Invasive Animals Cooperative Research Centre

Development of cyanide for feral pig and fox control

M. Gentle, C. Eason, D. MacMorran,
P. Aylett and D. Aster

Invasive Animals CRC

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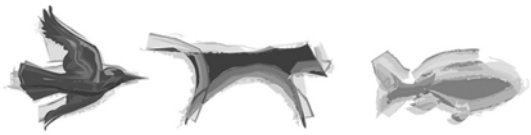
"Together, create and apply solutions"

Development of cyanide for feral pig and fox control

Research 2005–2010

Matthew Gentle, Charlie Eason, Duncan MacMorran,

Paul Aylett and David Aster



Development of cyanide for feral pig and fox control
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Postal address: University of Canberra, ACT 2600.

Office Location: University of Canberra, Kirinari Street, Bruce ACT 2617.

Telephone: (02) 6201 2887

Facsimile: (02) 6201 2532

Email: contact@invasiveanimals.com

Internet: http://www.invasiveanimals.com

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Contents

Summary **1**

1. Introduction **2**

2. Feral pig trials **4**

2.1 Background research 4
Eason and Henderson (1991) 4
Mitchell (2003) 4
Elsworth et al (2004) 4
Summary of previous research 5

2.2 Feral pig trials 2005–2007 5
Enclosure trial 1 5
Enclosure trial 2 7
Enclosure trial 3 10
Enclosure trial 4 13
Enclosure trial 5 14
Discussion 16

2.3 Landcare Research trials 2007 17

2.4 Feral pig trials 2007–2008 18
Enclosure trial 1 18
Enclosure trial 2 21
Discussion 22

2.5 Connovation enclosure trials 2008 22
Discussion 25

2.6 Emissions trials 2010 26
Background 26
Results 27

2.6 Connovation enclosure trials 2010 28
New Zealand trial 29
Australian trial 31
Discussion 31

3. Fox trials **32**

3.1 Background 32

3.2 Trials April–May 2008 34

Methods 34
Results 35
Discussion 39

3.3 Trials April–May 2009 41
Methods 42
Results 44
Discussion 50

4. General discussion 51

5. Recommendations for future research 53

5.1 Cyanide and feral pigs 53

5.2 Cyanide and foxes 54

6. Concluding remarks 55

7. Approvals 56

Animal use and experimentation 56

Field testing 56

8. Acknowledgements 56

9. References 57

Summary

Cyanide is a fast-acting toxin that has great potential for use as a disease sampling and research tool for invasive species such as feral pigs and foxes. Both species can be successfully targeted using poison baits, but current registered toxins are not suitable for disease sampling due to considerable delays between consumption and death.

Incorporation of cyanide into a stand-alone bait for both pigs and foxes would be the preferred product for dropping animals quickly for disease surveillance. The research detailed in this report focused on such products. We completed pen trials on feral pigs using a variety of bait packages, ejectors and cyanide formulations (powder, paste and liquid). Despite considerable successes, the results from these trials indicated that, with current encapsulation technology and at 'pig-size' doses, it appears difficult to disguise the distinctive smell and taste of cyanide. This in turn results in difficulties delivering effective lethal doses (since the pigs do not eat enough bait). It is uncertain whether consistent results suitable for disease sampling of feral pigs (60–80% efficacy would be needed) can be achieved with the current encapsulation and formulation technology. The mechanical ejector and sodium nitrite show more immediate potential for general control and perhaps also disease sampling of feral pigs.

The products developed for feral pigs, particularly the cyanide paste, showed enough promise to warrant field testing on foxes. Early results indicated that when baits are consumed, foxes are highly susceptible to cyanide. However, despite the fact that free-feed baits were readily consumed by foxes, baits were mostly rejected once cyanide had been added. From observations gathered during the field trial, we concluded that the detectability, environmental instability of cyanide and desiccation/ contamination of the carrier reduced the palatability and effective delivery of cyanide to foxes. We assumed that odour cues were largely responsible for foxes detecting and rejecting cyanide baits. We recommend that to reduce these cues and so improve the palatability and delivery of cyanide to foxes, the toxin should be better encapsulated, either chemically or physically.

Nevertheless, given the toxicity of cyanide to foxes, even a slight improvement in the palatability of the toxic bait may be enough for this technique to be successful. Further work on either foxes or pigs should consider a more systematic approach, highlighting design specifications based on our findings, before further field testing is done.

This report provides an overview of a series of pig- and fox-baiting research projects conducted 2005–2010. It is intended to collate and summarise the outcomes of these unpublished projects, including the completed pen and field trials, and provide recommendations for future research. This review will provide a useful reference document to support further research.

1. Introduction

Feral pigs (*Sus scrofa*) are a major vertebrate pest of Australia, causing more than $100 million damage to agriculture (Choquenot et al 1996). Perhaps more importantly, they pose a significant threat to livestock producers and public health as carriers of endemic and exotic diseases (see Henderson 2008, 2009 for review). As a result, considerable effort and expense is undertaken each year for feral pig control and disease surveillance. Current surveillance and monitoring techniques (such as helicopter or ground shooting) are highly intrusive and may disperse animals, complicating the success of such operations. Improved techniques for rapid disease sampling would be highly beneficial for exotic disease contingency planning and managing the impacts of this serious vertebrate pest.

One potential technique for surveillance and monitoring may be to poison animals using a fast-acting toxin. Such a sampling technique would be easy to initiate, be time and labour efficient and would reduce the potential to disperse the target population (Mitchell 2003). Monitoring sites could be established within the area of interest to contribute information on disease prevalence, spread, vaccination rates, and to help monitor population abundance (Algar and Kinner 1991, Lugton 1991, Mitchell 1993).

Currently, two toxins are registered for feral pigs in Australian states and territories: phosphorus and sodium monofluoroacetate (1080). Phosphorous is available to landholders but is not recommended due to welfare considerations and potential non-target impacts (Choquenot et al 1996, McGaw and Mitchell 1998). Fluoroacetate is widely used, but there are disadvantages to its use. The susceptibility of individuals appears to vary considerably, with some feral pigs surviving very high doses (McIlroy 1983). Vomiting is frequently reported (McIlroy 1983, Sheehan 1984), potentially reducing the absorption of the toxin (and hence its effectiveness) and increasing the exposure of non-target animals to vomitus. Also, the residue found in carcasses could pose a secondary poisoning hazard to non-target animals including humans (Gentle et al 2005).

Several other toxins for feral pigs have been identified, including warfarin, sodium nitrite and cyanide. Warfarin is an anticoagulant that has been shown to kill pigs effectively (O'Brien and Lukins 1990). Unlike fluoroacetate, it is more toxic to pigs than most other likely consumers, does not induce vomiting, and has an antidote (Vitamin K). However, due to its mode of action (anticoagulant) and long time to death (weeks) (eg Choquenot et al 1990, Parker and Lee 1995), there are serious welfare concerns with warfarin (Eason and Henderson 1991, Sharp and Saunders 2004). The extended period until death also makes warfarin unsuitable for disease surveillance purposes.

Sodium nitrite has been recently identified as a highly suitable toxin for feral pig control and offers many advantages over current toxins (Cowled et al 2008). It is a readily available product, is cheap and is safe to handle. Nitrite toxicosis in pigs is relatively quick (death occurs ~60 min after consumption), potentially reversible (ie with treatment of an available antidote) and results in low carcass residues, with negligible secondary poisoning hazard (Lapidge et al 2009). While toxin and carrier (bait) formulations are still under refinement, nitrite is likely to be registered for feral

pig control in Australia in 2012–13 (S. Lapidge, Invasive Animals CRC, pers comm 2010).

Despite their applicability for broadscale control purposes, none of the above toxins (fluoroacetate, warfarin, phosphorus and sodium nitrite) causes rapid death, making them less suitable for disease-surveillance purposes. Cyanide is known as a fast-acting and potent toxin (see Eisler 1991 for review). It is rapidly absorbed from the stomach, lungs, mucosal surfaces and skin. Cyanide inhibits mitochondrial cytochrome oxidase and hence blocks electron transportation, resulting in decreased oxidative metabolism and uptake. Essentially, it prevents the body's cells from receiving oxygen, which particularly affects the heart and brain. Initial symptoms from cyanide intoxication include headaches, faintness, excitement, anxiety, a burning sensation in the mouth and throat, breathing difficulty, increased heart rate and hypertension. Nausea, vomiting and sweating are common. Later effects include convulsions, paralysis, respiratory depression, coma, pulmonary oedema, arrhythmias, bradycardia and hypotension (Eisler 1991, Way 1981, Baskin and Brewer 1997, Manbir Online 2007).

The use of sodium or potassium cyanide as a fast-acting feral pig toxin appears promising. When presented in bait form to free-ranging feral pigs, the rapid toxin action means carcasses would be likely to be found close to the bait location. So, cyanide would be ideal for examining and collecting carcasses for disease sampling and generating population indices — especially for species targeted with poison baits, such as feral pigs and foxes. Cyanide also has the potential to be a suitable toxin based on humaneness and effectiveness criteria (Gregory et al 1998, Eason and Henderson 1991).

In recent years, a number of research projects have attempted to develop a suitable bait presentation and technique for feral pigs and/or foxes (eg Eason and Henderson 1991; Mitchell 2003; Elsworth, et al 2004; Aylett et al 2006; Fisher et al 2007; Gentle et al 2007, 2008; Aster et al 2009). This work has been completed as part of the general push to investigate new toxins for feral pig control and disease sampling and has been funded from a variety of sources including state, federal and international funders. This review is intended to collate and summarise the outcomes of these projects, including the completed pen and field trials, and provide recommendations for future research. The summary will provide a useful reference document to support further related research.

2. Feral pig trials

2.1 Background research

There have been a number of studies assessing cyanide as an alternative toxin for feral pig control. The outcomes of these trials provide useful background to the current research, and are summarised in the section below.

Eason and Henderson (1991)

Eason and Henderson (1991) assessed several toxins for feral pig control in New Zealand. Cyanide was highlighted as a suitable toxin based on humaneness and effectiveness. However, pigs rejected baits immediately after initial sampling, indicating that improved (encapsulated) cyanide formulations would be needed to ensure bait acceptability. Further development was discontinued due to insurmountable bait palatability issues.

Mitchell (2003)

Mitchell (2003) completed a total of 10 pen trials using potassium cyanide (KCN) on captive feral pigs in north Queensland. Initially, testing of a batch of Etox capsules (Connovation Pty Ltd, New Zealand) in a field situation only yielded one feral pig carcass from 55 bait takes. Due to this failure, pen trials on captive feral pigs were done to determine the palatability and lethality of the capsules. Ingestion of unbroken Etox capsules 'did not result in any symptoms or death', although one pig did succumb quickly (collapse after 2 min, death after 7 min) after cracking and partially consuming the tablet. Later analyses of capsules revealed the intact coating had failed to dissolve and therefore cyanide was not absorbed. As a result, an additional four presentation techniques were presented to five pigs each: 1) 300 mg of KCN mixed with lanolin, 2) KCN and vegetable oil in a 1 ml gelatine capsule, 3) 500 mg KCN in a hollowed-out dog biscuit sealed with lanolin, and 4) 500mg KCN inside a gelatine capsule placed inside a hollowed dog biscuit. The first and second combinations failed to provide any symptoms, while the third and fourth packages produced symptoms including uncoordination and vomiting, but did not result in any deaths.

A subsequent batch of Etox capsules (containing 600 mg of KCN coated with a dog biscuit material) was tested in another pen trial. All five pigs succumbed to the toxin with death within 2 to 3 min (Mitchell 2003). Outcomes from this work indicted that when cyanide is presented in an effective manner captive feral pigs are highly susceptible to the effects of cyanide (Mitchell 2003). This success prompted field testing in two field trials. Despite some success in removal of baits and capsules by feral pigs, no carcasses were found.

Elsworth et al (2004)

Elsworth et al (2004) presented captive feral pigs with the same formulation of Etox capsule that proved successful in earlier pen trials by Mitchell (2003). A total of 15

pigs were presented with cyanide capsules. From these, four pigs died, eight showed symptoms and three showed no obvious ill effects. Pigs that died took between 12 and 40 min to succumb to the toxin.

The results by Elsworth et al (2004) basically confirmed the earlier findings of Mitchell (2003). Pigs that ingested the capsules without fracturing them, or broke the capsule and ejected most of the contents may or may not have shown signs of illness but subsequently recovered. Pigs that died had cracked the capsules in the mouth and ingested sufficient powder for a lethal dose. The differences in mortality was attributed to an ineffective delivery technique: either the tablet failed to dissolve or, when cracked by the animal, the cyanide inside the tablet caked sufficiently to allow the pig to eject (spit out) sufficient cyanide to reduce its lethality. In addition, when tablets were inserted into fresh meat (an existing bait substrate for feral pig control), most pigs consumed the bait but not the tablet.

Summary of previous research

Findings from these studies indicate that there are significant problems with both the formulation and delivery of cyanide that hamper the application of the technique to feral pigs. It is envisaged that cyanide delivery needs to be improved through changing the formulation (eg a non-caking powder, liquid or gel) or delivery (eg a toxic rod or capsule within bait). Such changes should prevent the toxin from being spat out before a sufficient dose is ingested. An alternative approach would be to ensure that cyanide formulations remain lethal and fast-acting if swallowed by the animal.

The projects described below aimed to improve on these previous attempts of cyanide delivery to make it practical for use in feral pig disease surveillance and monitoring.

2.2 Feral pig trials 2005–2007

The following is a summary of Gentle et al (2007) and unpublished reports from collaborators Connovation, as part of the project funded by the Wildlife and Exotic Diseases Preparedness Program (WEDPP): *Development of cyanide bait for rapid disease sampling and surveillance of wild animals*.

Enclosure trial 1

In August 2005, Connovation developed a prototype capsule design for delivering cyanide to feral pigs. Although these capsules were conceptually similar to the brittle capsules used for foxes (eg Algar and Kinnear 1991), a compressed spring was added in an attempt to improve delivery. When the capsule is bitten the bite force cracks the capsule, releasing the spring tension, which in turn distributes the cyanide powder in the mouth. The cyanide then reacts with the saliva and kills the animal. The toxic capsule formulation contained up to 2000 mg of cyanide and bulking agent, encapsulated in palm stearine and crystalline wax (see Figure 1). Cyanide is highly reactive with moisture, so wax capsules were used to seal the cyanide from contact

with air and humidity. Sealed capsules were coated with palatable food stuffs (eg wheaten dough and ground dog biscuits) to encourage consumption (Figure 2).

Pilot trials on domestic pigs in New Zealand using a non-toxic, powdered food dye (as a cyanide substitute) showed that: 1) domestic pigs were capable of consuming the capsule, and 2) the ejector mechanism distributed the powder within the animal's mouth (D. MacMorran, Connovation, pers comm 2005).

Figure 1. The empty delivery capsule
Capsule with compressed spring ready for cyanide insertion (left), and capsule with spring extended (right). After the cyanide is inserted, the end of the capsule is sealed. The capsule is then coated in an attractive bait substrate.

Following this success, captive feral pigs were tested at Robert Wicks Pest Animal Research Centre (RWPARC), Inglewood, southern Queensland. Pigs were initially presented with non-toxic bait to habituate them to eating the bait (ie free feeding). After several individual pigs successfully ate the non-toxic bait, toxic capsules (containing 900 mg cyanide) were presented to two pigs. A dose of 900 mg of cyanide was thought sufficient for pigs >100 kg, given that a lethal dose is 5.8–8.2 mg/kg KCN (calculated from Couch and Bunyea 1939). One pig was housed individually in its own pen (Figure 3), while the second pig was housed with 19 other pigs in a group pen. The individually penned pig bit the capsule, rapidly ejected the capsule (including most of the contained cyanide) and subsequently failed to show any ill effects. However, the pig in the group pen quickly picked up, chewed and swallowed the capsule and subsequently died.

Following this pilot trial, lethal cyanide capsules were presented to 10 individually housed pigs. From the eight pigs that ate a capsule, three showed obvious symptoms (ie uncoordination), but none succumbed to the toxin. Observations and video recordings indicated that the pigs were particularly delicate in how they first sampled the bait. Pigs basically bit the capsule with their incisors, with most of the cyanide and casing spilling out on the concrete (Figure 4).

From these observations it became apparent that more work was needed to encourage the animal to rapidly consume, rather than just 'sample' the bait. Sampling is a common strategy when initially consuming new foods (Barnett 1958). It can be largely overcome through extending the free feeding or habituation period where the animal consumes a non-toxic capsule, before presenting a lethal capsule. Alternatively, changing the physical properties of the capsule (eg a softer

consistency) may help to encourage consumption. The spring mechanism appeared to result in the animal ejecting the capsule, which is not surprising given the unnatural feeling of its action. Pigs were observed to rapidly spit out the capsule when the spring was activated, which confounded the 'exploding' effect of the capsule. This spitting reaction would have reduced the spring's effect of spreading sufficient cyanide throughout the animal's mouth to deliver a lethal dose. The fact that the prototype baits contained only 900 mg of cyanide also meant that the dose actually consumed may have been inadequate for a lethal dose.

Figure 2. Capsules after coating with an attractive, palatable food to encourage consumption
These capsules have been coated with a wheaten dough and ground dog biscuits.

Enclosure trial 2

As a result of the issues associated with the initial pen trials, an alternative capsule was designed by Connovation. This capsule was tested at RWAPRC Inglewood in August 2006 in conjunction with RWPARC staff. The following section is a summary of that trial as reported by Aylett et al (2006).

Figure 3. Feral pig housed in an individual pen, as used for the majority of bait testing

Figure 4. A cyanide capsule that has been 'cracked' and subsequently ejected by a feral pig
Note the spilled cyanide powder.

The aims of this trial were to:

- test the palatability of non-toxic baits
- determine the toxicity and suitability of two different bait sizes
- confirm the appropriate toxic loading concentrations for baits.

Eleven individually housed feral pigs weighing 20–45 kg were presented with a small number of non-toxic baits containing three different flavours over three feeding sessions. The non-toxic baits were palatable to all pigs, and were extensively chewed (for at least 60 secs) before swallowing. Pigs consumed all flavours presented, showing no discernible preference for any of the different flavours.

The effectiveness and toxicity of KCN baits was determined in eight of these pre-fed feral pigs by offering them a single toxic bait each. Two baits type were tested. Bait 1, our preferred optimised standard bait was 45 mm x 20 mm in size and contained either 1 g or 1.5 g of cyanide active and non-toxic paste. Bait 2 was smaller (30 mm x 20 mm) and contained 1 g of cyanide and non-toxic paste. Five pigs were presented with Bait 1, and three pigs with Bait 2.

Bait 1 was highly effective: feral pigs died between 20 and 60 min after chewing on the bait (Table 1). The average time to death was 36 min. Observers estimated onset of symptoms within 4 min of chewing on the bait and most pigs were unconscious within 10–20 min.

Bait 2 was effective in only one pig out of the three tested, despite the similarity in dosage to Bait 1 (ie all Bait 2 capsules contained 1 g cyanide; four Bait 1 capsules contained 1 g, one contained 1.5 g). Bait 1 was chewed more thoroughly than Bait 2, which would likely have improved the spread of cyanide throughout the buccal cavity (mouth). We suggest that the larger bait size was responsible for the thorough chewing, both as a function of its size (ie larger size needing more chewing) and a masking effect (ie the greater volume of non-toxic paste helped to mask the taste and odour associated with cyanide paste).

The route of exposure appears to be an important determinant of the absorption and toxicity of cyanide. Oral exposure to mucous membranes appears to be a highly effective means of delivering a lethal dose. Previous experience with cyanide has shown that, when swallowed, its effectiveness and onset of symptoms appear to be markedly reduced compared to absorption across the mucous membranes in the buccal cavity (Mitchell 2003; Elsworth et al 2004; D. MacMorran and C. Eason Connovation, unpublished data). Bait size is therefore likely a crucial factor in delivering an effective dose; as a smaller bait size would be chewed less and have an increased likelihood of being swallowed whole, thus decreasing the effectiveness of the cyanide.

In contrast to the findings of Couch and Bunyea (1939), vomiting appeared to have little effect on survival. No animals that vomited after ingestion of cyanide survived. The lack of protection afforded by vomiting in our study is probably characteristic of rapid ingestion and absorption of cyanide. The rapid reactions of cyanide in the buccal cavity would have meant that sufficient cyanide was absorbed before the vomiting could eject little, if any, of the toxin. However, where cyanide is swallowed (eg oral solution as delivered by Couch and Bunyea 1939), and reactions are slowed, vomiting may help to protect the consuming animal from a lethal dose.

Table 1. Bait type presented and subsequent bait uptake and survival of pigs in Enclosure trial 2

Pig no.	Bait type	Sex	Time to onset of symptoms (min)	Time to vomiting (min)	Time to collapse (min)	Time to unconscious-ness (min)	Survival, time to death (min)
11	1	F	4	-	10	10	died, 31
13	1	M	4	-	13	15	died, 60
22	1	F	4	9	4	-	died, 41
24	1	F	3	5	6	7	died, 28
26	1	F	1	3	2	-	died, 20
23	2	F	25	-	-	~60	died, 120
8	2	M	-	-	-	-	survived
12	2	F	-	-	-	-	survived

The results suggested that Connovation had developed a very promising formulation of cyanide (Bait 1). The size, shape and formulation appear to ensure that the bait is extensively chewed and that sufficient cyanide is presented to kill pigs >40 kg. This was verified by demonstrating that a smaller bait containing the same amount of cyanide was less effective.

Even though the optimised cyanide capsule resulted in the death of all consuming animals (ie 5/5), the time to death was longer than anticipated, taking 36 min on average (range 28–60 min). This lag period between consumption and death suggested that carcasses of feral pigs could be found a considerable distance from where they consumed bait if these baits were used in the field.

Enclosure trial 3

The lethal trials on individually housed feral pigs as part of Enclosure trial 2 yielded positive results. However, ultimately the successful application of such a baiting technique for disease sampling would be the distance that feral pigs would travel before becoming incapable of further movement (ie the distance that carcasses would be found from where the bait is placed). In Enclosure trial 2, an average of 7 min (range 2–13 min) elapsed after consuming the toxic capsule before the pigs were significantly incapacitated. Despite that there were no indications that the pigs were disturbed and likely to move before this time, we thought it logical to test whether the animals would move considerable distances after consumption of the bait, before we progressed to field trials. If pigs move too far from the baiting point, this technique is likely to be unsuitable for disease sampling given the area that would need to be searched to locate carcasses.

Trials were done in December 2006 to determine the lethality of the capsules and the distance carcasses were likely to be found from the feeding site in a field-type

situation. The trial was done on ‘free-ranging’ feral pigs housed in a large enclosure (40 acres) at RWPARC. Although not strictly a field trial, we believed it was a suitable substitute since pigs were allowed the freedom of foraging and movement inside a large enclosure containing woodland of cypress pine (*Callitris glauca*) and some *Eucalyptus* spp. — a typical feral pig habitat in the Inglewood region.

Six feral pigs (25–45 kg body weight) were moved into the enclosure and free fed with non-toxic capsules over a 10-day period. Free feeding was done prior to presenting the cyanide capsules, to encourage the animals to consume the toxic capsules with minimal neophobia.

All feral pigs consumed the non-toxic baits readily. Given this result, toxic baits were presented in the paddock. Where possible, animals were observed when consuming the bait to determine their reaction. The following baits were presented, in order, to the six pigs in the paddock and an additional three piglets in the pens:

1. 2 g of KCN paste with 2 g of non-toxic pre-feed paste
2. 1 g of KCN in 3 g of peanut paste and various combinations.

At the first presentation of the toxic bait, the feral pigs either chewed the baits briefly (1–3 chews), or appeared to swallow them entirely, except for some small parts of the capsule. The toxic KCN/peanut paste combination appeared to be eaten more readily than the toxic KCN with the non-toxic paste. The typically strong odour and taste of peanut paste may have helped to mask the cyanide.

Although many toxic baits were eaten by the six pigs, only one animal died. The carcass of this pig was found 120 m from where it had consumed a large (2 g KCN) capsule. The other five pigs were observed to have no life-threatening cyanide symptoms. Two pigs had momentary staggers and salivation, and one pig had a small vomit. Following the initial consumption of a cyanide capsule, all pigs were wary of the following baits presented, appearing to carefully ‘sample’ the bait for the presence of cyanide. This aversion appeared to be linked to the taste or sensation associated with the cyanide paste rather than the capsule itself — given that most pigs resampled capsules again in subsequent presentations, rejecting them only where cyanide was contained. One clue may lie in the reactions of one pig, which spat out the cyanide capsule and rubbed its tongue on the ground, possibly in an attempt to rid itself of the caustic, burning effects of cyanide.

Conflicting data exist regarding the oral toxicity of cyanide to feral pigs. Hone and Mulligan (1982) state the LD_{50} (ie lethal dose required to kill 50% of the population) for pigs is 3.5–4.5 mg/kg KCN, while Sousa et al (2003) report no symptoms following oral dosing 3 mg/kg. Couch and Bunyea (1939) completed extensive cyanide trials on domestic pigs. Unfortunately they provide little detail of their dosing procedures apart from using a liquid to deliver a cyanide solution orally — most probably via gavage. Regardless, using hydrocyanic equivalent calculated from Couch and Bunyea (1939), 5.8–8.2 mg/kg KCN is needed for a lethal dose. Despite such conflicting data, given that pigs in the pen trials (<50 kg bodyweight) were exposed to over 20 mg/kg KCN, our dosage appears sufficient to kill these animals. Therefore, the low frequency of death in our trial must be due to deficiencies in delivering the dose, or the reactivity of the cyanide delivered.

These results seem to confirm two matters:

1. Once cyanide is in the stomach, it appears to have a markedly reduced effect compared to in the mouth. This is perhaps due to release and reaction at a rate that allows the animal to detoxify the cyanide.

2. To be effective, cyanide must somehow be retained in the buccal cavity for a period of time, or it must be in a form that can be readily absorbed in the stomach.

Perplexingly, this trial was largely unsuccessful, contrasting markedly with the second pen trial of August 2006. We compared baits used in these trials to help determine any differences (Table 2). The major difference relates to the construction of the wax capsule.

The capsule construction may have been sufficiently different to reduce the effect of the paste spreading throughout the mouth of a consuming animal. The capsule used in Enclosure trial 3 may have allowed cyanide to come out the capsule's end, which may then have been spat out or swallowed. Preliminary tests by Connovation suggest that this may indeed be the case.

Table 2. Comparison of bait package components used in Enclosure trial 2 compared to the unsuccessful Enclosure trial 3

Bait components	Enclosure trial 2	Enclosure trial 3
wax coating	crystalline wax	crystalline wax
manufacture of wax capsule	The cylinder was made in a mould 2 cm x 1.25 cm x 4 cm. The toxic bait components were poured (1 g non-toxic, 2 g toxic KCN, 1 g non-toxic) and then the cylinder was sealed with super hot wax so that the cap fused into the cylinder. This effectively created a 'single' cylinder with the material enclosed. The cylinder was then hand cut to make the top and bottom 1.25 cm. This involved shaving off the cylinder with a knife wax.	The cylinder was made form a mould 1.25 cm x1.25 cm x 4 cm with a wall of 1–2 mm. The insertion of the bait components was the same as Enclosure trial 2. However, it was not possible to seal this cylinder with super hot wax because the thinness of the wall (1–2 ml) meant that this wax would melt the wall. As a result, this was poured at a lower temperature. This had the effect of creating a plug as opposed to creating a single fused cylinder.
sticky coating	fruitrim mix	fruitrim mix
outer coating	cracked grains	cracked grains

Enclosure trial 4

Following the unsuccessful results from the paddock trial, another trial was done in April 2007 using the original, 'successful' capsule and paste formulation of Enclosure trial 2. Two additional cyanide formulations were manufactured by Connovation. The first was a simple paste made primarily from KCN and icing sugar; this paste was minimally encapsulated and therefore intended to be particularly reactive. The second was a liquid formulation of cyanide. Both were encased in the same wax capsule matrix as proved successful in the second pen trial. All capsules were coated with a biscuit-like dough and rolled in cracked mixed grain.

Trials were done at the RWPARC in early April 2007. Feral pigs were housed individually in pens and presented with non-toxic formulations of the bait capsule. Only pigs that consumed the free-feed baits (9 from 12 pigs in total) were presented with the toxic cyanide capsules. Results are shown in Table 3. The capsule with the original paste resulted in the death of one from four consuming animals. Consumption of either the KCN-icing sugar paste (by three pigs) or liquid cyanide capsules (by two pigs) failed to produce any strong symptoms in animals. Two of these five pigs ate most or all of the toxic bait (after a thorough chew), but most had a couple of quick chews and rejected the bait, only eating the biscuit-like casing on the outside (see Figure 5).

Table 3. Bait type presented and subsequent bait uptake and survival of pigs in Enclosure trial 4

Pig no.	Sex	Toxic bait type	Bait uptake	Time to symptoms	Survival/ time to death (min)
8	F	original paste	chewed, ingested	-	survived
11	M	original paste	chewed, dropped	-	survived
21	F	original paste	chewed, partially ingested	1 min 30 secs	died, 111
26	M	original paste	chewed, dropped	50 secs	survived
27*f*	F	liquid	chewed, dropped	1 min	survived
28*mp*	F	liquid	rejected		survived
9	F	icing sugar paste	chewed, rejected	3 min	survived
22	F	icing sugar paste	chewed, dropped	-	survived
23	F	icing sugar paste	chewed, dropped	-	survived

Figure 5. Wax capsule containing cyanide after an attempt at consumption by a feral pig
Note that the highly palatable biscuit-like coating on the bait has been eaten, and although the capsule has been at least partially chewed, much cyanide remains inside the capsule.

The one pig that died was the only pig to show any severe symptoms of cyanide intoxication. Other pigs showed very mild symptoms such as salivation, slight uncoordination and agitation, but they quickly recovered. No pigs vomited at any stage. Whether the formulation, dose or delivery technique was responsible remains unclear, but will be discussed further below.

Enclosure trial 5

The predicide ejector has been shown to be successful at delivering a variety of toxins (cyanide, para-aminopropiophenone [PAPP] and 1080) in Australia for wild dog and fox control. Its use is based primarily on the sodium cyanide ejector (better known as the M-44 ejector) in the United States for coyote control (see Eisler 1991) but has been adapted successfully to fox and wild dog control in Australia. The ejector delivers cyanide when an animal pulls on the bait or lure holder with its mouth and activates the spring-and-bolt mechanism, ejecting cyanide powder into the animal's mouth (components of ejector are shown in Figure 6).

Although the use of ejectors can be labour intensive and requires specialised equipment (van Polanen Petel et al 2007), ejectors have some benefits over stand-alone baits for toxin delivery. Ejectors may help in the absorption of cyanide, since the cyanide powder directly contacts the moist surfaces of the buccal cavity, producing hydrogen cyanide that is then inhaled (Fisher and Campion 2007). Ejectors may also increase the probability of ingesting a lethal dose, by reducing the likelihood of spitting the toxin/bait out. They may also reduce issues of bait acceptance that are common with voluntary ingestion of toxins and baits (Fisher and Campion 2007). The amount of upward pulling force required to activate the ejector

(1.6–2.7 kg) excludes many non-target species, improving the target specificity of the technique (Busana et al 1998, Hunt 2010). The toxin is held within a sealed capsule, reducing environmental degradation and allowing it to retain effectiveness for extended periods. Ejectors are also significantly more difficult to cache than baits, reducing the likelihood that they are moved to sites where more non-targets may be exposed to them (eg Gentle 2005).

Currently, ejectors with 1080 may be used as a control technique for foxes and wild dogs in New South Wales and the Australian Capital Territory under permit from the Australian Pesticides and Veterinary Medicines Authority (APVMA). The use of cyanide in ejectors for wild dogs and foxes is currently under review with the APVMA. The APVMA suggested that feral pigs may be at risk of primary poisoning from cyanide if they are able to trigger the ejector, or may be at risk of secondary poisoning if they scavenge on the carcasses of wild dogs that have taken the ejector.

Figure 6. Components of a cyanide ejector and wooden stake as used in the pilot trial
The hollow tube is driven into the ground, and the set ejector mechanism is inserted into this tube and a capsule holder (with cyanide capsule inside) is screwed on. When the capsule holder is pulled up by an animal, the ejector is activated and cyanide powder is ejected into the animal's mouth.

Given that ejectors have these advantages over stand-alone baits, and also have potential applications to feral pigs, we performed a pilot trial to determine whether feral pigs have the ability to activate the ejector mechanism. At RWPARC a combination of wooden stakes and unset ejectors (total of four) were driven into the ground in a fenced laneway adjacent to pig pens. A piece of kangaroo meat was attached to the capsule holder/top of each ejector/stake with an elastic castrating ring. Individually penned pigs were then released one at a time into a fenced laneway and their reactions to and ability to pull the stakes/ejectors were observed.

Figure 7. Feral pig pulling on buried stake to remove kangaroo meat attached to the top

A total of eight pigs were presented with four stakes/ejectors on two or three occasions. We observed 75% (21/28) of stakes/ejectors presented were pulled and consumed in the first presentation, 81% (26/32) in the second presentation and 75% (18/24) in the third. The difference between the percentage pulled/eaten in the three presentations was probably mainly due to behavioural differences in study animals, with some refusing to pull stakes on some occasions. Some pigs were also distracted by the proximity of the stakes/ejectors to other pig pens and were more interested in socialising with the other pigs. Nevertheless, most pigs showed little hesitation in pulling off the meat from the top of the stake/ejector using the same motion required to activate an ejector (Figure 7). Some individuals pulled the entire stake from the ground, while a few others used a bulldozing motion to remove the stakes from the ground. Observations from this pilot trial show that pigs are capable of activating ejectors and that ejectors have potential to deliver cyanide to feral pigs.

Discussion

We completed a series of five pen trials presenting non-toxic and toxic bait packages to captive feral pigs at the RWPARC. In the second pen trial, the large capsule trialled was effective and killed 5/5 pigs. However, this success could not be replicated in subsequent pen trials, despite efforts to exactly replicate the manufacture and composition of the capsule. To generalise, feral pigs readily consumed the non-toxic wax capsules in all our pen trials. This demonstrates that the capsule design itself, when filled or coated with palatable foodstuff, is both acceptable and palatable to feral pigs. However, when the toxic capsule was tested, pigs readily chewed the cyanide bait until they appeared to detect the cyanide, then rejected the bait. We conclude that the smell, taste or reactions to the cyanide significantly reduced its acceptability and palatability.

It appears to be difficult to disguise the cues associated with cyanide: our attempts to encapsulate the cyanide in a paste and a liquid, and flavouring it (with raspberry essence) were unsuccessful. The current formulation of cyanide paste appears to be problematic. The compromise is not successful between the need to encapsulate the KCN to stabilise it and mask its taste or odour, and the need for sufficient reactivity to cause rapid death. Nevertheless, the early successes (and potential payoffs) of existing KCN formulations support further attempts (without the wax capsule) to determine if they are acceptable and practical for feral pigs.

Formulations tested to date have suggested that the time to incapacitation and death can sometimes be considerable (in Enclosure trial 3 the average time to death was 38 min). When undertaking or reviewing such research the ability of cyanide to rapidly kill pigs must be determined — extended latent periods reduce the ability of carcasses to be located for disease sampling in a field situation. However, in these trials it has been difficult to distinguish the true effects of cyanide intoxication given the confounding issues of delivery and formulation. Potential exists to improve the delivery of paste formulations by directly placing it upon foodstuffs such as grain, after a period of free feeding. This direct delivery may reduce the ability of an animal to eject the cyanide as is possible with the capsule. If current formulations of cyanide cannot be adequately delivered to feral pigs, delivering a powder formulation directly into the mouth via an ejector may be a more effective delivery mechanism and warrants further investigation. This work should be undertaken in collaboration with Landcare Research, New Zealand, given their preliminary work using domestic pigs (see below).

2.3 Landcare Research trials 2007

Trials were undertaken by Landcare Research in June 2007 (Fisher and Campion 2007) to develop a modified deployment configuration of the M-44 ejector for pigs. A number of configurations were tested in pen trials, and the optimal configuration was subsequently tested for efficacy on domestic weaner pigs.

Six weaner (31–45 kg) domestic pigs were presented with cyanide ejectors once or twice. These pigs readily activated ejectors to reliably receive an oral dose of KCN. However, doses of KCN (~1 g) presented to these pigs had poor kill efficacy, with only two out of six pigs dying following activation of the ejectors. Furthermore, the relatively long latent period following cyanide intoxication (32 and 70 min) suggested a longer progression to unconsciousness and death than in some other species.

Despite successes with delivering cyanide to pigs, Fisher and Campion (2007) concluded that pigs may require large oral doses to receive a lethal dose. Lethal doses may be higher than expected; surviving pigs receiving in the range of ~14–25 mg/kg cyanide, in excess of the published LD_{50} of 3.5–4.5 mg/kg for pigs (Hone and Mulligan 1982). Fisher and Campion (2007) also postulate that the relatively long period before unconsciousness and death in this study, when compared to other mammals (eg wild dogs, Hooke et al 2006) suggests that cyanide may not have the advantages to animal welfare as seen in other species.

2.4 Feral pig trials 2007–2008

Following the results of the WEDPP-funded project (see Section 2.2 above), a new project was established to progress the delivery of cyanide for feral pig disease sampling and monitoring. The following is a summary of the project *Development of a cyanide pig bait for monitoring,* funded by the Bureau of Rural Sciences (BRS) under the National Feral Animal Control Program and the Invasive Animal Cooperative Research Centre's Detection and Prevention Program (Gentle et al 2008a).

Following the recommendations from the WEDPP project (Gentle et al 2007), the project proceeded as detailed below:

1. The potential for completing further trials using alternative delivery mechanisms for feral pigs was discussed with Connovation and project collaborators. Connovation suggested alternative bait presentations to trial and, in light of previous successes, subsequent trials were planned and undertaken at the RWPARC. These trials are reported below.

2. Discussions were held between Landcare Research and the project team regarding the potential for trials to test the cyanide ejector to deliver cyanide. Landcare Research had already initiated these trials and results were provided in November 2007. These results and their impact upon this project are discussed in the General Discussion below.

3. Discussions between Connovation and the project team concluded that, to date, it has been difficult to distinguish the true effects of cyanide intoxication given the confounding issues of delivery and formulation. This became even more apparent following the testing of alternative bait presentations from Connovation. As a result, further trials were planned and undertaken in New Zealand to determine the toxicity of cyanide in sedated pigs.

4. Application of off-the-shelf manufactured cyanide formulations to foxes was further investigated through discussions with Connovation. Of the manufactured cyanide formulations available, the cyanide paste was identified as having the best potential for application to foxes. Pen and field trials were subsequently planned to test this presentation (see fox trial section).

Enclosure trial 1

In view of issues associated with previous bait presentations, alternative cyanide packages were developed by Connovation for testing on pigs. These packages were macadamia nut-sized pellets; toxic versions contained ~2.5 g of powdered KCN while non-toxic free-feed baits contained either sweetened condensed milk or brown sugar (see Figure 8 and 9). Importantly, the cyanide was uncompressed, to help disperse the toxin in the mouth of the consuming animal. The outer coating was similar to the standard Feratox® coating of sugar and flour with either macadamia powder or with raspberry flavour added.

Figure 8. Prototype pellet baits as tested in pen trials
The brown pellet on the far left is a macadamia nut for size comparison

The round pellet cyanide presentation was considered a potentially effective matrix for a number of reasons. The outer coating of the pellet was quite hard, requiring a considerable bite force to crack it. Given this hardness and the round shape of the pellet, it was hypothesised that pigs would bite the pellet using their molars rather than their incisors. This should help to grip and enable sufficient force to crack the pellet. If this were the case, the pellet would be cracked at the back of the mouth, which would potentially reduce the ability of the pig to reject the bait. The size of the pellet allowed the free-feed baits to be filled with highly palatable foods such as sweetened condensed milk or brown sugar. Free feeding with such attractive baits would help to overcome neophobia towards the bait material. In turn, this would help to encourage quick uptake of the toxic bait when presented. Once a toxic bait was cracked, the cyanide powder inside would spill out into the animals mouth, and react within the buccal cavity. The pellet and powder combination may help to ensure reaction within the buccal cavity and reduce the problem of decreased cyanide toxicity of swallowing entire baits, as reported during earlier studies (Mitchell 2003, Elsworth et al 2004, Gentle et al 2007).

In October 2007, eight individually housed feral pigs were presented with a small number of non-toxic baits on at least two different occasions. These baits consisted of pellets containing either sweetened condensed milk or brown sugar. A cross-section of the pellets in shown in Figure 9**.**

Figure 9. Free-feed pellets used in pen trials October 2007
The red pellet (top) contains sweetened condensed milk, the green pellets (bottom) contain brown sugar (ie golden sugar).

Six of the eight pigs readily consumed these non-toxic baits. Two animals were particularly shy eaters and eventually ate most of the non-toxic baits presented. However, given their hesitation and often only partial consumption of non-toxic baits, these animals were not used for toxic baiting.

The effectiveness and toxicity of KCN baits was determined in the remaining six of these pre-fed feral pigs by offering them a single toxic bait each (Table 4). All the pigs presented with the toxic bait survived. Only one of the six pigs consumed the entire bait. The remaining animals picked up and chewed the bait for several seconds before ejecting it. The one pig that ate the bait, and three pigs that partially ate the bait, showed some symptoms of cyanide ingestion (mainly vomiting) but quickly recovered.

Table 4. Bait type presented (1= pellet) and subsequent bait uptake and survival of pigs in Enclosure trial 1

Pig no.	Bait type	Sex	Time to onset of symptoms (min)	Time to vomiting (min)	Time to collapse (min)	Time to unconsciousness (min)	Survival/ time to death
1*	1	M	13	13	-	-	survived
2*	1	M	-	-	-	-	survived
3*	1	M	<35	<35	-	-	survived
5	1	F	9	9	-	-	survived
7*	1	F	-	-	-	-	survived
8*	1	F	18	18	-	-	survived

*incomplete or partial consumption of toxic bait

These results showed similar outcomes to the previous cyanide trials. Non-toxic baits were generally readily accepted and eaten by feral pigs, and cyanide baits were generally rejected and/or only partially eaten. In addition, where cyanide bait was entirely consumed, death did not follow.

Enclosure trial 2

In view of issues associated with previous bait presentations, three alternative cyanide presentations were developed by Connovation. These were: (1) a cyanide gel matrix, (2) the cyanide gel matrix contained within a flat wax capsule, and (3) a pellet containing lightly compressed cyanide powder encased within a hard coating. The pellet was of similar construction to that used in Enclosure trial 1, containing ~2.5 g of KCN.

The cyanide gel was considered to be a potentially effective matrix for delivering cyanide to feral pigs, given some success in earlier trials (Connovation, unpublished data). Gel has the potential to be added or mixed with a variety of foodstuffs that pigs are familiar with or can be habituated to eating. This habituation may help to overcome any neophobia surrounding the acceptance of a novel toxic bait (ie previously unseen bait). The gel used in this trial contained encapsulated cyanide within an oily, sweet, jam-like matrix.

The flat wax bait was simply the cyanide gel contained within a flat wax package. We hypothesised that the flat shape would increase the surface area of the gel that contacts the buccal cavity of the consuming animal. This may act to increase the reactivity of the cyanide, and reduce the potential of the animal ejecting the bait.

In November 2007, five individually housed feral pigs and 10 group-housed pigs in two pens were presented with a small number of non-toxic baits. These baits consisted of non-toxic gel, large flat-wax capsules containing gel, and pellets containing either sweetened condensed milk or brown sugar. The large flat capsules were eaten ‘begrudgingly’ after several minutes, while the remaining pellet baits were readily accepted and consumed by all pigs. As a result of this poor acceptance, flat wax capsules were withdrawn from the toxic trials.

The effectiveness and toxicity of KCN baits was determined in nine of these pre-fed feral pigs by offering them one toxic bait each (Table 5). These baits were 1) a lightly compressed cyanide powder encased within a hard coating (ie pellet), and 2) a cyanide gel matrix (ie paste). The cyanide gel matrix was coated with additional non-toxic gel in an effort to improve its palatability.

Five of the seven pigs presented with the paste completely ate the bait, while two pigs chewed and only partially consumed the bait. Three pigs died 19–70 min after eating it. Interestingly, two pigs that ate the entire pellet did not show any symptoms of cyanide poisoning.

Table 5. Bait type presented (1= pellet, 2 = paste) and subsequent bait uptake and survival of pigs in Enclosure trial 2

Pig no.	Bait type	Sex	Time to onset of symptoms (min)	Time to vomiting (min)	Time to collapse (min)	Time to unconsciousness (min)	Survival/ time to death (min)
1g	2	M	7	7	12	15	died, 70
2g	2	F	1	2	15	~16	died, 50
3g	2	F	-	-	-	-	survived
26	2	F	3	-	10	~11	died, 19
24	2	F	-	-	-	-	survived
25*	2	F	12	12	-	-	survived
13*	2	M	-	-	-	-	survived
11	1	M	-	-	-	-	survived
23	1	F	-	-	-	-	survived

*incomplete or partial consumption of toxic bait

Discussion

These two pen trials did not show any dramatic improvement in results to previous trials. Despite efforts to habituate feral pigs to consuming free-feed baits, the toxic baits were still less palatable, with about half the pigs (7/15, 46%) only partially consuming them. The inconsistency of death from bait consumption, even when large doses are ingested (2.5 g KCN was equivalent to >50 mg/kg bodyweight) continues to raise questions as to the applicability of cyanide to feral pigs. Evidence from the trials undertaken during this study and previous work suggests that feral pigs may be more resistant to cyanide than originally envisaged. These issues need to be resolved before further pen trials are done.

2.5 Connovation enclosure trials 2008

In June 2008, Connovation completed enclosure trials in New Zealand to test the toxicity of different formulations of cyanide to domestic pigs. This trial was initiated in response to the outcomes of previous trials, particularly the strong indications that pigs are resistant to cyanide intoxication, and the need to test for any differences in efficacy between cyanide formulations.

Importantly, testing was performed on sedated pigs. This ensured that the delivery of cyanide was consistent, minimising any confounding acceptance issues from delivering different cyanide formulations.

The outcomes of this trial should help to further investigate the toxicity of cyanide to feral pigs and determine the optimal cyanide formulation for future testing. The results of this trial and the objectives of future trials are summarised below by Connovation.

Toxicology with pigs was investigated using different formulations of cyanide. The objectives were to:

- determine whether or not pigs are susceptible to cyanide (a topic of some debate — Fisher et al 2007 have suggested that pigs are resistant to cyanide)
- identify the kill efficacy of the most suitable cyanide formulation to kill pigs
- determine the most suitable cyanide formulation to progress testing in conscious animals.

Domestic pigs were weighed, ear tagged, sexed and individually penned at the Lincoln University, Lincoln, New Zealand. Pigs were fed on a commercial grain-based diet with water provided *ad libitum.* Pigs were acclimatised for approximately seven days before the toxic trial, and lightly fasted the day before the trial. Prior to being dosed, individuals were lightly sedated and the cyanide formulation placed inside the animal's mouth. Bait formulations were initially tested on two individuals, with additional animals treated in pairs (up to six animals in total) based on positive results.

The four toxic cyanide bait types tested for efficacy are shown in Table 6.

Table 6. Cyanide treatments on sedated pigs

Treatment	Description
1	1 g cyanide powder (new formulation)
2	1 g cyanide powder (normal)
3	1 g cyanide paste
4	1 g sticky cyanide paste

Initially two pigs were anaesthetised and dosed with Treatment 1. The results were remarkable, with both animals succumbing within 13 min. As a result, two further pigs were administered Treatment 1. One pig died within 9 min and the other within 18 min (Table 7).

Following the initial success with Treatment 1, six pigs were dosed in pairs for each of the remaining three treatments. One pig died 90 min after administration of Treatment 3. One pig that had been administered Treatment 4 did not recover fully and was euthanased after 139 min. All other pigs fully recovered.

Based on the results achieved above, two more pigs were administered Treatment 1. Both animals fully recovered (Table 8).

Table 7. Results of first dosing round of Connovation trials

Pig no.	Treatment no.	Sex	Weight	Time to death/or recovery (min)
489	1	F	33	11
380	1	M	37	13
479	1	F	26.5	9
390	1	M	36	18
478	2	F	38.5	fully recovered, 92
386	2	M	36	fully recovered, 88
488	3	F	25.5	90
387	3	M	32	fully recovered, 86
487	4	F	32.5	fully recovered, 135
379	4	M	31	euthanased, 139 *
477	Control	F	27	fully recovered, 79
396	Control	M	37	fully recovered, 59

* Pig 379 never recovered fully and was euthanased.

Table 8. Results of second dosing round of Connovation trials

Pig number	Treatment no.	Sex	Weight	Time to death/ recovery (min)
480	1	F	32.5	fully recovered, 94
388	1	M	33.5	fully recovered, 81

This very short time to death recorded for the four pigs in Treatment 1 is comparable with that in other species such as possums and dama wallabies (Table 9). This is a vast improvement in terms of time to death and the severity and duration of sickness when compared to all previous pig poisoning results.

It is initially perplexing that two pigs did not succumb to Treatment 1; these results were unexpected given the early successes. Procedural differences may be responsible. The first pigs dosed received the treatment as soon as practicable. The remaining two animals received the treatment after they had been under the anaesthetic for several minutes. We are uncertain whether this difference was enough to affect the results. Ideally, additional animals should to be dosed in an attempt to repeat the success achieved to date with Treatment 1, and establish if the new formulation of cyanide powder is effective.

Table 9. Cyanide data for possum (Gregory et al 1998) and wallaby (Shapiro et al 2008)

Poison/ study	Species	Time to onset of symptoms (min)	Duration of symptoms before unconsciousness (min)	Duration of symptoms before death (min)	Time to death (min)	Signs prior to uncon-sciousness
Cyanide -Feratox®	possum	3	3.5	15	18	staggering
Cyanide -Feratox®	dama wallaby	2.1	5.6	11.4	13.5	loss of balance, then prone

Discussion

Presentation of a variety of cyanide formulations has demonstrated that, in doses presented in voluntarily consumed baits, cyanide did not consistently intoxicate feral pigs. The discussion below will examine potential reasons for this inconsistency.

Was the dose of delivered cyanide sufficient for pigs to receive a lethal dose? The literature is largely conflicting on the oral toxicity of cyanide to pigs. Hone and Mulligan (1982) report the LD_{50} for pigs as 3.5–4.5 mg/kg KCN. Interestingly, Sousa et al (2003) reported no mortality (or symptoms) in pigs following an oral 3.0 mg/kg dose of KCN. This is supported by Manzano et al (2007) who dosed animals twice daily with up to 3.0 mg/kg KCN for 70 consecutive days (ie delivering up to 6.0 mg/kg daily) with no resulting deaths. Couch and Bunyea (1939) completed extensive cyanide trials on domestic pigs; using hydrocyanic equivalent a calculated 5.8–8.2 mg/kg KCN is required for a lethal dose. In more recent trials, where pigs were presented with between ~1–2.5 g KCN, many pigs survived exposures in excess of 20 mg/kg KCN (Gentle et al 2007, Fisher and Campion 2007, recent Connovation trials), and even 50 mg/kg (this current study). These exposures far exceed any published lethal dose values.

The findings of other studies testing cyanide delivery to feral pigs are similarly inconsistent, despite some successes. Perhaps what is most consistent in cyanide studies on pigs is the *inconsistency* of the outcomes. Despite using a variety of bait types, all studies have struggled to consistently kill pigs following voluntary consumption of cyanide baits (Eason and Henderson 1991, Mitchell 2003, Elsworth et al 2004, Gentle et al 2007, Fisher and Campion 2007, this study). It is important to recognise that in such trials it is often difficult to determine the actual dose of KCN ingested, given that many animals only partially consumed the bait. However, even where animals were anesthetised and accurate doses could be delivered to pigs (see Section 2.5), mortality was still inconsistent. Additionally, there are many recorded cases in these trials of animals ingesting large doses of KCN up to 50 mg/kg, with little or no apparent ill-effects.

Collectively, these results indicate that pigs may be relatively tolerant to cyanide ingestion. Couch and Bunyea (1939) suggested that monogastric species (such as pigs) may be more tolerant than ruminants (goats) to thiocyanite (a product of cyanide

metabolism). Without any direct dose-ranging study on feral pigs, particularly via direct oral consumption of cyanide, it is difficult to determine the level of tolerance. Regardless of the tolerance shown by feral pigs, it is our ability to exceed or overcome this tolerance that is the important question.

In addition to toxicity and mortality issues, it appears difficult to formulate and present cyanide in a manner that will be readily accepted by feral pigs. Regardless of the type and physical properties of the bait substrate, non-toxic versions are always eaten more readily, and entirely, when compared to toxic versions.

Trials by Landcare Research indicate that modified cyanide ejectors are effective at delivering cyanide into the mouth of a feral pig. The low mortality reported during these trials also showed that the dose of cyanide delivered was largely inadequate. Given the results of these trials, the potential of modifying the ejector to effectively deliver a larger dose of cyanide depends largely on the effectiveness of cyanide as a feral pig toxin. This would require knowledge of suitable doses as determined through dose-ranging studies. If more effective formulations are developed, the ejector may provide the most promising means of delivering such formulations in feral pigs.

The outcomes of the recent Connovation trials (June 2008) need to be reconsidered in the context of previous findings. Connovation trial results indicated that one cyanide powder formulation was more successful than the others tested (normal KCN powder, and two paste formulations). This may suggest that current paste formulations are not as effective as powder at delivering KCN doses. Perhaps more importantly, even KCN powder was inconsistent in its effects, with two animals recovering after dosing with 1 g of KCN powder (representing >29 mg/kg). For these two animals, a several-minute delay between anesthetising and dosing with cyanide may have contributed to their recovery, and this inconsistency. Whether larger doses of cyanide can overcome these mortality inconsistencies is not understood. As discussed above, results thus far, albeit using a variety of formulations, indicate difficulties even with animals ingesting massive doses (>50 mg/kg). Regardless, future trials planned by Connovation to continue testing the most promising powder formulation at higher doses will provide further evidence of cyanide toxicity. Above all, an improved knowledge of cyanide toxicity is critical to determine the practicality of cyanide as a feral pig toxin.

2.6 Emissions trials 2010

Background

In 2009, Connovation developed a new microencapsulation technique for cyanide. This was developed to help overcome the sharp 'mouth-feel' effect/response observed in feral pigs and carnivores, (but not in possum and wallabies) when exposed to cyanide. These new formulations aimed to reduce the detection/taste of KCN compared to cyanide powder (Figure 10) and previous encapsulated formulations to improve applications for pest animals, particularly feral pigs and/or foxes.

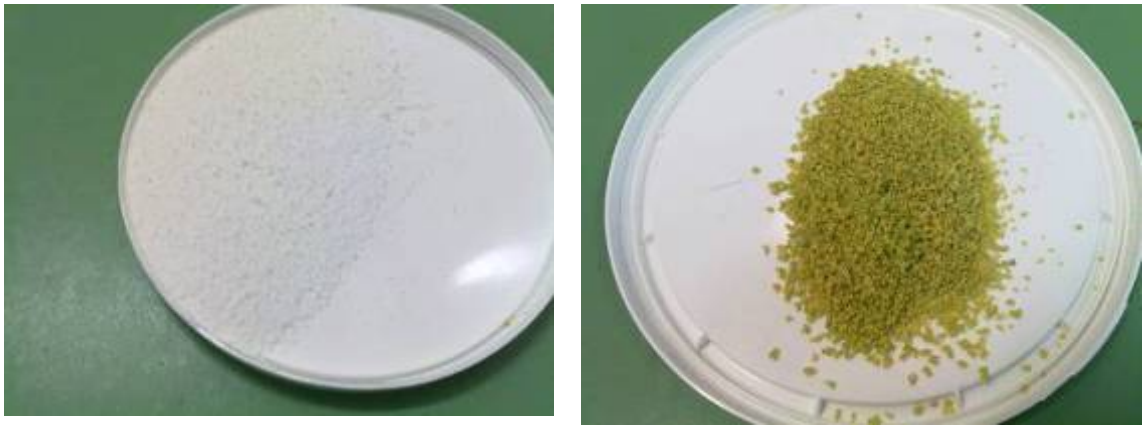

Figure 10. Cyanide powder (left) and microencapsulated cyanide (right)

Given the bait acceptance and palatability issues observed during the series of enclosure trials, we believed that more stringent design specifications for products were needed. Most importantly, design specifications for cyanide formulations plus delivery system (bait) must consider levels of HCN gas emissions before progressing to enclosure testing. Emissions tests must determine that HCN emissions are low enough to be acceptable to the consuming species, to reduce the likelihood of bait rejection. Given intended field use, laboratory HCN emission testing from any new formulations of cyanide (and bait) should also be undertaken using simulated Australian field conditions of temperature and moisture.

In consideration of these design specifications, this approach was used to assess the potential of the new cyanide formulations for applications for feral pigs/foxes. Details of the emissions testing of KCN formulations are provided below and include testing of both micro- encapsulated cyanide and macro-encapsulated cyanide.

Stage 1: Emissions testing of all candidate formulations (Table 10) run at room temperature (20°C) for 24 hours.

Stage 2: Emissions testing of successful candidate formulation(s) from Stage 1 were then tested at 40°C for 24 hours.

Stage 3: Emissions testing of successful candidate formulation(s) from Stage 2 were then tested over 30 days at room temperature (20°C).

Table 10. KCN powder and encapsulant formulations and the different carriers

Formulation	Carrier	
KCN powder with Encapsulant 1	standard paste	heat-resistant grease
KCN powder (sieved) with Encapsulant 2	standard paste	heat-resistant grease
KCN powder	standard paste	heat-resistant grease

Results

Emissions tests were completed in August 2010. The results show that Encapsulant 1 induced cyanide instability in the heat-proof grease at 20ºC and 40ºC. Subsequently, it was not tested in heat-proof grease at 30 days. Similarly, KCN

powder was unstable in heat-proof grease after 30 days at 20ºC, and in both carrier pastes at 40ºC. Encapsulant 2 was stable in both carrier pastes and both temperatures (Figure 11).

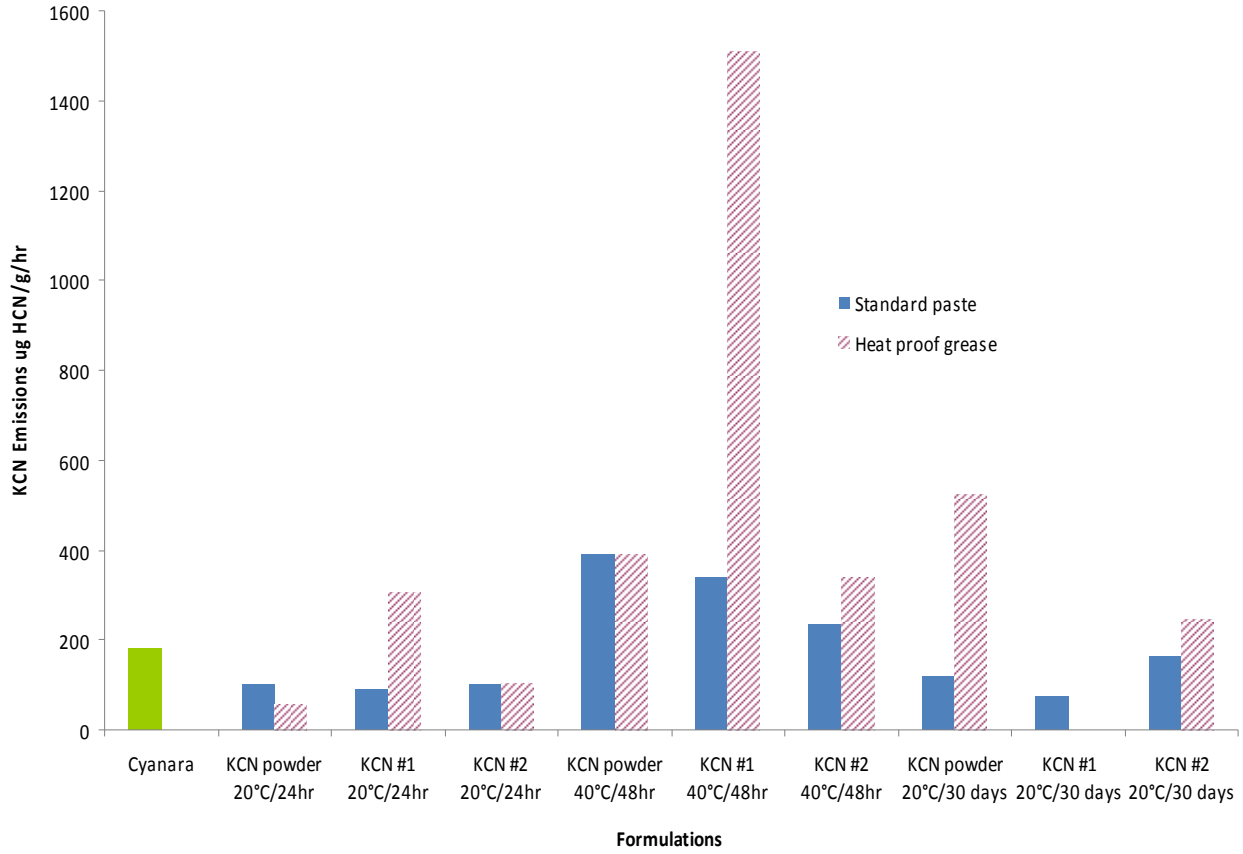

Figure 11. Emissions-testing results from three formulations of KCN (KCN powder, KCN + Encapsulant 1 and KCN + Encapsulant 2) in standard and heat-proof grease
Cyanara, a cyanide paste developed for possum control, is shown for comparative purposes.

2.6 Connovation enclosure trials 2010

Connovation recently (2009) established microencapsulation technology for sodium nitrite and applied this to cyanide powder. In addition, new mechanical ejector systems for delivery of cyanide to pigs were developed, incorporating an improved formula 'activator' substance to accelerate HCN release. This improved cyanide formulation (consisting of microencapsulated cyanide powder and 'activator') was designed to liberate HCN more rapidly, giving the animal less time to spit out the cyanide powder. This improved formulation may also increase the toxicity and lethality of cyanide to the consuming animal, helping to overcome the toxicity issues noted in earlier trials. This new formulation was also designed to overcome the unpleasant mouth feel and mask the sharp taste of the KCN powder.

The following section summarises trials with a microencapsulated form of cyanide completed in New Zealand (with domestic pigs) and Australia (with captive feral pigs). The two delivery systems tested were: 1) fish-meal wax baits containing encapsulated cyanide, and 2) a new mechanic ejector delivery system developed

specifically for delivering cyanide to pigs. Two formulations of wax bait delivery methods were tested in the New Zealand trial and the most promising formulation was selected for the Australian trial.

New Zealand trial

Ten large white domestic pigs (six males and four females) housed at Lincoln University Farm, Lincoln, New Zealand were used. Pigs were kept in a large outdoor enclosure and had access to water *ad libitum*. They were weighed, ear tagged and sexed. Pigs were acclimatised for approximately two weeks before the trial and were lightly fasted on the day before the trial. Individual pigs were presented with a single bait and when the bait was eaten or partially eaten, the times to first symptoms, lying prone, unconsciousness and death, were recorded.

Wax cylinder baits coated with fish meal (Figure 12) contained KCN powder (unencapsulated) in the 'standard' carrier paste.

Figure 12. Wax baits prior to filling with KCN powder and 'standard' paste

Five pigs were presented with the wax baits containing KCN powder and the remaining five pigs were presented with wax baits containing microencapsulated KCN powder. Two pigs cracked a single wax cylinder bait containing KCN powder in their mouths and one of these ingested a lethal dose (Table 11). The three remaining pigs discarded the baits without cracking them.

Four out of five pigs fed a single wax cylinder bait containing microencapsulated KCN powder cracked a bait in their mouths and one of these ingested a lethal dose (Table 11). One other pig was fed a single wax bait containing microencapsulated KCN powder but also discarded the bait without cracking it. Despite this, pigs were markedly less deterred by the microencapsulated powder than the unencapsulated powder.

Table 11. Response of individual pigs that cracked a KCN wax bait in their mouth

Pig no.	Sex	Weight (kg)	Bait type	Time to (min):			
				First symptom	Prone	Uncon-sciousness	Death
2	F	31	wax + microencapsulated KCN powder	12	recovered		
8	M	34	wax + microencapsulated KCN powder	4	11	33	38
9	M	33	wax + microencapsulated KCN powder	5	8	recovered	
4	F	32	wax + microencapsulated KCN powder	9	recovered		
5	F	33	wax + KCN powder	4	5	18	33
6	M	34	wax + KCN powder	5	recovered		

This new mechanical delivery system designed and developed by Connovation (Figure 13 and 14) is similar to the previously trialled ejectors (see Section 2.2, Enclosure trial 5 and Fisher et al 2007). The design has been significantly re-engineered to allow cyanide activation by the addition of two chambers (ie total of three chambers) containing a synergist powder. The KCN/synergist mixture was seen to improve the effectiveness of the KCN powder on pigs in previous trials. The ejector was mounted inside a bucket attached to a wooden board to help orientate pigs in front of the ejector rather than approaching and activating the ejector from the side. A strip of meat was attached via cable ties to the nozzle to encourage pigs to activate the ejector.

Figure 13. The ejector mounted inside a metal bucket and attached to a backboard

Figure 14. The ejector with nozzle removed

A total of five pigs were presented with the ejector delivery system. One pig activated the system and was prone in 2 min, unconscious in 15 min and dead in 30 min.

Australian trial

Eleven feral pigs (two males and nine females) were captured, weighed, sexed, ear tagged and placed in a one-hectare enclosure at RWPARC Inglewood. Access to water was *ad libitum*.

Twenty non-toxic wax baits were presented to the 11 pigs the night before the toxic trial. For the following two nights, 15 toxic baits containing microencapsulated KCN powder were presented to all 11 pigs. Infra-red video cameras were used to record and monitor bait uptake. Five pigs removed a single wax bait each and one female and one male pig received a lethal dose (Table 12). Of the remaining three pigs, one lay prone for approximately 5 min before recovering while the last two were observed to spit the baits out and displayed no obvious symptoms.

On the second night of toxic baiting, all nine remaining pigs were observed to put a single bait in their mouths and two female pigs received a lethal dose. The seven pigs were observed to spit the baits out and one pig staggered briefly while the rest displayed no obvious symptoms.

Table 12. Individual pigs that died following presentation of a KCN wax bait

Pig no.	Sex	Weight (kg)	Bait type
42	F	57.5	wax + microencapsulated KCN powder
188	M	15	wax + microencapsulated KCN powder

The ejector was attached to a post at a height of about 400 mm. All 11 pigs had access to the ejector system over four nights and infra-red video cameras were used to monitor pig interactions with the device. A total of five pigs were observed eating the meat bait off the nozzle of the ejector but none of these managed to activate the device.

Discussion

Microencapsulation of the KCN powder appeared to offer some improvement in the consumption of the wax baits. Pigs were still able to detect the KCN, particularly after sampling/partially eating the bait, and subsequently largely avoided consumption.

The ejector system does show promise as a delivery method for feral pigs: when the ejector system was activated it resulted in quick death. However, some technical difficulties limiting the activation of the ejector became apparent during the Inglewood trial and these prevent further interpretation of the results. The issues have since been rectified and further trials are needed to thoroughly assess the efficacy and efficiency of this device.

3. Fox trials

The following is a summary of Aster et al (2009) and as part of the project funded by the Wildlife and Exotic Diseases Preparedness Program (WEDPP): *Development of cyanide bait for rapid disease sampling and surveillance of wild animals*.

3.1 Background

The red fox (*Vulpes vulpes*) is a well known pest in Australia, causing significant environmental and economic damage (Saunders et al 1995). Foxes are also potential carriers of exotic epizootic diseases such as rabies (Marks and Bloomfield 1999) and it would be beneficial to develop improved carcass-sampling techniques to aid in disease control. One potential technique for disease surveillance and monitoring is to poison animals using a fast-acting toxin. This technique may also have other benefits for general control and research purposes where carcasses need to be inspected; for dietary analyses for example.

Currently only sodium fluoroacetate (1080) and strychnine are registered for fox control in Queensland (Gentle 2006). Cyanide has only been used as a research or management tool by government agencies, as further research is needed to refine the use of cyanide for fox control (Saunders et al 1995). Recently the use of 1080 has been viewed by some observers as inhumane for the control of feral animals (Sherley 2007). It is probably more plausible that animals are not experiencing conscious pain or distress, due to the effects of 1080 poisoning on the nervous system (Saunders and McLeod 2007). Nevertheless, the use of sodium cyanide (NaCN) delivered by the M-44 ejector has been shown to be a more rapid, and probably more humane, method for wild dog control than 1080 baits (Hooke et al 2006).

1080 is commonly used to control fox populations, as canids are relatively more susceptible to 1080 than native fauna, effectively reducing potential impacts to many non-target animals (Cremasco et al 2007). Unfortunately, the latent period of 1080 translates to a considerable period between ingestion and death. A lag time of 4.68 $\pm$ 0.28 hours has been reported (Staples et al 1995). As a result, carcasses of animals may be found at a considerable distance away from where the bait was initially consumed (Busana et al 1998). The use of cyanide as a fast-acting fox toxin appears more promising, with a lag time to death being a few minutes to an hour (Saunders et al 1995). For instance, trials delivering 0.88 g NaCN to wild dogs by M-44 ejectors have been shown to have an average time to death of 2 min 28 secs (Hooke et al 2006). The significantly shorter latent period than 1080 results in carcasses being found relatively close to the point of consumption, making NaCN potentially ideal for carcass retrieval (Marks et al 2003).

Modified M-44 ejectors have been shown to be effective at delivering cyanide to foxes and more efficient at recovering carcasses than other surface-deployed baits (Busana et al 1998). However, ejectors are more labour intensive than other known control methods such as hunting with hounds, spotlight shooting, treadle snaring and 1080 baiting (van Polanen Petel et al 2004; Gentle 2005). Additionally, the technique requires specialised equipment and is time-consuming and potentially dangerous to

the operator to activate. Incorporating cyanide into stand-alone baits may offer considerable advantages over the use of ejectors. Ease of handling, lack of need for specialised equipment, improved operator safety, and the ability to distribute baits over a large area suggests that stand-alone bait may offer significant gains in effectiveness and efficiency over the use of ejectors.

Recent improvements in the formulation of cyanide suggest that it has the potential to be incorporated into stand-alone baits that could be used to target species including foxes (Saunders and McLeod 2007). These improvements have included microencapsulation of cyanide, which reduces the amount of cyanide gas emissions by the bait material, drastically improving the palatability and effectiveness of the bait material (see Section 2.6). Such bait presentations have been successful for possums, suggesting that cyanide may have applications to other species, including wallabies (Eason et al 2008). Application of these 'off-the shelf' manufactured cyanide formulations to foxes warrants further investigation, given the potential dividends. From current manufactured cyanide formulations, the cyanide paste was identified as the best potential for application to foxes.

Following successful ejector trials, Busana et al (1998) suggested future research should determine ways to enhance the attractiveness of the bait material, thereby increasing the rate of bait uptake and improving the field efficacy. This work aims to build upon such experiences by offering a highly attractive bait with an alternative presentation of cyanide.

Algar and Kinnear (1991) and other anecdotal sources have reported the use of a 'paraffin wax' capsule filled with 600–800 mg NaCN powder. Such wax is brittle and is designed to crush easily (with minimal bite pressure), spilling the powder into the fox's mouth, and resulting in rapid death. Algar and Kinnear (1991) report success with using: 1) capsules coated with condensed milk and icing sugar and 2) capsules coated with a mixture of blood and liver. Typical strategies include the use of a tether, a short length of string or fine wire attached to the bait and pegged to the ground, to prevent caching (Algar and Kinnear 1991).

Lugton (1991) reports that capsule design is critical to ensure 'break up in the fox's mouth to be effective'. Lugton (1991) also reports that acceptability of baits to foxes is a problem due to a general neophobia. Many techniques were attempted to reduce this aversion, including the use of food and scent lures, with mixed success. Despite this, Lugton (1991) reports that a capsule dipped in molten mutton fat, placed directly on a piece of meat, and both buried beneath the soil is 'highly acceptable' (16/38 taken).

Historic anecdotes from hunters suggest that presenting cyanide with sweetened condensed milk (SCM) may be effective for targeting foxes. Analysis of bait preferences in foxes has shown that foxes have a 'sweet tooth' with a high preference for sweet baits, sugar or honey (Saunders and Harris 2000). Trials were undertaken in this study to determine the potential of such a method to target foxes.

3.2 Trials April–May 2008

Given historic anecdotes and bait preferences, SCM appeared to be a sound choice of bait substrate for testing for attractiveness and palatability to foxes. We first trialled this substrate in pen trials, then in the field with cyanide paste, to test whether this combination is effectively lethal to foxes and an efficient method for obtaining carcasses. Cyanide field trials were done using KCN rather than NaCN since a commercial KCN paste was available through Connovation.

Methods

Pen trials
The palatability of SCM and a non-toxic paste produced by Connovation was tested on five captive adult foxes. These foxes were obtained for another research project, so the testing was opportunistic rather than planned. These foxes were captured using soft-jawed traps from Inglewood Farms (a local free-range chicken producer) and transferred to holding pens at RWPARC Inglewood. Initially, the SCM and non-toxic paste was offered to the foxes on the pen floor but were not consumed. As a result, tubes containing the SCM and non-toxic paste were presented directly to the foxes. This allowed the foxes to sample the contents of each tube.

Field trials
Three sites in southern Queensland were chosen based on the presence of foxes and isolation from residential areas. Site 1 was located at Yarranbrook Farm, 10 km west of Inglewood on Cremasco Road. At this site two transects were set up totalling 7.5 km with 30 bait stations spaced approximately 500 m apart. Site 2 (Hooker's Farm) was located 9 km south of Inglewood on Goodwins Road, and had one 4-km transect with each bait station approximately 200 m apart. Site 3 at Inglewood Farms was also located off Goodwins Road, had one transect 9.5 km around the boundary with bait stations approximately 500 m apart. Sites incorporated typical farming and/or grazing lands of the Inglewood district, with lightly timbered and grazed areas interspersed with cropping paddocks.

Pre-feeding
Bait stations consisted of a rough circle of sieved sand and substratum approximately 1 m diameter. In the middle a 1–5 cm deep hole was made, to which SCM was added and covered over with soil. This technique was used to entice foxes to become accustomed to eating SCM, a novel food not previously encountered. Bait stations were checked daily for signs of animal visitation and SCM consumption. On several bait stations, remote cameras were used to confirm the identity of the animal that visited the plot and consumed the bait. Up to 20 bait stations were laid on each site to give a total of 100–101 bait nights from each site (Table 13).

Toxic baiting: KCN + SCM
The field trial permit from the APVMA authorised up to 30 toxic bait stations to be active at any one time. As a result, 10 toxic baits and 10 non-toxic SCM baits were laid at each of the three sites.

Two types of KCN paste were supplied by Connovation; each containing 50% encapsulated KCN. The plain paste KCN-1 contained KCN paste only, while the

Table 13. Fox visits and uptake of SCM at the study sites during the pre-feed trial

Site	Total fox visits	SCM uptake	Bait nights
1. Yarranbrook Farm	27	12	100
2. Hooker's Farm	18	7	100
3. Inglewood Farms	26	16	100
Total	71	35	300

second paste KCN-2 contained KCN paste and banana essence to potentially mask the odour of KCN. Each paste was tested in a separate trial.

Each trial followed the same protocol. Bait stations were identical to those used in pre-feeding — approximately 1 m² of raked sieved sand and substratum. Following free feeding, up to 10 bait stations that had been frequented by foxes were presented with a mixture of KCN paste and SCM. This placement of the toxic baits was deliberately biased to areas of high pre-feed SCM uptake in an effort to increase the probability that a fox would visit or consume the bait. Toxic bait stations were made by using a small plastic pipette to place a ~500 mg amount of KCN paste into a 1–3 cm deep hole made with a pick. A small amount of SCM was then used to coat the KCN paste, which was then covered with soil.

Each bait plot was checked daily. The KCN paste was replaced every second day to ensure that it remained toxic. Remote cameras were used at a sample of plots (eight in Site 3 and four in Site 1) to aid in identifying animals visiting and consuming baits. All tracks present on the plot and the consumption of baits were recorded. In total, 100 bait nights for toxic and non-toxic was recorded. Data collection involved recording what tracks were present on the plot ('activity'), whether the bait was consumed, uncovered or moved ('uptake'), the distance from the bait station to the recovered bait and the distance from a plot to a carcass. Differences in the activity of SCM and toxic baits were tested using Fishers exact test (Sokal and Rohlf 1995).

Toxic baits that were taken resulted in a $\geq$100 m radial search pattern from the bait plot to locate the carcass. This followed Marks et al (2003) who found that, using cyanide ejectors, carcasses are found 1–90 m (mean 7 m) from a M-44 ejector site.

The initial trial testing KCN-1 was undertaken between 21/4/08 and 25/4/08. The second trial testing KCN-2 was undertaken between 13/5/08 and 17/5/08.

Results

Pen trials

During the pen trials, all five foxes became accustomed to licking SCM from the tubes after repeated exposures (1–3 presentations). SCM was highly palatable and foxes quickly learned and continued to eat from the tube when offered. The same procedure was repeated with the non-toxic paste. At first, all five foxes consumed the non-toxic paste. However, on subsequent presentations, three foxes expelled the

paste from their mouths, and one did not approach the tube. In contrast, when the foxes were re-exposed to the SCM they all continued to eat it. This test was replicated twice with similar results.

Field trial pre-feed

A summary of the data collected during the field trial is in Table 13. In total, 71 of 300 stations (~24%) were visited by foxes, and 49% of the baits visited were eaten. Remote cameras and sand plots were used to identify animals that were consuming SCM (Figures 15 and 16), and showed that foxes ate 35 of the 44 SCM baits consumed (~80%). Examples of different animal tracks observed at SCM bait stations are shown in Figure 16.

Figure 15. Fox taking SCM at a bait station during pre-feed

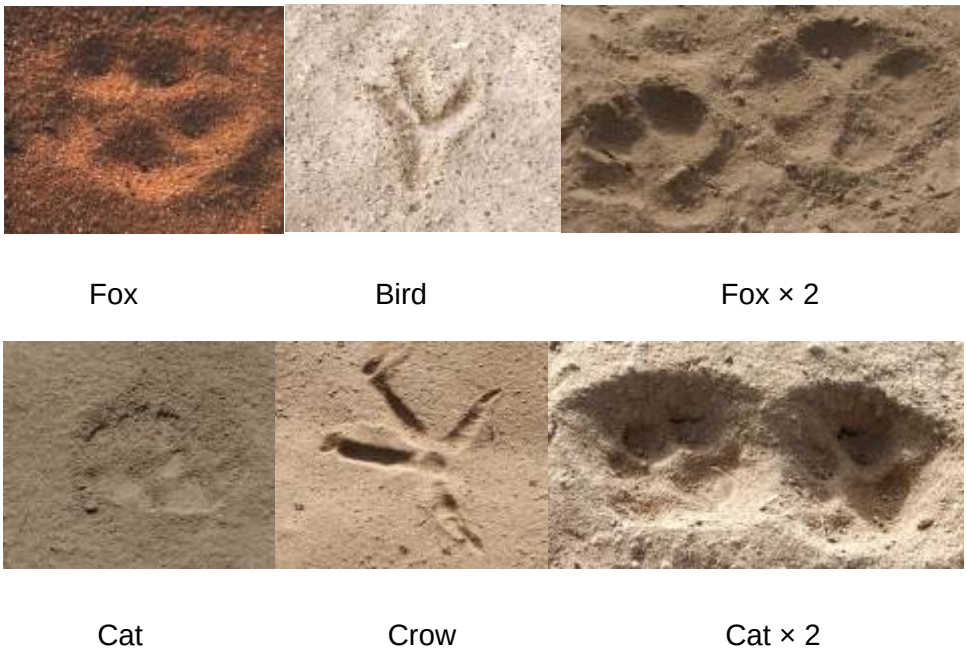

Figure 16. Examples of tracks observed on SCM bait stations

Figure 17 illustrates the species visiting each station, and the percentage consumed by these species. Three non-target groups — birds (mainly corvids), macropods

(mainly eastern grey kangaroos) and a dog — were recorded consuming SCM from the pre-feed trial.

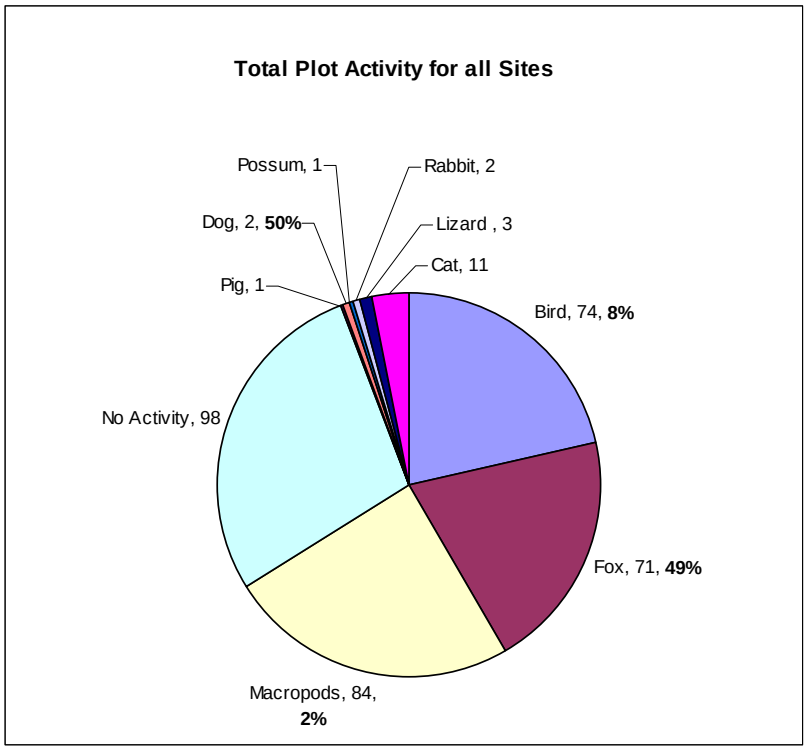

Figure 17. Plot activity for all sites in the pre-feed trial.
Number of visits and percentage of bait consumption (in bold) is indicated.

Toxic baiting: KCN + SCM

Over the two trials using KCN-1 and then KCN-2, KCN uptake was primarily by foxes, with one exception where the KCN-2 bait was consumed by crows. Foxes visited 27% of SCM bait stations (n=201), and 22% of toxic bait stations (n=199). In total, foxes removed 47 of 54 SCM baits visited (~87%) and uncovered or moved 33 of 44 toxic baits visited (75%).

There was no significant difference between fox activity (number of visits) at SCM plots or KCN plots during both field trials ($P > 0.05$) (see Table 14). A total of four foxes were killed, with one juvenile male and two adult female fox carcasses retrieved from Site 1 and one adult female retrieved from Site 2. No carcasses were obtained from Site 3. Fox carcasses were found 0–16 m from the bait station at an average distance of 7.3 m. Typically, foxes were found lying on their sides, with legs and tail extended, faeces at the anus, and urine present on the substrate (see Figure 18). Only three KCN baits were not recovered and none of these baits resulted in a carcass. Remains of the rest of the KCN baits taken were expelled between 0–3 m from the bait station, with apparently little of the toxic baits eaten. Thirty of the 33 KCN baits taken or uncovered by foxes were recovered (Table 14). Non-target animals were also identified on or near toxic bait stations through the use of the remote cameras (Figure 19).

Table 14. Summary of KCN and SCM bait uptake, activity and carcass recovery on the three sites
Trial 1 used plain KCN-1 paste and Trial 2 used banana essence KCN-2 paste.

	Treatment - trial no.				
Data collected	**SCM-1**	**KCN-1**	**SCM-2**	**KCN-2**	**Total**
bait nights	101	99	100	100	400
fox activity (n)	28	18	26	26	98
uptake (n)	23	15	24	18	80
recovered baits	0	14	0	16	30
carcasses recovered (n)	-	1	-	3	4
carcasses/ KCN bait uptake %	-	6.6	-	16.6	12.1
carcass / KCN bait nights %	-	-	-	3	2
bait uptake /activity %	82.14	83.33	92.31	69.23	81.63

Figure 18. Fox poisoned by KCN-2 bait

Figure 19. Non-target animals recorded with remote cameras on (*) or near (#) toxic bait stations.
Clockwise from top left; feral cat*, kangaroo*, feral pig#, hare,* possum* and Maremma dog.*

Discussion

This study delivered some positive results, but showed the delivery of cyanide gel to foxes appears to be problematic due to issues with cyanide detectability, environmental stability, and desiccation/contamination. It became apparent during testing that both cyanide formulations were less palatable than non-toxic bait and largely rejected by foxes. Despite high levels of bait visitation by foxes, we observed low KCN bait uptake and hence retrieved only a few carcasses. After foxes visited bait stations, they frequently uncovered and rejected KCN baits. Such behaviour was never observed with SCM baits — although foxes did not uncover all baits when visiting a bait station, all baits that were uncovered were subsequently eaten. Given that non-toxic and toxic baits were presented in the same manner, the rejection of toxic baits indicates that foxes can detect the KCN and generally view it as unpalatable.

Carcass retrieval in this study was low, due to the low palatability and therefore low uptake of cyanide baits. In total, 90% of the cyanide baits that were taken were rejected by foxes and found within 3 m of the plots. The remaining 10% (ie three baits) could not be found. Given the ability of foxes to readily consume SCM from plots, the overall rejection of cyanide by foxes indicates that the cyanide paste baits are largely unpalatable to foxes. Given that baits were at least uncovered before being rejected, it is obvious that foxes were deterred by the odour, taste or the effects of the bait consumption rather than any cues associated with the bait location. Combined with evidence from previous work (eg Allen 2002), this suggests odour cues are likely to be responsible. Furthermore, given that consumption of cyanide would result in the death of a fox, this aversion is not formed via a classic conditioned aversion, (ie through a previous illness-inducing exposure). Rather, a primary aversion to the cyanide odour cues is likely to be responsible for the rejection of cyanide.

Interestingly, similar behaviour has been noted during the presentation of M-44 ejectors to wild dogs, where non-toxic ejectors were favoured over toxic ejectors (Allen 2002). The M-44 ejectors that contained a cyanide capsule were often rejected by wild dogs, which Allen (2002) attributed to dogs detecting the odour of cyanide. This is despite the use of plastic capsules (containing the cyanide) with ends ‘sealed’ with wax. It appears that odour cues from cyanide may be detectable, especially to animals with a sensitive olfactory ability, such as canids (Allen 2002).

Foxes within our study sites became highly accustomed to taking SCM baits during the pre-feed trial and often the same plots were repeatedly visited. By biasing the positioning of KCN baits to areas that showed high uptake of SCM (in pre-feeding) we attempted to increase the probability of visitation to, and consumption of KCN baits. Although this was successful in attracting foxes to the cyanide baits, it may have reduced the acceptance of the toxic bait. Free feeding may habituate the animal to the taste of the non-toxic bait, and where the toxic bait is markedly different, consumption of this bait may be reduced (Gentle 2005). The strong odour and taste cues of cyanide may have been amplified due to the contrast with the highly palatable bait used in the free feed. This reinforces the need to produce a highly palatable bait, but also a free-feed cue as close as possible to the toxic bait.

We found the use of cyanide gel also appears to have problems associated with desiccation/contamination from the surrounding soil. The three plots that produced carcasses had similar soil conditions: fine sand, free of small rocks and grit. This

substrate appeared to reduce desiccation of the bait, helping to retain at least some of its fluidity (Figure 20). This in turn may have increased the exposure of foxes to the cyanide paste, reducing their ability to eject or 'spit out' the dried, harder parts of the bait. On many other plots that did not result in carcass retrieval, the cyanide gel was exposed to coarse sand, dirt, grit and small rocks. These baits often formed a hard congealed mass that crumbled when picked up, probably allowing foxes to easily spit the baits (Figure 21). Previous studies note that the consistency of the cyanide appears to be an important issue affecting efficacy; for example, powder in cyanide ejectors is more efficient at killing foxes, as caked NaCN can be spat out (Connolly et al 1986).

To avoid these problems, one solution could be to encase the cyanide within an outer shell to provide protection from desiccation and contamination by the soil. Ideally, this shell would have to be soft but sufficiently brittle to ensure that foxes cannot mouth and eject the bait without receiving a lethal dose of cyanide. It would also have to be highly impervious to ensure foxes would not detect any cyanide odour and reject the bait. The idea of an easily fragmented bait is not new; others have tried using cyanide powder encased within brittle wax, with mixed success (eg Algar and Kinnear 1990, Busana et al 1998).

The cool temperature of the trials may also have affected bait texture and thereby reduced cyanide delivery to foxes. The KCN paste appeared to become quite solidified when exposed to temperatures less than 15°C. With the two trials being run in autumn, baits were exposed to temperatures as low as about 10°C and it is likely they were quite solid when foxes attempted to eat them. As observed with the coarse soil, this solid texture may have allowed the baits to be more easily ejected, and stopped a lethal dose from being delivered.

Figure 20. **KCN bait that was rejected and the fox that was retrieved after exposure to this bait**

Figure 21. Rejected KCN bait that has formed a congealed mass of rocks and grit No fox carcass was obtained from this bait.

Non-target uptake of buried toxic baits was limited to crows (one bait) while SCM baits were consumed by a dog, pig, birds (mostly crows) and macropods. Although no bird carcasses were found after conducting a 100 m radial search pattern, it is possible that the birds were able to travel a distance further than this before succumbing to the toxic effects of KCN. The consumption of SCM by macropods was only observed during the pre-feed. These results were not definitive, as the bait was consumed and the only visible prints on the plots were from macropods. It is quite possible that the two SCM baits that were assumed to be eaten by macropods were actually consumed by birds or a fox and their tracks were then masked by macropod tracks. It was also observed with remote cameras that macropods were present on many other plots where baits were not consumed.

Toxic baits outside the bait stations, left exposed or rejected by foxes, could also offer a risk to non-target species. These baits could be a higher non-target risk since they could be more readily taken by non-target animals than buried baits. So, improving the palatability of bait to foxes would not only improve the efficiency of the technique but would also reduce the availability of toxic bait to other species.

Overall, despite the low palatability of the KCN, these trials yielded some positive results that may have future applications for fox control. SCM proved to be an attractive and highly palatable bait material for foxes in the field trials, with baits being consumed at 87% of plots that were visited by foxes. The use of SCM should be considered for future applications to aid or promote consumption of bait material. Greater encapsulation of the cyanide, either chemically (ie within the gel) or physically (ie within an external coating), should also be considered to reduce the cyanide odour cues and bait desiccation and contamination problems.

3.3 Trials April–May 2009

Field trials in 2008 tested the cyanide paste for application for foxes (Gentle et al 2008). A trial tested a small amount of cyanide paste (~500 mg) coated with SCM in the field. This trial had some success, showing that, when baits are consumed, foxes are highly susceptible to the effects of cyanide. However, despite SCM free-feed baits being readily consumed, baits were largely rejected by foxes once cyanide had been added. This indicated there was some issue with the cyanide baits that made them largely unacceptable to foxes.

From observations gathered during this field trial, we concluded that the detectability, environmental stability, and desiccation/contamination of the paste from the surrounding soil reduced the palatability and effective delivery of cyanide to foxes. Odour cues were surmised to be largely responsible for foxes detecting and rejecting cyanide baits. We recommended that, in order to improve the palatability, and hence delivery of cyanide to foxes, a 'greater encapsulation of cyanide, either chemically (ie within the gel) or physically (ie within an external coating) may be required to reduce the associated odour cues.'

The trial of 2009 aimed to further refine the 2008 method to develop an appropriate cyanide presentation to target foxes, based on the recommendations. The next logical step was to physically encapsulate the cyanide paste (to reduce odour cues) to attempt to increase field acceptance and palatability. Given the success of SCM in previous trials, these alternative bait presentations were based on a combination of SCM and KCN paste (supplied by Connovation).

Methods

Bait types
In view of the issues associated with previous bait formulations (Gentle et al 2008), three bait formulations were considered to be worthy of further testing. These were:

- encapsulated cyanide gel and oil-based sweetened condensed milk (OSCM) contained within a water balloon ('water-balloon baits')
- encapsulated cyanide gel and OSCM contained within food grade plastic cling film ('Gladwrap baits')
- encapsulated cyanide (Feratox® pellets) within dried dog food or marshmallow baits.

OCSM was used to reduce any potential reaction (ie ‘gassing off’) of KCN with moisture in the bait, as was found in previous trials (Gentle et al 2008).

Study sites
The baits were tested in the field at Inglewood Farms, Qld; a mixed farming/grazing and chicken farm enterprise situated 8 km outside of Inglewood on Tobacco Road. This site was chosen because it has a resident fox population and is isolated from residential areas. The farm had already been used for previous cyanide trials (Gentle et al 2008) but the 2009 work was done in a different area and also over 12 months later.

This property was divided into three different areas (sites) where baits were laid. Sites 1, 2 and 3 respectively tested water-balloon baits, Gladwrap baits and Feratox® pellets in baits. On each site, between 19 and 20 bait stations were laid approximately 500 m apart. Pre-feeding with non-toxic baits was undertaken for about seven days at each site. Toxic baits were laid at those bait stations showing high fox activity from the pre-feeding. Up to 10 toxic baits were laid at each site depending on non-toxic uptake, interference from non-target species and prevailing weather.

Water-balloon baits
Pre-feed baits consisted of water balloons filled with 20 ml of OSCM. The OSCM was manufactured from milk powder, icing sugar and vegetable oil. Each bait was placed on a sand plot and covered in SCM and buried 2–3 cm below the surface (Figure 22). Small beads (~1 mm diameter) and glitter were added to baits for the first two

days of free feeding. This was done to help ascertain whether baits were consumed, through visual confirmation of the material in any fox scats discovered.

Figure 22. Pre-feed bait covered in SCM

Toxic baits consisted of water balloons filled with approximately 500 mg of microencapsulated KCN and 10 ml of OSCM. Baits were tethered with nylon fishing line to a 30-cm metal tent peg hammered into the ground at the side of the 1 m² sand plots. The bait was then placed in a small depression in the centre of the plot, covered with SCM and lightly buried under 2–4 cm sand.

Baits were classified as either having been taken, mouthed or chewed (uptake) or visited. Taken baits included baits that had been removed from the bait station, while visited baits had simply been uncovered or shown other signs of being located by foxes (eg footprints or scratches on plots).

Gladwrap baits
Pre-feed Gladwrap baits consisted of 10 ml of OSCM in Gladwrap. The Gladwrap was then twisted so that the paste formed a compressed ball, and tied. Toxic Gladwrap baits were identical but also contained ~500 mg KCN paste. These baits were presented to foxes in the same way as water-balloon baits.

Feratox® pellets
Initially, pre-feeding was done using dog biscuits covered in SCM. Although this seemed to attract foxes to bait stations, they appeared to consume very few dog biscuits. As a result, dog biscuits were placed in plastic trays covered in OSCM (see Figure 23). This was done to prevent sand and soil contaminating the bait, but was also unsuccessful in enticing foxes to eat baits.

Figure 23. Dog biscuits covered in OSCM and finished tray set

Toxic baiting was undertaken using Feratox® KCN pellets (~3–5 mm diameter) supplied by Connovation. Two pellets were inserted into each marshmallow; this equated to a dosage of ~500 mg KCN. One marshmallow was then placed into a plastic tray, covered with OSCM and then a square piece of baking paper was placed overtop of the tray (Figure 24). This was then buried in the middle of the sand plot.

Figure 24. Non-toxic marshmallow bait in plastic tray covered in OSCM

Results

Water-balloon baits
Free-feed water-balloon baits were readily visited and consumed by foxes (see Table 15). Very few free-feed baits located by foxes were not taken.

Remnants of balloons, glitter and scat beads were found in fox scats (Figure 25). The presence of beads and glitter in scats confirmed that foxes were consuming free-feed baits. Additionally, since these scats were found on bait stations, this confirmed that foxes were revisiting bait stations over multiple days.

Figure 25. Fox scats showing water balloon (left) and glitter (right)

Table 15. Uptake and visitation of non-toxic (NT) and toxic (T) water-balloon baits by foxes at Site 1
The number of fox carcasses collected in also shown after the uptake of toxic baits. The date and amount of rainfall is also shown.

Date	Rain (mm)	Uptake NT	Visitation NT	Uptake T, carcasses	Visitation T
		No. baits /total			
24/03/2009		2/20	3/20		
25/03/2009		6/20	6/20		
26/03/2009		9/20	11/20		
28/03/2009		14/20	15/20		
30/03/2009	1	15/20	15/20		
31/03/2009	0.4	11/19	11/19		
2/04/2009	4.2	13/20	14/20		
3/04/2009	0.4	3/10	3/10	0/10	2/10
4/04/2009	10	2/10	3/10	3/10, 1 fox	3/10
5/04/2009	0.4	1/10	1/10	0/9	1/9
6/04/2009		0/10	0/10	0	0

From the three toxic baits taken by foxes, one was snapped at the tether but remained relatively intact, while the other two had been chewed considerably. One fox carcass was found within 5m of a chewed bait.

Rain appeared to affect foxes' visitation to and uptake of both toxic and non-toxic baits. We observed that water-balloon baits appeared to absorb water from the soil. This resulted in the KCN within baits 'gassing off' after 1–2 nights exposure in the field (Figure 26). This was most likely assisted by the extra moisture in soil following rain. The absorption of moisture into baits and subsequent reaction with the encased cyanide may have also reduced the bait uptake and palatability by foxes. We also observed that water balloons perished and were easily broken after two days exposure to the environment.

Under field conditions, we observed that that the OSCM was not homogenous; over time the oil separated and the remaining ingredients (milk powder, icing sugar and cyanide paste) formed a solid mass. These solid baits would be more readily expelled from a fox's mouth once KCN is detected. This may help foxes to reject baits and therefore reduce the likelihood of receiving a lethal KCN dose.

Figure 26. A toxic water-balloon bait that has split and gassed off due to moisture
Note the brown stains where moisture has reacted with the KCN paste. Balloons were also notably larger (probably as a result of filling with HCN gas) after being exposed for only one day.

No toxic balloon baits were entirely consumed during this trial. The bait that produced a carcass was considerably chewed (Figure 27).

Like the non-toxic baits, rain appeared to have a deleterious effect on uptake of toxic baits. Fox activity and bait uptake declined following each rain event.

Toxic bait uptake was higher than non-toxic bait uptake on the site when both types were simultaneously presented (Figure 28). This possibly indicates that foxes may not necessarily form an aversion to toxic baits, although further replication is needed to confirm this.

Figure 27. Toxic balloon bait that produced a carcass but was not entirely consumed
Note very little OSCM remained in the balloon.

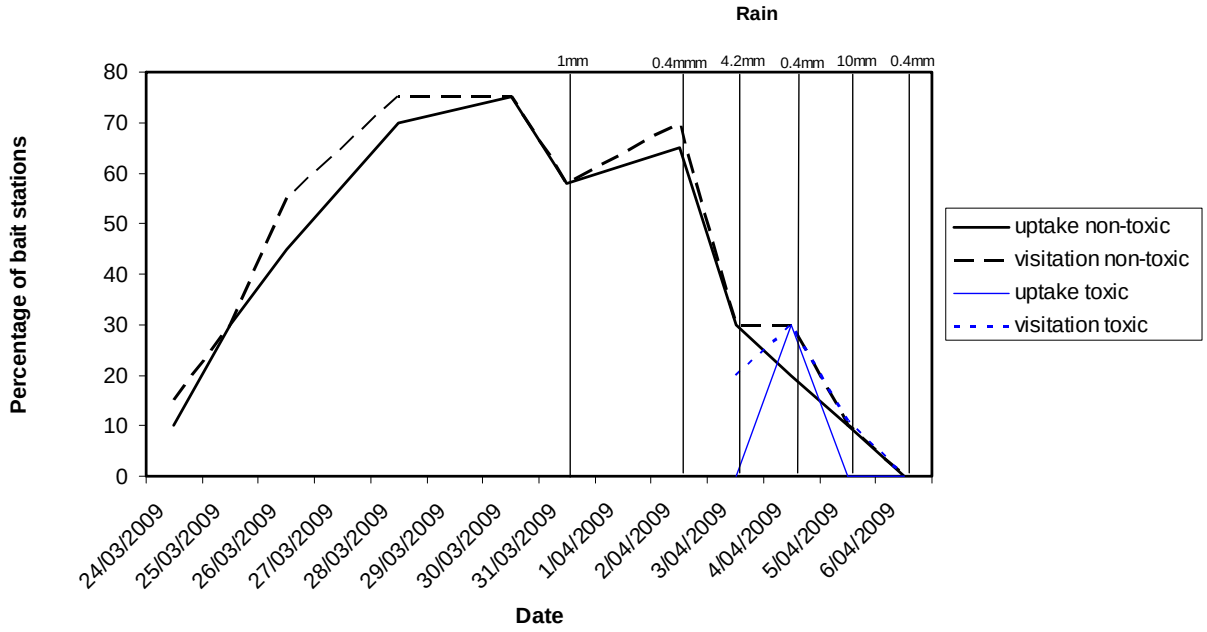

Figure 28. Visitation and uptake of water-balloon baits

Gladwrap baits

Gladwrap baits appeared to be stronger and were less likely to break from the tether than water-balloon baits. Toxic Gladwrap baits also appeared more waterproof than toxic water-balloon baits, although some gassing off did occur in some after two days (Figure 29).

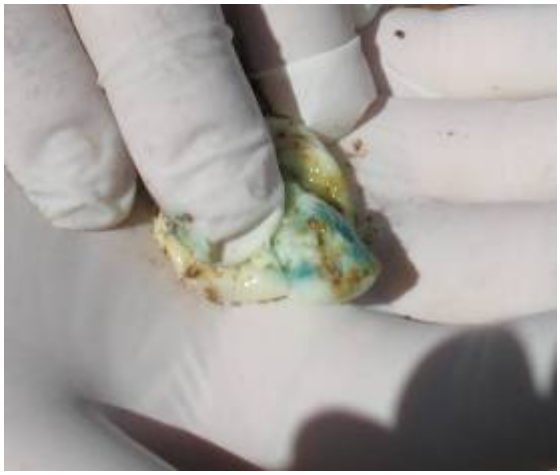

Figure 29. Gladwrap bait that has started to gas off due to moisture contact

Rain appeared to reduce the uptake of both free-feed and toxic Gladwrap baits. Only one fox was killed using this bait type and this occurred before the site received large amounts of rain (Table 16). Two toxic Gladwrap baits were taken by foxes; both were considerably chewed before being rejected by foxes (Figure 30). The amount of bait residue remaining in the Gladwrap appeared to be greater than that left by water-balloon baits.

Figure 30. Toxic gladwrap bait that produced a fox carcass

Table 16. Uptake and visitation of non-toxic (NT) and toxic (T) gladwrap baits by foxes at Site 2
The number of fox carcasses collected is also shown after the uptake of toxic baits. The date and amount of rainfall is also shown.

Date	Rain (mm)	Uptake NT	Visitation NT	Uptake T, carcasses	Visitation T
		no. baits/total			
24/03/2009	-	6/19	8/19		
25/03/2009	-	8/19	8/19		
26/03/2009	-	9/19	10/19		
28/03/2009	-	12/19	12/19		
30/03/2009	1	12/19	14/19		
31/03/2009	4.6	8/19	8/19		
3/04/2009	0.4	12/20	13/20		
4/04/2009	10	2/10	2/10	1/10, 1 fox	1/10
5/04/2009	0.4	1/9	2/9	0	0
6/04/2009	0.2	0	1/9	0	0
7/04/2009	-	0	0	1/10	1/10
8/04/2009	-	0	0	0	0

As with the water-balloon baiting, there was a substantial decline in fox activity and uptake for non-toxic baits following rain (Figure 31). Feral pig activity in the study area and on bait stations notably increased after the rain.

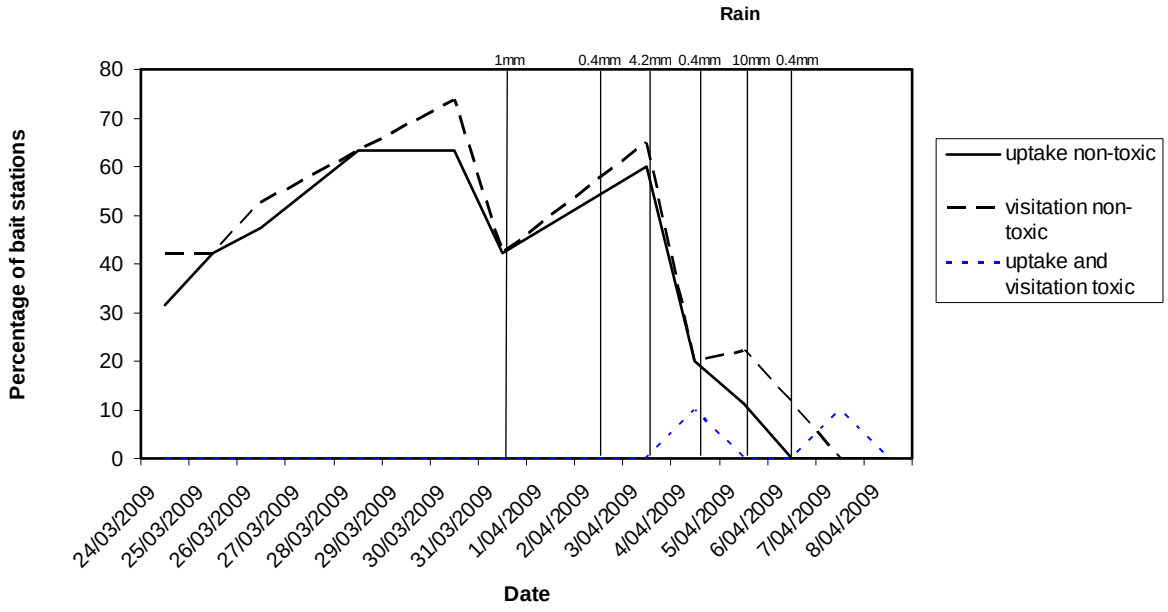

Figure 31. Visitation and uptake of Gladwrap baits

Feratox® pellets

In many cases the dog food was still not consumed after placing it into trays. During toxic trials both bait types were found uncovered and not consumed (Table 17). No fox was found to have consumed a lethal amount of KCN, despite numerous baits being taken from bait stations. The baits that were visited by foxes were largely rejected, with most baits visited only being exposed or uncovered, with little evidence of chewing.

Marshmallows could be easily spat out by a fox, given their consistency.

The uncovering and rejection of baits by foxes could result in greater exposure of non-target species to the bait. This bait type was highly attractive to birds such as crows due to the use of the trays and baking paper. Almost every plot that was uncovered by a fox also showed high levels of bird activity, evidenced by numerous bird prints. This suggests that the risk of non-target poisoning may be exacerbated by the increased visitation of non-targets, such as birds, to the bait stations.

Despite this high level of bird visitation, no bird carcasses were discovered within a 100 m radial search pattern. However, it is possible that birds were removing toxic bait materials and consuming them further away. As a result of this non-target interference, trials using this bait type were terminated.

Table 17. Uptake and visitation of non-toxic (NT) and toxic (T) dog food (D) and marshmallow (M) baits by foxes at Site 3
The date and amount of precipitation is also shown.

Date	Rain (mm)	Uptake NT	Visitation NT	Uptake T	Visitation T
		no. baits/total			
25/03/2009	-	2/20	8/20		
26/03/2009	-	3/20	9/20		
28/03/2009	-	0/20	6/20		
30/03/2009	1	9/20	13/20		
31/03/2009	0.4	4/20	4/20		
1/04/2009	4.2	2/20	4/20		
3/04/2009	0.4	4/10 D 7/10 M	5/10 D 7/10 M		
4/04/2009	10.4	2/10 D 7/10 M	4/10 D 7/10 M		
6/04/2009	0.2	3/5 D 2/5 TM	3/5 D 2/5 M	2/5 TD 5/5 TM	3/5 TD 5/5 TM
7/04/2009	-	1/10 M	1/10 M	5/10 TM	6/10 TM

Discussion

Non-toxic OSCM water-balloon baits were highly palatable during free feeding, with foxes taking >90% of baits visited. It appeared that most of the baits taken were actually consumed, as evidenced by the scant bait casings remaining. These baits remained highly palatable following rain, and during the presentation of toxic baits on the site, even though general trends in visitation to baits were declining. When presented in Gladwrap, uptake and consumption of OCSM was similar to water-balloon baits. However, less bait material was eaten by foxes from Gladwrap baits, suggesting that water-balloon baits are relatively superior at delivering bait material.

The dog biscuit/marshmallow baits containing Feratox® were unsuccessful. Dog biscuits were highly unpalatable to foxes, with very little bait material consumed. Furthermore, marshmallows that contained Feratox® tablets were easily expelled and therefore able to be rejected by foxes, further reducing their chance of delivering a lethal dose. Finally, the use of plastic trays and paper, and any marshmallows previously exposed by foxes, proved to be highly attractive to non-target species,

particularly crows. As a result of this increased potential for non-target uptake, testing of this bait type ceased and is not recommended for future trials.

The visitation rate to toxic baits was relatively low compared to non-toxic baits. However, the acceptance of toxic OSCM baits ((water-balloon or Gladwrap with KCN paste) was still high, with >80% of baits visited by foxes subsequently taken. However, after being taken, many of these baits were subsequently rejected by foxes, and many baits were found on the ground within a short distance of the bait station. There are a number of possibilities that may explain the reduced toxic bait uptake by foxes. Presenting non-toxic bait for extended periods may have resulted in foxes becoming satiated to the bait, reducing bait uptake. It is also possible that over-consumption of the OSCM may result in some digestive discomfort due to its high oil content. Thirdly, feral pigs were noted in the general area on each site, and their increased activity following rain may have discouraged foxes from visiting bait stations. These potential causes are worth noting but remain speculative. Regardless of the precise reason/s for the decreased bait uptake, it is clear that free feeding may reduce the acceptance and therefore, efficacy of toxic baits.

4. General discussion

Our research suggests that cyanide is a humane toxin for feral pigs when effective formulations are successfully delivered. Results indicate that time to death in pigs is generally rapid (particularly in comparison to 1080) and symptoms are comparable to other species — suggesting a humane death. Although high levels of efficacy were not consistently achieved in our trials, lower levels (60-80% efficacy) may still be acceptable for disease-sampling purposes. This being the case, it may still be beneficial to pursue cyanide as a humane toxin for disease sampling of feral pigs if delivery and toxicity issues can be overcome. However, there remain significant issues requiring considerable levels of further research.

Pigs are susceptible to cyanide intoxication, but achieving consistent delivery of lethal doses remains problematic. It is difficult to determine a suitable ‘lethal dose’ for bait loading given the conflicting methods used between studies, both in the literature and unpublished data. Feral pigs are difficult to poison, partly due to their large body size but also due to apparent inconsistent dose:response relationship (eg McIlroy 1983, Sheehan 1984, Eason and Henderson 1991, Gentle et al 2008b). For example, Sheehan (1984) notes that 15–20% of animals survived treatments when presented with 1080 doses greater than an LD_{100} (described as twice the upper limit of the 95% confidence interval of the LD_{50}). While increasing the toxic loading of bait may help increase efficacy, it may compromise palatability, non-target or operator safety, or cost. Despite conjecture about determining appropriate lethal doses, baiting pigs with any amount of cyanide in stand-alone bait is particularly difficult, given palatability concerns.

Foxes are known to be highly susceptible to cyanide. Our studies indicate that delivery of cyanide gel to foxes is problematic due to issues with detectability, environmental stability, and desiccation/contamination from the surrounding soil. More research is needed to improve palatability to effectively deliver cyanide to foxes. Although no consistent delivery technique was developed during this study, the results were encouraging and suggest that even a slight improvement in the

palatability of the toxic bait may be sufficient to dramatically improve the bait delivery of cyanide.

Similar to feral pigs, foxes appeared to find toxic baits unpalatable, despite readily accepting non-toxic versions of the bait. In delivering cyanide to both species, the taste of, or reactions to cyanide appear to be problematic despite advances in microencapsulation to disguise cues and the use of synergists to promote reactivity (for pigs). In general, most feral pigs partially consumed, or at least substantially sampled/chewed the first toxic bait they encountered. Observations on feral pigs showed that once an attempt to consume a toxic bait was made (and animals became aware that cyanide was in the bait), subsequent presentations of the cyanide bait were basically sampled and rejected. This may be more than simple 'cyanide-shyness' or low palatability of cyanide; it may be a learned aversion to the taste of cyanide (Warburton and Drew 1994). Also, where an animal suffers illness following cyanide ingestion, they are likely to acquire a conditioned taste aversion (see Garcia et al 1974), associating with its fast action and strong taste or odour cues (ie through associating illness with consumption of cyanide).

Such palatability concerns have been demonstrated in other species, including possums. Cyanide pastes used to control possums in New Zealand reportedly 'have a characteristic smell produced by the hydrogen cyanide gas' (Eason and Wickstrom 2001) that can deter possums from feeding. Some possums appear to have an innate aversion to this smell, which has hampered the effectiveness of cyanide paste baiting campaigns (Warburton and Drew 1994). Encapsulating cyanide was suggested as a means to improve acceptance of cyanide by possums (Warburton and Drew 1994) and feral pigs (Eason and Henderson 1991). However, even with recent improvements in encapsulation technology (as tested by this study), the palatability of cyanide bait to feral pigs is still relatively poor. Despite encapsulation and attempts to mask with flavours, it appears difficult to disguise the cues associated with cyanide given its distinctive smell, taste and unpleasant caustic reaction. In addition, pigs appear to be remarkably efficient at rejecting/ejecting foodstuffs recognised to be unpalatable, as demonstrated on numerous occasions in our trials through rejecting cyanide bait. The taste of, or reactions to cyanide appear to reduce the palatability of bait.

Regardless of the mechanism, such aversion would hamper bait applications and provide additional justification for continuing to develop the ejector. Ejectors have significant advantages over baits to disguise the cyanide. There may be additional scope to mask odour cues with cyanide ejectors (ie cyanide would be contained within a sealed unit) and less potential for rejection once activated (ie more difficult to eject powder than a semi-intact bait). To improve the efficacy of the technique, and to reduce the potential for developing bait-shy animals, more work would be required to concentrate efforts on an attractive, palatable-but-lethal bait package. Such a compromise is difficult to achieve in bait with current cyanide formulations, but potentially less difficult in ejectors.

Improving the palatability of cyanide bait would improve consumption by feral pigs, but this may still fail to increase mortality following cyanide consumption. Mode of ingestion also affects toxicity and mortality (*sensu* Eason and Henderson 1991). Studies have shown that, even when cyanide is swallowed, the effectiveness and onset of cyanide intoxication appears to be markedly reduced compared to absorption across the mucous membranes in the buccal cavity (Mitchell 2003, Elsworth et al 2004, Gentle et al 2007, D. MacMorran unpublished data). This may be

due to the high acidity in the stomach inhibiting the formulation of hydrogen cyanide gas (Fisher and Campion 2007). However, even when cyanide powder is delivered directly into the buccal cavity, as with ejectors, mortality is still relatively poor at doses up to 25 mg/kg KCN (eg Fisher and Campion 2007).

This apparent tolerance to cyanide in pigs, perhaps due to metabolic processes adapted from dietary cyanide exposures (Fisher and Campion 2007), may provide sufficient justification to question the applicability of cyanide as a toxin for feral pigs. However, when combined with the practical difficulties of delivering cyanide in bait to feral pigs, it is difficult to deliver a sufficient dose of cyanide without rejection of the bait material. These issues, evident when delivering cyanide to feral pigs in a variety of pen trials, have resulted in no suitable presentation method being developed.

While considerable research has shown that foxes and pigs are susceptible to cyanide, we have not been able to successfully deliver the toxin with the efficacy required for a new control technique. Until cyanide formulation and delivery can be improved, sodium nitrite may offer greater potential as a humane toxin to 1080 for pig control, and even for some level of disease monitoring, given the results of recent trials (S. Lapidge, Invasive Animals CRC pers comm 2010; Connovation unpublished data 2011). When field trials on sodium nitrite are undertaken, additional criteria to efficacy should be considered to ascertain the potential applications to disease sampling. These criteria should focus on practical deployment and usage issues and assess the difficulty of locating carcasses, such as the distance from the bait-consumption site and the habitat structure where carcasses are found. This may provide additional scope for the further development of sodium nitrite.

5. Recommendations for future research

5.1 Cyanide and feral pigs

Given the difficulties associated with cyanide toxicity and bait palatability, even using microencapsulated cyanide powder formulations, we recommend abandoning the testing of cyanide for general control and disease sampling of feral pigs. We suggest that further research to progress feral pig control and disease sampling should focus on the development and use of sodium nitrite and the mechanical ejector. Specific recommendations are as follows:

1. Cyanide should only be considered for future applications for feral pigs when there is a significant advancement in toxin-encapsulation technology. Even then a definitive assessment of the toxicity, lethality and humaneness of cyanide would need to be undertaken, preferably including a dose-ranging study, to determine appropriate lethal doses. To date, it has been difficult to distinguish the true effects of cyanide intoxication given the confounding issues of delivery and formulation. This work would need to determine:
    - the susceptibility of feral pigs to cyanide
    - an effective oral lethal dose of cyanide
    - whether incapacitation is sufficiently rapid for disease sampling purposes or to offer significant advantages over currently available toxins on welfare grounds.

2. The mechanical ejector designed by Connovation has shown promise as a mechanism to deliver toxins to feral pigs. However, further testing and modification is needed to improve toxin delivery, making it more consistent. Given the substantial investment in developing the device, Connovation intend to conduct further testing of the ejector system in 2011/2012. This testing should consider previous work by Landcare Research, given their successes with ejector deployment with domestic pigs (Fisher and Campion 2007). This device has potential to deliver a variety of toxins, including sodium nitrite, to feral pigs with minimal non-target risk.

3. Until improvements in cyanide delivery can be demonstrated, sodium nitrite offers greater potential as an alternative toxin to 1080 for pig control, and may even offer some use for disease monitoring.

5.2 Cyanide and foxes

Although foxes were attracted to both non-toxic and toxic baits, the palatability of toxic baits remained relatively low. Nevertheless, given the toxicity of cyanide to foxes, even a slight improvement in the palatability of the toxic bait may be sufficient to dramatically improve this approach. Considering this, specific recommendations are as follows:

1. Free feeding should be reduced or abandoned to reduce the likelihood of toxic baits being rejected by foxes. Although it is likely that free feeding contributed to the bait rejection we observed, it is uncertain as to what extent the palatability of toxic baits can be improved by reducing or abandoning free feeding. Nevertheless, if free feeding needs to be done, it is essential to ensure that the free feed used mimics the toxic bait presentation as close as possible, to minimise any rejection of the final bait material offered.

2. The results from using water-balloon baits are sufficiently promising to attempt such trials again, albeit with no free feeding. Similarly, SCM should be considered for future applications to attract or deliver bait to foxes. However, current formulations of OSCM need to be modified to make it equally palatable as SCM (ie reducing associated odour cues), while remaining homogenous under environmental conditions (particularly low temperatures).

3. Tethering baits should be continued as a means of reducing bait caching by foxes or removal of baits by non-target species. However, the tether and the peg should be buried close to the bait to help reduce non-target disturbance by accidental or deliberate pulling on tethers and exposing the bait.

4. Work to pursue the registration of the cyanide ejector should be continued for use as a control tool for foxes. Although stand-alone baits do offer some advantages over ejectors, as yet there is no consistent bait delivery.

6. Concluding remarks

Trials for both pigs and foxes were warranted to test ‘off-the-shelf’ and new cyanide formulations, particularly given the potential dividends for disease surveillance. This research has highlighted a variety of significant issues that must be addressed for the technique to progress. Significant further work is needed for feral pigs, and would be difficult with current available technologies and dosage/mortality concerns. The use of cyanide with foxes appears more promising and small progress in reducing detection may yield outstanding results. However, further work on either species should consider a more systematic and thoughtful approach, highlighting design specifications (including hydrogen cyanide [HCN] emissions), before further field testing. Design specifications for cyanide formulations plus the delivery system (bait) must prove acceptable levels of HCN gas emissions compared to previous unsuccessful packages (in simulated laboratory tests). Ideally, such emissions should be acceptable under simulated Australian field conditions of temperature and moisture. These specifications should be included in any initial further trials to reduce the likelihood of bait rejection by consuming animals.

Given their involvement and experience in this field, Connovation should be considered to be included, if not lead future forays into cyanide research on feral pigs. Connovation has a proven record in delivering vertebrate pesticides including cyanide. For example, Feratox® is a cyanide presentation developed by Connovation to target possums and has been registered in New Zealand since 1997. More recently, Connovation have developed cyanide products to target Tammar (registration granted 2010) and Bennett’s wallabies (registration expected mid-2011) in New Zealand. Connovation is currently focused on a continuing research program using cyanide on ferrets (2011/2012), which may yield dividends for applications to other species (particularly pigs and foxes). Future efforts into the development and use of cyanide for feral pigs and foxes should consider the findings of these ongoing programs before embarking on any new programs.

7. Approvals

Animal use and experimentation

Animal use and experimentation associated with this project was completed under the relevant ethics approvals:

- Queensland, Australia: Department of Natural Resources and Water Pest Animal Ethics Approval No. 050702. This initial approval was extended under the Department of Primary Industries & Fisheries Community Access Animal Ethics Committee.

- New Zealand: Lincoln University Animal Ethics Committee Approval No. 176 and Approval No. 348.

Field testing

Supply and use of cyanide in field testing products in Australia was approved by the Australian Pesticides and Veterinary Medicines Authority under permit PER 8998.

8. Acknowledgements

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