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

# The Sensitivity of Australian Animals to 1080 Poison II. Marsupial and Eutherian Carnivores

*J. C. McIlroy*

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

*Abstract*

Eutherian carnivores tested were more sensitive to 1080 poison than marsupial carnivores. Both groups of animals displayed similar symptoms but there was wide intra- and interspecific variation in the time to onset, the sequence of occurrence and duration of the symptoms. The risks that individual carnivores face from primary and secondary poisoning have been assessed. Theoretically, dingoes probably face the greatest risk amongst the species studied, followed by members of the smaller dasyurids and feral cats. Members of the larger dasyurids and long-nosed bandicoots probably face the least risk. Factors likely to influence the actual effect of 1080-poisoning campaigns on carnivore populations are discussed.

## Introduction

Sodium fluoroacetate, commonly known as 1080 poison, is widely used for vertebrate pest control in Australia, particularly against rabbits *Oryctolagus cuniculus*, dingoes *Canis familiaris dingo*, pigs *Sus scrofa*, and, in Tasmania, brush-tailed possums *Trichosurus vulpecula*, pademelons *Thylogale billardierii*, and Bennett's wallabies *Macropus rufogriseus*. The effect that these poisoning programs are having on non-target or native animal populations is not known, despite occasional reports of individuals of these species being found dead or 'vanishing' from areas in which 1080 has been used.

Since 1972 the Division of Wildlife Research, CSIRO, as part of a comprehensive study of the effects of poisoning programs on non-target animals, has been determining the sensitivity of many species to 1080. Although by itself this obviously cannot reveal exactly what may happen to free-living populations, it can provide the first indication of the relative vulnerability of members of a species to 1080 poisoning campaigns. This paper reports studies on the sensitivity to 1080 poison of marsupial and eutherian carnivores.

In Australia there are at least 38 species of dasyurids (Dasyuridae), nine species of bandicoots (Peramelidae), two species of canids (Canidae) and one species of felid (Felidae) (Kirsch and Calaby 1977). Many occur in areas where 1080 is used for vertebrate pest control and thus may possibly be at risk. To test the susceptibility of representatives of these families I selected the feral cat *Felis catus*, dingo *Canis familiaris dingo*, long-nosed bandicoot *Perameles nasuta* and nine of the

**Table 1.** LD$_{50}$ **values (including 95% confidence limits) and experimental details for marsupial and eutherian carnivores**

| Family and species | Sex | Age | No. per dose level | Mean wt (kg) | Ambient temp. (°C) | Source | LD$_{50}$ and 95% CL (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|
| Marsupialia | | | | | | | |
| Dasyuridae | | | | | | | |
| Fat-tailed dunnart, *Sminthopsis crassicaudata* | M | Ad. | 3 | 0·013 | 26–29 | Fowlers Gap, N.S.W. | 2·06 (1·58–2·69) |
| Stripe-faced dunnart, *Sminthopsis macroura* | M&F | Ad. | 3 | 0·022 | 22 | Lab. colony, S.A. | 0·95 (0·57–1·60) |
| Brown antechinus, *Antechinus stuartii* | M | Ad. | 5 | 0·036 | 22 | Brindabella Mts, N.S.W. | 1·85 (1·43–2·40) |
| Dusky antechinus, *Antechinus swainsonii* | M | Ad. | 5 | 0·062 | 22 | Schlink Pass, N.S.W. | 3·21 (2·43–4·23) |
| Kowari, *Dasyuroides byrnei* | M | Ad. | 1[A] | 0·135 | 22 | Lab. colony, S.A. | *c.* 2·85 |
| Northern native cat, *Dasyurus hallucatus* | M&F | Ad. | 3 | 0·75 | 22 | Nourlangie, N.T. | 5·66 (3·91–8·20) |
| Eastern native cat, *Dasyurus viverrinus* | M | Ad. | 5 | 1·45 | 19–23 | SE. Tasmania | 3·73 (3·18–4·38) |
| Tiger cat, *Dasyurus maculatus* | M&F | Ad. | 3 | 2·79 | 13–22 | SE. Tasmania | 1·85 (1·28–2·68) |
| Tasmanian devil, *Sarcophilus harrisii* | M | Ad. | 5 | 4·67 | 19–23 | SE. Tasmania | 4·24 (2·76–6·60) |
| Peramelidae | | | | | | | |
| Long-nosed bandicoot, *Perameles nasuta* | M | Ad. | 3 | 1·19 | 17–30 | Mossy Point, N.S.W. | 7·70 (5·28–11·23) |
| Carnivora | | | | | | | |
| Felidae | | | | | | | |
| Cat, *Felis catus* | M&F | Imm. | 3 | 1·00 | 22 | Canberra, A.C.T. | 0·40 (0·31–0·52) |
| Canidae | | | | | | | |
| Dingo, *Canis familiaris dingo* | M&F | Ad. | 3 | 16·23 | – | Lab. colony, A.C.T. | 0·11 (0·09–0·15) |

[A]Pilot dose only.

dasyurids, ranging in size from the small fat-tailed dunnart *Sminthopsis crassicaudata*, up to the dog-sized Tasmanian devil *Sarcophilus harrisii*, and measured their sensitivity to 1080. The species tested are listed in Table 1.

Admittedly, the smaller mouse-like dasyurids are mainly insectivorous and the bandicoot omnivorous, but all the species selected are known to eat meat given the opportunity, including in some instances dingo baits (unpublished data), and dead birds and mammals. Individuals of these carnivore species, therefore, would seem potentially at risk from 1080 poisoning programs, either primarily through eating meat baits intended for dingoes or, secondarily, through eating birds, rats, rabbits, macropods or other animals poisoned by other baits, such as carrots or oats, during control campaigns against herbivores.

## Methods

The basic experimental procedure used to determine $\mathrm{LD}_{50}$s (median lethal doses – a measure of the sensitivity of each species to 1080), has previously been described (McIlroy 1981).

All animals were acclimatized to captivity for at least 2 weeks before dosing, either in small box cages (38 by 30 by 15 cm) with attached nest boxes (10 by 10 cm) and perforated perspex fronts (e.g. dunnarts and antechinus), small weldmesh cages of various sizes (e.g. native cats and Tasmanian devils) or weldmesh pens (e.g. dingoes). The smaller dasyurids were provided with exercise wheels. Each species was given a variety of food according to its preference, ranging from mealworms, eggs, high-protein baby food, tinned and dry dog food, young mice, rats and guinea pigs, to finely cut meat and bones. Vitamins and calcium were regularly provided along with water *ad libitum*. The eastern native cats, Tasmanian devils and dingoes were fasted overnight before dosing but this practice was discontinued with the remaining species (see McIlroy 1981). The tiger cats, dingoes and bandicoots were kept outdoors and hence experienced some variability in environmental conditions, particularly temperature (Table 1). The remaining species were kept inside controlled-environment buildings. Indoor environmental temperatures fluctuated only slightly around 22°C. Relative humidities in both situations ranged between 27 and 60%, and daylight (natural and/or artificial) between 9·5 and 14·5 h $\mathrm{day}^{-1}$.

Groups of three or five animals, depending upon numbers available (Table 1), were orally dosed with 1080, with a ratio of 1·26 between dose levels. The range in body weights within each species varied from $\pm 11$ to 67% of the mean shown in Table 1, and the weights of animals within each dose group, from $\pm 1$ to 19% of the mean. Preferably adult males were used, but again choice depended on the availability of specimens. During dosing, animals were held either in the hand or in a cloth or hessian bag, wire cone or weldmesh crush. Dosing via a syringe with blunt-ended needle or oesophageal catheter was facilitated by use of a wooden or metal mouth gag or incisor holders. Dingoes were given 1080 in gelatin capsules inside small pieces of meat. All 1080 used was AR sodium fluoroacetate (*c.* 100% purity).

Most individuals were dosed only once. Because of a shortage of specimens, a few northern native cats, bandicoots, feral cats and dingoes from trials in which no animals had died received second, higher doses, but only after an interval of at least 8 days. Each individual appeared to be in good condition at the time of dosing. Records were kept of all symptoms and deaths during the next 7 days after dosing.

$\mathrm{LD}_{50}$s, including 95% confidence limits, were calculated by the method of Thompson (1947) and Weil (1952) for 11 of the species. They were not obtainable for the kowari because of inadequate numbers of sample animals; pilot dose data (McIlroy 1981), therefore, have been used to provide an estimate of the $\mathrm{LD}_{50}$ for this species.

Some data were collected, before each trial began, on the amount of dingo bait or carrion some of the species can eat within 24 h. Sufficient quantities of meat were fed to each animal per day and the residue collected, weighed, corrected for moisture loss and the means, ranges and individual and daily variations calculated.

Throughout the study every effort was made to treat the animals as humanely as possible under conditions similar to those recommended in a code of practice for the care and use of animals in research in Australia (National Health and Medical Research Council and CSIRO 1979).

## Results

### *Symptoms*

There is no constancy in the pattern of symptoms of poisoning in marsupial and eutherian carnivores; there is as much variation in response between individuals as between species.

In all cases where symptoms were shown there is initially a period of variable duration (0·1–23 h, see Table 2) in which the animals appear normal. Often, the greater the amount of 1080 ingested, the shorter this latent period becomes; an example is given in Fig. 1.

**Table 2. Length of latent periods and time until death or first indications of recovery of all individuals exhibiting symptoms of 1080 poisoning**

*N*, number of latent periods observed

| Species | *N* | Latent period (h) | Time until death (h) | Recovery time (h) |
|---|---|---|---|---|
| Fat-tailed dunnart | 8 | 1·5–5·7 | 2·8–46·5 | <24 |
| Stripe-faced dunnart | 7 | 1·7–4·0 | 3·4–13·1 | 5·5 |
| Brown antechinus | 57 | 0·6–23·0 | 2·1–146·6 | 5·8–<60 |
| Dusky antechinus | 30 | 0·7–3·8 | 1·6–62·1 | 3·3–<24 |
| Kowari | 3 | 0·1–1·0 | 6·4–13·5 | <24 |
| Northern native cat | 5 | 3·0–361·9 | 10·9–450·7 | – |
| Eastern native cat | 26 | 0·2–2·4 | <2·0–63·2 | 2·0–<6·2 |
| Tiger cat | 10 | 0·4–3·2 | 1·5–11·8 | 6–<60 |
| Tasmanian devil | 26 | 0·3–1·6 | 2·6–<22·3 | 3·1–26·0 |
| Long-nosed bandicoot | 7 | 1·7–6·4 | 3·9–56·3 | >25·8–<42·3 |
| Cat | 20 | 1·0–5·6 | 20·7–21·0 | <24–28 |
| Dingo | 9 | 4·8–14·6 | 5·3–10·8 | 0·4–19·8 |

After the latent period, symptoms may appear in one of three different ways:

(1) Some animals, particularly the smaller dasyurids, suddenly begin to look 'unwell' or depressed and sit or lie quietly, breathing slowly and occasionally trembling. Some of them recover, while the others either become increasingly sensitive to stimuli (hyperexcited), or suddenly experience convulsions.

(2) More commonly, affected animals suddenly become hyperexcited, with rapid breathing, bouts of trembling and sometimes periodic circling within their cages. Again, some animals may then recover while others begin to vomit, convulse, or both.

(3) With some animals, particularly the eastern native and tiger cats and Tasmanian devil, the first symptom is the sudden onset of vomiting. The time before this did not depend on the amount of 1080 ingested. Vomiting follows even when the 1080 is given via intraperitoneal injection. Thereafter, the animals may either still recover or instead become hyperexcited or experience convulsions.

Although vomiting has probably evolved as a natural protective mechanism, especially for carrion eaters, it does not necessarily ensure their survival from 1080 poisoning. For example, although 90% of the eastern native cats and 95% of the devils vomited within 13–49 min (mean 26 min) and 18–82 min (mean 55 min) of ingesting 1080, respectively, this was still sufficient time for many of them to absorb a lethal dose. There is obviously considerable individual variability in absorption rates and sensitivity; some of the animals slowest to vomit survived but those that vomited after 13 and 18 min died.

Convulsions were usually preceded by a variety of symptoms, depending on both the individual and the species, and were sometimes triggered by disturbance, such as the opening of a door, sudden movement of an observer, or convulsion by a neighbourng animal. Briefly, and in rough order, these symptoms include: restlessness; increasing hyperexcitability or response to stimuli; bouts of trembling; rapid, shallow breathing; incontinence or diarrhoea; excessive salivation; twitching of the facial muscles; nystagmus (involuntary eyeball movement exposing the whites) or bulging eyes with large (dilated) pupils and rapid blinking (plus, in domestic cats, discharge of mucus from the eyes); slight lack of coordination or balance; abrupt bouts of vocalization; and, finally, sudden bursts of violent activity

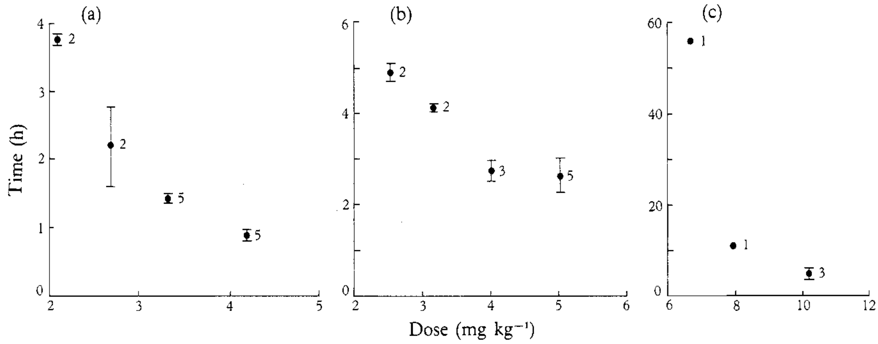


**Fig. 1.** Inverse relationships between the amount of 1080 ingested and: (*a*) time until onset of symptoms in the dusky antechinus (five animals dosed in each group); (*b*) time until first convulsions in eastern native cats (five in each group); (*c*) time until death in long-nosed bandicoots (three in each group). Means and standard errors of times are shown. Numerals beside means indicate the number of animals affected.

such as racing around the cage, or biting at the cage mesh or other objects. All affected animals then fall to the ground in a tetanic seizure, with hind limbs or all four limbs and sometimes the tail extended rigidly from their arched bodies. At other times the front feet are clasped together, clenched or used to scratch frantically at the cage walls. This tonic phase is then followed by a clonic phase in which the animals lie and kick or 'paddle' with the front legs and sometimes squeal, crawl around or bite at objects. During this phase the tongue and penis may be extruded, the eyes rolled back so that only the whites show and the teeth ground together. Breathing is rapid but laboured, with some animals partly choking on their saliva. Finally, such individuals begin to relax, breathing more slowly and shallowly and lying quietly with the hind legs still extended but apparently semiparalysed (paresis).

From then on individuals either: (1) gradually recover; (2) die shortly afterwards; (3) after a short or long delay (e.g. 5 min or 3–4 h) experience another one or two series of convulsions and then die shortly afterwards or eventually recover; (4) remain lying quietly, scarcely breathing or moving, until death up to 6 days later.

There were sometimes inverse relationships between the amount of 1080 ingested and the time until the onset of convulsions or death; examples are given in Fig. 1. The ranges in times until death or signs of recovery (i.e. animals no longer showing any obvious symptoms although they might remain weak for another 2 or more days) for affected individuals of each species are shown in Table 2. Time until death ranged from 1·5 to 146·6 h (*c.* 6 days) and until signs of recovery from 2 to 60 h.

The northern native cats are not covered by these ranges. Briefly, none of the three animals per dose level showed any symptoms after the lowest dose but one showed symptoms 3 h after the next dose. It died 8 h later. Two out of three animals in each group showed symptoms after the next two higher doses but, inexplicably, not until 294–362 h (*c.* 12–15 days) later. During the intervening period the animals appeared normal except that their daily food consumption was much lower than previously. The first symptoms to appear were sudden restlessness, frantic circling of the cage, biting at objects and then the characteristic series of convulsions. Finally, the affected individuals remained lying quietly, breathing slowly and shallowly and becoming weaker and colder until they died. One individual did recover briefly and fed normally for 2 days but then died.

**Table 3. $LD_{50}$s of 1080 for eutherian carnivores**

Values for dog and kit fox recalculated on a 100% 1080 basis to allow comparison with those from this study; purity of 1080 used for other species not known

| Species | $LD_{50} \pm 95\%$ CL (mg kg$^{-1}$) | Reference |
|---|---|---|
| Mustelidae | | |
| Marten, *Martes americana* | *c.* 1·0 | Robinson 1953 |
| Ferret, *Mustela putorius* | *c.* 1·0–1·4 | Marshall 1963; Tucker and Crabtree 1970 |
| Badger, *Taxidea taxus* | *c.* 1·0–1·5 | Ward and Spencer 1947 |
| Felidae | | |
| Cat, *Felis catus* | 0·40 (0·31–0·52) | This study |
| Bobcat, *Lynx rufus* | <0·66 | Ward and Spencer 1947 |
| Canidae | | |
| Kit fox, *Vulpes macrotis* | 0·20 (0·14–0·31) | Schitoskey 1975 |
| Grey fox, *Urocyon cinereoargenteus* | <0·3 | Ward and Spencer 1947 |
| Coyote, *Canis latrans* | 0·10 | Ward and Spencer 1947 |
| Dog, *Canis familiaris* | 0·06 | Tourtellotte and Coon 1951 |
| Dingo, *Canis familiaris dingo* | 0·11 (0·09–0·15) | This study |

More clinical descriptions of fluoroacetate poisoning in cats and dogs, *Canis familiaris*, are provided by Chenoweth and Gilman (1946), Foss (1948) and Staples (1964).

### *$LD_{50}$s*

The marsupial carnivores tested were clearly far more tolerant of 1080 poison than eutherian carnivores which have been tested (Tables 1, 3). The eastern native cat, for example, is at least three times more tolerant than an eutherian counterpart, the marten *Martes americana*, and nine times more tolerant than the domestic cat, while the Tasmanian devil, Australia's largest living marsupial carnivore, is nearly three times more tolerant than the slightly larger American badger *Taxidea taxus*, and over 38 times more tolerant than dogs or the dingo. Despite the crudeness of the data available, the Canidae and Felidae appear to be more sensitive to 1080 ($<0 \cdot 7$ mg $kg^{-1}$) than the Mustelidae (*c.* $1 \cdot 0$–$1 \cdot 5$ mg $kg^{-1}$).

**Table 4. Amount of meat consumed per day by marsupial and eutherian carnivores**

Sources of data: (1) Morton 1980; (2) present study; (3) Nagy *et al.* 1978; (4) Woolley 1971; (5) Green and Eberhard 1979; (6) B. Green, personal communication 1979; (7) Lyne 1971; (8) Howard 1957; (9) B. M. Fitzgerald, personal communication 1979; (10) G. Richards, personal communication 1979; (10) Green and Catling 1977

| Species | No. of individuals and days | Mean daily amount per animal (g) | Mean daily amount per kg body wt (g) | Max. daily amount per animal (g) | Change in body wt (%) |
|---|---|---|---|---|---|
| Fat-tailed dunnart[A] (1) | 7:7 | 5·0 | 337 | 6·3 | +1 |
| Stripe-faced dunnart (2) | – | *c.*6·0 | *c.*273 | – | 0 |
| Brown antechinus (2) | 12:10 | 6·8 | 193 | 25·8 | +6 |
| Brown antechinus[A] (3) | 10:8 | 8·3 | 368 | – | 0 |
| Brown antechinus[AB] (3) | – | 15·4 | 598 | – | 0 |
| Dusky antechinus (2) | 10:7 | 16·4 | 287 | 26·6 | +7 |
| Kowari (4) | – | 20·0 | *c.*148 | – | – |
| Northern native cat (2) | 3:3 | 28·3 | 43 | 38·0 | −11 |
| Northern native cat (2) | 3:10 | 97·8 | 190 | 191 | +20 |
| Eastern native cat (2) | 10:10 | 135·6 | 85 | 319 | +0 |
| Eastern native cat (5) | 4:10 | 186·5 | 138 | – | +13 |
| Tiger cat (6) | 5:7 | 134·0 | 71 | 202 | 0 |
| Tasmanian devil (2) | 10:10 | 218·3 | 47 | 480 | 0 |
| Tasmanian devil (5) | 6:10 | 305·8 | 80 | – | +3 |
| Long-nosed bandicoot (7) | – | *c.*100–200 | – | – | – |
| Cat (8) | 1:15 | 180·0 | 95 | 413 | +14 |
| Cat (9) | 12:15 | 158·2 | 42 | 308 | +1 |
| Cat[B] (10) | 10:12–14 | 273·6 | 114 | – | +4 |
| Dingo (6) | 6:10 | 364–410 | 26–29 | 846 | −3 |
| Dingo[B] (11) | 20:6-30 | *c.*1000 | *c.*70 | – | – |

[A]Values refer to arthropods. [B]Free-ranging animals.

### *Food Consumption*

The amount of meat consumed per day by marsupial and eutherian carnivores is shown in Table 4. The data include the results of my trials on six captive species of dasyurids and those from other studies of captive and free-ranging Australian carnivores. The nine dasyurids can eat a daily mean of 5–306 g meat per animal in captivity, depending on the species involved, or up to 60% of their body weight. Captive long-nosed bandicoots can eat approximately 100–200 g of meat per animal daily, and free-ranging feral cats and dingoes up to 274 and 1000 g per animal daily, respectively.

My trials on six species of dasyurids showed that there is considerable variation in daily food consumption (g $kg^{-1}$ body weight), both between the amounts different individuals of the same species eat during any one day and the amounts one individual eats from day to day. Cowan *et al.* (1974) found similar variation in the daily food consumption of dusky antechinus. Some of my individuals, for example, ate up to 2·5 times more food per kilogram body weight during the trials than other members of their species, but their daily consumption varied from quite large amounts to only very small amounts. Generally, both species of antechinus and the eastern native cats alternated between above-average daily consumption for 1–3 days and below-average consumption for the next 1–2 days, and the mean intake of the Tasmanian devils progressively rose and fell every 3–4 days. The mean daily intake of three northern native cats remained basically steady over 10 days apart from above-average consumption (i.e. 267 g $kg^{-1}$) during the first day and below-average consumption (i.e. 132 and 162 g $kg^{-1}$) on the seventh and eighth days, respectively.

The three northern native cats gained an average of 20% in weight over the 10 days while three others, which ate a daily mean of only 43 g $kg^{-1}$ during the three days before they were dosed with 1080, lost an average of 11% in weight during this period. Nelson and Smith (1971) commented on this characteristic of northern native cats (and eastern native cats) to gain and lose weight quickly.

The mean daily consumption of the three other northern native cats dropped from 43 to 19 g $kg^{-1}$ after they were dosed with 7·56 mg $kg^{-1}$ of 1080. This is a highly significant decrease ($P<0\cdot01$), but its correlation with the ingestion of 1080 must remain doubtful given the inexplicably long period before the cats showed symptoms of poisoning and their variability in daily food consumption. Three males ate even significantly less than the females (i.e. 8·6 g $kg^{-1}$ per day, $P<0\cdot01$) after being dosed with 6·0 mg $kg^{-1}$ of 1080, but their daily consumption before being dosed is not available for comparison.

For practical purposes I wanted to extrapolate the food consumption in Table 4 to estimate how much bait or poisoned animals each free-living animal might eat in one feeding session. Although the data refer to food or meat eaten per 24 h, the food is probably consumed within a much shorter period. Captive dusky antechinus, for example, ate all their food within 6–8 h, with intervening rest periods (Cowan *et al.* 1974). Information on the food consumption and energy requirements of free-living animals is still generally not readily available and further studies are needed. The studies of G. Richards (personal communication, 1979), B. Green (personal communication, 1979), Green and Catling (1977) and Nagy *et al.* (1978), however, indicate that the daily food consumption of free-ranging carnivores is roughly twice that of captive individuals. The data on the daily consumption of meat by carnivores in Table 4, therefore, can provide a basis for evaluating primary poisoning risks to each species.

## Discussion

### *Symptoms*

Biochemically, it is not 1080 that is toxic but one of its metabolites, fluorocitric acid. This inhibits the enzymes responsible for catalysing citrate and succinate metabolism and so blocks the Krebs cycle. As a consequence, energy reserves are depleted and cellular functions impaired. Eventually the breakdown in intracellular processes results in the appearance of gross disorders of organs or organ systems. Generally, herbivores tend to exhibit cardiac effects, carnivores develop disorders of the central nervous system, and omnivores disorders of both systems (Chenoweth 1949; Pattison 1959).

In the dog, the onset of the effect on the central nervous system is indicated by the sudden appearance of hyperexcitability and abrupt bouts of running and barking. Death is typically the result of the effects of repeated and prolonged convulsions on the respiratory centre (Chenoweth 1949). The same occurs in cats, although occasionally death may be due to ventricular fibrillation (Chenoweth and Gilman 1946; Staples 1964). Other eutherian carnivores exhibit similar symptoms: violent epileptiform convulsions in the coyote *Canis latrans*, and the badger, and progressive depression in the bobcat *Lynx rufus* (Ward and Spencer 1947); respiratory, central nervous system and muscle effects in the ferret *Mustela putorius* (Tucker and Crabtree 1970). In field situations coyotes have been observed to wander 0·4–0·8 km from poison stations before beginning to vomit. After this they either ran wildly for a few hundred metres and suddenly died, or took shelter and lapsed into a coma until death (Spencer 1945).

*$LD_{50}$s*

There is clearly a pronounced difference between the relative sensitivities of the eutherian and marsupial carnivores tested to 1080. There seems to be no obvious physiological basis for this difference apart from the general inference that it is related to differences in metabolism in some way, such as differences in metabolic processes or rates. Mead *et al.* (1979), for example, suggest that the wide variation in response amongst different species may be associated with differences in the inhibition of citrate transport through mitochondrial membranes. It is also now accepted that there are different levels of energy metabolism in different phylogenetic groups of animals, and that the basal metabolic rate of dasyurids and bandicoots is considerably lower than that of equivalent-sized eutherians (e.g. 32% lower for dasyurids; MacMillen and Nelson 1969). This reduced metabolic rate of the marsupial carnivores might in some way confer on them a higher tolerance, compared with their eutherian counterparts, to a metabolically interfering poison such as 1080.

The differences in sensitivity between members of the same family may reflect either inherent specific or sample individual variations in metabolic rates, and variations arising from different levels of activity or experimental conditions, particularly ambient temperatures, during the trials. For instance, even between closely related species, differences in the level of metabolism can be related to differences in behaviour in various habitats (Kinnear and Shield 1975). It is also known that many of the dasyurids, such as the western native cat *Dasyurus geoffroii*, vary considerably in individual basal metabolic rate, that of some being close to those of eutherians of equivalent size and that of others lower than those of other marsupials of equivalent size (MacMillen and Nelson 1969; Arnold 1976). At least some of the dasyurids (e.g. the fat-tailed dunnart and brown antechinus) also vary their metabolic demands in response to ambient temperatures or other environmental conditions (Arnold and Shield 1970; Kennedy and Macfarlane 1971; Kinnear and Shield 1975; Wallis 1976).

A. J. Oliver (personal communication, 1979) has recently demonstrated that different ambient temperatures cause from two- to fivefold differences in the susceptibility of mice and guinea pigs to 1080. Both species are more susceptible at both low and high ambient temperatures than they are at medium temperatures. If similar responses occur amongst other, larger homeotherms, this might explain the relatively low $LD_{50}$ for the tiger cat compared to those for the other native cats. Table 1 shows that most trials were carried out at about 22°C (many in a controlled-environment room); the only real exceptions were for the tiger cats, where some trials were carried out at 13°C. The possibility exists, therefore, that if these trials had been carried out at 22°C, the $LD_{50}$ would have been slightly higher than 1·85. Ambient temperatures obviously vary considerably between different field poisoning situations, both geographically and diurnally, so a $LD_{50}$ obtained at 22°C, or the dose that will kill 50% of a population experiencing this ambient temperature, must be regarded as only a general value. Greater population mortality may be expected at much lower or higher environmental temperatures.

**Table 5. Differences between marsupial carnivores, the cat and the dingo in tolerance, body weight and the amount of 1080 necessary for a $LD_{50}$**

Tolerance ratio, number of times non-target species is more tolerant than dingo. Weight ratio, number of times dingo is heavier than non-target species; weights from Table 1, except cat (4·2 kg, see text). The amount of 1080 required is based on mean weights of species from Table 1, except cat (4·2 kg)

| Species | Tolerance ratio | Weight ratio | Amount of 1080 for $LD_{50}$ (mg) | Percentage of that required for dingo |
|---|---|---|---|---|
| Fat-tailed dunnart | 18·7 | 1248·5 | 0·03 | 2 |
| Stripe-faced dunnart | 8·6 | 737·7 | 0·02 | 1 |
| Brown antechinus | 16·8 | 450·8 | 0·07 | 4 |
| Dusky antechinus | 29·2 | 261·8 | 0·20 | 11 |
| Kowari | 25·9 | 120·2 | 0·38 | 21 |
| Northern native cat | 51·5 | 22·2 | 4·13 | 231 |
| Eastern native cat | 33·9 | 11·2 | 5·41 | 302 |
| Tiger cat | 16·8 | 5·8 | 5·16 | 288 |
| Tasmanian devil | 38·5 | 3·5 | 19·80 | 1106 |
| Long-nosed bandicoot | 70·0 | 13·6 | 9·16 | 512 |
| Cat | 3·6 | 3·9 | 1·68 | 94 |
| Dingo | 1·0 | 1·0 | 1·79 | 100 |

*Primary Poisoning*

Carnivores in Australia face a risk of primary poisoning from 1080 if they consume meat baits intended for dingoes during dingo control operations. Initially, the marsupial carnivores would seem to have less chance of being affected than the dingo, because of their higher tolerance to 1080, but this is negated for some species by their smaller size. Thus, although the brown antechinus is nearly 17 times more tolerant than the dingo, it requires, because of its small size (1/450th of that of the dingo), only 0·07 mg of 1080 for a $LD_{50}$, compared to 1·79 mg for the dingo. Only the native cats, Tasmanian devil and bandicoot have a greater tolerance ratio than weight ratio (Table 5), and because the dingo and devil do not occur in the same area, comparison between their susceptibilities to poison baits laid for dingoes is of only theoretical interest.

The feral cat is in much the same position as the dingo; what it gains by being slightly more tolerant, it loses through being smaller. The mean weight of cats used in this comparison is 4·2 kg (the mean weight of 46 sexually mature males collected by CSIRO personnel from central Australia and the Eastern Highlands; G. Richards and H. Wakefield, personal communication, 1979). This weight has been used in preference to that of the immature animals for which the $LD_{50}$ was obtained (Table 1), to allow a comparison between adults of all species.

One could argue that size is not important, because smaller animals will naturally eat less than the dingo (e.g. 1–44% of the dingoes' intake, see Table 4), and thus should ingest far less 1080. However, the amounts they do ingest represent a much higher proportion of their body weight compared with what the dingo ingests. So small size plus relatively large appetites combine to place some of the marsupial carnivores at risk from primary poisoning.

The size of baits and concentrations of 1080 used against dingoes in different regions of Australia vary considerably. Sizes range from 6-g manufactured baits to 230–250-g (½-lb) chunks of muscle tissue from horses, cattle or kangaroos. Concentrations of commercial 1080 (i.e. 90% purity) in baits have ranged as high as 1·2 mg $g^{-1}$ of bait and amounts of 1080 in a single bait to 50·4 mg. Generally, nowadays, the range in concentration is 0·015–0·11 mg $g^{-1}$ of bait, equivalent to 3·5–8·5 mg per bait.

**Table 6. Amount of 1080-poisoned bait that carnivores need to eat in order to ingest a $LD_{100}$, and amount that free-living carnivores might eat**

Bait assumed to be dingo bait containing a 1080 concentration of 0·014 mg $g^{-1}$ (see text). Mean weights of species from Table 1, except cat (4·2 kg). $LD_{100}$ taken as twice $LD_{50}$. Values for the amounts of bait eaten are from free-living animals, or twice the amount eaten per day by captive animals (Table 4), measured or recalculated on the basis of zero change in body weight during feeding trial

| Species | Amount of bait containing c. $LD_{100}$ (g) | Probable amount of bait eaten per day in wild (g) | Percentage of $LD_{100}$ eaten |
|---|---|---|---|
| Fat-tailed dunnart | 3·8 | 9·9 | 261 |
| Stripe-faced dunnart | 3·0 | c. 12·0 | 400 |
| Brown antechinus | 9·5 | 15·4 | 162 |
| Dusky antechinus | 28·4 | 30·5 | 107 |
| Kowari | 55·0 | 40·0 | 73 |
| Northern native cat | 590·3 | 106·0 | 18 |
| Eastern native cat | 772·6 | 271·2 | 35 |
| Tiger cat | 737·1 | 268·0 | 36 |
| Long-nosed bandicoot | 1309·0 | 200–400 | 15–31 |
| Cat | 240·0 | 273·6 | 114 |
| Dingo | 255·0 | c. 1000 | 392 |

Table 6 shows that in a field situation where a concentration of 0·015 mg 1080 $g^{-1}$ of bait (i.e. 0·014 mg of 100% 1080) is used in 230-g baits, each fat-tailed and stripe-faced dunnart, brown and dusky antechinus, feral cat and dingo could eat enough bait to kill it. In similar circumstances the mortality amongst kowari, tiger cats and eastern native cats might be approximately 35–73%. The northern native cats and bandicoots seem to be less at risk. The overall situation would obviously be far worse if each bait were to contain a much higher concentration of 1080. Admittedly, the data on the amount of bait eaten by free-living animals are only approximate and for ease of analysis the 1080 was assumed to be evenly distributed throughout each bait, whereas there is evidence (T. Korn, personal communication, 1979) that this is not so, but in many cases the estimated amounts eaten are smaller or not greatly different from the maximum amounts captive animals ate in a day (Table 4). Captive female kowari, for example, which are suckling young, can consume up to 70 g of meat per day (Woolley 1971), while some feral cats can eat up to 500 g of rabbit in one feeding session (Gibb *et al.* 1978).

In reality many factors are involved in determining whether an individual or what proportion of a population may be killed by a poisoning campaign. The preceding theoretical analysis involved mean body weights of only small samples of animals, $\text{LD}_{50}$s obtained under specific experimental conditions, and a particular concentration of 1080 in each bait plus the assumptions about bait intake by free-living species. All are likely to vary in different field situations, altering the risk each individual carnivore faces. The distribution and density of baits in relation to the distribution and density of the target and non-target species, the range in size of the baits, and the length of time the poison in the baits remain unleached by rainfall or available to each species, will also obviously affect the potential impact on the carnivores. For example, up to 90–100% of dingo baits can be removed from an area within 24 h, particularly by foxes *Vulpes vulpes*, pied currawongs *Strepera graculina*, and ravens *Corvus* spp. (unpublished data). Even when there is a high density of baits, not every member of the population will necessarily find or eat a lethal quantity. Some brown antechinus, for instance, do not eat dingo baits, even when they are present within their home ranges, others eat a non-lethal amount and yet others eat a lethal amount (unpublished data).

The data on sensitivities, however, do provide fundamental information for the planning of dingo-poisoning operations. For example, if the aim is to obtain maximum control with minimum dose it would be best to plan the baiting on the basis of a $\text{LD}_{100}$ based on twice the upper confidence limit of the $\text{LD}_{50}$ and the weight of the heaviest specimen reported. In contrast, to assess the hazard to a non-target species, calculations might be best based on the lower confidence limit of the $\text{LD}_{50}$, or some lower figure, and either the mean weight or much lower body weights of, for instance, immature animals.

The dingoes I tested represent the general hybrid ‘wild dog’ of eastern Australia. The heaviest such individual caught by CSIRO personnel in the Eastern Highlands weighed 25 kg (P. Catling, personal communication, 1979). Thus, if the $\text{LD}_{100}$ is assumed to be approximately twice the upper confidence limit of the $\text{LD}_{50}$ (i.e. $0 \cdot 3$ mg $\text{kg}^{-1}$), it would be necessary to get $7 \cdot 5$ mg of 1080 into a dog of this size to kill it. Similar calculations for tiger cats, using twice the lower confidence limit of the $\text{LD}_{50}$ (i.e. $2 \cdot 56$ mg $\text{kg}^{-1}$) and taking the mean body weight as $2 \cdot 8$ kg, indicate that $7 \cdot 17$ mg of 1080 is a lethal dose for them. Thus in a field situation where 230-g baits containing $3 \cdot 22$ mg of 1080 are used (i.e. $0 \cdot 014$ mg $\text{g}^{-1}$ bait), a 25-kg dog would have to ingest $2 \cdot 3$ baits to receive a lethal dose, an average-sized dingo (e.g. 16 kg) $1 \cdot 5$ baits, and an average-sized tiger cat $2 \cdot 2$ baits. Free-living dingoes are known to eat up to four baits of this size but tiger cats would probably eat only one bait (Table 6). This type of poison baiting, therefore, might cause up to 45% mortality in tiger cats and 100% mortality in dingoes, provided each dingo found and ate four baits. Increasing the concentration of poison in each bait will clearly reduce the amount of bait each dingo needs to find the ingest to receive a lethal dose, but, equally, will increase the risk for non-target species. For example, although each dingo would have to eat only one 230-g bait containing $7 \cdot 5$ mg of 1080 for all the population to die, similar consumption by each tiger cat would also result in 100% mortality. As Table 6 indicates, it is clearly possible for a tiger cat to eat a 230-g bait. From the viewpoint of trying to safeguard tiger cats, therefore, it is obviously necessary to keep 1080 concentration in baits as low as possible.

*Secondary Poisoning*

Carnivores may also face a risk from secondary poisoning, either by eating animals that have been poisoned by meat baits during campaigns against carnivores, or by eating animals such as birds, rats, rabbits or macropods that have been poisoned by eating baits of plant origin during campaigns against herbivores.

At present there are not enough data available to form a basis for a theoretical assessment of secondary poisoning risk. As mentioned earlier, 1080 itself is non-toxic and its lethal action is due to its conversion to fluorocitric acid. The precise mode of action of fluorocitric acid, though, is still poorly known (Kirsten *et al.* 1978). Thus it is still not clear whether the fluorocitrate in the tissues of poisoned animals is also toxic to carnivores eating those tissues, or whether it is only the unabsorbed 1080 in the stomach contents and 1080 present in the tissues that subsequently leads to secondary poisoning in carnivores. If it is only the 1080 residues that are toxic then the carnivores, on the basis of their sensitivity to 1080, probably face the same theoretical order of risk from secondary poisoning as they do from primary poisoning. In reality much will depend on what tissues they consume from poisoned animals and on the 1080 residues in these tissues. For example, lower levels of 1080 have been found in the livers of poisoned rats, fallow deer *Dama dama*, and red deer *Cervus elaphus*, than in their hearts, muscle tissue or other parts of the body (Hagan *et al.* 1950; McIntosh *et al.* 1959). Ultimately, as with primary poisoning, the actual extent of secondary poisoning amongst carnivore populations will depend upon many factors, particularly the proportion of each population which find and eat lethal quantities of poisoned animals.

*Conclusion*

The study reported here indicates that the possibility of primary and secondary poisoning of non-target carnivores could be reduced or averted by the careful management of poisoning operations. These should be carried out in such a way as to minimize the concentration of 1080 in meat baits that non-target carnivores may eat, or, in the case of other baiting campaigns, to reduce the number of lethal doses of 1080 that animals ingest by eating poisoned plant-derived baits.

Finally, it must be stressed that this paper has been a hypothetical evaluation, based on $\mathrm{LD}_{50}$s, of the dangers carnivores face from primary and secondary poisoning with 1080. Although more data on the amounts of bait or parts of a carcass and their toxic residues that each member of a free-living population will consume would no doubt refine the hypothetical evaluation, an exact evaulation could be obtained by monitoring field populations before and after poisoning campaigns. Such monitoring studies are currently being undertaken.

**Acknowledgments**

Many people assisted in catching, providing, handling or feeding the trial animals; some are not mentioned here but their help was appreciated. In particular I wish to acknowledge the cooperation of the following in supplying or helping to catch experimental animals: Dr S. Morton (*Sminthopsis crassicaudata*); Dr R.

Sinclair and Mr P. Bird (*Sminthopsis macroura*); Mr H. Dimpel (*Antechinus swainsonii*); Dr C. H. S. Watts and Dr P. Baverstock and the Institute of Medical and Veterinary Science, Adelaide (*Dasyuroides byrnei*); Mr M. A. Elliott, Dr R. J. Begg and other staff of the Conservation Commission of the Northern Territory (*Dasyurus hallucatus*); Dr I. Eberhard, Mr K. Harman and other rangers of the National Parks and Wildlife Service, Tasmania (*Dasyurus viverrinus, D. maculatus* and *Sarcophilus harrisii*); and Dr A. Newsome and members of the CSIRO dingo research group (*Canis familiaris dingo*). Facilities and assistance were provided by Messrs B. Munday, G. Gregory and their colleagues of the Department of Agriculture in Tasmania; the University of New South Wales at Fowlers Gap, New South Wales; and the Snowy Mountains Council at Schlink Pass, New South Wales. 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 Conservation Commission of the Northern Territory.

Messrs M. Jones, V. Kowalski and J. Lemon helped with some early trials but the majority of assistance, both in the field and laboratory, was provided by Mr R. Cooper and, more especially, Mr E. Gifford.

## References

**Arnold, J. M.** (1976). Growth and bioenergetics of the chuditch, *Dasyurus geoffroii*. Ph.D. Thesis, University of Western Australia.

**Arnold, J.**, and **Shield, J.** (1970). Oxygen consumption and body temperature of the chuditch (*Dasyurus geoffroii*). *J. Zool. Lond.* **160**, 391–404.

**Chenoweth, M. B.** (1949). Monofluoroacetic acid and related compounds. *J. Pharmacol. Exp. Ther.* **97**, 383–424.

**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.

**Cowan, I. M., O'Riordan, A. M.**, and **Cowan, J. S. M.** (1974). Energy requirements of the dasyurid marsupial mouse *Antechinus swainsonii* (Waterhouse). *Can. J. Zool.* **52**, 269–75.

**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.

**Gibb, J. A., Ward, C. P.**, and **Ward, G. D.** (1978). Natural control of a population of rabbits, *Oryctolagus cuniculus* (L.), for ten years in the Kourarau enclosure. N.Z. Dep. Sci. Ind. Res. Bull. No. 223.

**Green, B.**, and **Catling, P.** (1977). The biology of the dingo. In 'Australian Animals and their Environment'. (Eds H. Messel and S. T. Butler.) pp. 49–60. (Shakespeare Head Press: Sydney.)

**Green, B.**, and **Eberhard, I.** (1979). Energy requirements and sodium and water turnovers in two captive marsupial carnivores: the Tasmanian devil, *Sarcophilus harrisii*, and the native cat, *Dasyurus viverrinus*. *Aust. J. Zool.* **27**, 1–8.

**Hagan, E. C., Ramsey, L. L.**, and **Woodard, G.** (1950). Absorption, distribution, and excretion of sodium fluoroacetate (1080) in rats. *J. Pharmacol. Exp. Ther.* **99**, 432–4.

**Howard, W. E.** (1957). Amount of food eaten by small carnivores. *J. Mammal.* **38**, 516–17.

**Kennedy, P. M.**, and **Macfarlane, W. V.** (1971). Oxygen consumption and water turnover of the fat-tailed marsupials *Dasyurus cristicaudata* and *Sminthopsis crassicaudata*. *Comp. Biochem. Physiol. Ser. A* **40**, 723–32.

**Kinnear, A.**, and **Shield, J. W.** (1975). Metabolism and temperature regulation in marsupials. *Comp. Biochem. Physiol. Ser. A* **52**, 236–45.

**Kirsch, J. A. W.**, and **Calaby, J. H.** (1977). The species of living marsupials: an annotated list. In 'The Biology of Marsupials'. (Eds B. Stonehouse and D. Gilmore.) pp. 9–26. (Macmillan: London.)

**Kirsten, E., Sharma, M. L.**, and **Kun, E.** (1978). Molecular toxicology of (-)erythro-fluorocitrate: selective inhibition of citrate transport in mitochondria and the binding of fluorocitrate to mitochondrial proteins. *Mol. Pharmacol.* **14**, 172–84.

**Lyne, A. G.** (1971). Bandicoots in captivity. *Int. Zoo Yearb.* **11**, 41–3.

**McIlroy, J. C.** (1981). The sensitivity of Australian animals to 1080 poison. I. Intra-specific variation and factors affecting acute toxicity. *Aust. Wildl. Res.* **8,** 369–83.
**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.
**MacMillen, R. E.,** and **Nelson, J. E.** (1969). Bioenergetics and body size in dasyurid marsupials. *Am. J. Physiol.* **217,** 1246–51.
**Marshall, W. H.** (1963). The ecology of mustelids in New Zealand. N.Z. Dep. Sci. Ind. Res. Inf. Ser. No. 38.
**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.
**Morton, S. R.** (1980). Field and laboratory studies of water metabolism in *Sminthopsis crassicaudata* (Marsupialia : Dasyuridae). *Aust. J. Zool.* **28,** 213–27.
**Nagy, K. A., Seymour, R. S., Lee, A. K.,** and **Braithwaite, R.** (1978). Energy and water budgets in free-living *Antechinus stuartii* (Marsupialia : Dasyuridae). *J. Mammal.* **59,** 60–8.
**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.)
**Nelson, J. E.,** and **Smith, G.** (1971). Notes on growth rates in native cats of the family Dasyuridae. *Int. Zoo Yearb.* **11,** 38–41.
**Pattison, F. L. M.** (1959). 'Toxic Aliphatic Fluorine Compounds.' (Elsevier Publ. Co.: London.)
**Robinson, W. B.** (1953). Coyote control with compound 1080 stations in national forests. *J. For.* **51,** 880–5.
**Schitoskey, F.** (1975). Primary and secondary hazards of three rodenticides to kit fox. *J. Wildl. Manage.* **39,** 416–18.
**Spencer, D. A.** (1945). Compound 1080, sodium fluoroacetate, as a control agent for field rodents. Partial interim report. U.S. Natl Res. Counc. Insect Control Comm. Rep. No. 161.
**Staples, E. L. J.** (1964). Veterinary toxicology in New Zealand. A review of 1236 cases of poisoning. *J. Sci. Technol.* **10,** 129–54.
**Thompson, W. R.** (1947). Use of moving averages and interpolation to estimae median-effective doses. I. Fundamental formulas, estimation of error, and relation to other methods. *Bacteriol. Rev.* **11,** 115–45.
**Tourtellotte, W. W.,** and **Coon, J. M.** (1951). Treatment of fluoroacetate poisoning in mice and dogs. *J. Pharmacol. Exp. Ther.* **101,** 82–91.
**Tucker, R. K.,** and **Crabtree, D. G.** (1970). Handbook of toxicity of pesticides to wildlife. U.S. Fish Wildl. Serv. Res. Publ. No. 84.
**Wallis, R. L.** (1976). Torpor in the dasyurid marsupial *Antechinus stuartii. Comp. Biochem. Physiol. Ser. A* **53,** 319–22.
**Ward, J. C.,** and **Spencer, D. A.** (1947). Notes on the pharmacology of sodium fluoroacetate – compound 1080. *J. Am. Pharm. Assoc.* **36,** 59–62.
**Weil, C. S.** (1952). Tables for convenient calculation of median-effective dose ($LD_{50}$–$ED_{50}$) and instructions in their use. *Biometrics* **8,** 249–62.
**Woolley, P.** (1971). Breeding pattern and the breeding and laboratory maintenance of dasyurid marsupials. *Exp. Anim.* **22,** 161–72.

Manuscript received 3 March 1980; accepted 6 October 1980