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 1 Report. Audit of current tools, techniques and practices for managing feral pigs both in Australia and overseas.

Published May 2004.

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This report should be cited as: Cowled, B., Lapidge, S. and Twigg, L. (2004). 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 1 Report. Pest Animal Control Cooperative Research Centre, Canberra, Australia.

This project (ID number: 44380) was funded by the Australian Government Department of the Environment and Heritage through the national threat abatement component of the Natural Heritage Trust.

Natural Heritage Trust
Helping Communities Helping Australia
An Australian Government Initiative

Australian Government
Department of the Environment and Heritage

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ACKNOWLEDGEMENTS

The authors thank John Parkes, Penny Fisher, Graham Nugent and Cheryl O'Connor at Landcare Research (New Zealand) who provided valuable comments on an earlier draft of the report. Thanks must also go to Associate Professor Tony English from the NSW Game Council who provided information on some aspects of non-commercial hunting and to John McIlroy for his unpublished review (*Current and possible future toxins for the control of feral pigs, Sus scrofa, in Australia)* which was utilised in the preparation of this report .

EXECUTIVE SUMMARY

1. The aim of this Stage 1 report is to document a comprehensive audit of the current tools, techniques and practices for managing feral pigs both in Australia and overseas. The report provides a description of each of these current tools, techniques and practices and a bibliography of the reference material audited.
2. The past focus on feral pig control in Australia was on reductions of pest animal populations. Feral pig management is attempting to change from this ideology, to one involving strategic, integrated and coordinated control campaigns focused on optimising the efficiency of reducing the impacts of feral pigs. The use of feral pig control tools discussed herein should be considered in this context.
3. Poisoning campaigns to control feral pigs are one of the most efficient, effective and widespread control tools for managing feral pig impacts. Currently sodium fluoroacetate (1080) and yellow phosphorous (CSSP) are the only registered toxins. Limited use of warfarin occurs under special permit in restricted areas.
4. Feral pig baiting substrates are currently grain, fruit, vegetables, pellets and meat in different areas of Australia. Aerial baiting is also becoming an increasingly utilised tool in the management of feral pigs in large, remote areas.
5. Aside from poison baiting, trapping is one of the most widely used methods of feral pig management. Although labour intensive, the technique can be profitable and incorporated into daily land management practices. The ability of this method to control widespread feral pig populations is largely unknown.
6. Hunting by non-commercial hunters and commercial harvesters using ground shooting, dogging and trapping can have a significant localised reduction on feral pig numbers. Initiatives such as the NSW Game Council may improve the application, coordination and ethics of hunting. Generally, however, the benefits of hunting and harvesting feral pigs are unquantified. A criticism of hunting as a control method is that non-commercial and commercial hunting may hold feral pig numbers at a point where the benefits of hunting exceeds the cost of hunting.
7. Aerial Shooting is a useful method of feral pig control in relatively open habitats, and produces a rapid, efficient, humane knockdown in feral pig numbers. However, the technique can be expensive, generally undertaken in isolation, and the effect can be short-lived.
8. Fencing can be a useful additional method of feral pig management through reducing impacts on small, valuable areas. Its use is however expensive and time consuming and is generally limited to small areas or islands to allow eradication and exclusion.
9. The Judas pig technique can be applicable to aid detection of small isolated populations, and to improve the overall planning and effectiveness of control operations.
10. Neck snaring can be a useful means of managing feral pigs overseas, but would not be applicable to Australia due to animal welfare concerns, non-target issues and the inefficiency of the method.
11. Habitat modification includes active management of feral pig food, water and shelter sources. Removal of water sources through the capping of boar drains is currently occurring on some properties in the Australian rangelands. However, generally habitat modification would not have wide-spread value due to potential undesirable impacts associated with vegetation clearing.

12. A review of the effectiveness and humanness of each feral pig control method discussed within will form the basis of subsequent reports, prior to the deliverance of recommendations for future control of feral pigs.

THE REASONS FOR FERAL PIG CONTROL

The economic, environmental and social impacts that feral pigs have on Australia and other countries is difficult to define accurately (Choquenot et al 1996), although it is reportedly significant (see Choquenot et al 1996; Hone 2002; Braysher 2003). Pigs predate upon and compete with native and domestic animals, spread weeds and plant pathogens, and are responsible for significant erosion and habitat degradation (Masters 1978; Choquenot et al 1996; McDougal et al 2002; Braysher 2003). Feral pigs have been listed as a threatening process of nationally listed threatened species and ecological communities under the Environmental Protection and Biodiversity Conservation Act (Braysher 2003). The economic impacts of feral pigs on agriculture in Australia, as summarised by Choquenot et al (1996), have been more extensively researched and are in excess of $100 M annually. Some parallels, such as the costs associated with feral pig impacts may be drawn between conservation impacts and known agricultural impacts.

Feral pig management should be considered as part of a strategic management approach (Choquenot et al 1996). This means that the impact of feral pigs must be quantified and reduced, rather than simply trying to reduce feral pig populations in the hope that this will reduce feral pig damage. A strategic management approach first seeks to quantify the damage that feral pigs are causing to a valued resource. Next a management plan is developed based on the methods of control available for feral pigs. Thirdly, the plan needs to be implemented in a coordinated fashion across the landscape. The final step is to monitor the results of the management plan and evaluate the results in terms of reducing the defined impact of feral pigs. This management approach to vertebrate pest control was prompted in recent times with the realization that a widespread vertebrate pest has never been eradicated from Australia, and the ad-hoc and uncoordinated control methods were not necessarily reducing the impacts caused by feral animals (Braysher 1993). However, feral pigs can, in some instances be eradicated from local areas.

The change to management of feral pig populations in recent times has also included the adoption of coordinated feral pig control across management units and agencies (Choquenot et al 1996). This is essential since feral pigs have an ability to emigrate rapidly from non-controlled areas to controlled areas where they can quickly re-establish populations, thus compromising management strategies. The way pest management is carried out is consequently changing, with integrated and adaptive pest management obtaining precedence. It is now recognised that the application of multiple control techniques is more effective than the application of a single technique in many situations (Braysher 1993; Olsen 1998). However, the sequential use of single control techniques as pig densities change may also be useful.

This review of the methods available to control feral pig populations should be considered in the context of strategic, coordinated, and integrated management of feral pigs.

USE OF FERAL PIG CONTROL METHODS

An internet (http://www.pestanimal.crc.org.au/hot.htm) and mail survey of graziers, station managers, veterinarians, pest animal state councillors, land protection officers, zoologists, rangers, property and environmental planners, ecologists, game harvesters and rural merchant sales representatives has recently been conducted by the Pest Animal Control Cooperative Research Centre (PAC CRC) to assess the use of feral pig control methods in Australia and the requirements and market potential of a manufactured feral pig bait. Responses have only been received from 50 people to date. One area that has not had a strong representation is animal welfare lobbyists, although this stakeholder group has been included in all requests for input. These groups are now being selectively followed up. Major findings so far include:

- 36% of respondents were private landholders, 42% government land managers and 14% zoologists.
- 92% of respondents were from NSW or Queensland where the most significant feral pig problems arise.
- More respondents elected environmental degradation (90%) as the most common impact of feral pigs, however, disease transmission (64%), infrastructure damage (52%) and lamb predation (50%) also scored highly.
- Although some respondents believe feral pigs have some positive attributes (eg harvestable resource), most (92%) believe that they are a pest that must be controlled.
- Ground shooting (70%), ground baiting (66%) and trapping (66%) were the most common methods of control, and the reasons that these choices were most commonly chosen were cost-effectiveness (78%) and target specificity (70%).
- Most baiting programs used either grain, fresh meat and carcasses to deliver the toxin. 1080 was the most commonly used toxin for feral pig control.
- When respondents were asked whether they felt current feral pig control methods (primarily trapping, baiting and shooting from the survey) were target-specific, humane, effective and cost-effective most respondents (60-80% in each category) agreed.
- Despite this, 80% of surveyed individuals would consider purchasing a commercially manufactured bait, with most (78%) preferring to pay $1 or less per bait.
- 54% of surveyed individuals wanted to see a single, highly toxic dose baits, even if this increases non-target impacts.

Although less detailed, the PAC CRC survey complements the more widespread state-based surveys conducted using standardised methodology by the New South Wales and Western Australian Departments of Agriculture in recent years.

Results from the NSW survey (West and Saunders 2002) include:

- Feral pigs inhabit 61% of NSW and the ACT, having increased their range some 20% between 1996 and 2002.
- 75% of respondents rated agricultural damage and 80% of respondents environmental damage in the moderate to very high range.
- Pasture damage, soil erosion and land degradation and exotic disease risk were the three highest ranked perceived impacts of feral pigs.
- The most commonly used feral pig control techniques in NSW are trapping (29%), recreational hunting (22%), poison baiting with 1080 (18%) and ground shooting (14%).
- 1080 usage for feral pig control increased from 3.6 kg a year during 1993-1999 up to nearly 20 kg in 2000 as a result of increased feral pig numbers due to favourable conditions.
- 'It is uncertain whether the current increased control efforts has had little or no effect on pig abundance, or whether it is simply a response by land managers to increasing pig abundance' (West and Saunders 2002).

Results from the Western Australian survey (Woolnough, Gray, Martin, Lowe, Rose and Kirkpatrick, 2002 unpublished) suggest that:

- Feral pigs are currently widespread in Western Australia. Significant populations were reported in the Kimberley and the De Grey River catchments in the pastoral region of WA. There were many feral pig populations reported in the Agriculture Region with these ranging from high density populations in the Northampton and Frankland River areas to smaller isolated populations throughout south-west of the state. Apart from a few localities, these populations have yet to be verified with ground truthing.

- Feral pigs were believed to be increasing in number and distribution as a result of deliberate releases, reduced control efforts and changes in agricultural practices (e.g. increased crops of white lupins – a seemingly preferred pig food).

- The main negative impacts of feral pigs were thought to be soil erosion, damage to native vegetation and pastures, and competition with native animals for food.

- Negative impacts were perceived to be most apparent in the winter months, when crop damage was greatest. In summer months, feral pigs tended to be more concentrated around permanent water.

- Only foxes, rabbits and cats were perceived to have a greater environmental impact (negative) than feral pigs.

- There has been an apparent increase in control efforts for feral pigs in the Agricultural Region of WA. This is in contrast to a general decline in control efforts in recent years for other pest species such as rabbits.

- Where control of feral pigs was undertaken, respondents reported that hunting/shooting and trapping were the most common methods used. Targeted poisoning with 1080 was only a minor method for control (about 11% of the respondent's that were actively involved in controlling pigs). This overall trend was repeated for the effectiveness of control methods for feral pigs.

METHODS OF CONTROL

1. POISONING

1.1) Introduction

Poisoning is one of the main methods used to control pig numbers. It is widely accepted in rural communities, it can provide fast and efficient knockdown of feral pig numbers over a large area, and can enhance feral pig control options in remote areas (O'Brien et al 1986; Choquenot et al 1996; McIlroy 2004). Generally after successful pre-baiting with non-toxic substrate, poison is added to the carrier. The toxin is subsequently ingested as the pig eats the familiar bait substrate, with death occurring if the pig consumes a sufficient toxic dose. Together the bait substrate and the toxin will be referred to as the bait package or bait in this review.

- *Current toxins for feral pig*

Numerous toxins have been researched and used for feral pig management in Australia in the past (McIlroy 1983; Hone and Kleba 1984; McIlroy 1985; O'Brien 1988; O'Brien and Lukins 1988; O'Brien et al 1988; McIlroy et al 1989; O'Brien and Lukins 1990; Parker and Lee 1995; Mitchell 2003; McIlroy 2004), and feral pig damage has been reduced due to this toxin research and its associated application in the field. However, no feral pig toxin is without potential drawbacks, and these can include animal welfare concerns, effectiveness or low target specificity. Additional toxins developed in the future may solve a number of these problems.

Currently only two poisons are registered for use on feral pigs in Australia, sodium fluoroacetate or '1080' and yellow phosphorous or 'CSSP'. The use of these poisons is currently being reviewed by the Australian Pesticides and Veterinary Medicine Authority (APVMA) (Anon 2002; Anon 2003). Other toxins are used for feral pig control, both legally and illegally. Warfarin is used in the ACT and NSW with a special off-label registration permit from the APVMA (see Anon 2001). Fenthion ethyl or Luci-Jet®, an organophosphate insecticide, has reportedly been used illegally in some instances (McIlroy 1985; McIlroy 2004).

1.2) Baiting strategies for poisoning feral pigs

The application of appropriate baiting strategies can improve the success of feral pig baiting campaigns, and can reduce the negative consequences of these campaigns. McIlroy (2004) stated;

'The most important factor in bait distribution is to ensure that as many pigs as possible find and eat lethal amounts of the bait. This can depend on the method of distribution; sowing rates and dispersion, including when, for how long and often, and over what size area the baiting is carried out; the feeding habits, movements and population densities of the pigs; and the extent of bait removal by non-target animals'.

- Non-target intake reduction

Laboratory and desk based studies can identify animals of concern for monitoring during baiting campaigns. Studies can also identify appropriate baiting strategies for use during baiting campaigns. Baiting strategies are methods of using baits and toxins which reduce non-target impacts in baiting campaigns. The proportion of a non-target population which actually consume baits will influence any potential for long-term undesirable non-target effects. That is, with respect to non-target effects, any pest control program should be assessed at the population level. Thus, provided control techniques are effective and considered to be humane, then the overall program should be assessed in terms of the net benefits to the environment, non-target species, and agricultural production.

Baiting strategies are an important means of reducing non-target bait take, since many baits are platable to both target species and non target species. To attempt to reduce non-target bait take baits can be dyed green to reduce bird take (value of dye is controversial, see below), exposed only at night or removed or covered during the day, and be buried with non-toxic baits on the surface (McIlroy 1983). Feeding stations with specific fencing can exclude domestic stock whilst still allowing feral pig access, although this is time consuming and expensive to establish.

The Australian Capital Territory Parks and Conservation Service, in conjunction with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), has developed a practical, field based impact assessment model used in warfarin baiting campaigns, which is also used by the New South Wales National Parks and Wildlife Service (NSW NPWS) (see section on Warfarin). This impact assessment model, also functions as a baiting strategy outline to reduce non target intake of warfarin grain.

Another method to reduce non-target take would be to use baits that are attractive or toxic (specific) to pigs only, although a practical bait has yet to be developed.

Other methods that can be used are environmental impact assessments to estimate the effect that a poisoning campaign may have on a valuable environmental area. This will allow exclusion of baiting campaigns from areas where such a baiting campaign has impacted on non-target species.

It is important to realise that some non-target intake may occur in any feral pig baiting campaign. However, in these situations, provided no non-target population impact occurs, the overall benefit to the environment through reduced feral pig impacts can still be high.

- Free feeding

When beginning a baiting campaign it is important to offer free (non-toxic) feed to increase the number of target pigs feeding and to increase the likelihood that feral pigs which encounter baits will eat them (O'Brien and Lukins 1988). It is generally accepted that this should be continued till bait consumption has plateaued. O'Brien and Lukins (1988) suggested however that this may not be the best time to poison since the plateau in consumption may reflect a change in proportion of baits in the daily food intake. The current recommendation for free feeding in NSW is a minimum of 3 days (Saunders et al 1993). Poison baiting is best undertaken within 10 days of pre-feeding commencing. A pulsed baiting technique can also be used until all pigs are destroyed.

Saunders et al (1993) found that the free-feeding time in alpine regions was more critical than in semi-arid regions. The general recommendation of 3 days free-feeding in semi-arid regions should be increased in alpine regions to 6 days.

- Location of baits

The location of the baits are also important. Bait stations or trails must be located where feral pigs are likely to locate them. This mean that in order for all feral pigs to be at risk in a baiting campaign, all pigs must come into contact with baits. This means that a blanket coverage of all pig habitats is needed for an effective baiting campaign

O'Brien and Lukins (1988) suggested that pigs may be more likely to consume baits which are near water since feral pigs generally move from cover to water before foraging begins. Mitchell (2001) found that bait uptake was likely to be greater when strategic bait placement was practiced rather than 'broad-scale distribution' since pigs were clustered around waterholes. However, this was probably because feral pig habitat contracts around waterholes during the northern dry season.

The use of fermented wheat bait stations or trails can be used to help determine the best location for poison bait or trap placement (Saunders et al 1993).

- Bait shyness

Some baiting studies have shown that a large proportion of the population may not consume baits and this may be due to wariness, unfamiliarity with the bait or insufficient free feeding (Hone 1983). Some authors have demonstrated that a level of 70% kill is required to produce a long term reduction in feral pig populations (Giles 1980; Hone and Robards 1983) Thus, a successful feral pig control campaign may need to utilize more than one method of control, rather than relying on just a poisoning campaign if bait uptake is poor.

- When is bait uptake by feral pigs optimal?

Generally, baiting campaigns should occur when pigs are suffering from peak nutritional stress as related to natural lows in food resources. This may be during drought in the semi-arid rangelands, during colder times of year when little food is available in alpine areas, or at the end of the dry season in northern Australia.

Bait uptake by feral pigs is integral to the success of trapping and poisoning campaigns (O'Brien and Lukins 1988). Many factors may influence bait uptake. Choquenot and Lukins (1996) showed that as pasture biomass increased, a decline in pig density corresponding to the given index of bait-trail uptake occurred. This suggested that per capita bait-trail consumption by pigs declined as the availability of other foods increased. This has implications for control techniques that rely on baiting (trapping and poisoning), and for methods that rely on baiting to estimate pig abundance (trapping, bait trail consumption and mark-recapture studies).

O'Brien and Lukins (1988) showed that feral pigs consumed baits depending upon a number of factors. Females consumed more bait than males, whilst larger pigs consumed more bait, but lower concentrations of 1080 than smaller pigs. They also showed that bait type influenced bait consumption with pellets being more readily consumed that cereal baits. However, for reasons not understood, 1080-pellet baits are less toxic to feral pigs than are grain baits (see below).

Saunders et al (1993) found that whilst bait uptake was often similar between spring, summer and autumn, bait uptake was likely to be higher in autumn unless bait is offered for longer times at other times of the year. This higher uptake of baits in autumn also coincided with the poorest body condition of pigs, indicating that the time that coincided with the poorest availability and quality of food was the best time to bait pigs.

1.3) Sodium fluoroacetate (1080)

Summary
Compound 1080 is the main pesticide used in feral pig control in Australia. It is used in meat, grain, fruit, vegetables and pellet bait substrates. On a body weight basis, relatively large doses of 1080 are required to kill feral pigs. Some poisoned pigs also tend to vomit after ingesting. Despite this, 1080 is still an effective tool, and in the absence of additional/alternative toxins, the use of 1080 is a vital tool in the management of the impacts of feral pigs. 1080 is one of only two registered feral pig toxins in Australia. The relatively large doses of 1080 used in feral pig baits means that these baits can be lethal to some non-target animals, particularly those with a much smaller body weight than feral pigs. However, it is important to remember that the actual risk to free-ranging non-target animals will depend upon a number of factors including whether individual animals encounter baits and, if so, whether they consume sufficient quantities for adverse effects to occur. It also depends upon the sensitivity of these animals to 1080, their size relative to that of the target species, the toxic loadings of the baits used, where the toxin is located within the bait, and which part of the bait is eaten (edge versus centre). The hardness of bait products can also influence the amount of toxin ingested as the small dasyurids lack the dentition to eat substantial quantities of dried baits (Calver et al. 1989a; Martin et al 2002). The size of an animal's home range, and the density at which baits are laid, will also influence whether, and how often, individuals will encounter baits. The proportion of the population which actually consume baits will also influence any potential for long-term undesirable non-target effects.

In Western Australia, and in parts of the Northern Territory and Queensland, native animals can exhibit greater tolerance to 1080 due to the natural occurrence of fluoroacetate in some locally endemic plant species (Twigg & King 1991). Further, due to differences in basic metabolic pathways, marsupials often have a higher innate base level

of tolerance than do equivalent-sized eutherians (placental mammals). The development of tolerance to 1080 in native animal populations further enhances the target specificity of 1080 baiting campaigns in areas where the fluroacetate-bearing vegetation occurs. This includes a reduced potential for non-target impacts from feral pig poisoning campaigns on native wildlife. However, there is no effective antidote to 1080 at present, although research into antidotes has been undertaken previously in Australia and New Zealand. The use of 1080 in pest control is also currently being reviewed in Australia (APVMA) and New Zealand as part of the ongoing review of agricultural and veterinary chemicals.

In NSW 330mg kg^{-1} of 1080 is used in grain, fruit or vegetable bait. Bran pollard pellets are also used with 1080 at a dose of 500 mgkg^{-1} of bait (Bryant 2004). In Queensland 1080 can be used in meat (western and northern grazing areas), or grain, pellets or vegetables (McGaw and Mitchell 1998). 1080 is not used in the Northern Territory for feral pig control (Bryant 2004). In Western Australia, 1080 is used at 570mg kg^{-1} in wheat bait, feeder pellets or lupins, whilst baiting with fruit and vegetable is banned due to the potential for non-target impacts (Oliver et al 2002). In all situations pre-feeding is recommended to increase the number of feral pigs attracted to bait stations or trails.

- *What is 1080?*

Compound 1080 is an odourless, white, non-volatile powder that is highly water soluble. Its chemical name is sodium fluoroacetate (FCH_2COONa) (Eason and Wickstrom 2002). Fluoroacetate is found in naturally high concentrations in three genera of Australian plants. Where these plants occur naturally, native animals exhibit varying degrees of tolerance to fluoroacetate and hence to 1080 (Twigg and King 1991; Martin et al 2002). 1080 is a registered toxin that can achieve rapid reductions in pig numbers (Hone and Pederson 1980; Hone 1983). It is the only poison available for aerial application (McIlroy 2004) and is biodegradable in the environment (Walker & Bong 1981; King et al 1994).

- *Mode of action*

Eason and Wickstrom (2002) and Twigg and King (1999) reviewed the pathogenesis of 1080. After absorption, fluoroacetate is converted to fluorocitrate, which inhibits a critical enzyme, aconitate hydratase in the tricarboxylic acid cycle (TCA). The TCA is the main energy producing pathway within aerobic animals. The inhibition of the TCA results in the accumulation of citrate in the tissues and plasma, energy deprivation and, ultimately, death. Fluorocitrate is synthesized in the mitochondria, where the TCA is located. Some evidence also suggests that fluorocitrate can inhibit citrate transport into and out of mitochondria, and that fluorocitrate has an inhibitory effect on succinate dehydrogenase. The high levels of citrate during 1080 poisoning inhibit the glycolytic enzyme phosphofructokinase, and interferes with the ionic balance within cells (Twigg & King 1991).

The systems of many species are affected, but the effects are more pronounced in the cardiac system of herbivores and the central nervous system (resulting in convulsions and respiratory compromise) in carnivores.

Canids are particularly sensitive to 1080. Herbivores are less sensitive than carnivores whilst birds and then reptiles are increasingly tolerant to 1080 (Eason 2002, Twigg et al 2003).

- *Effect of 1080 on feral pigs*

Although feral pigs are relatively sensitive to 1080, their large size often means they need to consume relatively large amounts of bait to succumb. Thus, in some situations, feral pigs can be less susceptible to poisoning by 1080 than many other animals potentially exposed to poison bait during feral pig baiting campaigns (McIlroy 1983). Of 40 animals tested for sensitivity to 1080, pigs were the 13th most sensitive on a dose per kilogram basis. However when they were considered relative to the absolute amount of 1080 required to cause death their overall susceptibility declined relative to many other species. Thus 36 of the 40 species considered, with the exception of emus (*Dromaius novaehollandiae*), cattle (*Bos taurus*), horses (*Equus caballus*) and red kangaroos (*Macropus rufus*) were theoretically more susceptible to 1080 baiting than feral pigs. This assumes that all animals tested were equally as likely to eat the poisoned bait. However, baiting strategies and species bait preferences considerably reduce the risk to non-target animals.

McIlroy suggested the feral pig LD_{50} dose for 1080 was 1 mg kg^{-1} (for 1080 in saline by oesophogeal gavage) whilst O'Brien (1988) calculated the LD_{50} dose to be 4.11 mg kg^{-1} (1080 delivered via wheat). Research in New Zealand found that some pigs survived following a dose of 10 mg kg^{-1} (Eason and Hendersen 1995). Boars generally range up to 115 kg and sows to 75 kg in Australia (Choquenot et al 1996). This means significant amounts of 1080 must be in baits to ensure that enough bait is consumed in one feeding session to reduce sub-lethal dosing. However, increasing concentrations of 1080 in baits may increase potential non-target risks (McIlroy 1983).

In addition, pigs frequently vomit toxic material upon exposure to 1080 baits, in pen trials, which may further increase non-target risks. The non target risk posed by vomitus is unknown.

McIlroy (2004) in an unpublished report reviewed the effectiveness of 1080 feral pig baiting campaigns based on currently used 1080 concentrations and dietary requirements of feral pigs. He found that the effectiveness of some feral pig poisoning campaigns must be in question, in some instances, because sub-lethal dosing of large pigs is likely to occur. He discussed that large pigs (30-80 kg) would need to consume 1-1.27 kg of wheat bait (containing 330mg kg^{-1} of 1080), 0.7-1.8 kg of pellets (containing 500mg kg^{-1} of 1080) or 4.7-12.5 Queensland meat baits (each containing 72 mg of 1080) to consume an LD_{90} dose of 1080. O'Brien and Lukins (1988) reported, during an extensive study of poisoned feral pigs, that the average intake of pellet bait was 780 g and wheat was 402 g. The average dose of 1080 eaten in pellets was 13.3 mg kg^{-1} per pig, and in cereal bait the average was only 5.8 mg kg^{-1} per pig which represented less than a LD_{70} dose. McIlroy (2004) also reviewed studies by Hone and Kleba (1984), Hone et al (1985), Kleba et al (1985), Saunders (1988) and McIlroy et al (1993) that showed a daily feed consumption by feral pigs of 1.2-2.4kg per day. This indicates that some large pigs may not eat lethal amounts of bait (O'Brien and Lukins 1988). When the number of pigs that don't find or consume bait are considered (23% in one instance by Hone 1983), the likelihood is that some feral pig baiting campaigns with 1080 may not always be effective (McIlroy 2004).

When feral pigs are poisoned with 1080, the earliest signs are vomiting or increased lethargy, and a laboured respiration with or without a white froth around the nostrils or mouth. Following this, affected pigs usually lie quietly whilst breathing laboriously until death (McIlroy 1983). Pigs that vomited generally died with some pigs experienced convulsions and/or hind limb paralysis. However, O'Brien (1988) found that during pen trials with limited food choices, almost all pigs poisoned with 1080 vomited, although higher doses of 1080 were use in his study than in McIlroy's study. The time to death varies between doses and pigs, but was 244 minutes (median time) in an extensive pen study (O'Brien 1988). The sex and weight of the animal did not influence the likelihood of vomiting, time to death or possibility of survival (O'Brien 1988).

As discussed above, 1080 ingestion frequently leads to vomiting in feral pigs. This has a number of implications according to McIlroy (2004);

1. Potential secondary poisoning of non-target species even at a distance from poisoned areas is possible. However, the liquid component of vomitus is quickly absorbed in the soil leaving only the dry bait material. Since 1080 is water soluble, much of the 1080 may be abosorbed by the soil, before it can be eaten.
2. Secondary poisoning of feral pigs could enhance the effectiveness of poisoning campaigns,
3. Vomiting may cause sub-lethal dosing of feral pigs which will depress the effectiveness of 1080 poisoning campaigns, but this contrasts with pen trials in which all pigs which vomited died,
4. Pigs surviving a sub-lethal dose may develop an aversion to 1080 (or enhanced neophobia to bait), decreasing their susceptibility to further poisoning programs (O'Brien et al 1986).

Various authors (Hone and Kleba 1984; Rathmore 1985; O'Brien et al 1986) have trialed the use of anti-emetics (such as metaclopramide) in 1080 baits to prevent vomiting. Mix results have been achieved and no broad scale application of the results has yet occurred.

- *Other problems with 1080*

Lack of an effective 1080 antidote. Although animals that receive a sub-lethal dose may recover with veterinary treatment, no specific antidote exists for 1080 once signs of poisoning become obvious.

- *Environmental impact assessment.*

The use of poisons to reduce the impact of feral pigs and protect natural resources can have unintended negative effects. Non-target impact can occur following consumption by native or domestic animals of 1080 feral pig baits (see below). Environmental impact assessments need to be made when using poisons in areas of high environmental value to reduce the chance of impacting on endangered species or ecological communities.

However, environmental impact assessments need to look at the effect of baiting campaigns on non-target population levels, rather than individuals.

- *Non-target risks*

Non-target animals are potentially at risk from being poisoned due to bait consumption, consumption of carcasses, preying on poisoned animals and consumption of vomitus. In many non-target species, particularly for 1080-laced grain and pellet baits, the amounts of baits containing the equivalent of a LD_{50} represents less than 5% of their bodyweight (McIlroy 2004). However, this doesn't mean that non-target animals will consume baits. The knowledge of which animals could potentially consume a toxic dose of feral pig bait can allow a baiting strategy to be developed which takes advantage of various characteristics of non-target species. This will reduce potentially susceptible non-target intakes. Additionally, this information can be used to decide which non-target animals should be monitored during a baiting campaign (Martin et al 2002).

Prior research and anecdotal reports have reported 1080 bait/carcass take, especially by birds, such as native raptors and corvids (Hone & Pederson 1980; Bryant 2004) and non-target mortalities in feral pig 1080 baiting areas in the past (McIlroy 1983).

Bryant et al (1984) trialed the use of dyed baits to reduce bait take by birds. Colouring agents were found to reduce the acceptance of grain by birds. Furthermore, Kleba et al (1985) showed that the addition of dyes to grain baits did not reduce acceptance by feral pigs. However, Hone et al (1985) found no difference in consumption of dyed or undyed grain by birds or feral pigs in paddock trials. He hypothesized that this may have been due to a difference in bird species composition and lower species richness in the area. He also made the point that the birds at risk of poisoning in his study were species of abundant and widespread populations that were unlikely to be compromised by poisoning campaigns (Galahs and crested pigeons). More recent research on grain take by captive corellas (*Cacatua tenuirostris*) found that this species quickly learnt to eat coloured grain and that dyed grain may only provide temporary protection from non-target poisonings (Jongman et al 2000). However, despite these studies, few major investigations of the impact of 1080 feral pig poisoning campaigns on non-target species have occurred (Bryant 2004).

Non-target risks can be minimized by climatic conditions that rapidly reduce the toxicity of available baits (so that large amounts of toxic baits are not in the environment after bait operations), by targeted strategies to reduce non-target bait take, and by using species-specific bait packages. Non-target bait take is important in terms of the effectiveness of feral pig baiting operations. Some studies have found that only small amounts of deployed baits are available to feral pigs due to non-target takes (native birds and foxes) (Fleming et al 2000).

Eason (2002) reviewed the environmental fate of 1080 in New Zealand. During cool dry times baits may remain toxic for long periods of time. Since 1080 is water soluble, heavy rainfall rapidly leaches baits of toxin, although bait substrate affects the rate with which this occurs. Soil microbial action and plant uptake results in defluorination (detoxification) of 1080. 1080 is rapidly excreted from animals that have received a sub-lethal dose (Twigg & King 1991). Carcasses contaminated with 1080 may remain contaminated for many months depending upon the rate of decomposition of the body, since 1080 has been found to remain in meat baits for extended periods of time when decomposition is slow (Flemming & Parker 1991). In contrast, research by Twigg et al (2003) in Australia showed that carcass decomposition of rabbits and rats poisoned with 1080 was very rapid, and that these carcasses posed little risk to native non-target animals.

The decision to bait feral pigs can be assessed against the risk of poisoning non-target animals and affecting their population levels, as well as the benefits to the environment if feral pigs were removed. If the risk is unacceptably high, then alternative methods of control are recommended. McIlroy (1986) reviewed the potential risks to various animals. Mammals are more sensitive than birds and birds are more sensitive than amphibians and reptiles. Reptiles and birds are considered to be at such a low risk of being poisoned that they are not a priority when reviewing the use of 1080 (Anon. 2002). However, birds probably should be considered, since research has shown that birds are theoretically at risk during 1080 baiting campaigns (Martin & Twigg 2002). Within the mammals, carnivorous animals are generally more sensitive than granivorous, herbivorous or omnivorous animals. Eutherian animals originating from overseas are generally more sensitive than Australian marsupials (Twigg and King 1991). However, there can be considerable variability in response to 1080 within species and between groups of species, particularly in south-eastern Australia. (McIlroy 1986). Again, the use of careful baiting strategies can reduce the potential risk to non-target species.

McIlroy (1986) estimated the risk of non-target species receiving an LD_{50} dose of 1080 from various 1080 baits. This was done through comparing a species LD_{50} dose with the type and volume of food it consumes and the concentration of 1080 in baits. For example, rabbit baits have the potential to deliver an LD_{50} to around 50-60 species, whereas dingo baits only have a potential to deliver an LD_{50} to 2 of the species reviewed by McIlroy. Pig baits have the potential to affect approximately 14 of over 50 species tested.

Martin et al (2002) researched, during laboratory trials, the theoretical susceptibility of various native animals to 1080. They found that few species would be at risk during 1080 baiting campaigns in South Western Australia. Other theoretical studies have indicated that a number of native species (*Dasyurus geoffroii* and *Dasyurus hallucatus*) can be susceptible to 1080 baiting campaigns, but populations of these species have not found to be susceptible during field baiting situations (Martin et al 2002). However, it is important to remember that the actual risk to free-ranging non-target animals will depend upon a number of factors including whether individual animals encounter baits and, if so, whether they consume baits or sufficient quantities for adverse effects to occur. It also depends upon the sensitivity of these animals to 1080, their size relative to that of the target species, the toxic loadings of the baits used, where the toxin is located within the bait, species food preferences, species feeding behaviours and which part of the bait is eaten (edge versus centre). The hardness of bait products can also influence the amount of toxin ingested as the small dasyurids lack the dentition to eat substantial quantities of dried baits (Calver et al. 1989a; Martin et al 2002). The size of an animal's home range, the time of year and the density at which baits are laid, will also influence whether, and how often, individuals will encounter baits These factors can be taken into account to develop robust baiting strategies to reduce non-target bait take.

In summary, Cremasco (2002) concluded following a review of 1080 non-target impacts in Queensland that;

a) Many Australian native animals (especially from Western Australia) exhibit a significant tolerance to 1080, which means that they are unlikely to succumb during well planned and executed control programs. Thus, 1080 is a useful toxin for use in Australia. 1080 does not build up in the environment due to degradation .

b) Even with native wildlife's inherent tolerance to 1080, some species can still be poisoned in 1080 baiting campaigns. The impacts from 1080 baiting campaigns may be difficult to detect, even following major non-target impacts. The impact on non-target wildlife can be exaggerated with laboratory studies.

c) The monitoring of baiting campaigns for potential detrimental non-target effects should be adjusted, to take into account the difficulty of detecting population changes in significant species during baiting campaigns. Data generated from captive studies will help to identify which species are best monitored.

d) The long-term effects of sub-lethal 1080 baiting may be significant (and could include organ dysfunction, such as the kidneys and teste dysfunction). An effective, practical antidote is also desirable.

- *Bait substrate for delivery of 1080*

The carrier or bait substrate used to deliver poisons to feral pigs is important for a number of reasons. The carrier used will affect the bioavailability of the poison, the bait uptake by feral pigs, the persistence of poison in the environment, the specificity of the poisoning campaign and the applicability and cost effectiveness of a bait.

Grain and pellet baits comprise 61% of baits used in NSW and QLD (O'Brien et al 1988). O'Brien and others (1988) compared mortality in pigs receiving 1080 in grain baits or pellet baits. Mortality was higher in pigs receiving 1080 in wheat. This was surmised to be because pigs absorbed more 1080 from wheat than from pellets, either due to increased availability of

1080 or a change in the availability of 1080 over time as food was digested. Similar work in possums *Trichosurus vulpecula* showed that the toxicity of 1080 to possums was lower in carrots than pellet baits (Henderson et al 1999). Some work has shown that 1080 in meat baits is particularly strongly bound, and is probably less likely to be absorbed when given in meat compared with grain or pellets (Livanos and Melham 1984 quoted in McIlroy 2004). The dose of 1080 in polymer baits that was required to kill feral pigs in New Zealand exceeded that previously published (Eason and Hendersen 1991). This supports the idea that the bait substrate can affect the bioavailability of 1080.

Bait uptake is affected by the dietary preferences of feral pigs, and of any non-target species of concern. Feral pigs are omnivorous and many grains are included in their diets (Hone et al 1985). Therefore grains are used frequently to trap and poison feral pigs (Hone et al 1985). Whilst pigs are omnivorous, they are primarily herbivores and only consume meat opportunistically (Giles 1980). O'Brien and Lukins (1988) found that pigs were more likely to consume pellet baits than wheat baits. During pen and paddock trials feral pigs preferred fermented, extruded grain-based baits with additional odourant attractants over fresh grain or meat baits (Lapidge et al 2004 unpublished). Thus the food preferences of feral pigs may vary across space and time.

Eason (2002) reviewed the use of 1080 in New Zealand. He found that the degradation (defluorination) of 1080 to non-toxic metabolites by soil bacteria and plants followed the leaching of 1080 from baits. However he suggested that leaching will be affected by bait type. For example, studies have shown that 1080 is rapidly leached from cereal baits, but only slowly leached from carrots. Other environmental factors such as low temperatures and lack of rain will reduce the leaching of baits to the soil, although some degradation will occur within the baits, even in cool dry temperatures. Specifically, during warm (11-20 C) and moist conditions 1080 may be significantly degraded in 1-2 weeks but during cool dry conditions the toxicity of baits may persist for several months. Australian research has shown that 1080 can be lost from some grains in as little as 5-10 days with small amounts of rain (6mm).

1.4) Yellow phosphorus (CSSP)

Summary

CSSP is phosphorus-based poison applied to carcases that is believed to be effective at killing pigs. However, only anecdotal reports exist as to the efficacy of CSSP in the field and its potential impact on non-target species. CSSP is generally used in an ad-hoc manner rather than in a coordinated campaigns since it is available as a restricted ’ take home’ poison. It is the only take home feral pig poison registered in Australia, and as such, it is valuable to individual land managers. Its registration is currently being reviewed for a number of reasons, including the perception that it compromises animal welfare and may have large non-target impacts.

In New South Wales and Northern Territory CSSP is registered to be used in carcasses at 60 grams/carcass in cropping situations. It can only be used on sheep, cattle, pigs, goats and kangaroo carcasses (Bryant 2004). In Queensland the use of CSSP is legal but not supported due to welfare and non-target concerns (McGaw and Mitchell 1998). CSSP is not used in Western Australia (Oliver et al 1992).

- *What is CSSP?*

CSSP is a yellow phosphorus based Schedule 7 poison with 4% active phosphorus. It is manufactured in Queensland by FH Treweeke Pty Ltd and is used in NSW, QLD and the NT (Choquenot et al 1996). Unlike 1080, it is available as an 'off-the-shelf' toxin, and is not subject to government land manager distribution. Thus, it is a well-utilized poison in more remote parts of eastern Australia where feral pigs are a problem, where the associated logistics make it difficult or impossible to use 1080 (Choquenot et al 1996).

In NSW, 50% of Rural Lands Protection Boards use CSSP (Bryant 2004). It is registered for use in NSW in agricultural (non crop) situations at 60 grams per carcass (sheep, cattle, pig, goat and kangaroo carcasses) (Bryant 2004). NSW agriculture generally does not support the use of CSSP (Bryant 2004). This is because CSSP is seen as;

a) not target specific,

b) not used in a strategic manner,

c) of questionable humaneness, and

d) possibly an occupational and environmental hazard.

The use of CSSP is being reviewed by the APVMA for a number of reasons, including poor label instructions, does not meet contemporary standards of humaneness, non-specificity for target due to use in carcasses, OH&S problems, no data on the effectiveness of control programs and the use of CSSP as a reactive measure, rather than as part of a planned program (NRA letter to NSW Agriculture July 2001 quoted in Bryant 2004).

The withdrawal of CSSP would leave private land managers with no 'take home' feral pig toxin, and thus they would be dependant on government officers for broad-scale baiting of feral pigs . That is, because of the logistics involved, poison baiting as a control option would not be available in remote areas. This has the potential to reduce feral pig control on many private lands, thus indirectly, negatively impacting on biodiversity protection since 70% of Australia’s biodiversity is on non-reserved land, much of it privately held (Braysher 2003). However, the potential non-target issues of CSSP may balance this. Thus, it is a priority to develop safe, humane and target-specific take home poisons which can be registered for use 'off-the-shelf".

- *Effect of CSSP*

The LD_{50} of phosphorus is 5.3 mg kg^{-1} (O’Brien & Lukins 1990). Phosphorus is absorbed from the respiratory and gastrointestinal tract, but the mode of action is still unknown (O’Connor et al 2003). Phosphorus poisoning symptoms generally include abdominal pain and vomiting, and sometimes vomiting blood, followed by cyanosis, coma and death (O’Connor et al 2003).

Generally, death from CSSP can take 1-2 days, however there can be a temporary improvement before vomiting, diarrhoea, convulsions, coma and death ultimately occurs. It can take up to 3 weeks after ingestion for death to occur in animals receiving smaller doses.

In a study of CSSP toxicity in feral pigs, O'Brien and Lukins (1990) found that pigs that received high doses (17.3mg kg^{-1}) of the toxin died relatively quickly (as quickly as 6 hours), probably from circulatory collapse. However, even at most high doses, pigs typically took 2-4 days to die, with death probably associated with liver or myocardial toxicity. High doses of CSSP were found to reduce the acceptability of baited grain, which precludes the use of high doses of CSSP to increase the welfare of CSSP. This decrease in acceptability is probably due to painful local irritation of mucosal surfaces (Seawright 1982 quoted in O'Brien and Lukins 1990). Poisoning in humans causes pain, cramps nausea and vomiting (Diaz-Rivera 1950, quoted in O'Brien and Lukins 1990). Clinical signs in pigs included lethargy and depression, decreased food consumption, recumbency and paddling of feet and occasional vocalizations. Pigs rarely vomited with CSSP poisoning (O'Brien and Lukins 1990). Post mortem signs of poisoning included rectal and nasal haemorrhages, gastrointestinal pathology, which included haemorrhages in the stomach, intestine and rectum. Liver damage was common.

However, even though CSSP is likely to have adverse welfare outcomes, it is nonetheless probably an effective feral pig toxicant when correctly administrated, Phosphorus is similar to 1080 in it's toxicity to feral pigs.

- *Use of CSSP for management purposes*

CSSP is used on an 'on-farm' basis, generally in uncoordinated and ad-hoc feral pig management approaches (Bryant 2004). This is in contrast to the suggestions by Choquenot et al (1996) that successful long-term management of feral pigs requires control programs to be coordinated across the landscape in large practical management units, since feral pigs can rapidly recolonise from surrounding non-controlled areas. However, as its use can alleviate localised damage or agricultural losses, the use of CSSP (or any future 'off-the-shelf' poison) can still be advantageous to individual land managers, even if the management unit is as small as one station. This is because the time frame over which control is required influences the size of the management unit (Choquenot et al 1996). For example, the local use of CSSP can reduce pig abundance for short periods of time, which can protect valuable resources during this period. Choquenot et al (1996) uses the protection from predation that this control can give to lambs during the lambing season as a further example. However, this short-term control could extend to other situations such as ground nesting birds or reptiles, if pigs were shown to be negatively impacting on these species during certain times of the year.

The use of CSSP provides land managers with a cheap and effective tool to control feral pig numbers. Its cost effectiveness is due to the fact that no free feeding is required since carcasses are used, it is low cost, and poisoning has been shown to be one of the most cost-effective management tools for feral pigs (Choquenot 1990; Bryant 2004).

The effectiveness and target-specificity of CSSP in the field needs to be evaluated, as there is no data apart from anecdotal reports (Bryant 2004).

- *Non-target effects and environmental contamination*

Eason and Wickstrom (2001) advise that phosphorus has no effective antidote. Poisoning may be treated by removing CSSP by inducing vomiting or gastric lavage, followed by dosing with 0.1% potassium permanganate or 2% hydrogen peroxide.

Repeated exposure to low doses may result in chronic toxicity and hazard to operators (Rammell and Fleming 1978).

Non-target take of poisoned carcasses may be high. All animals which consume offal are probably at risk of ingesting phosphorus baits. The toxicity of CSSP to non target animals is sufficiently high that current dose rates (60g in a carcass) may affect most animals (humans, dogs, cats, ruminants, poultry) (Hone and Mulligan 1982). Presumably, native carnivores and scavengers would be at risk.

One of the main risks to non-target animals is that the use of CSSP occurs with no baiting strategy to protect animals that are potentially at risk from poisoning. That is, it is placed in carcasses where all animals which scavenge can access the non-specific toxin.

Phosphorus is unlikely to persist in the environment and is rapidly oxidized to non-toxic phosphates on exposure to the air (Eason and Wickstrom 2001). Phosphorus is rapidly oxidized to non-toxic phosphates in the body, which suggests that secondary poisoning would be unlikely (Rammell & Fleming 1978).

1.5) Anticoagulants

The anticoagulants used for pest animal control, especially rodent control are vitamin K antagonists (Green & Thomas 1995). Vitamin K is an essential part of the coagulation (clotting) cascade. In the healthy animal, only small amounts of vitamin K are required to maintain sufficient levels of vitamin K-dependant coagulation factors in order to prevent bleeding (Green & Thomas 1995). Normally, routine activity can lead to small vascular injuries, which are repaired by the body's normal physiological activities such as the coagulation cascade. When an anticoagulant is ingested, the ability of an animal to utilize vitamin K to regenerate used clotting factors (II, VII, IX and X) is prevented (Green & Thomas 1995). Vitamin K is also required to produce protein C and protein S in this cascade. This leads to the inability to repair normal vascular injuries, resulting in widespread haemorrhage and death due to circulatory collapse or haemorrhage within vital organs.

Green and Thomas (1995) reviewed the clinical signs of anticoagulant poisoning in small domestic animals. The clinical signs are broad, since they are associated with bleeding. Acute death with no other signs can occur due to haemorrhage into the brain, pericardial sac or thoracic cavity. Respiratory distress can occur due to shock and thoracic bleeding. Pale mucosal membranes and anemia, bleeding nose, bloody faeces and extensive haematomas can be seen. Lameness is a common sign in many animals, particularly those with relatively large body mass (eg. feral pigs), due to bleeding into joint spaces leading to arthritis.

Treatment of anticoagulant poisoning depends upon the severity of signs when treatment is sought. Initially, before clinical signs develop, vitamin K is an effective antidote. However, if disease is further advanced, additional therapy such as blood transfusions, intravenous fluids and respiratory support may be needed.

The anticoagulants can be divided into generations, based on when they were first developed.

First generation anticoagulants such as warfarin, pindone and indandione, were the first anticoagulants developed and persist in the body for only short periods of time (ie. have short half-lives) (Green & Thomas 1995). Warfarin is used in human medicine for clot prevention. The toxicity of these anticoagulants to many animals is fairly low, and repeat dosing is more toxic than a single dose. Often repeat dosing is needed to produce a lethal dose. Due to their short half-life, large amounts of these anticoagulants are often metabolized and excreted before death of the poisoned animal. This leads to a reduced risk to non-target species of secondary poisoning through reduced toxicity of carcasses. However, poisoned feral pigs which have died of warfarin poisoning have been found to contain warfarin in their livers (Saunders et al 1990).

The second generation anticoagulants were developed later, due to increasing resistance in rodents to the first generation anticoagulants. Second generation anticoagulants are much more potent than their first generation counterparts. Brodifacoum is the most persistent and toxic of the second generation anticoagulants. Second generation anticoagulants (such as bromadiolone, diphacinone and brodifacoum, mainly hydroxycoumarins) also have a much longer half-life than the first generation anticoagulants because they bind to plasma proteins and consequently, are only slowly released. Due to their persistence in the body, they are more likely to lead to non-target poisoning, since animals that eat a poisoned carcase will generally ingest anticoagulant.

1.6) Warfarin (hydroxycoumarin - Schedule 6 poison)

Summary.

Warfarin is a first generation anticoagulant to which feral pigs are reasonably sensitive. The effectiveness of warfarin in controlling feral pig populations has been well demonstrated when used in grain over a number of consecutive days (Hone 1987; McIlroy 1989; Saunders et al 1990; Clarke 1993). Large decreases in feral pig numbers have occurred in field trials, resulting in reduced environmental damage. Warfarin is however a toxin not supported for feral pig use by animal welfare societies due to the long time it takes for feral pigs to succumb to its effects (4-17 days).

The use of warfarin in grain can be labour intensive and impractical due to the requirement for repeat dosing and no aerial delivery method being available. Consequently, initial trials have been conducted into the feasibility of using a 'one-shot' warfarin formulation with some success.

The effects of warfarin on non-target animals and native communities has not been adequately researched. This information will be essential to register a new toxicant.

- *Use of warfarin for feral pig management in Australia*

In Australia, warfain is only used for feral pig control in NSW and the ACT annually under an off-label permit from the APVMA. The toxin is also used in research trials in Queensland (Mitchell 2003). In NSW, its use is restricted to the New South Wales National Parks and Wildlife Service (NSW NPWS) for use in Brindabella NP, Scabby Range Nature Reserve, Bimberi Nature Reserve and north-eastern Kosciuszko NP (Bryant 2004). In the ACT its use is restricted to Namadgi National Park (Bryant 2004). Warfarin has been trialed in commercial baits in New Zealand where it was found to be an effective toxicant (Henderson et al 1993).

Warfarin is used on grain (Choquenot et al 1990; Saunders et al 1990). This is because it becomes highly protein bound (unavailable as a toxin) when added to meat, unless it is encapsulated (McIlroy 2004). Its use is approved at 0.13% in blue or green dyed grain for the control of feral pigs (Anon 2001). In some situations, warfarin can be a more consistent and effective toxin than 1080 for controlling feral pigs (Wilson and Choquenot 1993). When warfarin was used in polymer baits in New Zealand the dose required for consistent kills was 25 mg/kg for 4 days (Eason and Hendersen 1991). The LD_{50} dose of warfarin given in 2 doses separated by 24 hours was 2.9mg kg^{-1} (O'Brien & Lukins 1990).

- *The effect of warfarin*

Hone and Kleba (1984) investigated the use of warfarin relative to 1080 in feral pigs. They found that warfarin is a more potent toxicant in pigs than 1080, particularly when given as two consecutive daily doses (at 0.1% w/w) compared with a single dose. Females were more susceptible to warfarin than males. Unlike 1080, which was found to reduce the acceptability of baits (Hone & Kleba 1984), warfarin produced no change in bait consumption when compared with controls (O'Brien & Lukins 1990). This may be due to the long lag time between consumption and the onset of clinical signs, which is likely to reduce bait aversion

(McIlroy 2004). However, a short lag time exists with the onset of clinical signs following 1080 ingestion. Bait aversion can reduce the success of future baiting campaigns (see above).

Similar results were shown by O'Brien and Lukins (1990). Warfarin was consistently highly toxic when used over two days (at 6.8mg kg^{-1}), but was less toxic than brodifacoum. Warfarin was found to be highly acceptable to feral pigs in baits. This is in contrast to phosphorus, that was less acceptable but as toxic as 1080. The LD_{50} dose for warfarin was estimated to be 20 mg kg^{-1}. However, its LD_{50} and LD_{90} dose when given 24 hours apart was 2.9 mg/kg (1.85-5.2 mg kg^{-1}) and 6.1 mg kg^{-1} (3.9-54.3 mg kg^{-1}), that is, it was more toxic when given as two doses. The average time to death was similar for the single dose and two dose treatments (7 days apart); however, the range was shortened from 6-31 days for a single dose to 7-10 days for two doses (O’Brien & Lukins 1990).

The clinical signs of poisoning included reduced feed intake, lameness, lethargy, blood in the faeces and urine, and haemorrhage from the nostrils. Some of these clinical signs had an extended temporal occurrence, for example decreasing food consumption by the tested pig groups occurred for around 6 days following a latent period of several days after poisoning. O'Brien and Lukins (1990) also found that for 6 days before death anticoagulant intoxicated pigs showed distinct behavioural changes such as inappetence, lethargy and depression. This has implications for exotic disease outbreaks since a rapid knockdown of feral pig populations is needed for disease control (Hone and Kleba 1984).

- *Non- target issues*

The theoretical risks to non-target animals during warfarin feral pig baiting campaigns must be assessed using the sensitivity of non-target animals to warfarin, the baiting strategy used in warfarin baiting campaigns and the actual likelihood of non-target animals consuming baits.

Little is known of the effects of warfarin on non-target species (McIlroy 2004). However, the effects of pindone (a similar first generation anticoagulant used in rabbit control operations) have included non-target bandicoot deaths in the past in Western Australia. McIlroy (1989; 1993) recorded 9 species of birds and 7 species of mammals feeding at bait stations used for warfarin baiting. Recent research during feral pig warfarin baiting campaigns has confirmed that non-target animals consumed small amounts of warfarin grain, and that a large collection of native species ate non toxic grain from free feed bait stations (Cowled & Lapidge unpublished data 2004). The difference in bait consumption between free feeding stations and toxic bait stations was likely to be due to the baiting strategy used during the warfarin baiting campaign.

However, no research has been conducted on the sensitivity of Australian animals to warfarin poisoning, although dogs, cats, rodents and cattle are all less sensitive to warfarin than pigs (McIlroy 1993). Some veterinary authors have stated that birds have a different clotting process than mammals (Fudge 2000). Avian clotting depends more heavily on the extrinsic clotting pathway that relies on platelets than the intrinsic clotting pathway that utilizes Vitamin K. (Fudge 2000). This implies that birds may be more resistant to the effects of warfarin than mammals. However, birds can die from warfarin poisoning with a reference documenting this in the veterinary literature (Dumonceaux & Harrison 1994).

Furthermore, little monitoring of non-target impacts on native species or communities has occurred (Hone 2002; Braysher 2003), despite well over a decades use of warfarin in a number of national parks in eastern Australia. This information is essential if registration of warfarin as a toxicant is to be achieved (Choquenot et al 1996). New Zealand monitoring of a feral pig poisoning campaign with warfarin in cereal baits showed a non-target population reduction associated with the baiting campaign (Clarke 1993).

Hunt (1998), Young (2000) and O'Donovan (2002), summarized rigorous baiting protocols which have been developed by CSIRO in partnership with Environment ACT and are used by NSW NPWS. These protocols were developed to reduce non-target takes.

1. Free feeding with unpoisoned soaked grain for ten days.
2. Placing 1 kg of free feed grain at a minimum distance of 100-200 metre intervals along established trails. Identification of tracks of target and non-target species is facilitated on roadside verges where there is a lack of vegetation and sand plots can be placed.
3. Placing the bait in prime feeding areas of pigs.
4. Checking baits every day/alternate days to identify the feeding of target species and the absence of non-target species.
5. Suspending baiting in areas where non-target species are identified on bait stations.
6. Excluding all areas from the baiting program where rare species are known to exist, such as the Broad-toothed Rat, *Mastacomys fuscus.*
7. Using the minimum concentration of poison (at 0.13%) and amount of bait (3x1 kg) sufficient to kill a pig. Laying a maximum of three poison baits (3 kg) at any one bait station.
8. Dyeing poisoned grain green or blue and identifying poisoned bait stations with a coloured marker.
9. Covering poisoned baits with vegetation or earth. Braysher et al (1993) however found that covering baits with leaf litter did not reduce the take by some non-target species.
10. Picking up all uneaten poisoned grain after two to three days.
11. Continuing free-feed baiting after poison baits taken. Re-laying poison baits where necessary after a few days break.
12. Conducting poisoning programs in autumn when feral pig consumption is greatest and reduced risk of take by birds.
13. Conducting pre and post counts/assessment of bait uptake and monitoring the areas of pig disturbance to measure the effectiveness of the program. Bait sites mapped and numbered to compare effectiveness of programs from year to year.
14. Trapping in areas where pigs are considered ‘bait shy’ or where non-target species are consistently disturbing bait stations, and as a follow up to the warfarin baiting program.
15. Coordinating control programs with neighbouring National Parks and Nature Reserves in the ACT and NSW.

The use of three consecutive poisoning nights may increase the effectiveness of poisoning campaigns, but it could also reduce the non-target impacts. This is because the longer period of baiting allows lower concentrations of warfarin to be used, which reduces the chance that a non-target animal will be poisoned (Hunt 1998, Young 2000 and O'Donovan 2002).

Warfarin is not persistent in sub-lethally poisoned animals and hence is a low hazard in secondary poisoning terms, especially in comparison to second-generation anticoagulants (McIlroy 2004). Warfarin undergoes relatively extensive metabolism and the water-soluble metabolites are readily excreted in the urine (Eason and Wickstrom 2001). O'Brien et al (1987) reported a rapid decline in warfarin concentration in all tissues of pigs fed one or two doses. However, feral pigs that die of warfarin poisoning will still retain warfarin in tissues such as the liver, and this constitutes a secondary poisoning risk (Saunders et al 1990).

‘One-shot’ Warfarin

Warfarin used in grain has a low toxicity when ingested once (47.2%) compared with its use over 2 and 3 days (83.8% and 86.3% respectively) (Hone and Kleba 1984). This means that the efficiency of control programs using warfarin, are lower than when using other toxicants which are toxic after one dose, since 2-3 nights of poisoning must occur. In addition, there is no guarantee that feral pigs will return to the same place to feed after the first day (Parker & Lee 1995). Thus the efficiency of warfarin could be improved through the development of a 'one-shot' encapsulated warfarin delivery system. However, unless the toxin delivery system was target specific, this could potentially result in increased non-target impacts in comparison with multi-dose warfarin.

In Queensland fresh meat is the preferred bait as grain cannot be aerial delivered (Mitchell 2003). The development of a one-shot warfarin capsule which can be delivered aerially and in meat could enhance feral pig control, especially in remote areas (Mitchell 2003). The theory behind one-shot warfarin is that a warfarin capsule with enteric coating will release warfarin slowly over 48 hours after ingestion. In theory, the capsule would pass through non-target animals before it was digested, whilst pigs due to a different post prandial response (post consumption digestion) would retain the capsule till it was digested (McIlroy 2004). If this theory is correct, then the target delivery system would be target specific.

Commercial harvesting of feral pigs (see below) is a popular method of control in some areas of Australia if conducted responsibly. Commercial harvesting may positively impact on biodiversity, and as such may be a valuable feral pig control tool. New Zealand previously contributed to the European wild boar market but this has ceased due to anticoagulant (brodifacoum) contamination of pig carcasses, following possum and rodent control operations (Eason et al 1999) It is recommended that a nine-month withholding period be implemented in these areas (Eason et al 1996). Whilst warfarin, is a first generation anticoagulant and doesn't persist in pigs for any length of time (O'Brien et al 1987), consumer safety, market perception and consumer confidence are important issues. A withholding period for harvested pigs should be imposed in all areas where warfarin is used (Robert Parker, quoted in dialogue in Lapidge 2003). This should include areas surrounding national parks where warfarin is used that have an active feral pig harvesting industry nearby, in order to safeguard market access and consumer safety if the use of warfarin increases.

1.7) Other toxins not currently used in Australia

<u>1.7.1 Other anticoagulants</u>

Brooks et al (1988) and McIlroy (2004) have reviewed other anticoagulants agents for feral pig control and concluded that these anticoagulants, such as coumatetralyl, diphacinone, pindone (all first generation anticoagulants) and brodifacoum, bromadiolone and flocoumafen (all second generation anticoagulants) offered no real advantages over warfarin.

- Coumatetralyl (hydroxycoumarin)

This anticoagulant has been trialed in pigs and apparently can reduce the palatability of baits, however this can be masked with lures (Henderson et al 1993). It has a similar mode of action and properties to warfarin (Eason and Wickstrom 2001). The LD_{50} is 1-2 mg kg^{-1} when given over 1-7 days (Hone and Mulligan 1982). It has produced 86% mortality in penned pigs with a dose range of 7.5-20 mg kg^{-1} over 1-4 days (Henderson et al).

Trials in Pakistan, in a collaboration between Pakistan authorities and the United States Department of Agriculture (USDA) comparing warfarin and comatetralyl found no bait or poison shyness, however significant non target deaths occurred despite attempts to limit non-target takes (Brooks 1985). Furrow baiting reduced non-target takes.

- Diphacinone (indandione)

Eason and Wickstrom (2001) stated that pigs are generally tolerant of diphacinone. The LD_{50} has been reported as 150 mg kg^{-1} and needs to be ingested over several days to be a lethal dose (Hazelton 1957 quoted by John Eissman USDA, pers comm 2004; Eason and Wickstrom 2001). However, this figure was established after research conducted on 3 domestic pigs (John Eissman USDA, pers comm 2004).

Keith et al (1990) also investigated the use of diphacinone in pigs and found no mortalities when applied at 0.6 mg kg^{-1} for 2 days. No clinical signs associated with anticoagulant poisoning were reported.

Recently, the USDA has been attempting to register an aerial rodenticide containing diphacinone to assist in bird conservation in Hawaii (John Eissman USDA, pers comm March 2004). Pigs are heavily harvested on Hawaii for human consumption and consequently non-target bait take and residues are important issues. In an attempt to determine the residues associated with aerial use of diphacinone bait (50 ppm diphacinone) a telemetry study was conducted in a baited area. Nine of ten pigs were killed by diphacinone rodent baits and a further 5 dead pigs were found in the study area (John Eissman USDA, pers comm March 2004). The majority of pigs had detectable diphacinone residues in muscle and liver samples.

- Pindone (indandione)

No data has been published on the use of pindone in feral pigs (McIlroy 2004).

- Brodifacoum (hydroxycoumarin)

Brodifacoum has not been used to deliberately kill pigs in New Zealand or Australia but it's use for possum and rodent control has lead to deaths of pigs in New Zealand (McIlroy 2004). Residues have also been detected in feral pigs where rodent control with brodiafacoum has occurred (Morris et al 2003). It has a reported LD_{50} of only 0.1 mg kg^{-1} and only a single dose of toxin is required to induce death (Eason and Wickstrom 2001). Eason and Henderson (1991) found that brodifacoum was highly toxic to feral pigs at a single dose of 2 mg kg^{-1}.

Brodifacoum persists in sub-lethally poisoned animals for long periods of time (O'Brien et al 1987). This attribute potentially leads to high non-target hazards through secondary poisoning. Brodifacoum is extremely insoluble in water and binds strongly to soil and is only slowly degraded by soil micro-organisms (Eason and Wickstrom 2001). Extensive surveys of wildlife in New Zealand have found contamination of animals with brodifacoum (Eason et al 1999). It's use in New Zealand is now limited to areas such as offshore islands for one off eradications (K. Broome DOC, pers comm May 2004). It is not registered for use against feral pigs but pigs may be killed (deliberately or as non-target by catch) in areas where the baits are laid against other pests.

The use of brodifacoum for feral pig control was trialed by the USDA in Pakistan (Brooks 1985). It was found that 0.025% brodifacoum may be effective when given under a multiple dosing regime basis. However, a finding was also made, that one of the most effective methods of control in that area may be economic utilization of feral pigs. This entails hunting and the use of brodifacoum in hunting areas is contraindicated due to meat residues (see above).

Although an effective toxin for feral pigs, the persistence of this toxin in sub-lethally dosed animals and the environment means that it is not suitable for use in Australia.

- Bromadiolone and flocoumafen (hydroxycoumarin)

These are both second-generation anticoagulants and have an LD_{50} of 3 mg kg^{-1} (Hone and Mulligan 1982) and 60 mg kg^{-1} (Eason & Wickstrom 2001) respectively.

1.7.2 Cyanide

- *Use of Cyanide*

Both sodium or potassium cyanide have been recommended as a humane alternatives to 1080 by the RSPCA (Sherley 2002). Despite this, cyanide is only used as a vertebrate pesticide in Australia in M-44 mechanical ejectors for wild dog control under permit in Queensland and previously in cyanide fox baits trialed in Western Australia. The use of cyanide for feral pig management is current being investigated by the Qld DNRME (Mitchell 2003).

Cyanide can be used either as a paste or encapsulated in pellets as a powder. The LD_{50} of cyanide for feral pigs is approximately 3.5-4.5 mg kg^{-1} (Hone and Mulligan 1982). Cyanide as a paste is fairly unstable, has significant occupational health and a safety issues since it can release HCN vapour, and is more likely to kill non-target species due to the way it is generally applied (Eason & Wickstrom 2001). Encapsulated cyanide pellets offer greater stability and is less likely to harm operators when used correctly, since they do not produce HCN gas (Eason & Wickstrom 2001). Encapsulated cyanide is also less likely to cause bait aversion since encapsulation lowers the chances of sublethal dosing (John Parkes Landcare Research pers comm April 2004). Cyanide has the further advantage of having an antidote, although its application must be extremely rapid and can be controversial (Eason & Wickstrom 2001).

Manufactured cyanide pellets from New Zealand have been found to be extremely tough and indigestible in pigs and needed to be cracked in the mouth to be effective (Mitchell 2003). The use of cyanide tablets in pigs was similarly found to be ineffective by New Zealand researchers as well (Hendersen et al 1993). However, cyanide pellets have been effectively used for possum control in New Zealand (Eason & Wickstrom 2001). Sub-lethal doses of cyanide can also lead to bait shyness (Eason & Wickstrom 2001).

- *Effect of Cyanide*

Cyanide is not target specific and can affect a wide range of animals. It is a rapidly acting, cellular toxin that generally causes death within minutes of the first onset of symptoms (Saunders et al 1995). This was found to be the case when feral pigs absorbed a dose of cyanide in the mouth, however when penned feral pigs ate cyanide tablets whole, death did not occur due to vomiting (Mitchell 2003). Compressed cyanide inside dog biscuits was found to be lethal to feral pigs in pen trials, but not in field trials (Mitchell 2003). The conclusion of Mitchell's 2003 study was that cyanide could be a useful means of feral pig management (especially for disease surveillance) provided an innovative method of delivery could be developed.

Clinical signs of cyanide poisoning in various animals include; salivation, voiding of faeces and urine, gasping for breath and staggering, collapse and convulsions (Eason & Wickstrom 2001). The biomagnification of cyanide in food webs is considered unlikely by Eason and Wickstrom (2001) since cyanide is rapidly detoxified by sub-lethally dosed animals and excreted in urine. On exposure, cyanide is rapidly degraded by micro-organisms to harmless ammonia and water (Eason & Wickstrom 2001).

1.7.3 Cholecalciferol

Eason and Wickstrom (2001) reviewed the toxicity and use of cholecalciferol. Cholecalciferol is a relatively new toxin in NZ for rodent and possum control but was used in the 1980's in the USA, Europe and Australia as a rodenticide. It acts by disrupting calcium metabolism. It induces various clinical signs including loss of appetite, lethargy and rapid, shallow breathing. The speed of onset of these symptoms and their severity are dose dependant. In dogs and cats, nausea, vomiting, diarrhoea, renal failure and gastrointestinal haemorrhage can occur. Addition of calcium to the poison increases the effectiveness of the toxin, but death takes 4-7 days. Treatment for poisoning is complex, but is possible. Cholecalciferol was voluntarily withdrawn from sale as a rodenticide in Australia in the late 1980s because of unexpected hazard (deaths) to domestic dogs.

Cholecalciferol is relatively expensive in NZ, where it is used. Current research should focus on primary and secondary non-target risks, it's relative humanness and it's persistence in the environment and animals (Eason & Wickstrom 2001). It is possible that primary or secondary toxin intake can occur, so it is strongly recommended that a 1-3 month withholding period for game harvesting be observed in treated areas (Eason and Wickstrom 2001).

1.7.4 Zinc phosphide (ZP)

Little information is available regarding the potential of ZP for feral pig control (McIlroy 2004). In Pakistan, the use of encapsulated ZP (0.7grams in 100grams of bread dough) led to an 80-90% reduction of wild boar activity in rice fields (Khokhar and Rizvi 1998). Capsules of ZP were placed in dough and sealed with paraffin to attempt to disguise the smell (strong garlic odour that can promote bait shyness) and allow maximal absorption of the toxin. Nine dead pigs were found in adjoining areas implying that the speed of action of the toxin is less than cyanide. The use of ZP was also trialed in Pakistan in 1985 (Brooks 1985) and was not successful due to poor palatability.

Mitchell (2003) had planned to investigate the use of ZP for disease surveillance, but concluded that the length of time for death to occur (hours) was too long to allow the use of ZP for this purpose. ZP also has the drawback of being toxic to many birds (Mutze 1989).

1.7.5 Strychnine

Strychnine has been banned in NZ due to hazards to operators and on the grounds of humanness (Eason and Wickstrom 2001). It is no longer registered for use in Australia. According to Eason & Wickstrom (2001), strychnine is a stable, bitter alkaloid that retains it's toxicity indefinitely in baits and poisoned animals. It is highly toxic to a wide variety of animals. That is, it is not target specific. Poisoned animals can die in less than an hour or can take 24 hours or longer if a low dose is received. Signs include convulsive seizures for up to 45 minutes or more before death (Rammell and Fleming 1978). Feral Pigs have also been found to be somewhat resistant to strychnine (Eason 1989).

1.7.6 Fenathion ethyl

Luci-Jet® is a registered organophosphorous insecticide for the control of blowfly strike, lice and keds on sheep (McIlroy 2004). It has reputedly been used to kill feral pigs illegally in the past. Research by McIlroy (1985) has shown that pigs are more tolerant to fenathion than birds, therefore its use poses considerable risks to non-target birds. Death in pigs occurs 7-44 hours post dosing and males are more sensitive than females (McIlroy 1985).

2. AERIAL BAITING OF FERAL PIGS

Aerial baiting involves application of feral pig baits from a specially modified fixed wing plane or helicopter. The technique is a useful means of reducing the impacts of feral pigs in broad-scale, remote or inaccessible regions, especially during the wet season in the north of eastern Australia. Aerial baiting in semi-arid rangelands is reportedly most effective during dry seasons when aerial baits are delivered around watering points, and is less likely to be successful during seasons of high food abundance. The lack of feral pig free-feeding in the current planning of aerial baiting campaigns, and the potentially large non-target takes can reduce the effectiveness of aerial baiting campaigns.

Aerial baiting to reduce feral pig densities is a widely used management technique in Queensland, but is illegal in most other states except under permit. The technique is particularly effective for broad-scale integrated feral pig control campaigns involving multiple properties and land tenures. This management technique may also be necessary in the face of an exotic disease outbreak, such as Foot-and-Mouth Disease, in Australia. The effectiveness of aerial baiting to control feral pigs has recently been researched by Mitchell (1998), and Fleming et al (2000).

3. FENCING

Fencing to exclude feral pigs is expensive in terms of construction and maintenance and is only suitable for small, high value areas such as lambing paddocks or nesting grounds. Feral pig-proof fencing designs have been developed using a hinge joint fence with an outrigger electric wire and where maintained correctly, feral pigs should be indefinitely excluded. Overseas experience has shown that exclusion fencing can enhance control operations to allow feral pig eradication over relatively large areas, with the technique being particularly applicable to island feral pig eradications.

Fencing is not a popular method of managing feral pigs in Australia. In responses to surveys conducted by NSW Agriculture and PAC CRC fencing was selected as the least popular form of feral pig management (West and Saunders 2002; PAC CRC unpublished data 2004), with only 6% of respondents to the CRC survey, and 1% of respondents to the NSW Agriculture survey electing fencing as a utilised method of control.

Some studies in Australia have shown that fencing can protect valuable enterprises in relatively small areas (Mitchell et al 1977; McIlroy 1993). Examples of enterprises that may benefit are sheep producers through fencing lambing paddocks and orchardists through fencing highly valuable fruit crops. However, the method would also be applicable to biodiversity protection over small, well defined areas, such as ground-nesting bird eggs.

Fencing to exclude feral pigs in Australia has generally been shown to fail eventually due to human error, electrical failure, failure of maintenance or physical damage (Choquenot et al 1996). This coupled with the expense of constructing and maintaining a fence, and the fact that the feral pigs will simply redirect their attentions to another local areas (Choquenot et al 1996) explains why fencing is not a popular means of feral pig impact management. In the end, a feral pig is a determined animal and if something is behind the fence that is particularly attractive or essential a feral pig will likely be able to force its way through.

Fence design in Australia has been shown to be critical in completely excluding feral pigs. Hone and Atkinson (1983) tested 8 fences and only one fence, a hinge joint (8:80:15) fence with a stand-off electric wire was able to exclude pigs during the trial period. However, large reductions in pig passage occurred with other fences that were trialed, even though they were unable to exclude feral pigs completely. However, the success of these fences must be assessed with the knowledge that they were short and easily maintained over the course of a trial. If they were applied across a large area, maintenance would be extremely difficult for long periods of time.

In contrast with Australian experiences, overseas experience with island and mainland biodiversity conservation has shown that fencing can be a successful and viable feral pig management method when used in an integrated pig management strategy (Garcelon 2004).

Garcelon (2004) discussed the use of fencing as part of integrated feral pig eradication attempts in the US. Fencing was used to restrict re-invasion of feral pigs into previously cleared areas on the isolated Santa Catalina Islands, and to prevent feral pigs from entering the mainland Pinnacles National Monument after the feral pigs had been removed. He reported that fencing allows feral pig populations to be divided into manageable units, which allows eradication of local feral pig populations before moving onto the next unit. Thus fencing became part of an integrated control strategy, although the cost of establishing fences in remote areas is high.

The use of exclusion fencing also allows the success of a part completed eradication attempt to be maintained in the event of a stall in proceedings. Otherwise pig numbers can build up to preceding levels and re-colonisation of the treated area would occur. However, again, the cost of maintaining fences indefinitely on islands would be high.

- *Non-target impacts*

Other issues to consider with fencing to restrict feral pig movement are the impact this can have on native animal movements and its associated effects on the likely viability of some populations. Some fencing designs overseas can take into account native wildlife requirements and allow some native animals to pass through or over the fence (Garcelon 2004).

4. TRAPPING

4.1) Use of trapping as a control technique in Australia

Trapping is a popular and widely used method of feral pig management in Australia and overseas. Trapping utilizes baits and lures to attract feral pigs into humane traps. Baits are usually animal carcasses, fermenting grain or both (Caley 1994). Once an animal is trapped, it is humanely destroyed through shooting. Feral pig trapping has the advantages

of being target-specific, humane, commercially profitable if trapped pigs are sold (this only occurs in NSW or Qld), and it can be incorporated into routine property management practices. Trapping does, however, need to be expertly applied since pigs can become trap shy after a negative experience with a trap (Saunders et al 1993). Trapping is most successful when pre-baiting is used and it is carried out in areas of high pig activity when food resources are low (Choquenot et al 1993). However, responsible trapping programs can be labour intensive, since daily trap checking is required and are therefore sometimes expensive.

A number of trap styles are available, from weld mesh 'silo traps' to commercial panel and cage traps. These are documented and reviewed in Choquenot et al (1996). A simple trap can be made from star posts and welding mesh placed in a circle. These traps are relatively inexpensive, can be assembled and reassembled from the back of a utility, and can be left permanently in the one place with minimal maintenance after they are established. They also have the ability to undertake multiple captures. Panel traps and cage traps (box) can be useful since they can be moved, and require little set up time. However, they can only catch and hold a small number of pigs, such as small groups of juveniles or one adult (Garcelon 2004). New technology such as shape-recognition automatic traps and trap lures and monitoring equipment may improve the efficiency of trapping in the future.

Trapping has been assessed as acceptable by the RSPCA provided precautions are taken, such as regular checking and the provision of shelter (Anonymous 2002). 66% of 50 respondents surveyed by the PAC CRC said that trapping was a preferred means of control. Trapping is the most common method of feral pig control in NSW (West and Saunders 2002). Trapping is also used in Western Australia, with some cooperative pig control projects utilizing trapping as the primary control method (Higgs 2002).

The advantages of trapping are (from Choquenot et al 1996);

1. that it can be incorporated into routine land management activities (which improves the economics of this method of control),
2. allows the exact number of pigs killed to be recorded,
3. usually doesn't interfere with normal pig behaviour (eg aerial shooting can lead to pig dispersal),
4. traps can be moved and reused,
5. traps are humane if routinely checked,
6. no risks to dogs such as occurs with poisoning or dogging.

The disadvantages of trapping are (Choquenot et al 1996);

1. not practical for large scale control,
2. labour intensive and relatively costly, trapping is best used as a follow up control,
3. traps must be checked regularly.
4. can be inhumane if not used responsibly

4.2.2 Commercial attractants for trapping

The ability to trap pigs depends on the desire of animals to enter a trap. Fermented grain, whole grain and carcasses are used to attract pigs to the traps. Some interest has been shown by land managers in purchasing commercially prepared bait attractants for feral pig traps. Such baits are being considered for development by private industry for use in the field (M. Smith Animal Control Technologies, pers comm March 2004).

4.2.3 Radio-transmitter, automatic feeders and food dumps in traps

Some novel uses of technology have also been used in the US to increase the efficiency of trapping operations (Garcelon 2004). Trapping operations in remote areas are often planned around a central point with radio transmitters attached to cage trap doors to assess daily trap success. This allows the trap to be checked each day remotely, thus reducing the time and staff resources for all traps to be checked and minimising disturbance in the trapping area. Automatic feeders are also used in traps so that during the pre-baiting period when traps are open re-baiting is not required by staff. Some national parks services in Australia are reported to also use satellite surveillance and automated feeders to increase the efficiency of trapping operations (Braysher 2003).

5. AERIAL SHOOTING

Aerial shooting occurs using appropriately trained staff following approved protocols using helicopters and suitable calibre semi-automatic weapons. It is a useful method of feral pig management in achieving a fast population knockdown in a short time period (Hone 1990b). It allows control over broad areas of land, including areas inaccessible by ground travel, and is possible during all times of the year. Aerial shooting can also encourage broad-scale, coordinated feral pig control campaigns due to its high profile. The technique is generally labour efficient, humane and target specific. Some disadvantages include the high cost (particularly when pig numbers are low), public perception, limitations in heavily vegetated areas and that single annual shoots can be ineffective in keeping pig populations at low levels. As such aerial shooting is best used in combination with other control methods (as part of an integrated control program) to increase the length of time that a reduction in population can be sustained.

Aerial shooting of feral pigs in New South Wales has been a popular method of control since 1980 (Saunders 1993; Bryant 2004). Each animal must be killed or a second shot must be used before moving onto the next animal. Aerial shooting allows for a labour efficient, fast reduction over wide areas of open land that can sometimes be seasonally inaccessible from the ground (Saunders 1993; Dexter 1996).

Aerial marksmen used in government control operations in NSW and Queensland are trained under the Feral Animal Aerial Shooter Training Course (FAAST) scheme. Only FAAST accredited shooters can conduct aerial shooting in NSW (Bryant 2004). The FAAST scheme ensures shooters undergo rigorous and ongoing training, encompassing all aspects of the safe use of firearms, humane destruction of animals and helicopter safety (Pitt 2000). In non-government managed control procedures, aerial shooting may not always be conducted proficiently, since enforceable codes of conduct do not apply outside government departments (Braysher 2003). This could be an impediment to aerial shooting as a control method due to reduced public acceptance, and possible welfare problems.

In Western Australia the Department of Agriculture Western Australia (DAWA) also has a rigorous training process for aerial shooters. Aerial shooters undergo an advanced course which assesses competency during live firing from helicopters. Shooters are required to renew this license every 2 years (Nick Everet DAWA, pers comm May 2004).

In the United States of America, aerial shooting sometimes occurred from slow moving fixed wing aircraft due to cheaper hire rates compared with helicopters (Cody Stemler USDA, pers comm March 2004). However, the humanness of this method would be difficult to guarantee, since no follow up shooting of wounded animals would be possible due to the plane quickly moving on from shot animals.

6. JUDAS PIG TECHNIQUE

The Judas pig technique utilizes a radio transmitter to allow the tracking of a collared feral pig post-capture to locate and destroy other feral pigs in the area. This can allow more efficient tracking and hunting of feral pigs and can help to direct the resources during a baiting campaign more efficiently. It is most effective for use on small and isolated populations, rather than for broad scale control.

McIlroy and Gifford (1997) successfully trialed this method on feral pigs in Australia based on the successful use of the Judas feral goat technique. They reported that the method was useful when the collared animal was a female sow from the same area. They found that all collared pigs came into contact with other pigs upon release, but that only local sows came into regular contact with mobs of pigs after release. This is probably because local sows had already established social groups and adult males are more solitary than sows.

The technique has since been used in the Northern Territory to eradicate a small isolated population of feral pigs that had resisted all previous attempts to eradicate (McIlroy & Gifford 1997). As such it shows promise as a method of eradicating isolated populations (McIlroy and Gifford 1997).

A novel technique of applying a radio-collar to a Judas feral pig has been recently been investigated in the USA (Russ Mason, USDA NWRC, pers comm March 2004). A modified neck snare has been developed which has a radio transmitter attached. After the animal places it's head in the snare it tightens up to a certain point, so the animal won't be harmed by over tightening. The animal then escapes with the snare (and transmitter) around it's neck. This could improve the efficiency of the Judas technique due to lower labour costs associated with trapping feral pigs and fitting collars.

7. SNARING

Neck snaring of feral pigs is a method of control used in the United States (Anderson and Stone 1993). It works by catching a feral pig by the neck and strangling it as it attempts to escape. Pigs generally die quickly, although many can take up to an hour and sometimes pigs can survive extended periods of time whilst trapped in a snare (Cody Stemler, District Field Assistant USDA APHIS, pers comm March 2004). Katahira et al (1993) described snares that were used in Hawaii Volcanoes National Park. A snare consists of a multi-strand cable that is 0.3 cm in diameter and 3.96 m long. The cable is looped into a diameter of 25-40 cm and anchored firmly between two immovable objects such as trees 5-20 cm off the ground. At the lower height snares are aimed to catch smaller pigs, and at the higher height it catches larger pigs. Snares are set in groups of 10-20 and are placed along trails or in areas of recent pig activity. Snares are often used in conjunction with baits to attract feral pigs. Snaring is not a method of feral pig control used in Australia, likely due to humanness, efficiency and target-specificity issues. This method would be unsuitable for large areas.

8. HUNTING AND HARVESTING

8.1) Principles of hunting and harvesting

Hunting of feral pigs is a recreational past time in Australia, and can also provide valuable economic returns to rural communities through tourism and harvested game meat. Game harvesting only occurs in NSW and Qld. Hunting can occur through 'dogging' (see below) or shooting on foot or from vehicles. Pigs are considered one of the major feral animals to be hunted in Australia (Tony English NSW Game Council, pers comm April 2004).

Commercial harvesting of feral pigs can occur via hunting or trapping then slaughter of feral pigs. The harvested pigs are then brought into regional chillers and sold to game meat processing companies such as Wild Game Resources Pty Ltd. Specific health guidelines need to be followed regarding the commercial harvesting of feral pigs for human consumption.

Generally, however, the benefits of hunting and harvesting feral pigs are unquantified. A criticism of hunting as a control method is that non-commercial and commercial hunting may hold feral pig numbers at a point where the benefits of hunting exceeds the cost of hunting. The issue is whether this level of control can reduce feral pig numbers to a level where environmental and economic damage is acceptable (John Parkes Landcare Research, pers comm May 2004).

8.1.1 Non-Commercial Hunting

Non-commercial shooters have been involved with initiatives to protect biodiversity in the past. Hunters assisted with feral pig eradication on Lord Howe Island. In South Australia, during Operation Bounceback, feral goat numbers were lowered by accredited hunters to levels which aided native animals and plant species (English and Chapple 2002).

In NSW, the Game Council of NSW has a statutory obligation to coordinate the effective management of introduced species of game animals and feral animals, and to promote responsible and orderly hunting of these animals on public and private lands (Tony English NSW Game Council, pers comm April 2004). The NSW Game Council comes under the jurisdiction of the NSW Minister for Agriculture. The NSW Game Council with the permission of the relevant land management authority can manage hunting of feral pigs where it occurs on crown land. Currently the NSW Game Council is working with NSW State Forests to improve the management of feral pigs on State Forest estates (Tony English NSW Game Council, pers comm April 2004).

The NSW Game Council is keen to demonstrate the idea that non-commercial hunters are conservationists (Tony English NSW Game Council, pers comm April 2004). To this end the NSW Game Council has an enforceable code of practice (which is to be incorporated into the *NSW Game and Feral Animal Control Act 2002*). This is designed to promote responsible, humane and conservation friendly hunting. The NSW Game Council is also developing a Hunter Education Handbook. Part of the revenue from the NSW Game Council, which will be derived from hunting licenses, will be directed at habitat restoration and control of feral animals. Hunting on crown lands will require a higher level of training and licensing to ensure that hunting is carried out appropriately.

Bryant (2004) reviewed Game Management Plans that were developed in northern Tasmania in order to improve pest management outcomes and a number of problems that had been associated with hunting. These plans have been adapted as wildlife management plans in western NSW in order to control feral pigs and goats, as a direct result of the Lower Murray

Darling Catchment Committee identifying total grazing pressure as an impediment to sustainable grazing practices.

In the north of Western Australia around the Fitzroy River region feral pigs are in locally high numbers. The Sporting Shooters Association of Australia (Northern Territory Branch) has been involved with an initiative with local land managers to reduce feral pig numbers through annual shooting. For the several years now, around 500-600 feral pigs have been removed every year. During shooting operations, data on age and sex parameters have been recorded and provided to DAWA for analysis (Laurie Twigg, DAWA pers comm May 2004).

8.1.2 Feral pig harvesting

The profile and support for wildlife harvesting have increased in recent years with the support of the Standing Committee on Agricultural and Resource Management (SCARM). In 1994, SCARM supported the commercial use of wild animals, provided the use was built on ecologically sustainable principals and considered animal welfare (Choquenot et al 1996). SCARM is now known as the Primary Industries Sub-committee.

Bryant (2004) has reviewed the interest in sustainable utilization of wildlife and listed a recent senate inquiry into Commercial Utilization of Australian Native Wildlife (1998), studies by the Cooperative Research Centre for Tourism, and a session at the 2001 Wildlife Health and Management in Australasia Conference as evidence of this interest in this report.

Commercial harvesting is tightly regulated so as to protect an export industry valued at $10-$40 M annually (Ramsay 1994). For example, in Queensland, all harvesters must have accreditation with Safe Food Queensland, a section of the Department of Primary Industries, and operate to an approved quality assurance program (Anon 2004).

In Queensland during 2001, approximately 240 000 feral pig carcasses were processed at six export licensed processing works after collection from 220 regional chillers supplied by 2100 accredited field harvesters (Anon 2004). The 2002/2003 drought depleted feral pig numbers in Queensland and this reduced the commercial harvest of feral pigs (Anon 2004). In NSW, 120 000 carcasses were harvested in 10 months during 2002 (Bates 2002). The 2002 NSW commercial harvest was approximately 50% of the normal harvest due to the drought depleting feral pig populations (Bryant 2004).

Number of ‘Wild Boar’ carcasses processed in Australia (1990-92), Qld (2001) and NSW (2002 =10 months) (modified from Anon 2004).

Year	1990	1991	1992	2001 (Qld only)	2002 (NSW 10 months)
Carcasses	96 962	101 006	271 133	240 000	120 000

In total since 1998, between 140 000 and 332 000 feral pigs have been inspected annually at game meat processing plants in Australia (John Parkes, Landcare Research, pers comm April 2004).

These rates of commercially harvested pigs, although significant when applied to some local areas are small in comparison to the total numbers of feral pigs in Australia. These figures don’t include the numbers of feral pigs killed by non-commercial hunters each year. Hone

(1990a) estimated that between 3.5 million and 23.5 million feral pigs exist in Australia depending on prior seasonal conditions.

A common criticism of commercial harvesting of feral pigs as a control method is that pigs between 30 and 60 kg are preferred, with pigs under 21 kg often being rejected (Anon 2004). This may encourage some harvesters to only control larger pigs with smaller animals not being controlled. Pigs over 90 kg are also difficult to process. Recently markets have been developed for smaller carcasses and this is a positive step. An additional criticism is that commercial harvesters may only harvest feral pig populations to a level that will sustain the long-term harvest of feral pigs in their area.

Non-Commercial hunters have been estimated to be responsible for up to 15-20% of the annual cull of feral pigs in Australia (Tisdell 1982); however Choquenot et al (1996) believed this figure to be an overestimation. Non-commercial hunting totalled 22.2% of control efforts in a recent NSW Pest Animal Survey in 2002 (Bryant 2004). Nonetheless, effort does not necessarily reflect returns and it is likely that control efforts using other broad-scale techniques (such as baiting or aerial shooting) may produce larger population decreases with similar effort. Figures are not available for the exact number of animals culled by non commercial hunters, since the industry is generally an uncoordinated and ad-hoc enterprise with no central management. Hopefully, regulatory bodies such as the newly established NSW Game Council will be able to quantify the effect that non-commercial hunters and commercial harvesters have on feral pig populations.

An important criticism of non-commercial hunters in Australia is that the desire to hunt feral pigs may lead to translocation of feral pigs to establish new populations for hunting (Hampton 2003). Although this was previously thought to occur, definitive proof has been provided in Western Australia using the known genotypes of feral pigs (Hampton 2003). This obviously increases the range of feral pigs and increases the negative impacts of the species and the costs of management. It can also counteract previous control programs. It must be noted that the extent to which this illegal practice actually occurs has not yet been determined.

There may always be conflicting desires between harvesters and non-commercial hunters who believe that feral pigs are a valuable resource and should be managed as a resource, and land managers who attempt to manage the impacts of feral pigs by reducing feral pig numbers. The long term goal of feral pig management should reflect the fact that feral pigs are a net loss to the community, although they do benefit a small section of the community. Therefore, feral pigs should be controlled to a level which reduce their impact to an acceptable level, or eradicated where possible, rather than that which provides a resource for hunters or harvesters. However, this doesn’t preclude a pragmatic approach being taken to hunting which allows responsible hunting of feral pigs as a supplementary control tool.

8.2) Hunting with dogs

Hunting with dogs ‘dogging’ is commonly practiced in Australia for non-commercial hunting, but the use of dogs as a management tool in feral pig control is uncommon in Australia (Caley and Ottley 1995). Hunting dogs have been used in eradication programs in Hawaii (Katahira et al 1993), and on Lord Howe Island (Miller and Mullette 1985 quoted in Caley and Ottley 1995). In New Zealand hunting with dogs provides the principal means of control, and pigs are only present in substantial numbers where they are protected from hunting (McIlroy 2004). Hunting with dogs may be helpful in Australia to remove residual populations of feral pigs after other control methods have produced a population knockdown, for example trap or bait shy animals or animals that avoid helicopters (Caley and Ottley 1995).

Hunting with dogs involves using 'pig dogs' to locate and catch feral pigs so that hunters can then kill the pig. A dog can 'catch' the pig through physically biting and holding ('pinning'), or by causing the pig to turn and hold it's ground facing the dog ('baling'). Dog breeds commonly used are pure-breds or cross-breeds and include Great Danes, Bull Mastiffs, German Shorthaired Pointers, Wiemeranas and Blue Heelers.

Saunders and Bryant (1988) found that feral pigs could disperse small distances when persecuted or disturbed, but generally returned after a period to their previous home range. McIlroy and Saillard (1989) however documented that feral pigs hunted with dogs did not disperse following hunting. They also went on to report that feral pig numbers were more easily controlled by broad scale methods such as poisoning, although 'dogging' could be useful for disease surveillance and for killing pigs that had survived other control methods. Generally, they found that 'dogging' was not an efficient means of controlling feral pig numbers. However, in New Zealand long distance movements of feral pigs have occurred during hunting with dogs (Nugent et al 2003).

Caley and Ottley (1995) reviewed the use of hunting dogs for removing feral pigs in relation to mob size encountered and the population density of pigs being hunted. They found that dogs were very successful at 'catching' solitary pigs (especially males), and that success rapidly declined as the size of groups of pigs increased. The success of hunting was higher than in the study by McIlroy and Saillard (1989), probably due to the terrain, vegetation and lower experience of the hunted pigs. Caley and Ottley (1995) concluded that the rate of population reduction achieved with hunting as a control method is slow, but that the rate of removal is probably comparable to other control methods at similar pig densities.

There are several disadvantages to hunting with dogs:

1. The use of dogs to pursue and hold pigs is considered inhumane by some welfare groups (G. Oogies, ANZFAS, pers comm quoted in Choquenot et al 1996).
2. The use of hunting dogs can lead to the loss of dogs and the establishment of feral dog populations, which can impact on native animal species (Corbett 2001).
3. The use of dogs may also lead to non-target impacts on native wildlife through depredation. However, no studies have occurred in Australia on the impacts of recreational hunting on non-target fauna (Bryant 2004).
4. It can be expensive if full cost-recovery is accounted for. However, most hunting is carried out as a recreational pursuit and this is unlikely to be relevant

Dogging is used extensively in the USA (Garcelon 2004). It is particularly effective when pigs are in low densities and is not affected greatly by pig behaviour since dogs can generally detect hiding pigs (Garcelon 2004). Garcelon (2004) reported on the use of 'bay dogs', or dogs which do not physically attack pigs but instead subdue the pig by barking until the hunter arrives to humanely dispatch the pig. For this purpose Catahoula and Plott breeds are used.

Electric collars can also be used in the US to train dogs to avoid native animals and this method can be especially useful in areas with endangered species (Garcelon 2004). However, the use of electric shock collars has been under intense debate recently, with some veterinarians believing it is a legitimate training aid and some believing it is inhumane. This is evident from the numerous letters recently published in the Australian Veterinary Journal regarding this debate.

Other aids for 'dogging' are the use of Kevlar and nylon vests to protect dogs from injury, and the use of transmitting collars on dogs to prevent loss of dogs during hunting operations.

8.3) Ground shooting

Ground shooting of feral pigs needs to be undertaken with the appropriate calibre firearms (eg. .243 rifle), with rounds fired at the heart/lungs target zone that reliably produces the most humane outcome (Tony English NSW Game Council, pers comm April 2004).

Ground shooting is a target-specific and humane feral pig management technique if it is undertaken responsibly by experienced shooters. It is often opportunistically incorporated into existing control practices. The technique has the added advantage of allowing commercial utilization of pigs shot and/or providing revenue for farmers from paying recreational hunters. Shooting from the ground is, however labour intensive, and may cause dispersal of pigs. It is generally not suitable for controlling feral pigs in large areas (Saunders and Bryant 1988).

10. BIOLOGICAL CONTROL

Biological control of feral pigs in Australia could theoretically be attempted using African swine fever (ASF) and classical swine fever (CSF). Both viruses are passed on by direct contact and fomites and are highly contagious, with porcines being the only natural vertebrate hosts (Geering et al 1995). Rates of mortality from acute infections of both diseases can be in excess of 90%, generally significantly greater than other feral pig control methods discussed herein (Hone et al 1992). However, Choquenot et al (1996) cast doubts over the usefulness of CSF due to the disease remaining in low prevalence in areas that have previously had outbreaks of the disease.

An intentional or accidental release of either ASF or CSF could potentially decimate the Australian pork industry in Australia, currently valued at $2.58 billion annually, and exports of domestic (currently $270 M p.a.; Australian Pork Ltd website- www.apl.au.com) and wild pork (currently $15 M p.a.), valued at ~$285 million annually. Hence, biological control of feral pigs in Australia is unlikely to ever occur. The one exception to this rule could be the deliberate release of ASF to control widespread feral pig populations in the event of an outbreak of the potentially more financially disastrous foot-and-mouth disease if the disease has been shown to be endemic in feral pigs (Choquenot et al 1996).

11. HABITAT MODIFICATION

Feral pigs require vegetation and water daily for survival, especially in drier and hotter areas of Australia (Choquenot et al 1996). The removal of vegetation in order to remove harbourage sites for feral pigs is however not recommended, as it can affect other benign species using the habitat (Hone 1984). The restriction or removal (bore drains) or open water sources could be a useful means of limiting feral pig numbers and facilitating the trapping of feral pigs at point-source waters. The conversion of open artesian bore tanks and drains to sealed tanks and pipes is a process currently occurring in the semi-arid rangelands of Queensland and New South Wales.

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