Controlling vertebrate pests with fluoroacetate: lessons in wildlife management, bio-ethics, and co-evolution

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Introduction

Pest management is one of the most important aspects of applied ecology included in school biology curricula. This reflects the need to regulate pest numbers to maximize agricultural production, reduce damage to buildings, check the risk of the spread of serious diseases of humans and domestic animals, and minimize the nuisance to people and livestock caused by some pests. Additionally, conservation policies sometimes involve culling predators or competitors of threatened species using pest control techniques. However, the discussions of pest control in biology textbooks are biased heavily towards control of invertebrate and plant pests, while vertebrate pests are neglected. While no doubt motivated by the relative economic importance of vertebrate and invertebrate pests, this attitude prevents a comprehensive coverage of pest control issues.

Compound 1080 (sodium monofluoroacetate) was used as a vertebrate pesticide in the USA from the 1940s until its ban for use on federal lands in 1972, and is still used widely in private lands. In Australia, it has been in increasing use since its introduction in the early 1950s. This paper compares and contrasts the use of 1080 in both countries, focusing on the aims and methods involved, the biological peculiarities of each system, and the role of public opinion and pressure in determining the nature of 1080 use.

Abstract
The uses of sodium monofluoroacetate (compound 1080) as a vertebrate predacide in the USA and Australia are reviewed. The US applications centre on control of native species, while many of Australia's vertebrate pests are introduced species. This, coupled with the natural resistance of some Australian native fauna to 1080, has contributed to different patterns of use in both countries and different public attitudes to control programmes. The 1080 case corrects the omission of vertebrate pest control examples from the discussions of pest control in school biology texts, and highlights the interplay of economics, public opinion, bio-ethics, and biological principles in pest control programmes. Exercises on scientific vs emotive writing, data presentation, and co-evolution in Australia are suggested as possible curriculum extension exercises.

Early history of compound 1080

Fluoroacetic acid was first synthesized in Belgium in 1896, but its toxicity was not noted until 1934 (Atzert, 1971). Its development as a vertebrate pesticide was accelerated by research during World War II to develop potent rodenticides to protect troops from rat-carried diseases, and the sodium salt of fluoroacetic acid (sodium monofluoroacetate, or compound 1080) was found to be extremely effective. It was employed extensively as a rodenticide in the post-war years, and was especially successful in confined environments such as ships, sewers, and warehouses. Because of its high toxicity a lethal dose of 1080 can be contained in a small 'one-shot' bait likely to be eaten entirely even by a rat which is only sampling a new food. Such baits are still necessary because of the increasing resistance of rats to anti-coagulants such as Warfarin.

Desirable characteristics of a vertebrate pesticide against which 1080 can be measured are:

1. The pesticide should be acceptable to the target species and selectively toxic to it.
2. The toxicity should be high but without cumulative effects.
3. The poison should degrade to harmless products over a short period and remain at the site of application.
4. The pesticide should be cheap in relation to total control costs.

Using these criteria, 1080 has clear advantages and disadvantages.

On the credit side, 1080 is tasteless and odourless to most species (for exceptions see Sinclair and Bird, 1984), so it can be added easily to favoured foods for target specificity. Because it is water soluble it leaches from baits readily and the very small concentrations used are dispersed quickly and detoxified by soil bacteria. It is cheap to use as well, and does not accumulate in body tissues.

Against this must be balanced several disadvantages. The toxicity of 1080 is extremely high, and the

LD50 figures (the amount of poison required to kill 50 per cent of a sample of animals receiving it) given in Atzert (1971) are as low as 0.1 mg/kg body weight, showing it to be one of the most toxic substances known. Within the mammals, primates are amongst the most resistant species, while canids (the dog family) are very susceptible. There is no antidote for 1080 poisoning and hence stringent safety precautions are required in its use. However, this high general toxicity is not really a problem when rodent baiting is restricted to enclosed areas.

Finally, 1080 does not kill animals quickly. In the body it is metabolized to fluorocitrate, which is a potent inhibitor of the enzymes aconitase and succinate dehydrogenase. Consequently, citrate metabolism in the Krebs cycle is impaired, leading to death if the dose is strong enough. Symptoms include hyperexcitability, convulsions, trembling, vomiting, salivation, rapid breathing, and incontinence or diarrhoea, with considerable interspecific and intraspecific variation in their number and intensity. Death may be caused directly by cardiac failure or respiratory arrest, or by CNS depression leading finally to cardiac and respiratory failure. Herbivores tend to suffer cardiac effects while carnivores display CNS effects, and omnivores show both. Although the symptoms of 1080 poisoning appear to indicate acute distress and suffering, Anon. (1978) reported that in two cases where humans survived these clinical stages of poisoning they subsequently reported feeling nothing except a slight itch. Despite the symptoms, 1080 may not cause pain, assuming that other species have similar experiences to humans. Possibly, 1080's inhibitory action on the CNS prevents acute suffering despite the overt symptoms of disorientation. The slowness of death may actually be an advantage to the pest controller as animals do not die at a bait source, warning others away.

With the exception of speed of death, the possible disadvantages of 1080 can be overcome if it is used carefully against rodents. Psychologically, most humans are not attracted to rats, so the unpleasant facts of their deaths by 1080 poisoning do not often distress people. However, this scenario needs re-evaluation when 1080 is used against other vertebrates outside confined spaces.

Use of 1080 in the United States for predator control

Well before 1080 became available in the USA, poisoning was in use to regulate numbers of predators, especially wolves and coyotes, which preyed on livestock. Wade (1978) noted that strychnine baiting was first recorded in 1847, sodium cyanide was used in trials before 1940, and field experiments with thallium sulphate began in 1937. The overriding motive behind all poisoning programmes was the reduction or elimination of stock losses. Following its development as a war-time rodenticide, 1080 was adapted rapidly for use in coyote control, with the first field trials beginning in 1944 (Wade, 1978).

The standardized procedures adopted for 1080 baiting operated on the principle that summer culling of coyotes was inefficient, and that it was better to reduce numbers in winter when food was less abundant and animals were more likely to take baits. This in turn should reduce the number of coyotes breeding during the lambing season and killing sheep to feed themselves and their pups. Stock carcasses, usually sheep, were injected with 1080 solution to give a final concentration of 32 mg 1080/kg of carcass (Atzert, 1971), and positioned in the field in winter. They were placed in a ratio of one carcass or 'bait station' per township, giving a density of one each 36 square miles (*c.* 92 km^2). Each station was to be clearly marked with warning posters, and the carcass was to be securely staked to the ground so that it could not be dragged away. In spring, the stations were removed and destroyed.

The procedure was designed to both reduce coyote numbers and minimize the risk to non-target species. Because coyotes travel widely, they would be likely to encounter and feed at a bait station, while other predators and scavengers with more limited home ranges would only be endangered if they lived in the immediate vicinity of one of the scattered stations. Furthermore, hibernating animals would be protected by the timing of station use. The high toxicity of 1080 to canids relative to non-target species such as badgers, raccoons, hawks, and eagles was also held to improve its selectivity especially since it allowed low concentrations of poison to be used in the stations. Robinson (1949) recommended that bait stations be kept away from stream areas, where non-target species were more common.

Assessment of the impact of the stations on the numbers of both coyotes and non-target species by direct means was difficult, since the latent period of several hours between poisoning and death meant that few carcasses were found near bait stations. Despite this limitation, the species of animals reported by Robinson (1949) to have been poisoned included coyotes, bobcats, dogs, domestic cats, badgers, weasels, eagles, magpies, hawks, and ground squirrels. Indirect evidence provides a better measure of population damage caused to coyotes. For example, Robinson (1949) reported a 75–100 per cent fall in sheep losses to coyotes in areas where bait stations were used, and interpreted this as meaning that the stations were extremely effective against coyotes. In relation to non-target species, Robinson (1961) found that population trends of bobcats, skunks, badgers, and raccoons were independent of coyote control measures over the period 1940–1960. He interpreted this as showing that the control measures were specific, as well as suggesting that coyote predation did not regulate the numbers of any of these species. However, he conceded that his population estimates for non-target species were based on returns from commercial fur-trapping, and suffered from bias related to trapping intensity. Further, he admitted that some poisoning of non-target species did occur, and would be inevitable with such a programme.

Non-target poisonings can result not only from these species feeding on poisoned baits, but also from predators taking animals that have been killed or incapacitated by baits. Robinson (1949) and Atzert (1971) report that 1080 concentrations are highest in the viscera of poisoned animals, so predators eating viscera preferentially would seem to be at the greatest potential risk.

Despite the apparent success of 1080 baiting in reducing stock losses, an increasing level of opposition to its use developed. Underlying it was a major change in the attitudes of Americans towards wildlife. The arguments of the opponents to culling of predators, especially by poisoning, are summarized by Anon. (1978). On a practical level, it is argued that predators are needed in ecosystems, that they control numbers of other vertebrate pests, and that culling their numbers does not reduce stock losses. Further, the use of poisons inevitably endangers non-target species. Ethical views against control claim that wildlife should be preserved on principle, and that systematic killing of wild animals is wrong under any circumstances.

Anon. (1978) reviewed studies on American attitudes towards predator control. They suggested that people opposed to predator control were most likely to be urban; aged 18–29 years; white females; students or those with a college education; single; and birdwatchers, backpackers or anti-hunting advocates. Conversely, people in favour of control tended to be rural, to be associated with the livestock or fur trapping industries, and to have less than an eighth grade education. Clearly, from this profile the anti-poisoning lobby could be expected to be more articulate and better able to argue its case, and it would be helped by a general cultural opposition to poisoning. The overall result of this pressure was the ban on the use of 1080 and other toxicants on federal lands which was introduced in 1972.

Nevertheless, proponents of 1080 use have continued to argue their case. For example, Lynch and Ness (1981) argued that the aerial hunting which was substituted for 1080 baiting was expensive and difficult to use in timbered, mountainous areas. Their data suggested that, since the ban was imposed, livestock losses to predators on western national forests increased, while before the ban the numbers of toxic bait stations were inversely correlated to stock loss numbers in the period 1960–1972. At the other extreme, there is pressure from those who want all control methods stopped. The compromise which is in use is to destroy coyotes by alternative methods. Increasingly, the argument has been for selective elimination of known problem animals rather than wholesale reduction of predator populations (Sterner and Shumake, 1978).

The rise and fall of poisoning as a method of predator control in the United States reflects the power of public opinion in changing government policy on pest regulation. It also shows how public attitudes shift with time, but after a lag phase come to be reflected in legislation.

Use of 1080 in Australia

The Australian pest problem

The vertebrate pest problem in Australia has important similarities and differences to that in the United States. The Australian pest fauna comprises not only such native species as the predatory dingo (*Canis familiaris dingo*) and the herbivorous brush-tailed possum (*Trichosurus vulpecula*), pademelon (*Thylogale billiardieni*), and Bennett's wallaby (*Macropus rufogriseus*), but also introduced species such as rabbits (*Oryctolagus cuniculus*), feral pigs (*Sus scrofa*), foxes (*Vulpes vulpes*), feral cats (*Felis catus*), black rats (*Rattus rattus*), Norway rats (*Rattus norvegicus*), and house mice (*Mus musculus*). As well as being direct pests of agricultural and pastoral interests, some introduced species threaten native species by competition or predation. This has led in recent years to different control objectives for native and introduced species. Eradication is the goal in dealing with introduced pests, while conservation issues temper control measures for native animals. Public opinion about control measures may be ambivalent because of this dichotomy, with concern being restricted to the welfare of native species, while feral animals are more likely to be seen as vermin to be destroyed. Principal target species controlled by 1080 poisoning are dingoes, foxes, pigs, and rabbits, although in parts of the country some possums and wallabies are also poisoned deliberately.

History of 1080 use in Australia

Compound 1080 was first used in Australia for rabbit control in the 1950s and was found to be extremely effective. It was adopted for the control of predators, principally dingoes and foxes, in the 1960s, replacing strychnine as the common poison used for their control.

There are two main types of predator baits in use, one using beef crackle as a main ingredient and the other, cubes of fresh meat (Thomson, 1986). Finished crackle baits are about 2 cm cubes, while meat baits weigh approximately 110 g when fresh, but considerably less after sun-drying to facilitate transport and laying. A single bait of each type contains a lethal dose of 1080 for a dingo. They may be laid by dropping them from aircraft or by ground-based personnel. Aerial baiting is particularly useful in the vast, sparsely-populated inland sectors of the Australian pastoral industry.

Improving 1080 target specificity

Although the exotic status of many target species has reduced ethical objections to their control, there is still considerable concern over potential danger to non-target species either directly or through secondary poisoning. Bait size, palatability, and 1080 concentration are all important factors in reducing the danger, and suitable bait design can be supplemented by careful timing of baiting and the placement of baits. For example, when nocturnal animals are targets diurnal species such as birds are protected by laying baits at dusk and removing them at dawn. Experience in the United States indicated that baiting away from watercourses improved specificity. Unfortunately, in semi-arid pastoral areas in Australia baiting is most practical along watercourses and at water-holes where animals gather, because of the large areas to be covered. This increases the importance of bait design to improve specificity. Secondary poisoning remains a poorly understood problem, largely because of lack of a suitable assay for 1080 or its toxic metabolites in animal tissue where background fluoride readings may be high. There is evidence that foxes and feral cats have been poisoned from the carcasses of rabbits killed by 1080, and other predators and scavengers may be endangered.

Fluoroacetate is not only an artificial compound; it is synthesized naturally in several plant genera. Of these, several species of the genera *Gastrolobium* and *Oxylobium* occur in the south-west of Western Australia, but not in south-eastern Australia. Comparisons of LD50 levels for populations of the western grey kangaroo (*Macropus fuliginosus ocydromus*), the eastern grey kangaroo (*Macropus giganteus*), the bush rat (*Rattus fuscipes*), and the brush-tailed possum (*Trichosurus vulpecula*) have shown that the Western Australian populations have a much higher resistance to fluoroacetate than other herbivores, or eastern conspecifics (table 1). *Gastrolobium* and *Oxylobium* species are papilionaceous legumes, and their high nutritive value, abundance, and relative succulence compared to other coarse or spiny species should make them attractive food. Dietary analysis for the western grey kangaroo confirms this prediction (Mead *et al.*, 1985), and strongly suggests that the plants evolved the ability to produce fluoroacetate as a defence against herbivores. Conversely, several species of herbivores evolved resistance to fluoroacetate so that they could continue to feed on the plants. However, western grey kangaroos eat more of the less toxic species of the fluoroacetate-producing plants than of the highly toxic species.

These results have considerable significance for 1080 control programmes, since many native marsupials and eutherians are much less susceptible to poisoning than are introduced mammals. Native carnivores and omnivores often have high tolerance for 1080 as well as native herbivores, perhaps because of selection in native communities for resistance against being secondarily poisoned by prey which had fed on *Gastrolobium* and *Oxylobium*. This gives potential for design of target-specific baits. Dingoes, having arrived in Australia only recently in evolutionary time, have no increased resistance to fluoroacetate and show the normal canid susceptibility.

Compound 1080 may also be a powerful target-specific agent for controlling fox numbers, and so reducing their pressure on threatened native species. King *et al.* (1981) considered the special case of three species of rat-kangaroos (*Bettongia* spp.) and reviewed literature suggesting that their current diminished distributions are the result of fox predation. Since two of the three species are highly tolerant to 1080, they suggested that fox control with 1080 baits could be a powerful weapon in their conservation.

Data on fluoroacetate resistance are significant in tracing the evolutionary history of some Australian marsupials as well (Mead *et al.*, 1985). This is particularly valuable because of Australia's poor fossil record, which has forced reliance on techniques such as comparative serology, protein polymorphism, and chromosome morphology in evolutionary studies. In the case of the bush rat, for example, the high tolerance of Western Australian animals compared to their eastern conspecifics, suggests that they radiated from the east to the west. Crosses of eastern and western populations gave progeny an intermediate tolerance, confirming the genetic basis of tolerance (Mead *et al.*, 1985).

Overall, in the Australian situation 1080 shows

Table 1 LD50 values in mg 1080/kg body weight for selected mammals. Western Australian native marsupials have greater resistance than exotic pest species, and in species with a wide range western populations are more resistant than eastern ones

Species	Locale	LD50 (mg/kg)	Reference
Red kangaroo	south-western Australia	5	Oliver *et al.* (1977)
Western grey kangaroo	south-western Australia	40	Oliver *et al.* (1977)
Bush rat	south-western Australia	80	Mead *et al.* (1985)
	eastern Australia	1.13	Mead *et al.* (1985)
Brush-tailed possum	south-western Australia	100	Oliver *et al.* (1977)
	eastern Australia	0.68	Oliver *et al.* (1977)
European rabbit	—	0.8	Atzert (1971)
Fox	—	0.1	McIlroy (1981)
Dingo	—	0.11	McIlroy (1981)
Feral cat	—	0.4	McIlroy (1981)

greater potential for target specificity than it does in the United States, while introduced vertebrate pests are less likely to arouse public sympathy than are native species. However, the ethical issues of poisoning have yet to surface in Australia to the same extent as in the US, and may in the future modify the use of 1080. Despite this, the potential of 1080 in protecting threatened native fauna from exotic predators ensures that the management issues in any such debate will be complex indeed. Clearly, control programmes must be sufficiently flexible to adapt to the specific needs of different regions, and to exploit any unique potential available.

Suggested classroom exercises

Scientific and emotive writing

Much of the material published during the 1080 debate in the 1960s in the US was intended for lay readers, and an emotional approach frequently predominated. Extracts from such articles could be the basis of classroom discussions on the nature of scientific writing, and the characteristics of emotive or rhetorical approaches that make the excerpts unsuitable for scientific communication. One example is this passage from Rieder (1964):

> 'A few hours after partaking of a satisfying meal on a portion of a chunk of horse meat, the little prairie wolf feels a twinge of pain deep in his belly. Moments later, he sets up a frenzy of howls and shrieks of pain, vomiting and retching as froth collects on his tightly-drawn lips. Blindly, the coyote tries to run from his unknown assailant, through down-fall and thorn-infested thickets, bouncing off trees, and over piles of rocks, running himself into complete and final exhaustion. A scant 6 to 8 hours after eating his meal, Mr Coyote is breathing his last, racked by painful convulsions, as the most inhumane poison ever conceived by man applies the "coup de grace" to the gallant little animal. We wonder if this creature of nature was not meant to have a fairer life. By a 25 to 1 ratio, the coyote's deeds have been beneficial to man. He has reduced rodent numbers, has cleaned up domestic and wild carrion, and has been a leading factor in keeping game herds healthy.
>
> The poison used to erase so-called "predators", is scientifically known as Sodium Fluoroacetate and commonly called "1080". It is tasteless, odorless, colorless, nonselective and has no known antidote. Ten-eighty poison is particularly lethal to members of the canine family. Death is unduly violent and an animal may go as far as 10 miles from the bait before dying.'

Here, students should notice such characteristics of emotive writing as anthropomorphism ('Mr Coyote'), value-laden epithets ('inhumane poison' and 'gallant little animal'), and unsubstantiated quantitative statements ('by a 25 to 1 ratio . . . beneficial to man'). A little harder to spot is the contradiction in calling 1080 both 'nonselective' and 'particularly lethal to members of the canine family'. Discussion could be directed to identifying these factors, and noting why they are unacceptable in scientific argument. Students could then identify the main issues in the extract including wildlife rights, the inhumaneness of poisoning, and the ecological value of coyotes. They might then rewrite the extract aiming to present Rieder's case forcefully in a scientific style. Teachers may wish to make available some quantitative data from Anon. (1978) and the papers collected in Bekoff (1978) to help students.

In case students believe that emotive argument is restricted to the anti-poisoning lobby, this extract from Anon. (1965) could be used as well:

> 'Quite apart from the heavy financial losses caused in the sheep industry by the depredations of wild dogs (we use the term to cover both the true dingoes and various breeds of domesticated dogs running wild), the ghastly suffering which they cause should make every sheep-owner anxious to destroy these canine scourges wherever an opportunity offers.
>
> Wild dogs on killing sprees will maim and kill far more sheep than they can eat, but they cause the greatest suffering when teaching the pups to kill. At such times, the adult dogs will disable sheep and leave them till the pups are brought up to inflict further suffering on the helpless victims. This process will be repeated again and again until the pups are able to make their own kills.'

This exercise could be used solely within a science class, or perhaps form the basis of team teaching with an English teacher.

Data representation and misrepresentation

In assessing the impact of predation on flocks and herds, data may be presented as the total number of animals lost, the percentage of all animals grazed killed by predators, and the percentage of all deaths caused by predators (Anon., 1978). Which of these figures is presented can depend on whether one is arguing for or against predators as a major cause of stock deaths. For example, table 2 gives all three figures for sheep and goat losses on US forest service lands from 1965 to 1976. Clearly, if one wanted an anti-predator argument it would sound more impressive to say '62 per cent of all sheep and goat losses in 1976 were caused by predators' than '1.88 per cent of stock grazed in 1976 were killed by predators'.

Students could be given a copy of the table without the percentages calculated, and asked to fill them in. If necessary, the numbers could be rounded to the nearest hundred or thousand to simplify the calculation. Next, discussion could be guided to emphasize how either percentage could be used to discuss predation depending on whether or not one favoured predator control. Students might note, for instance,

Table 2 Sheep and goat losses on US forest service lands, 1965–1976. (Modified from Anon., 1978.)

Year	Total sheep and goats grazed	Number killed by predators	Other losses	Total losses	Predation losses as percentage of total grazed	Percentage of total lost
1965	2 099 815	26 183	27 600	53 783	1.25	49
1966	2 071 228	30 747	27 587	58 334	1.48	53
1967	1 972 759	26 785	28 698	55 483	1.36	48
1968	1 910 878	27 235	24 213	51 448	1.43	53
1969	1 865 434	34 953	27 772	62 725	1.87	56
1970	1 780 357	32 639	22 175	54 814	1.83	60
1971	1 737 172	32 075	24 704	56 779	1.85	56
1972	1 702 189	40 686	25 188	65 874	2.39	62
1973	1 515 362	31 331	26 243	57 574	2.07	54
1974	1 422 766	36 967	24 721	61 688	2.60	60
1975	1 465 492	31 766	17 971	49 737	2.17	64
1976	1 748 163	32 879	20 014	52 893	1.88	62

how the percentage of the total number of animals grazed killed by predators fell between 1969 and 1970 and again between 1974 and 1975, while predator kills as a percentage of stock lost rose. Graphing the data may emphasize these trends. This exercise combines numeracy skills in calculating percentages with practice in presenting and interpreting tables and graphs.

Plant–animal co-evolution and 1080 resistance

Students may be familiar with a range of methods used by animals to reduce their chances of being eaten (see examples in Edmunds, 1974, and the classroom exercises in Barker, 1983, and Tranter, 1982). However, plant defences are covered less frequently. In the context of fluoroacetate-producing plants, directed discussion or library work could be used to develop a list of plant defences against herbivores. Students could consider the problem of how much energy to divert to defence at the expense of growth or reproduction, and so realize what factors determine the poison concentrations in plant tissue.

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