Aust. Wildl. Res., 1982, **9**, 487–503

The Sensitivity of Australian Animals to 1080 Poison III.* Marsupial and Eutherian Herbivores

J. C. McIlroy

Division of Wildlife Research, CSIRO, P.O. Box 84, Lyneham, A.C.T. 2602.

Abstract

Most marsupial and eutherian herbivores that have been tested exhibit a similar high sensitivity to 1080 poison. The main exceptions are marsupial herbivore species in Western Australia, which, because of their exposure to indigenous food plants containing fluoroacetate, have acquired a much greater tolerance to 1080. The most common signs of poisoning amongst herbivores are either hypersensitivity to stimuli or, more frequently, lethargy, respiratory distress and finally respiratory or cardiac failure. Some species experience convulsions, particularly just before death. Signs of poisoning amongst species tested during this study first appeared 1·0–39·4 h after dosing. Deaths followed 3–156 h after dosing.

The overall susceptibility to 1080 of 25 species of herbivores is compared with that of the rabbit. Three groups of marsupials are either relatively more, equally or far less susceptible to 1080 than rabbits. Eutherians tested are also less susceptible. The actual risk an individual of each species faces during a rabbit-poisoning campaign is also governed by other factors, particularly the amount of bait consumed and the concentration of 1080 in the bait.

Introduction

In Australia and New Zealand compound 1080 (sodium monofluoroacetate) is frequently used in poisoning campaigns against herbivorous vertebrate pests, such as rabbits *Oryctolagus cuniculus*, brushtail possums *Trichosurus vulpecula*, Bennett's wallabies *Macropus rufogriseus*, and red-bellied pademelons *Thylogale billardierii*. Pieces of carrot, oat grains, or pellets manufactured from bran or pollard are usually used as bait, which is either spread from the air or laid in trails within furrows on the ground. The baits, because of their vegetable origin, may also be eaten by other herbivores, such as sheep *Ovis aries*, cattle *Bos taurus*, or various species of native wildlife. This may then lead to both primary and secondary poisoning of non-target animals.

Since 1972 the Division of Wildlife Research, CSIRO, has been undertaking a comprehensive study of the effects of 1080 poisoning campaigns on non-target fauna. One aspect of this study has been the determination of the sensitivity of different species of animals to 1080, to obtain an indication of their relative vulnerability to the poison. This paper, the third in a series (McIlroy 1981*a*, 1981*b*), reports on the sensitivity to 1080 of a range of marsupial and eutherian herbivores found either in Australasia or elsewhere in the world. Rodents (Rodentia) and feral pigs, *Sus scrofa*, are not included, even though a number of species may be regarded as herbivorous, but will be discussed in subsequent papers in this series.

*Part II. *Aust. Wildl. Res.*, 1981, **8**, 385–99.

Table 1. Details of experimental conditions for LD_{50} trials on marsupial and eutherian herbivores

Source: B, Bombala, N.S.W.; C, Canberra; T, Tasmania; KI, Kangaroo I., S.A.; SC, South Coast, N.S.W.; ST, Southern Tablelands, N.S.W.; SA, South Australia; Y, Yaouk, N.S.W. Season: Sum., Summer; Au., Autumn; Win., Winter; Spr., Spring.

Species	Age	Sex	*N*/dose level	Body weight (kg) Mean	Body weight (kg) Range	Source	Time of dosing (h)	Season	Ambient temp. (°C)	Daylength (h)
Brushtail possum	Imm.	M+F	5	1·3	0·7–1·8	B	1130–1230	Sum.	17–30[A]	14·5
Brushtail possum[B]	Ad.	M+F	3/5	2·6	1·4–3·8	B, C	0915–1600	All year	10–11, 21–27[C]	8·2–12·0
Tasmanian bettong	Ad.	M+F	1	1·8	1·8–1·9	T	0950–1030	Win.	9–21	10·9
Tammar wallaby	P.y.	M+F	3	0·9	0·3–2·0	KI	1000–1230	Spr.	18–21[A]	12·5–13·7
Tammar wallaby	Ad.	M	5	7·0	6·0–8·2	KI	1000–1100	Win.–Spr.	10–15[A]	10·9–11·8
Eastern grey kangaroo	Ad.	M+F	1	42·0	21·8–60·0	C, T	1000–1230	Sum.–Win.	—	9·4–13·5
Bennett's wallaby	Ad.	M	5	13·1	8·8–20·6	T	1000–1400	Au.	—	9·4–9·5
Long-nosed potoroo	Ad.	M	1	1·1	1·1	SC	1200–1500	Spr.	18–21[A]	12·6–13·8
Red-bellied pademelon	Ad.	M	5	5·2	2·4–7·8	T	1100–1520	Au.	—	9·4–9·5
Common wombat										
Free-ranging	Ad.	M+F	3	24·9	20·2–28·5	ST	1030–1230	Win.	—	10·3–10·8
Captive	Ad.	M	5	22·6	18·0–26·5	ST	0920–1130	Spr.–Sum.	18–25[A]	13·2–14·4
Hairy-nosed wombat	Ad.	M+F	3	24·4	20·5–28·2	SA	0930–1145	Win.	1–19	10·5
Sheep	Ad.	M[D]	5	36·4	32·9–42·8	C	1030–1300	Win.	9–11[A]	10·3–10·6
European rabbit[B]	Imm.	M+F	3/5	0·8	0·6–1·0	Y	0830–1645	Sum.	21–25[C]	12·0
European rabbit[B]	Ad.	M+F	3/5	1·5	0·8–1·9	C, Y	0900–2030	Au.–Win., Sum.	21–26[C]	12·0

[A]At time of dosing only. [B]Data represent range from several trials. [C]Controlled environment. [D]Wethers.

Methods

Median lethal doses (LD_{50}s), a measure of the sensitivity of a species to 1080, were determined for nine species of marsupial herbivores and two species of eutherian herbivores, according to the basic experimental procedure described by McIlroy (1981*a*, 1981*b*). Summarized details of the procedures are shown in Table 1. LD_{50}s for another 10 species of marsupial herbivores and six species of eutherian herbivores were also obtained, either from other scientists or published literature. The western pygmy possum, *Cercatetus concinnus*, a member of the Phalangeridae, has been included despite its predilection for nectar and insects.

With three exceptions (two field trials, see later, and a short trial on hairy-nosed wombats, *Lasiorhinus latifrons*) all experimental animals were kept in captivity, in either outdoor enclosures of up to 0·2 ha or indoor weldmesh pens and cages, for at least 2 weeks before being dosed with 1080. Shelter was provided in all outdoor enclosures, including artificial burrows for common wombats *Vombatus ursinus*. Food provided depended upon each species' requirements but included pellets for rabbits; lucerne, lucerne chaff and oat grain for tammar wallabies *Macropus eugenii* and potoroos *Potorous tridactylus*; plus bread, apples, sweet potatoes and dog-biscuits for Tasmanian bettongs *Bettongia gaimardi*; bread, tree leaves, clover, fruit and vegetables for brushtail possums; pellets and apples for pademelons; *Stipa* grass for hairy-nosed wombats; and for common wombats, Bennett's wallabies and eastern grey kangaroos *Macropus giganteus*, pasture, with or without pellets, oat grain, bread and apples. All animals except the hairy-nosed wombats of semi-arid South Australia were also provided with water *ad libitum*.

As only the rabbits and some brushtail possums were kept in controlled-environment rooms, most species experienced some variability in environmental conditions during the trials, particularly in ambient temperatures. All ambient temperatures shown in Table 1, except those for the hairy-nosed wombat, refer either to those at the time of dosing or the range experienced in the controlled-environment rooms. Daylight, either natural or artificial, ranged from 8·2 to 14·5 h per day for all species.

Depending upon the species involved, groups of either three or five animals were dosed with 1080. At least four dose levels were administered to each species, with a ratio of 1·26 between dose levels. Animals were held either in the hand, in cloth or hessian bags, or in a weldmesh crush, and the 1080 was administered orally via a syringe and either a blunt-ended needle or oesophageal catheter. A wooden mouth gag was used to facilitate dosing. Four groups of brushtail possums received their 1080 by intraperitoneal injection. The times at which doses were administered varied between 0837 and 2024 h, depending upon trial requirements, but were generally during the mornings.

Only adult animals were used except for age-specific trials. Males were also preferably used except for sex-specific trials or where availability of specimens limited choice.

All 1080 used was AR sodium monofluoroacetate (*c*. 100% purity), dissolved in deionized water. To keep to a minimum the volume of solution administered, stock solutions were made up for the individual species as follows: pouch young of tammar wallabies 0·2 mg ml^{-1}; pademelons, potoroos, Bennett's wallabies, tammar wallabies, bettongs, possums, rabbits and common wombats in captivity 1 mg ml^{-1}; sheep, free-ranging common wombats and hairy-nosed wombats 2 mg ml^{-1}; eastern grey kangaroos, 10 mg ml^{-1}. In some cases, to increase the accuracy of the administration via a hypodermic syringe, deionized water was added to the amount of stock solution which was given to each animal. The amounts added for each species were as follows: rabbits, 1 ml water per 100 g body weight; brushtail possums, 1 ml per 200 g; bettongs, 1 ml per 500 g; tammar wallabies and hairy-nosed wombats, 1 ml per 2 kg; common wombats, 1 ml per 5 kg. Equivalent doses of deionized water were also given to one additional animal at each dose level in most trials as a control measure. They were not given to bettongs, potoroos, grey kangaroos or free-ranging wombats because of a shortage of experimental animals.

Dosed animals were inspected frequently during the first 7 days after dosing and signs of poisoning or deaths recorded. LD_{50}s were then calculated for most species according to the moving average method of Thompson (1947) and Weil (1952), and additionally by probit analysis (Finney 1952) for grouped data on rabbits, brushtail possums and common wombats. Because of a shortage of experimental animals, LD_{50}s could not be calculated for bettongs, potoroos, Bennett's wallabies or grey kangaroos; crude estimates have been made, however, from dose response data.

The field trials on common wombats, and eastern grey kangaroos in Tasmania, varied only slightly from normal experimental procedure. Selected trapped individuals were weighed, dosed with 1080 and then released and radio-tracked for the next 7 days or until they died. During both these and the laboratory-based trials every effort was made to treat all animals as humanely as possible, as outlined in a recommended code of practice for the care and use of animals in research in Australia (National Health and Medical Research Council and CSIRO 1979).

Results

Signs of Poisoning

The first signs of poisoning were exhibited by the animals tested during this study 1·0–39·4 h after the 1080 was administered (Table 2). Deaths occurred 3–156 h after dosing. Time until death was clearly positively related to the amount of 1080 ingested by some species (see examples in Fig. 1) but not by others.

Table 2. Length of latent period and time until death for herbivores poisoned by 1080

Unless stated, data are from this study. Numbers of individuals, where known, given in parentheses. p.c., personal communication

Species	Latent period (h)	Time until death (h)	Reference
		Marsupials	
Brushtail possum	1·0–19·8 (*40*)	5·0–97·0 (*90*)	
Brushtail possum	4·0–5·0	4·0–45·5 (>*42*)	Bell 1972; Rammell and Fleming 1978
Tasmanian bettong	—	5·2–14·8 (*2*)	
Tasmanian bettong	—	<15·0–*c*.24·0 (*3*)	Statham p.c. 1981
Tammar wallaby (p.y.)	—	11·5–80·5 (*8*)	
Tammar wallaby (ad.)	—	13·8–37·1 (*11*)	
Eastern grey kangaroo	<13·2–23·9 (*3*)	20·9–62·1 (*7*)	
Bennett's wallaby	<16·9–23·2 (*7*)	8·9–38·9 (*23*)	
'Wallabies' (N.Z.)	—	12·0–24·0	Elgie 1961
Long-nosed potoroo	—	9·6 (*1*)	
Long-nosed potoroo	—	9·0–21·0 (*6*)	Statham p.c. 1981
Red-bellied pademelon	18·5 (*1*)	8·3–130·7 (*27*)	
Common wombat	5·8–<20·5 (*4*)	9·8–156·0 (*15*)	
Hairy-nosed wombat	5·1–39·4 (*4*)	16·2–59·3 (*6*)	
		Eutherians	
Horse	*c*.1·5–2·0 (*2*)	6·0–10·5 (*2*)	Frick and Boebel 1946
Cattle	—	1·5–29·3 (*15*)	Robison 1970
Goat	—	1·0–168·0 (*20*)	Chenoweth and Gilman 1946
Sheep	6·2–37·6 (*19*)	9·6–61·6 (*19*)	
Sheep	2·3–24·9 (*10*)	2·8–16·7 (*10*)	Jensen *et al.* 1948
Mule deer	0·5 (*1*)	1·9–>18·5 (*2*)	Bissell and Brunetti 1956
Fallow deer	—	*c*.2·0–30·0	Daniel 1966
Rabbit	1·1–10·1 (*23*)	3·0–44·3 (*75*)	
Rabbit	0·3–4·0	0·5–24·0	Chenoweth and Gilman 1946; Quin and Clark 1947; Foss 1948

Brushtail possums behaved normally and continued to feed during the first 1·0–29·8 h after being dosed. Thereafter, some animals suddenly became hypersensitive to noise or movements, occasionally defaecated and then became lethargic, either sitting huddled up or lying outstretched on their sides. Many individuals had shallow respiration and displayed poor coordination and balance; a few exhibited brief convulsions, frequently gripping the cage, squeaking and ejaculating.

Most of the affected macropodids were observed simply lying quietly or found dead on their sides, without signs of convulsions having occurred. Affected Bennett's wallabies were sometimes observed sitting hunched up, with heads held shakily just above the ground. Generally they appeared non-alert and 'sick', with shivering or shaking forelimbs and unsteady balance. Most individuals then eventually experienced convulsions, falling to the ground and lying on their backs and sides, kicking or making running motions with their hind legs before dying. Many individuals also ejaculated shortly before death and, with others, exuded a white froth from their nostrils and mouth. Red-bellied pademelons, in contrast, showed no signs of frothing or convulsions and only one male ejaculated upon death. Post-mortem examinations indicated that both species died from gradual cardiac failure but no obvious or diagnostic symptoms of 1080 poisoning were found. Eastern grey kangaroos also showed no signs of convulsions but simply sat hunched over like the Bennett's wallabies, or lay on their sides breathing much more deeply and slowly than usual.

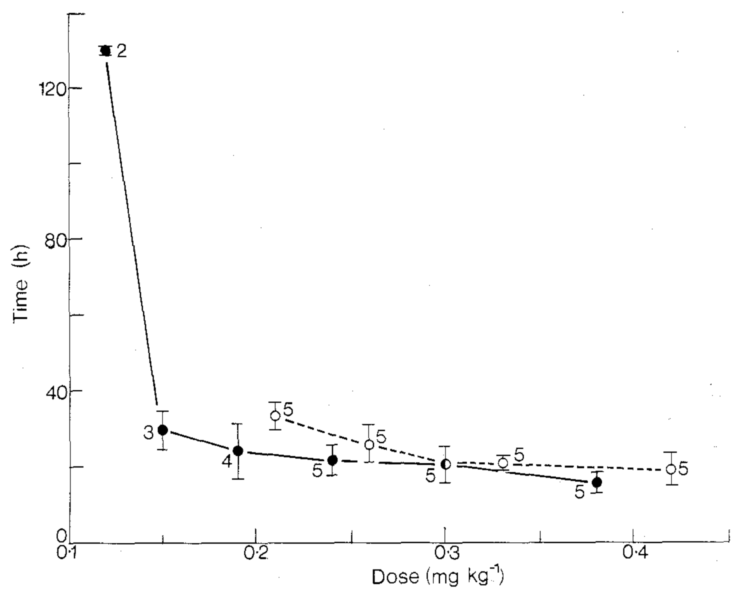

Fig. 1. Relationship between amount of 1080 ingested and time until death for red-bellied pademelons, *Thylogale billardierii* (———) and Bennett's wallabies, *Macropus rufogriseus* (– – – –). The numbers of animals that died at each dose level are shown.

Signs of poisoning amongst common wombats were difficult to observe, because they usually sheltered inside their artificial or natural burrows. Affected individuals were lethargic, did not eat, and lay on their sides like the macropodids, breathing heavily. One individual was observed convulsing. Unlike the free-ranging common wombats, which all died within their burrows, two out of the five captive individuals that died did so out in the open. Some poisoned common wombats have also been found dead above ground in areas in which rabbit-poisoning campaigns have been undertaken (McIlroy, unpublished data). Affected hairy-nosed wombats were also noted as being lethargic or sitting and lying quietly, or were simply found dead, without signs of convulsions. Some individuals did feed, however, both shortly after being dosed and even after signs of poisoning appeared.

Table 3. LD_{50}s and 95% confidence limits for marsupials and eutherian herbivores

Unless otherwise stated, data are from this study. Values in parentheses are 95% confidence limits. W.A., animals from Western Australia

Family and species	*N*	Weight range (kg)	LD_{50} (mg kg^{-1})	Reference
Marsupialia				
Phalangeridae				
Western pygmy-possum, *Cercartetus concinnus* (W.A.)	8	0·007–0·014	*c.*>10·0	D. King, p.c. 1981
Common brushtail possum, *Trichosurus vulpecula*				
Immature	20	0·7–1·8	0·86(*0·67–1·09*)	
Adult	144	1·4–3·8	0·47–0·79(*0·34–1·03*)[A]	
Western Australian	20	0·8–2·1	*c.*>125·0	King *et al.* 1978
Macropodidae				
Tasmanian bettong, *Bettongia gaimardi*	2	1·8–1·9	*c.*1·0	
Burrowing bettong, *B. lesueur* (W.A.)	6	1·0–1·4	*c.*10–20	King *et al.* 1981
Brush-tailed bettong, *B. penicillata* (W.A.)	15	1·0–1·5	*c.*100–200	
Banded hare-wallaby, *Lagostrophus fasciatus* (W.A.)	2	1·8–2·0	*c.*100–125	D. King, p.c. 1981
Agile wallaby, *Macropus agilis*	3	6·0–15·0	*c.*0·22	Tomlinson and Gooding 1971; D. King, p.c. 1981
Tammar wallaby, *M. eugenii*				
Pouch young	12	0·3–2·0	0·15(*0·12–0·20*)	
Adult	20	6·0–8·2	0·27(*0·23–0·31*)	
Western Australian	19	3·2–6·8	*c.*>2·0–10·0	Oliver *et al.* 1979
Western grey kangaroo, *M. fuliginosus*	9	16·5–24·0	*c.*20	
Western Australian	8	11·3–34·5	*c.*40–60	King *et al.* 1978
Eastern grey kangaroo, *M. giganteus*	8	21·8–60·0	*c.*0·1–0·35	
Western brush-wallaby, *M. irma* (W.A.)	8	5·7–8·3	*c.*5·0–10·0	Oliver *et al.* 1979
Bennett's wallaby, *M. rufogriseus*	20	8·8–20·6	*c.*>0·21	
Red kangaroo, *M. rufus* (W.A.)	4	21·5–38·5	2·0–*c.*4·4	Tomlinson and Gooding 1971; King *et al.* 1978

Long-nosed potoroo, *Potorous tridactylus*	2	1·1	*c.*0·15–0·20	
Quokka, *Setonix brachyurus* (W.A.)	9	1·9–3·3	*c.*2·0	D. King, p.c. 1981
Red-bellied pademelon, *Thylogale billardierii*	20	2·4–7·8	0·13 (*0·09–0·19*)	
Vombatidae				
Common wombat, *Vombatus ursinus*				
Free-ranging	12	20·2–28·5	0·15 (*0·12–0·19*)	
Captive	20	18·0–26·5	0·22 (*0·18–0·27*)	
Southern hairy-nosed wombat, *Lasiorhinus latifrons*	12	20·5–28·2	0·21 (*0·15–0·29*)	
Perissodactyla				
Equidae				
Mule, *Equus asinus* × *E. caballus*	—	—	0·20–0·40	Tucker and Crabtree 1970
Horse, *E. caballus*	—	—	0·32–0·50	Tucker and Crabtree 1970
Artiodactyla				
Bovidae				
European cattle, *Bos taurus*				
Immature	20	104–213	0·22 (*0·15–0·33*)	Robinson 1970
Adult	9	469–607	0·39 (*0·25–0·63*)	Robinson 1970
Goat, *Capra hircus*	24	—	0·3–0·7	U.S.P.H.S. 1949[B]
Sheep, *Ovis aries*	20	32·9–42·8	0·5 (*0·42–0·64*)	
Cervidae				
Mule deer, *Odocoileus hemionus* (Imm.)	—	—	0·27–0·90	Tucker and Crabtree 1970
Lagomorpha				
Leporidae				
European rabbit, *Oryctolagus cuniculus*				
Immature	32	0·6–1·0	0·35–0·37 (*0·30–0·42*)[A]	
Adult	112	0·8–1·9	0·34–0·50 (*0·26–0·58*)[A]	
Black-tailed jack rabbit, *Lepus californicus*	—	—	5·55	Atzert 1971

[A]Range from a series of LD_{50} trials. [B]U.S. Public Health Service, cited by McGirr and Papworth 1955.

Affected sheep usually stood apart from other sheep or sat on their rumps. Most appeared to be very weak, and breathed slowly and noisily, with traces of froth frequently issuing from their noses and mouths. Many that survived experienced at least one brief convulsion, falling onto their sides and kicking, before regaining their feet and resuming grazing. Thereafter, they remained very unsteady for a while, with stiffened rear legs placed apart for balance, using only the front legs for propulsion. Complete recovery took from 45·5 to 120 h (5 days) after ingestion of the 1080. Most deaths occurred at night. Dead animals were invariably found lying on their sides with their heads arched back, tongues protruding and legs extended. Frequently there was signs of convulsions, with paddling or running movements of all four legs. A copious white froth (sometimes containing blood) had also often exuded from the mouth and nostrils.

All affected rabbits exhibited increased sensitivity to noise or disturbance. Thereafter some recovered while the remainder experienced one or more convulsions, during which they coughed and squeaked, kicked with their hind legs and struggled for breath. Most convulsing rabbits eventually died but a few recovered. All rabbits that survived began recovering 5·0–23·2 h after being dosed.

$LD_{50}s$

The LD_{50}s obtained for marsupial and eutherian herbivores during this and other studies are shown in Table 3. Values obtained for the brushtail possum in eastern Australia (i.e. 0·47–0·86 mg kg^{-1}) depended upon the age, sex and reproductive status of the individuals and the experimental conditions under which the trials were carried out. The LD_{50} obtained by probit analysis for a combined sample of 92 immature and adult male and female possums which experienced similar experimental conditions is 0·67 (0·58–0·79) mg kg^{-1}.

An LD_{50} could not be determined for Bennett's wallabies, because all died at each dose level. As a consequence, the LD_{50} has simply been taken as less than 0·21 mg kg^{-1}, the lowest dose administered. Values for the bettong, potoroo and eastern grey kangaroos were simply based on the range between survival and death of individual animals. Two out of three eastern grey kangaroos died after receiving 0·1 mg kg^{-1} of 1080, but stress was probably a contributory factor. All three animals, kept in enclosures, were chased and captured five times within 48 h of being dosed, so that blood samples could be obtained for a collaborative study of fluoroacetate tolerance in eastern and western grey kangaroos. Both animals that died showed signs of distress when caught 24 h after being dosed, and died during or shortly after being recaught, 48 h after being dosed. The LD_{50}, therefore, is likely to be more than 0·1 mg kg^{-1} but less than 0·35 mg kg^{-1}, the lowest dose at which a free-ranging grey kangaroo in Tasmania died.

The LD_{50} obtained by probit analysis for the combined free-ranging and captive common wombats is 0·19 (0·16–0·24) mg kg^{-1}. The LD_{50}s obtained for rabbits varied slightly (i.e. 0·34–0·50 mg kg^{-1}), depending upon the age and sex of the individuals tested, and on the experimental conditions. The LD_{50} obtained by probit analysis for a combined sample of 124 immature and adult male and female rabbits which experienced similar experimental conditions is 0·37 (0·34–0·40) mg kg^{-1}. The LD_{90} (i.e. the dose that will kill 90% of a population) is 0·51 (0·44–0·58) mg kg^{-1}. LD values greater than this (e.g. LD_{99}) have very large confidence limits and are of limited practical value.

Discussion

Signs of Poisoning

Although 1080 is a highly toxic compound, it does not affect animals immediately, even when comparatively high amounts are ingested. The length of the delay or latent period until signs of poisoning appear depends upon the time it takes for the 1080 to be hydrolysed to monofluoroacetic acid and translocated, the time it takes for biochemical synthesis of a toxic quantity of fluorocitrate, and the time required for this to disrupt cellular functions sufficiently to produce toxic symptoms.

In this and other studies all affected marsupial herbivores first showed signs of poisoning from 1·0 to 39·4 h after being dosed with 1080, and affected eutherian herbivores, from 0·25 to 37·6 h after being dosed (Table 2). Deaths in both groups occurred from 4·0 to 156·0 h and from 0·5 to 168·0 h after the dose, respectively.

The signs of poisoning observed amongst the animals in this study were similar to those described for other herbivores, namely horses (Chenoweth and Gilman 1946; Frick and Boebel 1946; Foss 1948), cattle (Schnautz 1949; Robison 1970), goats (Chenoweth and Gilman 1946; Foss 1948), and mule deer *Odocoileus hemionus* and fallow deer *Dama dama*, (Bissell and Brunetti 1956; Daniel 1966). Similar signs of poisoning amongst brushtail possums, sheep and rabbits to those observed in this study have also been reported, respectively, by Batcheler (1978) and Rammell and Fleming (1978); Jensen *et al.* (1948); and Chenoweth and Gilman (1946), Quin and Clark (1947) and Foss (1948).

Depending upon the species involved, the signs of poisoning and death result from different degrees of response of the heart and central nervous system to fluoroacetate (Chenoweth and Gilman 1946). In some species death results from either gradual cardiac failure or ventricular fibrillation; in others, from progressive depression of the central nervous system, with either cardiac or respiratory failure as the terminal event; and in still others, from respiratory arrest following disruption of the central nervous system and severe convulsions. Most herbivores tend to experience either the first (cardiac) response or the second (mixed) response, whereas carnivores tend to experience solely central nervous system responses.

LD_{50}s

Apart from one major exception, most of the marsupial and eutherian herbivores that have been tested in this and other studies exhibit a similar high sensitivity to 1080, with LD_{50}s falling in the range 0·1–1·0 mg kg^{-1} (Table 3). This is in marked contrast to the carnivorous mammals that have been tested, marsupial carnivores being decidedly more tolerant to 1080 than eutherian carnivores (McIlroy 1981*b*).

The one major exception involves the marsupial herbivores in Western Australia. Studies on some of these species (Table 3) have shown that they are much more tolerant to 1080 (e.g. LD_{50}s of *c.* 2·0–200 mg kg^{-1}) than marsupial and eutherian species in eastern Australia and elsewhere in the world. For example, brushtail possums in south-western Australia can tolerate doses of 125 mg kg^{-1} of 1080, and possibly higher (King *et al.* 1978; Mead *et al.* 1979). This is in sharp contrast to the LD_{50}s of < 1 mg kg^{-1} obtained for brushtail possums in eastern Australia during this study, and 0·8 (0·7–0·9) mg kg^{-1} for those introduced into New Zealand from eastern Australia (Bell 1972; Rammell and Fleming 1978).

These different levels of tolerance to 1080 between marsupial herbivore species in Western Australia and their counterparts in eastern Australia appear to reflect the formers' length of exposure in evolutionary time to food plants in Western Australia that contain fluoroacetate (Oliver *et al.* 1979). Differences in tolerance between the different species of phalangerids and macropodids in Western Australia itself, and even between populations of the same species in different areas or on different offshore islands, also appear to reflect different feeding habits and the amount of genetic interchange between more or less tolerant populations (Oliver *et al.* 1979).

Almost every macropodid species in Western Australia that has been tested can tolerate much higher doses of 1080 than macropodid species in eastern Australia. The only exception reported to date is the agile wallaby, *Macropus agilis*, with its LD_{50} of approximately $0 \cdot 22$ mg kg^{-1} (Tomlinson and Gooding 1971; D. King, personal communication 1981). This species, though, only occurs in the northern section of Western Australia and across northern Australia where fluoroacetate-bearing plants are absent or rare, so it has possibly never had the opportunity to develop a tolerance to 1080. The value for the Tasmanian bettong appears slightly higher than that obtained for other species of macropodids in eastern Australia, but the figures are based on a sample of only two animals. King *et al.* (1981), working with four individuals, found that they could tolerate *c.* $0 \cdot 2$–$1 \cdot 0$ mg kg^{-1}.

All eutherian herbivores that have been tested, mainly domestic stock, share a similar high sensitivity to 1080. The black-tailed jack rabbit, *Lepus californicus*, (more properly regarded as a hare) in North America is reportedly more tolerant to 1080 than other eutherian herbivores, with an LD_{50} of $5 \cdot 55$ mg kg^{-1} (Atzert 1971). However, the reliability of this figure can not be ascertained because details of the trial have not been published.

Toxicity data for the mule, *Equus asinus* × *E. caballus*, and horse, *E. caballus*, shown in Table 3 have been converted to a 100% pure 1080 basis for comparative purposes, as Tucker and Crabtree (1970) used only approximately 90% pure 1080. Other LD_{50}s previously published for the horse include *c.* $0 \cdot 5$–$1 \cdot 75$ mg kg^{-1} (Chenoweth and Gilman 1946) and *c.* $1 \cdot 0$ mg kg^{-1} (Ward 1946). Only rough estimates are available for the goat, *Capra hircus*, including the $0 \cdot 3$–$0 \cdot 7$ mg kg^{-1} from the U.S. Public Health Service (1949) listed in Table 3, *c.* $0 \cdot 7$ mg kg^{-1} by Ward (1946) and less than $0 \cdot 6$ mg kg^{-1} for methyl fluoroacetate, by Chenoweth and Gilman (1946).

In New Zealand the LD_{50} for sheep is generally accepted as $0 \cdot 4$ mg kg^{-1} (Rammell and Fleming 1978). Analysis of data provided by Jensen *et al.* (1948) for sheep in Colorado gives a value of $0 \cdot 35$ mg kg^{-1}. During the trials on sheep in Canberra two groups experienced sub-zero, nocturnal temperatures after being dosed with 1080. However, despite some evidence that low ambient temperatures may increase the sensitivity of animals to 1080 (McIlroy, unpublished data; A. Oliver, personal communication 1980) the LD_{50} obtained (Table 3) was still slightly higher than, although quite comparable with, the other reported values for sheep.

No precise values are known for deer. From limited data provided by Bissell and Brunetti (1956) on 'deer' (most probably mule deer) the LD_{50} is *c.* $0 \cdot 29$–$0 \cdot 89$ mg kg^{-1}. This is similar to the value (converted to a 100% pure 1080 basis) shown in Table 3 from Tucker and Crabtree (1970) for immature mule deer.

LD_{50}s previously reported for rabbits are $0 \cdot 2$–$0 \cdot 25$ gm kg^{-1} (Chenoweth and Gilman 1946; Ward and Spencer 1947) and $0 \cdot 3$–$0 \cdot 4$ mg kg^{-1} (Ward 1946; Wodzicki and Taylor 1957). LD_{100}s are $0 \cdot 7$–$0 \cdot 8$ mg kg^{-1} (Lazarus 1956; Rowley 1963). Nowadays an LD_{50} of $0 \cdot 4$ mg kg^{-1} and LD_{100} of $0 \cdot 7$ mg kg^{-1} are the generally accepted values in New Zealand (Rammell and Fleming 1978), which correspond closely with the data obtained by probit analysis in this study. No significant differences occur in the sensitivity to 1080 of rabbits in eastern and western Australia (Wheeler and Hart 1979). Thus this species has apparently not had sufficient time since its introduction or spread into Western Australia to develop a tolerance to 1080 like the marsupial herbivores. Nor, probably, have the other eutherian herbivores introduced into Western Australia. It would be interesting, though, to discover whether native eutherian herbivores in South Africa and South America, where some plants also contain fluoroacetate, have acquired a tolerance to 1080.

Relative Susceptibility of Herbivores to Rabbit-poisoning Campaigns

At least eight species of marsupial herbivores and possibly five species of eutherian herbivores listed in Table 3 are more sensitive to 1080 than the rabbit. Sensitivity, however, is not the only factor that governs the risk that an individual of a species faces during poisoning campaigns. Size or, more correctly, body weight, is also important. Obviously the larger an animal is, the more 1080 it will have to ingest to receive a lethal dose. Thus, although an eastern grey kangaroo is more sensitive to 1080 than a rabbit, because of its size (e.g. 14–40 times that of a rabbit) it would require approximately 2·1–21·0 mg of 1080 for an LD_{50}, compared with 0·55 mg for a rabbit (Table 4).

Table 4 lists the amount of 1080 each herbivorous species would have to ingest to receive an LD_{50}. This was obtained by multiplying their LD_{50}s from Table 3 by their generally accepted range of adult weights (shown in Table 4), gleaned from various sources, including those of the trial animals in this study. The average weight of an adult rabbit is taken as 1·5 kg. This was the mean weight of all rabbits used in the LD_{50} trials and has been confirmed as the weight of an average rabbit in Australia by I. Parer and D. Wood (personal communication 1981). The amounts of 1080 for an LD_{50} are then expressed as a ratio to that of the rabbit, to show more graphically those species more or less susceptible to 1080 than the rabbit. Obviously, because of the range in weights and LD_{50} values present the ratios for each species can cover a wide range. Despite this, it is still possible to discern four groups of herbivores according to their relative susceptibility to 1080.

The first group consists of macropodids such as the long-nosed potoroo and red-bellied pademelon, which are more sensitive to 1080 than the rabbit and which may also be lighter and thus require less 1080 for an LD_{50}. The western pygmy-possum also belongs to this group despite its much higher tolerance to 1080 than rabbits, because of its very small size. Other small marsupial herbivores in eastern Australia also probably belong to this group. Because of the far greater susceptibility to 1080 of this group than of rabbits, rabbit-poisoning campaigns should be avoided in areas which contain these non-target species. Certainly, if poisoning campaigns must be carried out, field studies are necessary to find out whether these non-target species eat the baits used, what amounts they eat and, given the concentration of 1080 in the baits, what proportion of each population could ingest an LD_{50}. For example, long-nosed potoroo, which will readily eat carrot bait because their natural food is underground tubers and roots, are killed during rabbit-poisoning campaigns (A. Rose, personal communication 1979; H. Statham, personal communication 1981).

The second group of herbivores consists of marsupials such as Bennett's wallaby, agile wallaby, tammar wallaby from Kangaroo I., eastern grey kangaroo, common wombat and hairy-nosed wombat, which, although heavier than the rabbit, are more sensitive to 1080 and overall are only slightly less susceptible. The quokka, *Setonix* *brachyurus*, from Rottnest I. off the coast of Western Australia, the Tasmanian bettong and the brushtail possum in eastern Australia, although slightly more tolerant to 1080 than the rabbit, also belong to this group, mainly because of their similar size or weight. Other medium-sized marsupial herbivores in eastern

Table 4. Relative susceptibility of rabbits and other herbivores (in decreasing order) to 1080 poison, based on LD_{50}s and body weights

Approximate ranges in weight of 'average' individuals (adult unless otherwise indicated) taken from trial animals or literature

Species	Range in weight (kg)	Amount 1080 for LD_{50} (mg)	Ratio of amount 1080 for herbivore:rabbit
Western pigmy-possum (W.A.)	0·007–0·04	0·07–0·14	>0·1–0·3
Long-nosed potoroo	1·0–1·5	0·15–0·30	0·3–0·5
Red-bellied pademelon	2·4–7·8	0·3–1·0	0·5–1·8
Rabbit	0·8–1·9	0·55[A]	1·0
Brushtail possum (Imm.)	0·7–1·8	0·6–1·5[A]	1·1–2·7
Tammar wallaby	6·0–8·2	0·9–1·2	1·6–2·2
Brushtail possum (Ad.)	1·4–3·8	0·9–2·5[A]	1·6–4·5
Tasmanian bettong	1·0–2·2	1·0–2·2	1·8–4·0
Agile wallaby	6·0–19·0	1·3–4·2	2·4–7·6
Bennett's wallaby	8·8–20·6	<1·8–4·3	<3·3–7·8
Eastern grey kangaroo	21·0–60·0	2·1–21·0	3·8–38·2
Common wombat	20·0–39·0	3·0–8·6	5·4–15·6
Quokka (W.A.)	1·9–3·3	*c*.3·8–6·6	*c*.6·9–12·0
Hairy-nosed wombat	19·0–32·0	4·0–6·7	7·3–12·2
Black-tailed jack rabbit	2·1–3·3	4·2–18·3	7·6–33·3
Tammar wallaby (W.A.)	3·2–6·8	<6·4–68·0	<12–124
Goat	31–44	9·3–30·8	17–55
Burrowing bettong (W.A.)	1·0–1·9	*c*.10·0–38·0	*c*.18–69
Mule deer	60–180	16·2–162·0	29–294
Sheep	33–43	17·2–22·4	33–41
Cattle (Imm.)	104–213	22·9–46·9	42–85
Brush wallaby (W.A.)	5·7–8·3	*c*.28·5–83·0	*c*.52–151
Red kangaroo (W.A.)	21·5–60·0	43–*c*.264	78–*c*.480
Mule	*c*.300–400	*c*.60–160	*c*.109–291
Banded hare-wallaby (W.A.)	0·9–2·0	*c*.90–250	*c*.164–455
Brush-tailed bettong (W.A.)	1·0–1·5	*c*.100–225	*c*.182–409
Brushtail possum (W.A.)	0·8–2·1	>100–263	>182–478
Horse	400–545	128–273	233–496
Cattle (Ad.)	469–607	183–237	333–431
Western grey kangaroo	16·5–60·0	*c*.330–1200	*c*.600–2182
Western grey kangaroo (W.A.)	11·3–34·5	452–2070	822–3764

[A]Using probit LD_{50} for grouped data, rabbit, 0·37 mg kg^{-1}; possum, 0·67 mg kg^{-1}, plus mean wt of rabbit 1·5 kg (see text).

Australia, such as the swamp wallaby, *Wallabia bicolor*, also probably belong to this group. The fate of members of this group during a rabbit-poisoning campaign, as will be discussed shortly, will depend on a number of factors but particularly the concentration of 1080 in the baits and how many baits each individual eats.

The third group of herbivores consists of most marsupial herbivores from Western Australia that have been tested. These species, almost regardless of their size, are in a very secure position during rabbit-poisoning campaigns because of their tolerance to fluoroacetate. This leads to the interesting possibility of using 1080 for conservation of rare or endangered fauna in Western Australia, particularly on the offshore islands, by using it to kill more sensitive introduced competitors or predators such as rabbits, foxes and feral cats *Felis catus*.

Finally, there is a fourth group of herbivores, all eutherians, such as cows, sheep, goats and horses, which although similar in sensitivity to 1080 to the rabbit, are much larger and therefore much less susceptible to 1080.

Table 5. Actual or potential bait intake by herbivores and number of LD_{50}s ingested when baits contain different concentrations of 1080

1080 assumed to be 100% pure

Species	Actual or potential bait intake per day (kg)	No. LD_{50}s ingested when 1080 concn is: 0·014%	0·035%	0·06%
Brushtail possum (A.C.T.)	0·39–0·47[A]	22–70	54–175	92–301
Brushtail possum (W.A.)	0·3	0·2–0·4	0·4–1·1	0·7–1·8
Western grey kangaroo (W.A.)	3·0	0·2–0·9	0·5–2·3	0·9–4·0
Long-nosed potoroo	Up to 0·04[A]	19–37	47–93	80–160
Hairy-nosed wombat	0·12–0·57	3–20	6–50	11–86
Sheep	0·70	4–6	11–14	19–25
'Average N.Z. deer'	Up to 2·0[A]	4–14	10–35	18–59
Rabbits				
Basis of intake per day	0·006–0·34[A]	1–161	3–402	5–689
Basis of intake per 3 h	0·145[A]	29–69	72–172	124–294
Basis of intake per 20 min	0·05[A]	10–24	25–59	43–101

[A]Actual consumption of carrot baits.

Despite these differences in susceptibility, many herbivores can still be poisoned during rabbit-poisoning campaigns if they eat sufficient bait. In this regard bait placement and palatability, and particularly the concentration of 1080 used in the baits, can be critical in determining what proportions of non-target populations may be killed. This is partly illustrated by Table 5, where the actual or potential amounts of bait each species could eat per day are shown together with the number of LD_{50}s they would then ingest, given three typical concentrations of 1080 used for rabbit control in Australia. The data on bait intake are from Carrick (1956), McIntosh *et al.* (1959), Rowley (1960, 1963), Wells (1973), King *et al.* (1978), Tiver (1980), McIlroy (unpublished data) and H. Statham (personal communication 1981). Weight ranges of animals are from Table 4 and LD_{50}s from Table 3. Admittedly the data in Table 5, particularly that on bait consumption, are probably very rough and could be improved, but they do indicate that even species much less susceptible to 1080 than rabbits, such as sheep and deer, can face a risk of being poisoned during a rabbit-poisoning campaign. Other species, such as brushtail possums in eastern Australia, and potoroos, would appear to face a risk equal to or even greater than the rabbit.

Practical evidence that other herbivores can be killed by baits used for rabbits is provided by data from Tasmania. There, deliberate poisoning of forest-browsing pests with carrot baits containing 0·014% of 1080, the same concentration as used elsewhere in Tasmania for rabbits, has resulted in up to 94% mortality amongst brushtail possum populations, 96% mortality amongst red-bellied pademelons and

86% mortality amongst Bennett's wallabies (Johnson 1978; Mooney and Johnson 1979; H. Statham, personal communication 1981). Other evidence is shown in Table 6, which lists the number of non-target animals found dead in 15 State forests in New South Wales after 22 rabbit-poisoning campaigns between 1971 and 1975 (unpublished files, Forestry Commission of N.S.W.). Carrot or pellet baits were either broadcast from the air or laid as trails on the ground in areas in which plantations of pines, chiefly *Pinus radiata*, were being established. Not every dead animal recorded was necessarily poisoned by 1080 (e.g. echidna, *Tachyglossus aculeatus*), nor should the frequencies of occurrence be taken as possible population

Table 6. Numbers of non-target animals found dead in New South Wales State Forest areas after 22 rabbit-poisoning operations between 1971 and 1975

Species	No. found dead	Frequency of occurrence (%)
Fox	238	31·4
'Wallaby'	218	28·8
'Possum'	82	10·8
Grey kangaroo	56	7·4
Wombat	54	7·1
Swamp wallaby	24	3·2
'Rats'	15	2·0
Hare	14	1·9
Magpie	12	1·6
'Parrots'	10	1·3
Cat	10	1·3
Sheep	6	0·8
Dog (inc. dingo)	5	0·7
Kookaburra	3	0·4
'Bandicoot'	2	0·3
Scrub wren	2	0·3
'Pigeon'	1	0·1
'Hawk'	1	0·1
Lyrebird	1	0·1
'Crow'	1	0·1
Echidna	1	0·1

mortality. Instead, the figures probably simply reflect the relative abundance of each species in the areas involved, their access to and acceptance of the baits (or in the case of the carnivores, of poisoned animals) and their ease of detectability after death by Forestry personnel.

What the N.S.W. Forestry Commission's figures confirm is that some individual herbivores, particularly those in the first two groups discussed earlier (e.g. Bennett's wallaby, brushtail possum and common wombat) are killed during present rabbit-poisoning campaigns. Although more accurate data on bait consumption and body weights might alter the figures shown in Table 5, the general impression gained is that in many instances in Australia the concentration of 1080 in baits used against rabbits could be lowered. This would then lessen the risk to non-target species. This idea, however, is not a new one. Rowley (1960) and Poole (1963) recommended this years ago, when they demonstrated that the concentration of 1080 in carrot bait could be reduced to 0·02% with no loss in efficiency and without the need to lay more bait. What ultimately counts from a conservation point of view, though, is not the death of individuals or small numbers of animals in different areas during poisoning campaigns, but the overall effect on their population numbers and stability. Monitoring of population numbers before and after poisoning campaigns has already been carried out (McIlroy, unpublished data) and this aspect will be discussed in detail in forthcoming papers.

Acknowledgments

Many people who are not mentioned here assisted in the catching, handling or feeding of trial animals; their help was appreciated. I wish to thank Dr I. Eberhard, Messrs N. Mooney and R. Pearse and other personnel of the National Parks and Wildlife Service, Tasmania, for supplying or helping to catch *Bettongia gaimardi*, *Macropus giganteus*, *M. rufogriseus* and *Thylogale billardierii*; the Division of Plant Industry, CSIRO, Canberra, for supplying *Ovis aries*; and Drs B. Cooke and R. Sinclair of the Vertebrate Pests Control Authority, South Australia, for collaboration during the trial on *Lasiorhinus latifrons*. Facilities for trials and assistance were provided by Mr B. Munday and his colleagues in the Department of Agriculture, Tasmania; the National Parks and Wildlife Services of Tasmania and South Australia; the Forestry Commission of New South Wales; and the Division of Plant Industry, CSIRO, Canberra. All protected animals were collected under permits granted respectively by the National Parks and Wildlife Services of New South Wales, South Australia and Tasmania, and the Department of the Capital Territory, Canberra.

I am grateful to Dr D. King, Mr A. Oliver, Mrs H. Statham and the Forestry Commission of New South Wales for permission to quote their unpublished data. Mr Kim Malafant, Division of Mathematics and Statistics, CSIRO, Canberra, kindly provided statistical advice and assistance with probit analyses. Messrs B. V. Fennessy and W. E. Poole read the manuscript and gave helpful criticism. Mr K. Newgrain constructed all the radio transmitters used in the studies involving free-ranging animals and assisted in the field trial on grey kangaroos in Tasmania. Finally, and most important, Messrs R. Cooper and E. Gifford capably assisted with all stages of the study.

References

Atzert, S. P. (1971). A review of sodium monofluoroacetate (compound 1080)—its properties, toxicology and use in predator and rodent control. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Wildl. No. 146.

Batcheler, C. L. (1978). Report to Minister of Forests and Minister of Agriculture and Fisheries on Compound 1080, its properties, effectiveness, dangers, and use. (New Zealand Forestry Service: Wellington.)

Bell, J. (1972). The acute toxicity of four common poisons to the opossum, *Trichosurus vulpecula*. *N.Z. Vet. J.* **20**, 212–14.

Bissell, H. D., and **Brunetti, O. A.** (1956). Investigations on the toxicity of 1080 and Mexican narrow-leaf milkweed to deer. Pittman-Robertson Project, California, W-25-R. (Mimeograph.)

Carrick, R. (1956). Radioiodine as an indicator of free-feeding activity of the rabbit, *Oryctolagus cuniculus* (L). *CSIRO Wildl. Res.* **1**, 106–13.

Chenoweth, M. B., and **Gilman, A.** (1946). Studies on the pharmacology of fluoroacetate. I. Species response to fluoroacetate. *J. Pharmacol. Exp. Ther.* **87**, 90–103.

Daniel, M. J. (1966). Early trials with sodium monofluoroacetate (compound 1080) for the control of introduced deer in New Zealand. N.Z. For. Serv. For. Res. Inst. Tech. Pap. No. 51.

Elgie, H. J. (1961). Wallaby eradication by aerial poisoning. *N.Z. J. Agric.* **102**, 25–31.

Finney, D. J. (1952). 'Probit Analysis: a Statistical Treatment of the Sigmoid Response Curve.' 2nd Ed. (Cambridge University Press: Cambridge.)
Foss, G. L. (1948). The toxicology and pharmacology of methyl fluoroacetate (MFA) in animals, with some notes on experimental therapy. *Br. J. Pharmacol.* **3**, 118–27.
Frick, E. J., and **Boebel, F. W.** (1946). Clinical observation of '1080' poisoning. *Vet. Med.* **41**, 196–7.
Jensen, R., Tobiska, J. W., and **Ward, J. C.** (1948). Sodium monofluoroacetate (compound 1080) poisoning in sheep. *Am. J. Vet. Res.* **9**, 370–2.
Johnson, K. A. (1978). Methods for the census of wallaby and possum in Tasmania. Tasmanian Natl Parks Wildl. Serv. Wildl. Div. Unpubl. Rep.
King, D. R., Oliver, A. J., and **Mead, R. J.** (1978). The adaptation of some Western Australian mammals to food plants containing fluoroacetate. *Aust. J. Zool.* **26**, 699–712.
King, D. R., Oliver, A. J., and **Mead, R. J.** (1981). *Bettongia* and fluoroacetate: a role for 1080 in fauna management. *Aust. Wildl. Res.* **8**, 529–36.
Lazarus, M. (1956). The toxicity and relative acceptability of some poisons to the wild rabbit. *CSIRO Wildl. Res.* **1**, 96–100.
McGirr, J. L., and **Papworth, D. S.** (1955). The toxicity of rodenticides. I. Sodium fluoroacetate, Antu and Warfarin. *Vet. Rec.* **67**, 124–31.
McIlroy, J. C. (1981*a*). The sensitivity of Australian animals to 1080 poison. I. Intra-specific variation and factors affecting acute toxicity. *Aust. Wildl. Res.* **8**, 369–83.
McIlroy, J. C. (1981*b*). The sensitivity of Australian animals to 1080 poison. II. Marsupial and eutherian carnivores. *Aust. Wildl. Res.* **8**, 385–99.
McIntosh, I. G., Staples, E. L. J., and **Morris, L. G.** (1959). The toxicity of muscle, liver, and heart of deer poisoned with sodium monofluoroacetate (1080). *N.Z. J. Sci.* **2**, 371–8.
Mead, R. J., Oliver, A. J., and **King, D. R.** (1979). Metabolism and defluorination of fluoroacetate in the brush-tailed possum (*Trichosurus vulpecula*). *Aust. J. Biol. Sci.* **32**, 15–26.
Mooney, N. J., and **Johnson, K. A.** (1979). Methods for the census of wallaby and possum in Tasmania. Tasmanian Natl Parks Wildl. Serv. Wildl. Div. Unpubl. Rep.
National Health and Medical Research Council and CSIRO (1979). Code of practice for the care and use of animals in research in Australia. (Australian Government Publishing Service: Canberra.)
Oliver, A. J., King, D. R., and **Mead, R. J.** (1979). Fluoroacetate tolerance, a genetic marker in some Australian mammals. *Aust. J. Zool.* **27**, 363–72.
Poole, W. E. (1963). Field enclosure experiments on the technique of poisoning the rabbit, *Oryctolagus cuniculus* (L.). V. A study of concentration of '1080' in bait material. *CSIRO Wildl. Res.* **8**, 154–65.
Quin, J. I., and **Clark, R.** (1947). Studies on the action of potassium monofluoroacetate (CH_2 F COOK) [*Dichapetalum cymosum* (Hook) Engl.] toxin on animals. *Onderstepoort J. Vet. Res.* **22**, 77–90.
Rammell, C. G., and **Fleming, P. A.** (1978). Compound 1080. Properties and use of sodium monofluoroacetate in New Zealand. (Animal Health Division, Ministry of Agriculture and Fisheries, New Zealand.)
Robison, W. H. (1970). Acute toxicity of sodium monofluoroacetate to cattle. *J. Wildl. Manage.* **34**, 647–8.
Rowley, I. (1960). The effect of concentration on the ingestion of '1080' poisoned baits by the rabbit. *CSIRO Wildl. Res.* **5**, 126–33.
Rowley, I. (1963). Bait materials for poisoning rabbits. I. Studies on the acceptance of bait materials by caged rabbits. *CSIRO Wildl. Res.* **8**, 56–61.
Schnautz, J. O. (1949). Sodium fluoroacetate (compound 1080) poisoning in cattle. *Am. Vet. Med. Assoc. J.* **114**, 435.
Thompson, W. R. (1947). Use of moving averages and interpolation to estimate median-effective doses. I. Fundamental formulas, estimation of error, and relation to other methods. *Bacteriol. Rev.* **11**, 115–45.
Tiver, P. J. (1980). Distribution and abundance of the hairy-nosed wombat *Lasiorhinus latifrons* and their impact on the rural industry in the Fowler's Bay area. Natl Parks Wildl. Serv. South Aust. Unpubl. Rep.
Tomlinson, A. R., and **Gooding, C. D.** (1971). Wildlife hazards from 1080 baiting. *J. Agric. West. Aust.* **12**, 268–70.
Tucker, R. K., and **Crabtree, D. G.** (1970). Handbook of Toxicity of Pesticides to Wildlife. U.S. Fish Wildl. Serv. Res. Publ. No. 84.
U.S. Public Health Service (1949). Rat-borne disease: Prevention and control. (Atlanta, Georgia.) [Not seen; cited by McGirr and Papworth 1955.]
Ward, J. C. (1946). Rodent control with 1080, Antu, and other war-developed toxic agents. *Am. J. Public Health* **36**, 1427–31.

Ward, J. C., and **Spencer, D. A.** (1947). Notes on the pharmacology of sodium fluoroacetate—compound 1080. *J. Am. Pharmacol. Assoc.* **36**, 59–62.
Weil, C. S. (1952). Tables for convenient calculation of median-effective dose (LD50 or ED50) and instructions in their use. *Biometrics* **8**, 249–63.
Wells, R. T. (1973). Physiology and behavioural adaptations of the hairy-nosed wombat, *Lasiorhinus latifrons* (Owen) to its arid environment. Ph.D. Thesis, University of Adelaide.
Wheeler, S. H., and **Hart, D. S.** (1979). The toxicity of sodium monofluoroacetate to wild rabbits, *Oryctolagus cuniculus* (L.) from three sites in Western Australia. *Aust. Wildl. Res.* **6**, 57–62.
Wodzicki, K., and **Taylor, R. H.** (1957). An experiment in rabbit control; Kourarau poison trials. *N.Z. J. Sci. Tech. Ser. B* **38**, 389–99.

Manuscript received 25 November 1981; accepted 23 February 1982