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Secondary Poisoning Hazards Associated with 1080-treated Carrot-baiting Campaigns against Rabbits, *Oryctolagus cuniculus*

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Abstract

The potential hazards that rabbits, *Oryctolagus cuniculus*, and other animals that may be poisoned during rabbit-control campaigns present to different carrion-eating animals were evaluated by comparing the amounts of 1080 that carrion-eaters could ingest from feeding on poisoned corpses with their measured sensitivity to the poison. Foxes, *Vulpes vulpes*, dingoes, *Canis familiaris dingo*, dogs, *Canis f. familiaris*, and cats, *Felis catus*, probably face a greater risk of secondary poisoning than other animals from feeding on rabbits poisoned with 1080-treated carrots. The extent to which other carrion-eating animals, particularly some birds and small dasyurids, may be affected depends on their feeding habits, particularly what and how much of the different tissues and organs of poisoned animals they eat, whether they vomit or regurgitate partly digested food, and whether they quickly develop an aversion to the taste or smell of 1080. Secondary poisoning hazards during rabbit-control campaigns can be minimised by using the minimum effective concentration of 1080 in the baits for rabbits, by using the minimum effective number of 'free feeds' of bait, and by removing all dead animals that can be found from the treated area.

Introduction

Sodium monofluoroacetate (1080 poison) is widely used in Australia to help control a number of vertebrate pests, particularly rabbits, *Oryctolagus cuniculus*. Generally, when used in aerial- or trail-baiting campaigns with carrot, oat grain or bran-pollard pellet baits, it is a very effective method of control, resulting in very high reductions of rabbit numbers. Little is known, however, about the risk faced by animals that may feed on the dead rabbits or on other animals accidentally poisoned during the campaigns.

The extent to which populations of non-target animals may be affected by secondary poisoning from 1080-poisoning campaigns is difficult to measure. The aim of this paper is to evaluate the theoretical or potential hazard that rabbits and other animals killed during rabbit-poisoning campaigns using 1080-treated carrot bait present to a range of carrion-eating animals. The evaluation is based on the known sensitivity to 1080 of the carrion eaters and the concentration of 1080 measured in the tissues and organs of a sample of animals poisoned during two rabbit-poisoning campaigns.

Methods

Measurements of the Concentrations of 1080 in Poisoned Animals

Rabbits

A random sample of 10 rabbits was picked up from amongst those lying dead along, or close to, a carrot-bait trail after a rabbit-poisoning campaign at Dutton Plains, near Cooma in south-eastern New South Wales, during February 1986. The carrot bait was loaded with a nominal concentration of $0\cdot333$ mg g^{-1} of 1080. The rabbits were subsequently dissected and all their muscle tissue, plus their kidneys, livers, hearts, stomachs and their contents were removed, weighed and oven-dried to a constant weight. Comparable material was also obtained from six unpoisoned rabbits collected near Canberra.

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The concentrations of 1080 in the samples from the poisoned rabbits were measured by the alkaline fusion–fluoride ion electrode method (McIlroy *et al.* 1988). This method, which is known to accurately detect 1080 concentrations of 0·002 mg g^{-1} (C. L. Batcheler, personal communication), converts the fluoroacetate present to inorganic fluoride and measures the total fluoride present. The measurements were corrected for the 3% free (inorganic) fluoride present in the commercial brand of 1080 used and for the mean background level of free fluoride in the muscle, organs and stomach contents of the unpoisoned rabbits. Any background fluoride in the carrot bait was ignored, as were any organofluorine metabolites in the samples. Savarie (1984) reported that only very small amounts (less than 3%) of fluorocitrate (which is less toxic than 1080 when ingested) are metabolised from fluoroacetate in animals, while Frost *et al.* (1989) found no evidence of other organofluorine compounds in aged meat baits that had initially been dosed with 1080. The resultant figures were then converted to concentrations of 1080 present and multiplied by relevant correction factors to allow for incomplete recovery of 1080 from the sample materials when using this method of assay. The correction factors were 1·015 for stomach contents (i.e. *c.* 98·5% recovery from carrot bait: C. L. Batcheler, personal communication) and 1·195 for other samples (i.e. based on 83·65% recovery from meat baits: McIlroy *et al.* 1988).

Birds and other mammals

Samples of muscle, some organs and stomach contents were obtained from three birds and seven marsupials found dead during a systematic search of 368 ha of Bondo State Forest, near Tumut in south-eastern New South Wales, during five consecutive days after an aerial-poisoning campaign against rabbits in May 1980. The birds were two crimson rosellas, *Platycercus elegans*, and an Australian magpie, *Gymnorhina tibicen*, and the marsupials, four common wombats, *Vombatus ursinus*, a brushtail possum, *Trichosurus vulpecula*, and two red-necked wallabies, *Macropus rufogriseus*. The carrot bait used was loaded with a nominal concentration of 0·36 mg g^{-1} of 1080, which was higher than the concentration used at Dutton Plains. The samples were frozen and later treated and assayed for 1080 in the same way as those from the rabbits. However, because no samples of muscle and organs were obtained from the species in areas where no poisoning campaigns had been carried out, background levels of free fluoride from unpoisoned rabbits were used to correct the data obtained and provide approximate concentrations of 1080 in the samples.

Samples of muscle, some organs and stomach contents were also obtained from 35 mammals that had died after deliberately being dosed with known amounts of 1080 in solution during sensitivity trials (McIlroy 1981, 1982*a*, 1982*b*, 1983). The six species involved were the bush rat, *Rattus fuscipes*, brown antechinus, *Antechinus stuartii*, dusky antechinus, *A. swainsonii*, long-nosed bandicoot, *Perameles nasuta*, Tasmanian pademelon, *Thylogale billardierii*, and sheep, *Ovis aries*. Sheep are sometimes inadvertently poisoned during or after rabbit-poisoning campaigns by being allowed to graze in treated areas while toxic bait remains, and Tasmanian pademelons are sometimes deliberately poisoned with the same baits used for rabbit control in Tasmania. The other species, although less likely to be poisoned by baits intended for rabbits, represent animals that, if poisoned, would be difficult to find dead during searches in treated areas.

The samples from these experimentally dosed animals were treated and assayed for concentrations of 1080 in the same way as the rabbits except that no correction was made for the free fluoride present in the 1080 because analytical grade rather than commercial grade 1080 was used during the dosing. Corrections were made for the background levels of free fluoride in the samples, based on levels in samples from undosed control animals, except for sheep.

Evaluation of Risk of Secondary Poisoning

Two methods were used to evaluate the risk that animals which may eat animals poisoned by carrot bait might face from secondary poisoning.

Threshold concentrations

The first method indicated which parts of poisoned animals were a potential hazard to carrion-eaters because they contained higher concentrations of 1080 than the threshold concentrations necessary for a carrion-eater to receive an LD_{50}. Threshold concentrations were calculated by dividing the average amount of 1080 (in milligrams) that a species required for an LD_{50} (based on its mean weight and LD_{50}) by its estimated daily dry-matter intake (g day^{-1}). LD_{50}s and mean weights used were those given by McIlroy (1981, 1982*b*, 1983, 1984), McIlroy *et al.* (1985), O'Brien (1988), McIlroy and King (1990) and McIlroy (unpublished data). Daily dry-matter intakes were estimated from the allometric equations for feeding rates of free-living animals provided by Nagy (1987).

Food intake

The second method assessed whether carrion-eaters could eat sufficient amounts of the potentially hazardous parts of poisoned rabbits to receive the equivalent of an LD_{50}. This method could be used only in relation to poisoned rabbits because weights of the complete tissues, organs or stomach contents of other poisoned animals were not obtained. The proportion or numbers of the muscle, organs or stomach contents of poisoned rabbits that an average individual of carrion-eating species could eat (obtained by dividing its daily dry-matter intake by the mean dry weight of the respective samples) was compared with those that contained the equivalent of an LD_{50} for that individual. The latter were obtained by dividing the amount of 1080 required for an LD_{50} for each species by the mean amount of 1080 that was estimated to be present in the samples from the poisoned rabbits.

Results

Concentrations and Amounts of 1080 in Corpses

Rabbits

The concentrations of 1080 in the dry muscle, organs and stomach contents of the poisoned rabbits ranged from 0·004 to 0·423 mg g^{-1} (Table 1). Stomach contents (mainly masticated carrot bait) and livers generally contained the highest concentrations of 1080, followed by the tissues of stomachs, kidneys, hearts and muscle.

Table 1. Concentrations of 1080 poison (mg g^{-1}) found in the dried tissues and organs of dead rabbits, other mammals and birds poisoned at Dutton Plains or Bondo State Forest

Dash indicates organs not analysed

Animal	Concentration of 1080 (mg g^{-1})					
	Kidneys	Liver	Heart	Muscle	Stomach	Stomach contents
Rabbit 1	0·054	0·057	0·030	0·024	0·100	0·193
Rabbit 2	0·230	0·112	0·129	0·034	0·112	0·215
Rabbit 3	0·063	0·100	0·057	0·032	0·123	0·165
Rabbit 4	0·040	0·063	0·032	0·032	0·130	0·243
Rabbit 5	0·142	0·363	0·083	0·025	0·103	0·178
Rabbit 6	0·031	0·125	0·020	0·016	0·084	0·140
Rabbit 7	0·035	0·103	0·022	0·014	0·080	0·132
Rabbit 8	0·263	0·423	0·151	0·040	0·136	0·242
Rabbit 9	0·028	0·145	0·004	0·007	0·106	0·141
Rabbit 10	0·027	0·109	0·011	0·009	0·026	0·060
Wombat 1	0·016	0·014	0·029	0	–	0·074
Wombat 2	0·110	0·013	0·027	0	–	0·348
Wombat 3	0·040	0·021	0·029	0·002	–	0·276
Wombat 4	0·016	0·013	0·027	0	0·129	0·100
Possum	0·012	0·060	0·026	0·002	–	0·174
Wallaby 1	0·011	0·011	0·031	0·001	–	0·148
Wallaby 2	0·012	0·014	0·030	0	–	0·226
Magpie	–	–	–	0	–	0·039
Rosella 1	–	–	–	0	–	0·023
Rosella 2	–	–	–	0·001	–	0·033

The amounts of 1080 present in the muscles and organs of the rabbits (obtained by multiplying concentrations by total dry weight of the tissues or organs) ranged from 0·01 to 4·88 mg (Table 2). The amounts of 1080 in the muscles, bodies minus stomachs and intestines, and total corpses of rabbits were generally correlated with the amounts present in their kidneys, livers, hearts or stomach contents. The muscles generally contained the highest amounts of 1080, as might be expected given their high proportion of total body weight, followed by the stomach contents and livers. One rabbit carcass contained over 15 mg of 1080.

Table 2. Amounts of 1080 poison (mg) in tissues and organs of rabbits poisoned at Dutton Plains

Rabbit	Amount of 1080 (mg)							
	Kidneys	Liver	Heart	Muscle	Stomach contents	Stomach	Total	Total less stomach and contents
1	0·19	0·45	0·06	2·53	0·42	1·60	5·25	3·23
2	0·60	1·95	0·57	4·04	0·48	2·49	10·13	7·16
3	0·11	1·02	0·06	3·14	0·45	0·96	5·74	4·33
4	0·07	0·74	0·05	2·69	0·34	1·87	5·76	3·55
5	0·63	2·72	0·58	3·29	0·40	2·69	10·31	7·22
6	0·07	1·66	0·01	1·43	0·37	1·12	4·66	3·17
7	0·10	1·32	0·04	1·85	0·47	1·21	4·99	3·31
8	1·10	3·64	1·07	4·88	0·26	4·21	15·16	10·69
9	0·08	2·28	0·01	0·87	0·43	1·50	5·17	3·24
10	0·06	1·53	0·04	1·16	0·12	0·34	3·25	2·79
Mean	0·30	1·73	0·25	2·59	0·37	1·80	7·04	4·87
s.e.	0·11	0·30	0·12	0·41	0·04	0·35	1·16	0·83

Other animals

The stomach contents and the one stomach collected from the three species of marsupials found dead in Bondo State Forest contained higher concentrations of 1080 than did the muscles and other organs (Table 1). The kidneys and hearts generally contained the next highest concentrations, while the muscle tissues contained either no measurable 1080 or very low concentrations.

No measurable amounts, or only very low concentrations, of 1080 were found in the muscle tissues and stomach contents of the three birds found dead in Bondo State Forest (Table 1). No assays for 1080 were carried out on the other organs from the birds.

Many of the samples of muscle, organs and stomach contents from the animals that died during the laboratory-based sensitivity trials contained either no measurable amounts, or only minor traces, of 1080 (Table 3). The highest concentrations of 1080 occurred in the muscles of bush rats and brown antechinus. No relationship was found between the doses given to the different animals and the concentrations of 1080 in their muscle and organs.

One-way analyses of variance and the Newman–Keuls multiple-range test with unequal sample sizes indicated that there were significant differences between the orally dosed animals, marsupials found dead at Bondo and rabbits with respect to the concentrations of 1080 in their kidneys, livers, hearts and combined stomach and contents, but not between the concentrations of 1080 in their muscles or overall tissues and organs (Table 4). The rabbits had significantly higher concentrations of 1080 in their livers than did the other animals. In contrast, the orally dosed animals had significantly lower concentrations of 1080 in their stomachs and their contents than did those found in animals killed during rabbit-poisoning campaigns.

Table 3. Mean concentrations of 1080 in dried tissues and organs of mammals that died after being orally dosed with 1080 during sensitivity trials

Numbers of animals from which samples taken are shown in parentheses

Animal	Dose (mg kg^{-1})	Mean concentration of 1080 (mg g^{-1}) ± s.e. Kidneys	Liver	Heart	Muscle	Stomach and contents
Brown antechinus	1·2–2·8	0·004 ± 0·004 (7)	0·003 ± 0·003 (7)	0·010 ± 0·010 (7)	0·057 ± 0·046 (6)	0 (7)
Dusky antechinus	2·1–4·2	0·055 ± 0·040 (9)	0 (6)	0 (6)	0·021 ± 0·017 (9)	0·053 ± 0·035 (9)
Brown rat	0·8–3·2	0 (5)	0 (8)	0 (2)	0·060 ± 0·029 (8)	0 (8)
Long-nosed bandicoot	8–10	0·016 ± 0·008 (4)	0·042 ± 0·003 (4)	0·017 ± 0·003 (4)	0·013 ± 0·002 (4)	0 (4)
Tasmanian pademelon	0·3	0 (2)	0·001 ± 0·001 (2)	0 (2)	0·001 ± 0·001 (2)	0·004 ± 0·004 (2)
Sheep	0·4–1·0	0·006 ± 0·003 (5)	0 (5)	0·002 ± 0·002 (5)	0 (5)	0·011 ± 0·007 (5)

Table 4. Analysis of variance of mean concentrations of 1080 in dried tissues and organs of rabbits, marsupials and other mammals poisoned by oral dosing with known amounts of 1080 or during control campaigns

Within organs, different superscripts indicate significant differences between means (SNK test, $P<0 \cdot 05$)

Tissue or organ	Mean concentration of 1080 (mg g^{-1}) ± s.e. Orally-dosed mammals	Marsupials	Rabbits	*F*-value	d.f.	*P*
Kidneys	$0 \cdot 019^{a} \pm 0 \cdot 011$	$0 \cdot 031^{a,b} \pm 0 \cdot 014$	$0 \cdot 091^{b} \pm 0 \cdot 028$	4·36	2,46	<0·05
Liver	$0 \cdot 006^{a} \pm 0 \cdot 004$	$0 \cdot 021^{a} \pm 0 \cdot 007$	$0 \cdot 160^{b} \pm 0 \cdot 040$	25·49	2,46	<0·01
Heart	$0 \cdot 006^{a} \pm 0 \cdot 003$	$0 \cdot 028^{a,b} \pm 0 \cdot 001$	$0 \cdot 054^{b} \pm 0 \cdot 016$	11·98	2,40	<0·01
Muscle	$0 \cdot 031^{a} \pm 0 \cdot 011$	$0 \cdot 001^{a} \pm 0$	$0 \cdot 023^{a} \pm 0 \cdot 004$	0·86	2,48	>0·05
Stomach and contents	$0 \cdot 015^{a} \pm 0 \cdot 010$	$0 \cdot 184^{b} \pm 0 \cdot 033$	$0 \cdot 135^{b} \pm 0 \cdot 013$	37·84	2,60	<0·01
Total	$0 \cdot 016^{a} \pm 0 \cdot 004$	$0 \cdot 055^{a} \pm 0 \cdot 014$	$0 \cdot 100^{a} \pm 0 \cdot 011$	0·08	2,252	>0·05

Evaluation of Risk of Secondary Poisoning

Threshold concentrations

None of the tissues, organs or stomach contents of the poisoned animals contained concentrations of 1080 above the threshold levels for the three species of lizards: the blotched blue-tongued lizard, *Tiliqua nigrolutea*, shingle-back lizard, *T. rugosa*, and Gould's monitor, *Varanus gouldii* (Tables 4 and 5). In other words, even if their daily intake consisted solely of animals killed by carrot bait, or parts of those animals, they could never ingest enough 1080 to receive an LD_{50}.

The livers and stomach contents of rabbits and stomach contents of field-poisoned marsupials were the most dangerous parts of animals poisoned by carrot bait for other animals to eat. Mean concentrations of 1080 in these parts exceeded the threshold concentrations for all birds (except two species of raptors: the black kite, *Milvus migrans*, and the wedge-tailed eagle, *Aquila audax*), and for the mammals listed in Table 5 (Tables 1 and 5). Mean concentrations of 1080 in the other viscera of poisoned rabbits and marsupials and the stomach contents and viscera of laboratory-dosed animals exceeded the threshold concentrations for up to 8 species of birds and for 2–8 species of mammals (Tables 4 and 5). Mean concentrations of 1080 in the muscles of rabbits and laboratory-dosed mammals exceeded the threshold concentrations for 1–2 species of birds and for 7–8 species of mammals. These were, in decreasing order of threshold surpassment, the dingo, *Canis familiaris dingo*, fox, *Vulpes vulpes*, cat, *Felis catus*, brown antechinus, fat-tailed dunnart, *Sminthopsis crassicaudata*, bush rat, swamp rat, *Rattus lutreolus*, dusky antechinus, little raven, *Corvus mellori* and Australian raven, *C. coronoides* (Tables 4 and 5). Mean concentrations of 1080 in the muscles of field-poisoned marsupials were below the threshold concentrations for all carrion-eating species.

Concentrations of 1080 in the muscles of the birds found dead did not exceed the threshold concentrations for any species in Table 5, but those in the stomach contents exceeded the concentrations for the two species of ravens and eight species of mammals listed above (Tables 1 and 5).

Food intake

As indicated by threshold concentrations, 4–8 species of the birds and 9–16 species of the mammals listed in Table 5 could theoretically eat sufficient amounts of the viscera or stomach contents of poisoned rabbits to ingest the equivalent of an LD_{50}. Little ravens and

Table 5. Threshold concentrations of 1080 that animal tissues or organs would need to contain for different species to ingest an LD_{50}

Species	LD_{50} (mg kg^{-1})	Mean weight (kg)	Amount of 1080 for LD_{50} (mg)	Dry matter intake (g day^{-1})	Threshold concentration (mg g^{-1})
Blotched blue-tongued lizard	336	0·43	144·5	1·4	103·2
Shingle-back lizard	206	0·49	100·9	1·6	63·1
Gould's monitor	43·6	0·85	37·1	2·4	15·5
Black kite	18·51	0·56	10·4	39·9	0·26
Wedge-tailed eagle	9·49	3·10	29·4	121·5	0·24
Kookaburra	>6·0	0·32	>1·9	53·6	>0·04
Grey shrike-thrush	>12·0	0·07	>0·84	14·7	>0·06
Australian magpie-lark	8·83	0·09	0·79	18·2	0·04
Australian magpie	9·93	0·32	3·2	53·6	0·06
Pied currawong	13·09	0·29	3·8	49·3	0·08
Australian raven	c. 5·10	0·59	c. 3·0	90·2	c. 0·03
Little raven	3·10	0·56	1·7	86·3	0·02
Little crow[A]	13·37	0·40	5·4	64·8	0·08
Brown antechinus	1·85	0·036	0·07	5·5	0·01
Dusky antechinus	3·21	0·062	0·20	7·9	0·03
Tiger quoll[B]	1·85	2·80	5·2	102·8	0·05
Eastern quoll	3·73	1·45	5·4	66·0	0·08
Tasmanian devil	4·24	4·67	19·8	145·0	0·14
Fat-tailed dunnart	2·06	0·013	0·03	2·8	0·01
Short-nosed bandicoot[C]	c. 7·0	1·23	c. 8·6	59·1	c. 0·15
Eastern barred bandicoot[D]	c. 5·37	0·78	c. 4·2	43·5	c. 0·10
Long-nosed bandicoot	7·70	1·20	9·2	58·1	0·16
Water-rat[E]	c. 2·94	1·00	c. 2·9	30·6	c. 0·10
Bush rat	1·13	0·15	0·17	10·5	0·02
Swamp rat	1·71	0·15	0·26	10·5	0·02
Dingo	0·11	16·0	1·8	671·2	0·003
Fox	0·13	6·0	0·78	299·7	0·003
Cat	0·40	4·2	1·7	223·6	0·008
Pig	4·11	55·0	226·1	1852·0	0·12

[A] *Corvus bennetti*. [B] *Dasyurus maculatus*. [C] *Isoodon obesulus*. [D] *Perameles gunnii*.
[E] *Hydromys chrysogaster*. (Scientific names of other animals are mentioned in the text.)

six species of mammals could theoretically eat sufficient amounts of muscle. However, in many cases, to do so they would have to feed exclusively on the particular organs or stomach contents from more than one poisoned rabbit (see Appendix). All eight species of birds, for example, would have to feed on both kidneys from 3–18 poisoned rabbits to ingest the equivalent of an LD_{50}.

On this basis, foxes probably face the greatest risk of secondary poisoning because, to receive the equivalent of an LD_{50}, they need to eat only about one-third of the muscles or half the liver of one poisoned rabbit (Table 6). These amounts represent only 11% or 2%, respectively, of their estimated daily intake of food. They are followed, in terms of potential risk from eating muscle, by dingoes (and dogs, *Canis f. familiaris*, because of their similar sensitivity to 1080: McIlroy 1981), and to a lesser extent, fat-tailed dunnarts, cats, brown antechinus, bush rats, and little ravens. Much the same order of potential risk applies if the animals eat parts of the liver or viscera (Table 6) or the stomach contents (see Appendix) from one poisoned rabbit. Dusky antechinus, swamp rats, Australian magpie-larks, *Grallina cyanoleuca*, and grey shrike-thrushes, *Colluricincla harmonica*, may possibly face a risk of secondary poisoning if they eat parts of the liver (Table 6) or stomach contents (see Appendix) from a poisoned rabbit, but laughing kookaburras, *Dacelo novaeguineae*, would have to eat about 1·1 livers or stomach contents to do so.

Table 6. Species that could eat sufficient muscle or viscera from one poisoned rabbit to ingest a LD_{50}

Species	Proportion of rabbit muscle containing LD_{50}	Percentage of animal's daily food intake	Proportion of rabbit viscera containing LD_{50}	Percentage of animal's daily food intake
Fox	0·30	11	0·45[A]	2
Dingo	0·69	12	1·04[A]	2
Fat-tailed dunnart	0·01	33	0·02–0·12	8–10
Cat	0·66	34	0·98[A]	5
Brown antechinus	0·03	60	0·04–0·28	9–12
Bush rat	0·07	78	0·10–0·68	11–15
Little raven	0·66	87	0·98[A]	14
Dusky antechinus	–	–	0·12–0·80	18–24
Swamp rat	–	–	0·15–1·04	17–24
Australian magpie-lark	–	–	0·46[A]	30
Grey shrike-thrush	–	–	0·49[A]	40

[A] Only liver would have contained an LD_{50}.

Discussion

Concentrations of 1080 in Corpses

The concentrations of 1080 measured in the muscle, organs and stomach contents of poisoned animals in this study were similar to those that have been found in other poisoned animals (Table 7). Rabbits, which probably ingested 13–24 mg of 1080, or 9–16 mg kg^{-1},

Table 7. Mean concentrations (±s.e.) of 1080 measured in the tissues and organs of various poisoned animals

Concentrations are expressed on a wet weight basis for mammals but were only available on a dry weight basis for birds

Animals	No. of animals	Mean concentration ± s.e. of 1080 ($\mu g\ g^{-1}$) Muscle	Viscera	Stomach and contents	Reference
Deer	8	3·8±0·9	2·7±0·6	–	McIntosh *et al.* (1959)
Ground squirrels	4	0·6±0·2	1·6±0·8	33·8±22·0	Casper *et al.* (1986)
Laboratory-dosed mammals	35	8·1±3·0	2·5±1·1	2·6±1·6	This study
Marsupials	7	0·2±0·1	6·1±1·2	29·7±5·7	This study
Rabbits	10	6·1±0·9	23·2±4·2	22·3±1·8	This study
Birds	3	0·3±0·3	–	31·7±4·7	This study
Zebra finches	5	0·8±0·1	1·9±1·8	1·2±0·2	Burke *et al.* (1989)

based on the weight and nominal loading of the carrot bait in their stomachs, contained the highest mean concentrations of 1080 in their viscera, relatively high concentrations in their muscles, but relatively lower concentrations in their stomachs and stomach contents, compared with other animals. Laboratory-dosed mammals, which received doses of 0·3–10 mg kg^{-1}, contained the highest mean concentrations of 1080 in their muscles, but much lower concentrations in their stomachs than did the other mammals. This could indicate rapid absorption of the low volumes of 1080 solution administered to them by stomach tube. California ground squirrels, *Spermophilus beecheyi*, which received much lower doses than the rabbits (i.e. 0·8–4·8 mg kg^{-1}), contained the highest mean concentrations of 1080 in their stomach contents but low concentrations in their muscles and viscera (Casper *et al.* 1986). The concentrations of 1080 measured in the muscles of the poisoned rosellas and magpie were similar to those found in five zebra finches, *Peophila guttata*, that were fed millet seeds containing doses of 1·9–7·9 mg kg^{-1} (Burke *et al.* 1989). The rosellas and magpie, however, had higher concentrations of 1080 in their gizzards than in those of the finches.

Factors Affecting the Evaluation of Risk of Secondary Poisoning

The approach taken in this paper allows only an evaluation of potential secondary poisoning hazard and identification of some species that may be at risk, not actual proof that it occurs. The methods used (threshold concentrations and the proportions of muscle or organs that may be eaten) can provide only a general evaluation because they were based on mean concentrations of 1080 in the tissues and organs of poisoned animals and not on the wide range of concentrations found. In some cases, background fluoride levels in ingested bait or unpoisoned animals' tissues or organs were not determined or were based on those found in unpoisoned rabbits. Background levels in unpoisoned rabbits were similar to those measured in a Tasmanian pademelon, slightly lower than those found in a long-nosed bandicoot, but much lower than the levels in both *Antechinus* spp. and bush rats. Hence, in some instances, particularly with the poisoned birds, 1080 concentrations may have been overestimated.

The methods of evaluation were also based on mean weights of carrion-eating animals, their LD_{50} values, and daily feeding rates which were based on the allometric equations of Nagy (1987). Different evaluations could obviously be obtained by using, for example, the minimum weights of breeding individuals, minimum LD values, and maximum daily feeding rates (to allow for gorging) obtained on each species in the field. Feeding rates may also vary according to age, growth or reproductive stage, season, habitat and behaviour. Many animals, particularly smaller species such as some birds, fat-tailed dunnarts, antechinus and rats, for example, are unlikely to ingest their daily food intake at one time. The evaluations also did not consider consumption of other organs in poisoned animals, such as brains, lungs and spleens, that can also contain 1080 (e.g. 0·2–9·7 $\mu g\ g^{-1}$: Casper *et al.* 1986). The results of the evaluation can also be applied only to the species considered in this paper because in many cases it is not possible to accurately extrapolate LD_{50} values from one species to other closely related species. For example, there can be up to five-fold differences between the sensitivity to 1080 (LD_{50}s) of different hunting and scavenging raptors, or between canids (McIlroy 1986).

Factors Affecting the Actual Risk of Secondary Poisoning

The risk that different individuals or populations of animals actually face from secondary poisoning during or after rabbit-poisoning campaigns depends on a number of factors. These include the species' sensitivity to 1080, the number of poisoned animals that each member of the population encounters, and each individual's feeding habits, particularly the amounts of different tissues or organs from the poisoned animals that they may, or are able to, eat.

Although the evaluation of risk suggests that a number of different birds and mammals may face a potential risk from eating the muscles and viscera, particularly stomach contents of poisoned animals, in practice this is unlikely to occur. Very few animals eat stomachs or stomach contents of poisoned animals. Tasmanian devils, *Sarcophilus harrisii*, generally first eat some of the internal organs of poisoned wallabies and possums followed by muscle tissues, but leave most bones, skin and fur, and the stomach and intestines (Statham 1983). Similarly, coyotes, *Canis latrans*, are known not to feed on 26% of the gastrointestinal tracts of poisoned ground squirrels (Marsh *et al.* 1987). Raptors and many other birds and mammals appear to have similar eating habits, eviscerating carcasses before feeding on them (Hegdal *et al.* 1986; McIlroy, unpublished data). A few birds with more omnivorous feeding habits might eat partly digested stomach contents of poisoned animals, particularly if these are exposed. Large birds, quolls, dingoes and foxes could also inadvertently ingest the stomach contents of small poisoned animals such as antechinus or mice by swallowing them whole. Wild and farm dogs sometimes will also chew and then swallow a whole young rabbit.

If animals deliberately or inadvertently eat muscle, organs or stomach contents of poisoned animals, they may still not necessarily find or consume sufficient amounts to receive a lethal dose. A Tasmanian devil, for example, would have to find and selectively feed on the livers from 11 poisoned rabbits to ingest the equivalent of an LD_{50} (see Appendix). Although a devil might encounter 11 dead rabbits along or close to a bait trail, it is likely that the devil will also eat other organs and the flesh, in which the overall concentration of 1080 is below the threshold necessary for it to be fatally poisoned.

Even though some species may need to feed on only a small proportion of the muscles or organs of poisoned animals theoretically to receive an LD_{50}, they may not actually consume those amounts, for different reasons. Fat-tailed dunnarts, for example, need to eat only 1–12% of the muscles or organs of poisoned rabbits to ingest an LD_{50} (Table 6). Although estimates of their daily intake of food suggest that this is possible, in practice they are very unlikely to eat enough of the material at one time to ingest the equivalent of an LD_{50}. Small dasyurids such as fat-tailed dunnarts can also develop an aversion to the taste or smell of food containing 1080 (Sinclair and Bird 1984) and, together with other species such as Tasmanian devils, quolls, *Dasyurus* spp., pigs, *Sus scrofa*, and raptors and other birds such as pied currawongs, *Strepera graculina*, can vomit or regurgitate partly digested food (McIlroy 1981, 1983, 1984). This could lessen the amounts of 1080 they are likely to absorb. In contrast, some species such as dingoes, dogs and foxes could experience chronic secondary poisoning by feeding on sublethal amounts of poisoned corpses for several successive days (Marsh *et al.* 1987). However, they would probably detoxify the 1080, although this could cause temporary depletion of the levels of glutathione in their livers. Statham (1983) found that none of eight captive Tasmanian devils and five captive eastern quolls, *Dasyurus viverrinus*, that fed on field-poisoned corpses of Bennett's wallaby, *Macropus rufogriseus*, brushtail possums, a young rabbit or a rat, *Rattus rattus*, over 1–4 days showed any signs of 1080-poisoning.

The actual amounts of 1080 that carrion-eaters may ingest from poisoned animals may also depend on the length of time and environmental conditions before the corpses are found. Partial consumption of corpses and of 1080 by insects, defluorination of the 1080 present by micro-organisms during decomposition, leaching of some of the 1080 from the corpses by rainfall, or retention of 1080 in sun-dried or mummified corpses all affect the risk that animals face from eating them.

The concentration of 1080 used in baits and the amounts of bait eaten by different animals may also affect the risk that carrion-eaters face from secondary poisoning. The sample of rabbits from Dutton Plains probably contained higher concentrations of 1080 than those that are generally present nowadays in rabbits killed by eating carrot bait. The nominal concentration of 1080 used in the carrot bait at Dutton Plains was $0 \cdot 333$ mg g^{-1}. This has since been reduced to a standard of $0 \cdot 20$ mg g^{-1} throughout New South Wales and three other States and Territories, 0·18 mg g^{-1} in Queensland and 0·14 mg g^{-1} in Tasmania. The rabbits at Dutton Plains also had been fed three prepoisoning 'free' feeds instead of the customary two and had eaten very high amounts of poison bait. The mean wet weight of bait in the sample of 10 rabbits collected was 54 g (range 39–73 g), compared with averages of 9–16 g (range 0–33 g) of carrot containing the same concentration of 1080 and 13–20 g (range 1–28 g) of carrot containing 0·2 mg g^{-1} of 1080 from rabbits poisoned in other trials (Poole 1963; T. Korn, personal communication). Korn also found that rabbits subjected to extra 'free' feeds because of wet weather ate greater amounts of bait than normal. One such sample of 25 rabbits had eaten a mean weight of 32 g (range 0–62 g) of carrot containing 0·2 mg g^{-1} of 1080, and another sample of 25 rabbits had eaten a mean weight of 29 g (range 0–50 g) of carrot containing 0·3 mg g^{-1} of 1080.

The sample of 10 rabbits collected at Dutton Plains may also have contained higher concentrations of 1080 than other dead rabbits in the same area. The position of their corpses along or close to the bait lines suggests that they may have died more quickly than other rabbits further away. If so, they probably had ingested higher doses of 1080 because time to death for rabbits is positively related to dose of 1080 ingested (McIlroy, unpublished data).

Given these factors, eutherian carnivores, particularly foxes, are probably the species most likely to experience secondary poisoning from rabbit-poisoning campaigns in Australia. Data on carrion-eating animals found dead after rabbit-poisoning campaigns with pellet or carrot bait in New South Wales support this evaluation. Foxes were the carrion-eaters most frequently found dead (31% frequency) after 22 rabbit-poisoning operations between 1971 and 1975 in New South Wales State Forest areas (McIlroy 1982*a*). Other animals occasionally found dead (0·1–2% frequency), but not necessarily from secondary poisoning, were dogs and dingoes, cats, 'rats', 'crows', 'hawks', 'bandicoots', and kookaburras. McIlroy and Gifford (1991) similarly found that fox numbers were reduced by about 75% after a trail-baiting campaign against rabbits with 1080-treated pellets in New South Wales.

Although the use of different baits and loadings of 1080 in them (e.g. 0·36–0·6 mg g^{-1} in pellets and 0·4–0·6 mg g^{-1} in conventional oats) in different parts of Australia might affect the range and numbers of animals that may be killed by primary poisoning, the concentrations of 1080 in their tissues and organs, and the extent to which the corpses are potential hazards to carrion-eaters, it is unlikely to affect the relative susceptibility of different carrion-eaters to secondary poisoning. Eutherian carnivores were also the main species killed by secondary poisoning after a control campaign against California ground squirrels in the U.S.A. which used grain loaded with 0·75 mg g^{-1} of 1080 (Hegdal *et al.* 1986). Five of six coyotes and three of ten bobcats, *Lynx rufus*, carrying radio-transmitters, plus three unmarked striped skunks, *Mephitis mephitis*, were killed by eating poisoned rodents. Other radio-equipped skunks, racoons, *Procyon lotor*, and badgers, *Taxidea taxus*, survived the campaign. Nine species of raptors and other birds were observed feeding on poisoned animals without being affected, but a few insectivorous birds were poisoned, apparently from eating poisoned ants that had fed on the grain. Domestic dogs, cats and kit foxes, *Vulpes macrotis*, have also been reported to be poisoned by similar campaigns in the U.S.A. (Hegdal *et al.* 1986).

Conclusion

Many variables can affect the likelihood of secondary poisoning of animals during or after rabbit-poisoning campaigns. In general, foxes, dingoes, dogs and cats appear to face the greatest risk, particularly from poisoned rabbits. Although there may be little concern if these animals, which, apart from domestic dogs and cats, are also regarded as vertebrate pests, are poisoned, except where their predation may help hold rabbit numbers down, there is also a slight possibility that other more desirable animals could be killed by secondary poisoning. The approach used in this study could be used to evaluate the potential risk of secondary poisoning that desirable animals, including species not included in this study, may face from other types of rabbit- or pest-poisoning campaigns. It could also be used to select appropriate (susceptible) indicator species for population-level assessments of non-target impacts. Possible effects on their populations can obviously be minimised if attention is paid during rabbit-poisoning campaigns to using the minimum effective concentration of 1080 in baits, the minimum effective number of pre-poisoning 'free' feeds, and to the removal of all poisoned animals that can be found to prevent other animals from feeding on them.

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Appendix. Proportions or numbers of poisoned rabbits' tissues or organs that contained an LD_{50} for each non-target species, followed, in parentheses, by the percentage of the animal's estimated daily dry matter intake they represented

Mean dry weights (g) of tissues and organs are also shown. Dashes indicate where animals could not theoretically eat sufficient tissues or organs in one day

Species	Two kidneys (2·85 g)	Liver (11·91 g)	Heart (2·37 g)	Muscle (113·8 g)	Stomach lining (3·95 g)	Stomach contents (8·32 g)
Kookaburra	6 (34)	1 (24)	8 (34)	–	5 (38)	1 (16)
Grey shrike-thrush	3 (54)	0·5 (40)	3 (54)	–	2 (61)	0·5 (26)
Australian magpie-lark	3 (41)	0·5 (30)	3 (41)	–	2 (46)	0·4 (20)
Australian magpie	11 (57)	2 (41)	13 (57)	–	9 (64)	2 (28)
Pied currawong	13 (73)	2 (53)	15 (73)	–	10 (82)	2 (36)
Australian raven	10 (32)	2 (23)	12 (32)	–	8 (36)	2 (15)
Little raven	6 (19)	1 (14)	7 (19)	0·7 (87)	5 (21)	1 (9)
Little crow	18 (79)	3 (57)	21 (79)	–	15 (89)	3 (39)
Brown antechinus	0·2 (12)	0·04 (9)	0·3 (12)	0·03 (60)	0·2 (14)	0·04 (6)
Dusky antechinus	0·7 (24)	0·1 (18)	0·8 (24)	–	0·5 (27)	0·1 (12)
Tiger quoll	17 (48)	3 (35)	21 (48)	–	14 (54)	3 (23)
Eastern quoll	18 (78)	3 (56)	22 (77)	–	15 (87)	3 (38)
Tasmanian devil	–	11 (94)	–	–	–	11 (63)
Fat-tailed dunnart	0·1 (10)	0·02 (8)	0·1 (10)	0·01 (33)	0·1 (11)	0·02 (6)
Short-nosed bandicoot	–	–	–	–	–	5 (67)
Eastern barred bandicoot	14 (92)	2 (67)	17 (92)	–	–	2 (45)
Long-nosed bandicoot	–	–	–	–	–	5 (73)
Water-rat	10 (90)	2 (65)	12 (90)	–	–	2 (44)
Bush rat	0·6 (15)	0·1 (11)	0·7 (15)	0·07 (78)	0·5 (17)	0·1 (7)
Swamp rat	0·9 (24)	0·2 (17)	1 (23)	–	0·7 (26)	0·1 (11)
Dingo	6 (3)	1 (2)	7 (3)	0·7 (12)	5 (3)	1 (1)
Fox	3 (2)	0·5 (2)	3 (2)	0·3 (11)	2 (3)	0·4 (1)
Cat	6 (7)	1 (5)	7 (7)	0·7 (34)	5 (8)	1 (4)
Pig	–	131 (84)	–	–	–	126 (56)

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