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ABSTRACT: Animals in Australia vary greatly in their sensitivity to 1080 poison, with known LD_{50}'s ranging from 0.11 to over 800 mg kg $^{-1}$. Many native species, particularly in western Australia, have evolved tolerances to 1080 through ingestion of native plants that contain fluoroacetate or prey that consume those plants. Despite this, some native species, particularly a few herbivorous mammals, birds and rodents, could be poisoned during control campaigns against vertebrate pests. Field studies indicate that poisoning campaigns are not significantly affecting populations of common non-target animals, but further impact studies are required on vulnerable, rare, endangered, or uncommon species.

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INTRODUCTION

In Australia, 1080 poison (sodium monofluoroacetate) is used to help control a number of vertebrate pests, particularly European rabbits (*Orcytolagus cuniculus*), dingoes (*Canis familiaris dingo*), foxes (V*ulpes vulpes*) and feral pigs (*Sus scrqfa*). Baits generally consist of pieces of diced carrot, bran or pollard pellets, oat grains, or chunks of meat and small factory-produced meat baits. Toxic loadings (sprayed or injected) vary from 0.014-0.06% w/w for the carrot, pellet and oat baits, 2.5-10 mg per meat bait for foxes and dingoes, and 72 mg per meat bait for pigs. The baits are then distributed from the air or laid at bait stations or in swathes or furrows along the ground, or dropped at intervals along a trail.

Members of the Australian public frequently express concern that 1080-poisoning campaigns may deleteriously affect native or non-target animals. Some non-target animals have been observed feeding on baits or poisoned animals, while others have been found dead in baited areas (Hone and Pedersen 1980; McIlroy 1982a, 1983a; McIlroy et al. 1986a,b; McIlroy and Gifford 1991). This paper reviews the possible effect that 1080-poisoning campaigns are having on animals in Australia.

ASSESSMENT OF POTENTIAL RISK

The species most likely to be affected by 1080-poisoning campaigns in Australia can be identified from knowledge of their sensitivity to the poison, their body weight and whether they could consume lethal amounts of the different baits or poisoned animals.

Sensitivity to 1080

Animals in Australia vary greatly in their sensitivity to 1080. Median lethal doses (LD_{50}'s) obtained for 130 species range from 0.11 mg kg $^{-1}$ for dingoes to over 800 mg kg $^{-1}$ for the shingle-back lizard (*Tiliqua rugosa*) (McIlroy 1986, Calver et al. 1989, King et al. 1989, Twigg and King 1989, Twigg and Mead 1990, Twigg et al. 1990, D. King, personal communication). Generally, members of various phylogenetic groups share a similar sensitivity but large differences in sensitivity can occur between geographically separated members, such as herbivorous marsupials in eastern and western Australia (Table 1). Overall, sensitivity tends to decrease from (1) carnivorous eutherian mammals to (2) herbivorous eutherian mammals and marsupials, and then to (3) carnivorous marsupials, (4) herbivorous-granivorous rodents, (5) omnivorous mammals (e.g. bandicoots, pigs), (6) birds, and finally to (7) amphibians and reptiles (Table 1).

The most likely reasons for these differences in sensitivity between species are: (1) evolved differences in metabolic rates, or metabolism of fluoroacetate, and (2) the duration of the species' exposure to food plants that contain naturally-occurring fluoroacetate, or to prey which have fed on these plants (McIlroy 1984, Twigg and King 1991).

Evolved Tolerance to 1080

In Australia, 41 species of leguminous plants are known to produce monofluoroacetate in their leaves, flowers and seeds. Thirty nine of these species, all *Gastrolobium* spp. (Hopper 1991), are confined to the south west corner of Western Australia, where they form a substantial and often dominant element in the shrub layer (Twigg and King 1989). The other two species, *G. grandiflorum* and *Acacia georginae* occur in northern and central Australia. Fluoroacetate concentrations in the 41 plant species vary regionally, seasonally, among species, and among parts of the plants, reaching 2,600 mg kg $^{-1}$ in air-dried leaves and over 6,500 mg kg $^{-1}$ in seeds (Aplin 1971, Twigg and King, 1991).

Populations of insects, reptiles, birds and mammals, which have co-existed with these plants for at least several thousand years, have evolved varying degrees of tolerance to fluoroacetate (King et al. 1978, Oliver et al. 1979, Mead et al. 1985). Tolerances can differ between populations of conspecifics and congenerics from areas inside and outside the range of the plants (Mead et al. 1985). The differences appear dependent upon the length of time and extent to which ancestral populations of each species have included parts of the plants, or animals that feed on them, in their diet, and the gene flow between different populations of each species (Oliver et al. 1979). Animals that have not co-existed with these plants, or have done so only recently, are generally less tolerant to fluoracetate (Twigg and King 1991)(Table 1).

Vulnerability During Poisoning Campaigns

Other factors besides sensitivity to 1080 can determine the effect of 1080-poisoning campaigns on animal populations. Body size, for instance, can determine whether an individual receives a lethal dose of poison or not. For example, although foxes and dingoes share a similar sensitivity to 1080 (i.e. LD_{50}'s of 0.13 mg kg $^{-1}$ and 0.11 mg kg $^{-1}$, respectively, McIlroy and King 1990), a fox can be poisoned by ingesting approximately only half the amount of 1080 than a dingo, because it is twice as light.

The vulnerability of different animals during poisoning campaigns also depends on how much bait or portions of poisoned animals they may eat. Estimates, based on the sen-

Table 1. Approximate mean LD_{50}'s of 1080 for different groups of animals with known past or continuing exposure to naturally occurring fluoroacetates, and for introduced animals and those with no known past exposure.

	Known Exposure			Unadapted		
		LD_{50} (mg kg^{-1})			LD_{50} (mg kg^{-1})	
Groups of animals	No. species	Mean	Range	No. species	Mean	Range
Eutherian carnivores	—	—	—	3	0.2	0.1-0.4
Marsupial herbivores	10	42.0	10-100	10	0.3	0.1-1.0
Eutherian herbivores	—	—	—	5	0.4	0.4-0.5
Marsupial carnivores	12	8.3	3.0-17.5	9	2.7	1.0-4.2
Rodents	10	21.6	3.5-80	10	3.1	0.7-9.0
Pigs	—	—	—	1	4.1	—
Bandicoots	4	13.2	8.9-20	4	5.9	3.5-7.7
Birds	14	28.4	1.8-102	45	7.8	0.6-25
Reptiles	2	525	250-800	5	163.0	44-336

sitivity to 1080, body weight, and measurements or calculations of the amount of food animals can eat per day, indicate that many non-target animals could potentially eat lethal amounts of bait or poisoned animals (McIlroy 1986, and unpublished data). The extent to which lethal quantities are eaten will depend on many factors. The baits or poisoned animals and 1080 present may be eaten by other animals or by insects, or they may gradually decompose. Rain may leach the 1080 or bacteria and fungi may defluorinate it (McIlroy et al. 1988). The probability of an animal encountering a bait will depend partly on the pattern of distribution of the baits, the population densities, ranges and movements of the different animals in relation to the baited area, and environmental conditions. The amounts of baits or poisoned animals consumed can depend also on preferences for various types of bait or parts of carrion (Brunner 1983, McIlroy, unpublished data), the time of the year in relation to the availability of other foods and the animals' physiological requirements, and whether the baiting methods have been modified to increase specificity (e.g. lures) or to reduce non-target hazard (e.g. dyeing or covering baits, or exposing them only during darkness). The amounts of 1080 ultimately ingested can differ according to the size or quality of the baits (Batcheler 1982), the concentration or amount of 1080 in each bait (which varies in practice) or in the organs and tissues of poisoned animals, whether the animals can vomit or regurgitate toxic material before absorbing lethal amounts of 1080, and whether animals quickly develop an aversion to the toxic material. Some animals, such as rabbits, brushtail possums (*Trichosurus vulpecula*), and fat-tailed dunnarts (*Sminthsopsis crassicaudata*), for example, appear to be able to smell or taste 1080 and either reject the baits or stop eating them before ingesting a lethal amount (Rowley 1963, Morgan 1982, Sinclair and Bird 1984, Calver et al. 1989). Other animals such as pigs, raptors and Tasmanian devils (*Sarcophilus harissii*) often vomit or regurgitate toxic material (McIlroy 1981,1983a, 1984).

Consequently, with such a mix of variables, it is difficult to predict which species are likely to be the most affected during 1080-poisoning campaigns. Some general guidelines, however, are possible:

1. Some “unadapted” native animals, particularly small herbivorous macropodids, such as the long-nosed potoroo (*Potorous tridactylus*) and red-bellied pademelon (*Thylogale billardierii*), and some rodents and birds, probably face a greater risk of being poisoned during rabbit-poisoning campaigns than do rabbits. Other species such as wombats (Vombatidae) and unadapted brushtail possums, larger macropodids, bandicoots and some birds probably face only a slightly lesser risk (McIlroy 1982a,b; 1983b; 1984, 1986).
2. Most “adapted” native herbivorous and granivorous birds and mammals, particularly those in western Australia, probably face a lesser risk of being poisoned than do rabbits during rabbit-poisoning campaigns. This is particularly so in some areas, such as on some islands off Western Australia, where differences in tolerance and the resultant increased target-specificity enable poisoning campaigns to be used to enhance the conservation of rare or endangered native fauna through destruction of their more sensitive introduced competitors and predators (King et al. 1981).
3. Many native carnivorous mammals, including some “adapted” species in Western Australia, and some rodents and birds, could be poisoned by meat or meat-based baits during baiting campaigns against dingoes, foxes and pigs (McIlroy 1981, 1983a, 1986; King et al. 1989). Most herbivorous and granivorous birds and mammals face a high risk of being poisoned if they eat grain, pellet or carrot baits intended for pigs (McIlroy 1983a).
4. Foxes, dingoes, dogs and cats appear to face a greater risk of secondary poisoning than native birds and mammals, particularly from eating poisoned rabbits, whose muscle tissues may contain residues of up to 5 mg of 1080 per rabbit (McIlroy, unpublished data).
5. Reptiles are highly unlikely to be affected by either primary or secondary poisoning during 1080-poisoning campaigns (McIlroy et al. 1985).

EVIDENCE OF MORTALITY FROM POISONING CAMPAIGNS

There is very little information available on mortality of non-target animals due to 1080-poisoning campaigns in Australia. At times the public report finding dead animals, particularly wallabies, in some areas after rabbit-poisoning campaigns, but no evidence is available that the animals were poisoned, or the extent to which their populations were affected. Certainly, wallabies and other macropodids such as red-bellied pademelons, and brushtail possums can be poisoned at times, either accidentally during rabbit-poisoning campaigns, or deliberately during poisoning campaigns to reduce browsing damage in some forest areas (McIlroy 1982a). Other macropodids such as potoroos, swamp wallabies (*Wallabia bicolor*) and grey kangaroos (*Macropus giganteus*) plus common wombats (*Vombatus ursinus*), 'bandicoots' and eight species of birds also have been found dead during extensive searches in State forests after rabbit-poisoning campaigns (McIlroy 1982a). Eight birds, representing three species, were found dead after a pig-poisoning campaign with meat baits (Hone and Pedersen 1980).

One of the main reasons for the lack of field studies on the impact of 1080-poisoning campaigns on animal populations is the difficulty in obtaining data because of the sparseness of many species, the need for large, replicated, treated areas as part of experimental design, and the number of variables that may be involved. While carcass searches are carried out and can be used to indicate the species being poisoned, population mortality can be estimated only when we know proportions found of the animals killed and their initial densities. Pre-and post-poisoning counts of many species can be affected by their movements or seasonal fluctuations in their numbers. Disappearance from a treated area is not necessarily synonymous with death from poisoning, and immigration can rapidly replace poisoned animals (McIlroy 1982c, McIlroy et al. 1986b). Mark-recapture methods are practical only for relatively sedentary or territorial species where sufficient numbers can be captured and marked before a poisoning campaign and re-identified afterwards. Monitoring the fate of animals to which radio transmitters have been attached, while an excellent method in principle, is usually practical for only a few species, such as rare or particularly vulnerable species.

The results from the few field studies of dingo-poisoning campaigns indicate that the campaigns have no significant effect on populations of small mammals and birds in mountain forest areas in southeastern Australia (McIlroy 1982c, McIlroy et al. 1986b) or on populations of northern quolls (*Dasyurus hallucatus*) and probably other dasyurids and rodents in pastoral areas of Western Australia (King 1989).

Similarly rabbit-poisoning campaigns appear to have no significant effect on populations of some of the more common birds and mammals (McIlroy and Gifford 1991, McIlroy unpublished data). Pellet baits for rabbits, however, appear to have killed all adult residents in a marked population of the patchily distributed silky mouse (*Pseudomys apodemoides*) in one area in western Victoria. Fortunately, the effect was only temporary, with juvenile animals quickly recolonizing the area (A. Cockburn, personal communication, in McIlroy 1982b).

CONCLUSION

Vertebrate pest control in Australia is facilitated by many of its native animals having a greater tolerance of 1080 than most introduced animals pests. This factor, together with continuing modifications to different 1080-poisoning campaigns to improve their target-specificity, such as substituting large, sundried meat baits containing lower concentrations of 1080 for smaller manufactured meat baits for dingo control in areas containing rare dasyurids, burying baits for feral pigs, or dyeing baits to deter consumption by birds (McIlroy 1983a, 1984, King et al. 1989) can considerably reduce the risk of non-target mortality. Despite this, complacency is unwarranted. Although the few field studies undertaken indicated that 1080-poisoning campaigns did not significantly affect populations of many common species in Australia, more studies of impact or risk assessment are needed on rare, endangered, or uncommon species considered to be potentially vulnerable. Continued efforts are also needed to improve the effectiveness of some poisoning campaigns, such as those carried out against dingoes and wild dogs (*Canis f. familiaris*) (McIlroy et al. 1986a,b) and to compare their cost-benefits with alternative methods. Poisoning campaigns with 1080 should be used only when they are the best choice from a suite of alternative methods, rather than as a frequently repeated panacea for pest control.

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