Aust. Wildl. Res., 1983, **10**, 139–48

The Sensitivity of Australian Animals to 1080 Poison V.* The Sensitivity of Feral Pigs, *Sus scrofa*, to 1080 and its Implications for Poisoning Campaigns

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Abstract

Acute oral LD_{50}s (median lethal doses) and 95% confidence limits of 1080 poison for feral pigs, *Sus scrofa*, obtained by moving average and probit analysis methods are 1·04 (0·84–1·27) mg kg^{-1} and 1·00 (0·72–1·28) mg kg^{-1} respectively. These values are slightly higher than LD_{50}s obtained for pigs by intraperitoneal dosing but similar to those obtained by oral dosing for other eutherian mammals. Signs of poisoning, either vomiting or increasing lethargy and laboured respiration, appeared from 1·9 to 47·3 h (median 6·2 h) after dosing, and deaths from 2·8 to 80 h (median 16·1 h) after dosing. Although 1080 is one of the most toxic poisons for pigs it has disadvantages, including the relatively large amounts that must be distributed in baits to kill pigs, and the comparatively greater susceptibility to it of many non-target birds and mammals. For example, 36 species out of a selection of 40 non-target species likely to feed on poisoned baits are more susceptible to 1080 than pigs. In practice many other factors such as bait acceptance will govern what proportions of target and non-target populations will be poisoned. Attention to methods of poisoning or baiting techniques could minimize the risk non-target animals face from pig-poisoning campaigns.

Introduction

Feral pigs, *Sus scrofa*, are one of the most successful mammalian pests in Australia. They are widespread, particularly in the Northern Territory, Queensland and New South Wales. They cause considerable damage to crops and pastures, fencing and stock watering facilities, waterfowl habitat and native vegetation. They also prey on lambs and native fauna. At present they disseminate pathogens such as leptospirosis and sparganosis, and veterinary authorities feel concern that they could become vectors and reservoirs of other diseases of stock, such as foot and mouth, swine fever and rinderpest (Pullar 1950; Keast *et al.* 1963; Appleton and Norton 1976; Giles 1976; Plant *et al.* 1978).

The main methods for controlling feral pigs are trapping, poisoning and shooting. Poisons used, either legally or illegally, include strychnine, phosphorus, organophosphate insecticides and, more recently, compound 1080 (sodium fluoroacetate). Poisoning with 1080, with grains or bran–pollard pellets as baits, is generally considered the most successful method for crop and lamb protection, and much less dangerous to non-target fauna than other poisons (Giles 1976).

Since 1972 the Division of Wildlife Research, CSIRO, has undertaken a comprehensive study of the effects of 1080 poisoning campaigns on non-target animals (McIlroy 1981*a*, 1981*b*, 1982*a*, 1982*b*). One aspect of this study has been the determination of the sensitivity of different species to 1080. Although this alone cannot indicate the risk to populations of non-target animals from various pest-poisoning campaigns, it can indicate the relative vulnerability of each species compared to the target species. A knowledge of the sensitivity

0310-7833/83/010139$02.00

*Part IV. *Aust. Wildl. Res.*, 1982, **9**, 505–17.

of the target species to the poison being used can also be used to develop a more efficient method for its control. Any method which limits the concentration of poison in baits to the minimum known to be effective against the target species must also help reduce the risk of poisoning non-target species.

During January 1977 the opportunity arose to determine the sensitivity of feral pigs to 1080. This paper reports on the results obtained, their implications in regard to the control of pigs by 1080, and the potential hazards such poisoning campaigns represent to non-target animals.

Methods

The study was carried out near Cuttaburra Creek, 160 km north-west of Bourke, N.S.W. Hone and Pedersen (1980) provide a detailed description of the area, including conditions present during the study. Pigs were caught in weldmesh traps (Giles 1977) baited with wheat grains, and selected individuals were transferred to individual pens. Each pen (5 by 1 by 1 m), was situated amongst a grove of trees and was partly covered by hessian to provide shade. Ambient temperatures during the trial were 17–38°C and daylength 14·3–14·4 h. All dosing was carried out between 0725 and 1030 h.

Only adult male pigs (age 30–60 months) were selected for the trial; they weighed 40·9–66·1 kg (mean 55·0 kg). All were kept in captivity for at least 2–4 days before being dosed with 1080 and, depending upon their appetite, given 1–3 kg of wheat grain to eat each day, including during the 24 h before they were dosed. Water was provided *ad libitum*. Although this period of acclimitization was shorter than that usual for other species tested (see McIlroy 1981*a*), it was felt to be adequate, given the apparent ease and speed with which the pigs appeared to accept captivity.

Before being dosed, individuals were transferred to a steelmesh crush, weighed, and then restrained with a neck-bail arrangement, so their heads protruded from the crush. A metal mouth gag was then used to facilitate dosing by means of an oesophageal catheter and syringe. The oesophageal route of administration was chosen because it is that by which animals normally ingest the poison. Four groups of five pigs were dosed with 1080; the dose given on different days differed by a factor of 1·26. A sixth, control pig in each group received an equivalent volume of water. All 1080 used was AR sodium monofluoroacetate (*c.* 100% purity) administered as a 10 mg ml^{-1} solution in deionized water.

The behaviour and fate of each pig dosed with 1080 was monitored for the first 7 days after dosing. During the first 24 h after dosing each pig was inspected at least once per hour and any signs of poisoning or deaths recorded. Over the next 6 days inspections were made at less regular intervals, ranging between 1 and 4 h depending upon the condition of the pigs and other field-work commitments. Median lethal doses (LD_{50}s), a measure of the sensitivity of the pigs to 1080, were then calculated by the moving-average method of Thompson (1947) and Weil (1952) and, together with other LD values, by probit analysis (Finney 1952). Although probit analysis is generally considered to provide the most precise estimate of the LD_{50} and its fiducial limits, interpolation methods such as the moving-average method can also provide satisfactory values (see Armitage and Allen (1950) for a practical comparison of several methods). Although normally I prefer to use only the moving-average method to obtain LD_{50}s because of its simplicity and speed (see McIlroy 1981*a*), in this instance I also wanted other LD values, not obtainable by this method. Consequently, probit analysis was used to obtain these and the LD_{50} value for comparison.

Results

Signs of Poisoning

Signs of poisoning appeared only in pigs given 0·95 mg or more of 1080 per kg body weight. The first signs appeared within 1·9–47·3 h of dosing (mean 10·9 h, median 6·2 h) (Table 1) and were either vomiting or increasing lethargy and laboured respiration, often with a white froth appearing around the mouth and nostrils. Only four out of the 13 pigs showing visible signs of poisoning vomited; these were individuals that had received either 1·2 or 1·5 mg kg^{-1}, the two highest doses of 1080. Each pig that vomited subsequently died. One pig was observed experiencing convulsions. Another pig remained partly paralysed in the hind legs for 24 h but upon release, 6 days later, ran away rapidly.

Deaths occurred 2·8–80·0 h (mean 23·4 h, median 16·1 h) after pigs were dosed with 1080 (Table 1). Usually, affected animals simply lay quietly, breathing slowly and laboriously until death. The three affected animals that survived appeared normal at the end of the 7-day observation period. Overall, only the lower time limits and median times before signs of poisoning appeared, and the lower time limits until death, were related to the amount of 1080 given (i.e. they decreased markedly as the dose of 1080 increased). Median times to death, and the mean and upper time limits before signs of poisoning or death, were not related to dosage.

Table 1. Mortality and length of time between dosing with 1080 and appearance of signs of poisoning or death amongst feral pigs

Median values are shown in parentheses *N*, number of individuals observed

Dose (mg kg^{-1})	*N*	Latent period Hours	Mortality No. dosed	No. died	Time to death (h)
0·75	0	—	5	0	—
0·95	3	<11·6–13·3 (12·8)	5	3	<11·6–16·9 (13·8)
1·20	5	4·2–47·3 (6·2)	5	3	7·0–32·8 (25·2)
1·50	5	1·9–15·9 (2·5)	5	4	2·8–80·0 (21·7)

LD_{50}s

The LD_{50} and 95% confidence limits for feral pigs given *c.* 100% pure 1080, based on the moving-average method are: 1·04 (0·84–1·27) mg kg^{-1}. The LD_{50} and other LD values, including 95% confidence limits, based on probit analyses, are:

LD_{50}, 1·00 (0·72–1·28) mg kg^{-1}
LD_{75}, 1·26 (0·90–3·83) mg kg^{-1}
LD_{90}, 1·57 (1·23–41·62) mg kg^{-1}
LD_{95}, 1·78 (1·36–185·95) mg kg^{-1}
LD_{99}, 2·26 (1·58–3381·43) mg kg^{-1}

Discussion

Signs of Poisoning

The signs of poisoning observed among feral pigs in this study were similar to those reported amongst domestic pigs by Chenoweth and Gilman (1946) and Schwarte (1947). The latent periods and times until death, however, were much longer than the 0·5–2·0 h and 0·7–20 h, respectively, reported by these authors.

Although vomiting has probably evolved as a natural protective mechanism, many species can still absorb a lethal dose of 1080 before vomiting (e.g. marsupial and eutherian carnivores, see McIlroy 1981*b*). Rathore (1981) has found that in pigs given oral doses of 1 mg kg^{-1} of 1080 there are no significant differences in the time before onset of signs of poisoning or death between individuals which vomited and those prevented from vomiting by being given an anti-emetic agent. In both cases the time between dosing and signs of poisoning was *c.* 0·5–0·6 h and the time between dosing and death was 2·0–2·75 h. For some reason, though (possibly because the pigs fasted for 48 h before dosing), these times are much shorter than those recorded after similar doses in this study.

LD_{50}s

The LD_{50} of 1·0 mg kg^{-1} obtained by both moving-average and probit analysis methods for the feral pig is similar to those obtained for eutherian herbivores (i.e. 0·2–0·9 mg kg^{-1}) and carnivores (i.e. 0·1–*c.* 1·5 mg kg^{-1}) (McIlroy 1981*b*, 1982*a*). It is higher than the approximate values of 0·3 and 0·4 mg kg^{-1} obtained for other pigs by Ward (1946) and Chenoweth and Gilman (1946), respectively, but these were obtained by intraperitoneal doses and, while perhaps clinically correct, are less practically useful because they do not allow for vomiting. [The latter value, for young swine, has since been erroneously requoted as an oral LD_{50} by Atzert (1971).] An oral LD_{50} of <1 mg kg^{-1} is frequently attributed to

Schwarte (1947) by others (e.g. by Chenoweth 1949) but, in fact, all he did was administer doses of 1–30 mg kg^{-1} to domestic pigs by stomach tubes. As all the animals died, he could not obtain a LD_{50}.

The LD_{50}s obtained in this study are, strictly, only applicable to adult male pigs under the described experimental procedures and conditions (see McIlroy 1981*a*). Research by McIlroy (1981*a*) on six species of birds and mammals, though, suggests that, apart from very young or senescent animals and individuals experiencing increased metabolic demands, such as pregnant or lactating females, there are no substantial differences in sensitivity to 1080 between males and females, immatures and adults, or within and between different populations of each species in eastern Australia.

Although the LD_{50}s obtained by both moving average and probit analysis methods are acceptable, given the narrow range of the 95% confidence limits, the other LD data obtained by probit analysis are increasingly less reliable as their confidence limits widen. For normal control purposes, though, a dose of 2·3 mg kg^{-1} (the 'LD_{99}') can probably be regarded as a 'lethal dose' or the dose that would kill close to 100% of a pig population.

The Positive and Negative Aspects of Using 1080 to Poison Pigs

Although 1080 is the only poison recommended by State authorities for control of feral pigs, other poisons are still used in different areas of Australia. In some instances their use is illegal and in others simply traditional, even though in many cases they, together with other poisons tested overseas against pigs, are inferior to 1080 in terms of acute toxicity (Table 2). Strychnine, for example, is nowadays a restricted poison in New South Wales. It is also 1·5–10 times less toxic to pigs than 1080. Organophosphate insecticides, particularly stock jetting or dipping compounds such as 'Luci-jet' (fenthion-ethyl), are also less toxic than 1080. In addition, in contrast to 1080, male pigs can be more susceptible to them than females, so their use could conceivably enhance the breeding nuclei of pig populations. Despite this, and restrictions on their use imposed by the Pesticide Act in New South Wales, organophosphates are still frequently used, illegally, to poison pigs; no doubt because they are more easily obtained than 1080. Unfortunately these compounds are *more* rather than *less* toxic than 1080 to many other species of non-target animals (McIlroy, unpublished data) and their use can result in the death of native birds and other wildlife (Morris 1979; Barnett 1980). Only two of the anticoagulants, warfarin and brodifacoum, developed for use against murids, have an acute toxicity for pigs similar to that of 1080, and perhaps some potential as a chronic poison. Both also have a lower toxicity for cats and dogs than 1080. The LD_{50}s of brodifacoum, warfarin and 1080, respectively, for cats are 25, 2–80 and 0·4 mg kg^{-1}, and those for dogs are 0·25–1·0, 3–250 and 0·11 mg kg^{-1} (Papworth 1958; Anon. 1976; Bull 1976; McIlroy 1981*b*). More important, both anticoagulants have an effective antidote—vitamin K1 (Rammell and Fleming 1978). Brodifacoum, however, has only recently been developed and requires further evaluation, particularly in respect to its possible effects on the foetus in pregnant domestic livestock, before its widespread use can be safely advocated. It is also much more expensive, at approximately $12,000 per kilogram, than either warfarin (*c*. $40–$100) or 1080 (*c*. $125).

Despite 1080's superior acute toxicity there are still some problems or disadvantages in its use against feral pigs. First of all, it has no antidote so extreme care is needed in handling it. Because of this, the necessary restrictions on its availability and use by unauthorised personnel lead, as mentioned earlier, to farmers and graziers often attempting their own control efforts with other, commercially available compounds, rather than taking part in an officially coordinated control campaign with 1080.

Pigs also commonly (but not invariably) vomit after ingesting 1080. Although it has been suggested (M. Sheehan, personal communication 1977) that this might enhance the survival of some pigs but increase the chance of killing other pigs which eat the vomitus, its main importance is the risk of secondary poisoning of non-target animals. Such a disadvantage could possibly be overcome by the use of anti-emetic agents in the baits, as suggested by Rathore (1981).

The two main problems in use of 1080 for pig control, (which apply in most cases to other poisons as well) are the amount that a pig has to ingest to receive a lethal dose and the lack of selectivity in relation to non-target species. Because a pig is a relatively large animal, the concentration of 1080 in baits must be high enough for individuals to easily ingest a lethal dose during one feeding session. Depending upon the amounts and types of bait available, this concentration can present a risk to non-target animals, most of which are smaller or lighter than pigs and can eat a much higher percentage of their body weight per day.

Table 2. Acute toxicity of various poisons to pigs

All poisons administered orally except the first 1080 listed (intraperitoneal) and strychnine (unknown)

Poison	LD_{50} (mg kg^{-1})	Reference
1080	*c.* 0·3–0·4	Chenoweth and Gilman 1946; Ward 1946
1080	1·04 (0·84–1·27)	McIlroy, unpublished
Strychnine (alkaloid)	1·5–7·5[AB]	Rudd and Genelly 1956
Strychnine (alkaloid)	10	Fitzwater and Prakash 1973
Phosphorus (white)	1–6	Buck 1978
Zinc phosphide	20–50	Fitzpatrick *et al.* 1955; Kaukeinen 1979
Antu	*c.* 25–50	Anderson and Richter 1946; McGirr and Papworth 1955; Buck 1978
Red squill	*c.* 100[A]	Fitzpatrick *et al.* 1955
Pyriminyl	500	Dubock and Kaukeinen 1978
Anti-coagulants		
Brodifacoum	0·5–2·0	Dubock and Kaukeinen 1978
Warfarin	<1·0	Papworth 1958
Warfarin	1–5	Bull 1976; Buck 1978; Kaukeinen 1979
Warfarin	*c.* 15	McGirr and Papworth 1955
Difenacoum	80–100	Bull 1976
Diphacinone	150	Fairchild 1977
Organophosphates[C]		
Luci-jet (Fenthion-ethyl)	M, *c.* 9–10 F, *c.* 25–35	McIlroy, unpublished
Schradan (Ompa)	Marked symptoms after *c.* 14 mg kg^{-1}	McGirr and Papworth 1953
Parathion	Marked symptoms after *c.* 27 mg kg^{-1}	McGirr and Papworth 1953

[A] Half of stated 'lethal dose'.
[B] Originally stated in milligrams per pig; recalculated assuming pig weighs 50 kg.
[C] Sexes can differ markedly in susceptibility.

The concentrations, in milligrams per gram, of 1080 (commercial, *c.* 90% pure) used in various baits are as follows:

	Queensland	New South Wales
Grain	0·288	0·33
Pellets	—	0·50
Fruit and vegetables	Not known	0·33
Meat	0·144	—

(Anon. 1980*a*; J. Hone, personal communication 1981). The meat baits contain 10 times the concentration of 1080 used for dingoes, *Canis familiaris dingo*, in both these States and thus could greatly increase the risk of primary poisoning that marsupial and eutherian carnivores already face from dingo-poisoning campaigns (McIlroy 1981*b*).

The relative sensitivity of 40 non-target species to 1080, compared with that of the pig, is given in Table 3. Species are listed in order of decreasing susceptibility—a term that takes into account their sizes and, consequently, the amount of 1080 each would have to ingest to obtain a LD_{50} dose. The body weights listed are means from data from the CSIRO

Table 3. Relative susceptibility of pigs and non-target animals to 1080
1080 approximately 100% pure. Data from McIlroy 1981*a*, 1981*b*, 1982*a*, 1982*b*, and unpublished

Species	Wt (kg)	LD_{50} (mg kg^{-1})	Amount of 1080 for LD_{50} (mg)
Fat-tailed dunnart, *Sminthopsis crassicaudata*	0·013	2·06	0·03
Brown antechinus, *Antechinus stuartii*	0·035	1·85	0·07
Crimson rosella, *Platycercus elegans*	0·140	*c*.0·87	*c*.0·12
Bush rat, *Rattus fuscipes*	0·120	1·13	0·14
Grassland melomys, *Melomys burtoni*	0·070	2·65	0·19
Canefield rat, *Rattus sordidus*	0·150	1·28	0·19
Dusky antechinus, *Antechinus swainsonii*	0·060	3·21	0·19
Red-rumped parrot, *Psephotus haematonotus*	0·060	*c*.5·25	*c*.0·32
Eastern rosella, *Platycercus eximius*	0·100	*c*.3·45	*c*.0·35
Rabbit, *Oryctolagus cuniculus*	1·5	0·37	0·55
Fox, *Vulpes vulpes*	4·7	*c*.0·12	*c*.0·56
White-winged chough, *Corcorax melanorhamphos*	0·330	*c*.1·75	*c*.0·58
Australian magpie-lark, *Grallina cyanoleuca*	0·090	*c*.6·75	*c*.0·61
Grey shrike-thrush, *Colluricincla harmonica*	0·070	*c*.>12·0	*c*.>0·84
Cat, *Felis catus*	4·2	0·40	1·68
Little raven, *Corvus mellori*	0·560	3·1	1·74
Brushtail possum, *Trichosurus vulpecula*	2·6	0·67	1·74
Dingo, *Canis familiaris*	16·0	0·11	1·76
Laughing kookaburra, *Dacelo novaeguineae*	0·300	*c*.>6·0	*c*.>1·80
Galah, *Cacatua roseicapilla*	0·310	6·4	1·98
Sulphur-crested cockatoo, *Cacatua galerita*	0·800	3·56	2·80
Water-rat, *Hydromys chrysogaster*	1·0	*c*.2·94	*c*.2·94
Australian raven, *Corvus coronoides*	0·585	*c*.5·1	*c*.2·98
Australian magpie, *Gymnorhina tibicen*	0·320	9·91	3·17
Pied currawong, *Strepera graculina*	0·300	13·1	3·93
Red-necked wallaby, *Macropus rufogriseus*	19·0	<0·21	<3·99
Northern quoll, *Dasyurus hallucatus*	0·750	5·66	4·25
Tiger quoll, *Dasyurus maculatus*	2·8	1·85	5·18
Little crow, *Corvus bennetti*	0·400	13·4	5·36
Long-nosed bandicoot, *Perameles nasuta*	1·2	7·70	9·24
Eastern grey kangaroo, *Macropus giganteus*	47·0	*c*.0·22	*c*.10·34
Black kite, *Milvus migrans*	0·560	18·5	10·36
Goat, *Capra hircus*	37·0	*c*.0·5	*c*.18·50
Sheep, *Ovis aries*	38·0	0·52	19·76
Wedge-tailed eagle, *Aquila audax*	3·1	9·5	29·45
Sand goanna, *Varanus gouldii*	0·840	43·6	36·62
Pig, *Sus scrofa*	55·0	1·04	57·20
Red kangaroo, *Macropus rufus*	30·0	*c*.3·2	*c*.96·00
European cattle, *Bos taurus*	520·0	0·39	202·80
Horse, *Equus caballus*	500·0	*c*.0·41	*c*.205·00
Emu, *Dromaius novaehollandiae*	40·0	*c*.250	*c*.10,000·00

Division of Wildlife Research and LD_{50} trials (McIlroy 1981*b*, 1982*a*, 1982*b*, unpublished data). They simply represent the 'average adult' for each species, even though the adult body weight for each species probably varies widely. From the LD_{50}s presented, it can be seen that 12 of the 40 species are more sensitive to 1080 than pigs, but 28 are more tolerant. On a susceptibility basis, though, individuals of every species except red kangaroos *Macropus rufus* (at least those in Western Australia, see McIlroy 1982*a*), cattle *Bos taurus*, horses *Equus caballus*, and the emu *Dromaius novaehollandiae* require far less 1080 for a LD_{50} than the pig. Cows and horses are more than twice as sensitive to 1080 as the pig but, because of their greater size, require more than three times as much 1080 for a LD_{50}. Red kangaroos and emus, in contrast, are lighter than pigs, but because they are

Table 4. Amount of poisoned pig bait needed to be eaten for a LD_{50}, and proportion of body weight it represents

Baits contain 1080 approximately 90% pure. Only those species which might eat the baits specified are included

Species	Grain bait, N.S.W. Amount (g)	Grain bait, N.S.W. Percentage body wt	Pellet bait, N.S.W. Amount (g)	Pellet bait, N.S.W. Percentage body wt	Meat bait, Qld Amount (g)	Meat bait, Qld Percentage body wt
Fat-tailed dunnart					0·2	1·5
Brown antechinus					0·5	1·4
Crimson rosella	c.0·4	0·3	c.0·3	0·2		
Bush rat	0·5	0·4	0·3	0·3	1·1	0·9
Grassland melomys	0·6	0·9	0·4	0·6		
Canefield rat	0·6	0·4	0·4	0·3	1·5	1·0
Dusky antechinus					1·5	2·5
Red-rumped parrot	c.1·1	1·8	c.0·7	1·2		
Eastern rosella	c.1·2	1·2	c.0·8	0·8		
Rabbit	1·8	0·1	1·2	0·08		
Fox	c.1·9	0·04	c.1·3	0·03	c.4·4	0·1
White-winged chough	c.1·9	0·6	c.1·3	0·4	c.4·4	1·4
Australian magpie-lark					c.4·6	5·1
Grey shrike-thrush					c.>6·5	>9·3
Cat					12·9	0·3
Little raven	5·8	1·0	3·9	0·7	13·4	2·4
Brushtail possum	5·8	0·2	3·9	0·2		
Dingo					13·5	0·1
Laughing kookaburra					c.>13·9	>4·6
Galah	6·7	2·2	4·4	1·4		
Sulphur-crested cockatoo	9·6	1·2	6·3	0·8		
Water-rat					c.22·6	2·3
Australian raven	c.10·0	1·7	c.6·6	1·1	c.23·0	3·9
Australian magpie	10·7	3·3	7·0	2·2	24·4	7·6
Pied currawong	13·2	4·4	8·7	2·9	30·3	10·1
Red-necked wallaby	<13·4	<0·07	<8·9	<0·05		
Northern quoll					32·8	4·4
Tiger quoll					39·9	1·4
Little crow	18·0	4·5	11·9	3·0	41·3	10·4
Long-nosed bandicoot			20·5	1·7	71·2	5·9
Eastern grey kangaroo	c.34·8	0·07	c.22·9	0·05		
Black kite					79·9	14·3
Goat	c.62·2	0·2	c.41·1	0·1		
Sheep	66·5	0·2	43·9	0·1		
Wedge-tailed eagle					227·1	7·3
Sand goanna					282·3	33·6
Pig	192·4	0·3	127·0	0·2	441·0	0·8
Red kangaroo	c.322·9	1·0	c.213·1	0·7		
European cattle	682·1	0·1	450·2	0·1		
Horse	c.689·5	0·1	c.455·1	0·1		
Emu	c.33,636	84·0	c.22,200	55·5	c.77,083	192·7

approximately 3 and 240 times, respectively, more tolerant to 1080, require 1·7 and 175 times the dose for a LD_{50}.

When these values for susceptibility are translated into terms of the weight of bait in each State which average individuals of each species would have to eat to ingest a LD_{50}

(Table 4), it is clear that, apart from the emu, all the non-target animals could easily eat enough to be poisoned. In almost all cases the amounts of bait containing a LD_{50} represent less than 10% of body weight.

From the point of view of pig control the ideal objective would be to poison every member of the population, including the largest, but economically, this is probably not possible. Thus a 132-kg pig (the heaviest feral individual recorded in the Australian Capital Territory: R. McIlroy, personal communication 1981) would have to ingest about 303·6 mg (132×2·3 mg) of 1080 for a LD_{99} or 'lethal dose' (excluding the wide confidence limits of the LD_{99}). This would be present as commercial 1080 (i.e. *c*.90% purity) in 1·02 kg of grain baits or 675 g of pellet baits as used in New South Wales, or 2·34 kg of meat baits as used in Queensland, and represents 0·5–1·8% of the pig's weight. Increasing the concentrations of 1080 in the baits would decrease the amount of bait each pig would have to eat to be poisoned, but it would also increase the risk to non-target animals. Reducing the concentration would mean that more baits might have to be laid in a specific area, but is unlikely to significantly reduce the risk to non-target animals, because both they and the pigs could eat many more baits in terms of percentage of their body weight. It could, however, increase the number of pigs killed, particularly in situations where some pigs (e.g. adults) exclude others (e.g. immatures) from eating sufficient baits to ingest a lethal dose.

In the final outcome the numbers of non-target animals and pigs that are poisoned will depend upon many other factors, such as the proportions of each population that find and eat sufficient bait before insects or other animals consume it or it decomposes and the 1080 is leached out by dew or rainfall. The methods used for poisoning the pigs are also of crucial importance. In New Zealand feral pigs are poisoned by inserting up to 10 gelatin capsules, each containing 100 mg of 1080, into the carcasses (or offal) of various mammals (Rammell and Fleming 1978). The poisoned carcasses may remain edible for more than 2 months during the autumn and winter, when poisoning is carried out, and the 1080 is leached out only when the carcass completely disintegrates. Another technique used involves injecting 1080 gel into the bronchioles of beef lung, and a third involves boring out holes in apples, potatoes and other fruit and vegetables, inserting a capsule of 1080 and replacing the plug. Specific approval is needed for each operation, because these techniques are acknowledged as potentially the most dangerous forms of use of 1080 in New Zealand. The danger is high because 1080 powder rather than a diluted solution is used, and because the baits are so lethal to scavengers.

Such techniques are not acceptable in Australia, with its far greater numbers of scavenging or carrion-eating birds and mammals, but smaller meat baits (e.g. 190–500 g), injected with 1080 solution, have been tried experimentally in New South Wales (Hone and Pedersen 1980) and are regularly used in Queensland (Anon. 1980*a*). Even these baits may poison non-target animals. Hone and Pedersen (1980) and myself, for example, observed 88 individuals of 10 species of birds (mainly raptors), one cat *Felis catus*, and eight foxes *Vulpes vulpes* eating baits, eating pig carcasses, or lying dead after a pig-poisoning campaign. The species of birds observed eating either poisoned or non-poisoned baits or poisoned pig carcasses were whistling kite *Haliastur sphenurus*, Australian little eagle *Hieraaetus morphnoides*, wedge-tailed eagle *Aquila audax*, black kite *Milvus migrans*, brown falcon *Falco berigora*, Australian kestrel *Falco cenchroides*, brown goshawk *Accipiter fasciatus*, Australian magpie-lark *Grallina cyanoleuca*, Australian raven *Corvus coronoides*, and crows (Australian crow *Corvus orru* or little crow *C. bennetti*). The species of birds found dead after the baiting were black kite (two), magpie-lark (one), little crow (one), and 'corvids' (five). Other birds, particularly willie wagtails *Rhipidura leucophrys* and pied butcherbirds *Cracticus nigrogularis*, were also observed at, but not feeding on, pig carcasses. In that area and at that time of year, pig carcasses rapidly decomposed in the heat, so these species may have been feeding on the multitudes of maggots and ants present and could conceivably be poisoned from this source. Birds were mainly responsible for the removal of baits during daylight (up to 8% of those distributed between late afternoon and sunset and 25% of those distributed at the start of the day) and foxes and pigs for bait removal during the night. Most baits (up to 98%) were taken during the first night after distribution. Some pigs ignored the baits while others ate from one to three baits each.

Laying baits just before sunset and picking them up or covering them early the next morning should thus reduce the risk of poisoning non-target animals, especially birds. So should the dyeing of baits, particularly grain baits, a green colour (Caithness and Williams 1971) or burying baits just below ground, with unpoisoned bait left above as a lure. This latter technique is already in practice in Western Australia, half apples containing oat grains impregnated with 25 mg of 1080 being buried 15 cm below the ground for pigs to root up and eat, with normal apples on the ground above (Anon. 1980*b*). A similar technique used in the Australian Capital Territory involves coring a potato, inserting an absorbent material such as bread, injecting 290 mg of 1080 in solution and replacing part of the core (R. McIlroy, personal communication 1981). The potatoes are buried just below ground level and wheat grains left on the surface.

It is clear from this study that many non-target animals are more susceptible to 1080 than are pigs. What need to be done next, then, are field studies to determine the actual impact of different pig-poisoning campaigns, including those involving modified baiting techniques, on non-target animal populations. It is only then that we can either be satisfied with the safety of current pig-poisoning methods in regard to non-target wildlife or be aware of the need for further changes in either type of poison or baiting techniques.

Acknowledgments

I wish to thank Dr J. Giles, National Parks and Wildlife Service, New South Wales, and Mr J. Hone, Department of Agriculture, New South Wales, for assistance in trapping and handling the pigs. Mr K. Malafant, Division of Mathematics and Statistics, CSIRO, Canberra, kindly provided statistical advice and assistance with probit analyses. Messrs B. V. Fennessy and P. C. Catling, Division of Wildlife Research, CSIRO, constructively criticised an earlier draft of this paper. Mrs R. McIlroy and Messrs E. Gifford and R. Cooper provided the capable technical assistance necessary during the trial.

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Manuscript received 22 February 1982; accepted 18 May 1982