Manaaki Whenua
Landcare Research

Department of Sustainability and Environment

FINAL REPORT FOR THE AUSTRALIAN GOVERNMENT DEPARTMENT OF THE ENVIRONMENT AND HERITAGE

REVIEW OF EXISTING RED FOX, FERAL CAT, FERAL RABBIT, FERAL PIG AND FERAL GOAT CONTROL IN AUSTRALIA. II. INFORMATION GAPS

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Department of the Environment and Heritage

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Executive Summary

Project and client

Red foxes, feral cats, feral rabbits, feral pigs, and feral goats separately and in various combinations are believed to be responsible for the extinction or decline of a wide range of native species and for adverse changes in ecological communities in Australia. Predation by foxes and feral cats are key threatening processes under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act), whilst competition with native species and land degradation by feral rabbits, feral pigs and feral goats are also listed as key threatening processes under that Act. The belief that pest animals have caused declines in native species (and damage production values) is reflected in legislation and has led to many attempts to control the pests. Many agencies and organisations including Federal, State and Local governments commit significant resources managing these species. However, there is limited hard evidence that this management has led to a reduction in threats and to a reversal in the decline.

The Department of the Environment and Heritage (DEH) commissioned the Arthur Rylah Institute for Environmental Research to undertake a project aimed at increasing the understanding on whether control of foxes, feral cats, feral rabbits, feral pigs, and feral goats lead to a reduction in threats to native species and ecological communities. The project is being completed in three stages. The first stage detailed an audit of 1306 existing pest animal control programs in Australia (Reddiex et al. 2004). This, the second stage, identifies gaps in knowledge on control activities and recommends priorities for filling these gaps. Other stages include the development of protocols for monitoring pest species, and designing a process to determine priority ranking for control of pest animals in order to minimise threats to native species and ecological communities.

Objectives

The objectives of this report are to:

1. Identify gaps in existing information on control activities, especially in relation to the success in reducing/removing pest species, and in subsequent recovery of native species/ecological communities, especially those listed under the EPBC Act, across Australia.
2. Identify the native species perceived to be threatened by foxes, feral cats, feral rabbits, feral pigs, and feral goats, for which there is still limited information on results of pest control activities.
3. Recommend priorities for filling gaps in existing knowledge, by both experimental control and monitoring of existing control activities, to cover as large a range of threatened species as possible, especially those native species perceived to be threatened by foxes, feral cats, feral rabbits, feral pigs, and feral goats.
4. Design specific control experiments that include varied levels of control and the consequences for a range of native species and ecological communities, in particular, those that are difficult to target through monitoring of existing control activities, and include the cost of conducting these experiments.

Methods

1. We considered both the amount and reliability (Reddiex et al. 2004) of knowledge available for the following four areas:
   - *Monitoring techniques;* are there techniques for monitoring changes in relative and/or absolute abundance of the pest animal as a consequence of control?
   - *Effectiveness of control;* are there control programs or research studies documenting the effectiveness of the commonly-used control techniques in terms of changes in the abundance of the pest animal and/or residual densities?
   - *Costs of control;* have the costs of the commonly-used control techniques been documented?

- *Benefits of control for native species/ecological communities;* have the benefits of pest animal control for native species and ecological communities been investigated in a reliable manner?

2. Based on (1), we identify the native species for which there is limited information on the benefits of pest animal control. We focused on the benefits of control for EPBC Act listed threatened species known or perceived to be threatened by the pest animal species, and then identified any other species/ecological communities for which information was available.

3. Our priorities for filling information gaps were as follows. First, if there were no adequate methods for monitoring changes in the abundance of the pest animal then the development of monitoring techniques was given the highest priority. Given that adequate monitoring techniques are available, the next highest priority was obtaining reliable information on the benefits of pest animal control for native species/ecological communities.

4. Since the most reliable information is obtained from a designed experiment, we proposed one experiment to identify the benefits (or not) of (i) feral goat, (ii) feral pig, (iii) feral rabbit, and (iv) fox control for native species/ecological communities. We give *indicative* costs for conducting the experiment. The actual costs will depend on the area(s) where the work is conducted, and the charge-out rates of the organisations involved in the work. Our costs should be used for broad budgeting purposes only.

Results and Discussion

1. The first stage of this review (audit of existing pest animal control programs in Australia; Reddiex et al. 2004) found that there was little reliable knowledge about the benefits of fox, feral cat, feral rabbit, feral pig and feral goat control for EPBC Act listed threatened species. Few control programs monitored changes in the pest species targeted for control and the native species of interest. In addition, monitoring designs rarely included non-treatment areas or were randomly allocated, and few had assessed the species/habitat of interest prior to control. However, experimental studies have provided some information on the benefits of control for some species known to be threatened by foxes (see Reddiex et al. 2004; Robley et al. 2004).

2. The highest priority for filling these gaps in knowledge for each species are as follows:
   - Feral goats; assessing the benefits of feral goat control for native plant species.
   - Feral pigs; assessing the benefits of feral pig control for ground disturbance, native plant species and below-ground processes.
   - Feral rabbits; assessing the relationship between feral rabbit density and their impact on native plant species.
   - Foxes; assessing the benefits of fox control for native fauna species.
   - Feral cats; developing techniques for estimating relative and absolute abundance of feral cats.

3. Experiments are proposed for reliably evaluating the benefits of control for feral goats, feral pigs, feral rabbits, and foxes. An experimental assessment of the benefits of feral cat control for native species/ecological communities should not be undertaken until adequate methods are available for estimating the abundance of feral cats. Each experiment should run for at least five years before being reviewed in the light of both results and environmental variables (e.g., rainfall) that are likely to influence the results. We strongly recommend that monitoring designs are based on an underlying modelling framework, thereby ensuring the correct information is collected for system models.

Experiments can then continually update system models and decrease the amount of time it takes to improve the reliability of management decisions.

Until study sites are identified the costs of these experiments should be considered indicative for long-term budgetary purposes. The start-up costs of these experiments ranged from c. $325K (for feral goats) to c. $2.1 million (for foxes), and annual costs ranged from c. $250K (for feral goats) to $1.8 million (for foxes). The large costs reflect the need for experimental designs that can reliably demonstrate the benefits of pest animal control. Failure to adopt the elements of experimental design outlined here will lead to the continued accumulation of unreliable knowledge and an inability to predict the effects of pest animal control.

Recommendations

1. The proposed experiments evaluating the benefits of feral goat, feral pig, feral rabbit, and fox control should be undertaken as funding permits. The experimental design should not be compromised in order to reduce the costs of the experiments: it would be preferable for just one experiment to be adequately funded rather than several experiments inadequately funded.

2. Research to develop methods for estimating the relative and absolute abundance of feral cats, and the absolute abundance of foxes should be funded.

1. Introduction

The Department of the Environment and Heritage (DEH) commissioned the Arthur Rylah Institute for Environmental Research (Department of Sustainability and Environment, Victoria) to undertake a project to increase understanding of the threats to native species and ecological communities from foxes, wild dogs, feral cats, feral rabbits, feral pigs, and feral goats. The key aims of the project were to investigate; 1) control activities currently undertaken across Australia for from foxes, wild dogs, feral cats, feral rabbits, feral pigs, and feral goats; and 2) pest control that is necessary to secure the recovery of affected native species and ecological communities, especially those listed as threatened (under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act)). The project is being completed in three stages. The first stage, an audit of 1306 existing pest animal control programs in Australia, has been completed (Reddiex et al. 2004). This stage includes identification of gaps in information on control activities and recommendations for filling these gaps. The third and final stage involves development of pest species monitoring protocols, and designing a process to determine priority ranking for control of pest animals in order to minimise threats to native species and ecological communities.

2. Background

Red foxes (*Vulpes vulpes*), wild dogs (*Canis lupus familiaris*, *Canis lupus dingo*, and hybrids), feral cats (*Felix catus*), feral rabbits (*Oryctolagus cuniculus*), feral pigs (*Sus scrofa*), and feral goats (*Capra hircus*) separately and in various combinations are believed to be responsible for the extinction or decline of a wide range of native species and for adverse changes in ecological communities in Australia. Predation by foxes and feral cats are listed key threatening processes under the EPBC Act, whilst competition with native species and land degradation by feral rabbits, feral pigs and feral goats are also key threatening processes under that Act. Some of these species also have important impacts on agricultural values (through competition for resources and depredation of livestock) and may impact on historic cultural heritage and act as vectors of animal and human diseases (Braysher 1993).

The belief that pest animals have caused these declines in native species (and damaged production values) is reflected in legislation and has led to many attempts to control these pests. Many agencies and organisations including Federal, State and Local governments commit significant resources managing these species. However, there is limited hard evidence that this management has led to a reduction in threats and to a reversal in the decline (e.g., Hone 1994; Dickman 1996). Benefits of pest control are likely to depend on a wide range of factors, including the intensity and frequency of pest control, pest abundance following control, the size of an area controlled, and the ability of impacted species or resources to recover (Hone 1994; Choquenot and Parkes 2000; Coomes et al. 2003).

To our knowledge, this is the first national audit of pest animal control operations by conservation focused organisations in Australia. The distributions and abundances of some pest animals have been reviewed for some states of Australia (West and Saunders 2003), but there have been no detailed reviews of the characteristics of existing pest animal control operations. This review reports on pest animal control information collected in interviews conducted across all states and territories of Australia. Since the key focus of this review was to increase understanding of the threats by pest animals on native species and ecological communities, an emphasis was placed on collecting data from 'conservation' focused rather than 'agricultural' focused control activities. Monitoring of the impact of pest animal control is not absent but less likely to be undertaken by private landholders in the agricultural sector.

3. Objectives

The objectives of this report are to:

1. Identify gaps in existing information on control activities, especially in relation to the success in reducing/removing pest species, and in subsequent recovery of native species/ecological communities, especially the listed threatened species in the EPBC Act, across Australia.
2. Identify the native species perceived to be threatened by foxes, feral cats, feral rabbits, feral pigs, and feral goats, for which there is still limited information on results of pest control activities.
3. Recommend priorities for filling gaps in existing knowledge, by both experimental control and monitoring of existing control activities, to cover as large a range of threatened species as possible, especially those native species perceived to be threatened by foxes, feral cats, feral rabbits, feral pigs, and feral goats.
4. Design specific control experiments that include varied levels of control and the consequences for a range of native species and ecological communities, in particular, those that are difficult to target through monitoring of existing control activities, and include the cost of conducting these experiments.

4. Study species

Foxes (*Vulpes vulpes*)
The red fox was deliberately introduced into Australia in the mid to late 1800's. Foxes are now common throughout most of Australia, except the tropical north and some offshore islands (Figure 4.1). Foxes occupy many habitats, including urban, alpine and arid areas, but are most common in woodland and semi-open habitats (Saunders et al. 1995). Foxes have been shown to eat a wide range of native species (reviewed in Robley et al. 2004) and are thought to have played a major role in the decline of many ground-nesting birds, small to medium sized mammals, and reptiles (see Table 1; Pg 10, for a list of native species for which foxes have been identified as a known or potential threat).

Feral cats (*Felis catus*)
Cats probably became established in Australia soon after the arrival of the first Europeans. Feral populations now occupy most parts of the mainland, Tasmania and many offshore islands (Figure 4.1). Cats eat a wide range of native wildlife (Dickman 1996; reviewed in Robley et al. 2004), and for this reason are thought to have a major impact on many native species, especially on islands (see Table 1; Pg 10, for a list of native species for which feral cats have been identified as a known or potential threat).

Feral rabbits (*Oryctolagus cuniculus*)
The rabbit is one of the most widely distributed and abundant mammals in Australia (Williams et al. 1995). Rabbits were first released in 1859 in Geelong, Victoria, and spread rapidly to cover most of Australia, except the far north, by 1910 (Figure 4.1). Feral rabbits occur in many habitats, but are sparsely distributed in the arid north and are most abundant in areas with deep and sandy soils (Myers et al. 1994). They are predominantly grazers and are thought to compete with native wildlife for resources. They may also alter the distribution and abundance of native plant species and physically alter habitats (Williams et al. 1995). Feral rabbits have been implicated in the extinction of a number of small mammals in Australia's arid regions, and may have contributed to the decline in numbers of many native plant and animal species (see Table 1; Pg 10, for a list of native species for which feral rabbits have been identified as a known or potential threat) (Williams et al. 1995).

Feral pigs (*Sus scrofa*)
Domestic pigs were introduced to Australia by European settlers, and populations of feral pigs were widespread by the 1880s. Feral pigs are now common in the Northern Territory, Queensland, Australian Capital Territory and New South Wales, and less common in western Victoria, Western Australia, and on a few offshore islands (Figure 4.1). Feral pigs are omnivorous habitat generalists, occupying subalpine grasslands, woodlands, tropical forests and, semi-arid and monsoonal floodplains. The primary environmental impacts of feral pigs are habitat degradation and predation of native species. By wallowing and rooting feral pigs modify streamsides, increase erosion, and decrease food resources and habitat for native wildlife (Choquenot et al. 1996). Feral pigs are also thought to compete with native animals for food, eat the eggs of ground-nesting species, spread environmental weeds, and transmit disease. Feral pigs have destroyed breeding sites and degraded key habitats for a number of species (see Table 1; Pg 10; Choquenot et al. 1996).

Feral goats (*Capra hircus*)
Feral populations of goats established in Australia from the escape, abandonment, or deliberate release of domestic goats (Parkes et al. 1996). Feral goats live in all States and Territories and on many offshore islands, but are most common in areas of western New South Wales, South Australia, Western Australia, and Queensland (Figure 4.1). The diet of feral goats includes grasses, leaves, bark, flowers, fruit, and the roots of many plant species (Parkes et al. 1996). Feral goats are thought to have major effects on native vegetation, and may also compete with native wildlife and stock for food, water and shelter (see Table 1; Pg 10, for a list of native species for which feral goats have been identified as a known or potential threat).

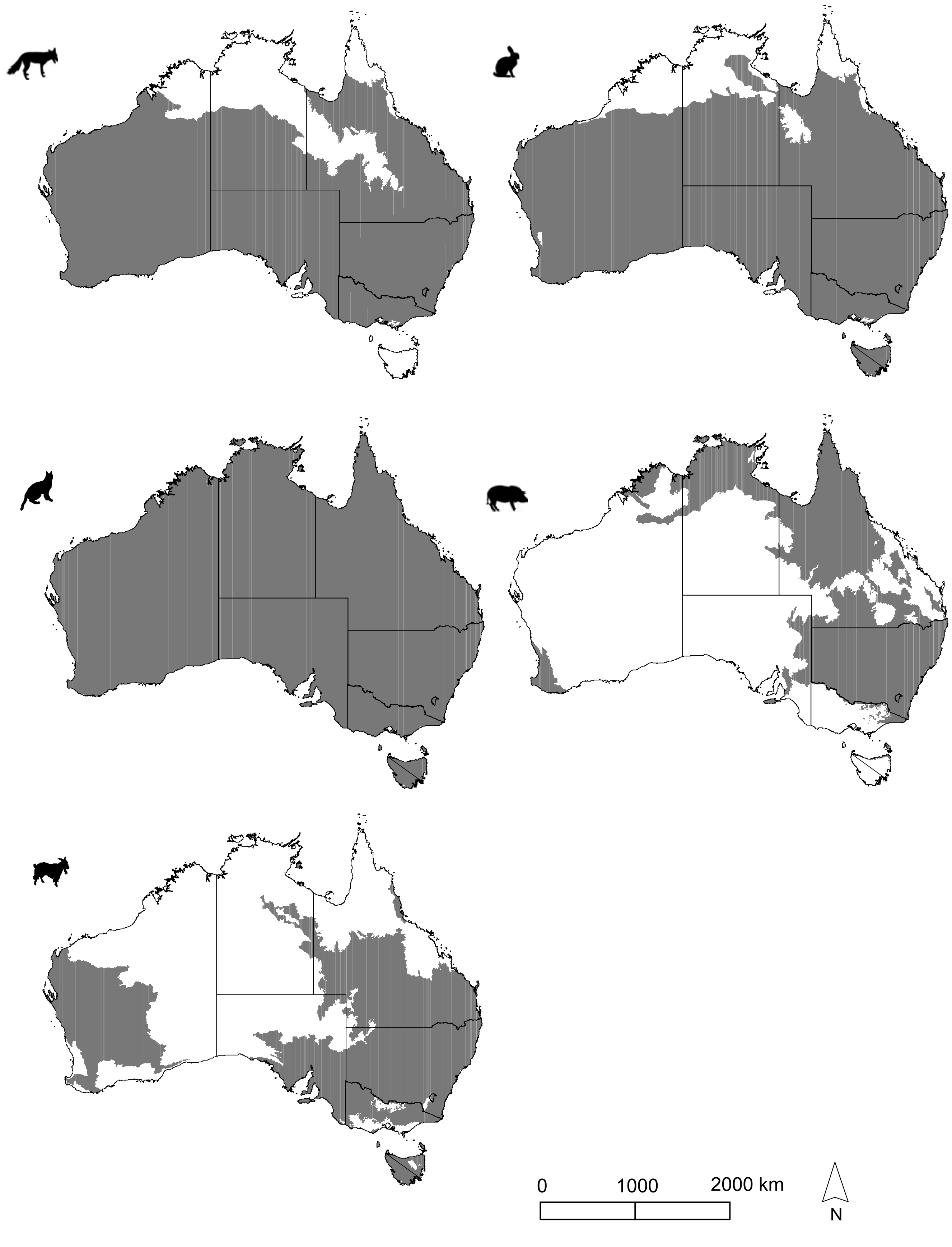


Figure 1. Distribution of foxes, wild dogs, feral cats, rabbits, feral pigs, and feral goats in 2001, in Australia (electronic distributions are from subregional or bioregional scale data from the Natural Land and Water Resources Audit, Landscape Health in Australia database, 2001).

5. Native species threatened by pest animals

The listed threatened species under the EPBC Act that are known or perceived to be threatened by at least one of the pest animals reviewed are shown in Table 1. Data on EPBC Act listed threatened species known or potentially threatened by the various pest animal species was constructed from the relevant threat abatement plans (Environment Australia 1999a, 1999b, 1999c, 1999d; Department of the Environment and Heritage 2003) and recovery plans, as at 2002. The list does not constitute a comprehensive list of all native species threatened by these pests, since the list includes only EPBC Act (nationally) listed threatened species, and only those for which the pests were identified as a threat at the time the data was compiled.

Table 1. EPBC Act listed threatened native species for which pest animal species have been identified as a known or perceived threat. Data were collected from the relevant pest animal threat abatement plans and recovery plans. Shaded boxes represent a listed species that is threatened by a pest animal species. Conservation status under the EPBC Act; V is Vulnerable, E is endangered, EX is extinct, and CE is critically endangered.

	Scientific name	Common name	Status	Fox	Cat	Rabbit	Pig	Goat
Birds								
	Acanthiza iredalei iredalei	Slender-billed thornbill	V			■		
	Amytornis textilis modestus	Thick-billed grasswren (eastern)	V			■		
	Amytornis textilis myall	Thick-billed grasswren (Gawler Ranges)	V			■		
	Amytornis textilis textilis	Thick-billed grasswren (western)	V	■	■	■		■
	Calyptorhynchus lathami halmaturinus	Glossy black cockatoo	E			■		■
	Casuarius casuarius johnsonii	Southern cassowary	E				■	
	Cyanoramphus novaezelandiae cookii	Norfolk Island parrot	E		■			
	Dasyornis brachypterus	Eastern bristlebird	E	■	■		■	
	Diomedea exulans	Wandering albatross	V		■	■		
	Geopsittacus (Pezoporus) occidentalis	Night parrot	E	■	■	■		
	Lathamus discolor	Swift parrot	E		■			
	Leipoa ocellata	Malleefowl	V	■	■	■		■
	Macronectes giganteus	Southern giant-petrel	E		■	■		
	Macronectes halli	Northern giant-petrel	E			■		
	Neophema chrysogaster	Orange-bellied parrot	E	■	■	■		
	Ninox novaeseelandiae undulata	Norfolk Island boobook owl	E		■			
	Pardalotus quadragintus	Forty-spotted pardalote	E		■			
	Pezoporus wallicus flaviventris	Western ground parrot	E	■	■			
	Pterodroma leucoptera leucoptera	Gould's petrel	E			■		
	Stipiturus malachurus intermedius	Southern emu-wren	E	■	■			
	Thalassarche chrysostoma	Grey-headed albatross	E		■	■		
	Turnix melanogaster	Black-breasted button-quail	V	■	■		■	
Fish								
	Maccullochella macquariensis	Trout cod	E			■		
	Scaturiginichthys vermeilipinnis	Red-finned blue-eye	E				■	
Frogs								
	Geocrinia alba	White-bellied frog	E				■	
	Geocrinia vitellina	Orange-bellied frog	V				■	
	Heleioporus australiacus	Giant burrowing frog	V	■	■			
	Litoria aurea	Green and golden bell frog	V	■	■			
	Litoria lorica	Armoured mistfrog	E				■	
	Litoria nannotis	Waterfall frog	E				■	
	Litoria nyakalensis	Mountian mistfrog	E				■	
	Litoria rheocola	Common mistfrog	E				■	

	Scientific name	Common name	Status	Fox	Cat	Rabbit	Pig	Goat
	Mixophyes fleayi	Fleay's frog	E				■	
	Mixophyes iteratus	Southern barred frog	E				■	
	Nyctimystes dayi	Lace-eyed tree Frog	E				■	
	Philoria frosti	Baw Baw frog	E	■	■	■		
	Pseudophryne corroboree	Southern corroboree frog	E				■	
	Pseudophryne pengilleyi	Northern corroboree frog	E				■	
	Rheobatrachus silus	Gastric brooding frog	EX				■	
	Spicospina flammocaerulea	Sunset frog	E				■	
	Taudactylus acutirostris	Sharp-snouted day frog	EX				■	
	Taudactylus pleione	Kroombit tinker frog	V				■	
	Taudactylus rheophilus	Tinkling frog	E				■	
Invertebrates								
	Engaeus martingener	Furneaux burrowing crayfish	E	■				
	Paralucia spinifera	Copper butterfly, purple	V				■	■
Mammals								
	Bettongia lesueur	Burrowing bettong	V	■	■	■		
	Bettongia tropica	Northern bettong	E	■			■	
	Burramys parvus	Mountain pygmy-possum	E	■	■	■		
	Crocidura tenuata var. trichura	Christmas Island shrew	E		■			
	Dasycercus cristicauda	Mulgara	V	■	■	■		
	Dasycercus hillieri	Ampurta	E	■	■	■		
	Dasyuroides byrnei	Kowari	V	■	■	■		
	Dasyurus geoffroii	Western quoll	V	■	■	■		
	Dasyurus maculatus gracilis	Spotted-tailed quoll or yarri	E	■	■	■		
	Hipposideros semoni	Semon's leaf-nosed bat	E		■			
	Isoodon auratus	Golden bandicoot	V		■			
	Lagorchestes fasciatus	Banded hare-wallaby	V	■	■			
	Lagorchestes hirsutus	Rufous hare-wallaby	E	■	■	■		
	Lasiorhinus krefftii	Northern hairy-nosed wombat	E		■		■	
	Leporillus conditor	Greater stick-nest rat	V	■	■			
	Macrotis lagotis	Greater bilby	V	■	■	■		
	Myrmecobius fasciatus	Numbat	V	■	■			
	Notoryctes caurinus	Northern marsupial mole	E	■	■			
	Notoryctes typhlops	Southern marsupial mole	E	■	■			
	Onychogalea fraenata	Bridled nailtail wallaby	E	■	■	■		
	Parantechinus apicalis	Dibbler	E	■	■			
	Perameles bouganville bouganville	Western barred bandicoot	E	■	■			
	Perameles gunnii gunnii	Eastern barred bandicoot (TAS)	V		■			
	Perameles gunnii unnamed sub sp	Eastern barred bandicoot	E	■	■	■		
	Petaurus gracilis	Mahogany glider	E		■			
	Petrogale lateralis (West Kimberley)	Black-footed rock-wallaby	V	■	■			■
	Petrogale lateralis (Macdonnell Ranges)	Black-footed rock-wallaby	V	■	■			■
	Petrogale penicillata	Brush-tailed rock-wallaby	V	■	■	■		■
	Petrogale persephone	Proserpine rock-wallaby	E		■			
	Petrogale xanthopus	Yellow-footed rock wallaby	V					■
	Phascogale calura	Red-tailed phascogale	E	■	■			
	Potorous longipes	Long-footed potoroo	E	■	■		■	
	Potorous tridactylus gilberti	Gilbert's potoroo	E	■	■			
	Pseudomys fieldi	Djoongari	V	■	■	■		■
	Pseudomys fumeus	Smoky mouse	E	■	■			
	Pseudomys oralis	Hastings river mouse	E	■	■			
	Rhinolophus philippinensis	Greater large-eared bat	E		■			
	Sminthopsis aitkeni	Kangaroo Island dunnart	E		■			
	Sminthopsis douglasi	Julia Creek dunnart	E	■	■			
	Sminthopsis psammophila	Sandhill dunnart	E	■				
	Zyzomys pedunculatus	Central rock-rat	E	■	■		■	

	Scientific name	Common name	Status	Fox	Cat	Rabbit	Pig	Goat
Reptiles								
	Caretta caretta	Loggerhead turtle	E	■			■	
	Chelonia mydas	Green turtle	V	■				
	Delma impar	Striped legless lizard	V	■	■			
	Dermochelys coriacea	Leathery turtle	V	■				
	Elusor macrurus	Mary River tortoise	E	■				
	Eretmochelys imbricata	Hawksbill turtle	V				■	
	Eulamprus leuraensis	Mountain water skink	E		■			
	Eulamprus tympanum marnieae	Corangamite water skink	E	■	■	■		
	Natator depressus	Flatback turtle	V				■	
	Pseudemydura umbrina	Western swamp tortoise	E	■				
	Tympanocryptis pinguicolla	Grassland earless dragon	E			■		
Climbers								
	Cynanchum elegans	White Cynanchum	E			■	■	■
Herbs								
	Ballantinia antipoda	Southern shepherd's purse	E			■	■	
	Borya mirabilis	Grampians pincushion-lily	E			■		■
	Brachyscome muelleri		E					■
	Conostylis micrantha	Small flowered conostylis	E			■		
	Cullen parvum	Small scurf-pea	E				■	
	Eriocaulon carsonii	Salt pipewort	E				■	■
	Patersonia spirafolia	Spiral-leaved patersonia	E			■		
	Thesium australe	Austral toad flax	V			■		
Orchids								
	Burmannnia sp (Melville Island)		E				■	
	Caladenia amoena	Charming spider orchid	E			■		
	Caladenia bryceana bryceana	Dwarf spider orchid	E			■		
	Caladenia busselliana	Bussell's spider orchid	E			■		
	Caladenia caudata	Tailed spider orchid	V			■		
	Caladenia elegans	Elegant spider orchid	E			■	■	
	Caladenia formosa	Blood-red spider orchid	V			■		
	Caladenia gladiolata	Bayonet spider orchid	E			■		
	Caladenia hastata	Melblom's spider orchid	E			■		
	Caladenia hoffmanii subsp graniticola		E			■		
	Caladenia lowanensis	Wimmera spider orchid	E			■		
	Caladenia rigida	Stiff white spider orchid	E			■		
	Caladenia robinsonii	Frankston spider orchid	E			■		
	Caladenia rosella	Little pink spider orchid	E			■		
	Caladenia tensa	Rigid spider orchid	E			■		
	Caladenia thysanochila	Fringed spider orchid	E			■		
	Caladenia vericolor	Candy spider orchid	V			■		
	Caladenia viridescens	Dunsborough spider orchid	E			■		
	Caladenia winfieldii		E				■	
	Caladenia xanthochila	Yellow-Lip spider orchid	E			■		
	Drakonorchis drakeoides		E					■
	Phaius australis	Lesser swamp orchid	E				■	
	Phaius tankervilleae	Greater swamp orchid	E				■	
	Pterostylis basaltica	Basalt greenhood	E			■		
	Pterostylis despectans	Lowly greenhood	E			■		
	Pterostylis gibbosa	Illawarra greenhood orchid	E			■		
	Pterostylis sp. Halbury	Halbury greenhood	E			■		
	Pterostylis sp. Northampton	Northhampton midget greenhood orchid	E			■	■	
	Thelymitra epipactoides	Metallic sun orchid	E			■		
	Thelymitra mackibbinii	Brilliant sun orchid	E			■		
	Thelymitra manginii	Cinnamon sun orchid	E				■	

	Scientific name	Common name	Status	Fox	Cat	Rabbit	Pig	Goat
Shrubs								
	Acacia araneosa	Spidery wattle	V					■
	Acacia cretacea	Chalky wattle	E			■		
	Acacia insolita subsp. recurva	Yornaring wattle	E			■		
	Acacia rhamphophylla	Kundip wattle	E			■		
	Banksia cuneata	Matchstick banksia	E			■		
	Chamelaucium sp. Gingin	Gingin wax	E			■		
	Darwinia carnea	Mongumber bell	E			■		
	Daviesia bursarioides	Three spring daviesia	E			■		
	Eremophila nivea	Silky eremophila	E			■		
	Eremophila viscida	Vanish bush	E			■		
	Grevillea althoferorum		E	■		■		
	Grevillea beadleana	Beadle's grevillea	E					■
	Grevillea floripendula	Drooping grevillea	V					■
	Grevillea iaspicula	Wee Jasper grevillea	E					■
	Grevillea maccutcheonii	MacCutcheon's grevillea	E			■		
	Grevillea scapigera	Corrigin grevillea	E			■		
	Hemiandra gardneri	Red snake bush	E			■		
	Hemiandra rutilans	Sargent's snake bush	E			■		
	Prostanthera eurybioides	Monarto mintbush	E			■		
	Rulingia sp. Trigwell Bridge	Trigwell's rulingia	E			■		
	Synaphea quartzitica	Quartz-loving synaphea	E			■		
	Tetratheca deltoidea	Granite tetratheca	E			■		
	Tetratheca gunnii	Shy susan	CE			■		
	Verticordia fimbrilepis subsp. fimbrilepis	Shy feather flower	E			■		
	Verticordia spicata subsp. squamosa	Scaley-leaved featherflower	E			■		
	Westringia crassifolia	Whipstick westringia	E			■		■
Trees								
	Eucalyptus rhodantha	Rose mallee	E			■		
	Ptychosperma bleeseri		E				■	

6. Methods

For each of the five pest animal species we evaluated the following:

6.1 Information gaps

We considered both the amount and reliability (Reddiex et al. 2004) of knowledge available for the following four areas:

- *Monitoring techniques;* are there techniques for monitoring changes in relative and/or absolute abundance of the pest animal as a consequence of control?
- *Effectiveness of control;* are there control programs or research studies documenting the effectiveness of the commonly-used control techniques in terms of changes in the abundance of the pest animal and/or residual densities?
- *Costs of control;* have the costs of the commonly-used control techniques been documented?
- *Benefits of control for native species/ecological communities;* have the benefits of pest animal control for native species and ecological communities been investigated in a reliable (*sensu* Reddiex et al. 2004) manner?

6.2 Native species for which there is limited information

Based on the last point in 6.1, we identify the native species for which there is limited information on the benefits of control. We focused on the benefits of control for native threatened species/ecological communities (under the EPBC Act) for which the pest animal species is a known or perceived threat, and then identified any other species/ecological communities for which information was available.

6.3 Priorities for filling information gaps

Our priorities for filling information gaps were as follows. First, if there were no adequate methods for monitoring changes in the abundance of the pest animal then it would be pointless attempting to understand the effectiveness of control and the benefits of control for native species/ecological communities. Hence, the development of monitoring techniques would have the highest priority. Given that adequate monitoring techniques are available, we believe that the next highest priority is gathering reliable information on the benefits of pest animal control for native species/ecological communities. Obtaining information about both the costs and effectiveness of control were given a low priority because that information could be collected during ongoing control work and/or the proposed experiments.

6.4 Experimental design

Since the most reliable information is obtained by experimentation (see Reddiex et al. 2004), we propose experiments that will yield reliable information about the benefits of (i) feral goat, (ii) feral pig, (iii) feral rabbit, and (iv) fox control for native species/ecological communities. It was not possible to propose experiments for feral cats as there are no reliable techniques available to estimate their relative or absolute abundance.

Our experimental design should be applied to a set of control operations selected to enable the most robust experiment to be designed. The data from each experiment should be incorporated into a meta-analysis (Osenberg et al. 1999) and/or system model, with new data continually updating the analyses/model and thus knowledge about the benefits of pest animal control. In this design, data from control operations conducted at great distance in both space and time are analysed simultaneously. We thus see our broad designs as being a template for the design of pest animal control operations in the future. Hence, the acquisition of knowledge should be seen as an ongoing component of future pest animal control operations rather than something generated by a one-off experiment.

Since the reliability of inferences using this design increases with the number of control operations that they are applied to, the onus is on funding agencies to impose these designs on the pest animal control operations that they fund. We therefore give *indicative* costs for conducting the experiment at just one area. The actual costs will depend on the area(s) where the work is conducted, and the charge-out rates of the organisations involved in the work (charge out rates used in this report ranged from $500–$900 per day). The indicative costs should be interpreted with caution and used for general budgeting purposes only.

7. Results and Discussion

The first stage of this review (audit of existing pest animal control programs in Australia; Reddiex et al. 2004), found that there was little reliable knowledge about the benefits of pest animal control in Australia. Few control programs monitored changes in the pest species targeted for control and the native species of interest. In addition, monitoring designs rarely included non-treatment areas or were randomly allocated, and few had assessed the species/habitat of interest prior to control.

Experimentation is required to gain reliable knowledge: that is, the proposed control should (where possible) have replicated treatment and non-treatment areas, have suitable monitoring designs for both pests and resources, randomly assigned treatment and non-treatment areas, and be undertaken over an appropriate scale and duration for both the pest animal and native species of interest. Failure by pest control programs to meet the basic experimental requirements makes it impossible to separate an observed response in native species/habitat following pest control from climatic factors and/or a suite of potentially threatening processes, namely; habitat change and degradation, impact of introduced animals and plants, disease, exploitation, and climate change. We acknowledge that few experiments/control programs have met all of the requirements for reliable knowledge due to the fact that large-scale manipulative experiments are difficult to implement in the field, and require long-term support and significant financial investment from management agencies. In nearly all cases the most expensive component of an appropriately designed experiment is monitoring.

The following section outlines proposed experiments that enable the benefits of pest animal control to be investigated for feral goats, feral pigs, feral rabbits, and foxes. We strongly recommend that the monitoring design is based on an underlying modelling framework, thereby ensuring the correct information is collected for system models (see Robley et al. 2004). The development of dynamic system models allow the effects of changing parts of a system (e.g., pest animal control) to be predicted. Such a model has been developed for the interactions between foxes, cats, feral rabbit and native prey species in Australia (see Robley et al. 2004). If experiments are designed with an underlying modelling framework in place, they can be used to continually update system models and decrease the amount of time it takes to improve the reliability of management decisions.

This report does not provide exact locations of proposed experiments, and therefore the costs can only be estimated. Experiments that include varied levels of control are only proposed for feral rabbits. The recommended experiments for feral goats, feral pigs and foxes could be replicated with different frequencies or intensities of control. However, there are significant costs associated with this (see below). We believe the first priority is to identify whether benefits of pest animal control exist when control is maximised. If benefits do exist, then future studies can investigate the effects of various frequencies or intensities of control on those benefits.

7.1 Feral goats

7.1.1 Information gaps

The first stage of this review (Reddiex et al. 2004) concluded that there was little reliable knowledge about the benefits of feral goat control for native species and ecological communities. In contrast, there are reliable methods for estimating the absolute abundance of feral goats in open or semi-open habitats (i.e., aerial survey; Pople et al. 1998), and the effectiveness and costs of control are well-known (e.g., Table 2 in Environment Australia 1999a).

7.1.2 Native species for which there is limited information

There is very little information on the impacts of feral goats on, or benefits of feral goat control for, native species or ecological communities. There is some information from an exclosure study in the Flinders Ranges (Henzell 1991). It was shown that feral rabbits (rather than feral goats or euros *Macropus robustus*) were a critical factor in determining mulga (*Acacia aneura*) regeneration because they killed nearly all of the seedlings.

The eleven plant, one invertebrate and eight fauna listed threatened species under the EPBC Act for which feral goats are a known or perceived threat appear to have that status because goats either have been observed feeding on those species, or because browse on those species has been attributed to feral goats, or because feral goats compete with native herbivores for resources or cause land degradation. Hence, there is extremely limited information for all of the listed threatened native species (EPBC Act) for which feral goats are either a known or perceived threat.

7.1.3 Priorities for filling information gaps

We consider that the greatest priority is understanding the benefits of feral goat control for native plant species. Aerial survey (e.g., Pople et al. 1998) appears to be an adequate method for estimating the abundance of feral goats in most habitats except gorges and forests with a closed canopy.

7.1.4 Recommended experimental design

We advocate an experiment that assesses the benefits of feral goat control for a combination of listed threatened species (EPBC Act) for which feral goats are known threat and common native species. Our preferred experimental design (outlined in Figure 2) first involves identifying as many (minimum of 5; see below) potential feral goat control programs around Australia. Each potential control program must contain native plant species that are predicted to respond to feral goat control (either in abundance and/or condition). Our preferred option is that both EPBC Act listed threatened species and common plant species are present in each potential feral goat control program. The more programs that can be included in the experiment the more reliable the inferences will be. We suggest five is the minimum number of feral goat control programs that should be included.

Each feral goat control program is then divided into pairs of potential control areas, with each pair of areas being as similar as possible in terms of vegetation composition and structure, and soil types; this is usually achieved by selecting adjacent areas. The most reliable inferences will come from the most pairs of areas. However, as long as there are at least five control programs there can be a minimum of one pair in each control program. The paired areas are then randomly assigned as treatment or non-treatment. Within all paired areas (i.e., both treatment and non-treatment) at least 20 similar pairs of sites will then be selected (Figure 2). These pairs of sites should be selected so that they each include the plant species predicted to increase in abundance following pest animal control, and at least half of the pairs (but as many as possible) should include the EPBC Act listed threatened species predicted to respond to control. These sites should be a minimum of 10×10 m and a maximum of 25×25 m. One of each pair of sites is randomly assigned an exclosure. The purpose of the exclosure is to exclude feral goats, and several fence designs achieve this (review in Long and Robley 2004). If it is believed that feral rabbits are also affecting the species of interest, then there are two options. Our favoured option is to select trios of similar sites rather than pairs of sites, and a goat exclosure is randomly assigned to one of the trio, a goat+rabbit exclosure to another, and the remaining site is open to both goat and rabbit herbivory.

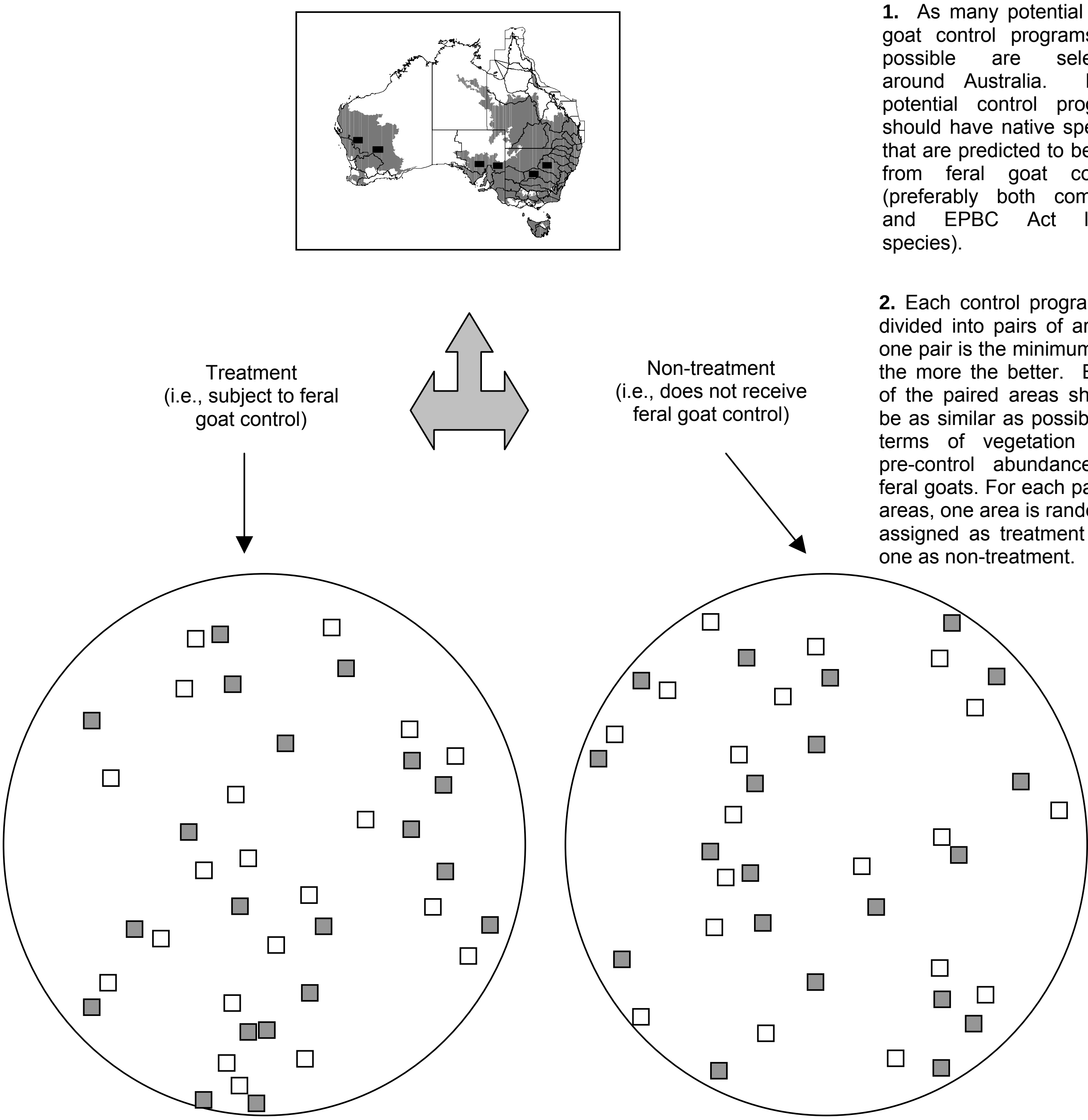
At least 12 months prior to feral goat control beginning, the plant species of interest are sampled in all of the pairs (or trios) of sites. Because monitoring protocols have not been developed (or at least, published) for most plant species of interest, we do not attempt to prescribe methods for monitoring changes in the abundance and condition of native species; rather, these must be developed as appropriate on a case-by-case basis. However, it is important to think about the life-history of each plant and how the feral goats (and possibly feral rabbits) might be affecting the population dynamics of the plant. Monitoring of plant abundance/condition should be conducted at least annually.

The feral goat control should aim to achieve residual densities that are as low as possible in the treatment area, but should not affect goat density in the non-treatment area. This may mean that treatment and non-treatment areas are some distance apart. Common techniques for controlling feral goats are aerial and ground shooting, trapping, and aerial and ground mustering (see Reddiex et al. 2004).

The abundance of feral goats (and feral rabbits if thought to be important) should be estimated in each area at least annually, and in the same month each year. We recommend aerial survey for feral goats (and kangaroos) and spotlight counts for feral rabbits, though the suitability of this technique will depend on the habitat at the treatment areas. Exclosures should be inspected at least every six months, depending on the potential for incursion (e.g., overhanging branches that might fall on the fences, or proximity to creeks that might erode the fence).

It will be important to measure other covariates at each pair or trio of sites. For example, rainfall is thought to be important for the germination of some seeds. Hence, a response to pest animal control might not occur until a threshold soil moisture has been exceeded. Other covariates might be the abundance of introduced mice, native herbivores (e.g., kangaroos), or domestic livestock.

How long should such an experiment run for? The answer will depend on the plant species monitored and the environmental conditions that occur during the work. And there is always the possibility of 'demonic intrusion' (e.g., the goats in the supposed non-treatment area are actually controlled) ruining even the best design. However, we believe that there should be at least 1 year of pre-control monitoring and at least 5 years of control before the experiment is reviewed.



1. As many potential feral goat control programs as possible are selected around Australia. Each potential control program should have native species that are predicted to benefit from feral goat control (preferably both common and EPBC Act listed species).

2. Each control program is divided into pairs of areas: one pair is the minimum but the more the better. Each of the paired areas should be as similar as possible in terms of vegetation and pre-control abundance of feral goats. For each pair of areas, one area is randomly assigned as treatment and one as non-treatment.

3. Within each treatment and non-treatment area, at least 20 similar pairs of sites (similar in the plant species that are to be monitored) are selected. Feral goat-proof exclosures (shaded squares) are constructed at one of each paired site (randomly selected). Monitoring of plant species is undertaken in the exclosures and paired areas to which feral goats have access.

Figure 2. The key elements of the experimental design for understanding the benefits of feral goat control for native species/communities.

The key parameter of interest is the mean difference in abundance (or condition) of plant species between the treatment area and the non-treatment area in the sites without exclosures (i.e., exposed to goat herbivory). This is the mean effect (or benefit) of feral goat control. The abundance (or condition) of plant species in the exclosures is the outcome if feral goats (and feral rabbits if that species was also excluded) had been eradicated from the area. (However, we note that eradication of feral goats is impossible for most of the feral goat range in mainland Australia; Parkes et al. 1996). One possibility is that there is no difference between the sites exposed to goats and the exclosures in both the treatment and non-treatment areas. If this was observed then we would conclude that there is no benefit to either controlling goats to low densities or eradicating goats.

Each pair of treatment and non-treatment sites contributes one data point to the final comparison. We estimate that at least five pairs of treatment and non-treatment sites are needed to provide a reasonable confidence interval around the benefits of feral goat control for native species.

One potential problem with assessing the benefits of feral goat control for native species/ecological communities is the ability to partition the benefits of feral goats from sympatric large herbivores (i.e., kangaroos and in some rangelands, domestic sheep). Forsyth and Parkes (2004) recommended that feral goats and kangaroos be incorporated into stocking rates in the rangelands. Feral goats should thus be considered one component of herbivory affecting native species/communities, and benefits to those species/communities may not accrue if feral goats – but not the other herbivores – are controlled to low densities. Thus, some programs may need to control kangaroos (and other herbivores) within the treatment area(s). In this situation the abundance of kangaroos should also be monitored (both kangaroos and feral goats can be monitored simultaneously with aerial survey; Clancy et al. 1997; Pople et al. 1998).

Until study sites are identified, the cost of this experiment can only be considered indicative. An indication of the cost of the experiment is shown in Table 2. Note that these costs are for one pair of areas, and that at least five pairs of areas (i.e., five control programs each with a minimum of one pair of areas) are recommended. Hence, the start-up cost of the experiment would be c. $325K, and the annual cost of running such a design $250K. The final-year costs are higher because of the need to analyse the data and publish the work.

Table 2. Indicative start-up and ongoing costs of an experiment assessing the benefits of feral goat control for biodiversity. The costs are for one pair (i.e., treatment and non-treatment) of areas (see Figure 2 for detail).

Item	Start-up (year 1) costs ($000)	Ongoing (year 2 and beyond) costs ($000)	Final year costs ($000)
Labour[1]	$40	$20	$40
Materials	$10	$0	$0
Transport	$15	$10	$20
Feral goat control	$0	$20	$0
TOTAL	$65	$50	$60

[1] Assumes 100% overheads, but not all organisations charge for these.

7.2 Feral pigs

7.2.1 Information gaps

The first stage of this review (Reddiex et al. 2004) showed that there was little reliable knowledge about the benefits of feral pig control for native species and ecological communities (see also Choquenot et al. 1996). This contrasts with the state of knowledge concerning the benefits of feral pig control for agricultural production (e.g., lamb marking rates; Choquenot et al. 1997).

There are reliable methods for estimating the absolute abundance of feral pigs in both open and closed habitats (i.e., aerial survey and mark-recapture; Choquenot et al. 1996), and the effectiveness and costs of control are well-known (Choquenot et al. 1999).

7.2.2 Native species for which there is limited information

There is limited information for all of the 40 listed threatened species under the EPBC Act for which feral pigs are a known or perceived threat (Table 1; Department of the Environment and Heritage 2003).

7.2.3 Priorities for filling information gaps

We consider that the greatest priority is understanding the benefits of feral pig control for native species and ecological communities. The next priority would be methods for estimating the abundance of feral pigs in forest habitats.

7.2.4 Recommended experimental design

Choquenot et al. (1996: 41) claimed that "the most important environmental impacts that feral pigs are likely to have are habitat degradation and predation". Ground disturbance (or 'rooting') is a universal impact of feral pigs and alters the abundance of some plant species. Ground disturbance can reduce the abundance of earthworms (which may decline because they are eaten by feral pigs) and almost certainly alter important soil ecosystem processes (e.g., C and N storage, and the rate at which organic matter decays). It has also been suggested that ground disturbance may aid the establishment of weeds.

We therefore suggest an experimental design that focuses on the benefits of feral pig control for ground disturbance and its associated biodiversity and ecosystem functions. If any of the species listed under the EPBC Act for which feral pigs are a known or perceived threat occur in the control areas then changes in their abundance/condition could also be monitored.

We suspect that the benefits of feral pig control on ground disturbance will differ between the rangelands, sub-alpine grasslands and tropical (or semi-tropical) rainforests (Choquenot et al. 1996). We therefore suggest conducting the following experiment at sites in each of these three ecosystems. However, we encourage the adoption of this design at as many sites as possible throughout the feral pig range. Possible study sites include north-western New South Wales (rangeland) (Choquenot 1998), Namadgi/Kosciusko (sub-alpine) (Hone 2002) and the Wet Tropics World Heritage Area (Queensland) (Mitchell 1997). The advantage of these sites is that there is published information on either the dynamics of feral pigs and/or ground disturbance.

The experimental design would be the same for all three ecosystems. Pairs of potential control sites would be selected, with each pair as similar as possible in terms of vegetation, soil fertility and feral pig abundance. (Pre-control estimates of feral pig abundance would be useful.) The reliability of the inferences increases with the number of paired sites, and we suggest at least six pairs in each ecosystem. One of the pair would be randomly assigned as the treatment site and the other the non-treatment site. The treatment site receives feral pig control (as much as possible so that the densities are as low as possible) and the non-treatment site does not receive any feral pig control (Figure 3). Common techniques for controlling feral pigs are trapping, aerial and ground shooting and poison baiting (see Reddiex et al. 2004). The treatment and non-treatment sites must be sufficiently far apart that the abundance of pigs in the latter is independent of the control in the former.

Sites would be stratified into two areas based on the likelihood of ground disturbance. The 'high' stratum would be moist and fertile areas (Hone 1988; Mitchell 1997), and the 'low' stratum everything else. At each site, 100 20×20 m plots should be randomly located within the high stratum and the area of ground disturbance quantified within each plot (sampling is not undertaken in the low stratum areas). Ground disturbance, soil moisture (which has been hypothesised to increase the probability of ground disturbance) and the numbers of fresh dung pellets should be quantified on all 100 plots annually. Feral pig abundance should be estimated annually from capture-mark-recapture (CMR) analyses of trapped animals (Caley 1993), and/or by aerial survey at the rangeland sites (Choquenot 1998).

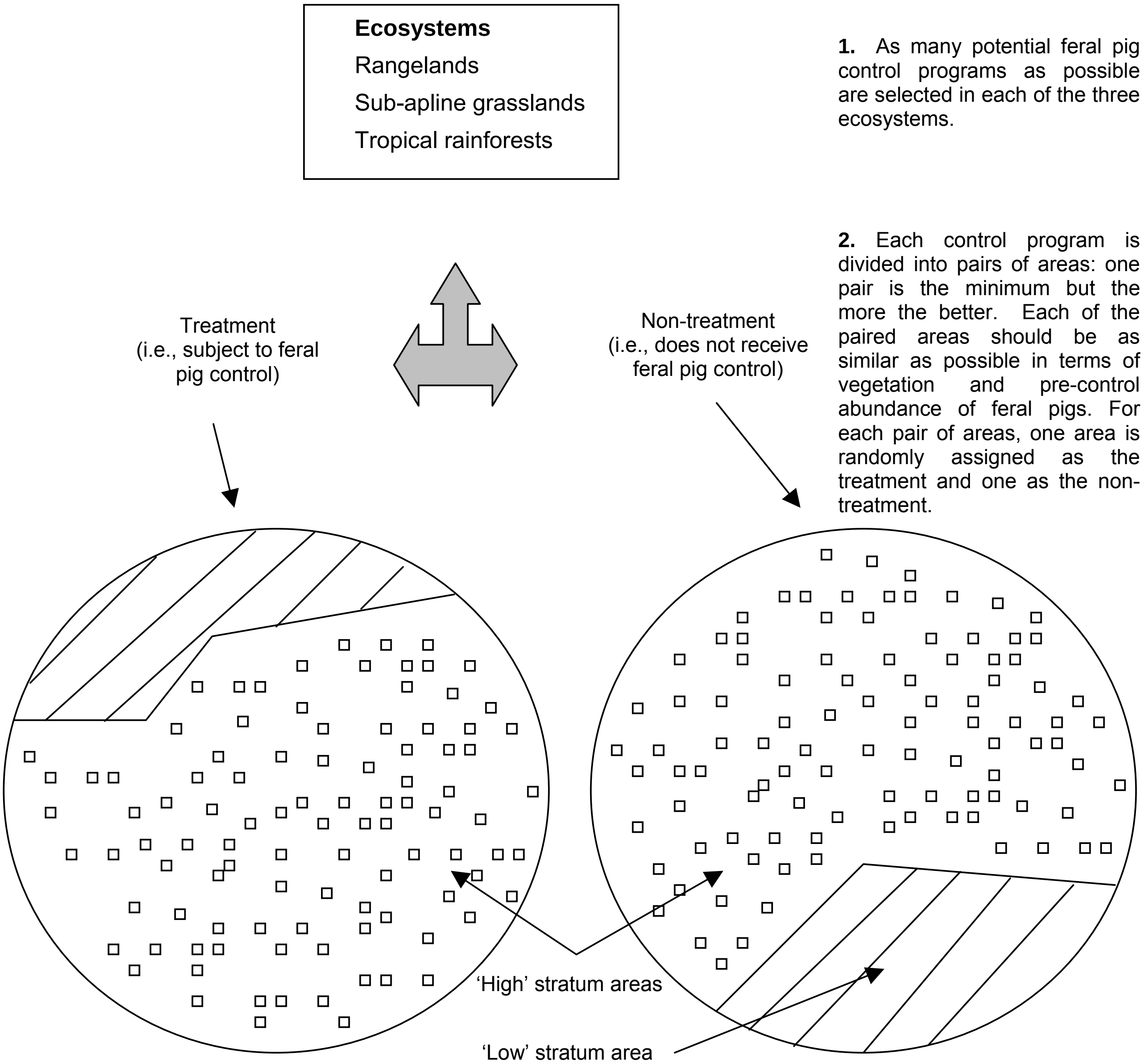
If any of the species listed under the EPBC Act for which feral pigs are a known or perceived threat (Department of the Environment and Heritage 2003) are present in the sites then their distribution(s) should be mapped. At least 20 20×20 m plots should be randomly located within the distribution of the listed species in each site. The abundance/condition of the listed species, and the amount of ground disturbance, should be monitored at the start of the experiment and at 2 year intervals.

It may also be possible to investigate the benefits of feral pig control for below-ground ecosystem processes using this design. Feral pig exclosures (5×5 m) could be constructed on a subset of disturbed and undisturbed plots and key below-ground structure and functions (e.g., C, N and P storage and earthworm abundance) quantified annually. The key comparisons would be between exclosed and open plots within sites and the magnitude of that difference between the treatment and non-treatment sites. A pilot study would be required to evaluate the practicality of this design and to test methods for measuring below-ground processes.

How long should the experiments run for? The answer will depend on the plant species monitored and the environmental conditions that occur during the experiment. And there is always the possibility of 'demonic intrusion' (e.g., feral pigs in the supposed non-treatment area are actually controlled) ruining even the best design. However, we believe that there should be at least 1 year of pre-control monitoring and at least 5 years of control before the experiment is reviewed.

The experiment will yield six types of data for analyses:

- abundance of feral pigs (as estimated by CMR and dung counts)
- rate at which plots have ground disturbed (both undisturbed and re-disturbed)
- area of ground disturbed on plots that have been disturbed
- abundance/condition of EPBC Act listed species
- abundance of weed species
- possibly below-ground ecosystem structure and function



3. Within each treatment and non-treatment area, at least 100 plots (20x 20 m) are selected in the 'High' stratum areas. Feral pig exclosures may be constructed on a subset of plots (randomly selected) to investigate below-ground ecosystem processes. Monitoring of ground disturbance and EPBC Act listed species abundance/condition is undertaken in all plots

Figure 3. The key elements of the experimental design for understanding the benefits of feral pig control for ground disturbance and its associated biodiversity and ecosystem functions.

The appropriate comparison is the difference between the treatment and non-treatment sites in the mean values of these parameters. Hence, each pair of treatment and non-treatment sites contributes one data point to the key comparison. We estimate that at least six pairs of treatment and non-treatment sites are needed to provide reasonable confidence intervals around the benefits of feral pig control for the parameters outlined above in each ecosystem, but the more pairs the greater the precision around our estimates of the benefits of feral pig control.

Until study sites are identified, the cost of this experiment can be only considered indicative (Table 3). We estimate that the start-up costs of the experiment for one ecosystem with six treatment and non-treatment sites will be (including overheads) $430K. The annual ongoing cost will be $470K, approximately one third of which would be used for feral pig control.

Table 3. Indicative start-up and ongoing costs of the experiment assessing the benefits of feral pig control for ground disturbance and native species at one ecosystem. The costs are for six pairs of treatment and non-treatment areas.

Item	Start-up (year 1) costs ($000)	Ongoing (year 2 and beyond) costs ($000)	Final year costs ($000)
Labour[1]	$300	$220	$220
Materials	$70	$20	$10
Transport[2]	$60	$50	$50
Feral pig control[3]	$0	$180	$0
TOTAL	$430	$470	$280

[1] Assumes 100% overheads, but not all organisations charge overheads.
[2] Helicopter transport may be required to access some sites, and possibly for aerial survey at the rangeland sites.
[3] Costs based on aerial shooting (c. $1000/hour).

7.3 Feral rabbits

7.3.1 Information gaps

The first stage of this review (Reddiex et al. 2004) showed that there was little reliable knowledge about the benefits of feral rabbit control for native species and ecological communities. In contrast, there is some evidence of the impacts of rabbits on native species and ecological communities for rangelands and higher rainfall areas (see Williams et al. 1995). Feral rabbits are believed to impact on native fauna via direct competition for resources and through behavioural interactions such as exclusion of native animals from feeding areas (Williams et al. 1995). However, few studies have experimentally investigated these potential impacts (but see Robley et al. 2002).

There are reliable methods for estimating the relative abundance (i.e., spotlight counts; Caley and Morley 2002) and absolute abundance of feral rabbits (i.e., mark-recapture; Twigg et al. 2000) in most habitat types, and the effectiveness and costs of control are well known (Williams et al. 1995).

7.3.2 Native species for which there is limited information

There is limited information on the benefits of feral rabbit control for native species and ecological communities. Studies that have investigated the impacts of feral rabbits on pasture composition and biomass have largely focused on modified agricultural landscapes where few threatened native species are present (e.g., Gooding 1955; Myers and Poole 1963; Croft et al. 2002). The impact of feral rabbits on native plant species has largely been inferred from exclosure studies (e.g., Lange and Graham 1983; Leigh et al. 1989; Henzell 1991). The main limitation of such studies when attempting to infer benefits of feral rabbit control is that eradication is not feasible in mainland areas of Australia (i.e., exclosures have feral rabbit densities that are not possible via conventional control).

In rangelands, the current replacement rate of many shrubs and trees is insufficient to prevent their loss in the long-term. Lange and Graham (1983) studied feral rabbit browsing of arid zone acacia (*Acacia* spp.) seedlings when feral rabbits were at low densities, and found that only seedlings that were protected from feral rabbits and sheep showed good growth. Several other studies have indicated that feral rabbits may prevent regeneration of many shrub and tree species (e.g., Johnson and Baird 1970; Friedel 1985; Auld 1990; Henzell 1991). In the Gammon Range National Park in South Australia, Henzell (1991) reported that feral rabbits were a critical factor in determining mulga regeneration because they killed nearly all of the seedlings, and Foran et al. (1985) found the same response for *Acacia kempeana* seedlings. In a replicated field experiment, Mutze et al. (1997) reported that feral rabbit control resulted in higher levels of recruitment of the arid zone shrubs of moderate palatability in South Australia. However, it is extremely difficult to undertake field experiments to assess the benefits of feral rabbit control for regeneration in rangelands as germination and establishment of vegetation in rangelands may only occur at time intervals of 5–50 years, mainly as a response to rainfall (Ireland and Andrew 1992; Williams et al. 1995).

In the Coorong National Park in South Australia, Cooke (1987) reported that feral rabbits prevented regeneration of *Acacia longifolia* and the sheoak *Allocasuarina verticilliata*. In Kosciusko National Park, where feral rabbits were excluded two new species of forbes were found in seven years, but where feral rabbits were present there was a loss of nine forb species (Leigh et al. 1987). An exclosure study in the mallee in western Victoria found 17 indigenous species of ground layer plants inside feral rabbit exclosures after 2 years that were not present outside (Cochrane and McDonald 1966). However, other herbivores were present in the study area.

The benefits of a reduction in feral rabbit densities resulting from RHD have been monitored at a number of sites (>10) across Australia (Sandell and Start 1999). Despite most of the sites only being monitored for two years post-RHD all but one of the sites found evidence of native vegetation recovery as a result of reduced feral rabbit abundance (Sandell and Start 1999). The structure of vegetation has been reported to have improved due to regeneration of native trees and shrubs, however floristic changes have been variable and dependent on climatic factors (the results for most of these sites are not available). Sandell (2002) found no evidence of widespread germination of woody seedlings, which is not surprising given the episodic nature of such regeneration in many environments.

Feral rabbits are a known or perceived threat for 84 species listed under the EPBC Act (Table 1); 13 mammals, 13 birds, 1 fish, 1 amphibian, 2 retiles, and 54 plant species. Few of these species were identified in the above overview. The 54 plant species listed under the EPBC Act for which feral rabbits are a known or perceived threat appear to have that status because feral rabbits either have been observed feeding on those species, or because browse on those species has been attributed to feral rabbits, or species have shown a positive response in areas where feral rabbits are excluded. Hence, there is limited reliable information on the benefits of conventional feral rabbit control for nearly all of the species listed in the EPBC Act for which feral rabbits have been identified as a threat.

7.3.3 Priorities for filling information gaps

We consider that the greatest priority is understanding the benefits of feral rabbit control for native plant species/communities. The next priority would be to determine the indirect impact of feral rabbits on native fauna species.

7.3.4 Recommended experimental design

We advocate an experiment that assesses the functional relationship between feral rabbit density and damage to a combination of native species for which feral rabbits are a known key threatening process (Environment Australia 1999b) and other common native species that feral rabbits may impact upon. Our preferred experimental design is a response surface experiment (Mead 1988), and uses large-scale enclosures to assess the impact of feral rabbit density on native plant species diversity and composition, including seedling survival of planted shrub/tree species. We believe that the alternative approach of comparing vegetation response between feral rabbit control programs and paired non-control areas is less desirable due to potential difficulties in maintaining the desired treatments over extended periods of time and over a large scale, and limited control of other herbivores. The proposed enclosures have the advantage of enabling accurate assessment of feral rabbit densities and therefore relationship to damage, but are also large enough to simulate broad acre conditions (note that enclosures could not be used to simulate broad acre conditions for feral goats and feral pigs).

We suspect that the benefits of differing feral rabbit densities on native vegetation will vary between rangelands and high-rainfall areas (Williams et al. 1995). We therefore suggest conducting the following experiment at sites in each of these two ecosystems. However, we encourage the adoption of this design at as many sites as possible throughout the feral rabbit range. Where possible sites should be selected where published information is available on the dynamics of feral rabbit populations, including changes in abundance of feral rabbits following conventional control, and their associated impacts on native vegetation.

The experimental design would be the same for both ecosystems. The experiment should use a randomised design (see Figure 4), with different feral rabbit densities as the treatments at each site. There should be a minimum of four treatments (i.e., enclosures) at each site.

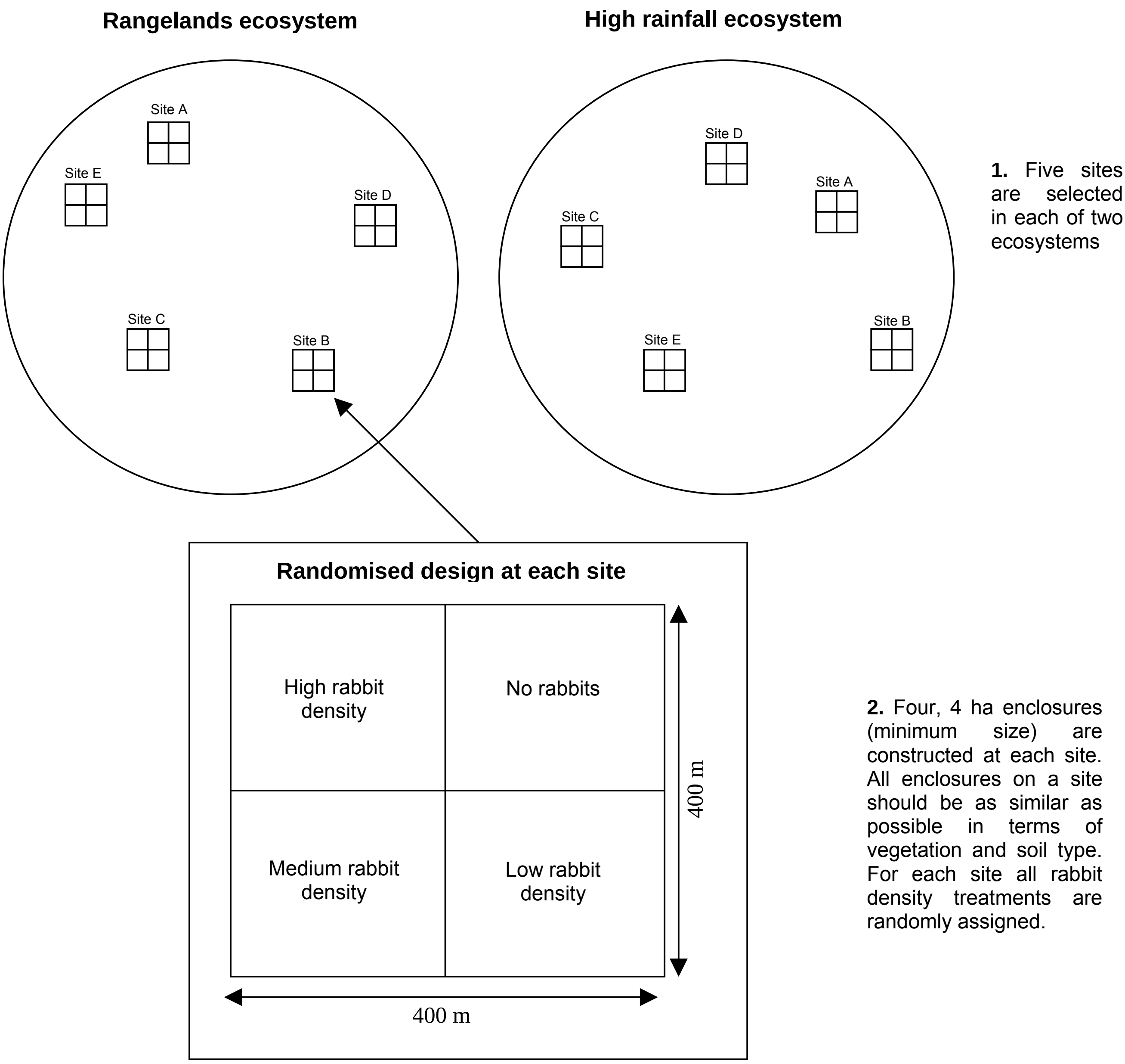


Figure 4. Experimental design for understanding the relationship between feral rabbit density and damage to native plant species in two ecosystems.

Recommended feral rabbit densities should represent typical feral rabbit densities for the regions studied and for the prevailing environmental conditions, but should include a low density and low-medium density representative of sustained conventional control of feral rabbits, and a medium-high and high density which is representative of uncontrolled feral rabbit populations. Each enclosure should include a number of relatively small exclosures that act as experimental controls. The experiment aims to examine the relationship between feral rabbit control and damage, therefore the densities within treatments should be treated to reflect management. We suggest the following management; low density treatment – remove 90–95% of feral rabbits once per year (small population levels may be prone to extinction in enclosures, and may require intensive management/reintroduction); low-medium density – remove 70–80% of feral rabbits once per year; medium-high density – remove 40–50% of feral rabbits once per year; and high density – no removal.

The reliability of the inferences increases with the number of sites and the number of replicates within each site. However, as long as there are at least five sites in each region there can be a minimum of one experiment in each site (i.e., no replication within sites). Sites should be selected so that they include the plant species predicted to respond to feral rabbit control (either in abundance and/or condition) and where possible include EPBC Act listed species for which feral rabbits are a known or perceived threat (Table 1). All treatments within a site would be undertaken on adjacent areas (see Figure 4), and all treatments should have similar soil types and vegetation composition and structure at the commencement of the study.

The size of each treatment enclosure should be at least 4 ha, but if resources permit we encourage the size of each enclosure to be increased (we have costed this experiment based on 4 ha enclosures). Feral rabbits generally do not forage far from their warrens. Wood et al. (1987) reported an inverse relationship between distance from warrens and the intensity of feeding, with 800kg/ha of forage removed <12m from the warren, 220kg/ha 25 m from the warren and 150kg/ha at 100 m from the warren. Feral rabbit home range differs markedly from one environment to another (range 0.05–4.70 ha; Myers et al. 1994). Each enclosure will be fenced in a manner that prevents feral rabbits from moving outside their intended enclosure, and they will be fenced to a height (c. 1.8 m) that prevents entry of other herbivores that are likely to affect the species of interest (e.g., Henzell 1991; Grice and Barchia 1992). Several fence designs achieve these requirements (review in Long and Robley 2004). Predator control will need to be undertaken around all enclosures throughout the duration of the experiment (predator control has been included in the experiment costing).

Prior to the treatments being imposed, the vegetation within each enclosure should be sampled. Monitoring protocols for assessing grassland species composition and biomass are widely available (e.g., dry-weight-rank technique; Mannetje and Haydock 1963; modified step-point sampling technique; Cunningham 1975). Monitoring of plant composition, condition and biomass should be undertaken quarterly as there are pronounced seasonal variation in many grassland systems.

The impact of feral rabbit densities on the survival of shrubs/tree species would be assessed through monitoring the survival of planted seedlings in all enclosure treatments. As mentioned above, germination and establishment of vegetation in rangelands may only occur at time intervals of 5–50 years, mainly as a response to rainfall (Ireland and Andrew 1992; Williams et al. 1995). Therefore, it is unlikely that establishment of shrub/tree species will occur naturally in the enclosures during the timeframe of the study. The shrub/tree species selected will act as a proxy for species that feral rabbits are believed to prevent regeneration of (e.g., *Acacia* spp.; Williams et al. 1995) and therefore be similar in palatability and structure. However, we have also costed the addition of a simulated rainfall treatment to this experiment that may enable natural regeneration to occur (i.e., doubling the number of enclosures at each site). This would involve replicating the above enclosures at each site and randomly selecting one block to be irrigated.

The abundance of feral rabbits should be monitored throughout the study (quarterly) using mark-recapture methods. Enclosures should also be inspected at least every fortnight, to ensure the fence has not been breached by feral rabbits or other herbivores and on the potential for incursion (e.g., overhanging branches that may fall on fences, or proximity to creeks that might erode the fence).

Other covariates should be monitored at each site. For example, rainfall is thought to be important for the germination of some seeds. Hence, a response of feral rabbit control might not occur until a threshold soil moisture has been exceeded. Other covariates might include the abundance of small native herbivores that may enter the enclosures, presence of disease (e.g., myxomatosis and RHD), and temperature.

This design will enable benefit-cost analyses to be undertaken as it will provide a relationship between incremental pest density and incremental damage, without which cost-benefit analyses are tenuous (Fleming et al. 2001).

How long should the experiments run for? The answer will depend on the plant species monitored and the environmental conditions that occur during the experiment. And there is always the possibility of 'demonic intrusion' (e.g., destruction of enclosure fences) ruining even the best design. However, we believe that there should be at least 1 sample in all treatments prior to the commencement of the study to gather accurate baseline information on the response variables that are to be assessed and at least four years of monitoring before the experiment is reviewed to enable sampling of different seasonal conditions. This design also enables the treatments to be reversed (i.e., feral rabbit densities changed between enclosures). The key relationship is that between feral rabbit density and damage. We expect that at least five sites are needed to provide a reasonable confidence interval around this relationship in each ecosystem.

Until study sites are identified, the cost of the experiment can only be considered indicative (Table 4). We estimate that the start-up costs of the experiment for one ecosystem with five sites will be (including overheads) $490K (excludes the simulated rainfall treatment). The annual ongoing cost will be $320K.

Table 4. Indicative start-up and ongoing costs of the experiment assessing the relationship between feral rabbit density and damage to native plant species for experiments that a) exclude the simulated rainfall treatment, and b) include the simulated rainfall treatment. The costs are for five sites within one ecosystem.

Item	Start-up (year 1) costs ($000)	Ongoing (year 2 and beyond) costs ($000)	Final year costs ($000)
a) Excludes simulated rainfall treatment			
Enclosure construction	$160	$0	$0
Labour[1]	$220	$220	$250
Materials	$40	$30	$30
Transport	$70	$70	$70
TOTAL	$490	$320	$350
b) Includes simulated rainfall treatment			
Enclosure construction	$300	$0	$0
Labour[1]	$280	$280	$310
Materials	$50	$35	$35
Transport	$70	$70	$70
Irrigation[2]	$40		
TOTAL	$740	$385	$415

[1] Assumes 100% overheads, but not all organisations charge overheads.
[2] Irrigation costs will depend upon the location of sites.

7.4 Foxes

7.4.1 Information gaps

The first stage of this review (Reddiex et al. 2004) showed that there was little reliable knowledge about the benefits of fox control for native species and ecological communities from control programs by 'conservation' based organisations. However, experimental studies have provided some information on the benefits of control for some species known to be threatened by foxes (Saunders et al. 1995; Reddiex et al. 2004).

There are methods available for estimating the relative abundance of foxes (i.e., sand plots; Roughton and Sweeny 1982; and spotlight counts (e.g., Newsome et al. 1989)), and the costs of control are well-known (e.g., Saunders et al. 1995).

7.4.2 Native species for which there is limited information

Saunders et al. (1995: 28) stated that "except for some detailed studies of fox predation on a limited range of Western Australian native mammals and… malleefowl, there is little quantitative information on the damage that foxes cause to native fauna". We briefly summarise those cited examples plus several more recent studies (see Reddiex et al. 2004; Robley et al. 2004 for more complete reviews). Many of the native species discussed below are listed threatened species under the EPBC Act.

Five populations of rock-wallabies (*Petrogale lateralis*) in the central wheatbelt region of Western Australia were studied by Kinnear et al. (1998). The trends in rock-wallaby abundance at the sites that did and did not receive ground based fox control were markedly different; rock-wallabies apparently increased greatly at the two sites that received control but either did not increase (1 site) or decreased (2 sites) at the sites that did not receive fox control. Hone (1999) argued that, since no data were presented on trends in fox abundance as a result of the fox baiting, it cannot be assumed that the mechanism for the increase in rock-wallabies at the baited sites was reduced fox predation.

Friend and Scanlon (1996) report on the effect of fox control on populations of red-tailed phascogale (*Phascogale calura*) in the Western Australian wheatbelt. Trap success data from 1994–1996 suggests that fox control benefits populations of red-tailed phascogale. However, it was also noted that rainfall and population abundance from the previous year were strongly related, which obscures the effect of other factors.

Friend and Thomas (2003) report changes in the sighting rates of numbats (*Myrmecobius fasciatus*) at Dryandra, Western Australia (see also Saunders et al. 1995). When fox control was undertaken the sighting rate increased from c. 5 numbats 100 km^{-1} in 1989 to c. 11 numbats 100 km^{-1} in 1992, but thereafter declined to pre-poison baiting levels. The cause of this decline was suspected to be a decline in the food supply induced by the increasing population (Friend and Thomas 2003).

Chuditch (or western quoll, *Dasyurus geoffroii*) apparently increased in abundance following the application of dried meat baits containing 1080 to kill foxes at Batalling forest, Western Australia (Morris et al. 2003). Chuditch trap success increased from c. 0.5% in December 1990, when fox control began, to a peak of 13% in July 1995. Thereafter, trap success has been lower but still an order of magnitude greater than when control began in 1990. Morris et al. (2003) describe examples of chuditch translocated to former range establishing populations when foxes were controlled.

Saunders et al. (1995) overview unpublished studies that report a 30-fold increase in the abundance of Rothschild's rock-wallaby (*Petrogale rothschildi*) following the removal of foxes from Dolphin Island by 1080 baiting. There was also an apparent increase in the abundance of bettongs (*Bettongia penicillata*) in the Tutanning Nature Reserve, Western Australia, following a 5 year baiting program. A recent review of interactions between feral cats, foxes, native carnivores, and feral rabbits in Australia noted several exceptions to the predicted responses of small mammals to fox control (Robley et al. 2004). The numbat, chuditch, Rothschild's rock-wallaby, and bettong case studies above all suffer from a lack of replication (Caughley and Gunn 1996). However, as Friend and Thomas (2003) argue, there are often no other areas available for replication. Also, some populations may be very close to extinction such that non-treatment sites may be ethically difficult to justify.

New South Wales National Parks and Wildlife Service has recently implemented the state's threat abatement plan for predation by the red fox (NSW National Parks and Wildlife Service 2001). Part of this plan includes monitoring the response of threatened species and fox abundance (in some cases) to fox control. Threatened species being monitored include; pied oystercatcher (*Haematopus longirostris*), rufous bettong (*Aepyprymnus rufescens*), alberts lyrebird (*Menura alberti*), beach-stone curlew (*Esacus neglectus*), brolga (*Grus rubicunda*), little tern (*Sterna albifrons*), Bellinger river emydura (*Emydura macquarii*), broad-toothed rat (*Mastacomys fuscus*), brush-tailed rock wallaby (*Petrogale penicillata*), southern brown bandicoot (*Isoodon obesulus*), long-nosed bandicoot (*Perameles nasuta*), hooded plover (*Thinornis rubricollis*), smoky mouse (*Pseudomys fumeus*), long-footed potoroo (*Potorous longipes*), malleefowl (*Leipoa ocellata*), Australasian bittern (*Botaurus poiciloptilus*), black-striped wallaby (*Macropus dorsalis*), plains wanderer (*Pedionomus torquatus*), and yellow-footed wallaby (*Petrogale xanthopus*).

Foxes are a known or perceived threat for 51 species listed under the EPBC Act (Table 1); 31 mammals, 8 birds, 3 amphibian, 7 reptiles, 1 invertebrate and 1 plant species. Some of these species were identified in the above overview. The 31 mammal species listed under the EPBC Act for which foxes are a known or perceived threat appear to have that status because foxes have been reported to eat those species, or species have shown a positive response in areas where foxes are excluded. Hence, there is limited reliable information on the benefits of fox control for the majority of the species listed in the EPBC Act which are threatened by foxes.

7.4.3 Priorities for filling information gaps

We consider that the greatest priority is understanding the benefits of fox control for native fauna species. The next priority would be developing methods for estimating the absolute abundance of foxes.

7.4.4 Recommended experimental design

We advocate an experiment that assesses the benefits of fox control for native species. Ideally, such an experiment would focus on the benefits of fox control for species that foxes are a known threatening process (Table 1; Environment Australia 1999c). We propose an experimental design for such species, but the cost of this experiment is high (see below) due to the intensive monitoring required for these species that are invariably at very low densities (known as 'threatened species experiment', hereafter). Therefore, we have also costed an experiment that focuses on more 'common' native species (e.g., possums; Molsher 1999) that foxes are believed to impact upon (hereafter, 'common species experiment'). The benefit of fox control for many common species is largely unknown.

The design for both experiments involves first identifying as many potential fox control programs around Australia as possible. Each potential control program must contain native species for which foxes are a known threat (threatened species experiment), or are common but are known to be impacted by foxes (common species experiment), and therefore would be predicted to respond to fox control (either in abundance and/or condition). The more programs that can be included in the experiment the more reliable the inferences will be. We suggest five is the minimum number of fox control programs that should be included. It may be possible to incorporate existing or planned fox control operations, as long as the treatments are randomly assigned (see below), pre-control monitoring has occurred, and that the monitoring methods suggested here are undertaken.

Potential control programs must comprise two areas (pairs) that are a minimum of 10 000 ha in size, and a minimum of 10 km apart so that the abundance of foxes is independent of the treatment at the other paired site. Each pair of areas must be similar in vegetation composition and structure and soil types. The paired areas are then randomly assigned as treatment or non-treatment. Intensive fox control would be undertaken on the treatment areas and should aim to achieve residual densities that are as low as possible. Common techniques for controlling foxes are ground and aerial baiting (Saunders et al. 1995; Reddiex et al. 2004). Due to the costs associated with undertaking these experiments we have not endeavoured to design an experiment that assesses the benefits of different fox control intensities.

The abundance of foxes and other predator species (e.g., feral cats and wild dogs) should be estimated in each area quarterly, and in the same month(s) for each monitoring occasion. Counts should be timed to include the peaks and troughs in annual fox abundance to aid development of system models (see below). We recommend the relative index methods of sand plots and spotlight counts (depending on the habitat of the study areas). It is important that an adequate sampling size (e.g., spotlight count transect lengths) for monitoring is undertaken (and replicated) to enable population changes to be identified. If methods for assessing the absolute abundance of foxes (e.g., DNA techniques) are developed then these methods should be used.

Within all areas (i.e., both treatment and non-treatment) the rate of change of the native species of interest and other potential native prey species will be estimated. Recruitment, survival, emigration and immigration rates of the response species would be undertaken through capture-mark-recapture analyses of trapped animals, with survival and kill rates of the key response species also being estimated through the use of mortality sensing radio-collars (c. 30 animals radio-collared at any one time per area). Robley et al. (2004) stated that to properly quantify and model the impact of foxes on native prey requires kill rates of these prey, assessed in relation to the availability of other prey types. At least two response species should be monitored at each pair of areas (these species need to be trappable). For the threatened species experiment this would likely include one species that foxes are a known threat, and one 'common' species.

A pilot study should be undertaken to determine detection rates and the required sampling effort (i.e., number of trapping grids and traps per grid), so that a minimum of 40 individuals will be detected at each area. We have estimated costs based on five trapping grids being required, and they should be randomly located within each area. If the habitat varies substantially throughout the area, then sites should be stratified based on habitat types, and grids randomly located within the preferred habitat type of the native species. The number of traps at each grid will depend on the detection rate of the native species. To enable this experiment to be costed, we estimate that the minimum number of traps required in each grid would be at least 100 for the threatened species experiment (White et al. 1982), but considerably lower for the common species experiment (c. 30). Trapping should be undertaken over a minimum of five nights, but potentially over a longer timeframe to obtain adequate sample sizes for the threatened species experiment.

Grid trapping should occur between two and four times per year (depending on the life history of the response species). At least 12 months prior to fox control beginning the above monitoring should be undertaken on all areas (i.e., ≥3 samples prior to the commencement of the fox control treatment).

It will be important to measure other covariates at each trapping grid and within each area. Covariates would include; other predator abundance (see above), rainfall, habitat structure, landscape type, temperature, management history, and other native species abundance.

How long should such an experiment run for? The answer will depend on the animal species monitored, the expected response rates, and the degree of confidence of the results that is required. We believe that there should be at least three samples of pre-control monitoring and at least five years of control before the experiment is reviewed. This design also enables the treatments to be reversed (i.e., fox control stopped on the treatment area, and started on the non-treatment area), which provides a further test of the regulatory effect of foxes on prey species (see Banks 2000).

The key parameter of interest is the mean difference in rate of population change of the response species between each treatment and non-treatment area. This is the mean effect (or benefit) of fox control. Each pair of treatment and non-treatment sites contributes one data point to the final comparison. We estimate that at least 5 pairs of treatment and non-treatment sites are needed to provide a reasonable confidence interval on the benefits of fox control for native species.

We strongly recommend that the knowledge on benefits of fox control for native species generated from these experiments be built into a system model (see Robley et al. 2004), as models of fox control strategies will be important in determining alternative management strategies for foxes.

One potential problem with assessing the benefits of fox control for native species is the ability to partition the benefits of foxes from sympatric predators (i.e., feral cats and quolls). Robley et al. (2004) identified a general lack of knowledge on the benefits to native species from control of only one of a suite of predator species, and also the numerical responses of predators to the removal of other predator species. It is possible that benefits to native species may not accrue if foxes – but not the other predators – are controlled to low densities. One approach would be for some programs to control the other predator species, however, there are no suitable techniques for assessing the abundance of feral cats, and therefore the effectiveness of feral cat control (note that the Arthur Rylah Institute for Environmental Research has been commissioned to undertake a review of feral cat control monitoring techniques).

Until study sites are identified, the cost of both experiments can only be considered indicative. An indication of the cost of the experiments is shown in Table 5. Note that these costs are for one pair of areas, and that at least five pairs of areas are recommended. Hence the start-up cost of the experiment would be c. $2.1 million (common species experiment), and the annual cost of running such a design $1.8 million. The final-year costs are higher because of the need to analyse the data and publish the results.

Table 5. Indicative start-up and ongoing costs of the experiment assessing the benefits of foxes for, a) experiments focused on 'threatened' native species, and b) experiments focused on 'common' native species. The costs are for one pair of treatment and non-treatment areas.

Item	Start-up (year 1) costs ($000)	Ongoing (year 2 and beyond) costs ($000)	Final year costs ($000)
a) Threatened species experiment			
Pilot study	$30	$0	$0
Labour[1]	$350	$350	$380
Materials	$140	$30	$30
Transport	$50	$50	$50
Fox control	$0	$25	$25
TOTAL	$570	$455	$485
b) Common species experiment			
Pilot study	$30	$0	$0
Labour[1]	$250	$250	$280
Materials	$80	$30	$30
Transport	$50	$50	$50
Fox control	$0	$25	$25
TOTAL	$410	$355	$385

[1] Assumes 100% overheads, but not all organisations charge overheads.

7.5 Feral cats

Dickman (1996) noted that "no… experiments have been completed to determine the effects of cats on native fauna". The first stage of this review (Reddiex et al. 2004) indicated that this situation has not changed. In the absence of reliable information, Dickman (1996) tabulated the responses of birds to the eradication or control of feral cats at seven sites in Australia. Six of the seven cases exhibited a "population increase" and one exhibited a "mixed" (i.e., increased and then declined) response. However, six of these seven responses were from feral cats being eradicated (primarily islands), and it is unclear if these responses would be observed in sustained control operations on mainland Australia. Dickman also noted that these inferences should "be treated with some caution", as many factors other than feral cats can affect population size. None of the species listed by Dickman are listed as threatened under the EPBC Act.

An experimental assessment of the benefits of feral cat control for native species/ecological communities should not be undertaken until adequate methods are available for estimating the relative/absolute abundance of feral cats. We note that the Arthur Rylah Institute for Environmental Research is undertaking a review of available methods for monitoring feral cat abundance and this is expected to be completed by December 2004.

8. Recommendations

1. The proposed experiments evaluating the benefits of feral goat, feral pig, feral rabbit, and fox control should be undertaken as funding permits. The experimental design should not be compromised in order to reduce the costs of the experiments: it would be preferable for just one experiment to be adequately funded rather than several experiments inadequately funded.

2. Research to develop methods for estimating the relative and absolute abundance of feral cats and foxes should be funded.

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