0.6)	18.7 (1.7)	22.8 (2.1)

feral cat TDI in the baited area had increased from 0.0 to 8.6, but it was significantly lower than the TDI in the unbaited area, which was 21.3 (Figure 1a). The virtual eradication of feral cats during this second feral cat baiting trial is ascribed to the higher density of baits delivered on the ground and to the below average rainfall during 1996, which probably resulted in a reduction in prey available to feral cats making them more inclined to consume the baits (Burrows *et al.* 2003).

The third baiting trial conducted in September 1998 at a density of 11 baits km^{-2} and following above average rainfall in 1997 and 1998 (Burrows *et al.* 2003) also reduced canid abundance dramatically, with the TDI falling from 3.9 to 0.0 for foxes and from 13.8 to 3.0 for dingoes (Table 5). When measured in May 1999, six months after baiting, fox TDI was 0.0 and the dingo TDI had increased to 5.7 (Figures 1b and c). The relatively rapid recovery of dingoes was probably a function of the small area baited and the large home range and dispersal capacity of dingoes. Following baiting, the feral cat TDI fell from 10.7 to 8.0, representing a 25% reduction in abundance (Table 5). However, feral cat density in the unbaited control area over the same period increased from 18.7 to 22.8 (Figure 1a), representing a 22% increase. The difference in feral cat density between the baited and the unbaited control prior to baiting may have been due to the higher density of dingoes in the baited area (Figure 1c), or to the previous feral cat control measures, or to both factors. It appears that the September 1998 feral cat baiting operation was less effective in reducing feral cat density than the previous operation in September 1996. As with foxes and dingoes, the capacity of feral cat populations to recover after successful baiting operations is probably a function of the effectiveness of the initial baiting in reducing the original population, the size of the area baited and precedent and antecedent rainfall.

The relatively poor feral cat baiting result in September 1998 (25% reduction in TDI) is attributed to above average rainfall during 1997 and 1998 (Figure 3) and the probable subsequent increase in abundance of prey species, and to the low density of baits (Burrows *et al.* 2003). Feral cats are not as adept at finding baits as canids (David Algar personal observation), so increasing the density of baits increases the likelihood of feral cats finding a bait before they have killed and eaten live prey. The above average rainfall was reflected in the condition of the vegetation, which was lush and green, and in the abundance of potential prey species particularly birds, small native mammals and the introduced house mouse. Working in a semi-arid environment on the Western Australian coast, Short *et al.* (1997) and Algar *et al.* (in press, a) found that bait uptake by feral cats was inversely proportional to rabbit density, the inference being that when prey (rabbits) were abundant, feral cats were less likely to consume a bait. In the Gibson Desert study area rabbits are present but at very low densities along fossil drainage lines (Burrows *et al.* 2003, Liddelow *et al.* 2002).

GDNR Baiting Trial 3 (2000)

Aim

Meso-predator release amongst sympatric populations of predators has been reported in North America (Lindstrom *et al.* 1995). The aim of this trial was to investigate the response of feral cat populations following the selective removal of foxes and dingoes. Earlier baiting (Trials 1 and 2 above) using standard fox baits demonstrated the effectiveness of this technique in reducing the abundance of canids, but feral cat abundance appeared to increase in some instances (see Figure 1a and Christensen and Burrows 1995). The hypothesis under test in this trial was that feral cat abundance is influenced by the abundance of canids such that felid abundance decreases with increasing abundance of canids. The importance of this is firstly knowing whether there is interspecific or intraspecific competition amongst the predators and secondly, managing dingo populations could be an important technique for managing feral cat populations, especially in areas where dingoes are important or have significance, such as on some Aboriginal land. There are also measures in some States (eg. NSW) to list the dingo as a threatened species; there is debate amongst scientists as to whether the dingo is in fact a native species.

Methods

To test this the original 40 km x 40 km (1 600 km^2) area that was baited in Trial 1 above, was again baited in May 2000 using standard fox baits. From previous trials (above) these baits are not attractive to feral cats so have little or no direct impact on feral cat abundance. This has been further substantiated by bait uptake trials where fox baits that have been carefully laid along transects have been consistently by-passed by feral cats (Neil Burrows personal observation). Surveys of the relative abundance of introduced predators (using the track count method) were carried out in the baited and unbaited (reference) area before, 1 week after, 8 weeks after and 16 weeks after baiting. If feral cat abundance increased rapidly following the removal of canids and before any effects of breeding, dispersal or migration, then it was likely that the feral cats had changed their activity behaviour in response to the removal of canids, rather than increased in abundance. On the other hand, if feral cat abundance steadily increased in the baited area (canids absent), but not in the control area (canids present), then we could assume a direct response between canids and feral cats, mediated by numerical changes.

Results and discussion

Canid TDI fell by about 90% within 1 week of baiting and by 8 weeks, no canid tracks were recorded in the baited area, whereas in the unbaited area their abundance remained constant, notwithstanding the lack of data at weeks 1 and 8 post-baiting (Table 6). There was a slight but insignificant increase in feral cat TDI in the baited

TABLE 6

Baiting trial 3: Mean relative abundance of introduced predators (foxes, dingoes and feral cats) as determined by the track density index (TDI) before and after baiting using standard fox baits in a 1 600 km^2 baited area and an unbaited control area. TDI standard errors shown in parentheses. Baiting was conducted in May 2000 and post-bait surveys carried out 1 week, 8 weeks and 16 weeks after baiting (nd = no data).

TDI	BAITED AREA				UNBAITED AREA			
	PRE-BAIT	1 WEEK AFTER	8 WEEKS AFTER	6 WEEKS AFTER	PRE-BAIT	1 WEEK AFTER	8 WEEKS AFTER	16 WEEKS AFTER
Fox	13.9 (1.3)	1.0 (0.1)	0.0	0.0	13.3 (1.3)	nd	nd	13.3 (1.3)
Dingo	11.2(1.2)	1.5 (0.1)	0.0	1.5 (0.1)	13.3 (1.2)	nd	nd	11.2 (0.9)
Feral cat	26.1(2.3)	28.6 (2.4)	36.7 (3.2)	33.3 (3.2)	23.3 (2.1)	nd	nd	30.0 (2.8)

area one week after baiting, but by 8 weeks, the TDI had increased from 26.1 to 35.0, representing a 34% increase in abundance. By 16 weeks after baiting, feral cat density had decreased slightly to 33.3 and dingoes had re-invaded the baited area, albeit at a very low density (TDI = 1.5). There was no evidence of re-invasion by foxes (Table 6). The relatively rapid increase in feral cat TDI following baiting of canids suggests that feral cats changed their activity patterns in response to the removal of canids. That is, it is most likely that actual feral cat density did not increase in the 8-week period post-baiting, but, in the absence of canids, used the roads more frequently. This trial suggests that feral cats change their behaviour following the removal of canids, giving the appearance of increased abundance, rather than actually increasing in abundance. Molsher *et al.* (1997) reported little change in feral cat abundance following the removal of foxes in eucalypt forests in south-east Australia and Edwards *et al.* (2001) suggested that the presence of dingoes could assist the survival of feral cats by providing a source of carrion. The findings reported here are inconclusive with respect to the longer-term response of feral cat populations following the removal of canids. If there is strong competition between feral cats and canids, then control measures that eradicate canids only could result in compensatory predation by increased feral cat abundance. This requires investigation, especially in the south-west where foxes are selectively removed using fox baits, but feral cats appear unaffected by the baiting.

GDNR Baiting Trial 4 (2001)

Aim

This trial, using the feral cat baits, aimed to a) determine bait uptake by feral cats under cool, dry winter conditions, b) compare the effect of different baiting intensities on bait uptake by feral cats and c) investigate bait uptake by non-target animals (Angus *et al.* 2002a). The hypotheses under test were a) the abundance of prey species (reptiles, small mammals and birds) is low over the cold, dry winter months, so feral cats are more likely to take baits, b) increasing the density of baits increases the chances of a feral cat finding and consuming a bait and c) native mammals and reptiles do not consume the baits.

Methods

Two non-toxic baiting densities were compared for both target and non-target (native) reptiles and mammals uptake over the cool, dry winter season (July 2001).

Non-toxic feral cat baits containing the biomarker Rhodamine B (RB) were used as this is an efficient systemic marker for determining bait consumption by feral cats and a wide range of non-target species (Fisher *et al.* 1999; Fisher 1998). When Rhodamine B is consumed, the compound causes short-term staining of body tissues, digestive and faecal material with which it comes in contact. Certain metabolites of RB are absorbed by the body and are incorporated into the structure of growing hair. This technique has advantages over other bait markers in being relatively non-invasive, simple and inexpensive. Analysis for the presence of Rhodamine in the mystacial vibrissae is described in Fisher *et al.* (1999). Trapping programs are employed to capture feral cats and non-target species to allow identification of those animals containing the biomarker and thus determination of the percentage of the population that consumed a bait (i.e. baiting efficiency).

This trial enabled the concurrent assessment of possible efficacy in feral cat control and risk to non-target species, in the absence of a toxin. Two densities of non-toxic bait distribution, 100 baits km^{-2} and 50 baits km^{-2}, were trialed with each treatment being approximately 350 km^2 in area and in similar habitats. These baiting intensities were selected following the success of feral cat baiting programs on Hermite and Faure Islands (see Sections 3.3.2 and 3.3.3) using high baiting levels compared with the variable responses achieved in the earlier trials in the GDNR at lower baiting intensities. The baiting operation was carried out under cool, dry conditions in July when daily air temperatures ranged from overnight minima of 0–4^{o} C to maxima of 22–25^{o} C. Baits were distributed from an aircraft with special navigation and bait delivery system to ensure accuracy in the location and density of baits delivered (Angus *et al.* 2002a). Ten days after baiting, introduced predators (foxes, feral cats and dingoes) were trapped using Victor Softcatch leghold traps. Traps were placed at 500 m intervals along transects within each treatment area with a total of 502 trap nights in the 100 baits km^{-2} treatment and a total of 773 in the 50 baits km^{-2}

treatment (see Angus *et al.* 2002a). Captured predators were destroyed and their vibrissae and stomachs were removed for later examination.

Bait uptake by non-target vertebrate fauna was examined by sampling the fauna using grids of pitfall and medium Elliott box traps at two sites in each treatment (Angus *et al.* 2002a). Baits were deliberately delivered close (<130 m) to the non-target trap sites. All trapped animals, including reptiles and small mammals, were examined for signs of staining by RB.

Results and discussion

Based on the trap data (Table 7), bait uptake by feral cats was high at 100% and 82% for the 50 baits km^{-2} and 100 baits km^{-2} treatments respectively, or about 89% overall. There was no statistically significant difference ($z=1.63$, $P>0.05$) in bait uptake between the two bait intensity treatments (Angus *et al.* 2002a). The greater percentage of marking from the 50 baits km^{-2} treatment suggests that this baiting intensity would be at least as efficacious as the 100 baits km^{-2} for the control of feral cats.

A summary of non-target fauna captures is presented in Table 8. Skinks were the most numerous captures, with a strong representation by *Ctenotus pantherinus ocellifer*. The only taxon represented at all sites was *Ningaui ridei*, with most taxa represented at two or three sites.

None of the non-target mammals or reptiles sampled during this trial was marked by RB. If any individual did consume bait material, the amount consumed was insufficient to produce a detectable marking by RB. The distance between the mid-point of the nearest bait drop and the edge of the fauna sampling grids varied. This distance may have been greater than that normally traversed by some individuals sampled, however no bait drop was more than 130 m distant from the nearest sampling grid and baits were delivered directly overhead at two of the sites. Based on published home range data (e.g. Strahan 1995; see Moro and Morris, 2000) many of the individuals sampled would have potentially encountered baits. Not all species known to occur in the same broad location were represented in the sample. For these reasons, the assessment of risk to non-target fauna requires further investigation. It is significant however, that three small mammal species were sampled from sites that had directly received a high concentration of baits and that none showed any sign of having consumed bait material. Future work, specifically aimed at assessing non-target risk, will require a maximisation of the quantity and diversity of non-target animals that are likely to come into contact with a field application of baits.

GDNR Baiting Trial 5 (2002)

Aim

To investigate the effectiveness of baiting using toxic feral cat baits delivered at a density of 50 baits km^{-2} under cool, dry conditions in June/July 2002. The hypothesis under test was that baiting feral cats would be most effective

TABLE 7

Summary of predator vibrissae marking with RB, as determined by examination under low intensity UV light source of fluorescence microscope.

	50 BAITS KM^{-2}			100 BAITS KM^{-2}		
	FERAL CAT	DINGO	FOX	FERAL CAT	DINGO	FOX
Marked animals (Total)	13 (13)	2 (3)	2 (2)	18 (22)	4 (7)	2 (2)
% Marked	100	66.7	100	81.9	57.1	100

TABLE 8

Non-target fauna captures (source Angus et al. 2002a).

TAXON	BAITING INTENSITY	
	50 BAITS KM^{-2}	100 BAITS KM^{-2}
Ctenophorus isolepis gularis	**4**	**1**
Pogona minor minor	1	-
Delma haroldi	3	2
Delma nasuta	5	-
Delma tincta	-	2
Ctenotus calurus	2	1
Ctenotus helenae	-	1
Ctenotus pantherinus ocellifer	10	4
Cyclodomorphus branchialis	1	-
Neobatrachus sutor	2	-
Ningaui ridei	8	3
Sminthopsis youngsoni	-	1
Notomys alexis	3	-
Pseudomys desertor	-	2
Pseudomys hermannsburgensis	3	-
Total	42	17

during cool, dry winter months when prey availability is at its lowest, and by baiting at a high density to increase the likelihood of feral cats finding a bait (see Liddelow *et al.* 2002).

Methods

The bait used during this trial was the same as that used in the RB trial described above, except that one flavour enhancing ingredient (no longer commercially available) was omitted and each bait was injected with 4.5 mg of the toxin 1080 instead of RB. The area baited was 625 km^2 and baits were aerially distributed at a density of 50 baits km^{-2}. Two track density transects (see method described above) were employed to assess predator activity, one within the area to be baited, the other within the non-baited reference (control) area. Assessment was carried out simultaneously on the two transects by two separate teams. Transects were assessed on the three days before baiting was carried out and for three consecutive days, commencing nine days after baiting. The unbaited control transect traversed 32.7 km of this treatment. The baited treatment transect traversed both the core (23.3 km) and nominal buffer zones (5 km). Following baiting, an additional 11.1 km transect was established within the core baited area. This transect was assessed post-baiting only.

Results and discussion

The baiting operation was highly successful with about a 96% decrease in the mean track density index (TDI), within the core baited area (Figure 1a and Table 9). Only one individual cat paw print was detected within the core-baited area following baiting. There was no detectable change in the cat density (TDI) in the unbaited reference area. The efficacy of this trial confirmed previous findings from this site that baiting for feral cats in the autumn-winter months, when prey availability and non-target risk are low, can achieve a substantial reduction in relative abundance measured soon after baiting.

The Pilbara Bioregion – Montebello Islands

Aim

The importance of islands to the conservation of Australian mammal species has been well documented (Burbidge and McKenzie 1989; Abbott and Burbidge 1995; Burbidge *et al.* 1997). One of the key factors in the historic importance of islands has been that most have remained free of introduced predators. Burbidge (1999) highlighted the current and future importance of islands to nature conservation and stated that '*Australian nature conservation agencies need to pay more attention to the eradication of exotic animals from islands.*' Burbidge and Manly (2002) analysed the relationship between disturbances and native mammal extinctions on Australian islands and implicated feral cats in the extinction of these species on arid islands. They concluded that high estimated extinction probabilities are associated with ground dwelling, herbivorous, 'critical weight range' mammals of high body weight on islands of low rainfall, low to moderate presence of rockpiles and the presence of feral cats, foxes and rats.

Feral cats and black rats (*Rattus rattus*) became established on the Montebello Islands during the late nineteenth century and were probably introduced from pearling vessels. Feral cats occurred on several islands at various times, but by 1995 were naturally restricted to Hermite (Burbidge *et al.* 2000). Montague (1914) attributed the recent extinction of the Golden Bandicoot (*Isoodon auratus*) to predation by feral cats and predicted that the Spectacled Hare-wallaby (*Lagorchestes conspicillatus*) would suffer the same fate. Later surveys by Sheard (1950) and Serventy and Marshall (1964) found that the above two species had become extinct on the islands, confirming Montague's prediction.

Montebello Renewal (part of '*Western Shield*') aims to eradicate feral cats and black rats from the Montebello Islands to allow the successful re-introduction of locally extinct species (Burbidge 1997, Burbidge in this issue).

TABLE 9

Relative abundance (TDI) of feral cats along transects assessed for three nights before and after toxic baiting at a density of 50 baits km^{-2} in winter (June/July) 2002.

	DATE	MEAN RELATIVE ABUNDANCE (TDI) UNBAITED REFERENCE AREA	MEAN RELATIVE ABUNDANCE (TDI) BAITED AREA
BEFORE BAITING			
	21/06/02	39.8	42.9
	22/06/02	33.6	34.4
	23/06/02	30.6	60.1
Mean TDI		34.7	45.8
AFTER BAITING	03/07/02	24.5	0.0
	04/07/02	42.8	0.0
	05/07/02	36.7	4.3
Mean TDI		34.7	1.4

This project provided our first opportunity to assess the effectiveness of the feral cat bait and trapping techniques that Department researchers had developed in the eradication of feral cats from an island.

Methods

The Montebello Islands comprise a group of over 100 islands, islets and rocks off the Pilbara coast of WA. The islands are located between 20°21' and 20°32' S and between 115°3' and 115°36' E, approximately 100 km off the WA coast. The total area of the islands is approximately 2300 ha with Hermite Island being the largest at 1020 ha. The archipelago has a tropical, arid climate. The nearest weather station is on Barrow Island, 30 km to the south, which has a median rainfall of 285 mm, and mean daily maximum and minimum temperatures of 30.3° C and 21.4° C respectively.

Hermite Island is a difficult location on which to conduct a feral cat eradication campaign because of its isolation, rugged terrain and absence of vehicle access. The shape of the island is elongated and highly convoluted, with a number of sandy beaches, areas of mangroves, cliffs and limestone ridges and peninsulas. Its interior is low, undulating and is vegetated with a dense mat of Spinifex (*Triodia* sp.) with occasional *Acacia coriacea* thickets on deep sand.

The program to eradicate feral cats on Hermite Island involved aerial baiting to remove the majority of the feral cats, followed by intensive trapping to remove the remaining individuals. A reconnaissance of Hermite Island was conducted prior to the baiting program to assess feral cat abundance. Searches for evidence of fresh feral cat activity were conducted around most mangrove stands and sandy areas on the island. These were examined daily over a five day period. The location of fresh feral cat activity on swept areas, its extent and the distances between sites suggested that at least 20 feral cats were present prior to baiting.

About 1 100 feral cat baits were dropped by hand from a helicopter on the 3 July 1999. Hermite Island has two main soil types—deep sand and skeletal sands on limestone. Aerial baiting primarily targeted sandy soils with the flight path essentially following the 140 km coastline and then through the centre of the island to maximise bait availability and the area covered. Monitoring feral cat activity along a number of the beaches post-baiting indicated that several feral cats were still present. A trapping program was implemented to remove the remaining feral cats. The trapping program, techniques and assessment of feral cat activity are discussed in detail in Algar and Burbidge 2000 and Algar *et al.* 2002b.

Results and discussion

The intensive searches showed that feral cats, prior to baiting, had been active across much of the island, mostly along the sandy beaches, mangroves and *Acacia* thickets where 'highways' of tracks and numerous scat piles were observed. Some evidence of feral cat activity was observed along the limestone ridges and in the Spinifex plains, but these areas were understandably less favoured habitat and were used as pathways to the more preferred sites.

Four feral cats were captured during the trapping program. No evidence of fresh feral cat activity was observed across the island once the four feral cats had been trapped and it was concluded that eradication had been successfully completed. This was confirmed by searches for feral cat activity in August 2000. The fact that only four feral cats remained after baiting indicates that it was responsible for removing at least 80% of the feral cats from the island.

Feral cat eradication programs on islands are usually conducted using a combination of baiting, trapping and hunting (Veitch 1985; Rauzon 1985; Bloomer and Bester 1992; Bester *et al.* 2000). These eradication programs have met with varied success, their success and time to completion, often taking months or years, or are still ongoing, having been limited in part by lack of effective bait and trap lures. Bait acceptance by feral cats is in part related to the abundance of prey species (Algar *et al.* in press, a). The major prey items available to feral cats on the Island would have been rats, birds, reptiles and insects. The baiting campaign on Hermite Island was conducted when rat numbers were very low after a rat eradication attempt (see Burbidge, this issue) and when the availability of natural prey items, particularly reptiles and insects, was likely to be at its lowest (mid-to late-winter). The feral cat eradication program on Hermite Island was achieved in a matter of weeks and could have been completed sooner using the modification to the trap set (Algar *et al.* 2002b).

The advances in feral cat control strategies developed by CALM and the successful eradication program on Hermite Island led to the planning of feral cat eradication programs for a number of additional islands off the Western Australian coast, as per the Western Shield Strategic Plan 1999-2004 (CALM 1999).

The Carnarvon Bioregion - Faure Island, Pimbee Station and Peron Peninsula

Faure Island

Aim

Feral cats became established on Faure Island, off the Gascoyne coast of Western Australia, during the late nineteenth century and were probably introduced from pearling vessels or by early pastoralists. Australian Wildlife Conservancy (AWC), lease holders of the Faure Island pastoral lease, is planning to establish the area as a site for the conservation of threatened mammals and ecotourism. No native mammals now occur on the island; however there is evidence from sub-fossil deposits that at least four species once occurred on the island. AWC propose to translocate five native mammal species to the island: the western barred bandicoot (*Perameles bougainville*), boodie (*Bettongia lesueur*), greater stick nest rat (*Leporillus conditor*), Shark Bay mouse (*Pseudomys fieldi*) and banded hare-wallaby (*Lagostrophus fasciatus*). To enable the successful recolonization of the island by these species it was necessary to implement a feral cat eradication program.

Following the success of the feral cat eradication program on Hermite Island, Montebellos (Algar and Burbidge 2000; Algar *et al.* 2002b; see above), a request was made to CALM to conduct the eradication program.

Methods

Faure Island is located between 25⁰48' S and 25⁰54' S and between 113⁰51' E and 113⁰56' E. The island, an area of 58 km^2, lies within the eastern gulf of Shark Bay at the head of the Hamelin Pool embayment, approximately 18 km east of Monkey Mia. The land systems on Faure are described by Payne, Curry and Spencer (1987). Climatic data for the general Bioregion, which includes Pimbee Station and Peron Peninsula (see below), is described as 'semi-desert Mediterranean' (Beard 1976). Payne *et al.* (1980) provide climatic data for a number of nearby centres. Mean maximum daily temperatures, for nearby reporting centres, are as high as 38⁰ C for summer months and as low as 21⁰ C for winter months. January and February are the hottest months while June and July are the coolest months. Annual average rainfall for the general area is in the vicinity of 220 mm. The area receives reliable winter rainfall with June being the wettest month at approximately 50 mm on average. Rainfall is extremely unreliable and often absent, outside the winter months. However mean annual rainfall may be exceeded during a single cyclonic event.

A preliminary study to assess the feasibility of feral cat eradication on the island was conducted in September 2000 (Algar and Angus 2000b). During this preliminary study a small-scale trapping program, feral cat bait acceptance trial and intensive searches for evidence of feral cat activity were conducted. These surveys of feral cat activity indicated a population of approximately 40 adult feral cats on the island at that time.

During this preliminary study, feral cats readily consumed non-toxic baits. On-track bait acceptance trials indicated that 67% of the sample population consumed at least one bait. During this period, the principal dietary item was reptiles in particular young *Varanus gouldii* which hatch in late winter/early spring depending on seasonal conditions. Activity of varanids and their relative size in September provided a reasonable prey source. Bait acceptance by feral cats is in part related to the abundance of prey species and bait consumption generally increases as prey availability declines (Algar *et al.* in press, a). On Faure Island, growth of hatchling varanids, through summer and into autumn, was likely to reduce their vulnerability to predation. Bait consumption by feral cats in autumn was therefore expected to increase from that recorded in September.

The feral cat eradication campaign was conducted during late February/March 2001 when bait acceptance was predicted to be high and the campaign was unlikely to be affected by rainfall. An aerial baiting campaign was adopted as the primary control technique. Following the baiting campaign a selective site ground-baiting, trapping and monitoring program was employed to remove any feral cats that remained.

In an attempt to maximize the availability of baits, a baiting intensity of 100 baits km^{-2} was used. This baiting intensity was aimed at maximizing the likelihood of feral cats encountering a bait when hungry. Feral cat baits were deployed from a Beechcraft Baron aircraft at an altitude of 150 m. One flight line followed the coast; another deployed baits in the interdunal swales and the remaining flight transects were at 1 km intervals across the island. A total of 10 000 baits was deployed on the 28 February 2001.

An intensive trapping and feral cat activity monitoring program across the island, commenced ten days following baiting. The trapping and monitoring exercise was conducted over 20 days in total and is discussed in detail (Algar *et al.* 2001).

The standard trapping technique is described by Algar *et al.* (2002b). Traps were positioned along all vehicle access and along the coastal/dune areas not readily accessible by vehicle. Traps using the Felid Attracting Phonic (FAP)/Pongo lure combination were located at 1 km intervals and those employing the pongo lure alone were positioned at the intervening 500 m intervals. Traps were set in position for a period of at least 11 days before retrieval. In total, 123 trap sets were placed over the island during the trapping period. Ninety-four of these were in place for more than 14 days to achieve a total of 1819 trap nights.

Four methods were used to monitor feral cat activity on the island: observation from the vehicle undertaking the on-track trapping program, cross-country transects conducted both by foot and by motor cycle and intensive on-foot searches along the beaches, interdunal swales and mangroves.

Vehicle access on Faure provided 59 km of transect. Evidence of feral cat activity along the tracks was assessed daily from a 4WD vehicle. On-foot searches were conducted on the southern part of the east coast, the entire south coast and much of the west coast, providing 22 km of walking transect. The beach areas on the eastern and northern coasts was inter-tidal and comprehensively covered by the vehicle transect. On-foot transects were completed every second day with all evidence of feral cat activity cleared on inspection. Further to the regular inspection of transects; intensive, random searches were made of dune and mangrove areas, not otherwise readily accessible. Any evidence of past feral cat activity was cleared from these areas which were re-examined routinely every two days. Motor cycle transects were established such that they bisected each block of inaccessible land, along the longest axis. FAP attractant stations were placed at nominal intervals of 1 km, along each transect. Each station consisted of a FAP hidden within the foliage of a shrub with a cleared sand pad at least 2 m wide. All transects were traversed prior to FAP station placement and all sign of feral cat activity removed from approximately 10 m either side of the alignment. Following FAP station placement, transects were traversed every second day, for at least 9 days. A total of 21 stations were placed along 28 km of transect.

A ground baiting program, using the feral cat bait, was implemented in areas where evidence of fresh feral cat activity was observed (see Results and discussion). Baits were deployed at approximately 20 m intervals along tracks or cross-country.

Results and discussion

Evidence of fresh feral cat activity, particularly kittens, was observed around the water points, homestead and Landing by the caretaker manager on a visit to the island in mid February (D. Hoult, pers. comm.). Following the aerial baiting program, evidence of fresh feral cat activity was noted on both foot and motor cycle transects that traversed an area of approximately 2 km^2 along the south coast. The intensive foot searches identified a core of activity immediately inland of the coastal dunes and indicated that 2-3 feral cats had survived the aerial baiting program. This activity was noted on the first day of monitoring and ground baiting was conducted in the area, that day and the following. Subsequent assessment of feral cat tracks and activity in the ground baited area over the next two days indicated that at least five baits were taken by feral cats. No fresh feral cat activity was found over the following 16-day monitoring period. Intensive searches in this area failed to locate any baits. Elsewhere on the island, baits were regularly found during such searches. It is believed that no baits were aerially deployed in the area where the 2–3 cats were located. The aerial baiting campaign was responsible for the removal of at least 90% of the feral cats on the island. Given that the remaining feral cats readily took baits, complete coverage of the island, with the prescribed baiting density, may have resulted in total eradication. No evidence of fresh feral cat activity was recorded at any other location during the 20-day monitoring period. An intensive survey for evidence of feral cat activity conducted in June 2001 by an independent team confirmed that eradication of feral cats on the island had been successful (Thomas and Whisson 2001).

Faure Island may be the second largest island in the world where feral cats have successfully been eradicated. The feral cat eradication campaign and monitoring program on Faure was achieved in a matter of weeks. Elsewhere in the world, feral cat eradication projects on islands have often taken months or years, or are still ongoing. The baiting intensity employed here was close to the maximum possible application given the current configuration of baiting aircraft in Western Australia and was conducted in the absence of any information on the impact of aerial baiting density on efficacy. Since the baiting program on Faure Island, research aimed at clarifying the optimum baiting density for feral cats has been conducted.

Pimbee Station and Peron Peninsula

Aim

A series of field experiments is being conducted aimed at maximising the efficiency of aerial baiting for feral cats. The relative efficacy of various baiting regimes is being compared by the aerial deployment of non-toxic baits containing the biomarker RB. Subsequent trapping and examination of feral cats is then conducted to determine the proportion of these populations that have consumed bait material. The first study in this series was conducted at the Gibson Desert Nature Reserve and compared the relative efficacy of 50 and 100 baits km^{-2} (Angus *et al.* 2002a; this review). The efficacy and efficiency of the baiting regimes examined was comparable to that achieved previously with this bait medium. The 50 baits km^{-2} regime was found to be as equally efficacious as the 100 baits km^{-2} regime, for the control of feral cats.

The trial, described here, was conducted to clarify the importance of prey abundance (particularly rabbits) to bait acceptance, under the above baiting regime, by feral cats. A single aerial baiting regime of 50 baits km^{-2} was conducted in an area (Pimbee Station) where prey abundance was low and the results compared to the same bait application in an area where prey availability was high (Peron Peninsula).

Methods

Pimbee Station is located at approximately 120 km ENE of Peron Peninsula at 25^{0}30' S and 114^{0}50' E. The lease was purchased by CALM in 2001 through funding by the National Reserve System Program of the Natural Heritage Trust. The lease is to be managed for the purposes of conservation (see McNamara *et al.* 2000). The study site is dissected by linear and convoluted sand dunes, 10–20 m in height, with broad swales and interdunal plains. Dunes are of red-orange Quaternary aeolian sand (Hocking *et al.* 1987). Dune crests are vegetated by low woodlands of *Acacia anastema* with a sparse mid-storey of *A. scleosperma* and *A. ramulosa* over wanderrie grasses (generally *Eriachne* spp and *Eragrostis* sp.). Swales are vegetated by dense to moderately dense tall shrublands dominated by *A. ramulosa*. Scattered emergents include *A. pruinocarpa* and *A. aneura*, associated shrubs include *Ptilotus obovatus*, *Senna helmsii* and *Eremophila* sp. over wanderrie grasses.

Peron Peninsula was formerly a pastoral station. The peninsula was purchased by the Western Australian State Government in 1990 to establish Francois Peron National Park on the northern end of the peninsula. The peninsula, an area of 1 050 km^2, lies between 25^{0}30'–26^{0}15' S and 113^{0}20'–113^{0}45' E, within the Shark Bay World Heritage Area and is joined to the mainland by a narrow neck (the 3.4 km Taillefer Isthmus). This area is now the site of 'Project Eden', part of the broader *Western Shield* program (see this review). Beard (1976) and Payne *et al.* (1980) describe the vegetation of the peninsula. Five broad vegetation units occur across the peninsula, described in more detail in Algar *et al.* (in press, a) - *Acacia ramulosa* scrub, *Acacia* thicket, *Acacia ligulata/Triodia plurinervata* shrub steppe, *Acacia/Lamarchea* thicket and the succulent steppe of the birridas. A minor association occurs in small, near-coastal strips. This is variously a *Spinifex longifolius* grassland or myrtaceous heath on coarse, pale sand or coquina deposits.

Non-toxic feral cat baits containing the biomarker RB were aerially deployed from a Beechcraft Baron aircraft at single rate of 50 baits km^{-2} on 7 March 2002 (Pimbee Station) and 6-7 March 2002 (Peron Peninsula). Baiting was conducted on the northern and western portions of Pimbee Station, an area of 400 km^2 and in Zone 4 (250 km^2) and approximately half (100 km^2) of zone 2 on Peron Peninsula (see Algar *et al.* in press, a; for zone locations).

The program on Pimbee Station is described in detail in Angus *et al.* (2002b). Trapping for predators on Pimbee Station was conducted between 17–26 March 2002. Trapping methodology follows that of Angus *et al.* (2002a). Traps were placed at 500 m intervals, along linear transects separated by a distance of approximately 2 km. The two lure systems, FAP + Pongo and Pongo only, were employed at alternate 500 m intervals along each transect. As existing vehicle access was insufficient to allow transects at 2 km intervals, Suzuki 300 cc ATVs were used to access transects where no conventional vehicle access was available. A total of 1 381 trap nights was conducted. Project Eden staff conducted feral cat trapping on Peron Peninsula over two periods 17-20 March and 21 March – 3 April. The trapping methodology on Peron differed slightly from that used at Pimbee in that, only existing vehicle access is used to locate traps. Stomachs of captured feral cats at both sites were collected for diet analysis, to provide information of the importance of rabbits in the diet of feral cats from the two sites.

A single transect 6.5 km in length, was established to assess rabbit activity on Pimbee Station. The transect was over existing vehicle access that was clear of vegetation and had a soft, sandy substrate. Previous animal activity was removed from the transect by towing two truck tyres behind a vehicle. The following morning, the transect was examined for rabbit tracks. Tracks were counted on a 10 m section of transect, every 100 m. The number of tracks at each 10 m sample station was recorded as one, two or three or more. The transect was traversed on three consecutive mornings between 23-25 March 2002. Further to the track count transect, a spotlighting transect was traversed on the nights of the 22 and 25 March 2002. A single 1.06 million Cd, variable beam spotlight was operated from a vehicle, driven at a speed of less than 15 kmh^{-1} and the location of all rabbits observed was noted. Rabbit activity on Peron Peninsula is monitored at fortnightly intervals during the Comprehensive Track Count (CTC) program (see 'Project Eden' protocols). Presence/absence of rabbit activity is recorded at 60 locations, over 10 m of track, along the CTC transect, and the presence data are then expressed as a percentage of the total.

Results and discussion

A total of 11 feral cats and 14 foxes was captured during the trapping exercise on Pimbee Station. In addition to these captures, a single feral cat was shot, at the homestead. All feral cats in the sample population were marked by RB as were all the foxes. The program on Peron Peninsula resulted in the capture of 38 feral cats between 17–20 March 2002 with 16 (42%) of the animals being marked by RB and a further 16 feral cats being trapped between 21 March - 3 April with 11 (69%) being marked by RB. The pooled sample on Peron Peninsula resulted in 50% of the population being marked by RB. There was a highly significant difference between the two sites in the percentage of individuals marked by RB ($z=3.19$, $P<0.001$).

No rabbit activity was recorded on the track count transect, during the three traverses on Pimbee Station. The only rabbits sighted at this site during spotlight transects were within a 100 m radius of the homestead complex. Rabbits were absent or extremely sparse over the remainder of the study site. In contrast, rabbit activity was recorded on 32%, 22% and 32% of the recording stations on Peron Peninsula for 26 February, 3 April and 17 April 2002 respectively.

Rabbit was not found in the stomach contents, dominated by reptiles and to a lesser extent invertebrates, of any of the feral cats collected on Pimbee Station. In contrast, rabbit was the most common dietary item of feral cats on Peron Peninsula, occurring in 70% of the animals containing stomach material.

This trial further confirmed the importance of rabbit abundance in influencing bait acceptance by feral cats. Rabbits were present over a very small percentage of the study site on Pimbee Station and were not important to the diet of feral cats or foxes at the time of sampling. In comparison, rabbit activity was relatively common on Peron Peninsula and rabbits were an important dietary item. Availability of prey influences the probability that bait material is accepted upon encounter (Short *et al.* 1997; Algar *et al.* in press, a). When prey is in abundance, the probability that an individual feral cat is hungry at any given time is lower than when prey is scarce. Several authors have suggested that baiting for feral cats is only efficacious when prey availability is low (Short *et al.* 1997; Burrows *et al.* 2003; Algar *et al.* in press, a). Short *et al.* (1997) predicted that bait acceptance by feral cats is likely to be poor when rabbit abundance is greater than 1.2 km-^{1}, measured via spotlight transects. It is therefore possible that a greater density of bait distribution may increase the probability of bait encounter at a time when an individual feral cat is hungry and efficacy may be improved by greater baiting density, during periods of high prey availability.

This exercise confirms the efficacy of 50 feral cat baits km^{-2} where rabbits are not abundant, for the control of feral cats. The level of feral cat control predicted by this baiting regime is equivalent to that achieved previously at the Gibson Desert (this review). The high level of marking of the sample populations from Pimbee Station and the Gibson Desert at this baiting intensity indicates that this density of baits was not close to the lower limit required for effective control of feral cats. Further significant improvement in the efficiency of aerial baiting for feral cats could be expected from investigating lower densities of bait distribution.

Following this research, a toxic aerial baiting program was conducted as part of *Project Eden* on 11–12 April 2002 and resulted in an 80% reduction of feral cat numbers on Peron Peninsula (see review paper by Morris *et al. Project Eden*, this issue).

The Murchison Bioregion – Wanjarri Nature Reserve

Aim

This is the second exercise in a series aimed at improving the efficiency of aerial baiting programs for feral cat control in WA by investigating whether or not high levels of efficacy can be achieved at low densities of bait distribution.

This study compared the relative efficacy of bait distributions of 50 and 25 baits km^{-2} in the north-eastern goldfields region of WA. A concurrent assessment of potential risk to non-target species was also conducted.

Methods

This study was conducted at Mt Keith ($27^0$10' S, $120^0$45' E) and Yakabindie Stations ($27^0$39' S, $120^0$44' E), to the north and south of Wanjarri Nature Reserve respectively. The two pastoral leases are owned and managed by WMC Resources Ltd for the grazing of sheep and more recently of cattle. The site is approximately 97 km south-east of the Wiluna township and 60 km north of the Leinster township, in the north-eastern goldfields region. Landform of the two areas is described by Pringle and van Vreeswyk (1994) as the Sand Sheet Landform of the Bullimore Land System. This Land System is of poor pastoral value and is therefore very occasionally grazed. The landform consists of broad, gently undulating plains of red-orange sand with occasional, scattered granitic outcrops. Vegetation is *Triodia basedowii* hummock grassland with sparse emergent shrubs of *Acacia coolgardiensis*, *A. colletoides*, *Senna* sp., *Eremophila* sp., *Grevillea* sp. and *Hakea* sp. Emergent trees include scattered mallees (*Eucalyptus* sp.), *A. pruinocarpa* and *A. aneura*, the latter forming close groves, up to tens of hectares in extent. Much of the Mt Keith treatment site was burnt in 1998 and again in January 2001. Therefore much of the site is vegetated by young spinifex and fire successors that include *Ptilotus* sp., *Swainsona* sp. and *Leptosema chambersii.* Areas of vegetation not burnt in the past 5 years were generally less than 1 ha in extent.

Climate of the area is desert, summer and winter rainfall (Gilligan 1994). Rainfall is erratic and generally low. Yeelirrie, the closest reporting centre, records a mean annual rainfall of 223 mm over 39 rain days. Significant summer rainfall can occur locally with the formation of thunderstorm cells and the passage of tropical depressions from the north-west. Autumn and early winter rainfall is generally lighter but more regular with the passage of rain-bearing cold fronts across the south-west corner of the State. The mean daily maximum temperature recorded at Yeelirrie in January is 37.9^0 C and the mean daily minimum in July is 3.9^0 C.

Non-toxic feral cat baits containing the biomarker RB, were deployed from a Beechcraft Baron aircraft using the AGNAV navigation system described previously (Angus *et al.* 2002a). A nominal 50 baits km^{-2} was deployed over the Mt Keith treatment area and 25 baits km^{-2} deployed over the Yakabindie treatment area. Although the dimensions of the two treatment sites varied, each was approximately 400 km^2 in extent. Baits were distributed at the Yakabindie treatment site on 8 May 2002 and the Mt Keith treatment site on 8–9 May 2002.

The trapping program employed in this study was as described by Angus *et al.* (2002a). A 2 km transect spacing was employed, with off-road access by Suzuki 300 cc ATVs. Insufficient traps were available for a 500 m trap spacing along transects, therefore traps were placed at 1 km intervals. The lure type used was alternated between trap sets along each transect, as described previously. A total of 593 trap nights was conducted at the Yakabindie site between the 24-31 May 2002. A total of 672 trap nights was conducted at the Mt Keith site between the 24 June–2 July 2002.

Bait uptake by non-target vertebrate fauna was examined by sampling the fauna using grids of pitfall and medium Elliott box traps at 16 sites in a 50 bait km^{-2} baiting intensity on Mt. Keith. All trapped animals, including reptiles and small mammals, were examined for signs of staining by RB.

Results and discussion

Eighteen feral cats were trapped at the Mt Keith site and 23 at the Yakabindie site. Within the sample of feral cats from the Mt Keith treatment (50 baits km^{-2}), 83% of feral cats were marked by RB. Within the sample of feral cats from the Yakabindie treatment (25 baits km^{-2}), 78% of feral cats were marked by RB. Although a greater proportion of marking occurred in the higher baiting density treatment, this was not significantly different ($z=0.41$, $P>0.05$) from the lower baiting density. From the overall sample population, 80% of feral cats were marked by RB.

A summary of non-target fauna captures is presented in Table 10. None of the non-target mammals or reptiles sampled during this trial was marked by RB.

This study confirms the high bait acceptance achieved previously by distributing 50 feral cat baits km^{-2} (Angus *et al.* 2002a; Liddelow *et al.* 2002; this review) and indicates that half this rate of distribution is likely to be equally efficacious under similar environmental conditions. The proportion of marking in the sample population from the 25 baits km^{-2} treatment was significantly lower than marking by the 50 baits km^{-2} distribution at the Gibson Desert (z=1.81, P<0.05; see Angus *et al.* 2002a) and that at Pimbee Station (z=1.74, P<0.05; Angus *et al.* 2002b; this review). However the distribution of 25 baits km^{-2} during this study was not significantly different from the proportion of marking from the simultaneously sampled 50 baits km^{-2} treatment at Mt Keith; nor the 100 baits km^{-2} distribution at the Gibson Desert (z=0.30, P=0.62) (see Angus *et al.* 2002a). This level of marking was also not significantly different from the proportion of individuals removed by toxic baiting at 50 baits km^{-2} at the Gibson Desert (z=1.58, P=0.06; see Liddelow *et al.* 2002). The high level of marking reported here suggests that this distribution is not near to the lower limit necessary for feral cat control, under these conditions. Similar results may be achieved at significantly lower baiting densities than those examined to-date.

TABLE 10

Non-target fauna captures.

TAXON	NO. INDIVIDUALS
Ctenophorus isolepis isolepis	**2**
Ctenotus helenae	1
C. quattuordecimlineatus	3
Diplodactylus elderi	1
D. strophrurus	1
Menetia greyii	*1*
Rhynchoedura ornate	1
Mus musculus	2
Ningaui ridei	16
Notomys alexis	3
Pseudomys hermannsburgensis	5
Sminthopsis hirtipes	1

Although rabbit density assessment was conducted during this exercise, the area is known to support few rabbits. Algar *et al.* (2002a) reported a mean (± s.e.) rabbit presence of 0.98% (±0.38) on transects assessed at Wanjarri Nature Reserve between January 2001 and January 2002. Rabbit presence during May and June 2001 was 0% and 0.46% respectively. This is in contrast to Peron Peninsula, for example, where Algar *et al.* (in press, a) recorded a mean (± s.e.) rabbit presence between November 1999 and March 2000 of 49.43% (±3.49), employing the same sampling technique. Mean (± s.e.) monthly rabbit abundance at Peron Peninsula for the months of May and June, for the period 1996-2000, was 50.87% (±4.57; n=15; range=30-85%) and 51.75% (±8.98; n=4; range=27–65%) respectively (Project Eden, unpublished data – note that these figures were obtained from 1 km sample stations and varying transect distances). This study as with the other baiting intensity trials, under conditions of relatively low prey abundance, particularly that of rabbits have all resulted in relatively strong bait acceptance by feral cats. This is in contrast to the seasonally poor results achieved in the Shark Bay area with this bait (Algar *et al.* this issue) and others (Risbey *et al.* 1997; Short *et al.* 1997), where prey species (rabbits) are in relative abundance. Sufficient evidence exists to suggest that prey availability (particularly that of rabbits) and seasonal factors influencing their abundance and breeding success are an important influence in seasonal/temporal/spatial variations in bait acceptance by feral cats (see also Burrows *et al.* 2003).

West Island, Cocos (Keeling) Islands

Aim

The early settlers first introduced cats to the southern atoll of the Cocos (Keeling) Islands in the late 1820s and throughout the island's history cats have arrived as domestic pets. Over the last two decades, the number of stray/feral cats present has concerned the community and a number of short-term control programs have been implemented (Garnett 1992; Reid 2000). These control campaigns have only reduced feral cat numbers over a limited period and the problem has persisted. A recent policy adopted by the Shire Council has restricted the importation of cats to sterilized animals only. The presence of feral/stray cats potentially poses health problems to the human population as cats are hosts and reservoirs for a number of diseases and parasites. The presence of feral/stray cats in residential areas has also presented a significant nuisance problem with cats calling and fighting through the night and urinating and defecating around the houses. The Cocos-Malay people were also concerned that feral cats were predators of their domestic chickens around the kampong and pondoks where chickens are allowed to range free.

Successful control of stray and feral cats would also benefit the proposed reintroduction of the endangered buff-banded rail (*Rallus philippensis andrewsi*) to several islands within the group (Garnett 1993; Parks Australia 1999; Garnett and Crowley 2000; Reid 2000). This taxon was once widespread on all the Cocos (Keeling) Islands but is now restricted to the cat-free North Keeling Island. The last record for this species, other than on North Keeling Island, was an individual killed by a feral cat on West Island in 1991 (Garnett 1993).

Members of the Shire Council on behalf of the Island Community made an approach to CALM to provide a long-term solution to the cat problem on the islands. The program on the Cocos (Keeling) Islands offered the opportunity to expand the range of environmental conditions under which the current control techniques have been assessed. Two broad climatic regimes under which the techniques have not been tested are the wetter temperate and tropical climates. The Cocos (Keeling) Islands offered the opportunity to assess current procedures on a closed population in a wet tropical climate with rats and chickens as the principal prey species.

Methods

The Cocos (Keeling) Islands are a remote Australian External Territory located in the Indian Ocean. They lie 2768 km north-west of Perth, 3658 km almost due west of Darwin, 900 km west of Christmas Island and 1000 km south-west of Java Head. The islands are two coral atolls only several meters above sea level which have developed on top of old volcanic seamounts. The inhabited southern atoll is 14 km long and 10 km across and comprises 26 islands. Some islands are linked together (or separated by very shallow water) at low tide, while others are in deeper water and are accessible only by boat. The islands of the southern atoll are located at latitude 12^0 12' S and longitude 96^0 54' E. The uninhabited northern atoll 26 km to the north comprises a single island, North Keeling Island, an area of 1.3 km^2 that is a seabird rookery of world-wide significance.

Climate is oceanic-equatorial and humid with a mean annual rainfall of approximately 2000 mm, high humidity (65-84%), and uniform temperatures year round (mean daily temperature: 25.8–27.5^0 C) (Falkland 1994). The southeast trade winds dominate for most of the year but with periods of doldrums during the tropical cyclone season (November-April).

The total land area of all the islands of the southern atoll is 14 km^2. The reef islands of the Cocos (Keeling) Islands are described in detail by Woodroffe and McLean (1994) and summarized below. The smaller islands are less than a hundred meters wide, some are virtually vegetated sandbanks, and all are made up of coral clinker and sand thrown up from the surrounding reef. All the islands are flat, their highest points being sand hills on the ocean side. The majority of islands in the atoll have a conglomerate platform on the ocean side, although there are extensive sandy/shingle areas on South and Horsburgh Islands. The ocean side of West Island is predominantly sand. The lagoon side of the islands is either sandy beaches or intertidal sands with variable areas of coral shingle. On a number of islands sandy spits extend into the lagoon.

The vegetation on the southern atoll is dominated by groves of coconut palms. This coconut woodland has ceased to be cleared and has become largely overgrown and difficult to penetrate. The understorey is mostly coconut seedlings with some shrubs, grasses or other perennials or a dense mat of decaying palm fronds and coconuts. These woodlands are fringed on the lagoon shore by shrub land of *Pemphis acidula* and on the ocean shores by cabbage bush (*Scaevola taccada*) and clumps of octopus bush (*Argusia argentea*) (Williams 1994; Woodroffe and McLean 1994). There are no native mammal species on the atoll; however, a number of species have been introduced. Two species of introduced rats, the brown rat (*Rattus norvegicus*) and black rat (*R. rattus*), are present on the islands (Wood Jones 1909). Two bird species have also been introduced and become established on the southern atoll (Carter 1994). 'Feral chicken', domestic chicken that have become semi-wild, occur on most if not all islands in the southern group. The green junglefowl (*Gallus varius*) of Java was also introduced to West Island.

A control program was implemented in November 2000 (see Algar *et al.* in press, b). During this exercise trials were also conducted to determine the value of baiting as a possible control option on this and other similar islands. Preliminary trials with non-toxic feral cat baits placed on the ground resulted in all baits being removed overnight by non-target species. Land crabs (*Cardisoma carnifex*) which dominate the forest floor, hermit crabs (*Coenobita perlata*) along the coastal areas and chickens were responsible for removing the baits. A subsequent trial using 30-cm wooden skewers to elevate the baits above the ground prevented land crabs from taking baits but over three-quarters of the baits were still taken by hermit crabs and chickens. Further trials examining bait placement and non-target interactions indicated that suspending the baits on a string from a stake angled into the ground overcame the problem. Baits suspended approximately 30 cm above the ground prevented non-target animals from removing the baits while maintaining their attractiveness to feral cats. This new approach to baiting provided a relatively simple means to control feral cats where non-target species posed a problem.

A second visit to the islands provided the opportunity to test this baiting technique as a control strategy for feral cats. A trial of the baiting technique was conducted on West Island, an area of 6.23 km^2. Bait stations were located at 100 m intervals along all unrestricted road and track access. Each bait station comprised a fence dropper angled into the ground from which a non-toxic feral cat bait was suspended, approximately 30 cm above the ground, using saddler's twine. The roads and tracks were not comprised of a sandy substrate that would permit identification of feral cat tracks along their length so a sand pad 40 x 40 cm, cleared of track activity was located beneath each bait. A total of 202 bait stations were located across the island. Each bait station was examined daily, over a 20-day period, for bait removal and activity on the sand pads was noted. Bait removal was assigned to a particular species; this was possible on most occasions except when rainfall had resulted in track activity being washed away. The original intention was to replace any bait removed by feral cats with a toxic feral cat bait that night at that bait station and those stations either side however, a cat or cats often removed a series of baits along a given road. As such, in many instances toxic baits were strung at a number of bait stations central to the location of feral cat activity.

It was assumed that continuous feral cat activity along a segment of a road or track as observed on the sand pads, was the same individual as it was impossible to differentiate between animals. If toxic baits had been consumed and further activity was observed at the same location at a later date, this activity was ascribed to a different individual. The number of feral cats present and those removed as a result of this baiting technique was therefore calculated upon feral cat activity at bait stations, removal of toxic baits from bait stations, their location across the island and subsequent disappearance of feral cat activity over time.

Results and discussion

An estimated total of 33 feral cats was removed as a result of this baiting technique (Brazell and Algar unpub. data).

The total number of feral cats on West Island was calculated to be 37 animals, the technique therefore resulted in an 89% baiting efficiency.

The technique did not exclude all non-target species from removing baits, as rats and hermit crabs were still able to climb up the dropper post and remove the baits. Bait removal by these species tended to be localised to several coastal areas where cabbage bush was present. Suspending the baits stopped land crabs accessing the baits and in all but one instance prevented chicken from removing baits. Utilising a different post, smooth and of thinner diameter, from which the baits are suspended should prevent rats, hermit crabs and other species capable of climbing from removing the baits.

This new approach to baiting small-scale areas provided a relatively simple means to control feral cats where non-target species posed a problem. The technique may have potential application at specific sites on the mainland (e.g. Two People's Bay Nature Reserve) where aerial or on-track deployment of feral cat baits may pose an unacceptable risk to non-target species.

NON-TARGET BAIT TAKE ISSUES

As discussed above, some work has been done on the uptake of feral cat baits by non-target animals and the indications at this stage are very encouraging, with no non-target species taking baits however, this work is incomplete. It is essential that a comprehensive assessment of risk to non-target species from the new bait medium be undertaken. This risk assessment is in part required to gain National Registration Authority registration of the bait and also to ensure the protection of native fauna. Further assessment of bait uptake by a range of non-target species likely to be at risk is to be conducted in the near future and a number of methods to reduce exposure to the toxin are also being investigated. Assessment of bait uptake by non-target species is presented in detail in the section discussing research needs (see pp. 156–157).

INTERACTION BETWEEN FERAL CATS, FOXES AND DINGOES/DINGO-DOG HYBRIDS

The extent of any interaction between feral cats and canids is not clear (Dickman 1996). Dingoes have been reported to predate feral cats (Corbett 1995), as have foxes (Coman 1973) however, the frequency appears extremely low. Both canid species also probably compete for food with feral cats, especially when food resources are limited. Molsher (1999) studied the ecology of feral cats at a site in NSW and their interaction with prey and foxes, finding that foxes potentially limited feral cats through competition for food resources and by excluding them from some habitats.

The abundance of feral cats at another site in NSW has been shown to be negatively correlated with both foxes and dingoes (Catling and Burt 1994, see Dickman 1996). Reduction in fox numbers following baiting programs has resulted in dramatic increases in feral cat abundance (Christensen and Burrows 1995; Algar and Smith 1999). Feral cat numbers have also increased following local declines in dingo abundance (Pettigrew 1993). However, there is no technique currently available for reliably measuring the abundance of dingoes, foxes or feral cats. The observed increases if feral cat numbers following the removal of canids may in part be an artefact of track based census methods. It is likely that tracks/roadways are preferred habitat by feral cats, particularly when foxes and dogs are absent, therefore feral cats may preferentially range toward road transects following reductions in fox and dog populations potentially giving higher index values unrelated to population size. The results of an experimental trial to examine the relationship between feral cat and canid abundance in the Gibson Desert (this review) suggested this was likely to be the case.

In the south-west of Western Australia where foxes are controlled using the fox bait, described earlier, there is the issue of how feral cat populations will respond long-term to a reduction in fox density, and what impacts this will have on native fauna. This requires careful monitoring and possible research action if the monitoring reveals a problem.

CRITERIA FOR DETERMINING WHERE AND WHY FERAL CAT CONTROL IS REQUIRED

Current knowledge suggests that feral cat control is required in semi-arid, arid, wet-dry tropical bioregions and offshore islands (essentially anywhere outside the south-west botanical province) where native fauna reconstruction/reintroduction programs are planned or where it can be demonstrated that feral cat predation is threatening extant populations of native fauna. As resources are limited, it is reasonable to assume that feral cat control will focus on strategic areas. At this stage these areas are in the semi-arid and arid regions. We suggest that management resources and research effort should focus on several potential fauna reconstruction sites in the arid and semi-arid zone where the objective would be to protect extant fauna and to reconstruct the original fauna through the amelioration of threatening processes (including controlling introduced predators) and reintroductions. Such an ecosystems focus will be more cost-effective than attempting to reintroduce individual, disconnected species across the State with discrete baiting programs. Nevertheless baiting programs may be warranted where individual species such as the Gilbert's Potoroo (*Potorous gilbertii*) at Two People's Bay Nature Reserve are threatened with extinction.

We suggest the advancement of *Western Shield* into the semi-arid and arid zones by the identification of three sites/reserves where operational scale research trials should progress with the objectives of a) refining baiting strategies b) demonstrating that feral cat control can be sustained (i.e., replicating the results reported above) and c) reintroducing fauna (reconstructing the original fauna). Candidates for focussed fauna reconstruction sites in the semi-arid and arid zones include one of the resumed pastoral leases in the Murchison-Gascoyne region, Wanjarri Nature Reserve in the northern Goldfields, and the Gibson Desert Nature Reserve in the Gibson Desert. A set of biological, climatic, information and management criteria would need to be established before selecting sites. The high priority research activities outlined below could focus on these sites.

While there exists variability in the vulnerability of species to predation by feral cats, our knowledge and understanding of predator-resilience for various species is inadequate. In the interim, we recommend that the precautionary approach is to assume all potential candidates for re-introduction are likely to be vulnerable to feral cat predation until it can be demonstrated otherwise or unless feral cats can be controlled. Apart from eradication, the appropriate level of feral cat control for each native species is largely unknown.

CURRENT OBSTACLES TO BROADSCALE IMPLEMENTATION, RESEARCH NEEDS AND TIMELINES FOR OVERCOMING THEM

While there are a number of outstanding research issues that need to be addressed to improve the effectiveness and reliability of baiting to control feral cats in a number of bioregions, the current operational obstacles to broadscale feral cat control are a) the need to register the feral cat bait for operational use and b) the provision of adequate resources to implement control strategies. There are a number of key factors (not necessarily obstacles) that need to be researched if an effective broadscale aerial baiting strategy for feral cats is to be developed. Optimizing the various parameters of baiting programs need to be examined in sequence if the control strategy is to be effective and cost-efficient. In addition to the baiting parameters it will be necessary to assess the potential impact of baiting programs on non-target species populations and to validate the reliability and accuracy of the census technique used to estimate feral cat abundance. These research areas are discussed below and the timeframe of activities is outlined in Table 11.

Examination of baiting intensity (number of baits laid km^{-2}) in relation to baiting efficiency to optimise control

Having defined the optimum time period to conduct baiting programs (see pages 134–135 'Bait uptake...'), the second stage in developing an effective broadscale aerial baiting strategy for feral cats is to examine baiting intensity (number of baits laid km^{-2}) to maximise baiting efficiency. For feral cat baiting programs to be efficient and cost-effective, baits must be delivered at a level that maximises their uptake by feral cats but minimises the number of baits required which will also minimise the potential risk posed to non-target species. A series of trials is currently being conducted with the objective of determining an optimum delivery of baits, from an aircraft, for the control of feral cats. Successful control has previously been achieved by deploying a nominal 100 baits km^{-2} in strategic areas (Algar and Burbidge 2000; Algar *et al.* 2001; Algar *et al.* 2002b; this review). This nominal distribution of baits was used as a benchmark, against which to assess the efficacy of lower baiting densities.

Assessing the efficacy of differing baiting intensities is being conducted in a series of trials using non-toxic Rhodamine B biomarked baits followed by trapping exercises to determine the extent of labelled animals in the trapped population. The use of this biomarker technique also enables concurrent study of bait consumption by non-target species and assessment of the potential risk to these species populations at various toxic baiting intensities (see page 156 'Assessment of the potential...'). To date, this series of trials has demonstrated that a baiting density of 50 baits km^{-2} is equally efficacious in the control of feral cats. This evidence has been supported by a highly efficacious toxic baiting for feral cats at the Gibson Desert Nature Reserve (this review). The high level of marking and good control of feral cats during these exercises suggests that further reductions in bait distribution, under similar environmental conditions, will not reduce baiting efficacy.

Further baiting intensity trials are to be conducted (as discussed in the section 'Baiting trials', p. 135), to refine the optimal baiting intensity. The encouraging results reported to date are to be replicated to be confident that baiting outcomes can be predicted within limits.

TABLE 11

Timeframe of activities.

ACTIVITY	YEAR				
	2001	2002	2003	2004	2005
Optimising timing of baiting	■	■			
Baiting intensity trials	■	■			
Non-target uptake assessment	■	■	■	■	
Census techniques			■	■	■
Toxic baiting and baiting frequency			■	■	■

Examination of baiting frequency (number of times/year or yearly intervals) required to provide sustained effective control.

Once the optimal baiting intensity has been defined, both in terms of effective feral cat control and risk to non-target populations, it will be possible to conduct toxic baiting programs to assess the required baiting frequency to provide cost-effective control over time. Re-introduction of native species to strategic areas can only occur if sustained feral cat control can be shown over time. However, it is important to recognise that the level of feral cat control required to allow re-introduced species to maintain viable populations is unknown, but may vary according to individual species, suite of species and site.

The level of control achieved over time with baiting will in part be dependent on the frequency of baiting (the time interval between baiting programs). Feral cat density post-baiting will be dependent on the number of resident individuals not removed during the baiting campaign and the rate of dispersal into the baited area over time. Natal recruitment from these two populations will also influence feral cat density over time. The relative abundance of non-baited resident animals and their potential recruitment can be determined. The density of feral cats immediately outside and distant from a baited site will determine the rate of reinvasion. This value would be unknown and highly variable, both temporally and spatially.

To provide a practical solution to optimising the frequency of baiting a theoretical framework is proposed where baiting frequency is examined in terms of the size of the baited area, potential buffer zones and the extent and timing of recruitment into a core area. Conservation sites where feral cat baiting is likely to be warranted differ according to size and the option of utilising a baited buffer and these factors tend to be related to geographic zone. It is proposed that three sites be selected where feral cat control is needed. These sites will differ in size and the degree to which a buffer zone can be included to protect a core area. Following standardised baiting programs at each site, regular, routine monitoring of relative feral cat abundance will be conducted at each site. This monitoring program will provide the first set of data on the time and extent of reinvasion and therefore a benchmark of baiting frequency for the different site types. Optimising baiting frequency will require a long-term commitment and is beyond the scope of the current program. It is suggested that in the long-term, as other areas are baited and Operation staff become involved, additional monitoring programs can be conducted and the information added to the database. Optimising baiting frequency in the long-term can therefore be responsive to the level of control achieved over time for a generalised site type.

Assessment of the potential impact of baiting programs on non-target species populations and development of methods to reduce the potential risk where possible

It is essential that a comprehensive assessment of risk to non-target species from the feral cat bait be undertaken. This risk assessment is in part required to gain National Registration Authority registration of the bait. Assessment of bait uptake by a range of non-target species likely to be at risk is to be conducted. A number of methods to reduce exposure to the toxin is also being investigated.

A desktop evaluation has been conducted to assess the likely risk to non-target species. This investigation has broadly defined a range of species potentially at risk from operational baiting campaigns. Assessment of risk to these species will be undertaken in both field and complementary laboratory trials. Assessment of bait consumption by non-target species in the field under natural conditions of climate and alternative food resources is being conducted concurrently with the non-toxic biomarker baiting intensity trials (see sections 'Baiting trials' and previous section). Maximum bait consumption by non-target species is expected to occur when their other food resources are lowest and therefore when prey abundance for feral cats is also at a minimum. As such, assessing bait uptake by non-target species when the baiting intensity trials are being conducted is appropriate. These trials will provide information on bait consumption by individuals in the field and thus the possible impact of an operational baiting program on species populations at the various baiting intensities.

The study areas selected are unlikely to contain the entire suite of native species across all the broad range of sites where operational feral cat baiting programs will eventually be conducted. It is anticipated that additional field studies, researching bait uptake by certain species with restricted ranges may also be required. The distribution pattern of baits deployed from a plane is being mapped to enable simulation by hand placement of baits on the ground. It will therefore be possible to mimic bait distribution of an aerial baiting program over a specific fauna-trapping site. This will permit non-target bait uptake studies to be conducted as part of other fauna programs to allow maximisation of species and individuals assessed at minimum cost.

To complement the field trials, a more rigorous assessment of the amount of bait consumed by a number of non-target species will be examined in penned laboratory trials. In addition, laboratory trials will be used to evaluate bait consumption by species not readily available in the field. Feral cats will consume the entire bait; however most non-target species have a much lower body weight and may be unable to eat the entire bait. The biomarking of individual animals in the field indicates potential risk to baiting programs, as its presence is qualitative rather than quantitative. The presence of the biomarker does not indicate the quantity of the bait consumed and therefore whether a lethal dose would have been acquired if the bait was toxic. Laboratory examination of bait consumption will provide information on actual risk from baiting for individual species.

The baiting intensity trials, described previously, are designed to reduce the number of baits deployed to a level that maximises effectiveness and cost efficacy. Any reduction in baiting intensity will also reduce the potential risk posed to non-target species. Currently, toxic feral cat baits are dosed at 4.5 mg of 1080 per bait. There is potential scope to reduce the dose per bait to 3.0 mg 1080 and thereby reduce the risk to non-target species from baiting programs. An oral LD_{50} value of 0.40 mg 1080 kg^{-1} was determined for immature feral cats after gastric intubation McIlroy (1981). More recent studies (Eason and Frampton 1991; Eason *et al.* 1992), using baits coated with 1080, on a mixed-age feral cat population determined an oral LD_{50} of 0.28 mg 1080 kg^{-1} and LD_{90} of 0.35 mg 1080 kg^{-1}. A series of pen trials, using 1080 injected baits, will be conducted to determine whether baits are lethal to feral cats at the reduced dose rate.

The majority of potential bait consuming, non-target mammal species are significantly smaller than feral cats and have different dentition. The carnassial teeth in cats are highly specialised and adapted to cutting and shearing. The loss of grinding pre-molars and reduced chewing efficiency leads to their propensity to swallow relatively larger portions of food and inert material such as bone. The potential of cats to ingest larger particles (eg. tablets or capsules containing toxin) relative to most non-target species has the potential to reduce exposure of many non-target mammals to bait toxicants and thereby decrease the risk of baiting to non-target species. The inclusion of toxic tablets in baits could be a practical vehicle for toxins that would be ingested by feral cats yet rejected by smaller mammals. Colleagues at the Victorian Institute of Animal Science, Department of Natural Resources and Environment (DNRE) are investigating the use of toxic tablets for the inclusion in feral cat baits. This investigation is part of their contribution to the collaborative research program between CALM, DNRE and Environment Australia for the development of a felid-specific toxin and delivery system.

Provide scientific validation of the Track Density Index (TDI) as a reliable estimate of relative feral cat abundance.

A technique that provides the capacity to efficiently and reliably estimate feral cat relative abundance is an essential prerequisite for the planning and implementation of clearly defined prescriptions for feral cat control, in particular the determination of optimum frequency of baiting operations. Also, it will provide an objective assessment of the effectiveness of operational control measures in reducing feral cat density. Any technique that is considered for use as an index of abundance must also be relatively inexpensive and simple to conduct as it will be used by researchers, wildlife managers and others alike.

Department researchers have employed a track count index (TDI) (Burrows *et al.* 2003; this review 'Project Eden' and Gibson Desert) to assess relative changes in feral cat abundance. Trials are required to scientifically validate the accuracy of this technique to measure relative feral cat abundance. Results from baiting intensity trials will provide information on the extent of feral cat removal following specific baiting regimes. These results will be used to establish a series of toxic baiting programs where feral cat numbers will be manipulated to approximate relative abundances. At each site, a number of feral cats will be trapped and radio-collared with mortality transmitters. Indices of relative feral cat abundance will be determined pre-baiting and ten days post-baiting. The difference between the pre- and post-baiting indices will then be compared to the reduction in the population size determined by the mortality transmitter returns. Five baiting programs will be conducted at different baiting intensities to provide different levels of population reduction. This will allow regression analysis of the data (change in population level as determined by mortality transmitters versus change in index pre- and post baiting) for assessing the accuracy of the index as a measure relative abundance.

Discuss how and when bait registration can be achieved and the likely cost of feral cat baits.

An experimental permit was recently obtained from the Australian Pesticides and Veterinary Medicines Authority (APVMA) (formerly the National Registration Authority) to allow completion of the research required to permit submission for full registration of the feral cat bait. An additional permit was issued for the ongoing feral cat baiting program on Peron Peninsula *Project Eden*. The experimental permits; Permit No. PER5356 is for the sites listed in Table 12 and Permit No. PER5112 is for Peron Peninsula. The permits are valid till the end of 2006 and 2005 respectively. The permits apply to an experimental 1080 bait used for feral cat control as described below:

Type:	Trial	Category:	Field
Reg. Category:	47	Section:	Ag
Permit Record No.	1213		

A number of sites were selected within Western Australia where research is proposed. Several sites were listed for baiting where an existing commitment to feral cat control is in place. Other sites were also nominated for potential feral cat baiting campaigns because of evidence that feral cats were threatening the continued survival of endangered species in the area. Toxic baiting will only be permitted at any of these sites following approval being granted under the 'Risk Assessment' guidelines of the State and Federal statutory regulations for the 'Code of Practice on the Use and Management of 1080.'

TABLE 12
Sites listed under the experimental permit.

SITE	AREA (KM^{2})	LOCATION (CENTROID)	TIMING OF BAITING PROGRAMS
FERAL CAT CONTROL RESEARCH SITES			
Gibson Desert Nature Reserve	2500	24^{0}45’31"S 124^{0}41’53"E	2002–2006
Wanjarri Nature Reserve	2000	27^{0}22’32"S 120^{0}43’12"E	2003–2006
Mt. Augustus	2000	24^{0}20’09"S 116050’46"E	2003–2006
Purnululu National Park	1000	17^{0}27’ S 128^{0}34’ E	2003–2006
ONGOING BAITING PROGRAMS			
Peron PeninsulaPermit (PER5112)	1500	25^{0}41’58"S 113^{0}33’06"E	12/2001–2005
Cocos Island	14	12^{0}12' S 96^{0}54' E	2002
Garden Island	11	32^{0}12’07"S 115^{0}40’40"E	2002
POTENTIAL FERAL CAT BAITING PROGRAMS TO PROTECT ENDANGERED SPECIES			
Lake Magenta Nature Reserve	1078	33^{0}29’31"S 119^{0}07’38"E	Potentially if required
Dragon Rocks Nature Reserve	322	32^{0}44’53"S 119^{0}02’06"E	As above
Cape Arid National Park	2781	33^{0}42’09"S 123^{0}22’16"E	As above
Stirling Range National Park	1157	34^{0}21’46"S 117^{0}59’25"E	As above
Dryandra State Forest	240	32^{0}48’26"S 116^{0}59’42"E	As above

The sites listed under the experimental permit to be granted are tabled by purpose, and described by size, location and timing of baiting in Table 12. It is anticipated that additional sites, both research and areas to protect endangered species, will be submitted to APVMA later this year for inclusion on this list.

It is anticipated that the research required to provide the information for full registration of the feral cat bait will be completed by the end of 2005 and that submission will occur the following year. Discussions with APVMA, the State Coordinator for APVMA and State and Federal reviewers have indicated that the research outlined in this review is that necessary for registration. These authorities have indicated that the key determinants to achieve registration will be baiting efficacy and non-target considerations.

The cost of feral cat baits is currently 30^{c} per bait at today’s level of production, one third of this cost is for materials, and the remainder is associated with labour and production equipment. The future costs of baits will depend on economies of scale (level of production), degree of automation and the cost and depreciation rate of the manufacturing equipment. It is also important to realise that the price of baits is not the total cost of baiting as there are additional costs associated with ground transport of the baits and aerial deployment.

WHAT IS THE FUTURE OF THE FELID SPECIFIC TOXIN AND HAVE NON-TARGET RISKS BEEN ASSESSED?

A toxicant compound, Felid Specific Toxin (FST), that exploits some unique physiological characteristics of cats, is being developed by the Victorian Institute of Animal Science, Department of Natural Resources and Environment (DNRE) as a selective lethal agent for bait delivery. The identification of this highly specific cat toxin creates the potential for significant improvement in the ability to control feral cats where the use of 1080 may pose a problem. A collaborative research program between CALM, DNRE, Environment Australia and now Landcare Research (New Zealand) is developing the toxin/bait combination.

The bait, toxin, target specificity (ie. particle size) and liquid delivery have been considered. The focus of current research is to bring these concepts together in a purpose designed delivery vehicle that contains an improved, high penetrating liquid solvent. This research is likely to be pursued by external groups that specialise in this work. A prototype delivery vehicle is to be used this year in a small-scale field demonstration.

Two approaches are being used to assess non-target risks; the inclusion of toxic pellets in baits as a practical vehicle for toxins that would be ingested by feral cats yet rejected by smaller mammals and direct non-target dose response testing. A number of non-target species, plains rats (*Pseudomys australis*), northern quolls (*Dasyurus hallucatus*), eastern barred-bandicoots (*Perameles gunnii*) and fat-tailed dunnarts (*Sminthopsis crassicaudata*) are being tested by DNRE in the laboratory for the ability to ingest pellets. Field assessment of pellet ingestion is also being conducted on populations of bush rats (*Rattus fuscipes*) and swamp rats (*R. lutreolus*). Non-target dose response testing has been conducted on tammar wallabies (*Macropus eugenii*), common brushtail possums (*Trichosurus vulpecula*), mallard ducks (*Anas platyrhynchos*), ferrets (*Mustela furo*) and stoats (*M. erminea*). The 'Memorandum of Understanding' with Landcare Research was recently completed but as yet the dose response data is confidential.

CONCLUSIONS AND RECOMMENDATIONS

If further fauna declines are to be averted and re-introductions are to succeed, integrated management programs, which address threats must be implemented. Effective control strategies for feral cats must be an integral component of these management programs. CALM researchers are leading the way, both nationally and internationally, in the development of feral cat control techniques and strategies that address these concerns. A step-wise approach is being pursued in the development of an effective and cost-efficient broadscale feral cat control strategy to provide wildlife recovery. The focus is on optimising feral cat control through aerial baiting campaigns and providing a comprehensive evaluation of any impact on non-target species populations. The program is structured to enable analysis of the cost-benefit of various baiting regimes on both feral cats and non-target species and provide information essential to gaining registration of the feral cat bait. Once registration is achieved, the baiting protocols developed will extend predator control and wildlife re-introductions to the arid and semi-arid interior of Western Australia under the umbrella program '*Western Shield*'. Results of this program will also be of considerable value to other States and Territories involved in feral cat control and re-introduction projects.

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