Pest Animal Control CRC

REPORT FOR THE AUSTRALIAN GOVERNMENT DEPARTMENT OF THE ENVIRONMENT AND HERITAGE

A project that investigates current options for managing feral pigs in Australia and assesses the need for the development of more effective and humane techniques and strategies.

Stage 2 Report. Review the effectiveness of the options identified in stage one.
Identify and prioritise gaps in existing knowledge.
Provide recommendations for future research.

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EXECUTIVE SUMMARY

<u>Objectives.</u>

1. The aim of this Stage 2 report is to review the effectiveness of feral pig control options identified in Stage 1 report. This review includes a special emphasis on the effectiveness of each control option in managing feral pigs for the protection of threatened species and ecological communities. Furthermore, gaps in existing knowledge concerning the effectiveness of feral pig control options have been identified and prioritised, and recommendations are provided as to areas of future research that will address those gaps identified.

2. The impact of feral pigs on conservation outcomes needs to be quantified in order to justify the application of feral pig control methods in environmentally sensitive areas and to allow the auditing of these control methods for effectiveness. The use of cost-benefit models based on agricultural production systems to strategically manage feral pig control programs has limited use to managing the impacts of feral pigs on conservation outcomes. Therefore the use of cost-minimisation and benefit-maximisation approaches and interactive models in feral pig control are more appropriate to conservation situations. The use of monitoring during control programs can allow the extrapolation of a relationship between feral pig density and damage.

<u>Method</u>

3. In the absence of definitive information regarding the impact of feral pig populations on conservation outcomes, and the overall ability of control methods to reduce these impacts, a number of parameters can be used to estimate the effectiveness of feral pig control methods.

   - Efficacy of control (at reducing feral pig populations)
   - Control method efficiency (costs)
   - Target specificity (ability of the control method to control feral pigs without impacting on non-target species)
   - Logistical practicality.

<u>Results</u>

4. Controlling the impacts of feral pigs on conservation outcomes will require that simple measures of feral pig abundance are utilised by land managers and that simple feral pig impact assessment measures are available for use by land managers and are applicable to a particular region. This will ensure that feral pig control measures are applied effectively.

5. Ground baiting is an accepted means of reducing feral pig populations across large areas in a cost effective manner. Potential non-target impacts during feral pig baiting campaigns in conservation areas have not been fully elucidated. The method is also generally limited to areas with reasonable road access. The availability of a ‘take home’ toxin for use by private land managers will have an unknown effect on conservation outcomes.

6. Aerial baiting is potentially a cost effective and efficacious means of controlling widespread and remote feral pig populations. However, research to investigate non-target impacts and improve the efficacy of the method is required. Increased efficacy will require refined baiting strategies.

7. Fencing can be used to eliminate feral pig impacts. However, the method is expensive and logistically difficult and should generally be confined to small valuable areas.

Ongoing maintenance requirements can be high. Fencing will potentially reduce the ease of movement by some terrestrial vertebrates but the non-target impacts of fencing have not been quantified. Fencing can improve the efficacy of other methods of control since it can prevent reinvasion and re-establishment of feral pig populations.

8. Trapping can produce large decreases in feral pig populations in localised areas and is generally target specific. The methods main drawbacks are that it is relatively expensive (high labour requirements) to apply across large areas and is logistically difficult and cannot be used in remote situations. New technology, such as shape recognition trapping may improve the applicability of this method. Research is required to assess the applicability of trapping to broad-scale feral pig control.

9. Aerial shooting is a method which can deliver rapid and large reductions in feral pig numbers across extensive areas in appropriate habitats, including remote locations. It is highly target specific and is cost effective. The main disadvantages are that the method is not applicable to all habitats and is expensive when feral pigs are in low densities.

10. The Judas pig method can improve the effectiveness of other control methods by allowing the targeting of control procedures to areas where feral pigs are present. However, it is expensive, and is generally not applicable to reducing feral pig populations in high densities.

11. Snaring is not an acceptable means of controlling feral pigs in Australia since it is not target specific.

12. The ability of hunting and harvesting to reduce feral pig impacts on conservation outcomes is unknown. However, the method is generally inexpensive to apply since hunters and harvesters will often volunteer their time. The method may be difficult to apply in remote areas and can result in feral pig translocations. The non-target effects of hunting and harvesting have not been researched (escape of hunting dogs, feral pig translocations), but if conducted responsibly they should be low.

13. Biological control may be an effective means of controlling feral pig populations in Australia. However, the non-target impact (on the commercial pig industry) will be unacceptable.

14. The application of combined methods of feral pig control in an integrated approach has been advocated as a means of improving the effectiveness of control programs. However, the order of application, intensity of application and the most effective combinations of control methods are unknown.

15. Elimination of feral pigs from mainland Australia is almost certainly impossible using current technologies and resources. However, the effective reduction of feral pig impacts may require the targeting of feral pig control efforts to areas of overlap between feral pigs and threatened species, the application of effective broad-scale control methods and localised eradications.

1) APPLYING CONTROL METHODS TO FERAL PIG POPULATIONS

1.1) Applying Feral Pig Control Programs.

Braysher (1993) reviewed the management of vertebrate pests in Australia and published principles for the strategic management of vertebrate pests. The first step in feral pig control is to research or estimate the effect that feral pigs are having on valuable resources, such as threatened ecological communities and species. The next step is to develop an efficient, accurate means of estimating feral pig populations relevant to the local area. The combination of damage levels and an index of abundance can allow the extrapolation of a relationship between damage and density. The third step is to attempt to establish a level of feral pig population at which the resource in question is damaged unacceptably. Then, the aim should be to control the feral pig population so that the population falls below this damage threshold level. This step will necessarily involve monitoring to check that feral pig numbers have reduced following control efforts, that resources have been protected and that the management campaign has been efficient.

However, this strategic management approach is generally more applicable to an agricultural situation where a cost benefit relationship can be established, where decisions based on economics can be made. In addition, complex trophic relationships between pests and conservation resources mean that the threshold point at which control costs are minimised and the viability of threatened populations are not affected are difficult to identify (Choquenot and Parkes 2001). A number of models can be used to determine at what pest thresholds control efforts should begin (Choquenot and Parkes 2001).

1. The damage function, which is based on the response of pests to resource abundance can be used to set pest thresholds that allow tactical conservation outcomes.

This model could be used to set a pest threshold when the conservation impact is linked to immediate pest density. An example may be the predation of nests by feral pigs.

2. The density dependant predator-prey models can help set pest threshold densities that have strategic consequences for resource conservation.

These models can be less applicable when external density independent factors (such as environmental fluctuations) cause a fluctuation in pest or resource abundance.

3. Interactive models can establish pest thresholds for imposition of pest control that are responsive to pest density, resource abundance and prevailing environmental conditions.

This model may be most applicable to Australia since variations in feral pig populations occur regularly due to climatic variations (see section 2.1).

Generally, when complex modelling and reliable data are not available the goal of feral pig management should be to estimate when feral pig impacts are unacceptable, and then control feral pig numbers. Whilst this control is occurring, the resource that is estimated to be damaged by feral pigs can be monitored and the effects of control can be assessed to determine if damage is reduced. Then control effort can be intensified or reduced depending upon the acceptability of the remaining feral pig damage.

1.2) Known and Estimated Impacts of Feral pigs on Natural Resources in Australia.

'Predation, Habitat Degradation, Competition and Disease Transmission by Feral Pigs' have been listed as a Key Threatening Process under the Commonwealth EPBC Act. More specifically, native ecosystems, flora and fauna are damaged due to the presence of feral pigs, their movement, rooting, wallowing, trampling, tusking or rubbing trees, and consumption of water, animals, plants and soil organisms. Ecological parameters affected include species composition, succession, and nutrient and water cycles. Impact can be direct or indirect, acute or chronic, periodic or constant, and may be seasonally influenced (Braysher 2004). Generally, the known impacts of feral pigs on resources are inconsistent, varied and extensive. The impacts are incompletely researched and much of the information on feral pig impacts is anecdotal. However, this doesn't preclude control efforts, since normal monitoring during feral pig control programs can allow the relationship between pest density and damage to be established. Improved knowledge of the impacts of feral pigs will increase the effectiveness and auditing of feral pig control programs.

Table 1 lists and reviews the known impacts of feral pigs on natural resources in Australia, with some added examples from around the world, where these where considered relevant to Australia. The table also lists some of the estimated impacts of feral pigs on natural resources based on anecdotal information. Where control methods have been utilised to manage impacts these are listed.

Table 1: Feral Pig Impacts (researched and anecdotal) and Optimal Control Methods

Feral Pig activity	**Environmental Impact**	**Factors which result in species/ community being susceptible to feral pig damage**	**Region**	**Season/ Habitat**	**Implicatio manageme**
Habitat Degradation					
Digging	Reduced rainforest tree seedling recruitment (Mitchell 2000)	Moist microhabitats at the beginning of the dry season targeted by feral pigs	Northern Queensland	Dry season, wet areas	Possible th pigs will a vegetation in these are
Digging (Mitchell & Mayer 1997)	Visual and unknown environmental impact such as soil arthropod changes, erosion, soil nutrient alteration, soil temperature change, reduced plant cover, erosion	Moist soil	Wet tropics World Heritage Area (Qld)	Dry season, lowlands along drainage lines (4% of land area), on flatter slopes	Control fer along wate during dry when pigs concentrat
Digging (Hone 2002)	Reduced species richness, altered vegetation composition, Ecosystem Engineers (Jones et al 1997 Hone 2002), visual impact	Moist soil, aspect, topography	Sub alpine national park (ACT)	All seasons, uplands along drainage lines	Large redu feral pig po needed to r rooting
Digging (Alexiou 1984)	Change in species composition		Sub alpine National Park (ACT)	Drainage lines, depressions and around grassy flats	Control fer maintain n biodiversit
Digging	Reduced water quality (Braysher 2004)	Moist soil			Maintenan quality nec feral pig co
Wallowing and rooting by feral pigs in alpine wet areas (ACT Government 1997)	Northern Corroboree frog (*Pseudophryne pengilleyi*) possibly less successful recruitment of offspring into population, potentially affects population	Reliant on habitat affected by feral pigs	ACT and NSW, Kosciusko National Park and Namadgi Park and alpine areas around these parks	Summer Subalpine national park (Sphagnum bogs, wet tussock and wet heath) especially,	Reduce fer numbers

Digging (Stork 1998)	Feral worm spread	Presence of feral worms (4WD access) and feral pigs	Tropical rainforest (Qld)	Moist areas within tropical rainforest	Feral pigs numbers need to be reduced to reduce worm spread	Control technique applied to worm infested areas. The optimal method will depend on the area of worm infestation
Feral pig rooting along water ways (Hone 2002, Mitchell & Mayer 1997)	May result in erosion of waterways/drainage lines which results in impacts downstream due to siltation or local impacts	Preferred habitat of feral pigs	Widespread potential	Riparian zones. Drainage lines etc	Feral pigs can contribute to erosion along some of the most important areas of conservancy areas	Control feral pigs, methods variable depending on situation
Feral pigs wallowing and rooting in breeding pools of Southern Corroboree frog (NSW NPWS 2001)	Southern Corroboree frog (*Pseudophryne corroboree)* possibly reduced breeding success, leading to poor recruitment into population	Reliant on sphagnum bogs in a small distribution where feral pigs are found	Alpine areas in Snowy Mountains (within Kosciusko National Park)	Alpine (sphagnum bogs, wet tussock and wet heath)	Reduce feral pig numbers in areas where SCF are present	Aerial shooting and ground based warfarin baiting currently utilized for feral pig control. Unknown effect on frog populations.
Digging and rooting	Potentially cause habitat damage for Orange and White-Bellied Frogs (*Goecrinia vitellina and Geocrina alba*) (Wardell-Johnson et al 1999). May cause population declines	Reliant on riparian zones with only a small distribution, which leaves the species vulnerable to feral pigs	South western Western Australia	Riparian zones in Jarrah forest	Reduce abundance of feral pigs from the habitat areas	Poison baiting every 2 years in nearby catchments. Eradication not possible using poisoning, shooting or trapping
Rooting of mounds at artesian wetlands (NSW NPWS 2002)	Predation and habitat damage which probably reduces survivability of Salt Pipewort (*Ericaulon carsonii*)	Small distribution and reliant on areas which feral pigs favour	Artesian springs of NSW, Queensland and South Australia	Artesian springs	Exclude feral pigs or reduce density to a level where impact on *E.carsonii* is acceptable.	Fencing (however, light grazing by herbivores may be beneficial), and pig control measures.
Feral pig rooting after deliberate releases of feral pigs at Mt Alexander (Alexander 1999)	Causes considerable damage to vegetation and soils, including the Southern Shepherds purse (*Ballantinia antipoda*)	Small distribution, occupation of preferred feral pig habitat	Mt Alexander, Victoria	Moss mats	Localized eradication of feral pigs	Poisoning and contracted shooters
Disease Spread						
Digging and tusking activity in areas contaminated with root rot fungus, *Phytohthora cinnamoni*.	Implicated in spread of root rot fungus (Kleijunas & Ko 1976)	Non native fungus can lead to massive dieback since many native species have little resistance to *P. cinnamoni*.	WA, other areas possible	Native vegetation	Prevent feral pigs from spreading fungus from contaminated areas to non contaminated areas	Control feral pig numbers in infected areas
Susceptibility of feral pigs to many endemic diseases	Spread of disease to susceptible native animals	Common habitat use. For example, the drinking of water contaminated with leptospirosis from pig urine could result in infection in native animals	Many regions within Australia	Many habitats depending on disease epidemiology	Monitor wildlife species for disease	Variable

Susceptibility of feral pigs to many exotic diseases	Disturbance of native animals during control operations (Braysher 2004) and spread of disease to native animals	Susceptibility of native species to exotic disease largely unknown. Many marsupial species have been shown to be affected by FMD (Snowdon 1968) Pseudo rabies likely to afflict many species overseas (SCWDS 2004). The implications of epidemic of disease on native wildlife species unknown.	Any	Any	Implications during exotic disease control operations and for effect of disease on native wildlife if an exotic disease became endemic	Eradication of feral pig populations (and other susceptible animals) using all control methods in affected areas. In absence of ability to eradicate, lower below disease threshold
Digging and predating frogs affected with chytrid fungus	Could possibly spread chytrid fungus to susceptible frog populations between watercourses (John Clarke QPWS pers com)	Frogs extremely susceptible to chytrid fungus	All	ALL	Exclude feral pigs from chytrid fungus infected frog areas, or reduce numbers as much as possible	Variable
Grazing and rooting for Cinnamon Sun Orchid (*Thelymitra manginii*) (Phillimore et al 1999).	Threaten the species survival of Cinnamon Sun Orchid through 'collateral damage', by grazing feral pigs (Andrew Brown, CALM, pers.comm. June 2004).	Limited distribution of the plant in areas of feral pig. Desirable to feral pigs.	Mundaring, WA	Open wandoo woodland	Monitor feral pig populations and control feral pigs if disturbance evident	Baiting and weldmesh (Andrew Brown, CALM, pers.comm. June 2004).
Weed Spread						
Consumption of mesquite	Spread viable seeds in faeces, thus increasing the area of weed distribution (Lynes & Campbell 2000)	Weeds and feral pigs present, feral pigs can roam over the landscape (especially solitary males)	Northern Qld	Tropical savannah Grassland	Feral Pigs can spread weeds	Control feral pigs or weeds. Optimal method variable depending on situation
Digging	Weed invasion, since feral pig rooting and disturbance has resulted in weed establishment (Peters 2000) Loss of biodiversity?	Presence of invasive weeds and feral pigs	Tropical rainforest	Variable season	Feral pigs digging can result in weed invasion	Control feral pigs or weeds. Optimal method variable depending on situation
Predation						

Predation of Cassowary (*Casuarius casuarius*) eggs/nests, scrub fowl (*megapodius reinwardt)* and brush-turkeys (*Alectura lathama*) (Crome & Moore 1990; Mitchell 1993)	Unknown population effects	Ground nesting	Tropical rainforest (Qld)	June-November (Pizzey & Knight 1997), all year for competition	Reduce feral pig numbers until impact is acceptable. Determine level of population damage (if any) at different densities (Crome & Moore 1990)	Trapping with cassowary "proof" traps has been identified as the control method least likely to impact on cassowary (QPWS 2001)
Predation of Eastern Bristlebird (northern population) and habitat change (Stewart 2002)	Unquantified population effect (Stewart pers com)	Small numbers through other threatening processes, ground nesting, reliance on native sorghum for habitat, which feral pigs utilise	South Eastern Qld, northern NSW (Stewart 2002)	August- October (Stewart 2001), all year for habitat change	Reduce feral pig densities for habitat change especially in dry times during times of high feral pig foraging, control numbers during spring breeding	Species critically endangered with less than 50 known birds remaining. Therefore fence the remaining occupied habitat to exclude feral pigs. Reduce feral pig densities in adjacent suitable habitat to aid in recovery. Methods utilized are poisoning and trapping (Stewart pers. comm.)
Lord Howe Island Wood Hen change to habitat and <u>predation</u> (Anon 2000a, NSW Scientific Committee 2004)	Extreme reduction in Lord Howe Island Woodhen population. No occurrence where feral pigs occurred (Miller & Mullete 1985)	Ground nests, forage for invertebrates in moist soil	Lord Howe Island	Spring during breeding season for nest predation or all year for habitat change	Eradicate feral pigs since an island	Good population response following feral pig eradication with hunting for bounties and wages using dogs (Miller & Mullete 1985)
Predation and destroying breeding habitat of Hutton's shearwater (*Puffinus huttoni*)	Likely caused decline in Huttons shearwater population (Miller & Mullete 1985)	Ground nesting	New Zealand	Coastal valleys of tussock grass.	Lower feral pig density and control other predators especially during breeding season	No feral pig control probably resulted in extinction of many breeding colonies
Predation of Providence petrel (*Pterodroma solandri*) DEH 2003a- draft TAP	Decline in providence petrel population	Ground nesting	Lord Howe Island	spring	Eradicate feral pigs since an island and this is possible	Hunting with dogs for bounties and wages eradicated feral pigs
Predation of frog species (and habitat damage) eg Kroombit Tinkerfrog, *Taudactylus pleione* (Hines et al 2002)	Possibly linked to declines in frog populations	Ground dwelling, occupy habitat utilized by feral pigs susceptible to predation	Kroombit National Park Qld.	Rainforest areas with permanent or ephemeral water	Determine the relative effects of feral cattle, pigs and horses and other threatening processes. Determine level to which feral pigs need to be reduced	Trapping has been assessed as the method of choice due to target specificity, ability to trap independently of toxin distributors (Qld. Dep NRME), and effectiveness. Fencing has been used without success due to maintenance

Earthworm predation by feral pigs (Pav Ecol 1992)		Moist soils	Tropical Queensland	Rainforest	Lowered soil nutrient cycling	Variable depending upon circumstances
Predation of marine turtles (especially flatback turtles) (DEH 2003b)	Predation of nested turtle eggs. Unknown population effects (Braysher 2004)	Ground nesting where feral pigs have access	Cape York	Beach	Reduce predation so that 70% of nests produce hatchlings	• Aboriginal involvement • Poisoning. • Exclusion Fencing.
Predation of eggs and juvenile green turtles (*Chelonia mydas L*) and giant tortoises *Geochelone elephantopus Harlan*	Population impacts due to reduced recruitment (Coblentz & Baber 1987)	Ground nesting where feral pigs have access	Galapagos	Coastal	Feral pigs can reduce the viability of reptile populations	Eradicate feral pigs since an island habitat.
Grazing and rooting for tubers of the Elegant Spider Orchid (*Caladenia elegans*)(Phillimore et al 2000)	Threaten the species survival of Elegant spider orchid through predation, however, unknown population effect	Limited distribution of the plant in areas of feral pig. Desirable to feral pigs	Geraldton, WA	Melaleuca scrub in winter wet depressions	Prevent access of feral pigs or reduce densities, re-bait as immigration occurs	1080 poison baiting. Fence to mitigate other threatening processes (could also incorporate feral pig proof fencing).
Predation of animals (Mitchell 1993)	Unknown population effects, animal species not identified, however, bone, fur, egg shells and feathers all found in faeces		Wet Tropics World Heritage Area	Rainforest/Rainforest Agriculture interface	Feral pigs may impact on susceptible animal species	
Competition						
Competition with cassowary for food (seasonally available forest fruits etc)	Unknown population effects	Reliance on common food source	Tropical rainforest of Qld.	all year for competition	Reduce feral pig numbers so that impact is reduced. Determine level of damage at different densities	Trapping with cassowary "proof" traps has been identified as the control method least likely to impact on cassowary (QPWS 2001).
Consumption of tubers and bulbs (Tisdell 1984)	Competition with brolgas, *Grus rubicunda*, may lead to population impacts	Reliance on a common food source	Northern Territory		Determine level of population decline due to competition, and determine abundance of feral pigs desirable	Reduce feral pigs using appropriate method, depending upon level of feral pig determined to be desirable

Consumption of fungal fruit bodies	Competition with several small threatened mammal species (eg Southern brown bandicoot, *Isoodon obesulus obesulus*, Rufus Bettong *Aepyprymnus rufescens*, Long-nosed potoroo, *Potorous tridactylus)* (Laurance & Harrington 1997, Pavlov 2000), Long footed potoroo *Potorous longipes* (NSW Scientific Committee 2004).	Reliance on a common food source.	Widespread	All year	Lower feral pig numbers to acceptable level, determined through research.	Method of control will vary depending upon habitat, level of control required and resourcing.

*Please note. For many of the endangered/threatened species listed, a number of threatening processes exist. Feral pigs have been addressed in isolation.

1.3) Summary of the Likely Impact of Feral Pigs

From the researched and anecdotal cases presented above it is possible to draw some general conclusions about the likely impacts of feral pigs on natural resources. These assumptions have been made pragmatically, so that feral pig control programs and methods can be targeted most effectively in the absence of rigorous research. That is, an adaptive management approach has been adopted. Our assumptions may be inaccurate because many of the feral pig impacts above are assumed based on obvious signs of feral pig damage rather than researched population impacts on native species or communities.

Impacts

1. Feral pigs have been shown to **predate** and eat many native animals and plants (Braysher 2004). Animal species vulnerable to predation tend to be those that have part or all of their lifecycle on the ground. For example, animals such as ground nesting birds (Lord Howe Island Woodhen and Southern Cassowary) and reptiles (Loggerhead turtle), or animals which are ground dwellers (e.g. some species of frogs, soil invertebrates).Vulnerable plant species tend to be plants which have underground tubers (lilies and orchids), or are desired by feral pigs for grazing.

2. Feral pigs have been shown to induce **habitat degradation** through their feeding, trampling, wallowing and rooting (Braysher 2004). Animal species which are especially vulnerable to habitat change include those which have an absolute requirement for specific ground based habitat which is preferred by feral pigs (e.g. Eastern Bristlebird and Northern and Southern Corroborree Frog). Plants species vulnerable to habitat change include those which are found in areas of preferred feral pig habitat. This varies over time and space, but is often in moist areas along riparian zones, drainage lines, flat areas or grassy areas. Vigorous plants (weeds or native) may tend to out-compete some slower growing endemic species in these areas which are recovering after feral pig activity.

3. Feral pigs have been shown to **spread endemic animal diseases (e.g. leptospirosis, tuberculosis) and plant diseases (***Phytohthora cinnamoni***)**. It is generally unknown to what extent this is occurring in Australia or what impact these diseases may be having. Feral pigs may impact on native animals during an exotic disease outbreak indirectly (e.g. disease control operations can have non-target impacts) (Brasher 2004). This impact may be direct as well (e.g. foot and mouth disease virus can infect native marsupials).

4. Feral pigs are suspected of **competing** with native animals for resources (Braysher 2004). Animals which are likely to be affected are those which share a similar diet to feral pigs (tubers, underground invertebrates, fungi, fruits etc). Feral pigs have a generalist diet and can change diet as different foods become available which means many animals could be affected. Animals which utilize vegetation around riparian zones, drainage lines and moist areas generally are likely to be most affected. Some affected animals may include the Cassowary, Long-footed potoroo and Brolga.

5. **Limited distribution species.** In all cases where feral pigs are likely to impact on populations of native animals and plants, the impact is likely to be exacerbated if the species in question has a limited distribution and/or abundance (e.g. threatened species or ecological communities). This is due to such populations having a lowered ability to recover from catastrophic events.

Using the information generated from the known and anecdotal impacts above, animals and plants potentially impacted on by feral pigs are those which have some of the following characteristics;

- a vulnerable part of their life cycle on the ground, where they can be predated by feral pigs;
- an overlapping geographical distribution with feral pigs with habitat that is susceptible to damage by feral pigs e.g. areas with moist soils;
- plant storage organs (such as tubers) and other underground vegetation, fungi, and/or fruits;
- have a limited distribution (e.g. threatened species or ecological communities); or
- are species which are susceptible to endemic disease which feral pigs can spread directly or indirectly.

1.4) Estimating Feral Pig Numbers

Choquenot et al (1996) discussed the importance of surveying feral pig numbers and impacts to decide on appropriate feral pig management plans. This allows monitoring of control program efficacy, for specific population reductions to be set in order to reduce damage to an acceptable level, or to allow the generation of relationships between feral pig density and damage. They listed a number of simple and complex survey techniques which can be used to generate an estimate, or index of abundance of feral pig numbers.

The more complex techniques generate estimates of abundance which are reasonably accurate, reproducible and comparable across different areas. However, these techniques are expensive, time consuming and sometimes require the services of an experienced wildlife biologist. Some examples include ground based surveys utilising mark-recapture techniques, quadrat sampling to assess extent of fresh dung (Hone 2002) and direct counts. In appropriate habitats, double count aerial surveys after control can also be used to generate estimates of abundance which can be useful to evaluate the success of feral pig management programs.

The simpler techniques for estimating indices of abundance such as the presence of pig sign (wallows, dung, rooting and footprints) are more easily applied and can give a quick estimate of the presence and are potentially indicative of the abundance of feral pig populations in the sample area. Caution should be taken in generating these indices of abundance and applying the same technique across the landscape between different habitats. Ideally, such techniques should be applied at the same time each year and in the same area since presence of feral pig sign may vary between seasons, and since pig signs can last for long periods of time.

Another simple method of generating an index of feral pig population can be through free feeding. The periodic application of free feeds across the year or during an annual baiting campaign can allow relative changes in abundance to be assessed. It can also allow the appropriate amount of bait to be laid for an effective control campaign of the local feral pig population rather that the first few hungry individuals. This technique is recommended and widely used throughout Australia. However, it is important to realise that bait consumption can vary between seasons and due to environmental conditions. The catch per unit of effort can also allow an index of abundance, although this is not a linear relationship. Estimating feral pig numbers using sign can be inaccurate in some situations. For example, softer substrates are more easily damaged and will fair worse when compared to harder substrates, and one large boar can potentially have a greater impact than a mob of sows and their offspring. The catch per unit effort and the increase in this measurement can also be used to estimate feral pig population changes (Forsyth et al 2001).

1.4.1) Estimating Feral Pig Abundance

Hone (2002) summarised the results of 15 years of management of feral pigs in Namadgi National Park in the ACT. The use of a survey technique for the presence of feral pigs was integral to the research and management program. He used fresh dung counts in permanent quadrats to accurately estimate a population index, and found that this index was related to pig rooting on line transects across the years. Pig rooting was reported to cause decreased plant species richness. This level of monitoring was relatively labour intensive (bi-annual field trips), long term and needed a considerable level of expertise. This method could be extremely useful at the park management level if the resources and expertise were available, since it is often pig rooting which causes unacceptable damage to ecosystems.

1.4.2) Estimating Feral Pig Activity

Engeman et al (2001) developed a *passive tracking index (PTI)* for estimating feral pig activity in a national park in Florida. The method took advantage of the thick vegetation in the park which caused feral pigs to use the unsealed roads. They raked sand plots on these roads and found that feral pig tracks were easily detected. The information obtained was used to generate an activity index. Changes in the index brought about through a subsequent control program indicated an 81% reduction in feral pig activity. A great advantage of the method was that the activity index was easily linked with a fresh damage and pervasiveness index. Research by the Queensland Department of Natural Resources and Mines around the forests of southern Queensland also used a passive tracking index (Lapidge 2003). This index used tracking plots around the edge of waterholes to assess feral pig activity in the summer when animals must drink daily. The banks of water holes were swept at midday each day, with pig activity from the previous 24 hrs recorded through the number of 5 m wide water-edge quadrats surrounding the dam that contained foot prints. This index was used to establish baseline activity prior to a baiting and trapping campaign, which resulted in a 93% reduction in feral pig activity. This technique is however only appropriate in drier areas where permanent water points are limited, as in the wet seasons it would be difficult or impossible to monitor all the sites where feral pigs were drinking. Schmidt (1982) used sand-plots to review the effectiveness of a control program in the Jarrah forests of Western Australia. These sand-plots were distributed on tracks and around waterholes throughout the area where feral pigs were present. Footprints were checked and recorded daily. This method was particularly effective since feral pigs have an absolute requirement for water and can be reliably tracked using this method. However, if low numbers of feral pigs are present, a large number of plots are required and the assessment should occur over a relatively long time period (longer than 2 weeks).

The *fresh damage index* was an approximate descriptor of feral pig damage, and was generated by looking at the incidence of fresh rooting along the route between plots. After this fresh damage index is established for a particular national park, it can be linked to the PTI for that particular area. Subsequently, the PTI can be used to estimate the environmental damage, since the PTI is more easily generated. Thus control programs in this particular national park can be instigated based on feral pig sign on roads (PTI). This process can allow a tailored management program to be developed for individual national parks, after an initial short research program (Engeman et al 2001). Caution must be taken with using PTI's since the assumption of a linear relationship between feral pig activity, density and damage is overly simplistic (Choquenot et al 1996). This is because intrinsic factors will influence rooting rather than density. However, a complex study of feral pig damage in relation to density will not occur in most situations in Australia, and in these situations a simple index of activity and environmental impact may be more practical.

The *pervasiveness index* is a useful measure of pig distribution within a local area. The spatial distribution of feral pig tracks on sand-plots throughout the national park allows targeting of control methods to areas of the landscape where feral pig numbers are high (Engeman et al 2001).

Pech et al (2002) made recommendations for identifying the impact of feral pigs on the forests of southern NSW. They recommended that feral pig indices of abundance should be measured by looking at trapping effort (or pigs/trap/day), sand-plots and records of pig signs. Sand-plots should be established on 10 km transects (utilising non-formed management trails) and should be every 200m. They should be read for 3 consecutive days in autumn and spring to provide a measure of feral pig activity. They recommended that an additional index of abundance be generated by establishing several 1 km transects parallel to the sand-plots. These transects should be used to record feral pig sign and the freshness of this sign (judged by vegetation regeneration). Feral pig impact should be measured by looking at the feral pig sign and by measuring plant species on 5 m by 5 m plots placed in disturbed and undisturbed areas (on similar habitats). Changes in vegetation abundance should be measured at the plots by recording species composition and coverage as well as the relative occurrence of lilies and orchids (and other tuberous species). Plots should be assessed in October or November and field sampling would require 10 days. They determined that no effective measure of the damage to animals could be easily generated (Pech & Doherty 2003).

1.5) Determining a Level of Unacceptable Damage by Feral Pigs

1.5.1) Damage measured by changes in biodiversity and social cost.

The cost of a native species or community being damaged, killed or threatened with extinction is often unquantifiable. However, the long term costs of loss of biodiversity are likely to be economically and socially high. The apportioning of the relative importance of various factors contributing to natural resource damage is often difficult. The resource in question can be negatively impacted upon by many factors. For example, feral pigs do consume turtle eggs, but juvenile turtles have a high mortality rate normally. Other factors such as fishing by-catch or loss of nesting sites could have a greater impact (Braysher 2004). If by-catch was found to be the major impact on turtle populations, and could be resolved, a higher rate of feral pig predation of turtle eggs would be acceptable. If, however, feral pig predation was the major process leading to declining turtle numbers, then the level of feral pig predation on turtle eggs acceptable would be lower, since this is the major process affecting recruitment. Therefore, the impact of feral pigs on a resource is difficult to determine. This will need to be assessed by a wildlife biologist in many circumstances to gain an accurate picture (Choquenot et al 1996).

In many situations involving threatened species or ecological communities, the picture is clearer. If small, vulnerable populations exist, even small impacts by feral pigs can be unacceptable. In these situations, if the species in question is likely to be susceptible to feral pig damage, then control is justified.

1.5.2) Economic Framework

The cost of control programmes should equal the cost of feral pig damage to resources (Choquenot et al 1996). Unfortunately the cost of feral pigs on the environment is difficult to quantify. In agriculture the cost of feral pigs can be calculated from lost production, the cost of control operations and the value of lost investment opportunities from the money spent on control operations (Choquenot et al 1996). Choquenot et al (1996) stated that feral pig environmental damage could be measured as the change of the environment from the undisturbed condition. Therefore a measure of the cost of feral pigs could be the cost of returning disturbed ecosystems to their original state, and the cost of control operations.

Engeman et al reviewed the cost of repairing damage by feral pigs in national parks in Florida (Engeman et al 2003). Although these are not the direct costs attributable to feral pig damage, they do give an indication of the severity of the damage associated with feral pigs. They found that the cost of repairing feral pig damage ranged up to US $43,257 per hectare, depending on prior feral pig management. The costs of habitat restoration were calculated from the actual monies spent on wetland restoration projects in the US, since this provides a realistic costing, rather than the estimated value required to return wetlands to pristine condition (replacement cost). Another more subjective measure of the environmental damage by feral pigs is the cost calculated from the value that society places on native species (Richard Engeman USDA, March 2004, pers. comm.). This method uses the systems of fines administered by society to protect native species. When a member of society kills a protected native animal, a fine is imposed under legislation. Engeman argues that this fine is set at the economic level that society values native species. This ‘fine’ can also be imposed on feral pigs when native species are damaged. In this way the cost of feral pigs can be calculated from the damage caused, and an appropriate level of control can be generated from this damage cost estimate.

However, the true costs of feral pig impacts on environmental values have never been fully quantified since the apportioning of the costs of environmental damage is generally a subjective, values driven exercise. Perhaps a better measure of the economics of controlling feral pigs could be generated by a cost-minimisation or benefit-maximisation approach (John Parkes, August 2004, Landcare Research, Pers. Com.). These approaches are useful to allow the development of control programs which provide the most economical benefits. A cost-minimisation approach identifies the control strategy that requires the lowest expense to achieve a set minimum level of benefit. A benefit-maximisation approach identifies the strategy that gives the best benefits for a specified budget.

1.6) Controlling Feral Pig Populations to a Level Where Damage is Reduced

This knowledge will need to be determined through long term scientific study, since many variables can affect the response of a resource to feral pig control. However, even with extensive monitoring the knowledge of when to intervene in complex systems can be difficult to elucidate. For example, the Eastern Bristlebird (Northern) is a critically endangered bird (Stewart 2002). The species is threatened by a number of factors such as changed fire regimes, fox predation, drought, feral pig damage to habitat and possibly predation by feral pigs (David Stewart QPWS, May 2004, pers. comm.). In this case, a positive response to feral pig control may be an increase in recruitment of Eastern Bristlebirds. However, in a good rainfall season it would be difficult to say whether feral pig control caused the increase since more than one variable has changed. The essential step in determining whether feral pig control has been effective is to monitor the feral pig population, to monitor the resource that is being damaged by feral pigs and to monitor other possible variables. Only by taking an integrated approach to these parameters can conclusions be made about the effectiveness of control operations, and even then a conclusion cannot always be reached.

Brasher (2004) stated that the relationship between feral pig density and environmental damage has generally not been researched and further research to investigate this relationship was required. Consequently the level of feral pig control required to achieve improved conservation outcomes is difficult to assess.

1.7) Where to Apply Feral Pig Control

Some areas are more susceptible to feral pig damage. Pigs require food, water and shelter for thermoregulation and seclusion (Choquenot et al 1996). Therefore they will tend to be found in areas with locally available water for drinking and wallowing and with vegetation for shelter. Monitoring of these sites is important, although feral pig habitat use can vary through space and time. Mitchell & Mayer (1997) investigated the occurrence of feral pig diggings in the wet tropics of northern Australia. They found that diggings were associated with wet areas, such as wet drainage lines, coastal swamp areas and lowland areas. They also found an association with roads and tracks. Caley (1997) found that feral pigs in the Northern Territory at his study site were likely to be in strips of forest along the riparian zone and crops. He proposed that this was due to the feral pigs need for water and shade, and because deep alluvial soils were easy to root in. Saunders et al (1993) found that feral pigs in the snowy mountains were more likely to encounter baits at the tree line rather than in the forest or in clearings. He also found that the presence of recent pig activity increased the chance of feral pigs finding baits. Hone (2002) found that feral pigs concentrated their rooting on elevated areas on drainage lines in Namadgi National Park. He found that management to control feral pigs should be directed towards these areas. Pech and Doherty (2003) found that feral pig damage was more likely to occur in moist soils in flatter parts of the landscape around the forests of southern NSW. This has implications for plant conservation because feral pigs tended to avoid wetter areas such as swamps or sphagnum dominated creeks.

The distribution and abundance of feral pigs will dictate control efforts, along with the distribution of susceptible endangered species and ecological communities. The application of non-strategic feral pig control activities across the landscape can consume the limited resources that are available to reduce feral pig impacts. This was recognized for another introduced pest, the European fox, in the recent NSW Threat Abatement Plan: Predation by the Red Fox (*Vulpes vulpes*) (Anon 2001b). The targeting of feral pig control resources to areas of high pig impact may produce more favourable conservation outcomes. Such favourable outcomes may be short term since feral pigs from non-controlled areas can rapidly re-invade control areas (Choquenot et al 1996). That is, although any control program needs to target areas of high impact, control programs also need to encompass all stakeholders and relevant land tenures to produce a sustained population control, otherwise immigration from non-controlled areas will rapidly negate control efforts (or the control intensity within the small area will need to be increased).

The treatment of larger land management units with the same intensity of control effort per hectare (as smaller control programs) in a sustained manner will produce a more significant reduction in feral pig numbers, since immigration and re-colonisation from non-controlled regions will be slowed. Thus, these larger management units can serve as buffers against feral pigs for valuable conservation areas within the management unit. Generally though, for a fixed budget, the trade-off is to have intensive control efforts over a relatively small management unit or less frequent control efforts over larger management units. It is also important to realise that improved broad-scale feral pig control tools can increase the ability of land managers to reduce feral pig densities across large areas.

The use of geographical information systems (GIS) may allow an overview of regional feral pig control needs. NSW agriculture has produced a map of feral pig abundances across NSW (West & Saunders 2002). In addition, the distribution of wildlife species has been mapped by the NSW National Parks and Wildlife Service (NPWS 2004). This can allow an overlaying of both maps which can indicate where feral pigs potentially can impact on susceptible threatened species. This can indicate which potentially susceptible native populations require monitoring and potentially where feral pig control should occur.

The feral pig distribution map was created using the inputs of land-manager perceptions of feral pig densities and as such may not reflect actual feral pig densities (Peter West, NSW Agriculture, June 2004 pers.comm.). An updated map is currently being produced (Peter West, NSW Agriculture, June 2004 pers.comm.) In addition, the NSW NPWS wildlife atlas has been compiled using a variety of sources of information which are not standard and are variable in their reliability. No map of feral pig distribution exists for WA (Laurie Twigg, DAWA, May 2004, pers. com.). The Queensland government produces a feral pest distribution map using 2500km^2 grids, which may have limited use for fine scale GIS analysis (Paul Papping, Qld Dep NRM, May 2004, pers. Com.).
Please see Appendix 1 which contains GIS generated overlap between feral pig distributions and some potentially susceptible threatened species distributions (identified by the NSW scientific committee) in NSW. From the small number of species assessed, the distribution of the Brolga coincides with many high density feral pig distributions.

1.8) When to Apply Feral Pig Control

- During times when resources are vulnerable.

Some resources are more vulnerable to feral pig damage at certain times of the year. For example the breeding season for ground nesting birds or reptiles is a time where recruitment into the population can be impacted by feral pig predation.
Feral pig populations may be more susceptible to control when drought has reduced their populations to low numbers.

- When feral pigs are susceptible to control.

For example, during drought feral pig populations are more easily reduced and the population reduction is likely to be sustained for longer. Feral pigs are more likely to take baits during dry seasons or when food is scarce (Saunders 1993; Caley 1994). Feral pigs are probably more easily controlled around waterways during the northern dry season (Mitchell 2003a).

- Control should be targeted to isolated, new, or small populations as soon as they are discovered.

These populations may be more susceptible to localised eradication before they become established and start to impact on conservation values (Bomford & O’Brien 1997; Braysher 2004).

1.10) Eradication of Feral Pigs versus Control of Impacts by Feral Pigs

The ability to eradicate a vertebrate pest is an attractive idea, since it would allow perpetual freedom from the pest and its damaging actions, and from the recurrent high control costs (Bomford and O'Brien 1995). However, few eradication attempts against a well-established vertebrate pest have been successful anywhere in the world, despite many large scale attempts (Caughley 1977; Macdonald et al 1989; Usher 1989; Bomford & O'Brien 1995). Coypu, a South American mammal have been eradicated from certain areas of the world where they were perceived as a pest (Carter & Leonard 2002). The ability to eradicate this pest depended on sustained control efforts, isolated coypu populations with no immigration and harsh winters.

For a population of vertebrate pests to be susceptible to control a number of essential criteria must be met (Parkes 1990; Bomford & O'Brien 1995).

1. *The rate of removal must exceed the rate of increase at all population densities.*

This relatively simple and obvious requirement becomes more difficult when a number of factors are considered. Controlled populations usually show compensatory responses (e.g. bait aversion, changes in behaviour). Many culled populations show increased reproductive rates due to increased resources. As the density declines it becomes more and more difficult to locate the 'last few' animals.

2. *Immigration is zero.*

Feral pigs have been shown to move large distances in small amounts of time and can quickly reinvade cleared areas (Spencer et al 2003 unpublished data). In addition, feral pigs are deliberately released in order to establish feral pig populations in new or controlled areas (Hampton et al 2003).

3. *All reproductive animals must be at risk.*

Some feral pig control techniques do not target the entire population equally, as different individual animals or age and sex groupings have differing vulnerabilities to the various techniques employed. Forsyth et al (2003) showed that all goats in a feral goat population must be exposed to control for a program to proceed from a control program to an eradication program. This illustrates why multiple integrated control methods are more successful than single control techniques.

The following points are not essential for success, but are important to the success of an eradication campaign, and will affect whether an eradication campaign will be attempted.

4. *Animals must be detectable at low densities otherwise the success of management campaigns cannot be verified.*

Feral pig detection is necessary to determine when eradication has failed and early detection can allow a reaction to this. At low densities, detection can be difficult unless monitoring resources are allocated as part of an eradication attempt.

5. *Discounted benefit-cost analysis favours eradication over control.*

Eradication efforts should be based on accurate benefit-cost analyses and the data needed for these calculations are often not available. However, benefit-cost analyses are best suited to agricultural production and are not as relevant to conservation values. In addition, risks of feral pig impacts can often be viewed in a wider context than production based benefit-cost analysis.

6. *Suitable socio-political environment.*

Conflicting community or administrative goals, or legal barriers can make eradication difficult or impossible.

Other factors important to eradication attempts are:

- *Timing of an eradication attempt.* The sooner eradication is attempted following population establishment, the greater the chance of a successful eradication occurring. This principal can also be applied to small, isolated populations of feral pigs that have been recently translocated.
- *The ability of the species to disperse.* The ability to isolate the species within the eradication area will also affect the success of eradication. Highly mobile species are unlikely to be eradicated.

Using these criteria, it is unlikely that feral pigs could be eradicated from mainland Australia based on existing techniques and current levels of resources. This is because 1) it would not be technically possible to find or remove the last few feral pigs in Australia; 2) feral pigs are highly fecund animals and reproductive success would quickly allow regeneration of feral pig numbers if the political will or funding of feral pig eradication efforts were lowered; 3) the desire to eradicate feral pigs would also be complicated by the perception in some parts of the community that feral pigs are a valued resource, and 4) domestic pigs would continue to escape or be deliberately released confounding eradication attempts.

If eradication was to be attempted on a landscape scale in Australia, increased funding, improved technical abilities and a fully supportive community would be required. The expense of eradicating feral pigs has been estimated at $3.4 billion over 5 years with little likelihood of actually eradicating feral pigs (NRMSC 2003). Therefore feral pig management should look to reduce feral pig impacts in Australia, with some local eradications, rather than attempts being made to eradicate feral pigs on a national scale. Therefore the focus of management efforts in Australia should be on applying feral pig control methods in a strategic, coordinated and efficient manner. The focus of this document is on the use of control methods for protecting natural resources, especially threatened species and ecological communities

2) WHAT ARE EFFECTIVE CONTROL METHODS?

The effectiveness of feral pig control methods for protecting natural resources can be judged by the ability of those methods to reduce the impact of feral pigs on natural resources to levels which are acceptable. Unfortunately, the impacts of feral pigs on conservation values are generally not researched adequately (Braysher 2004). For example, there are few studies which have defined population impacts of feral pigs on threatened populations. There are even fewer studies which have linked the density of feral pigs with damage to threatened populations by feral pigs. In the absence of this data, it is impossible to review the effectiveness of feral pig control methods for protecting natural resources (especially threatened species or ecological communities) definitively. Therefore, this review will utilise the following parameters to estimate the effectiveness of various control methods.

2.1) Efficacy

The efficacy of a feral pig control method is assessed here as the feral pig population reduction attained in past research through the use of the control method. The ability to assess the efficacy of control methods through damage reduction achieved by its use would be more useful but this is hampered by a lack of research and the practicality of such research. The population reduction attributable to a control method is assessed based on the numbers of feral pigs present at a study site before and after a control program. The measure can utilize direct counts of feral pigs or other abundance estimates or more commonly it utilizes changes in relative abundance or activity indices**.** Some research has indicated that a population reduction of at least 70% is required to produce a sustained drop in feral pig populations for over 12 months (Giles 1980). Hone and Robards (1980) also showed that the application of several annual control programs which reduce feral pig populations by 70% each year can lead to significant reductions in feral pig densities over 3-4 years.

However, variation in the rate of change of feral pig populations will affect the requirements of effective management of feral pig impacts (Choquenot et al 1996). More specifically, the level of population reduction due to a control method, that will achieve a sustained reduction in feral pig populations (and damage) is highly dependant upon the environmental conditions after control operations and the frequency at which feral pig control operations are instigated (John McIlroy pers.com. July 2004). For example, Choquenot et al (1996) summarised research in a number of habitats under different environmental conditions that investigated the population dynamics of feral pigs. In the semi-arid rangelands, rates of feral pig population change varied widely and was affected by previous rainfall or flooding which lead to increased survival of juveniles, through the availability of green feed rich in protein (Giles 1980). Probable maximum rates of increase varied between 0.6- 0.7. In the sub-alpine regions of NSW Saunders et al (1993) found that feral pig populations were relatively stable and were generally limited by food availability and quality over autumn and winter. In the wet dry tropics feral pig populations were found to fluctuate predictably with the wet and dry season (Caly 1993 quoted in Choquenot et al 1996). The maximum rate of population increase in the period towards the end of the wet season, after good rainfall (600mm in the wet season) was 0.78.

Therefore, the true level of feral pig population reduction that a control method will need to achieve to produce a sustained reduction in a feral pig population will vary in different habitats and in different seasons. However, for the purposes of this review a level of 70% reduction was assessed as an adequate level of control, in order to allow a general comparison between seasons, habitats and control methods.

2.2) Control Method Efficiency (cost)[1]

The control method efficiency (cost) of a control technique is an important determinant in the ability of land managers to deliver feral pig control. In other words, with finite resources, land managers must make a decision on which control technique to use, based partly on the costs associated with the method, and partly on other factors, such as the relative efficacy, logistical practicality and humaneness of the control method.

The control method efficiency of a control method can be measured by the economic cost to kill a feral pig (expressed as $ pig^{-1}). Other measures of the relative cost of various control methods can be generated from the models of Saunders (1988) which predict the cost of reducing feral pig populations to various proportions of the original population.

Another useful measure of the cost of a control method is the time taken to kill each pig (expressed as min pig^{-1}). Although measuring time expended for each pig doesn’t allow the measurement of all the resources used (e.g. helicopter hire, vehicle maintenance, trap purchase) and the relative expense of these resources (e.g. helicopter hire is far more expensive than car maintenance), it does allow one of the highest costs to be compared across years. This is important because much of the feral pig control efforts for biodiversity protection in Australia occur on government managed reserves. One of the major limiting factors for feral pig management by government land managers is staffing resources.

Another means of determining the control method efficiency of various control methods is to look at the cost of control per unit area, such as per hectare. Unfortunately the data to compare per hectare control costs across years, habitats and to a standard population reduction index are not extensive.

One way of assessing the control method efficiency of different control techniques in relation to environmental protection could be to measure the relative benefits, based on the reduction in economic damage, to valuable environmental resources. This approach would use strategic management principals where the impact of feral pigs are quantified in cost terms, and the outcome of control techniques could be evaluated in terms of reduced economic damage to

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[1] All Australian dollar figures in this report have been converted from the year of generation to 2003 costs using CPI data from the Australian Bureau of Statistics. This allows an easier comparison across years.

environmental resources (Brasher 1993). This approach was suggested for feral pig control in an agricultural setting (Tisdell 1982; Saunders 1993). Choquenot and Hone (2002) used bioeconomic modelling to compare the profitability of control methods when comparing control of lamb predation by feral pigs. However, it is difficult to place a value on environmental resources (or any non-market commodities), and in addition, research into the impact of feral pigs on environmental resources is scant. Thus, this report utilizes the more simplistic method that measures the relative costs to remove a feral pig and the time expended in doing this. These parameters could be used to generate cost-minimisation or benefit maximisation approaches (see section 1.5.2).

When assessing the control method efficiency of various methods of control, the costs and time taken per pig removed will vary depending upon the method used and the management goal. Localised eradication attempts can be more expensive than simple reductions in feral pig density, since costs generally increase as the density of remaining feral pigs fall (Saunders 1993; Fleming et al 2000). However, this level of control may be economical in the long term because once localised eradiation is achieved, no further control costs are generated if reinvasion can be stopped.

Rapid recovery of feral pig populations can occur following control operations (Choquenot et al 1996), and therefore follow-up control costs should be taken into account (Saunders et al 1990). This means the advantages of a control program can be rapidly lost as feral pig numbers build up and again damage natural resources. It also increases the costs of control operations in the future due to a higher feral pig population (for example if an annual control operation occurs). Thus monitoring costs and further control costs should be essential additions to any long-term control effort.

Another important aspect when considering the control method efficiency of control techniques must be the category of land manager involved with control operations. Private land managers can often conduct feral pig management campaigns with lower labour costs than government land managers. This is because the time taken for control operations by private land managers can be reduced because they are often resident on their properties and expensive travel time can be reduced (Saunders et al 1990). In addition, control operations such as ground baiting and trapping can be conducted in the normal operations of the farm and thus labour costs can be lowered. Conversely, it may be cheaper for government land managers to utilize methods which can appear to have high direct costs (such as aerial shooting or baiting) in order to reduce multiple individual labour costs over a broad area.

2.3) Target Specificity

The target specificity of a control method is the ability of the method to control feral pigs without adversely affecting other species. It can be defined as the number of feral pigs killed relative to the total number of animals killed or in other words it can be a measure of risk. The target specificity of a control method can vary across space and time based on a number of factors, such as the species composition of an area, the season, the bait substrate used and the strategies used when applying a control method. Unfortunately, the target specificity of many control methods hasn’t been well defined, but shooting, and trapping can be assumed to be very target specific, and poison baiting can be assumed to be relatively target specific when properly applied. The generation of data for the target specificity of poison baiting is only partially valid if generated in one landscape and extrapolated to another due to habitat and species differences.

The known or estimated non-target impacts of a control method are affected by the target specificity of a control method. However, the likely impact population impact must be assessed by looking at the population of non-target animals, not individuals. In other words, as long as the method of control is efficacious, and humane, the important criteria in assessing the impact of a control method is its potential impact on populations of non-target animals. This will require field studies during baiting campaigns and post control monitoring. Populations potentially at risk can be determined through theoretical, laboratory based studies.

Target-specificity of a control method also ensures that the maximum number of control units, such as baits, traps or bullets, are available for feral pigs and not taken up by other species. For example, Fleming et al (2000) reported that as little as 12% of aerially-broadcast meat baits may have been available to feral pigs. This high percentage of non-target take obviously would have affected the efficacy and control method efficiency of the baiting program.

2.4) Logistical Practicality

Control methods that place all feral pigs in a population at risk are the most efficacious. However, a control method can still be highly effective when a large proportion of the population is exposed to the control method. If a control method does not occur across an entire management unit immigration from non-treated areas or residual populations can quickly recolonise an area. Unfortunately, the appropriate scale of management units is not often known.

The logistical practicality of a control method, in this context, is the ability to supply the needs of a control program so that control can reach the majority of the management unit. Such ‘supplies’ may be labour, transport and materials. The ability to deliver some forms of control to most feral pigs can be logistically difficult in remote regions. For example, it may not be possible to easily use exclusion fencing (or some other ground based control methods) in remote areas due to the large amounts of material required, the high labour component of the method, the ability to monitor fences for breaches and the difficulty of transporting labour and materials (Mitchell & Kanowski 2003). Conversely, aerial shooting and aerial baiting may be much more logistically possible in remote areas (Mitchell & Kanowski 2003).

3) THE EFFECTIVENESS OF GROUND BAITING

3.1) Efficacy of Ground Baiting

The efficacy of ground baiting is affected by a number of factors, including bait substrate, toxin, placement and timing. Bait uptake can be reduced during periods of good food quality and availability (Saunders 1993; Mitchell & Kanowski 2003). The long-term efficacy of a baiting campaign (as with most control methods) can be markedly reduced without follow up monitoring and control efforts (Saunders et al 1990). The efficacy of individual toxins used in ground baiting are considered below.

3.2) Control method efficiency of Ground Baiting

Most authorities consider ground based poisoning to be one of the cheapest methods of feral pig control available regardless of the toxin used (Choquenot et al 1996; McIlroy 2004).

The costs (2003) of ground baiting in different habitats (From Choquenot et al 1996).

Habitat	Cost per Pig ($)	Cost per Hectare ($)	Source

Slopes and plains	43.01-117.70	-	Turvey (1978)
Wetland	13.19	1.94	Choquenot et al (1996).
Dryland	6.31	0.194	Choquenot et al (1996).
Dryland	6.50	0.58	Korn (1986)
Agricultural Land (eastern NSW)	55	107	Saunders et al (1990)
Arid rangelands (western NSW)	1.67	0.15	Bryant et al (1984)

The costs associated with baiting campaigns are (Mitchell & Kanowski 2003);

1. Travel costs (vehicles)
2. Labour - distributing bait
   - checking bait
3. Bait
4. Toxin

Costs can vary depending upon (Choquenot et al 1996);

1. Toxin used
2. Bait used
3. Period of free feeding
4. Habitat type
5. Feral pig density
6. Remoteness of the area to be controlled
7. Level of control required

3.3) Non-Target Impacts of Ground Baiting

The non-target effects of ground baiting are assessed in Stage 1.

3.4) Logistical Practicality of Ground Baiting

Ground baiting generally requires vehicular access to transport bait and people, and to cover the relatively large distances that enable proximity to all pigs in the habitat to be maximised. Many reserves and farms have vehicular access for routine purposes such as stock and fire management. This can allow ground baiting to be effectively applied across large management units. However, even with an extensive network of roads, in some reserves ground based baiting campaigns still cannot reach all feral pig habitat. For example, in Namadgi National Park helicopter access is required to allow ground baiting of remote alpine areas (Simon Tozer, Environment ACT, May 2004, pers. comm.).

Some areas don't have vehicular access, and during certain climatic events (e.g. the northern wet season) cannot be ground baited (Mitchell 1998). The remote nature of some areas can also mean that it is too time consuming (based on current staffing levels) to ground bait even though ground access exists. Ground baiting generally requires high labour requirements due to the necessary pre-feeding that occurs in baiting campaigns. This further increases the logistical difficulty of the method since remote areas generally should be re-visited daily for pre-feeding. In addition, it can sometimes take many days to encourage all the susceptible feral pigs to start taking baits (Saunders et al 1993).

3.5) Effectiveness of 1080 Ground Baiting

1080 ground baiting can be highly effective at reducing feral pig populations in the field. However, the efficacy of any baiting campaign can be reduced by a variety of factors ranging from plentiful food supplies in the treated area to unseasonably wet conditions. To increase the efficacy of baiting campaigns, follow up monitoring and control is required. The control method efficiency of ground baiting with 1080 can be high when conducted over broad areas. The logistics of ground baiting are affected by the necessity of reaching

all feral pig habitats across a landscape. As discussed in stage 1, the non-target impacts of 1080 ground baiting can be affected by bait substrate, baiting strategies and the native species locally present during a baiting campaign.

3.5.1) Efficacy of 1080 ground baiting

Hone and Pederson (1980) reported a population decrease of 58.8% when using 1080 in meat baits. However, with no follow up control, the feral pig population nearly doubled over the following year. This demonstrates that a control program needs to ensure a high knockdown or needs to include follow up control, especially if less than 70% of the population is destroyed. Hone (1983) later reported that the use of 1080 in pellets could reduce feral pig populations by 73% in the field when used in the semi-arid rangelands of NSW. However, 23% of feral pigs were estimated to have not eaten bait. Thus if localised eradication or a greater population reduction was desired, then a further control method would need to be utilised. 'Exercise Wild Thing' was an exercise to eradicate a simulated exotic disease outbreak in feral pigs (Anon 2002c) on Cape York. The control methods used were a combination of aerial and targeted ground baiting with 1080, followed by aerial shooting and limited ground shooting. The use of 1080 with aerial and ground baiting resulted in an estimated 68% reduction in the feral pig population (Mitchell 2003a). Schmidt (1982) researched the efficacy of 1080 impregnated oats placed in apples in controlling feral pigs in the Jarrah forest of WA. The results indicated that the poisoning campaign reduced feral pig activity by 49% and 37.9% over 2 years. This low success rate was likely due to unseasonably wet and cool years, which meant that feral pigs were not confined to waterways where baiting occurred and therefore did not come into contact with baits. It may also have been due to bait preferences. Campbell (1989) reported on the efficacy of baiting with 1080 on Sunday Island. The results indicated that a sparse population of feral pigs was present and was utilising wild passionfruit and other fruits as a major food source. Free feeding was unsuccessful, probably due to the sparse nature of the population and the ready availability of alternative, highly desirable food. Thus the success of a poison baiting campaign was likely to be low and no toxic bait deployment occurred. This demonstrates that some poisoning campaigns may be ineffective due to poor bait uptake and should not occur.

3.5.2) Control method efficiency of 1080 ground baiting

Bryant et al (1984) reviewed feral pig control operations in the early 1980's in the semi-arid rangelands of western NSW. The costs of control were estimated at \$1.67 pig^{-1}. The actual costs of 1080 are relatively low. 1080 as a solution is charged at \$0.06 ml^{-1} in NSW (Chris Lane NSW RLPB, June 2004, pers. comm.). The concentration of the solution is 30 mg L^{-1}. If a dose of up to 300 mg is required to kill the biggest pig, the amount of liquid applied to grain is 10 L^{-1} or \$0.60. The major cost involved with ground baiting exercises is the subsequent distribution of grain.

Choquenot and Hone (2002) used bioeconomic models to research the profitability of control programs which were aimed at reducing lamb predation in the arid rangelands of Australia. They found that 1080 ground baiting was less cost effective than helicopter shooting when pasture biomass was high (greater than 220kg ha^{-1}). Ground baiting was more profitable than helicopter shooting when pasture biomass was lower and pigs were more likely to eat baits.

3.5.3) Logistical practicality of 1080 ground baiting

Ground baiting with 1080 requires a pre-baiting period to encourage bait uptake, but is potentially lethal after one feed. This makes it more logistically effective than warfarin, but it is still restricted by the necessity to deliver baits throughout feral pig habitats by vehicle.

3.6) Effectiveness of Warfarin Ground Baiting

In the field warfarin has proved to be highly efficacious in decreasing feral pig numbers. However, as in all baiting campaigns, follow up monitoring and control is an important part of warfarin baiting campaigns. The control method efficiency of warfarin baiting campaigns is high, and the qualities of the toxin and the baiting strategies employed probably reduce the potential risks to non-target populations. The logistics of warfarin baiting campaigns are relatively high compared with other ground baiting methods because several consecutive doses of warfarin must occur for baiting to be lethal. A 'one shot' warfarin bait may improve the logistics of warfarin baiting campaigns, but may increase the potential non-target impacts.

3.6.1) Efficacy of Warfarin Ground Baiting

Hone (1987) reported an 87-90% reduction in feral pig numbers in Namadgi National Park during a warfarin baiting campaign. McIlroy et al (1989) later showed that death occurred in 30 of 32 (94%) radio-tagged feral pigs in a subsequent warfarin baiting campaign. However, death took between 6 and 14 days after baiting commenced. This would reduce the effectiveness of a control campaign in a situation which required rapid death of baited feral pigs, such as during disease surveillance or during an exotic disease outbreak.

Saunders et al (1990) achieved a 99% reduction in feral pig numbers on the central tablelands of NSW using warfarin in grain. A significant part of this control program consisted of post control monitoring and follow-up control efforts as monitoring revealed remaining feral pig populations. Post baiting monitoring and control efforts were reported to extend and improve the efficacy of the initial warfarin baiting campaign by delaying the re-establishment of immigrating feral pigs. This highlights the fact that control strategies need to include a monitoring phase. They also don't consist of one off control programs, since feral pigs can rapidly reinvade and recolonise controlled areas.

Other authors to report on the effectiveness of warfarin include Clarke (1993), who reported a significant feral pig reduction (85%) associated with warfarin in cereal baits in New Zealand. Brookes et al (1988) also researched the use of warfarin to control wild boar (*Sus scrofa*) in agricultural areas in Pakistan. They found that warfarin was an effective field toxicant of wild boar.

Pen trials have demonstrated that 'one shot' warfarin can be a highly effective toxicant of penned feral pigs (Mitchell 2003a). Mitchell (2003a) researched the efficacy of ground delivered 'one shot warfarin' in a feral pig population in northern Queensland and found that a 64% population reduction was achieved. This was a similar reduction to that achieved in 'Exercise Wild Thing' in the same area with aerially delivered 1080 meat baits (68%). However, the comparison occurred in different years, over different sized areas and used different delivery methods.

3.6.2) Control method efficiency of Warfarin Ground baiting

Saunders et al (1990) assessed the costs of a warfarin baiting campaign on rugged, forested and cleared land in eastern Australia. The control costs were \$55 pig^{-1} for the initial population control and \$66 pig^{-1} for follow up control and maintenance. The time taken in labour to kill each pig was 161 min pig^{-1}. This equated to a cost of control of \$107 per km^2. The major costs associated with this campaign were labour costs.

Saunders et al (1990) illustrated that follow up monitoring and subsequent control should be a part of a cost effective feral pig baiting campaign. Re-colonisation of the controlled area occurred over the following 12 months after the initial control program, to 28% of the initial population (Saunders et al 1990). The expenditure of resources during the post control monitoring and maintenance program were valued at 25% of the original control program. Thus, the expenditure to prevent a 28% increase during the maintenance program equated to roughly the same \$ pig^{-1} value of the initial control program. In addition, the maintenance program reduced the damage to natural resources that would have occurred with re-invasion of the feral pig population.

3.6.3) Target specificity of Warfarin

This was discussed in stage 1. However, it is worth noting that the baiting strategies used during current warfarin poisoning campaigns are thought to markedly reduce the potential risks through pre-feeding monitoring and only lacing grain at pig uptake sites.

3.6.4) Logistical practicality of Warfarin ground baiting

Warfarin requires several repeat feeds to be lethal to feral pigs as it is used in current baiting programs. This is both an advantage, in terms of potentially being able to restrict non-target take, and a disadvantage, through increasing labour costs and non-target exposure. Development of a ‘one shot’ warfarin would decrease the logistical requirements of a baiting campaign since the number of baiting days, and thus the labour requirement, will be reduced (Parker & Lee 1995). The logistical requirements of warfarin baiting campaigns are greater than 1080 ground baiting campaigns and ground baiting with yellow phosphorus.

3.7) Effectiveness of Yellow Phosphorus Ground Baiting

Yellow Phosphorus is likely to be effective at reducing feral pig numbers and the increased availability of the toxin probably extends the area over which feral pigs are controlled. However, the use of yellow phosphorus is often not coordinated across management areas. Non-target impacts on scavenging and carnivorous animals are probably high since no baiting strategy is used to reduce this impact. The logistics of using yellow phosphorus are relatively low compared with other ground based toxins since no free feeding is carried out with this method. Yellow phosphorus is relatively inexpensive.

3.7.1) Efficacy of Yellow Phosphorus

The efficacy of yellow phosphorus has only been assessed in pen trials. It was found in these trials to be effective in killing feral pigs (O’Brien & Lukins 1990). However, no research has occurred into the use or efficacy of yellow phosphorus in the field. Anecdotal reports imply that yellow phosphorus produces feral pig deaths in areas where it is used (Bryant 2004)

Regardless of the efficacy of yellow phosphorus in relation to other toxins, it’s usefulness for individual farmers in remote areas is likely to be high. This is because its registration makes it freely available to farmers as a ‘take-home’ toxin, where as 1080 and warfarin are only used by government land managers. This can mean that private land managers in remote areas (such as the semi-arid rangelands of NSW and Queensland) cannot always bait with 1080 since government staff need to be involved. Yellow phosphorus on the other hand is freely available and can be used to control feral pigs ad hoc when signs of feral pig damage are obvious. Thus, regardless of the merits of the various toxins, the ability of private land managers to reduce feral pig numbers when necessary relies to some extent on the availability of a 'take home' toxin. It is worth noting that the application of yellow phosphorus during uncoordinated programs across large management units is unlikely to produce a sustained drop in feral pig populations due to immigration from non-controlled areas.

3.7.2) Control method efficiency of Yellow Phosphorus

No research has been conducted on the control method efficiency of ground baiting with yellow phosphorus. Yellow phosphorus or CSSP is purchased at $28 for a 1.4 kg tin (Chris Lane NSW RLPB, June 2004, pers. comm.). Yellow phosphorus is registered to be used at 60 grams per carcass. Therefore the actual toxin costs are low and amount to $1.20 per carcass. However, the number of pigs that a carcass will kill is unknown and will vary depending on factors such as feral pig density and the size of feral pigs.

3.7.3) Target specificity of Yellow Phosphorus

These were discussed in Stage 1.

3.7.4) Logistical practicality of Yellow Phosphorus ground baiting

Yellow phosphorus is potentially more logistically efficient than 1080 or warfarin. Since a carcass is the delivery method in grazing areas where feral pigs are generally accustomed to feeding on carcasses, no free feeding is generally required. This toxin is potentially lethal after one dose (O'Brien & Lukins 1990).

3.8) Effectiveness of Other Toxins

3.8.1) The Effectiveness of Cyanide

The effectiveness of cyanide is at this stage unknown, since the method is in the early stages of development.

3.8.2) Efficacy of Cyanide Ground Baiting

Cyanide may be the most practical, fast acting and humane alternative toxin for feral pig control, however concerns exist regarding toxin stability in baits, target specificity and user safety. Cyanide encapsulation can be used to both increase the safety of cyanide for operators and make the toxin more stable in baits. However, macro-encapsulated pellets from NZ were found to be indigestible in pigs and needed to be bitten and cracked to be effective (Mitchell 2003a). The use of cyanide tablets in pigs was found to be ineffective by New Zealand researchers as well (Hendersen et al 1993). However, cyanide pellets have been effective in possum control in NZ (Eason & Wickstrom 2001).

The effectiveness of cyanide will likely be improved through using enhanced encapsulation techniques that reliably ensure that a dose of cyanide is absorbed (Mitchell 2003a). Such alternative means of delivery will need to take into account operator safety.

3.8.3) Control method efficiency of Cyanide Ground Baiting

No large scale, successful field trials have yet occurred.

3.8.4) Target specificity of Cyanide Ground Baiting

Cyanide is potentially rapidly lethal to a wide variety of animals (Eason & Wickstrom 2002). If the method proves to be effective at reducing feral pig numbers a target specific delivery system or strategy will need to be developed.

3.8.5) Logistical practicalities of Cyanide Ground Baiting

These should be similar to other ground baiting campaigns using a toxin which is potentially lethal after a single dose (e.g. 1080). Currently the use of cyanide for feral pig control is not registered in Australia, and the costs to research and register the toxin would be likely to be high, and this is a major constraint to its use.

3.8.6) Effectiveness of Other Toxins

Most other anticoagulants offer no real advantages over warfarin (McIlroy 2004) although diphacinone has recently proved to be less persistent in the livers of poisoned rodents (Fisher et al 2003), and this may reduce the small chance of secondary poisoning in feral pig warfarin baiting campaigns. The anticoagulants, zinc phosphide and cholecalciferol were reviewed in stage 1.

4) THE EFFECTIVENESS OF AERIAL BAITING

Aerial baiting trials, with meat baits have generally not achieved the same level of control as ground baiting campaigns that may be required to achieve sustained impact reduction. The reasons vary, but insufficient baiting intensities and high non-target takes of bait have possibly contributed to the low level of efficacy. However, as baits and baiting strategies are further refined, this method shows great promise as an effective method of broad-scale feral pig control, especially in more remote areas.

In aerial baiting campaigns, areas of high pig activity can be easily seen from the air and targeted. Aerial baiting is thus a useful feral pig control tool in reaching inaccessible regions due to easily attained logistical requirements. However, large quantities of bait may need to be deployed and bait uptake may be affected by climatic conditions. Non-target impacts of an aerial baiting campaign may also be high, especially when using meat baits in some areas.

4.1) Efficacy of Aerial Baiting

Aerial baiting studies using meat baits containing either biomarkers or 72 mg of 1080 have been funded by the Wildlife Exotic Disease Preparedness Program and the National Feral Animal Control Program. In one such study Mitchell (1998) found that non-toxic bait uptake (theoretical efficacy) was 63% when undertaken during the dry season on Cape York. This level is in theory too low to allow effective population control or to contain an exotic disease outbreak (Giles 1980, Pech and Hone 1988, Mitchell 1998). This low level of uptake may have been due to an inadequate baiting density of 18 baits km^{-2}.

A further study by Mitchell (2000) tested aerial baiting intensity against uptake of biomarked baits by feral pigs. This study found that a theoretical population reduction of 81% could be achieved in the wet season and 49% in the dry season. The study reported that 50 baits km^{-2} were required to achieve a theoretical (but likely unachievable) 100% reduction in feral pig numbers in the wet season, while during the dry season 150 baits km^{-2} were required. The reduced effectiveness of the baiting campaign during the dry season probably resulted from the pattern of bait distribution. Mitchell (2000) used a blanket baiting strategy during both seasons and a large number of baits were unlikely to be found by feral pigs that were concentrated around waterholes in the dry season. Thus, by increasing the baiting intensity during an aerial baiting campaign, and strategically targeting natural congregation points with aerially delivered baits, an effective baiting campaign is theoretically achievable. This was demonstrated during 'Operation Wild Thing' a greater than 70% efficacy was recorded. However a conservative 68% reduction was reported (Mitchell 2003a).

In a comparative aerial baiting study undertaken by Fleming et al (2000) in northern New South Wales it was found that unreasonably high levels of biomarked bait were required to achieve a theoretical (but again unachievable) elimination of feral pigs. Bait uptake by pigs (theoretical efficacy) was between 31% and 72% in this trial. Bait uptake was likely affected by foraging range, which is affected by cover, prevailing temperature and water and food availability. The large non-target take of ground deployed baits (88%) was likely to have reduced the availability of baits to feral pigs.

Mitchell & Kanowski (2003) compared aerial baiting at 50 baits per km of river front (with meat baits impregnated with 72 mg of 1080), trapping and aerial shooting. They found that aerial shooting and trapping both produced greater population reductions than aerial baiting. Aerial baiting produced an estimated population reduction of 59%. However, although it would appear from this study that trapping may be more effective than aerial baiting other factors must be considered, such as logistical practicalities (aerial baiting can be widely and easily applied in contrast to trapping) and control method efficiency. The authors made the point that aerial baiting is considerably less effective than ground baiting due to the lack of pre-feeding (something that could be undertaken), and that ground baiting can be more targeted.

Clarke (1992) assessed the uptake of manufactured (Du Pont) aerial delivered polymer baits in NZ and found that 100% of tested pigs (70) had consumed biomarked baits. The PAC CRC is attempting to develop a new manufactured bait (Du Pont bait no longer available) which can be aerially deployed for use in feral pig control campaigns. Lapidge et al (unpublished data) conducted an aerial baiting campaign with prototype manufactured feral pig baits during a season of high rainfall in the semi-arid zone of Queensland. They found that reasonable bait uptake by pigs could still occur (80% manufactured baits and 52% meat baits) even with large amounts of available forage. Non-target bait uptake of the prototype manufactured feral pig bait was zero. The prototype manufactured feral pig bait was more likely to be consumed than the currently used meat baits.

4.2) Control method efficiency of Aerial Baiting

Aerial baiting cost \$37.19 pig^{-1} and took 3.8 min pig^{-1}(Mitchell & Kanowski 2003). This method, like aerial shooting, also has the advantage of allowing feral pig control to be extended to remote or inaccessible areas (e.g. seasonally wet areas) where ground based control is likely to be expensive. However, this study utilised helicopter bait delivery rather than a cheaper and equally effective method of delivery with a fixed wing aircraft.

The costs associated with aerial baiting were;

1. Helicopter charter ($330/hr)
2. Helicopter fuel ($200/drum)
3. Kangaroo meat bait ($1.75/kg)
4. 1080 poison (supplied free by Qld Dep. NRME)
5. Labour- bait preparation ($17/hr)
   - poison application ($17/hr)

Mitchell and Kanowski (2003) recommended that the control method efficiency of this method can be enhanced by using fixed wing aircraft, and by treating large areas of land, instead of the small areas of land used in this study. Again, aerial baiting should be limited to the dry season in tropical savannas, since feral pigs are concentrated around riparian zones, and this decreases the total land area that is required to be treated.

As reported earlier, Fleming et al (2000) found that the control method efficiency of aerial baiting in the semi-arid rangelands was reduced by non-target meat bait consumption, which meant that a higher baiting intensity was required. A more target-specific omnivore feral pig bait may address this problem.

Current aerial baiting programs occur without a pre-baiting period (Mitchell 1998). Pre-baiting increases bait uptake and the success of feral pig poisoning campaigns (Saunders et al 1993). The reasons for this management approach are the costs associated with additional aircraft hire, and the difficulty in pre-baiting when bait consumption cannot be verified from the air. Research into the increased efficacy and cost-benefit of aerial pre-baiting is required.

4.3) Target specificity of Aerial Baiting

Little research has occurred looking at the target specificity of aerial baiting. Mitchell (1998; 2000), Mitchell and Kanowski (2003) and 'Exercice Wild Thing' all reported on the effectiveness of aerial baiting, but did not focus on the non-target impacts. Fleming et al (2000) has reported large non-target bait takes of aerial broadcast meat baits (58% by native birds and 30% by foxes) and that these takes could have reached 88% of available baits. This has implications for both the efficacy of the method (bait availability to feral pigs is reduced) and the population impacts on non-target species. However, aerial baiting in northern Queensland occurs using large 500g pieces of meat and these are larger than those used by Fleming (2000). The use of large pieces of meat may reduce the non-target impacts since many raptors and other birds may not be able to remove such large pieces of meat to consume them (Jim Mitchell Pers. Comm. Qld Dep. N.R.M. September 2004). Fleming et al (2000) suggested that an alternative toxin specific to feral pigs may be needed if aerial baiting was to be acceptable in terms of non-target impacts. An alternative means of reducing the non-target impacts would be to deliver a bait package, or bait substrate that is not taken by non-target animals. This would reduce the non-target risks of aerial baiting and in addition increase the efficacy of aerial baiting campaigns (more available baits for feral pigs). The use of creosote on meat baits has reduced the palatability of meat baits to non-target species, whilst retaining their palatability to feral pigs (Jim Mitchell Pers. Comm. Qld Dep. N.R.M. September 2004).

4.4) Logistical practicalities of Aerial Baiting

This method allows feral pig baits to be delivered easily across the landscape. However, some studies have shown that impossibly large amounts of generic bait must be delivered to eradicate feral pigs (Fleming et al 2000). The use of a strategy where aerial baiting targets waterways during dry times can improve the logistics of aerial baiting, since the whole landscape doesn't need to be treated (Mitchell 2000). This, combined with more target specific baits may dramatically increase the effectiveness of the technique.

5) THE EFFECTIVENESS OF FENCING

Fencing can reduce the impacts of feral pigs on natural resources through exclusion and can increase the effectiveness of other control methods. However, fencing is expensive to establish and maintain, especially in remote areas. The non-target impacts are not quantified and the logistics of the method are difficult to meet.

5.1) Efficacy of Fencing

Fences have been shown to be able to exclude feral pigs completely in the short term (Hone & Atkinson 1983). The effectiveness of fencing as a feral pig impact control method can be assessed by the reduction of feral pig impact on a measurable resource. Mitchell (2000) showed that rainforest tree seedlings were 36% more common in fenced enclosures in north Queensland. He also found that seedling germination and survival was 20% higher in fenced enclosures. The effectiveness of fencing to control feral pig impacts can be high as it has been used to assist in localised eradication of feral pigs in some Hawaiian rainforests (Anderson & Stone 1993; Katahira et al 1993). However, the application of fences often simply redirects feral pig impacts to other areas (Choquenot et al 1996) and thus additional control methods often need to be employed with fencing.

5.2) Control method efficiency of Fencing

Only a small amount of research has occurred into the control method efficiency of fencing for controlling feral pigs. Fencing needs to be considered in a different way from other control methods which generally depend upon lethal means to control feral pigs. The benefit of fencing continues long after erection provided fences are well maintained. In addition, the use of fencing can increase the efficacy of other feral pig control techniques through preventing re-invasion (Garcelon 2004). However, maintenance costs can continue to be high and the costs of establishing and maintaining fences in remote or inaccessible areas can be prohibitive. For example, feral pig exclusion fencing establishment and maintenance costs in a remote Hawaiian national park were estimated to be US$14,000-$24,000 km^{-1} (Hone & Stone 1989). This is $30,950- 53,058 km^{-1} in Australian dollars today[2].

Hone and Atkinson (1983) investigated fence designs for feral pig exclusion. The preferred electrified fence which completely excluded feral pigs cost $3,100 km^{-1}. However, this figure did not include labour, strainer posts, fence maintenance costs or an electric fence energizer. Labour is likely to be high in remote areas. An effective non-electrified version of the fence cost $2,864 km^{-1}. Caley (1993) found that fencing gave the best benefit to cost ratio in his study in the Northern Territory.

5.3) Target specificity of Fencing

The non-target impacts of feral pig proof fencing have not been researched. However, this research will be required to investigate the impacts that fencing may have on non-target populations (Mitchell 2000). While non-target issues are unlikely to be lethal, the disruption to dispersal and gene flow for most terrestrial animals could be significant.

[2] Based on an initial conversion to Australian dollars, where $1 (Aus) buys $0.69 (US), then conversion to current values using Australian Bureau of Statistics CPI figures.

5.4) Logistical practicalities of Fencing

Fencing is a labour intensive method to establish and requires vehicular access to allow transport of materials into erection areas. It also requires ongoing maintenance. In remote areas it is often not possible to supply the resources (especially labour) or access required to maintain fences.

6) THE EFFECTIVENESS OF TRAPPING

Trapping can produced large decreases in feral pig populations, especially in small localised areas. The effectiveness of trapping is determined by the attractiveness of the trap bait material, and the rate at which feral pigs encounter traps. No assessment of the efficacy of trapping as a broad-scale method of feral pig control has occurred.

Trapping is generally an expensive and time consuming means of feral pig control, with logistical practicalities meaning that it is best applied to small areas of high agricultural or conservation value rather than larger, remote areas. However, once feral pig trapping materials are purchased and traps are established, the costs and time taken for subsequent trapping campaigns are reduced significantly. The practice has the advantage of being highly target specific.

6.1) Efficacy of Trapping

Trapping is one of the most widely used control techniques for feral pigs. Saunders et al (1993) found that trapping removed 62% of pigs which were exposed to traps in the Kosciusko National Park, however this only comprised 28% of the entire population. Choquenot et al (1993) reported significantly greater efficacy, with 100% of feeding feral pigs removed from a central tablelands of NSW field site, which corresponded to 81% of the entire population as derived through spotlight counts. They found that trapping campaigns could be improved by baiting when the availability of food was low, and using alternative bait types. Choquenot et al (1993) also reported that if abundance indices are generated from the proportion of bait laid that is taken, an overestimation of the population reduction during a trapping campaign can be made. This was because only animals that take bait are likely to be trapped.

Bryant (2004) briefly discussed trapping as a means of broad scale feral pig control and reported that although trapping has been funded as one of the major NSW Government Feral Pig and Fox drought initiatives, no studies have researched the effectiveness of the technique for broad-scale control.

Feral pig trapping was seen to be a useful means of feral pig control by the Wet Tropics Management Authority in Queensland for a community based feral pig trapping program (Mitchell 1998). However, the scheme was also developed to generate a sense of community ownership of the problem, not just to reduce feral pig numbers (Mitchell, quoted in dialogue text in Lapidge 2003). The scheme was successful since it achieved coordination of feral pig management, achieved community involvement and ownership and awareness of the problem, and also reduced the feral pig population in targeted areas (Mitchell 1998). Mitchell (2000) stated that trapping was most usefully applied in the wet tropics in environmentally sensitive areas or where landholders are available to participate in the program. Higgs (2003) reported on a successful community trapping program on the south coast of Western Australia. He reported that significant progress was made in the control of feral pigs and the assessment of success was made by anecdotal reports and molecular ecology.

Mitchell and Kanowski (2003) found that trapping was the most effective method of feral pig population reduction in the Burdekin River area when they compared this method with aerial shooting and aerial baiting. The population reduction was measured by looking at the change in abundance indices along watercourses in the treatment areas. Trapping resulted in a 74% population reduction, and resulted in the euthanasia of 81 pigs. However, this population reduction was only achieved after excluding one study site from data analysis due to poor landholder trapping efforts resulting in a net increase in pig activity at that study site. This reinforces the point that trapping is a long term control method that requires significant labour. Mitchell and Kanowski (2003) recommended that trapping needs to be restricted to small, accessible areas. The efficacy of trapping can be reduced or completely compromised by an uncommitted workforce.

The efficacy of trapping programs must also be assessed by looking at the time over which they are applied. Mitchell and Kanowski (2003) made the point that the trapping program they assessed took several months to achieve the 74% population reduction. Thus if a rapid reduction in feral pig numbers is required, such as for protecting a bird nesting ground or during an exotic disease outbreak, trapping may be an ineffective means of control. This trapping program was enhanced by the availability of readily available, good quality pasture in the trapping area which tended to concentrate feral pigs. This is in contrast to many other studies that found that the availability of alternative feed sources can lower the success of trapping programs (Hone 1990; Caley 1993; Saunders et al 1993).

Trapping success has been found to be dependant on a number of factors (Choquenot et al 1993; Saunders et al 1993; Caley 1994) and these were reviewed by Choquenot et al (1996). Saunders et al (1993) stated that the major limitation of feral pig trapping is that not all pigs can be captured. However, with a knowledge of which factors influence trap success, the efficacy of trapping can be maximized. For example, in the United States where trapping is commonly used, the technique is thought to be more successful in areas where natural forage is low and pig numbers are high (Garcelon 2004).

Saunders et al (1993) found that two of the most important factors determining trap success were the season and signs of recent pig activity. The autumn and probably the winter were the times when pigs were most easily trapped, and this coincides with the seasons of lowest food availability when feral pigs are attracted to the good quality food in traps. The presence of recent pig sign simply indicates that feral pigs were present in the area, with certain areas exhibiting pig sign found to be more successful for trapping. Such areas included the tree lines and fire trails in autumn, and away from fire trails in the spring. This was likely because the area of home range probably increased during autumn due to the scarcity of food resources, which meant that feral pigs were probably using fire trails to travel their expanded home ranges.

Pre-baiting feral pig traps before setting is essential. In western areas of NSW, 3 days is the minimum recommendation for pre-baiting but Saunders et al (1993) suggested that a minimum of 6 days may be important in cooler, wetter alpine areas. This is because conditions which restrict the movement of feral pigs (dry and hot) are less likely to occur in alpine areas. In a similar fashion to Australia, feral pig traps in America are pre-baiting for a week with attractants and food in the USA (Garcelon 2004). Diesel is used as an attractant on corn in some local control operations (Cody Stemler, USDA Wildlife Services, March 2004, pers. comm.).

Caley (1994) reviewed the factors affecting trap success in a tropical habitat. He found that the season was the most important determinant, with the late dry season (the period of lowest food availability) being the most successful trapping time. The presence of pig sign was also an important determinant of trap success. Fresh pig tracks indicated that trap success would be high, whereas fresh pig rooting indicated that trap success would be low (probably because resource depletion had occurred due to the previous rooting and feral pigs were less likely to be using the area). Capture rates were higher in closed forest, open forest and woodland habitats than in open woodland and low open woodland habitats. Bait type was important in attracting pigs into traps with a mixture of fermented grain leading to the trap entrance and rotten carcasses attracting pigs from wide areas being important. In contrast to Saunders et al (1993) who reported that water didn't influence trap success, Caley (1994) found that proximity to water ways affected trap success, with traps closer to water being more successful, since pigs require water and wallowing opportunities daily during hot dry weather.

6.2) Control method efficiency of Trapping

The cost of trapping feral pigs was evaluated by Mitchell and Kanowski (2003) in the Burdekin River catchment in northern Queensland during the dry season when pigs were concentrated along the riparian zone. This study compared the control method efficiency and population reductions (efficacy) of aerial baiting, aerial shooting and trapping. They found that although trapping reduced the populations effectively, trapping was expensive in comparison to aerial shooting or aerial baiting ($62.90 pig^{-1}). The time taken to catch and kill a pig was 89 min pig^{-1}.They found that trapping was best restricted to small, well defined and accessible land areas. If the program was extended to larger areas in this study, the logistics and increased labour and travelling costs may have decreased the overall control method efficiency further.

In the Mitchell and Kanowski (2003) study, the costs associated with purchasing and establishing traps were included in the overall costs associated with trapping. The use of these traps is possible in subsequent trapping operations. The costs of the trapping materials constituted around one third (31%) of the overall trapping program, so this significantly lowers the costs of subsequent trapping programs. In addition, once traps are established, they can be left in that place and the labour costs associated with establishing the traps at the start of a trapping program are further reduced. Thus the cost of subsequent trapping programs would be likely reduced by at least a third. In addition, the labour cost associated with the trap maintenance (such as free baiting, checking traps) can be reduced by conducting trap maintenance with other land management tasks.

The costs associated with trapping were;

- Mesh panels ($100/trap)
- Star pickets ($50/trap)
- Tie Wire ($2/trap)
- Mixed grain ($75/trap)
- Molasses ($50/trap)
- Meat Meal ($38/trap)
- Labour- trap construction ($17/hr)
  - trap servicing ($17/hr)
- Vehicle ($0.52/km)

Mitchell and Kanowski (2003) recommended that a trapping program is generally to expensive to develop and maintain unless a small valuable area is being protected, where the costs are outweighed by the economic benefits. However, where a commercial feral pig harvesting industry exists, the carcasses of trapped pigs can offset the costs associated with establishing the traps. Trapping can also be subcontracted out to commercial harvesters or people with an interest in trapping feral pigs.

Saunders et al (1993) reported costs associated with feral pig trapping in Kosciusko National Park were \$136 pig^{-1}. The time spent was 477 min pig^{-1}. This trapping program was more successful than many reported in the literature, probably due to a resource poor environment causing feral pigs to desire baits more strongly than in other areas, and the targeting of trapping to areas of high pig activity. Generally, in mountainous areas (remote) of Australia trapping can cost in excess of \$160 pig^{-1} (Glen Saunders NSW Ag, June 2004, pers. comm.). Again, the costs and time associated with establishing and purchasing traps are included and these will be reduced in subsequent trapping programs.

Two studies espousing the virtues of feral pig trapping are Turvey (1978, quoted in Choquenot et al 1996) and Mitchell (2003b). Turvey (1978) found that trapping was more cost effective than poisoning in western NSW when feral pig numbers were low. The cost efficiency of trapping achieved in a community trapping program in the wet tropics management area was also high, since each trapped feral pig cost only \$29 pig^{-1} (Mitchell 2003b). The cost efficiency was high because local landholders participated.

Costs of trapping in different habitats

Habitat	Cost per Pig ($)	Source
Slopes, plain, scrub (NSW)	56-106	Turvey (1978)
Mountainous forest of eastern Australia	136	Saunders et al (1993)
Northern tropical savannah (Qld)	62.90	Mitchell & Kanowski (2003)

6.3) Target Specificity of Trapping

Choquenot et al (1996) reported that during trapping programs there is minimal risk to non-target species. Previously, some non target risks were evident in the wet tropics, since trapping feral pigs lead to cassowaries captures as well. A modification of trap design has since reduced these risks to low levels (Mitchell 1998). Generally by-catches can be release unharmed.

6.4) Logistical Practicalities of Trapping

Trapping is a labour intensive method and like ground baiting and fencing requires large amounts of materials to be transported into areas where feral pig control is required (vehicular access). Labour is required daily and the method requires pre-feeding, which like ground baiting, requires several days access to remote areas.

7) THE EFFECTIVENESS OF AERIAL SHOOTING

Aerial shooting is an efficient means of lowering pig populations when undertaken in suitable habitat, such as flat terrain without thick vegetation (such as wetlands and open

rangelands), especially when feral pig densities are high. Reductions of 80% are possible, with greater population declines rarely pursued for reasons of control method efficiency. Aerial shooting is especially useful to extend feral pig control to remote or inaccessible areas and is one of the efficacious techniques available for use over broad areas in many areas of Australia. Aerial shooting is often more efficacious if it is combined with another control method. However, aerial shooting is not safe for operators or efficacious in all habitats that feral pigs are found in, such as mountainous or heavily forested areas. The target specificity of aerial shooting is extremely high and the logistical practicalities are relatively easily met.

7.1) Efficacy of Aerial Shooting

The efficacy of aerial shooting for feral pig management has been assessed by a number of authors (Saunders & Bryant 1988, Hone 1990, Saunders 1993; Mitchell & Kanowski 2003). The most significant of these studies (Saunders 1993) showed that large, short-term reductions of feral pig populations (80%) are achievable with aerial shooting, although residual populations often remain (like most control methods). However, residual populations can quickly build up again between annual shoots, and this tends to lower the efficacy. Saunders (1993) discussed this scenario. Residual populations often remain because as pig numbers drop during an aerial shoot, the time taken to shoot remaining pigs increases exponentially which in turn decreases the control method efficiency of further aerial shooting. Therefore, greater reductions in numbers (greater efficacy) could be achieved, if the helicopter flying time could be extended through increased funding, but this generally does not occur.

Since the economics of aerial shooting do not allow population reductions which approach 100%, a close monitoring of environmental conditions should occur. Favourable environmental conditions can indicate when breeding is likely to occur. Such monitoring may therefore suggest when further control methods should occur (such as trapping or poisoning) (Saunders 1993). Short term reductions achieved through aerial shooting may be useful for short term resource protection (such as agricultural protection, lambs and ripening crops, and presumably biodiversity protection) or disease spread prevention. To produce long lasting control, follow-up control methods should be used.

Hone (1983) utilised 2 methods of control (aerial shooting and poisoning) in a simulated exotic disease control program. Combined, the methods of control were more successful than if 1 method was used alone. Poisoning achieved a 73% population knockdown, with 23% of pigs not eating baits. Aerial shooting achieved a further reduction in the population level, which would not have been achieved if reliance was placed upon poisoning only. This reconfirms that it is important to use integrated control methods during feral animal control programs.

Saunders & Bryant (1988) attempted to eradicate feral pigs in an area of the Macquarie Marshes and found that with available resources eradication was not possible using aerial shooting, ground shooting and trapping. With increased resources, eradication may still not be possible since some pigs may be left after each control method is applied. However, the use of multiple techniques will probably reduce the percentage of pigs surviving each control technique. As expected, a proportion of pigs survived the aerial shoot, and telemetry studies showed that this may be because they altered their behaviour during the aerial shoot to avoid detection. Choquenot et al (1996) listed the dispersal of feral pigs during aerial culling operations as a disadvantage of this method. However in the study by Saunders & Bryant (1988) pigs dispersed when they were hunted on foot rather than dispersed during aerial culling, where they went to ground. Dexter (1996) specifically studied the behaviour of feral pigs during aerial shooting in response to the study by Saunders & Bryant (1988). He found that no significant change in behaviour of feral pigs exposed to aerial shooting occurred. He concluded that feral pigs did not learn to avoid aerial shooting and in fact shooting may have reduced activity and dispersal.

Hone (1990) investigated the use of ecological theory (Predator Prey Theory) in improving the management and planning of aerial shooting of feral pigs. Although more data is required to evaluate how best to relate the predator prey theory to aerial shooting data, a number of applications of the predator prey theory can be made. The predator prey theory may estimate pre shoot populations more accurately than aerial surveys. Predator prey relationships can be used to decide when to move onto a new shoot area during an aerial shoot and to estimate the time it will take to remove a certain percentage of pigs.

Aerial shooting achieved a efficacy of 64% in the Burdekin River catchment (Mitchell & Kanowski 2003). They found that the control method was more effective when applied across a large area and produced a very rapid knockdown in numbers.

7.2) Control method efficiency of Aerial Shooting

This was the most cost effective method of control considered in the riparian zone in northern Qld by Mitchell and Kanowski (2003) It cost \$25.90 and 3.6 min pig^{-1} to find and shoot one pig, which was less than half the cost associated with trapping. Aerial shooting could be expected to increase in control method efficiency in relation to trapping or other ground based control programs when such methods are conducted in remote or inaccessible areas. For this reason Mitchell and Kanowski (2003) recommended that aerial shooting in the tropical savannah should be carried out in the dry season, when feral pigs are concentrated along riparian zones. This allows cost effective control since feral pigs are located in small areas at high densities. In addition a recommendation was made that cooperative approaches (between adjoining land-managers) be taken during aerial feral pig control operations, because this significantly lowers the overall costs associated with the helicopter use.

Saunders (1993) reviewed the costs of aerial shooting in wetlands in the semi-arid rangelands of NSW. He found that costs varied widely from year to year. This variation was probably due to changed helicopter models, and the improved skill and experience of the shooter and pilot, as well as the density of feral pigs. Costs to shoot a feral pig varied between \$3.75 pig^{-1} and \$17.46 pig^{-1}. Time taken per pig shot varied between 0.5 minutes and 1.5 min pig^{-1}.

Costs of aerial shooting as summarised by Choquenot et al (1996)

Habitat	Cost per Pig (\$)	Cost per Hectare (\$)	Source
Woodland	112.21	2.09	Hone (1983)
Wetland	20.92	-	Bryant et al (1984)
Wetland	9.70-30.08	0.49-0.35	Korn 1986
Dryland	5.65-30.08	0.19-0.29	Korn 1986
Wetland/dryland	22.86	1.82	Saunders & Bryant 1988
Wetland/woodland	11.22	0.56	Hone 1990
Rangeland	76	0.30	Lapidge et al 2003

The costs of aerial shooting in areas of low pig density and in difficult terrain have not been adequately documented (Bryant 2004), although Lapidge et al (2003) reported that at densities of approximately 0.1 pigs km^{-2} spread over 4,430 km^{2} shooting efficiency was reduced to 9 min pig^{-1} and \$76 pig^{-1}. Bryant (2004) suggests that a simple reporting system be established in NSW to allow a recording of the efficiency and control method efficiency of aerial culling in order to support its use.

The costs associated with aerial shooting are (Mitchell & Kanowski 2003);

1. Helicopter charter ($330/hr)
2. Helicopter fuel ($200/drum)
3. Ammunition ($1/bullet)
4. Labour for shooting ($17/hour)
5. Specialist training of shooters

The costs vary between years and across different land areas based on a number of factors (Choquenot et al 1996);

1. Feral pig density
2. Type of terrain
3. Vegetation cover
4. Flying conditions
5. Type of helicopter
6. Pilot experience
7. Shooter accuracy

The profitability of aerial shooting for lamb predation reduction was considered by Choquenot and Hone (2002). They found that at pasture biomasses above 220 kg ha-1, helicopter shooting was more profitable than ground baiting. They also found that helicopter shooting was most profitable when applied annually.

7.3) Target Specificity of Aerial Shooting

Aerial shooting of feral pigs has a high level of target specificity (Choquenot et al 1996). English & Chapple (2002) found that aerial shooting was target specific generally. This is because each feral pig is visualised before being shot. Visibility should be unrestricted during aerial shooting campaigns to ensure target specificity, and the technique should only used in appropriate areas with trained shooters.

7.4) Logistical Practicalities of Aerial Shooting

Aerial shooting can be delivered to most areas so is logistically possible under most circumstances. However, the efficacy is low in some areas where the landscape allows feral pigs to shelter away from the view of aerial shooters. In addition, a suitable helicopter and qualified shooters must be available. In many situations a ground crew will be required for refuelling and safety purposes.

8) THE EFFECTIVENESS OF THE JUDAS PIG METHOD

The Judas pig technique is not a method of control since it doesn't cause the death of feral pigs by itself. However, the method allows the effectiveness of other methods of control, such as baiting or shooting, to be increased. It is also likely to reduce the non-target impacts of the other method of control which is utilized with the Judas Pig Technique. However, this method is costly and can have some difficult logistical requirements.

8.1) Efficacy of the Judas Pig Technique

The use of Judas Pigs allowed the location of a residual population of feral pigs to be located in the Namadgi National Park. Targeted aerial baiting was then carried out and this resulted in a 75% reduction in the residual feral pig population (McIlroy & Gifford 1997). The technique was also used to eradicate a small population of feral pigs in the Northern Territory which had remained despite other attempts at eradication using conventional techniques (McIlroy & Gifford 1997). The method has since been used in New Zealand and Australia for control of feral pigs and other exotic ungulates (McIlroy & Gifford 1997), and has recently been used at Cathedral Rock National Park in NSW with some success (Tim Scanlon NSW NPWS, June 2004, pers. comm.).

8.2) Control method efficiency of the Judas Pig Technique

The Judas pig technique can be an expensive means of control (McIlroy & Gifford 1997) due to high equipment expenses, including;

1. Transmitter: $363 (VHF) or $5,000 (GPS)
2. Receiver: $1,500-$3,000
3. Antenna: $300-$1,300

It also has a high labour requirement and the potential to require. It took between 4.4 (local Judas sow) and 20 (boars) trap nights to catch Judas pigs and other control measures were attempted. However, if a high priority is placed on control or eradication, the method can be cost effective to locate and eradicate small isolated feral pig populations.

8.3) Target Specificity of the Judas Pig Technique

The non-target effects of the Judas Pig method itself are minimal. This is because only feral pigs have a radio collar fitted. The collar allows control methods to be targeted to areas of feral pig activity. If ground or aerial baiting is used, the Judas Pig technique may increase the target specificity of those methods because areas of known feral pig activity are targeted. This reduces the area over which non-target species are potentially exposed.

8.4) Logistical Practicalities of the Judas Pig Technique

This method is logistically difficult. It requires traps, and specialised equipment. It also requires the use of another control technique to kill the pigs when they are located. However, when its use is restricted to small populations for eradication or mopping up, it likely compares favourably with the application of resources during a widespread traditional program (such as ground baiting) to control pockets of feral pigs in a dispersed, low density population.

9) THE EFFECTIVENESS OF SNARING

Snaring is an effective means of eradicating feral pigs, provided immigration is prevented. However, the method requires many worker hours per pig removed from the population (up to 43 hr pig^{-1}) and also requires workers 'on the ground' in all pig habitats, which means it is not feasible for large land areas in remote places. It is likely to have extremely high non-target impacts and is not suitable to Australia.

9.1) Efficacy of Snaring

Snares were used for feral pig control in a remote Hawaiian rainforest since the usual control method of hunting with dogs was not practical in the area (Anderson & Stone 1993). Hunting was not an option due to the remoteness of the area, which deterred recreational hunters, and the steep terrain, rugged lava flows and cracks in the earth were a risk for hunting dogs. Snaring was consequently used as the main management tool in conjunction with fencing, to prevent ingress of pigs from surrounding areas which would otherwise have re-colonised the area.

Snaring was found to be a useful method and complete eradication was eventually achieved. Therefore the efficacy was extremely high. However, many hundreds of snares were used (1978) with over a million snare nights (1.6 million). The area of land treated was also relatively small at 14 km^2. Snaring can also be a useful means of lowering feral pig numbers when immigration is occurring and eradication is not possible (Anderson & Stone 1993). To be successful, the home range of feral pigs must be determined or estimated in the area where snares are to be used so that snares can be included in at least part of each feral pigs range (Anderson & Stone 1993).

9.2) Control method efficiency of Snaring

Anderson & Stone (1993) researched the use of snares to control feral pigs in 2 small fenced areas of Hawaii Volcanoes National Park. They found that it took 2,580 min pig^{-1} to eradicate feral pigs from the area. No mention of the costs associated with fencing the area was made. In Australian terms (at $17/hour labour costs) assessing labour costs only, that equates to $731 pig^{-1}.

9.3) Target specificity of Snaring

Snaring is used in the USA and has been well researched in Hawaii (Anderson & Stone 1993). In Australia, the method is likely to impact on many non-target species, in contrast to Hawaii which doesn't have large, susceptible native terrestrial mammals. The target specificity in Australia is probably low, since any animal which approaches a snare is likely to be equally at risk.

9.4) Logistical Practicalities of Snaring

Snaring requires that all parts of a feral pig habitat are visited by workers to set up snares. This is logistically difficult in remote areas.

10) THE EFFECTIVENESS OF HUNTING AND HARVESTING

The efficacy of hunting and harvesting feral pigs has not been determined. In some areas the methods have markedly reduced feral pig populations, however, the efficacy of the method is reduced by deliberate introductions and decreasing returns in hunted areas. The control method efficiency of this method is high since individual land-managers often have volunteers or people who will pay to conduct hunting. However, the logistics of hunting in remote areas reduce the area of land covered by hunters. The non-target impacts have not been quantified.

10.1) Efficacy of Hunting and Harvesting

Unfortunately, research to indicate the efficacy of recreational hunting and commercial hunting at reducing feral pig populations and impacts is lacking in Australia (Choquenot et al 1996; Bryant 2004; Forsyth and Parkes 2004). Forsyth and Parkes (2004) reviewed the effect of hunting and harvesting of feral goats on conservation outcomes and could reach no conclusions. However, key areas that need to be researched to determine this effect are;

- Is the reduction associated with hunting sufficient to reduce feral goat populations to a level where conservation is improved.
- Even if this reduction is enough, how frequently should harvesting or control be imposed to sustain conservation benefits.

These points are also applicable to the effect of feral pig harvesting on conservation outcomes. Feral pig harvesting has a number of factors which affect its sustainability (Forsyth and Parkes 2004). These are mostly to do with supply (rainfall) and demand (this is affected by exchange rates, and competing exporters). Therefore the ability of feral pig harvesting to affect conservation values is unknown, but will vary depending upon the sustainability of the industry which is mostly affected by the supply of, and demand for feral pigs.

In New Zealand Clarke & Dzieciolowski (1991) showed that hunters are the principal means through which feral pig numbers are controlled. Although it is likely that recreational hunting and commercial harvesting can control pig numbers in certain areas, for example north west NSW (O'Brien 1987), there is an overall net cost to the broader community from feral pigs (Anon 2004).

In Hawaii hunting is frequently used for feral pig control. Hunting with dogs was the major method of control when eradicating feral pigs from fenced rainforest (Katahira et al 1993). Professional national parks staff used trained dogs with tracking collars. During the eradication program 175 pigs were removed with hunting responsible for 150 pigs or 86%. The remaining pigs were removed by trapping and snaring.

Feral pigs were effectively eradicated from Lord Howe Island in order to protect the Lord Howe Island Woodhen. The major control technique used was bounty hunting and wages when feral pig numbers were reduced (Miller & Mullete 1985). However, McIlroy and Salliard (1989) found that hunting was not as efficacy as poisoning with warfarin grain in Namadgi National Park. Nevertheless, they did find that hunting could be effective at removing feral pigs that could not be removed through other means, and for disease surveillance during exotic disease outbreaks.

Caley and Ottley (1995) used hunting dogs for feral pig control in the Northern Territory. They found that hunting dogs were successful at catching solitary pigs, but that success declined as the mob size of feral pigs rose. They determined that residual feral pigs could be mopped up by hunting after another control technique had been applied to an area. This is one reason that many professional kangaroo hunters carry hunting dogs.

Hunting in California has been estimated to remove at least 40% of the feral pig population annually (Waithman et al 1999). Where reserves have no hunting, feral pig densities are often extremely high. Ironically, the large increase in feral pig range over the state is probably due to pig releases by hunters (Waithman et al 1999). Similarly in Australia, feral pigs have been shown to have been deliberately translocated to new areas in the past. This was probably by feral pig hunters, in order to create a hunting resource (Hampton 2003). The NSW Game Council totally opposes actions such as these (Tony English NSW Game Council, May 2004, pers. comm., April 2004). This is a significant problem and must be considered a detraction of the method when considering the efficacy of hunting. Similarly, hunters are often after trophies and generally only target the largest boars. In theory, this can increase feral pig populations through selectively removing the largest resource consumer, thus exacerbating the impact of feral pigs on threatened species. Responsible and ethical hunters are however likely to remove all feral pigs sighted.

10.2) Control method efficiency of Hunting and Harvesting

Commercial hunters frequently are allowed access to privately owned land for feral pig hunting and trapping. In some instances they are allowed to hunt on public estate. Generally hunting by commercial harvesters is conducted free of charge to the land-manager and is a cost effective way of controlling feral pigs when viewed from the land-managers perspective. However, when it is considered from the perspective of total input costs, it may not be a cost effective means of controlling feral pigs. In addition, the philosophy of sustainable commercial harvesting opposes that of hunting as a control technique. No data is available for the input costs per pig killed by commercial hunting.

The feral pig has been estimated to cost the Agricultural community in excess of $100 million. In addition, the environmental cost and the potential cost of an exotic disease outbreak (e.g. Japanese encephalitis or Foot-and-Mouth Disease) far outweighs this yearly cost. In return the commercial harvest yields approximately $20 million to rural communities directly (Anon 2004). Indirect benefits are difficult to quantify, but must be considered when assessing the net benefit to the community. Consequently, the feral pig can legitimately be considered as a resource to some sections of the community, but it should only be considered this way in the local context. In the wider context the feral pig should be considered to be a net cost to the community (Anon 2004).

10.3) Target Specificity of Hunting and Harvesting

Provided hunters apply trapping and ground shooting responsibly, the target specificity of the method is likely to be high and non-target impacts of hunting and harvesting low. The use of hunting dogs however, can result in non-target impacts through depredations by hunting dogs and the escape of hunting dogs which can establish feral dog populations. The deliberate release of feral pigs to colonise hunting areas has occurred, probably for hunting (Hampton 2003) and could be considered a non-target impact of hunting and harvesting.

10.4) Logistical Practicalities of Hunting and Harvesting

Many land managers have found that remote feral pig populations are not controlled by hunting and harvesting (Anderson & Stone 1993; Waithmann 1999). This is probably because logistics make it difficult to reach all areas of feral pig habitat. For example recreational hunters may not have the interest or time required to travel to a remote area from their homes in urban areas. Furthermore, the highly volatile nature of the wild game industry, where dressed feral pig prices fluctuate weekly between $1.50 kg to zero for a large proportion of the year, means that gains likely achieved through harvesting are quickly reversed when feral pig ‘chiller boxes’ are closed and pigs are left to breed up until the market re-opens.

10.5) The Effectiveness Of Ground Shooting
10.5.1) Efficacy of Ground Shooting

The efficacy is low since feral pigs are a cryptic animal and difficult to locate. In addition, this method can cause dispersal of feral pigs and has been found to be generally not suitable for controlling feral pigs over large areas (Saunders & Bryant 1988). Anecdotal reports reveal that recreational shooters can sometimes kill large numbers of feral pigs. For example, 500 feral pigs were shot in northern Western Australia in 10 nights by 7 recreational shooters (L.Twigg DAWA, June 2004, pers.comm.).

10.5.2) Control method efficiency of Ground Shooting

No data exists as to the costs associated with ground shooting. Equipment (vehicles, firearms) and harvesting costs are high.

10.5.3) Target specificity of Ground Shooting

Provided it is responsibly conducted, ground shooting should be target specific.

10.5.4) Logistical Practicalities of Ground Shooting

The logistical requirement can be high, especially in remote areas, since ground access over all feral pig ranges are required.

11) THE EFFECTIVENESS OF BIOLOGICAL CONTROL

It is unlikely that biological control of feral pigs would be possible in this country due to trade barriers to the domestic industry that would be imposed following the use of a biological control pathogen.

12) THE EFFICACY OF COMBINED METHODS

In many instances control programs have utilised more than one method to reduce feral pig populations. The efficacy of such combined programs are invariably higher than the application of a single control technique. This is because a proportion of the feral pig population will not be susceptible to each control method (Choquenot et al 1996). For example, Hone (1983) used 1080 baiting which left 27% of the population remaining. A substantial proportion of the population thus didn’t take baits, and aerial shooting was required to further reduce the population. Saunders (1993) also found a significant proportion of the population didn’t come into contact with traps in Kosciusko National Park, and of the proportion which did a certain percentage (19%) were not trapped. Finally, Saunders and Bryant (1988) found that even with three control techniques (aerial shooting, ground poisoning and trapping) eradication was not possible, and may not have been even with unlimited resources.

Examples of combined feral pig control techniques include:

- ‘Operation Wild Thing’ whereby a 75-80% reduction in feral pig numbers was achieved using aerial and ground baiting followed by aerial and limited ground shooting (Anon 2002).
- Snaring and fencing to allow the eradication of feral pigs over a small area in Hawaii (Anderson & Stone 1993).
- Hunting was combined with snaring, trapping and fencing in Hawaii to produce localised eradication (Katahira et al 1993).
- Other authors have stated that aerial shooting is usefully supplemented with other control methods because economics dictate that a residual population is always left during shooting control operations (Saunders 1993).

In addition, some researchers have found that some control techniques are not effective when applied as a first line treatment for a variety of reasons. For example, Choquenot et al (1996) stated that the use of trapping may be best as a follow up treatment after other control methods have produced an initial knockdown in population numbers. Other authors have suggested that hunting with dogs is best conducted as a mop up operation since it is not effective at high pig densities (McIlroy and Salliard 1989).

An important consideration when considering the use of multiple control tools is whether the control tools should be applied simultaneously or sequentially. Sequential use is likely to be more efficient. The costs to kill individual pigs can be a useful way of assessing the order in which control methods can be applied. For example, helicopter shooting is most efficient at high feral pig densities, and an initial reduction of the feral pig population may be best achieved with aerial shooting, rather than applying this control tool last.

13) COMPARISON OF THE EFFECTIVENESS OF FERAL PIG CONTROL METHODS

13.1) Comparison of the Effectiveness of Control Methods

Method of Control	Efficacy	Control method efficiency	Target Specificity	Logistical Practicalities	Overall Effectiveness	Advantages of method	Disadvantages of method
Ground Baiting with 1080 and warfarin	**High** (Hone 1983; McIlroy et al 1989; Saunders et al 1990).	**High** (Turvey 1978; Bryant et al 1984; R. Hosie (NSW Ag, Pers. comm. 1986 quoted in Choquenot et al 1996); Korn 1986; Saunders et al 1990).	**Variable, can be high** depending on baiting strategy and toxin. (Hone & Mulligan 1982; McIlroy 1983; Hone et al 1985; McIlroy 1986; McIlroy 1989, 1993; Cremasco 2002; McIlroy 2004)	**Moderate**	**High** although the impacts of baiting on non-target populations, and strategies to reduce potential impacts may require further research.	Allows a relatively target specific control method to be applied across broad areas of land, in a cost effective manner.	Potential Non-target impacts. Road Access required.
Aerial Baiting with 1080 and biomarkers	**Moderate**, but could be **high** as future research occurs. (Clarke 1992; Mitchell 1998; Fleming et al 2000; Mitchell 2000; Mitchell 2003a; Mitchell & Kanowski 2003).	**High** (Mitchell & Kanowski 2003)	**Unknown** (could be low or high depending on baiting strategies) (Fleming et al 2000)	**High** (Clarke 1992; Mitchell 1998; Fleming et al 2000; Mitchell 2000; Mitchell 2003a; Mitchell & Kanowski 2003).	**High** in the future as further research occurs. Potentially an excellent broad-scale control method	Broad-scale control over remote and inaccessible areas.	Potential Non-target impacts and efficacy needs research and refining with baiting strategies.
Fencing	**High** (if maintained) (Hone & Atkinson 1983; Katahira et al 1993; Anderson & Stone 1993; Mitchell 2000)	**Low** (Hone & Atkinson 1983; Anderson & Stone 1993; Mitchell 2000)	**Unknown** (could be significant or low)(Mitchell 2000)	**Low**	**High** in small defined areas, **low** across larger areas or in remote areas	Allows excellent protection of small areas of land, generally where road access is present and fence can be maintained	Requires continuing maintenance and cannot be applied across large remote areas
Trapping	**Moderate to high** in localised areas (Saunders et al 1993; Choquenot et al1993; Mitchell 1998; Mitchell & Kanowski 2003).	**Low** (Mitchell & Kanowski 2003)	**High** (Choquenot et al 1996)	**Moderate**	**Moderate to high** in defined areas, unknown effectiveness as a broad-scale control method.	Can allow targeted control of feral pig populations in localised areas, generally where road access occurs.	Generally requires road access. Difficult to apply in remote areas due to high labour requirements.

Method of Control	Efficacy	Control method efficiency	Target Specificity	Logistical Practicalities	Overall Effectiveness	Advantages of method	Disadvantages of method
Aerial Shooting	**High** (in appropriate habitat) (Saunders & Bryant 1988, Hone 1990, Saunders 1993; Mitchell & Kanowski 2003).	**High** (unless eradication attempted)(Saunders & Bryant 1988, Hone 1990, Saunders 1993;Mitchell & Kanowski 2003).	**High** (Choquenot et al 1996; English & Chapple 2002).	**High**	**High** if used appropriately. Can be used for local control or as a broad-scale control method.	Allows broad-scale control over remote, difficult to access areas.	Not applicable to all habitats and expensive, particularly at low feral pig densities.
Judas Pig Method	**High** (McIlroy & Gifford 1997)	**Low** (expensive but can increase control method efficiency of other methods) (McIlroy & Gifford 1997)	**High** (McIlroy & Gifford 1997)	**Low**	**Moderate**, but not a broad-scale control method	Allows targeted control of small residual populations of feral pigs.	Expensive and requires a high level of proficiency. Not applicable to populations which have a high density.
Snaring	**Moderate to high** (Anderson & Stone 1993)	**Low** (labour intensive) (Anderson & Stone 1993)	**Depends on other species present**	**Low**	**Low** due to logistical requirements and non target impacts	Not recommended in Australia due to non-target impacts.	Non-target impacts high.
Hunting and Harvesting	**Moderate**	**High** (hunters often perform for no charge to land manager)	**High** (but could impact depending on behaviour of hunters)	**Moderate**	**Unknown**	Generally free for land manager	Deliberate releases of feral pigs, not practiced in all remote areas, unknown benefit.
Ground Shooting	**Low** (Choquenot et al 1996, Bryant 2004)	**Unknown**	**High**	**Low**	**Low**	Target specific control	Difficult in remote areas, difficult to locate feral pigs
Biological Control	**Unknown**	**Unknown**	**Unknown** (probably high, although domestic pig populations affected)	**High**	**Unknown**	Unknown, but main advantage may be self dissemination of control technique.	Impact on commercial pork industry.

13.2) Comparison of the average efficacy and average control method efficiency of different feral pig control methods using trial data reviewed in this document[3]

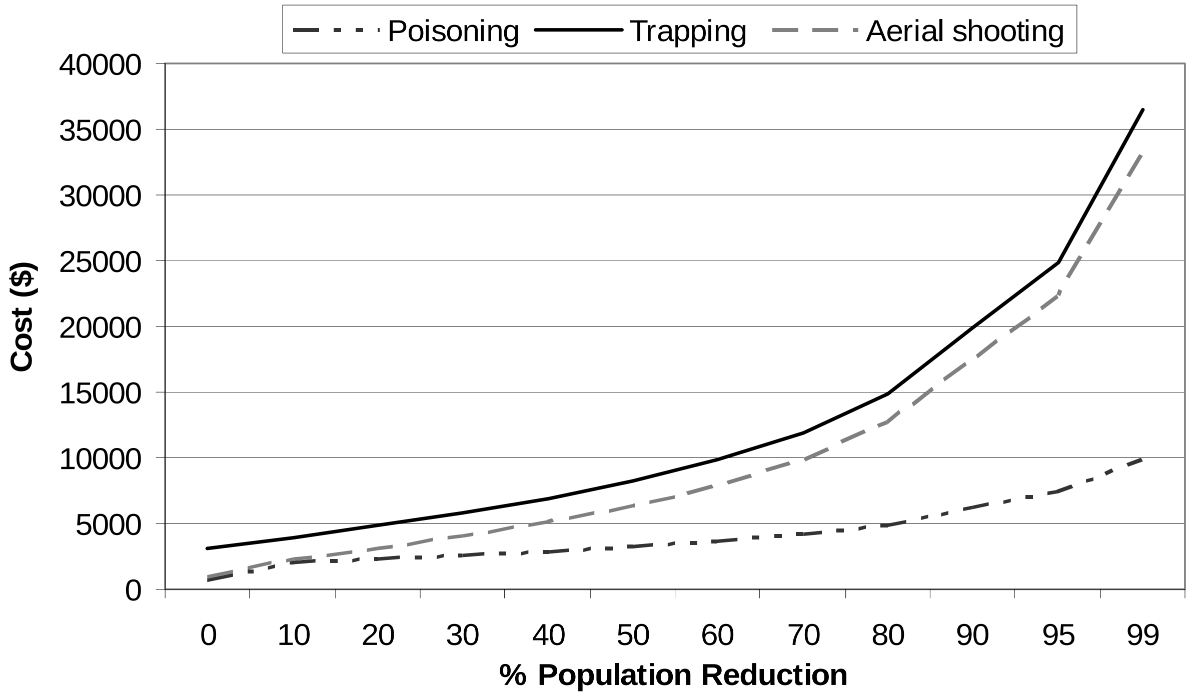
Method of Control	% Efficacy	Minutes pig^{-1}	\$ pig^{-1}
Ground Baiting	**74** (based on field trials of warfarin and 1080)	**161** (includes forested mountainous areas)	**35**
Aerial Baiting	**65**	**3.8**	**37.19**
Aerial Shooting	**72**	**2.3**	**31** (includes unfavourable trials in wooded areas and doesn't include shooter training costs)
Trapping	**73**	**283**	**77** (includes trap costs)
Snaring[4]	**100%** (with fencing to prevent immigration)	**2580**	**731** (based on labour only at \$17 hr^{-1} and excludes fencing costs)
Fencing	**N.A.**	**-**	**-**
Judas Pig Technique	**N.A.**	**-**	**-**
Biological Control	**NA**	**-**	**-**
Habitat Modification	**?**	**?**	**?**
Hunting and harvesting	**?**	**?**	**?**

[3] These figures are calculated by averaging all the figures listed under efficacy and control method efficiency in the relevant sections of this document. Therefore this comparison is only a guide, since the original figures are generated across a wide variety of landforms, with different feral pig densities (density sometimes not listed in the original literature), in different seasons and using different methodologies and may not reflect a valid comparison.
[4] Based on 1 study only (Anderson & Stone 1993)

13.3) Modelling Of The Relative Costs Between Poisoning And Trapping In Eastern NSW And Aerial Shooting In Western NSW.

The costs associated with feral pig population reductions for aerial shooting, poisoning and trapping were modelled by Saunders (1988). This was based on the level of reductions (% of feral pig population killed). Since the costs of each control method was closely linked with the time taken to reduce feral pig populations, costs could be predicted for specific population reductions. However, these predictions are only applicable to the habitat for which the data were generated, therefore only poisoning and trapping can be compared with each other. Aerial shooting data was generated in the semi-arid rangelands, and poisoning and trapping data were generated in eastern NSW.

Projected relative costs of feral pig population reductions in eastern NSW using poisoning, trapping and aerial shooting (from Saunders 1988)



14) CASE STUDIES OF FERAL PIG IMPACTS AND THE CONTROL METHODS APPLIED

14.1) Feral Pigs in Kakadu National Park

(Ann Ferguson, National Parks and Wildlife Service, June 2004, pers. comm.).

Impacts

The feral pig is thought to be impacting on Kakadu National Park. However, the impacts are anecdotal reports and have not been quantified through research. Initial steps to quantify this damage have been undertaken.

Feral pigs root up large areas of ground throughout the park in many different habitats and produce obvious signs of damage. Some of these habitats include monsoon rainforests especially around the margins of flood plains and campgrounds. This rooting is believed to lead to species composition changes, for example through weed invasion and establishment.

Traditional owners implicate feral pigs in predating nested reptile eggs, and digging for tubers of various plants such as yams which are used by traditional owners. This competition for yams is seen as a significant problem by some traditional owners. Feral pigs are also suspected of spreading mimosa (*Mimosa pigra*), and, Olive hymenachne (*Hymenachne* *amplexicaulis*) which are both invasive weeds of the riparian zone. These weeds are classified as weeds of national significance and severely impact on Kakadu National Park. Both these weed species are prevalent in areas favoured by feral pigs.

Feral pigs have also been involved in the spread of diseases such as Spargonosis and Tuberculosis in similar areas close to Kakadu. These diseases have an unknown impact on native animals, but have the potential to impact on the health of human hunters.

Feral Pig Management

During the wet season feral pigs tend to disperse throughout the region, but during the dry season areas occupied by feral pig contract around the permanent waterways. Therefore control generally occurs in the dry season so that control operations have maximum efficiency.

The occurrence of feral pigs is mapped as feral pigs are noticed and controlled in the park. Control is targeted to areas of known distribution, but preference for control efforts are given to areas of high conservation value, such as those where the distribution of rare plants and feral pigs overlap. Control is also sometimes targeted to areas identified by traditional communities as culturally significant. Furthermore, control of feral pigs also occurs around campgrounds and visitor areas.

Feral pig control operations have consisted mostly of aerial shooting. However, ground shooting, indigenous hunting and trapping are all utilised in the management of feral pigs. Traditional owners generally wish to see feral pigs controlled, although opinions vary with some traditional owners seeing them as a resource and some opposing control for local political reasons.

Aerial shooting is the most commonly utilised method of control for a number of reasons. Traditional owners and parks staff perceive aerial shooting as a benign method of control with few impacts on non-target wildlife. Aerial shooting is also less labour intensive, and more logistically possible than many other methods of feral animal control. A consultation process with the Northern Land Council (NLC) occurs before aerial shooting control operations begin. The NLC presents the National Parks Staff with a list of local people to be consulted before the action proceeds. Following this consultation with local people and approval being granted, the National Parks Staff then approaches the NLC for final permission.

In additional to aerial shooting, ground shooting is opportunistically undertaken by parks staff in the course of normal daily activities. This especially occurs during the activities of staff involved with Mimosa control. Trapping has also been utilised to a limited extent by staff, especially around campgrounds. However, the method is labour intensive and is therefore a drain on the parks limited resources. Traditional hunting also occurs but only small numbers of feral pigs are removed in this manner.

Ground baiting and aerial baiting have not been conducted since they are seen as not target specific by National Parks Staff and traditional owners. The use of toxins would likely be strongly opposed by traditional owners. In addition, it is unknown whether bait uptake would be high as during most years large amounts of food are available for feral pigs.

Recreational Hunting has not been utilised as a control method. However, a combined application has been made by some traditional owners and a nearby cattle station to conduct recreational shooting in the western part of the National Park. The cattle station currently conducts recreational shooting as part of a game hunting business. However, concerns about the use of firearms in the National Park, the spread of invasive weeds by hunters and the actual effectiveness of recreational shooting are potential reasons that the application may not proceed. Some people involved in the management of the park believe that the involvement of recreational hunters may change the perception of the feral pig from being a pest to a being a resource, which may decrease the desire to control feral pig populations.

The Judas Pig technique may be used in the future to target feral pig populations. However, the level of funding likely to be available for this method would reduce the methods effectiveness since only a few tracking collars could be purchased with the funds available.

Need to Manage Feral Pig Populations in Kakadu National Park

Two main issues inhibit the effective control of feral pigs in Kakadu NP; the lack of consensus by traditional owners for feral pig control, and the inability to control all feral pigs in all habitats. Other impediments to feral pig control are the lack of reliable knowledge of the actual impacts of feral pigs, and the density at which impacts are unacceptable.

- Consensus by indigenous owners is a major impediment to feral pig control, although generally indigenous owners believe that feral pigs should be controlled.

Some communities believe that the feral pig is a valuable harvestable resource. The availability of feral animals as a food source was identified as an issue during the Bovine Brucellosis and Tuberculosis Eradication Campaigns over recent decades (BTEC). In order to facilitate the eradication of swamp buffalo (*Bubalis bubalis)* authorities needed to preserve the availability of buffalo meat for indigenous people who valued this as a harvestable resource. Thus a 500 km^2 section of the park was fenced and is now run as a 'buffalo farm' and the meat is periodically distributed to local indigenous people. This allowed the control of feral buffalo populations in the wider park since a harvestable resource was still available to indigenous people.

Most indigenous communities are in favour of feral pig control because of the impacts on native wildlife and harvestable wild foods (such as yams). Other communities oppose certain control methods such as baiting due to the perceived impacts of the control method on the environment (non-target wildlife impacts) and harvestable resources (e.g. toxic residues in feral pigs). The Charles Darwin University in Darwin is attempting to address this issue by establishing a feral animal strategy for Kakadu National Park. This strategy has been researched for over three years now with the involvement of anthropologists, ecologists and local indigenous people. The aim is to produce decision making tools for indigenous people on the management of feral animals in the park.

- Feral pig control is likely to be of only short term and localised benefit in the park due to the inability to control all feral pigs in all habitats.

Feral pigs tend to increase rapidly in controlled areas following feral pig control efforts since remnant populations rapidly breed during good seasons and non-controlled populations rapidly immigrate to controlled areas. Some of this immigration is probably from non-controlled areas outside the park.

Feral pigs cannot be controlled over the entire park (20 000 km^2) at any one time because of problems with resourcing levels, logistics, traditional owner consent and the effectiveness of control methods (aerial shooting). The gains can however be significant in localised areas if control is sustained. The ability to deliver an additional effective, cheap and easily applied control method across the landscape, such as aerial baiting with a pig-specific bait package may improve the control of feral pigs. However, the use of aerial baiting would be opposed by indigenous owners unless the method was demonstrably target specific and didn't produce environmental contamination. Non-target species of concern during baiting campaigns could include dingos (*Canis lupus dingo*), the northern quoll *(Dasyurus hallucatus*; although numbers have declined markedly since the immigration of the cane toad) and other small dasyurids (although the use is probably safe if harder baits are used) if a meat based bait was used and various birds and herbivores if a grain based bait was used.

- The knowledge of the true environmental impacts of feral pigs, compared with obvious signs of damage is unknown.

This knowledge would allow justification of feral pig control and would also allow the level of control needed to reduce the environmental impacts of feral pigs to be determined.

14.2) Kroombit Tinkerfrog

Status

The Kroombit Tinkerfrog (*Taudactylus pleione*) is a critically endangered frog (IUCN) and is classified as endangered in Queensland and vulnerable by the Commonwealth (the Commonwealth is to review the species status soon) (John Clarke QPWS, May 2004, pers. comm.). Surveys during the Central Queensland Threatened Frogs Project have indicated that between 75 and 300 individuals remain in Kroombit National park (south-eastern Queensland), which is the only known location of the species (John Clarke QPWS, May 2004, pers. comm.). Certainly less than 500 individuals remain. The surveys are designed to monitor frog population trends since rapid declines in many frog species have occurred in recent years (Hines et al 2002).

Habitat

The Kroombit Tinker frog is a small, ground dwelling frog, which has been recorded in small narrow patches of isolated gully rainforest associated with permanent or ephemeral water sources (Hines et al 2002).

Threatening Processes

This species has been surveyed since 1996 and there has been a dramatic decline in the population since then. The cause of the decline is unknown, but other species at the same site did not decline during the same time period (QPWS 2003). However, there has been a major decline in many frog species in southern Queensland during recent years.

Threatening processes are suspected to include the unknown causal agents responsible for the decline or disappearance of several species of frogs, including 4 of the 6 taudactylus species in Queensland over the last 15 years. A possible cause is the chytrid fungus (a severely pathogenic fungus of native frogs) which has been found in dead frogs during frog declines (Hines et al 2002). Although considerable research and management is required to alleviate the regional declines associated with the possible major causal agent, local threatening processes still need to be managed (Hines 2002). These threatening processes probably include the trampling and altered hydrology associated with exotic ungulates (feral pigs, horses and cattle), increased sedimentation due to this grazing and habitat destruction and predation by feral pigs (QPWS 2003).

Feral Pigs as Threatening Process

It is strongly believed that feral pigs could predate frogs and alter habitat within the range of the Kroombit Tinker frog. It is believed that the biggest impact by feral pigs is habitat damage, leading to increased sedimentation. Increased silt is likely to decrease the survivability of embryos and tadpoles, since silt decreases the available food and reduces their fitness at metamorphosis (Hines et al 2002). Disturbance by feral pigs is also likely to increase the spread of riparian weeds such as mistflower and Crofton weed which may impact on frog habitat (Hines et al 2002). Feral pigs are in high numbers and are impacting on the habitat of the Kroombit Tinkerfrog in at least two sites that the frog is present in (Hines et al 2002).

Feral pigs only arrived in the Kroombit tops recently after travelling up creek beds from the lower elevation areas around the national park. The feral pigs selectively forage in wet areas, and are also believed to destroy the burrows in which frogs shelter (John Clarke QPWS, May 2004 pers. comm.). It is also suspected that chytrid fungus, which has recently been isolated in the national park, may even be spread by feral pigs when they travel from watercourse to watercourse (John Clark QPWS, May 2004 pers. comm.).

In order to quantify the impact that feral pigs may be having on the Kroombit Tinker frog, opportunistic sampling of feral pig damage along waterways has occurred during annual frog surveys. A subjective score has been recorded but these results are incomplete and have yet to be analysed (John Clarke QPWS, May 2004 pers. comm.). This simple feral pig damage measure is important to seek to quantify the impact that feral pigs may be having on frog populations.

Feral Pig Impact Management

Without a measure of feral pig abundance (generating an index of abundance is difficult due to the landscape, no open areas, few roads etc; John Clarke QPWS, May 2004 pers. comm.) linked to feral pig habitat damage of the Kroombit Tinker frog, a strategic management plan tis difficult to develop. In the interim, feral pig management consists of feral pig density reduction using trapping. However, replicated experiments with and without pig control could yield some valuable data

Feral pig control methods which have been considered in the park include poisoning, trapping and shooting. Aerial shooting is not possible due to the rugged nature of the park, and aerial baiting with meat baits is not favoured due to non-target impacts such as those which may occur on the small population of quolls in the park (John Clarke QPWS, May 2004 pers. comm.). Furthermore, poisoning was discarded as a method of control since grain free feeding indicated poor bait uptake by feral pigs. In addition, management of poison control operations is difficult since QPWS staff are reliant on Qld Dep. NRME staff for toxic baiting (John Clarke QPWS, May 2004 pers. comm.).

Fencing has been attempted in small defined areas of the national park to exclude feral animals from areas which contained the Kroombit Tinker frog. However, this method has not been successful in the long term due to falling trees damaging fences and lack of resources to maintain damaged fences (Hines et al 2002).

Trapping has seen large reductions in feral pig numbers, based on the numbers of feral pigs removed. However, damage along waterways is still higher than desired in the park, and addition of extra control options, such as opportunistic ground shooting will need to be considered in the future (John Clarke QPWS, May 2004 pers. comm.).

Control activities are difficult to target to all areas within the park because many areas within the park are inaccessible by road. The cooperation of neighbours is being sought to increase the area of landscape being treated. However, it is unlikely that all feral pig ranges will be reached during trapping campaigns (John Clarke QPWS, May 2004, pers. comm.).

Need of a campaign to reduce feral pig damage to the Kroombit Tinker frog

- A measure of feral pig density is required so that feral pig numbers can be linked with their environmental impact. This would allow the development of a strategic control program.

This program has excellent on the ground resources through the involvement of volunteers every year during the annual frog surveys. Therefore, resources should not really limit this aspect of a future campaign. However, the knowledge and resources to generate an on the ground abundance index will require considerable staff involvement. The cost of protecting and managing all frog species habitat within the region has been budgeted at $280 000 over the course of the 5 year recovery plan. These actions consist of assessing the impact of weeds, controlling feral pigs and other pests (other feral stock, introduced fish), managing giant barred-frog on private land and providing advice to landholders on private land. Other essential components in the recovery planning process for frogs in the area amount to a budgeted $1,002,000. This budget demonstrates that recovery plan implementation is an expensive process. Thus when recourses are scarce, land managers tend to spend scarce resources on the application of feral pig control operations rather than monitoring.

- A control method or strategy which can be applied across the entire landscape to allow a sustained lowering of feral pig numbers is required. Some steps are being taken in this regard by attempting to increase the management area being treated for feral pigs by involving neighbours. However areas within the park are still not being treated due to inaccessibility.

14.3) Eastern Bristlebird

Status

The northern population of the Eastern bristlebird (*Dasyornis brachypterus monoides*) is critically endangered in Queensland. The species is listed as endangered under the Commonwealth Environmental Protection and Biodiversity Conservation Act 1999 and the NSW Threatened Species Conservation Act 1995 (Stewart 2002). Less than 50 birds remain in 12 small scattered colonies in south-east Queensland and northern NSW (Stewart 2002).

Habitat

Eastern bristlebirds are usually found in small colonies in open woodland areas which are typically either interspersed or adjacent to luxuriant rainforests (Holmes 1989; Rohweder 1999 quoted in Stewart 2002). The ground stratum usually has diverse structural features, with common components including tussock grasses, particularly mature wild sorghum (*Sorghum leiocladum*), kangaroo grass (*Themeda australis*), blady grass (*Imperata cylindrica*), scattered small shrubs, logs, patches of tall ferns, woody herbs and/or tangled vines (Holmes 1989; Rohweder 2000). Eastern bristlebirds nest on the ground, in August and September, constructing nests among grass tussocks (for example sorghum tussocks) (Stewart 2001).

Threatening Processes (Ritter ND)

There are a number of factors that may threaten the grassy woodland habitat of the Eastern Bristlebird, and the bird itself:

- inappropriate fire regimes (this has been identified as the major threatening process; David Stewart, QPWS, May 2004, pers. comm.),
- weed proliferation,
- grazing,
- damage by livestock and feral animals,
- predation, and
- disturbance by humans.

These threats can be magnified by the ground nesting nature, poor flight and limited dispersal capabilities of the Eastern Bristlebird.

Feral Pig as a Threatening Process

Grazing livestock and feral animals, such as pigs, deer and cattle, can disturb the understorey by trampling and uprooting grasses. Furthermore, they may disturb birds during breeding (Stewart 2002) and contribute to the distribution of exotic plants (Holmes 1989 quoted in Stewart 2002). Generally feral pigs tend to impact on the Eastern Bristlebird during dry times, when they tend to disperse from waterways and travel up into the montane open forest with grassy under-stories (especially wild sorghum) where the Eastern Bristlebird is found (David Stewart QPWS, May 2004, pers. comm.). Feral pig damage varies from rooting in the softer soiled areas to clearing considerable areas of the Eastern Bristlebird's habitat by turning over tussocks of sorghum (David Stewart QPWS, May 2004, pers. comm.). This damage is often obvious for years after the feral pig has left. The potential also exists for feral pigs to predate Eastern Bristlebird eggs and chicks. Damage to the habitat by feral pigs which uproot the grassy vegetation and create tracks through the bristlebird habitat has been observed specifically in the Conondale Range population (Stewart 2002). Unfortunately, the QPWS is not in a position to study the impact of feral pigs on Eastern Bristlebird populations (David Stewart QPWS, May 2004, pers. comm.).

Feral Pig Management

Feral pig control measures have been introduced at the Cannondale range population and have included baiting with 1080 and trapping by commercial trappers on a retainer from the QPWS. The success of trapping has been compromised by damage to traps by other pig hunters (David Stewart QPWS, May 2004, pers. comm.), and by suspected deliberate feral pig releases in the area by hunters in order to obtain a feral pig population for hunting close to Brisbane (David Stewart QPWS, May 2004, pers. comm.). Therefore a feral pig problem will always exist in the area, since eradication is not feasible.

The success of feral pig control programs has been difficult to judge due to complications in assessing feral pig numbers in the area. Difficulties arise because of the extended land area over which the feral pig populations are found and the mobility of feral pigs (David Stewart QPWS, May 2004, pers. comm.). Generally, however, Eastern Bristlebird numbers have continued to decline (David Stewart QPWS, May 2004, pers. comm.). This decline is likely to be a combination of threatening processes outside the control of QPWS (e.g. drought and fire), although it is unknown which threatening process have contributed (David Stewart QPWS, May 2004, pers. comm.).

Other actions have included fencing of known Eastern Bristlebird habitat and nearby possible habitat to remove grazing stock (Stewart 2001). However, this fencing wasn't constructed at the Cannondale range where feral pigs are believed to be impacting on feral pigs. The reason for this was that the fence would be continually breached by falling trees. Staffing levels are too low to allow the constant maintenance that would be required to retain the integrity of the fence (David Stewart QPWS, June 2004, pers. comm.).

Need to Manage the Impacts of Feral Pigs on Eastern Bristlebirds

- An improved knowledge of the impacts of feral pigs on Eastern Bristlebirds is essential. This would need to be translated into simple, cost effective 'on the ground' measures of damage for field staff to assess. However, the scarce funds available are being funnelled into fire management, the major threatening process which affects the Eastern Bristlebird. To generate this knowledge would require increased funding. Currently, feral animal control and site management is budgeted to cost $176 000 over the course of the five year recovery plan.
- A robust 'on ground' measure of feral pig abundance to allow estimation of feral pig densities is required. This would allow auditing of feral pig control operations and to allow linking between abundance and damage/impact.
- An improved control method or control strategy is desirable, and funding which would allow more effective control of feral pig populations over larger management units.

14.4) Feral Pig Populations in South-West Western Australia

Feral Pigs in South-West Western Australia.

Recent molecular ecology studies have revealed that feral pigs in south west Western Australia are a series of discrete, isolated populations confined to water catchments (Hampton 2003).

Molecular Ecology

- What is molecular ecology?

Molecular ecology is the use of genetic variation to guide and assist the demographic studies of populations (Bergman and Lindenmayer 1998). A strength of molecular ecology has been its ability to complement field based ecology studies to gain information about population parameters of species which would otherwise be unobtainable using traditional methods (Hampton 2003; Hampton et al 2004). Molecular ecology can provide valuable data on the effective population size, relatedness and breeding systems of animal populations (Neigel 1996).

- Molecular ecology applied to feral pigs.

Molecular ecology is a relatively new study tool to the field of pest animal management, and compliments existing tools such as behavioural observations, mark-recapture and radio-telemetry. It has been included in this report due to its current application to feral pig management in Australia. While not a control technique by itself, it can be combined with existing management techniques discussed in this report to elucidate, evaluate and refine feral pig management tools, techniques and practices.

Information about long distance movement patterns, social organization and interactions among feral pig groups can be exceedingly difficult to attain using traditional methods (Sarre et al 2000; Taylor et al 2000). In feral pigs, 14 highly variable micro-satellite loci can be measured in tissue samples to allow the genetic variation of individual pigs to be determined (Hampton 2003). This information can be used to determine the relatedness of individual pigs, from which various population parameters can be extrapolated such as origin, dispersal, immigration/emigration and levels of population intermixing.

This approach was recently applied by Hampton et al (2004) in the south west of Western Australia. In this area it was determined through a molecular ecology approach that feral pigs were generally occurring in highly discrete, partially inbred, sedentary populations that tended to disperse along water catchments. Little contact occurred between pigs in separate catchments. Thus, control efforts should be based on water catchment management units rather than on arbitrarily assigned management units. The study also demonstrated that a small number of populations were acting as sites from which re-colonisation of control areas were occurring. Consequently a recommendation that the efficiency of control could be improved by controlling these populations first could be made. Other significant information gained from the study was evidence of illegal dumping of feral pigs.

Feral Pig Impacts

Feral Pigs are known to impact directly or indirectly on a large range of native plants and animals in Western Australia (Peter Mawson, CALM WA, May 2004, pers. comm.).

Feral Pig Management

Feral pig management on the Department of Conservation and Land Management estate in Western Australia has mostly consisted of trapping and ground shooting. The adoption of ground poisoning with 1080 is however likely to occur in the future, since this is a more effective method of feral pig control (Peter Mawson, CALM WA, May 2004, pers. comm.). The Department of Conservation WA is currently reviewing feral pig management.

Molecular studies (Hampton 2003; Hampton et al 2004) reveal that a number of the discrete feral pig populations in south west WA consist of genetically bottlenecked populations. This bottlenecking has occurred where considerable feral animal control has occurred. In addition, these populations are generally discrete and have a low level of migration between catchments (except where deliberate introductions have occurred, probably by irresponsible hunters). Thus, the application of increased feral animal control operations, and the continued policing of illegal translocation of pigs, may allow the localised eradication of some feral pig populations from south west Western Australia.

Needs for Control of Feral Pig Impacts in South-West WA

- The use of 1080 baiting campaigns with appropriate baiting strategies to reduce non-target impacts.

The Department of Agriculture, Western Australia, with the support of the National Feral Animal Control Program funds administered by the Bureau of Rural Sciences is currently investigating baiting strategies for feral pigs. This research is being conducted in a range of habitats across the State, including the agricultural and pastoral regions. It is mainly concerned with identifying the most accepted and efficacious bait and baiting method for controlling feral pigs. With some localised differences, cereal grains and lupins have all proven effective in eradicating localised populations of feral pigs.

- Policing of feral pig ‘dumping’.

14.5) Melville Island Feral Pig Eradication

(Keith Saalfeld, NTPWC, May 2004, pers. comm.).

Current Management of Feral Pigs in the Northern Territory (NT).

Currently feral pigs are only receiving limited control efforts by the Northern Territory Parks and Wildlife Commission (NTPWC). Trapping is the main method of control used by the Commission, but ground shooting (with limited use of the Judas pig technique) and contracted commercial feral pig harvesters (generally with dogs or traps) are used to control feral pigs. Limited shooting by recreational shooters occurs. The NTPWC provide technical advice to landholders wishing to carry out feral pig control and will provide further involvement in certain situations where biodiversity is affected by feral pigs. Little is known about the direct impact of feral pigs on conservation values, and a need exists to establish a link between feral pig densities and damage, so that management decisions can be made in the future. Funding will be sought in the future to attempt to quantify this relationship.

Impact of Feral Pigs on Melville Island

Feral pigs have recently become established in pockets on Melville Island and an urgent need exists to eradicate these populations before they become established over the entire island. Melville Island is home to endangered ecological plant communities and it is possible that feral pigs will impact negatively on these communities if they become established. It is believed that feral pigs were deliberately introduced onto the island.

Feral Pig Management

Feral pigs were deliberately introduced onto Melville Island despite strict import restrictions on pigs. Pigs are required to be sterilised by the Tiwi land council before importation. The local people on Melville Island have gone to considerable lengths to exclude feral pigs and consider the current outbreak to be unacceptable. The NTPWC is working with the Tiwi Land Council to develop an eradication campaign.

Melville Island is an exception to the rest of the NTPWC managed lands in the NT where feral pigs only receive limited attention. It is anticipated that funding will be obtained through Commonwealth schemes and that some useful research can be conducted as feral pigs are hopefully eradicated from the island during a well resourced feral pig control operation. Local people will be involved with on ground control operations, such as trapping and ground baiting.

Trapping will be carried out by local Tiwi island rangers and will continue until numbers of trappable feral pigs begin to decline. Ground baiting will then occur using yellow phosphorus, which is registered for use on feral pigs in the NT. The NTPWC has chosen yellow phosphorus for a number of reasons.

- *Yellow Phosphorus is currently registered.* The availability of a registered toxin will allow a control program to be instigated faster and will also allow a more streamlined process of control.
- *Target specificity advantages.* The NTPWC believes that the use of yellow phosphorus carries a lower non-target risk than warfarin. NTPWC believes that the use of Warfarin in grain would place macropods at risk which could result in resistance to control efforts by indigenous people. Indigenous people utilise macropods as a food source and warfarin may pose a secondary poisoning risk to local people.
- *1080 is not registered.* Registration would need to occur before 1080 could be used.

The feral pigs are located in a difficult to access area with dense vine thickets, so aerial survey and aerial shooting is not a possibility. Recently during aerial surveys, only 1 feral pig was seen despite evidence of feral pigs on the ground.

Needs to Manage the Impacts of Feral Pigs

- Knowledge of the relative risks of various toxins based on research. Currently no data exists on the non-target impacts of yellow phosphorus (McIlroy 2004). However, it is believed that the risks to non-target species may be high (Hone & Mulligan 1982).
- The development of baiting strategies to reduce non-target uptake.
- The application of a withholding period following toxic baiting programs to prevent accidental poisoning of indigenous people.

Registration of additional toxins for feral pig control (e.g. 1080).

14.6) Feral Pig Impacts on the Cinnamon Sun Orchid

Status
Critically Endangered (Phillimore et al 1999).

Habitat
Thelymitra mangineom was confirmed from two populations north east of Perth, where it is confined to open wandoo woodland on red/brown sandy loam associated with dolerite and granite outcropping. The associated vegetation consists of *Eucalyptus wandoo, E. accedens* and *E. calophylla,* over low scrub of *Acacia pulchella, A. saligna, Calothamnus quadrifidus, Melaleuca radula* and *Hakea lissocarpha* (Phillimore et al 1999). Generally, the species occurs in moist soils below granite outcrops where runoff from rainfall occurs which is also preferred feral pig habitat (A. Brown , WA CALM, June 2004, pers.comm.).

Threatening Processes (Phillimore et al 1999)
Grazing - digging up of tubers (possibly by bandicoots)
Road and firebreak maintenance activities Inappropriate fire regimes
Weed invasion
Feral pig activity
Trampling by visitors and picking of flowers.

Feral Pigs as a Threatening Process
Feral pig activity has been observed in the area of a number of populations. As well as grazing the orchids themselves, pigs can destroy the underground tubers of the orchid and also affect the growth of symbiotic fungi that are essential for germination and to providing starches for the plant (Hoffman and Brown 1992).

Management of Feral Pig Impacts
Management has included baiting campaigns which have been largely unsuccessful due to rapid immigration from surrounding, non-controlled areas (A. Brown WA CALM, June 2004, pers.comm.).
Another management activity which has proved to be successful is the laying of weldmesh (A. Brown WA CALM, June 2004, pers.comm.). The orchids are isolated to a number of small areas below granite outcrops. Weldmesh was placed over the populations of orchids to prevent feral pigs from digging in the areas and damaging the plants. Before the weldmesh was placed no orchids were evident following intense feral pig activity over the preceding years. However, within two years the orchids in weldmesh areas had recovered to levels seen before feral pig impacts were monitored. A potential disadvantage of this method is that the orchid is only protected in areas where weldmesh is laid.

Needs to Reduce The Impact of Feral Pigs
Coordinated feral pig baiting programs and adequate resources.

15) GAPS IN KNOWLEDGE AND RECOMMENDATIONS FOR FUTURE RESEARCH TO ADDRESS THE GAPS IN KNOWLEDGE[5]

Gaps in our knowledge of feral pig management which currently reduces the effective management and application of feral pig control methods for conservation outcomes.

1. The impacts of feral pig populations on ecosystems*.

Almost invariably, in all states and territories of Australia, feral pig managers and field staff in conservation bodies had a lack of knowledge about the impacts of feral pigs on local ecosystems during an extensive targeted phone and email survey of staff involved in feral pig management (B. Cowled, unpublished data, 2004). This was mostly due to a lack of resources needed to carry out creditable ecological research in areas of potential feral pig impact. It also partially results from the difficulty in clearly identifying cause and effect. Most staff had witnessed damage, but knowledge of the potential population impacts on susceptible species by feral pigs was deficient. This information is needed to allow the determination of which feral pig control methods are effective. There are only a few examples of research detailing the impact of feral pigs on conservation values (Braysher 2004).

Research to investigate the actual impacts of feral pigs on natural resources, especially threatened species or ecological communities*.

This research should initially focus on nationally listed threatened species and ecological communities. Where possible, projects should be designed to allow extrapolation between similar habitats in order to maximise the value of such research. Research should also trial the effectiveness of different feral pig control methods in reducing the impact to ensure that such methods do actually reverse the damage to the species or community in question. A practical research approach during feral pig control programs would be to monitor the following parameters;

- reduction of feral pig impact
- the resources expended
- the reduction in feral pig population (indices or abundance estimates)

This may allow the generation of a relationship between feral pig density and damage and allow the costs of a control program to be determined.

2. The relationship between feral pig population densities and the level of impact on conservation.*

This information is required to allow the appropriate level of feral pig control to reduce the impacts by feral pigs (Choquenot et al 1996). The knowledge of desirable feral pig density reductions will affect the method of feral pig control that is effective in any given situation.

Research to establish a relationship between feral pig population densities and the level of impacts on conservation outcomes.*

This may allow the determination of the optimum level to which feral pigs are required to be reduced in order to reduce feral pig conservation impacts to acceptable levels. This research should occur in areas where feral pigs are likely to impact on conservation outcomes and where feral pig impacts can be extrapolated to other areas within the country.

[5] Priority areas are identified with an *

3. Feral pig populations fluctuate in many areas of Australia due mainly to variable climatic conditions. Complex trophic relationships between pests and resources can exist.

The knowledge of when feral pig populations are most effectively controlled in relation to climatic variability can form best practice management recommendations for a local region.

Research, such as population modelling in each habitat could identify when feral pig populations are most effectively controlled. Research with interactive pest and resource models can predict when pest thresholds are reached which allow minimal costs to be expended on control in addition to maintaining conservation values.

4. The knowledge of how to estimate on ground feral pig damage to susceptible populations*

New, easily applicable damage measures for conservation managers to utilise 'on ground' will allow auditing of feral pig control programs, the knowledge of when feral pig populations are impacting on resources and the knowledge of when feral pig control programs should begin. This will maximise the effectiveness of feral pig control methods.

Research to develop simple on ground feral pig conservation damage indices*

5. The knowledge of which feral pig populations can undergo local eradication and which combination of control methods, abundance indices, damage indices and monitoring can most effectively help achieve this.

Research to show whether localised mainland eradication is possible and feasible with current resources, and which combination of control methods and monitoring could be best at achieving this.

Gaps in our knowledge of feral pig control methods which reduce the effective management of feral pig populations for conservation outcome.

6. The <u>use</u> of easily applied measures of feral pig population size.

The use of appropriate indices of feral pig activity or estimates of abundance by on the ground conservation and land managers will improve the management of feral pig populations.

7. The actual non-target impacts of various control methods.*

The population impacts on non-target species during many feral pig control methods, especially aerial baiting and ground baiting with 1080, warfarin and yellow phosphorus have not been researched conclusively. The non-target impacts of other control methods such as fencing, hunting and harvesting have also not been researched.

Research to investigate the actual non-target impacts of various control methods for feral pigs on potentially susceptible native animal populations.*

The impact of feral pig control methods on non-target populations will affect the efficacy of a feral pig control method for conservation of natural resources. Little research has occurred into the actual non-target population impact of toxins (especially at the current level that toxins are used at) used for feral pig control. This knowledge is especially deficient for yellow phosphorus and warfarin.

8. The costs of applying the various control methods across different habitats.*

Only a small amount of research assessing a limited number of control methods over dissimilar habitats has occurred. It is not possible with current information to compare control methods definitively with a cost per hectare of feral pigs controlled.

Research into the costs of applying the various control methods across different habitats.*

The relative costs of different control methods determine how often and over which area the control method can be applied across the landscape. Few studies have compared costs across landscapes using a standardised methodology. This knowledge is essential to allow the strategic planning of feral pig control programs.

A cost minimisation or benefit maximisation approach may allow the use of the most cost effective control programs, even if the economic costs of feral pig impacts on the environment are difficult to generate.

9. The knowledge of which methods of control are likely to allow effective broad-scale control of feral pig populations.*

Effective broad-scale feral pig control methods will allow feral pig populations and their impacts to be controlled over large management units (Bryant 2004). For example, trapping is utilised as a major means of control in many areas, but this is having an unknown effect on widespread populations (Bryant 2004). Aerial baiting has the potential to deliver feral pig control across broad and remote land areas (Bryant 2004). However, the baiting strategies to allow an efficacious and target specific baiting campaign have yet to be elucidated for all key situations, particularly areas with poor accessibility.

Research to develop broad-scale control methods for feral pig populations.*

The application of an effective and feral pig-targeted broad-scale means of feral pig control to areas of high conservation impact is potentially the greatest means of controlling feral pig impacts on the environment. Currently aerial shooting is the only effective means of broad-scale control of feral pigs on conservation estate. Ground baiting and trapping may allow broad-scale control over areas where road access occurs. Aerial baiting is a potentially alternative means of delivering effective feral pig control if it can be made more target specific.

The target specificity of aerial baiting and the ability of the method to improve conservation outcomes still requires research. Currently the Qld Dep. Of N.R.M.E are conducting a long term research program into aerial baiting in north Queensland (Jim Mitchell Pers. Com. August 2004). The Pest Animal Control Cooperative Research Centre is developing a manufactured feral pig-targeted bait for aerial and ground delivery.

10. The knowledge of whether the use of a ‘take home’ feral pig control toxin (yellow phosphorus) by private land managers can improve conservation outcomes.

Does the use of yellow phosphorus by private land managers improve conservation outcomes? Currently yellow phosphorus is being reviewed by the APVMA. If this feral pig control method was lost to private land managers, is an alternative ‘take home’ toxin required for conservation.

Research to investigate the effectiveness of ‘take home’ feral pig toxins (yellow phosphorus) for improving conservation on private estate.

11. Knowledge of the effectiveness of additional means of feral pig control.*

Additional means of control may improve our ability to control feral pig populations. The development of additional toxins, alternative baiting strategies and completely different control methods (such as immuno-contraception or shape recognition traps) may allow additional humane, efficacious, cost effective or target specific control methods to be applied to feral pig populations.

Researching the effectiveness of additional methods of feral pig control.*
Additional means of controlling feral pigs are being researched. However, the applicability of these methods to conservation protection are currently unknown.

- **Immunocontraception**

Currently the USDA has developed a long acting mammalian immunocontraceptive that induces long term infertility in feral pigs following a single injection. The next stage is the transition to an orally delivered version of the vaccine, which is expected to occur by 2006.

It is unknown how effective an orally delivered immunocontraceptive would be for managing feral pig populations, but this tool would not be likely to replace lethal means of control where they are available. It may be effective as a follow up means of control to induce long lasting infertility in remnant populations of feral pigs or to control feral pig populations in areas where lethal control could not be justified (urban fringes etc). This is the tool considered most likely to control feral pig populations in the U.K. (G. Massei-Smith Central Science Laboratories, March 2004, pers. comm.) and could be a major method of control in the U.S.A. (L. Miller USDA, March 2004, pers. comm.). However, both these countries do not utilise toxic baiting.

- **Additional toxins**

Additional toxins may be useful in the development of feral pig baiting practices if they are shown to be target specific, humane and affordable (Fleming et al 2000; McIlroy 2004). The PAC CRC will conduct a feral pig Achilles heel review in 2005 to attempt to identify potential new toxins for feral pig management. The Qld Dep. NRM&E is also currently researching a number of additional toxins such as cyanide and 'one shot warfarin'.

- **Shape Recognition Traps**

These traps are computer aided and differentially trap different animals based on body shape. These are currently being trialled for use around waterholes in the semi-arid rangelands of eastern Australia (N.Finch May 2004, Uni.Q., pers. comm.).

12. Knowledge of feral pig impacts, control and research by on-ground conservation managers.

A partnership between scientific staff and land managers can allow relevant, targeted research to occur which can improve the conservation outcomes of feral pig management. An example of a successful partnership between researchers and conservation managers is the management of feral pigs in Namadgi National Park. A long history of research into the impacts, and management of feral pigs in the park by researchers has improved feral pig control programs within the park.

Research links between land-managers and feral animal researchers should be fostered.
This can improve the information available to conservation managers to make decisions on feral pig control.

13. The knowledge of how best to apply multiple control methods in control programs.*
The use of multiple and integrated control methods has been advocated to increase the efficacy of feral pig control operations. However, there are many different combinations of control methods and these methods can be applied at varying intensities and in different orders. It is unknown which combinations of methods and efforts will produce the greatest conservation outcomes in the most effective way. The optimal combinations will vary across

space and time, and will depend on the impact that feral pigs are causing at different densities. However, research may reveal how best to apply integrated control programs.

The knowledge of how best to apply multiple control methods in single control programs.*

Research should be pursued to investigate how multiple control methods should be effectively applied during control operations.

14. Need to develop mechanisms to improve the coordination of pest animal management programs across *all* relevant land tenures and interest groups.

Pest animals do not ‘respect’ property and jurisdictional boundaries.

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18) Appendix 1. *A GIS generated map of feral pig distribution and some threatened species potentially impacted by feral pigs in NSW.*

Figure 1. Feral pig density distribution and the distribution of the Black Breasted Button Quail

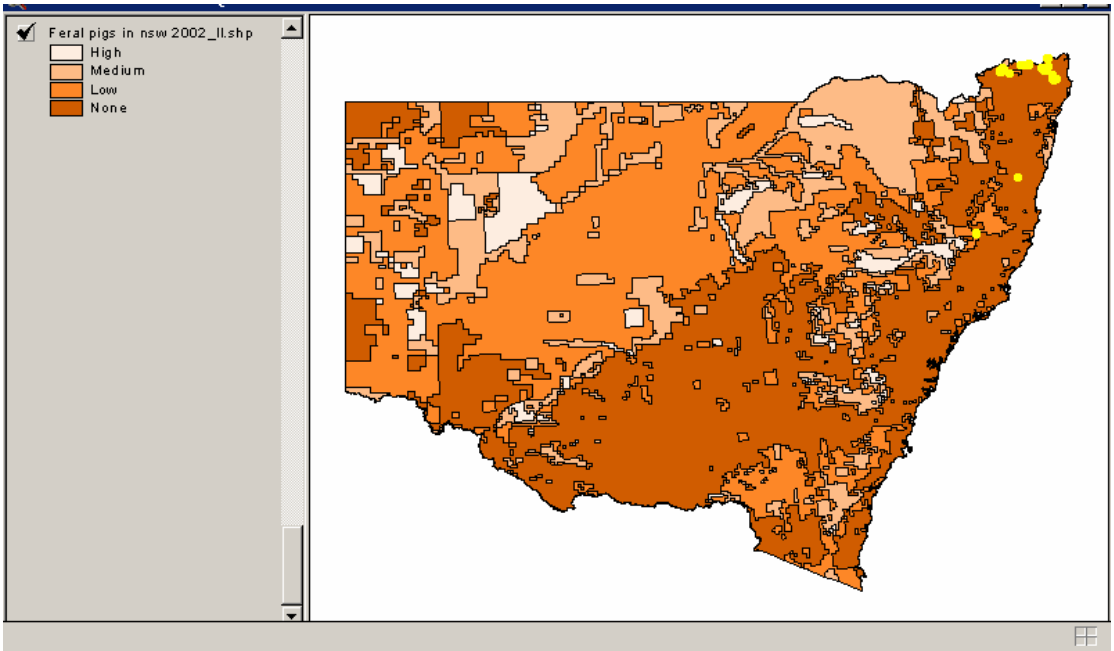

Figure 2. Feral pig density distribution and the distribution of the Southern Corroboree frog

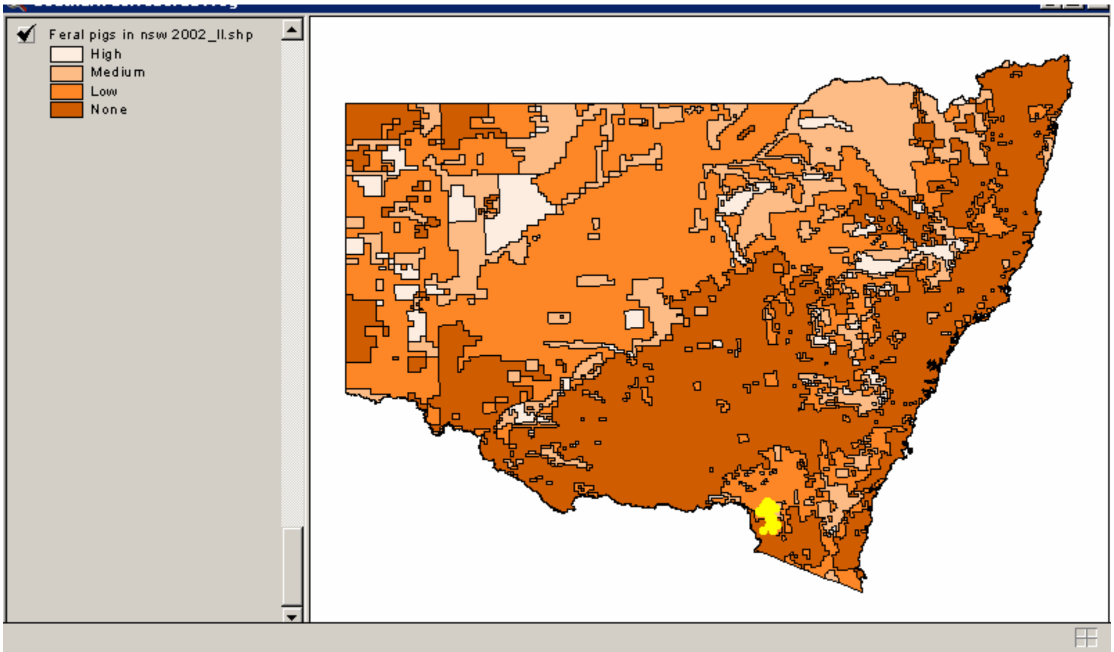

Figure 3. Feral pig density distribution and the distribution of the Brolga.

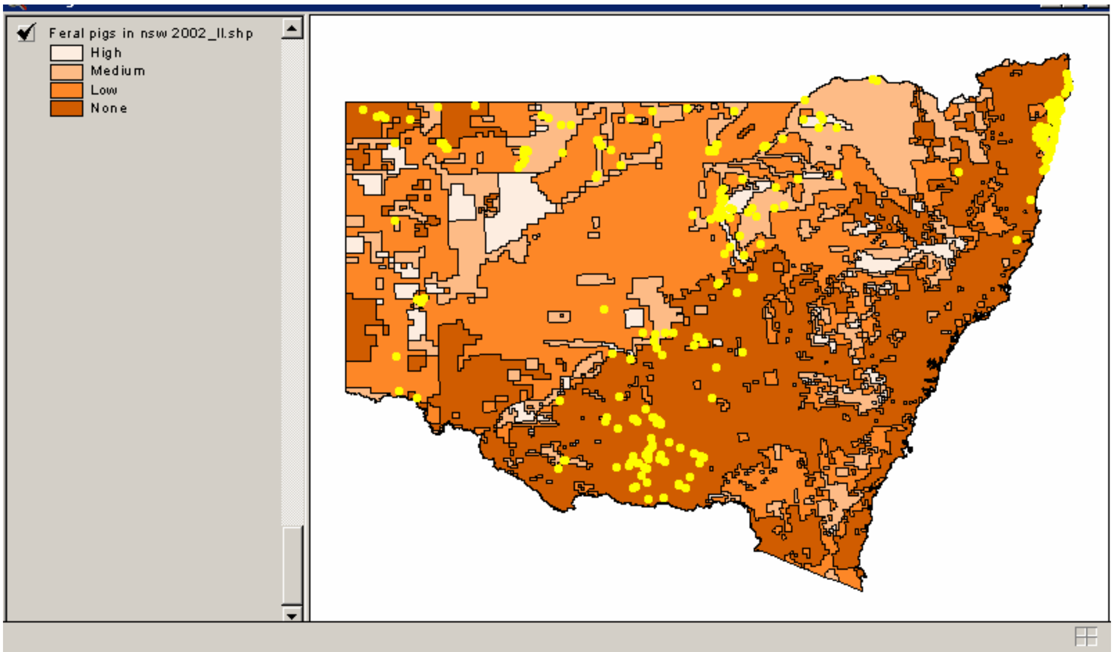

Figure 4. Feral pig density distribution and the distribution of the Loggerhead Turtle.

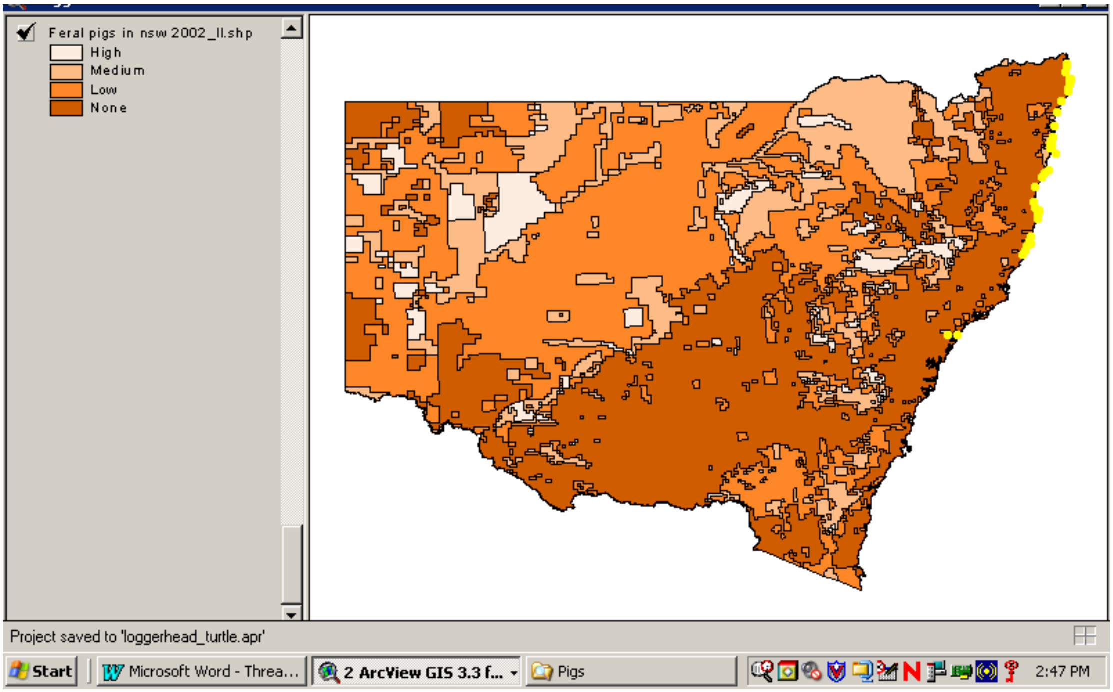

Figure 5. Feral pig density distribution and the distribution of the Fleay's Barred Frog.

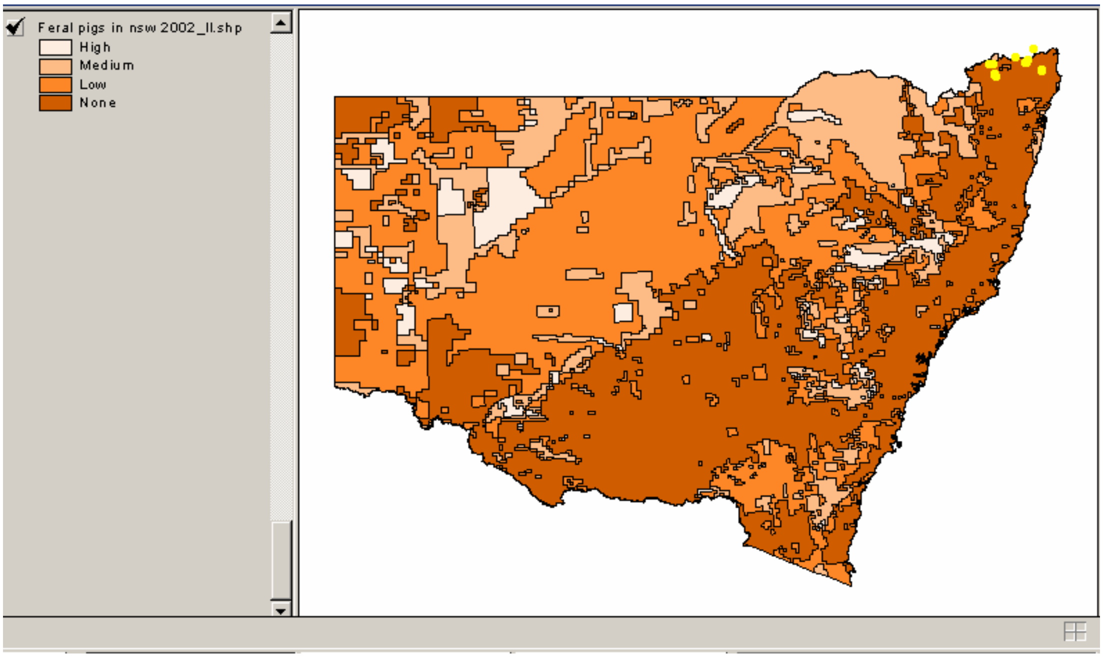

Figure 6. Feral pig density distribution and the distribution of the Eastern Bristlebird.