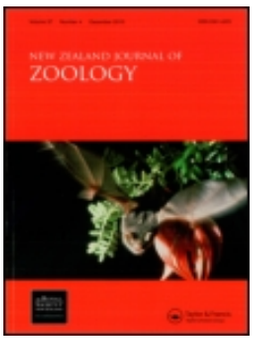

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REVIEW ARTICLE

Secondary poisoning risks from 1080-poisoned carcasses and risk of trophic transfer—a review

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In New Zealand, sodium fluoroacetate (1080) is used for the control of unwanted terrestrial vertebrate pests, some of which are carriers of bovine TB, and for the conservation of native flora and fauna. One key advantage of 1080 used for animal pest control is that it is biodegradable. In this short review, we focus on the persistence of 1080 in carcasses and the risk of 1080-poisoned carcasses to dogs, and the possible risk of toxicity in other non-target species via trophic transfer. The slower breakdown of 1080 in poisoned carcasses under certain conditions (e.g. cold, dry conditions), and the risks of secondary poisoning, have to be understood and managed following use of this toxin in conservation or as part of TB eradication programs. Poisoned possum carcasses can pose a risk to dogs even up to 75 days after the control operation. Lower, less hazardous concentrations have been found in deer bone marrow after 213 days. When other species (e.g. insects or birds) come into contact with 1080 in carcasses, sub-lethal poisoning is more likely. In these cases, as with sub-lethal poisoning in any non-target animals, any 1080 ingested will be metabolised and excreted, and trophic transfer will be minimal when compared to more persistent poisons.

Keywords: New Zealand; 1080; sodium fluoroacetate; possum; *Trichosurus vulpecula*; dogs; *Canis lupus familiaris*; secondary poisoning; non-target species

Introduction

Since the 1950s, sodium fluoroacetate (1080) has been used in New Zealand for terrestrial vertebrate pest control (Eason et al. 2011). It is the most widely used vertebrate pesticide in New Zealand due to being the only poison registered for aerial control operations on the mainland (Eason et al. 2011). Primary target species include possums (*Trichosurus vulpecula*) and rabbits (*Oryctolagus cuniculus*). Possums destroy indigenous flora and fauna, and act as a vector of bovine tuberculosis (TB), threatening New Zealand's meat export industry (Hickling 1994; Morgan 1994; Morgan & Milne 2002), while rabbits cause extensive economic and ecological damage to semi-arid land (Norbury & Norbury 1996). However, one unfortunate disadvantage to the use of any pesticide, including 1080, is the risk of secondary poisoning to non-target species (McIlroy 1994; Spurr 1994a, b; Hickling 1997; Spurr & Powlesland 1997).

Non-target poisoning can occur through primary, secondary or tertiary routes—direct consumption of 1080 baits (primary), consumption of 1080-poisoned prey or carcasses of animals that have fed on baits (secondary) or predation of prey or carcasses that have fed on a 1080-poisoned carcass (tertiary). The LD_{50} for various species, both target and non-target,

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have been shown to be highly variable (Rammell & Fleming 1978; Eisler 1995). This variability will therefore have an influence on secondary and tertiary poisoning risks. Dogs (*Canis lupus familiaris*), in particular, are extremely susceptible to 1080 poisoning (Egekeze & Oehme 1979; Sherley 2007; Eason et al. 2011), and must be kept away from toxic baits and poisoned carcasses; we therefore highlight the risks to dogs. Birds and invertebrates are also vulnerable to 1080 poisoning (e.g. Eason et al. 1993a, b; Spurr 1994a, b; Booth & Wickstrom 1999; Spurr & Drew 1999). However, the risk from carcasses will depend on the likelihood of exposure, the susceptibility of different species and the pharmacokinetics of 1080 in these species.

Because of: 1) the ongoing need to control agricultural and conservation pests; 2) New Zealand's heavy reliance on 1080 to achieve these outcomes; 3) the risks of 1080 use to non-target species and exceptionally high risk to dogs; and 4) the need for easily accessible, comprehensive information in one place for operational wildlife managers and concerned members of the public alike, we have reviewed literature relating to the risk of secondary poisoning of 1080 in animals relevant to the New Zealand situation. Here, we focus on the persistence of 1080 in poisoned carcasses, and the risk posed by poisoned carcasses to dogs; and explore the risk of toxicity in other non-target species via trophic transfer of 1080.

Persistence of 1080 in carcasses

In contrast to the fate of 1080 in live animals, where numerous studies show that sub-lethal amounts of 1080 are readily metabolised and excreted, and 1080 is therefore not persistent under these circumstances (see Eason et al. 2011 and references therein; Table 1), the persistence of 1080 in poisoned carcasses is, by comparison, prolonged. 1080 can persist in possum carcasses for many months (Meenken & Booth 1997). Breakdown in carcasses may be facilitated by microorganisms, degradation of fluoroacetate in the carcass, leaching of 1080 from the carcass into the soil (Gooneratne et al. 1994; Meenken & Booth 1997) and/or tissue autolysis (Gooneratne et al. 1994). Breakdown of 1080 in carcasses was studied in some detail following a possum control operation in the

Table 1 The elimination half-life of sodium fluoroacetate (1080) in plasma and muscle for possum, rabbit and mouse, plasma in sheep and goats, and of brodifacoum in blood and liver for possum.

Species	Compound	Sample	Route of administration	Dose (mg/kg)	Elimination half-life (hours unless specified)
Possum (*Trichosurus vulpecula*)	1080	Plasma	Oral	0.1	9.0[a]
		Muscle	Oral		n.d.
Rabbit (*Oryctolagus cuniculus*)	1080	Plasma	Oral	0.1	1.1[c]
		Muscle	Oral	0.1	0.4[c]
Mouse (*Mus musculus*)	1080	Plasma	IV injection	0.4	2.0[d]
Sheep (*Ovis aries*)	1080	Plasma	Oral	0.1	10.8[e]
Goat (*Capra hircus*)	1080	Plasma	Oral	0.1	5.4[e]
		Muscle	Oral	0.4	1.7[d]
Possum (*Trichosurus vulpecula*)	Brodifacoum	Plasma	Oral	0.1	Approx 8 days[f]
		Liver	Oral		>252 days[f]

Notes: n.d. = not determined; [a]Eason et al. 1994a; [b]Rammell 1993; [c]Gooneratne et al. 1994; [d]Sykes et al. 1987; [e]Eason et al. 1994b; [f]Eason et al. 1996.

Wairarapa in June 1994 (Meenken & Booth 1997). To assess the risk of secondary poisoning, samples of the stomach and their contents from 1080-poisoned possum carcasses were collected up to and including 75 days after the control operation. These were analysed for 1080 residues. All of the carcasses collected contained 1080 residues. Carcasses remained relatively intact throughout the first 39 days after death; however, between days 40 and 75, decomposition was observed to be well advanced. Mean 1080 concentration in the carcass stomachs at day 25 was 30.6 mg/kg, and 4.9 mg/kg at day 75 (Meenken & Booth 1997). This study represents just one example of the degradation of 1080 in possum carcasses over winter months in the North Island of New Zealand. Undoubtedly the rate of carcass decomposition and 1080 breakdown is influenced by prevailing weather conditions, and could occur at different speeds in other parts of the country at different times of the year. Research to investigate the rate of carcass decomposition and 1080 breakdown under different climatic conditions (e.g. dry, wet, hot, cold, under cover, in the open) would be beneficial.

A recent systematic study conducted by Ross and McCoskery (2012) compared the persistence of 1080 in Sika deer (*Cervus nippon*) bone marrow versus skin, muscle and stomach contents. The three deer examined were confirmed killed by lethal ingestion of 1080. This is the first time the concentration of 1080 in bone marrow and skin have been measured and compared to the concentration in the stomach. 1080 was shown to persist in deer bone marrow for 213 days, but it could be longer (Ross & McCoskery 2012). Concentrations in both muscle and stomach were still detectable (stomach 5.66 mg/kg, day 40; muscle 1.89 and 1.33 mg/kg, day 30), but carcass decomposition meant further sampling was precluded after day 40. Thirty days after poisoning, 1080 concentration in deer bone marrow was 0.59 mg/kg. Concentrations in deer bone marrow were always <1 mg/kg except on day 40, which implies that >1 kg of marrow would need to be eaten by dogs to put them at serious risk (Ross & McCoskery 2012). An exception to these low concentrations was seen on day 40, where a higher 1080 concentration (2.3 mg/kg) was found as a result of having to make a new cut in the bone to extract the marrow (Ross & McCoskery 2012).

However, 1080 concentrations recorded in poisoned deer muscle and stomach (mean at 9 days, 12.8 mg/kg; Ross & McCoskery 2012) were much lower than those recorded in poisoned possums (Meenken & Booth 1997); hence it is possible that higher concentrations also occur in possum bone marrow. It would be of value to repeat the bone marrow trial in poisoned possums to enable risks to dogs from 1080-poisoned possum bone marrow, and the full extent of 1080 persistence in bone marrow, to be clarified.

Risk of 1080-poisoned carcasses to dogs

A lethal dose of 1080 for a dog is extremely small compared to other mammals and birds, as seen from LD_{50} doses (Table 2), and survival of invertebrates exposed to, or dosed with, 1080 (Eason et al. 1993a, b; Booth & Wickstrom 1999). Dog deaths from 1080 poisoning creates enormous negative publicity around the use of 1080 in New Zealand. A comprehensive record

Table 2 Acute oral toxicity (LD_{50} mg/kg) of sodium fluoroacetate (1080).

Species	LD_{50} mg/kg	Reference
Dog (*Canis lupus familiaris*)	0.07	b
Rabbit (*Oryctolagus cuniculus*)	0.4	a, b
Cow (*Bos taurus*)	0.4	b
Deer (Family: Cervidae)	0.5	a
Rat (*Rattus* sp.)	1.2	b
Possum (*Trichosurus vulpecula*)	1.2	a, b
Weka (*Gallirallus australis*)	8.0	a
Duck (Family: Anatidae)	9.0	b

Notes: These results represent a very small proportion of the LD_{50} data available in the literature; [a]Rammell & Fleming 1978; [b]Eisler 1995.

of dog poisoning incidents throughout all of the years that 1080 has been used in New Zealand has not been kept. However, 254 dogs were reported killed by 1080 during the period 1960–1976 (Rammell & Fleming 1978), thus reinforcing the knowledge that dogs are very susceptible to secondary poisoning by 1080 (e.g. Eason et al. 2011; Goh et al. 2005). Working farm dogs and hunting dogs are especially susceptible, often because they are in or near operational areas. While the risks of 1080 to other non-target species are still important, for the above reasons, susceptibility of dogs from 1080 poisoned carcasses is highlighted here.

The slow breakdown of 1080 in possum carcasses (Meenken & Booth 1997) poses a risk to dogs, a fact that has been known for many years (Rammell & Fleming 1978). Based on the LD_{50} for dogs of 0.07 mg/kg (Meenken & Booth 1997), a 20 kg dog would be seriously at risk if it consumed 200 g of toxic offal containing 7 mg/kg. When considering the results of the persistence study of 1080 in possum carcasses (Meenken & Booth 1997) five out of six possum carcasses at day 25, and four out of 10 at day 75, exceeded this threshold (Meenken & Booth 1997). One of six possum carcasses at day 25 contained 70 mg/kg, which is 10 times the amount needed to kill a 20 kg dog (Meenken & Booth 1997). The results of Ross and McCoskery (2012) imply that a 20 kg dog would need to consume 2.4 kg of deer marrow at the concentration seen at day 30 to be seriously at risk of secondary 1080 poisoning. Dogs therefore potentially remain at risk of secondary poisoning from carcasses for months after the poisoning operation has ended, and dog owners should be made aware of this via 1080 signage around the operational area.

To further reduce the risk to dogs, a better understanding of their scavenging pattern would be useful. Typically, dogs eat the stomach of a carcass first; however, it is unknown which part of the carcass will be attractive after this, or at different times during decomposition. If bones become attractive at some point, then the risk of poisoning from bone marrow of 1080-poisoned carcasses becomes even more pertinent. The studies by Meenken and Booth (1997) and Ross and McCoskery (2012) indicate that most 1080 in carcasses should have degraded after 6–9 months, although it cannot be guaranteed that carcasses pose absolutely no risk, even after this length of time. The question of scavenging pattern also applies to other non-target species, not just dogs, and research to fill these gaps would be worthwhile.

1080 exposure in other non-target species, and food web transfer risks

Metabolism of 1080 occurs in living animals, but metabolic and excretion processes cease once an animal dies. Hence, 1080 is not metabolised in carcasses, instead degrading over time, probably by microorganisms as part of the putrefaction process that occurs after death. These processes are slow, as shown by the persistence of 1080 for many months in possum (Meenken & Booth 1997) and Sika deer carcasses (Ross & McCoskery 2012). The risk to non-target wildlife from 1080-poisoned carcasses will therefore depend on their likelihood of exposure, the susceptibility of different species, the pharmacokinetics of 1080 in the non-target species and the concentration of 1080 in the carcass, as well as what part and how much of the carcass is eaten. To a large extent, non-target species will be protected by their ability to detoxify 1080, although the biochemical basis for tolerance and species variation is not clear (Twigg et al. 1988; Twigg 1994). Food web transfer will be limited, as with each trophic level increase, the amount of 1080 present will be reduced given it does not readily bioaccumulate (Rammell 1993; Eason et al. 1994c). This is in contrast to biomagnification risks seen from other anticoagulant pesticides (Fisher et al. 2004).

In addition to studies investigating 1080 metabolism in mammals, research has also been undertaken in invertebrates, as they have been observed eating baits and 1080-poisoned

carcasses (Notman 1989). Under laboratory conditions, both cave and tree wēta (Family: Rhaphidophoridae and *Hemideina thoracica* respectively) were dosed with 1080. The persistence of 1080 residues at specified times after dosing was determined. 1080 was eliminated from wēta 6–10 days after exposure, and all wēta survived the maximum dose of 15 mg/kg (Eason et al. 1993a, b). Similar results were obtained from a laboratory study investigating 1080 exposure in a native ant (*Huberia striata*). Ants receiving a dose of 36 mg/kg of 1080 via sugar water metabolised this within 7 days, to a concentration of 0.27 mg/kg; however, some ants consumed enough 1080 to die (Booth & Wickstrom 1999). Field data monitoring insects for 1080 residues after toxic baits were aerially sown in forests for possum control were collected from 2 days, 1, 2, 3, 4, 8 and 16 weeks after baits were dropped. Results showed no 1080 was found in living earthworms (Order: Lumbricina), spiders, beetles, millipedes or centipedes. 1080 was found in some cockroaches (Family: Blattidae), tree wēta, and cave wēta during the period that baits were on the ground; however, after 3–4 weeks, all invertebrate samples were free from 1080 residues (Eason et al. 1993b). Whether any of these invertebrates died from consuming 1080 was not determined under field conditions; however, in insects where 1080 residues are found, there is always the chance of mortality. 1080 has been investigated as an insecticide for the control of fleas, wasps and aphids (Spurr 1994b), which indicates the potential of 1080 to kill invertebrates.

These results are consistent with observations that large invertebrates can eat both cereal and carrot bait (Spurr & Drew 1999), and indicates that 1080-poisoned carcasses are less important than direct consumption of 1080 baits for invertebrates. However, in either case, the window of opportunity for 1080 transfer from insects to insectivores is likely to be short-lived. These studies indicate that if invertebrates are contaminated by eating 1080-poisoned carcasses, they will void the toxin over a few days and the risk of tertiary 1080 transfer to insectivores will be limited.

These field and laboratory results for invertebrates show that 1080 is consumed by some invertebrate species, and therefore a risk of secondary poisoning exists. However, the persistence of 1080 in insects is short-lived, and thus the risk to insectivorous birds or other predators is confined to a short period after sowing poison baits. While there is a theoretical risk from carcasses via invertebrates to birds or other predators, previous field monitoring of invertebrates and birds has shown that long-term population effects on non-target birds and invertebrates, via both primary poisoning from baits and secondary poisoning from 1080-poisoned carcasses, is unlikely (Spurr 1994a, b; Spurr & Drew 1999). Furthermore, it is well recognised that a number of animals (e.g. *Sminthopsis crassicaudata*, a small Australian marsupial; *Dasyurus maculatus*, the spotted tailed quoll; and up to 18 other small mammals) are able to detect 1080 in their food, and either refuse to eat it, or reduce their consumption of 1080-poisoned food (Sinclair & Bird 1984; Calver et al. 1990; Kortner et al. 2003). This phenomenon may also work to protect birds, although the use of bird repellents is still considered essential to deter birds feeding on poison baits because of the number of at-risk species in New Zealand.

Bird species are able to metabolise 1080 (Eisler 1995). One example is the mallard duck (*Anas platyrhynchos*). In a laboratory study, concentrations of 1080 peaked in heart muscle and blood 4–8 hours after dosing, but had been markedly eliminated 24 hours after dosing (Ataria et al. 2000). Another example is the emu (*Dromaius novaehollandiae*), which has a high LD_{50}, particularly in areas where it has had evolutionary exposure to fluoroacetate containing plants (i.e. Western Australia). This species is reported as having an extensive capacity to detoxify fluoroacetate by defluorination (Twigg et al. 1988). However, as with the variation in LD_{50} observed among non-native bird species (Eisler 1995), metabolism

rates will also vary. There is limited information on the LD_{50} for many native New Zealand birds because of the contentiousness of conducting fatal testing on species we are trying to protect.

Despite improvements in baits for luring target species, Veltman and Westbrooke (2010) have highlighted uncertainties and the need for continued vigilance to reduce non-target impacts on birds. We conclude that these risks are more likely to occur through primary rather than secondary or tertiary poisoning routes, and suggest that more accurate LD_{50} are calculated for other at-risk native bird species using modelling approaches based on LD_{50} data in comparable, non-native bird species. Further studies of at-risk native birds focusing on populations of data-poor species, as suggested in Veltman and Westbrooke (2010), should also be carried out, particularly when baiting practices or bait types change.

A risk of secondary poisoning from 1080 exists for cats (*Felis catus*) and mustelids (stoats [*Mustela erminea*] and ferrets [*Mustela furo*]) after aerial operations to control possums and rats (e.g. Gillies & Pierce 1999; Murphy et al. 1999). Both studies reported that all monitored cats and mustelids (Gillies & Pierce 1999), and stoats (Murphy et al. 1999) that were radiotracked after aerial operations of 1080, died. However, all of these mammalian predators are unwanted terrestrial vertebrate pests that prey on native species and, as such, their deaths are beneficial to conservation outcomes. Their susceptibility to secondary 1080 poisoning indicates there may also be a risk of tertiary poisoning. A risk of 1080-poisoned carcasses to scavenging pigs (*Sus scrofa*) may also exist, as well as a risk to humans from consuming animals that have received sub-lethal doses of 1080. However, no published data addressing these risks exist for pigs or humans. Nonetheless, if sub-lethal doses are consumed, evidence from earlier studies (see Eason et al. 2011 and references therein) indicates that these will be excreted.

Although 1080 poses a risk to non-target species via transfer through the food web, the risk from second-generation anticoagulants, such as brodifacoum, is greater because second-generation compounds are not substantially metabolised and excreted before death. A clear example of this risk is the elimination half-life of 1080 and brodifacoum in possum plasma—9 hours for 1080 (Eason et al. 1994c) versus approximately 8 days for brodifacoum—and even longer for brodifacoum in possum liver (>252 days; Eason et al. 1996). A number of examples of contamination in wildlife and detrimental impacts on non-target populations from secondary and tertiary poisoning by brodifacoum exist (e.g. Eason & Spurr 1995; Dowding et al. 1999; Empson & Miskelly 1999; Booth et al. 2001; Eason & Murphy 2001; Eason et al. 2002 and references therein).

Recommendations for operational and wildlife managers

Despite the risks to non-target species, 1080 use remains essential to protect New Zealand's meat export industry from TB, and for the conservation of native flora and fauna. Because of the heightened risk to dogs from 1080 poisoning, we recommend additional information be added to 1080 signage, urging dogs be kept on a leash when in or near an operational area for 3–6 months after the operation has ended because of the risk from poisoned carcasses. The time period should be viewed as a guideline only, because under different conditions, baits and carcasses will breakdown at different rates. Further, we would recommend that any carcasses (possum or other animals) found in easily accessible areas are removed and disposed of in an appropriate manner. However, we acknowledge that this is impractical in inaccessible terrain.

Conclusions

Although 1080 is a broad-spectrum toxin, there are some marked differences in susceptibility

between species (Table 2; Rammell & Fleming 1978; Eisler 1995). Dogs are extremely susceptible, and most other carnivores are highly sensitive to poisoning. Herbivores are less sensitive, and birds and reptiles are even more resistant (Atzert 1971; Rammell & Fleming 1978; Eisler 1995). 1080 also has insecticidal properties (Negherbon 1959; Notman 1989; Booth & Wickstrom 1999). Extensive information exists with regards to the acute toxicity of 1080 to a diverse spectrum of species, including birds, mammals and reptiles (Atzert 1971; Harrison 1978; Rammell & Fleming 1978; Eisler 1995).

1080 has the potential to cause secondary poisoning. Dogs are a special case because of their unique sensitivity to 1080. In possums that have been sub-lethally poisoned, 1080 has a half-life of 9 hours, suggesting no significant amount of 1080 would be expected in the tissues of live possums 4 days after exposure. By contrast, 1080-poisoned possum carcasses collected from the field were shown to pose a serious risk to dogs even up to 75 days after the poisoning operation. Concentrations in deer bone marrow were <1 mg/kg, which implies that >1 kg of marrow would need to be eaten (Ross & McCoskery 2012), but 1080 can persist beyond 213 days. 1080 concentrations found in the stomachs of poisoned deer (mean at 9 days, 12.8 mg/kg; Ross & McCoskery 2012) were lower than those recorded in poisoned possums (mean at 25 days, 30.6 mg/kg; Meenken & Booth 1997). Hence it could be that higher concentrations occur in the marrow of possums and it would be of value to repeat the bone marrow versus tissue trial in poisoned possums to enable the risk to dogs from possum bone marrow, and the full extent of persistence in bone marrow, to be further clarified.

When other species, such as insects or birds, come into contact with 1080 in poisoned carcasses, sub-lethal poisoning, further biodegradation, and limited trophic transfer are the likely outcomes because insects and birds are less sensitive to 1080 than dogs. In cases of sub-lethal poisoning, any 1080 ingested will be metabolised and excreted, and trophic transfer will be minimal when compared to other more persistent poisons used for possum control. Ongoing research will help us to further minimise negative impacts of 1080 use on non-target species.

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