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The Sensitivity of Australian Animals to 1080 Poison IX.* Comparisons between the Major Groups of Animals, and the Potential Danger Non-target Species Face from 1080-Poisoning Campaigns

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Abstract

The sensitivity of a species to 1080 poison is difficult to predict from toxicity data for other, closely related species. LD_{50}s of practical use for evaluating the risk species might face from 1080-poisoning campaigns can be obtained for untested members of some groups by the use of either values for similar species, regression equations involving body weight, or the lower 95% confidence limits of the distribution of LD_{50}s of members in each group.

Among the 171 species for which there are data there was considerable variability in the time until signs of poisoning became apparent (0·1 h->7 days), the time to death (0·1 h->21 days) and the time until animals began to show signs of recovery (2 h-18 days). Marsupial carnivores generally showed signs earlier and died or recovered quicker than eutherian carnivores, eutherian herbivores and the marsupial herbivores of eastern Australia, even though the last three groups have lower LD_{50}s. Reptiles and amphibians generally were the slowest to show signs of poisoning, to die or to recover, and had the highest LD_{50}s.

All species in Australia for which toxicity data are available were ranked according to the percentage of their body weight they would have to eat of various poison baits to receive an LD_{50}. Many non-target species require lower percentages than the target animals but the actual consumption of lethal bait may be affected by various factors. Finally, an evaluation is given of the major groups of animals potentially most at risk in 1080-poisoning campaigns in Australia, based on their susceptibility to 1080.

Introduction

Compound 1080 (sodium monofluoroacetate) is a poison that is widely used throughout the world for the control of vertebrate pests. In previous papers in this series (McIlroy 1981*a*, 1981*b*, 1982*a*, 1982*b*, 1983*a*, 1983*b*, 1984; McIlroy *et al.* 1985) the sensitivity to the poison of 84 animal species native to Australia, 25 species introduced into Australia and 38 species found elsewhere in the world was discussed.

The objectives of this final paper in this series are threefold:

(1) To determine to what extent the sensitivity of one species to 1080 (expressed as an LD_{50}) can be estimated from LD_{50} data available for other, closely related species;

(2) To determine whether there are any broad differences between the major groups of animals in their sensitivity to 1080, by summarizing all available information on the time it takes different species to show signs of 1080 poisoning, to die or to visibly begin to recover, and the LD_{50}s of different species to 1080;

(3) To rank each species in Australia that has been tested as to the risk they may face from 1080-poisoning campaigns, using data on their LD_{50}s, body weights, possible bait consumption and the concentration of 1080 used in baits.

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Methods

Estimation of Sensitivity to 1080

The aim of this part of the study was to determine whether estimates of LD_{50}s of untested species which could be used to evaluate the risk they faced from 1080-poisoning could be obtained from values available for similar species. Three methods, each producing different types of information, were used.

The first method sought to determine the extent of the variability between LD_{50}s of species in groups of similar animals by making all possible pairings of different species within each group and determining the ratios of the LD_{50}s of each of the pairs. The distribution of the ratios was then examined and the number of times they exceeded certain limits (e.g. 1·5-fold, 2·0-fold) listed (see Tucker and Haegele 1971).

The second method used regression analyses to determine whether there was any relationship between the LD_{50}s of closely related species in different groups and body weight.

Because this method was generally not successful, another method involving the calculation of 95% confidence limits for the distribution of LD_{50}s in each group was used to provide a basis for conservative estimates of the LD_{50}s for untested species within the group. Initially, the distribution of the LD_{50}s in each group was examined by eye, and where it was judged to be normal the mean LD_{50} and 95% confidence limits were calculated. If the distribution was judged to be skewed, LD_{50} values were transformed to natural logarithms and the mean and 95% confidence limits were calculated and transformed back to absolute values.

LD_{50} values amended from those given by McIlroy (1982*a*) are 0·6 mg kg^{-1} for the Tasmanian bettong *Bettongia gaimardi*, on the basis of the results of both King *et al.* (1981) and McIlroy (1982*a*), and 30 mg kg^{-1} for the quokka *Setonix brachyurus*, following further trials by D. King (personal communication, 1983). The LD_{50} of 0·125 mg kg^{-1} for the red fox *Vulpes vulpes* (McIlroy, unpublished data) is also included. All other values used are those compiled by McIlroy (1981*b*, 1982*a*, 1982*b*, 1983*a*, 1983*b*, 1984) and McIlroy *et al.* (1985), and those listed by Kalmbach (1945), Spencer (1945), Ward and Spencer (1947), Robinson (1953), California Fish and Game (1962), Hunt and Keith (1962), Peacock (1964), McIntosh *et al.* (1966), Tucker and Crabtree (1970), Atzert (1971) and Hegdal *et al.* (1979).

Comparison of Signs of Poisoning and LD_{50}s

Median values were used to compare the periods until the onset of observed signs of poisoning or death occurred between the different groups of animals. Median rather than mean values were used because they were less affected by the occasional extreme value. Data are from Cottral *et al.* (1947), Sayama and Brunetti (1952), Robinson (1953), Peacock (1964), McIntosh *et al.* (1966), McIlroy (1981*b*, 1982*a*, 1982*b*, 1983*a*, 1983*b*, 1984, unpublished data) and McIlroy *et al.* (1985).

Student's *t*-tests were performed between all possible paired comparisons using the overall estimate of the variance to determine whether any significant differences in sensitivity to 1080 existed between the major groups of animals. Mean LD_{50}s for each group, weighted to allow for the variability in the number of individuals tested in each group, were transformed to log LD_{50}s to lessen the effect of extreme values. The emu was excluded from the analysis because it is clearly much more tolerant than any of the other non-passerine birds tested (McIlroy 1984) and its LD_{50} would have distorted the results.

Ranking of Risks from Poisoning Campaigns

The amount of commercial 1080 that an average individual of each species in Australia (for which toxicity data are available) would have to ingest to receive an LD_{50} was calculated by multiplying its body weight (in kilograms) by its LD_{50}. LD_{50}s obtained by McIlroy and by King and Oliver (see McIlroy 1981*b*, 1982*a*, 1982*b*, 1983*a*, 1983*b*, 1984; McIlroy *et al.* 1985) were multiplied by 1·065 and 1·023, respectively, to convert them to a commercial-grade 1080 basis.

The amounts of commercial 1080 constituting an LD_{50} for average individuals of each species were then used to calculate the amounts of different baits containing typical concentrations of 1080 used in poisoning campaigns against rabbits *Oryctolagus cuniculus*, dingoes *Canis familiaris dingo*, and pigs *Sus scrofa*, and expressed as a percentage of the animal's body weight. Each species likely to, or known to, eat the respective baits was then listed in order of the increasing percentage of bait to body weight required for an LD_{50}.

Results

Estimation of LD_{50}s

Ratios between LD_{50}s within groups. Honeyeaters, flycatchers and eutherian herbivores showed the least variability in species-to-species comparisons of sensitivity to 1080, with less than twofold differences between LD_{50}s of members of each group (Table 1). The variability in species-to-species comparisons thereafter continued to increase in the other groups examined, and lessened the chance of being able to estimate an LD_{50} for an untested species belonging to that respective group. The marsupial herbivores in Western Australia were not considered in this comparison because it is clear that their sensitivity to 1080 is largely a function of the previous exposure of the species to plants containing naturally occurring fluoroacetate (King *et al.* 1978; Oliver *et al.* 1979) rather than of their phylogenetic relationships. Other groups of closely related animals were not examined because there were insufficient numbers of species for comparison.

Table 1. The number of times comparisons between the LD_{50}s for species pairs in each group exceeded given ratios

Group	Number exceeding ratio class:							
	1·00–1·50	1·51–2·00	2·01–3·00	3·01–5·00	5·01–7·50	7·51–10·00	10·01–20·00	>20·0
Honeyeaters	10							
Flycatchers	4	2						
Eutherian herbivores	16	5						
Raptors[A]	10		5					
Rattus spp.	3	2	2	3				
Canids	4	5	4	2				
Macropodids (E. Aust.)	10	4	5	2				
Raptors[B]	17	10	6	3				
Waterfowl	5	5	7	2	2			
Gamebirds	8	4	11	3	2			
Marsupial carnivores	11	11	8	5	1			
Finches	15			5	1			
Marsupial herbivores	23	5	8	8	1			
Pigeons and doves	2	1	3	2	1	1		
Parrots	3	10	7	5	2		1	
Pseudo-mice	2	2	4	2		1	2	2
Cricetid rodents	8	12	11	11	4	4	3	2
Eutherian carnivores	10	14	11	17	7	7	10	2

[A] Hunting raptors. [B] Hunting and scavenging raptors.

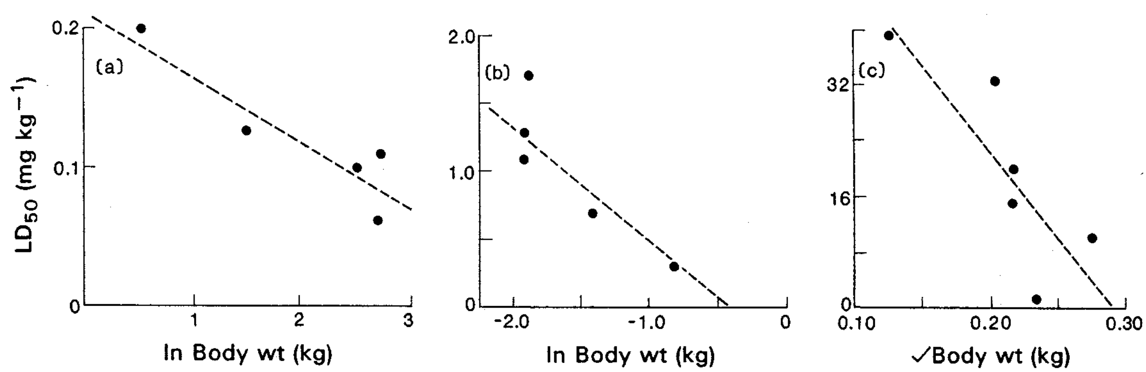

Fig. 1. Relationship between LD_{50} and a function of the body weight, for different groups of animals. (*a*) Canids, natural logarithm of body weight; $y = -0\cdot0478x+0\cdot216$, $r^2 = 0\cdot82$; $F = 14\cdot15$, 1,3 d.f., $P<0\cdot05$. (*b*) *Rattus* spp., natural logarithm of body weight; $y = -0\cdot982x-0\cdot525$, $r^2 = 0\cdot77$; $F = 10\cdot14$, 1,3 d.f., $P<0\cdot05$. (*c*) Pseudo-mice, square root of body weight; $y = -249\cdot4x+72\cdot645$, $r^2 = 0\cdot68$; $F = 8\cdot50$, 1,4 d.f., $P<0\cdot05$.

Relationship between sensitivity to 1080 and body weight. Significant negative relationships ($P < 0\cdot05$) were found between the sensitivity to 1080 and body weight of *Rattus* spp., pseudo-mice (Conilurini) and canids (Canidae) (Fig. 1). No significant relationships were found between sensitivity to 1080 and body weight for the other groups listed in Table 1.

Ninety-five per cent confidence limits. The lower confidence limits of the distribution of LD_{50}s within some groups of closely related species (Table 2) can be used as conservative estimates of the sensitivity of similar, untested species. The data in Table 2, for example, indicate that untested members of groups such as canids, macropodids and marsupial herbivores in eastern Australia, eutherian herbivores and *Rattus* spp. are likely to be highly sensitive to 1080. In these cases, particularly if the untested species is a rare or endangered one, the lower confidence limit (or 0·01 mg kg^{-1} for the canids, where the limit is given as zero) probably provide the safest estimate of the LD_{50} for conservation purposes. Estimates using this method appear much less feasible with the other groups, where some species in a group can be highly sensitive to 1080 but others only moderately so or quite tolerant.

Table 2. Ninety-five per cent confidence limits for LD_{50}s of closely related species of animals

*Values of LD_{50} transformed to logarithms for analysis and transformed back to arithmetic values

Group	No. of species	LD_{50} (mg kg^{-1}) Mean	95% C.L.
Canids	6	0·15	0·00–0·32
Macropodids (E. Aust.)*	7	0·23	0·09–0·61
Marsupial herbivores (E. Aust.)*	10	0·25	0·09–0·72
Eutherian carnivores*	13	0·36	0·04–3·45
Eutherian herbivores	7	0·44	0·24–0·63
Cricetid rodents*	11	0·83	0·11–6·28
Rattus spp.	5	1·05	0·02–2·08
Marsupial carnivores	9	2·60	0·89–7·65
Finches	7	2·73	0·83–4·62
Parrots	8	3·97	0·00–9·28
Waterfowl*	7	7·06	1·95–25·56
Gamebirds	8	7·35	0·00–16·42
Honeyeaters*	5	8·08	6·88–9·48
Hunting raptors	6	9·08	5·06–13·10
Pigeons and doves*	5	10·64	1·86–60·90
Flycatchers*	4	13·18	8·69–19·99
Pseudo-mice	6	19·38	0·00–48·14
Marsupial herbivores (W. Aust.)*	10	24·18	1·50–389·44

Signs of 1080-poisoning

The length of time before animals begin to show signs of 1080-poisoning is extremely variable, ranging from 0·1 h for the kowari, *Dasyuroides byrnei*, to 183 h for the brown bandicoot, *Isoodon obesulus*, and a questionable 362 h for the northern native cat, *Dasyurus hallucatus* (McIlroy 1981*b*, 1983*b*). Times until death are equally variable, ranging from 0·1 h for the desert gerbil *Meriones hurrianae* (Prakash *et al.* 1969) to 523 h for the blotched blue-tongued lizard *Tiliqua nigrolutea* (McIlroy *et al.* 1985). The time until signs of recovery were visible also varies, ranging from 2 h for the eastern native cat *Dasyurus viverrinus* (McIlroy 1981*b*) to 432 h for the sand goanna or Gould's monitor *Varanus gouldii* (McIlroy *et al.* 1985). The figure of 0·4 h previously stated for the dingo *Canis familiaris dingo* in table 2 of McIlroy (1981*b*) was a typographical error and should be 9·4 h.

Marsupial carnivores tend to be the first animal group to show signs of 1080-poisoning and the first to die*. This is surprising, given their relatively greater tolerance to 1080 than some other groups of mammals (Table 3). In contrast, eutherian carnivores, the most sensitive group of animals to 1080 (Table 3), tend to take longer to show signs of poisoning and to die than many other mammals. With the exception of the northern native cat, all the carnivores tested showed signs of poisoning within 24 h of dosing. All deaths of eutherian carnivores occurred within 24 h of dosing but some marsupial carnivores survived for about 6 days. Marsupial and eutherian carnivores generally showed signs of recovery before other animal groups. Eutherian herbivores generally showed signs of poisoning and died much more quickly than marsupial herbivores from eastern Australia, although the ranges of times are similar for both groups. No data are available for marsupial herbivores from Western Australia. Australian and exotic rodents both showed visible signs of poisoning and died at about the same time after dosing. Reptiles and amphibians tend to be the slowest to show signs of poisoning and to die or recover.

Comparison of LD_{50}*s*

The Texan pocket gopher, *Geomys personatus*, with an LD_{50} of $<0\cdot05$ mg kg^{-1} (Ward and Spencer 1947) is the most sensitive species to 1080 so far tested, and the shingle-back lizard, *Tiliqua rugosa*, from Western Australia (LD_{50} $543\cdot2$ mg kg^{-1}) the most tolerant. In Australia, dogs, *Canis f. familiaris* (LD_{50} *c.* $0\cdot06$ mg kg^{-1}) and dingoes (LD_{50} $0\cdot11$ mg kg^{-1}) are the most sensitive and the shingle-back lizard the most tolerant.

There were no significant differences in sensitivity among the most sensitive groups of animals—the eutherian carnivores, marsupial herbivores in eastern Australia and eutherian herbivores (Table 3). Eutherian carnivores, however, were significantly more sensitive to 1080 than marsupial carnivores, and marsupial herbivores in eastern Australia significantly more sensitive than those in Western Australia. Australian rodents and birds were significantly more tolerant to 1080 than those from other countries.

Overall, there is a general trend of decreasing sensitivity from the fairly strictly herbivorous mammals (excluding those from Western Australia) to herbivorous–granivorous mammals (e.g. rodents), carnivorous mammals, omnivorous mammals (e.g. bandicoots) and then birds and finally the poikilothermic amphibians and reptiles (Table 3).

Ranking of Risk from Poisoning Campaigns

The amounts of 1080 required for an LD_{50} by an average individual vary widely among the 110 species of animals in Australia for which there are toxicity data. The red-browed firetail, *Emblema temporalis*, a small passerine bird, requires the least, only $0\cdot007$ mg of 1080, and the emu requires the most, 7994 mg of 1080.

Of the 84 native non-target species tested, 69 are likely to or known to eat pellet, grain or carrot baits intended for rabbits or pigs. The majority need to eat only a small percentage of their body weight as bait to ingest an LD_{50}†. Foxes, sometimes target animals under other circumstances, need to eat the least percentage of their body weight of bait intended for rabbits or pigs to receive an LD_{50}. Marsupial herbivores, particularly macropodids and wombats, followed by introduced grazing livestock, are the next most susceptible groups of animals and there is some evidence (McIlroy 1982*a*, unpublished data) that individuals of some of these species are occasionally killed during rabbit or pig-poisoning campaigns. Some grazing marsupials in Western Australia and the emu and reptiles probably face the least danger, and may never eat enough bait to receive a lethal dose.

*Tables showing the times until signs of poisoning and death occurred, or visible signs of recovery began, in different groups of animals, have been lodged as Accessory Tables 1–3 with the Editor-in-Chief, Editorial and Publications Service, CSIRO, 314 Albert Street, East Melbourne, Vic. 3002.

†Tables showing the percentage of the body weight of different species that an LD_{50} of different types of baits containing different concentrations of 1080 represent, have been lodged as Accessory Tables 4 and 5 with the Editor-in-Chief, Editorial and Publications Service, CSIRO, 314 Albert Street, East Melbourne, Vic. 3002.

Table 3. Statistical differences between log mean LD_{50}s of 1080 for different groups of animals, expressed as 1% or 5% levels of significance

N, number of individuals. LD_{50} is the weighted mean in milligrams per kilogram. E.A., eastern Australia; W.A., Western Australia

Group	No. of species	*N*	LD_{50}	1	2	3	4	5	6	7	8	9	10	11	12
1. Eutherian carnivores	13	130	0·19		NS	NS	5%	1%	1%	1%	1%	1%	1%	1%	1%
2. Marsupial herbivores (E.A.)	10	215	0·34			NS	NS	1%	1%	1%	1%	1%	1%	1%	1%
3. Eutherian herbivores	7	201	0·40				NS	1%	1%	1%	1%	1%	1%	1%	1%
4. Non-Aust. rodents	30	966	0·44					1%	1%	1%	1%	1%	1%	1%	1%
5. Marsupial carnivores	9	131	2·70						NS	5%	1%	1%	1%	1%	1%
6. Australian rodents	11	195	5·17							NS	NS	1%	1%	1%	1%
7. Non-Aust. birds	31	579	6·85								NS	1%	1%	1%	1%
8. Bandicoots	3	24	7·03									NS	NS	5%	5%
9. Australian birds	36	492	7·51										1%	1%	1%
10. Marsupial herbivores (W.A.)	10	104	28·82											NS	NS
11. Amphibians	4	22	93·69												
12. Reptiles	5	30	129·70												

Summary

Group	No. of species	*N*	LD_{50}	1	2	3	4	5	6	7	8
1. Herbivores[A]	17	416	0·37		5%	NS	1%	1%	1%	1%	1%
2. Rodents	41	1161	0·66			NS	5%	1%	1%	1%	1%
3. Carnivores	22	261	0·71				NS	1%	1%	1%	1%
4. Bandicoots	3	24	7·03					NS	NS	NS	5%
5. Birds	67	1071	7·17						1%	1%	1%
6. Marsupial herbivores (W.A.)	10	104	28·79							NS	NS
7. Amphibians	4	22	93·69								NS
8. Reptiles	5	30	130·32								

[A] All herbivores tested except marsupial herbivores from Western Australia.

Of the 84 native non-target species tested, 35 are likely to or are known to eat meat baits intended for dingoes or pigs. Dingoes are the most susceptible animals during both types of campaigns, followed by other introduced animals, including cats *Felis catus*, rats and pigs. Reptiles and the emu are the least susceptible. Again there is evidence (McIlroy 1983*a*, unpublished data) that individuals of some non-target species are occasionally killed during actual poisoning campaigns.

Discussion

Estimation of LD_{50}*s*

This study has largely confirmed the conclusions of others (e.g. Tucker and Haegele 1971; Hill *et al.* 1975) that in most cases the sensitivity of one species to a given poison cannot be accurately predicted from data obtained for other, closely related species. The three methods of analysis, though, indicated that practical estimates of LD_{50}s of 1080 could be obtained for untested honeyeaters, flycatchers, canids, macropodids and marsupial herbivores in eastern Australia, eutherian herbivores, pseudo-mice and *Rattus* spp., and these estimates could be used in evaluating the risk the species might face from 1080-poisoning campaigns.

Signs of 1080-poisoning and Comparison of LD_{50}*s*

There is considerable inter- and intraspecific variability in the length of time before individuals show signs of poisoning, die or visibly begin to recover. Signs of poisoning, however, may be apparent in members of each group except amphibians and reptiles within 2 h of ingestion of the poison, deaths may occur within 6 h and visible signs of recovery within 24 h.

Variability is a major feature in the sensitivity to 1080 of individuals within species or species within groups. Some of the possible reasons for this have been discussed in earlier papers in the series (McIlroy 1981*a*, 1982*b*, 1984). It is possible that the variability in sensitivity within and between groups may have been less if all the trials to obtain LD_{50}s had been carried out on the same number of dosed individuals and with the same experimental conditions.

General trends in the sensitivity of different animal groups to 1080 that are evident are as follows:

(1) Mammals tend to be more sensitive to 1080 than birds and birds more sensitive than reptiles and amphibians.
(2) Herbivorous animals tend to be more sensitive to 1080 than granivores, carnivores, insectivores and omnivores.
(3) Eutherian mammals are equally or more sensitive to 1080 than marsupials.
(4) Animals originating from outside Australia tend to be more sensitive to 1080 than their Australian counterparts, and animals in eastern Australia more sensitive than their counterparts in Western Australia.

Ranking of Potential Risk from Poisoning Campaigns

It is difficult to grade hypothetical risk without data on actual bait intake by each species. Generally the mass-specific energy and food requirements of birds and mammals increase with decreasing body weight (Calder 1974; Kleiber 1975). Data available for 23 of the species in this study (McIlroy 1981*b*, 1982*a*, unpublished data) demonstrate that large animals, such as sheep *Ovis aries*, wombats and dingoes consume amounts of food representing approximately 2% of their body weight per day, and small dasyurids such as *Sminthopsis* spp. consume amounts representing 60%. It is probable, then, that most of the birds and mammals examined in this study consume more than 2% of their body weight as food per day. Data in Accessory Tables 4 and 5 show that the numbers of species for which the different baits containing an LD_{50} represent less than 2% of their body weight are as follows:

Rabbit baits	50–62 species
Dingo baits	2 species
Pig baits	14 species

Consequently, all these species could be at risk during the respective poisoning campaigns. There is also evidence that some animals which would have to eat amounts representing more than 2% of their body weight for an LD_{50} (e.g. 13·7% of body weight for black kites, *Milvus migrans*) have been killed during poisoning campaigns (McIlroy, unpublished data).

Many other factors can affect the position of each species on a ranking list. For example, species can show different preferences for the various baits (Brunner 1983) or have differences in feeding behaviour. *Sminthopsis crassicaudata*, for instance, can eat up to 33% of its body weight in unpoisoned meat bait per day in captivity but is reluctant to eat meat containing 1080 (Sinclair and Bird 1984). This species, like other small dasyurids, usually eats repeated small meals rather than one large one, so it is possible that they could ingest a sublethal dose in the first feeding session on a poisoned bait which would make them feel sufficiently unwell not to eat any further bait. A similar reason has been proposed for the reduced intake or avoidance of bait by rabbits (Rowley 1963) and brushtail possums, *Trichosurus vulpecula* (Morgan 1982). Other factors that can affect the impact of poisoning campaigns on populations of each species are the amount of bait used and its pattern of distribution, the size or quality of the baits and their palatability or acceptability (Batcheler 1982), the time of the year at which the baiting is done in relation to the availability of other foods, the amount of 1080 in each bait (which can vary in practice), modifications to baiting methods to increase specificity (e.g. lures) or reduce non-target hazard (e.g. dyeing baits or exposing them only during darkness), and the proportion of each population in the area that find and eat lethal quantities of bait before it is removed by insects or other animals, or before the 1080 is leached out by dew or rainfall.

Consequently, any prediction of the most vulnerable non-target species in Australia during 1080 poisoning campaigns must be partly subjective in the absence of data related to these factors. However, two general conclusions can be made:

(1) Macropodids, especially the smaller ones, and wombats appear to be most at risk during rabbit or pig-poisoning campaigns using pellet, grain or carrot baits. For example, common wombats, *Vombatus ursinus*, and hairy-nosed wombats, *Lasiorhinus latifrons*, need to eat only 10·1–16·5 g of pellet, grain or carrot baits containing 0·33–0·5 mg of 1080 to receive an LD_{50}. Hairy-nosed wombats can eat from 120 to 570 g of food per day (Tiver 1980) and common wombats can eat over 500 g of unpoisoned carrots per day (McIlroy, unpublished data), so both species could consume lethal amounts of bait. This is partly confirmed by the finding of poisoned common wombats in areas after rabbit-poisoning campaigns (McIlroy 1982*a*). Livestock appear the next most at risk, followed by brushtail possums, pigs and various rodents and birds.

(2) Carnivorous mammals, including the native marsupial carnivores, appear most at risk from dingo and pig-poisoning campaigns using meat baits. Several species of rats and some species of birds that may take the baits appear next at risk. The smaller, more insectivorous dasyurids are probably less at risk.

Studies to monitor the actual effects of rabbit and dingo-poisoning campaigns on populations of some of these species have been carried out, and the results from these will be presented in forthcoming papers.

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