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Sodium fluoroacetate residues and carcass degradation of free-ranging feral pigs poisoned with 1080

Laurie E. Twigg[A,B], *Tim Lowe*[A] *and Gary Martin*[A]

[A]Vertebrate Pest Research Section, Department of Agriculture, Western Australia, 100 Bougainvillea Avenue, Forrestfield, WA 6058, Australia.
[B]Corresponding author. Email: ltwigg@agric.wa.gov.au

Abstract. Sodium fluoroacetate (1080) residues in muscle and liver of free-ranging feral pigs, poisoned with 1080-treated grain in a range of habitats, were determined. The incidence of vomiting, and the degradation of poisoned carcasses were also monitored. The maximum recorded concentrations in muscle (n = 79) and liver (n = 16) were 2.42 and 4.28 μg g^{-1} tissue, respectively. Mean (±s.d.) concentrations were 0.702 ± 0.535 and 0.635 ± 1.091 μg g^{-1}, respectively. Muscle concentration in pigs sampled within 24 h of death were similar between those pigs poisoned with wheat (0.993 μg g^{-1}, n = 21) and malted barley (1.012 μg g^{-1}, n = 20) ($P > 0.05$), but muscle residues may have been lower in those pigs poisoned with lupin bait (0.178 μg g^{-1}, n = 3). Muscle concentrations were also lower in those pigs sampled 24–48 h after death (0.481 μg g^{-1}, n = 13) ($P = 0.004$). There were no differences between the sexes (northern rangeland: mean, females 0.883, males 0.869 μg g^{-1}; agricultural: mean, 0.420 and 0.324 μg g^{-1}) ($P > 0.05$), but adult pigs had lower muscle concentrations than did non-adult pigs ($P < 0.001$). There was no evidence of vomiting by any recovered poisoned pigs (n = 85), and all but one stomach contained substantial amounts of bait and other foods. Scavengers (mainly raptors) rapidly consumed poisoned pigs weighing <16 kg, within 2 days with no apparent ill-effects. Poisoned adults (≥25 kg) were scavenged less frequently but, because of microbial action and the activity of invertebrates (e.g. fly larvae), these pigs were degraded within 7–10 days (i.e. no longer represented a potential food source for vertebrates). The levels of residues recorded were such that 1080-poisoned pig carcasses pose little potential risk to the long-term viability of non-target species.

Introduction

Feral pigs (*Sus scrofa*) are a significant environmental and/or agricultural pest world-wide, particularly in parts of Australia where they occur over ~40% of the continent (Hone 1990; Choquenot *et al*. 1996). Although a variety of options are available for control purposes (e.g. trapping, shooting, baiting with warfarin or yellow phosphorus), baiting with 1080 (sodium fluoroacetate) is one of the main management options used to reduce the detrimental impacts of feral pigs in Australia (Choquenot *et al*. 1996). Grain-derived bait material is the main bait used in most Australian states, although single-dose, fresh meat baits (72 mg 1080 per bait) are also registered by the Australian Pesticides and Veterinary Medicines Authority for use in Queensland (Choquenot *et al*. 1996; Mitchell 1998; Anon 2004). Although several baiting strategies for feral pigs have been examined (e.g. bait stations, trails, carcass baiting), the development of best-practice baiting (control) techniques is still continuing (Hone and Pederson 1980; Hone 1983; O'Brien and Lukins 1988; O'Brien *et al*. 1988; McIlroy *et al*. 1989; Choquenot *et al*. 1990, 1996; Saunders *et al*. 1990; Mitchell 1998).

Best-practice control options need to include an assessment of any potential detrimental impacts on non-target species and/or the environment. With pesticides, this needs to include some understanding of the persistence of the toxin in the bait material and in poisoned animals. However, although the longevity and distribution of 1080 in treated grain (Twigg *et al*. 2003*b*), and 1080 residues in some species (Eason *et al*. 1993; Twigg *et al*. 2003*a*), have been determined, there is little information on tissue residues in 1080-poisoned feral pigs (O'Brien *et al*. 1987), and none for poisoned, free-ranging individuals. The potential risk to non-target species feeding on 1080-poisoned pigs will depend upon three main factors: the persistence of 1080 in tissues (i.e. tissue residue levels), the longevity of carcasses of pigs poisoned with 1080, and the amount of toxic carcass consumed by non-target animals. In this paper we examine these aspects for free-ranging feral pigs that had been poisoned with 1080-treated grain using standard field-baiting procedures. Because there is some concern that vomiting by 1080-poisoned pigs may provide a potential hazard to some non-target animals (McIlroy 1983; O'Brien *et al*. 1987, 1988; Choquenot *et al*. 1996), we also report on the incidence of vomiting by poisoned pigs. Finally, we assess the potential risk that the observed tissue residue levels are likely to represent to non-target scavengers that feed on pig carcasses containing 1080.

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Materials and methods

Baiting procedures

Tissue samples were collected from 1080-poisoned feral pigs during other research trials that examined the bait preferences of feral pigs as well as the efficacy of the preferred baits (see Twigg *et al*. 2005). These trials were conducted at various localities in the northern rangelands (Gogo Station (18°18′S, 125°35′E) August, dry season) and agricultural (mostly autumn and summer, one winter trial) regions of Western Australia (WA). Key locations were: Fitzroy Crossing (18°11′S, 125°33′E), Yarder Creek/Northampton (28°21′S, 114°31′E), Greenough/Ellendale (28°48′S, 114°58′E) and Boddington (32°48′S, 116°29′E). The number of pigs seen at these localities before poisoning ranged from 20–40+ (agricultural) to 33–75 (rangeland) individuals. The grain-based baits used included wheat, malted barley, lupins and commercial pig pellets. However, because of their relatively poor acceptance by pigs, no efficacy trials were conducted with pig pellets.

1080-baiting was undertaken following the standard practice in Western Australia using bait stations, except that raked-earth plots were used to monitor the species taking bait. A bait station consisted of two 1-m^2 raked-earth plots 5 m apart. There was at least 100 m, and often several hundred metres, between stations to reduce the likelihood of visits to multiple stations by pigs. Depending upon pig abundance, two 1- or 2-kg piles of 1080-treated grain were placed on each raked plot. 1080-treatment of grain was undertaken according to the current label directions for 1080 Black Concentrate (Agriculture Protection Board, Forrestfield, WA) and feral pig control in Western Australia where 100 mL of a 40 mg mL^{-1} aqueous 1080 solution is thoroughly mixed with 6 kg of bait. Poison bait was generally laid in the afternoon preceding the carcass searches.

Sample collection

Carcass searches commenced on the morning after bait was laid, and continued for 3–12 days. These searches were systematic and were undertaken using a combination of foot and vehicle searches, usually with 2–3 people for 1–3 h each day (see Twigg *et al*. 2005). However, in some instances, particularly in the bush remnants associated with the agricultural region, the recovery of carcasses was difficult. This meant that sample sizes were small in a few instances. The sex, estimated body mass, breeding status, and physical condition were recorded for each located pig. The occurrence of vomiting at each location was also recorded during the conduct of the poison-baiting trials, including the carcass-search periods. The stomach contents of all recovered pigs were examined to confirm that all pigs had consumed the 1080 bait material used, and that significant vomiting had not occurred, as indicated by the presence of significant amounts of food. Where possible, 50 g muscle (upper hind leg) and 30 g liver samples were collected from each poisoned pig located. Care was taken to avoid cross-contamination of collected tissues (i.e. knife wiped between samples and all equipment was washed in water after each pig). Tissue samples were kept individually in labelled, resealable plastic bags and stored frozen (–4°C) soon after collection until analysis. However, due to the associated cost of the analyses, only a random subsample of 16 livers was assayed.

Carcass degradation

The decay of carcasses was subjectively recorded using digital photographs taken of a random subsample of located poisoned pigs at each site (rangeland, $n = 24$; agricultural, $n = 14$). Photographs were taken over a 3–14-day period once the pigs were located. Most dead pigs were found on the morning after 1080-baiting commenced (see Table 2 for trends). The condition of each carcass was scored as: 1 = no/little change, 2 = moderate decay/scavenging but may still provide some food for scavengers, and 3 = considerable decay/scavenging, unlikely to provide a significant food supply for vertebrates. These observations were used to estimate how long poisoned pig carcasses are likely to remain available to potential vertebrate scavengers (i.e. potential non-target hazards from 1080-poisoned carcasses).

1080 (fluoroacetate) assay

The concentration of sodium fluoroacetate (1080) in the tissues of recovered pigs was assayed by the Alan Fletcher Research Station, DNRM, Queensland, using gas chromatography (Ozawa and Tsukioka 1989). Samples were blended with distilled water and the extracts coarse-filtered through glass wool and/or centrifuged. Fluoroacetate in the filtrate was then adsorbed onto an anion-exchange resin and eluted with 2% (w/v) sodium chloride solution. The eluents were acidified with hydrochloric acid and a fluoroacetate dichloroanilide derivative prepared by reaction with 2,4-dichloroaniline in the presence of N,N′-dicyclohexylcarbodiimide. The fluoroacetate dichloroanilide derivative was extracted from the reaction mixture with ethyl acetate, dried, concentrated and then quantified by gas chromatography with mass-spectrometry detection using single-ion monitoring at $m/z = 186$, and confirmed using the electron-impact mass spectrum. The limit of detection (LD) for muscle was 0.005 μg fluoroacetate g^{-1} with a mean recovery of 1080 from spiked (1.412 mg 1080) meat samples of 88.3% (s.d. = 10.7%, $n = 6$). Tissue residue levels were corrected for this recovery, and then expressed as sodium fluoroacetate (1080). These values can be expressed as fluoroacetate by multiplying by 77/100.

Statistics

A single-factor ANOVA was used to examine the differences in muscle residues between the bait types used, and the age and sex of recovered pigs (Zar 1984). Too few liver samples were assayed to undertake similar analyses.

Results

Tissue residues

The stomach contents of all poisoned pigs found contained some bait material, often in substantial amounts. A variety of other foods (e.g. grasses, other herbage, fruiting bodies, and bulbs, see Twigg *et al*. 2005) were also present to such an extent that it precluded any realistic estimation of the amount of toxic bait consumed by individual pigs. On the basis of the available evidence from the visual sightings, patterns of bait take, and the location of dead pigs, together with distance between stations, we believe visits to multiple stations by feral pigs on the same night occurred infrequently. There were very few instances of vomiting in the poisoned pig populations ($n = 9$), and vomiting was not recorded for any recovered pig (i.e. no vomitus in surrounding area and the stomach was full of food).

Sodium fluoroacetate was found in all 79 muscle samples assayed, irrespective of the type of bait used (Table 1). The grand mean, s.d., minimum and maximum concentrations in muscle were: 0.702, 0.535, 0.031 and 2.420 μg g^{-1}. Three of the 16 livers assayed were below the level of detection (LD = 0.005 μg g^{-1}); with these samples set to 0.0025 μg g^{-1}, corresponding values were: 0.635, 1.091, <LD/0.008, and 4.280 μg g^{-1}. However, there were some differences in residue levels between regions and between some bait types, although this may have resulted from differences in the age distribution of pigs (see below) and from small sample sizes

Table 1. The concentration of sodium fluoroacetate (1080) in the tissues of feral pigs (n = 79) recovered during 1080 grain-based baiting trials in Western Australia
The 16 liver samples were a random subsample of the pigs assayed for muscle

Bait type	Tissue	n	Concentration of 1080 (μg (g tissue)$^{-1}$)			
			Mean	s.d.	Min.	Max.
Wheat	Muscle	41	0.679	0.582	0.031	2.420
Malted barley	Muscle	33	0.803	0.473	0.098	1.710
Lupins	Muscle	3	0.178	0.034	0.143	0.210
Buried wheat	Muscle	2	0.311	0.379	0.043	0.579
Wheat	Liver[A]	5	0.419	0.375	0.094	1.000
Malted barley	Liver[A]	4	1.576	1.989	0.008	4.280
Lupins	Liver[A]	2	0.650	0.271	0.458	0.841
Buried wheat	Liver[A,C]	2	0.232	0.241	0.062	0.403
Wheat	Liver[B]	6	0.349	0.376	<LD	1.000
Malted barley	Liver[B]	5	1.261	1.861	<LD	4.280
Lupins	Liver[B]	3	0.434	0.420	<LD	0.841

[A]Excludes the 3 livers with less than the level of detection (0.005 μg g^{-1}).
[B]Includes livers with 1080 concentrations <LD with their values set to 0.005/2 = 0.0025 μg g^{-1}.
[C]None of the livers from the buried wheat treatment were <LD.

in some instances (Table 1). With muscle, although sample sizes were small, residue levels (concentrations) were lower when lupins or buried wheat baits were used. With lupins, residue levels also appeared to be greater in liver than in muscle tissue (Table 1).

After excluding those data where sample size was small (n < 3), and restricting the analyses to only muscle tissue, the following observations can be made. Sodium fluoroacetate concentrations in the muscle of poisoned pigs recovered on Gogo Station (northern rangeland region) were similar, regardless of whether wheat or malted barley bait was used (Table 2: <24-h samples; F = 0.012, d.f. = 1,39, P = 0.913). However, there was a significant decrease in residue concentration in feral pigs sampled over time (Table 2: malted barley only; F = 10.39, d.f. = 1,24, P = 0.004). That is, those pigs not found until 24–48 h after they were believed to have succumbed had lower residue concentrations than did pigs sampled within 24 h of death. This relationship also held when the data for the malted barley and wheat baits were pooled for the corresponding periods (F = 10.49, d.f. = 1,52, P = 0.002). Although, overall, the muscle residue concentrations collected within 24 h were lower in those pigs recovered in the agricultural region (Greenough, mean 0.375 *v.* Gogo Station 0.993 μg g^{-1}; wheat bait only, F = 16.67, d.f. = 1,38, P < 0.001: Table 2) this was the result of differences in the number of non-adult pigs (juveniles and subadults) present in these two populations. In all, 59% of poisoned pigs found on Gogo Station were non-adults compared with 37% at Greenough. Non-adult pigs were found to have greater residue concentrations (see below). Residue concentrations did not differ significantly between these two regions when only adult pigs were considered (Table 3; ANOVA, F = 2.70, d.f. = 1,23, P = 0.114). The Greenough

Table 2. The influence of time and region on the concentration of sodium fluoroacetate (1080) in the muscle tissue of feral pigs recovered during 1080 grain-based control exercises in Western Australia
Residue levels from only those pigs sampled within 48 h of death were used (i.e. the <24-h and 24–48-h classes)

Region, and time until found[A]	Bait type	Concentration of 1080 (μg (g tissue)$^{-1}$)				n	P[C]
		Mean	s.d.	Min.	Max.		
Northern rangeland (Gogo Station)							
<24 h	Wheat	0.993	0.648	0.031	2.420	21	A
<24 h	Malted barley	1.012	0.426	0.125	1.710	20	A
24–48 h	Malted barley	0.481	0.351	0.098	1.270	13	B
48–72 h	Malted barley/wheat[B]	0.202	0.140	0.046	0.314	3	n.a.
Agricultural (Greenough)							
<24 h	Wheat	0.375	0.222	0.039	0.778	17	C[D]

[A]Carcass searches were conducted daily, and these times represent the time-frame after ingestion of toxic bait, and death, in which the pigs were found. Most of these pigs were found within 24 h (n = 58) or 48 h (n = 13) of death.
[B]Bait types pooled because of small sample size.
[C]Different letters have a significant ANOVA at P < 0.05 (see Results); n.a., not applicable.
[D]Compared with <24 h wheat, rangeland.

pigs were sampled in June 2004, the Gogo Station pigs in August 2004.

There were no differences in the muscle residue concentrations between the sexes in either the northern rangeland (F = 0.01, d.f. = 1,52, P = 0.93) or agricultural (F = 0.76, d.f. = 1,15, P = 0.40) regions (Table 3). However, adult pigs (≥25 kg) generally had lower muscle concentrations than did non-adult pigs (juveniles and subadults). The corresponding ANOVA tests were: northern rangeland, F = 11.52, d.f. = 1,53, P = 0.001; agricultural, F = 0.85, d.f. = 1,15, P = 0.37; and the rangeland and agricultural regions pooled, F = 20.85, d.f. = 1,86, P < 0.001 (Table 3).

Carcass degradation

Most pig carcasses were found to degrade relatively quickly irrespective of where, and in which region, they were found. Young pigs (i.e. <16 kg) were generally completely scavenged within 1–2 days, particularly on Gogo Station, where birds of prey consumed these carcasses with no apparent lethal effects (no dead non-target species were found during the trial, including the lengthy searches for pig carcasses). Up to 30 raptors were seen around such carcasses at one time, but no other scavenger species were recorded feeding on these carcasses (see below) (Twigg *et al*. 2005). However, the gut was infrequently consumed. Larger, adult pigs appear to be less favoured by scavengers but were still well degraded by invertebrates (e.g. fly larvae) and microbial action within 7–10 days. Consequently, few of the recovered carcasses (n = 85) would have provided a viable food source for vertebrates after this time. The relatively rapid degradation of large carcasses may have been dependent on the activity of flies as most of these carcasses contained considerable numbers of fly larvae. Apart from the activity of birds of prey in the northern rangeland region, surprisingly few other scavengers were recorded at the poisoned carcasses (on the basis of tracks and other spoor). This includes the lack of any obvious feeding by other feral pigs. In one instance a fox (and in another, a wild dog) had fed on a poisoned carcass. Another carcass was moved by a feral pig but there was no evidence of actual feeding. Excluding raptor activity, this equates to three feeding events for the 40 carcasses monitored.

Discussion

The levels of 1080 (sodium fluoroacetate) residues recorded in the muscle and liver of our free-ranging pigs poisoned with 1080-treated grain were relatively low and were similar to those reported for other herbivorous/omnivorous mammals (see Table 5 in Twigg *et al*. 2003*a* and references therein). Furthermore, although slightly higher, the concentrations we report are also similar to those recorded in captive feral pigs administered a lethal dose (LD_{99}, 2.1 mg 1080 kg^{-1}: O'Brien *et al*. 1987). In the latter study, feral pigs were fed pellets *ad libitum* together with poisoned wheat. Mean (±s.e.m.) residue concentrations for six lethally poisoned pigs were: muscle, 0.48 ± 0.48; liver, 0.67 ± 0.42; and kidney 0.72 ± 0.47 μg g^{-1}. Irrespective of the tissue type, including the stomach contents and intestine, the maximum recorded concentration was 2.6 μg g^{-1} (range 0–2.6 μg g^{-1}: O'Brien *et al*. 1987). The maximum recorded levels in our study were: muscle, 2.42 μg g^{-1}; and liver, 4.28 μg g^{-1} (Table 1). Our levels were also similar to those reported for pigs killed with 1080-grain in Queensland where the muscle concentration of six pigs was 0.08–2.6 μg sodium fluoroacetate g^{-1} (Gentle *et al*. 2005). However, the residue concentrations seen in captive feral pigs lethally poisoned during preliminary studies with meat baits may be lower than those

Table 3. The influence of sex and age on the concentration of sodium fluoroacetate (1080) in the muscle tissue of feral pigs recovered during 1080 grain-based control programs in Western Australia

Residue levels from only those pigs sampled within 48 h of death were used, and the data for the malted barley and wheat baits are pooled.

Region	Sex/age[A]	Concentration of 1080 (μg (g tissue)$^{-1}$)				n
		Mean	s.d.	Min.	Max.	
Northern rangeland (Gogo Station)						
	Female	0.883	0.565	0.098	2.420	31[B]
	Male	0.869	0.540	0.031	2.170	23[B]
	Juvenile	1.021	0.558	0.031	2.420	39[C]
	Adult	0.503	0.300	0.098	1.180	15[C]
Agricultural (Greenough)						
	Female	0.420	0.230	0.175	0.778	9[D]
	Male	0.324	0.217	0.039	0.626	8[D]
	Juvenile	0.434	0.299	0.039	0.778	7[E]
	Adult	0.333	0.153	0.179	0.667	10[E]

[A]Pigs >25 kg classified as adults.

[B,D,E]These comparisons within each region were not significant (ANOVA, P > 0.05) (see Results).

[C]This comparison was significant (ANOVA, P < 0.05) (see Results).

that result from grain-based baits. Residue levels in five pigs killed with a 2.3–3.3-mg 1080 kg^{-1} dose in a 500-g piece of fresh meat were: muscle, 0.041–0.175 μg g^{-1}; liver, <0.005 (i.e. <LD) – 0.174 μg g^{-1}; and kidney, <0.005–0.031 μg 1080 g^{-1}. The highest level, 5.97 μg 1080 g^{-1}, was in stomach tissue (Matt Gentle, personal communication). The potential difference between the residue concentrations resulting from these different bait substrates is likely to relate to the ingestion of greater quantities of toxin where bait is provided *ad libitum*. Residue levels resulting from fresh meat baits would be expected to increase in the field if pigs ingest multiple baits and hence multiple doses. However, we reiterate that all these residue levels are relatively low and they are unlikely to result in any potentially adverse non-target effects (see below).

The potential for detrimental non-target impacts from primary and secondary poisoning will depend upon several factors. These include, but are not limited to, the sensitivity to the toxin used and the size of each non-target species relative to that of the target species, how often non-target animals encounter and consume toxic baits and/or scavenge poisoned carcasses, the toxic loads of these materials/tissues, and the longevity of the toxin in baits and poisoned carcasses. The level of residues we report, together with the relatively low sensitivity of many native Australian animals to 1080, and the maximum amounts of 1080 that such animals could ingest, indicate that there is little/no potential risk to those native species that are likely to consume 1080-poisoned carcasses. This is supported by our field observations which indicated that birds of prey were readily feeding on 1080-poisoned carcasses with apparent impunity (i.e. no dead non-target animals were found). Interestingly, the intestines/stomachs of poisoned pigs were rarely consumed, further reducing the potential toxic loads that could be ingested (these tissues often have the highest 1080 residue concentrations: McIlroy 1983; O'Brien *et al*. 1987; Gentle *et al*. 2005). This is consistent with current knowledge as many species, particularly raptors, eviscerate large prey items (Hegdal *et al*. 1986; Martin *et al*. 1994). The relatively rapid degradation of poisoned pig carcasses also means that edible tissue containing 1080 is available for a relatively short period only (i.e. 2–10 days: our study). Although we did not investigate the effects of temperature during our study, the rate of degradation of poisoned carcasses seems to be relatively independent of locality and season (also see Twigg *et al*. 2003*a*). Potential risks are likely to be further reduced where a rapid and comprehensive knockdown of the target species occurs, as this would also help to limit the time that poisoned carcasses are available.

Using the worst-case scenario, in which the total daily food consumption consists entirely of 1080-containing pig tissue, and this tissue contains the maximum amount recorded for muscle or liver in our study, then native animals with evolutionary exposure to fluoroacetate-bearing vegetation could only ingest 0.3–18.9% of an approximate lethal dose (ALD) or 0.6–13.4% of a LD_{50} in a single sitting (Table 4). Even where animals do not have enhanced tolerance to fluoroacetate, these values equate to 13.1–64.2% and 8.7–45.5%, respectively (Table 4). These results will be similar across different age classes because younger and/or smaller animals will proportionally consume lower amounts of 1080 as their daily food requirements are less. This potential risk is further reduced because some native animals can detect 1080/fluoroacetate in their food and thereby reduce their consumption of food containing fluoroacetate (Sinclair and Bird 1984; Twigg and King 1991). Furthermore, because 1080 is readily detoxified and/or excreted (Twigg and King 1991; Gooneratne *et al*. 1994), the consumption by non-target species of live prey that had received a sublethal dose of 1080 would need to occur within a relatively short time of this prey ingesting 1080 (<2–3 h) for substantial adverse effects to result. The conclusion that carcass residues of 1080-poisoned animals offer little potential risk to indigenous non-target species is also well supported by several other studies (e.g. rabbits: Twigg *et al*. 2003*a*; sheep: Eason 1994; Milne *et al*. 2001; pigs: O'Brien *et al*. 1987; deer: McIntosh and Staples 1959).

In contrast to native species, introduced vertebrate predators (e.g. foxes, wild dogs, feral cats) would be able to consume sufficient 1080-containing tissue from poisoned pigs to ingest a lethal dose (Table 4). This results mainly from their much greater sensitivity to 1080 (fluoroacetate), their relatively larger body size, which increases their food requirements (i.e. they can ingest greater amounts of 1080-containing tissue), and their greater potential exposure (because they are more often present where 1080-based control programs are carried out). These exotic predators have also been shown to be susceptible to secondary poisoning from the tissue of other target species that contain 1080 (e.g. rabbits: Algar and Kinnear 1996; Twigg *et al*. 2003*a*).

One potential disadvantage of using 1080 for feral pig control is that some poisoned pigs may vomit after ingesting 1080 (McIlroy 1983; O'Brien 1988; O'Brien and Lukins 1988). This has been most evident during captive pen trials in which pigs had been maintained on limited food choices. It also seems to occur in captivity with grain (O'Brien and Lukins 1988) and meat (Matt Gentle, personal communication) baits. However, vomiting does not affect the overall toxicity of 1080 to feral pigs as mortality is similar in pigs where vomiting does and does not occur (McIlroy 1983; O'Brien 1988; O'Brien *et al*. 1988). The amount of 1080 ejected in vomitus was also similar ($P > 0.05$) between those captive pigs that survived (mean (±s.d.) of ingested dose 26.0 ± 13.3%) and those that succumbed (17.9 ± 6.0%) (O'Brien *et al*. 1988). There is a latent period between the time fluoroacetate (1080) is ingested and when signs of poisoning first appear (McIlroy 1983; Twigg and King 1991). Presumably, the processes involved in fluoroacetate-

intoxication are sufficiently advanced that the loss of any active ingredient via vomiting, when it occurs, does not impinge upon the final fate of fluoroacetate-poisoned pigs. Differences in efficacy of 1080 between populations and individual feral pigs may simply arise from some pigs (e.g. large adults) not ingesting sufficient bait (i.e. toxin) to receive a lethal dose (also see O'Brien and Lukins 1988). This may be particularly so for single-dose baits such as meat baits. We are not saying that vomiting does not occur, but rather that its practical importance in feral pig control programs may have been overstated.

For the above reasons, the greatest concern from vomitus is therefore the potential risk that it may pose to non-target species. This, in turn, will be dictated by the frequency at which vomiting occurs during field control programs. Although vomiting has been recorded during 1080-grain-based baiting programs in New South Wales (O'Brien and Lukins 1988), we found no evidence that vomiting occurred during our field trials in north-western Australia, and we have had only a few occurrences where vomiting was recorded during our trials in the agricultural region. Only relatively small amounts (~50 g) of vomitus were observed in the field. We believe one plausible explanation for the observed differences in the frequency of vomiting in 1080-poisoned pigs is that some natural foods may have antiemetic properties, and this provides some protection to free-ranging pigs, which consume a range of 'natural' foods. Alternatively, toxic bait material such as grain may be more thoroughly mixed with natural foods within the stomach, such that it is less likely to be vomited than when pigs are fed grain alone. Clearly, the frequency of vomiting, and the potential role played by natural foods, requires further clarification, but the frequency of vomiting by feral pigs may be overestimated if it is based solely on captive pen trials.

Feral pigs can frequently be targeted by hunters, and the meat from shot pigs can be used for human consumption (Choquenot *et al*. 1996). Although the taking of any target species for human consumption is prohibited during baiting programs, there is a possibility that humans may be unwittingly or knowingly exposed to feral pig meat that contains 1080. Routine cooking procedures appear to have little impact on the level of 1080 in cooked tissue (Milne *et al*. 2001). However, on the basis of the maximum level of sodium fluoroacetate recorded in the muscle of our free-ranging, 1080-poisoned pigs (2.42 μg g^{-1}), there seems to be little potential risk to human health from the illegal taking and consumption of poisoned pigs. For example, a 70-kg or 20-kg person (LD_{50} 2 mg 1080 kg^{-1}) would need to consume ~58 kg and 17 kg of 1080-poisoned pig meat containing 2.42 μg 1080 g^{-1} in a single sitting, respectively, to ingest a

Table 4. Examples of the low risk to native animals, with and without exposure to fluoroacetate-bearing vegetation, from sodium fluoroacetate (1080) residues in the tissue of feral pigs killed during 1080 grain-based control programs in Australia

The likely worst-case scenario using the maximum recorded sodium fluoroacetate residue in muscle (0.00242 mg g^{-1}) and liver (0.00428 mg g^{-1}) tissue was used. The species indicated with an asterisk have, or may have, had evolutionary exposure to fluoroacetate-bearing vegetation (Twigg and King 1991)

Species	Average adult weight (g)	Daily food intake[A] (g)	ALD (mg kg^{-1})	LD_{50} (mg kg^{-1})	Amount of 1080 ingested (mg)[B]		% of toxic dose	
					Muscle	Liver	ALD[C]	LD_{50}[C]
Wedge-tailed eagle (*Aquila audax*)*	3100	465	6.1	9.1	1.13	1.99	6.0, 10.5	4.0, 7.1
Black kite (*Milvus migrans*)	560	84	11.8	17.8	0.20	0.36	3.1, 5.4	2.0, 3.6
Brown falcon (*Falco berigora*)*	440	66	20.0	30.1	0.16	0.28	1.8, 3.2	1.2, 2.1
Australian raven (*Corvus coronoides*)*	440	66	3.4	4.8	0.16	0.28	10.7, 18.9	7.6, 13.4
Tasmanian devil (*Sarcophilus harrisii)*	7000	1050	2.8	4.2	2.54	4.49	13.1, 23.2	8.7, 15.4
Western quoll (*Dasyurus geoffroii*)*	1500	225	4.7	7.1	0.55	0.96	7.7, 8.6	5.2, 9.1
Northern quoll (*Dasyurus hallucatus*)*	650	98	4.7	7.1	0.24	0.42	7.7, 12.6	5.2, 9.1
Eastern quoll (*Dasyurus viverrinus*)	1100	165	1.0	1.4	0.40	0.71	36.3, 64.2	25.7, 45.5
Yellow-footed antechinus (*Antechinus flavipes*)*	45	7	8.4	11.8	0.02	0.03	4.3, 7.6	3.1, 5.5
Brown antechinus (*Antechinus stuartii*)	28	4	1.3	1.8	0.01	0.02	28.1, 49.8	20.1, 35.5
Red-tailed phascogale (*Phascogale calura*)*	165	25	14.1	16.5	0.06	0.11	2.6, 4.6	2.2, 3.9
Brush-tailed phascogale (*Phascogale tapoatafa*)*	175	26	6.0	9.0	0.06	0.11	6.1, 10.7	4.0, 7.1
Southern brown bandicoot (*Isoodon obesulus*)*	1000	150	14.1	18.8	0.36	0.64	2.6, 4.6	1.9, 3.4
Woylie (*Bettongia penicillata*)*	1350	203	105.8	115.0	0.49	0.87	0.3, 0.6	0.3, 0.6
Dog/dingo (*Canis familiaris*)	19000	2850	0.09	0.11	6.90	12.20	427, 713	330, 583
Fox (*Vulpes vulpes*)	6000	900	0.09	0.12	2.18	3.85	403, 713	303, 535
Cat (*Felis catus*)	4500	675	0.25	0.35	1.63	2.89	145, 257	104, 183

[A]Calculated as 15% of bodyweight.

[B]Assumes that the total daily food eaten was 1080-containing tissue.

[C]Values are for muscle and liver, respectively. Bodyweights, and approximate lethal dose (ALD) and lethal $dose_{50}$ (LD_{50}) were taken, or adapted, from McIlroy (1981, 1984), Strahan (1983), Calver *et al*. (1989), Twigg and King (1991), Martin and Twigg (2002), and Martin *et al*. (2002). Where necessary, a 1.5 factor was used to estimate between published ALDs and LD_{50}s (see Calver *et al*. 1989). ALDs and LD_{50}s have been standardised to mg pure 1080 kg^{-1}.

LD_{50} dose. This essentially non-existent risk is consistent with that reported for other target species in which 1080 residues may occur (e.g. rabbits: Twigg *et al*. 2003*a*; sheep: Eason 1994; Milne *et al*. 2001). Further, the half-life of fluoroacetate in the plasma of 1080-poisoned sheep, goats, brush-tail possums and rabbits ranges from 1 to 11 h, and little fluoroacetate remains after 96 h (Eason 1994). This suggests that the retention of fluoroacetate (=1080) in mammals is relatively short and that, although strongly discouraged, the potential taking and consumption of sub-lethally poisoned, or moribund, pigs is unlikely to compromise human health. The requirement for notification of neighbours 24–72 h before baiting, the need for adequate signage, and the restriction on hunting where baiting is carried out further reduces the potential for the accidental consumption of poisoned pig meat.

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