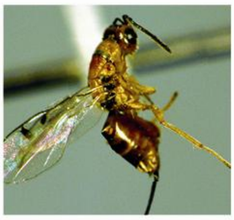
Non-target risks of using 1080 and pindone for rabbit control

Envirolink Advice Grant 1250-MLDC82



Landcare Research
Manaaki Whenua

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Summary

Project and Client

- Landcare Research (Envirolink 1250-MLDC82) undertook a review for Marlborough District Council of current knowledge regarding the risks to non-target animals from the use of the vertebrate pesticides sodium fluoroacetate (1080) and pindone for rabbit control. The review identified future information needs that would address priority gaps in knowledge to improve assessments of non-target risk.

Objectives

- Summarise current research knowledge and field/operational experience of the non-target effects of New Zealand rabbit control using toxic baiting.
- Complete a desktop evaluation of non-target risks potentially associated with the use of 1080 and pindone for rabbit control.
- Identify information gaps that currently limit understanding of non-target risk, and propose means to address these gaps.

Methods

- Science publications, unpublished research and operational reports and databases were reviewed to summarise information with relevance to rabbit baiting practices used in New Zealand, and the potential associated risk to non-target animals.
- A ranking of primary and secondary risk to non-target taxa (mammals, birds, reptiles, invertebrates) was compiled and used to identify information gaps and potential priorities for operational modifications to rabbit baiting practices, and recommendations for future field monitoring and research approaches.

Results

- Bait quality and toxic loading are key determinants of primary risk to non-target animals, particularly for chopped carrot bait.
- The suite of non-target animals potentially affected by rabbit baiting operations will vary with location
- Risk analyses for use of pindone were constrained by lack of relevant data from both experimental and field studies.
- Both 1080 and pindone baits for rabbit control pose significant risks of primary poisoning to non-target species, particularly mammmals and birds
- Use of both 1080 and pindone baits for rabbit control poses some risk of secondary poisoning to non-target species, particularly introduced mammalian carnivores
- Risks for non-target species from use of 1080 generally appear somewhat higher than from use of pindone, even though risks from pindone may have been over-estimated by use of multiple daily intakes rather than single doses.

- Information gaps related to use of 1080 and, particularly, pindone baits for rabbit control were identified in all components of the risk assessment process.

Recommendations

- Estimates of the annual usage of pindone and relative use of carrot, pellet and oat baits for rabbit control across New Zealand would help to prioritise areas where primary risk to non-target animals is likely to be highest.
- Field-prepared samples of both 1080 and pindone carrot bait should be monitored for size distribution, chaff content and toxic loadings of bait size classes to check whether primary risk is being minimised by current best practice.
- The rates at which toxic baits are removed, and by which animals, after aerial application for rabbit control should be assessed across a variety of field situations. Evaluation of the associated degradation / detoxification rates of uneaten bait would further assist in characterising the extent and duration of primary non-target hazard.
- Similarly, field assessments of the availability of rabbit carcasses to scavengers following 1080 or pindone baiting, and the rates at which carcasses degrade under various environmental conditions would provide increased certainty around secondary non-target risk.
- The suite of non-target animals potentially affected by rabbit baiting operations will vary with location. Rabbit areas that also have relatively high diversity of native wildlife species, (particularly where high profile native birds such as the New Zealand falcon or kea are present) should be considered as sites for formal monitoring of impacts on non-target populations, with a focus on detection and confirmation of the extent of mortality attributable to non-target poisoning.

1 Introduction

Declining efficacy of the rabbit haemorrhagic disease virus introduced to New Zealand in 1997 (Parkes et al. 2008) is driving renewed broad-scale application of conventional rabbit control methods such as shooting and poison baiting. Two vertebrate toxic agents (VTAs) are currently registered for rabbit control – 1080 (sodium fluoroacetate) and pindone (2-pivalyl-1,3-indandione). They are distinctly different in terms of their effects on metabolism and toxic action, and progression of poisoning in animals.

The main toxic action of 1080 is to inhibit cellular energy production (Twigg & Parker 2010). In mammals, signs of 1080 poisoning usually become evident within 3 h and death generally occurs within 24 h of a lethal exposure (e.g. McIlroy 1982a). 1080 has well-documented, broad-spectrum toxicity to mammals, birds and invertebrates (e.g. Eisler 2000). Animals that are sublethally exposed to 1080 metabolise and excrete it over a few days (Eason et al. 1997). There is no antidote for 1080 poisoning so veterinary treatment is largely symptomatic and supportive, and must be initiated rapidly to maximise the probability of survival (Shlosberg & Booth 2004).

Pindone is one of a range of anticoagulants that act to inhibit the formation of blood clotting factors in the liver, with lethal exposures eventually causing death through haemorrhage (World Health Organisation 1970). Anticoagulants in general have a delayed onset of action, and poisoning may not be evident for some days after ingestion of a lethal dose. In rabbits, the first signs of illness after pindone bait ingestion occur on average 8.5 days, and death at 10.7 days (Landcare Research, unpubl. data). Pindone has high acute toxicity to mammals, and based on limited data, also to birds. Its oral toxicity is substantially increased when repeateed doses are ingested, with less pindone required for a lethal dose when oral exposure occurs over a number of days (Twigg et al. 1999). There is an effective treatment (administration of Vitamin K_1) for accidental anticoagulant (including pindone) poisoning (Shlosberg & Booth 2004).

Marlborough District Council contracted Landcare Research (Envirolink 1250-MLDC82) to undertake a review of current knowledge regarding the risks to non-target animals in using the vertebrate pesticides sodium fluoroacetate (1080) and pindone for rabbit control. Future information needs are described that would address priority gaps in knowledge, towards improved assessments of non-target risk.

2 Background

The aerial application of 1080 bait for broad-scale control of possums and rodents in New Zealand has prompted considerable ongoing research and evaluation of the risks of accidental poisoning to domestic non-target animals and wildlife populations. Caution is required in directly extrapolating these findings to the use of 1080 for rabbit control, particularly in assessing primary non-target risk (where non-target animals eat bait) because there are differences in bait type, toxic loading and broadcast application rates between possum and rabbit baiting operations.

Higher concentrations of 1080 (0.08–0.15% w/w) are used in bait for possum and rodent control than for rabbit control. The latter include chopped carrot (0.02% w/w), oats (0.04%

w/w), cereal pellets (0.04% w/w) and paste (0.06% w/w). An estimated 600 t of carrot bait was used for rabbit control in 2012, comprising approximately 90% of the 1080 bait applied for rabbit control. Use of other 1080 bait types were approximated estimated as oats (9.5%,) pellets (0.4%) and paste (0.1%) (B. Simmons, Animal Control Technologies, pers. comm). In 2011, fourteen out of fifteen aerial 1080 rabbit control operations used 0.02% carrot baits with the other using 0.04% pellet baits (EPA 2012).

Pindone is also registered for possum and rodent control in bait stations only using a 0.05% pellet bait. Cereal pellet bait for rabbit control contains 0.025% pindone by weight, with two pellet formulations available, the 'Agtech' and 'RS5'. Both can be used for ground-based control, but only the latter is registered for aerial application at rates approximating 5 kg/ha (Malcolm Thomas, Pest Management Services, pers. comm.). A liquid concentrate containing 3.4% pindone is also registered, for application to chopped carrot or oat baits for rabbit control. Pindone is applied to carrot at a target rate of 0.17 gm/kg (i.e. 0.17% pindone) (NPCA 2012). Few (if any) pest managers in New Zealand currently use pindone oat bait for rabbit control perhaps because of the perceived primary risk of oat baits to grazing stock or granivorous birds. Estimates of the annual usage of pindone and relative use of carrot, pellet and oat bait with pindone were not available.

The habitats and ecosystems in which 1080 and pindone are used for rabbit control can differ substantially from those where the same toxins are used to control possums and rodents. The latter is typically undertaken in forested or bush margin areas to protect biodiversity values or for bovine tuberculosis vector (possum) supression. In contrast, rabbit control is typically conducted on cleared agricultural land, which is often dry and considered 'rabbit prone', to prevent damage to pasture, crops or forestry and reduce soil erosion. Rabbit baiting with pindone, unlike 1080, is sometimes used in areas close to human habitation, such as coastal reserves or lifestyle blocks where rabbits cause browse damage to natural vegetation or plantings.

3 Objectives

- Summarise current research knowledge and field/operational experience of the non-target effects of New Zealand rabbit control using toxic baiting.
- Complete a desktop evaluation of non-target risks potentially associated with the use of 1080 and pindone for rabbit control.
- Identify information gaps that currently limit understanding of non-target risk, and propose means to address these gaps.

4 Methods

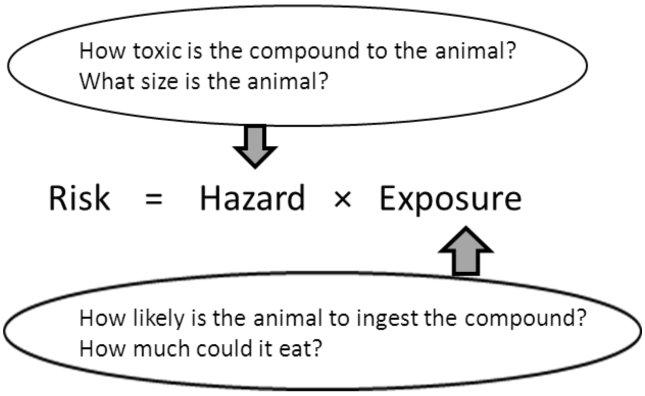
A literature review was undertaken, covering peer-reviewed scientific publications, unpublished material available from pest management agencies, and data available through the Vertebrate Pesticide Residues Database maintained by the Landcare Research Toxicology Laboratory, with special focus on New Zealand uses for pest animal management and the context of 1080 or pindone use for rabbit control.

Desktop (computer) assessments of non-target risk were made using the following approach:

- Animals were categorised by general groups and dietary habits rather than by species into mammals (carnivores, omnivores and herbivores), birds (granivores, omnivores, insectivores, and raptors), reptiles and invertebrates. Species in each category present in New Zealand were identified as representatives for use in the desktop assessment.
- Oral toxicity data for 1080 and pindone were summarised (Appendix 1), using 'lethal dose' estimates usually expressed as an LD_{50} value, which is the amount of ingested toxin (mg) per unit of animal bodyweight (kg) required to kill 50% of the tested number of animals. Where multiple toxicity values were available for the same combination of toxin and animal species, one value was selected using criteria of highest statistical confidence, conservatism (i.e. the estimate of highest toxicity) and the robustness of the test methodology used to estimate toxicity. Where a toxicity value was not available for an animal species, an available value for a similar species was used.
- Using known toxicity values and bodyweight ranges for different non-target animals, estimates were made of the amounts of toxic bait used for rabbit control (primary poisoning risk) or natural food items with toxic residues (secondary poisoning risk) that animals would need to ingest to be at risk of mortality.
- Available research and operational data concerning the evaluation of effects on non-target wildlife (both individual mortalities and population effects) from rabbit control using baiting were summarised to provide field-based evidence to complement the 'desk top' risk assessment.

5 Results

The simplistic relationship of risk = hazard × exposure was applied to derive rankings of very high to low risk for non-target species.



The 'hazard' component is indexed by the oral toxicity expressed as an LD_{50} value (Appendix 1). Use of LD_{50} values to estimate non-target risk rankings represents a 50% chance of mortality in individual animals through poisoning. Within a population, some individuals will be at relatively higher or lower risk of poisoning as a function of variable susceptibility to the toxin, e.g. some individuals could survive ingestion of quantities of bait that would kill conspecifics of similar bodyweight. The 'exposure' component estimates the likelihood of a particular animal ingesting the toxic compound and how much it could eat. This typically includes consideration of the animal's diet, habitat and size.

Risk rankings of very high, high, medium or low were determined by the amount of toxic bait/contaminated-prey considered likely to be lethal to an animal, in relationship to the bodyweight of the animal. 'Very high' risk was where an amount of toxic food less than 1% of an animal's bodyweight would be lethal, 'high' risk 1–5% of bodyweight, 'medium risk 5–10% of bodyweight and 'low' risk greater than 10% of bodyweight.

5.1 Primary poisoning risk

Non-target animals that might or are known to consume carrot, cereal pellet or oat bait and hence may have primary exposure to 1080 or pindone during rabbit baiting are summarised in Table 1. This is a representative summary rather than a comprehensive listing of wildlife that may be present in areas with rabbits, in particular for bird species.

For species not listed, broad extrapolations are possible from this theoretical assessment of risk. These should be made from the appropriate combination of group, diet category and weight range. The biggest assumption underlying such extrapolation is that of similar susceptibility to 1080 or pindone poisoning. Far more oral toxicity data are available for 1080 than for pindone (Appendix 1), representing a significant information gap for the latter. Hence for many groupings of non-target wildlife, the estimates of non-target risk for 1080 have higher certainty than those for pindone.

In the context of rabbit control using toxic baits, other factors that influence whether a non-target animal might ingest a lethal amount of bait include:

- Size and toxic loading of bait pieces – how many pieces of bait represent a lethal exposure?
- Application rate of bait – how likely is the animal to encounter and consume a lethal quantity of bait?
- Rate at which bait is removed or degraded after application - how long is the bait available and toxic?

Table 1 Representative non-target animal species that might or are known to consume carrot, cereal pellet or oat bait. Weight ranges for mammals were obtained from King (1998), and for birds from Heather & Robertson (1996), with the author's own estimates of weights for skinks and invertebrates

Group	Diet	Representative species	Weight range
Mammals	Omnivore	Mouse	15–20 g
		Rat (black, Norway)	55–200 g, 100–350 g
		Hedgehog	300–1300 g
		Pig	40–200 kg
	Herbivore	Hare	3.0–3.5 kg
		Possum	2.0–4.5 kg
		Sheep	40–65 kg
		Fallow deer	50–80 kg
		Red deer	80–150 kg
		Cow, horse	100–800 kg
Birds	Herbivore	Paradise shelduck	1400–1700 g
		Canada goose	4.5–5.4 kg
	Insectivore+herbivore	Blackbird	90 g
		California quail	180 g
		Goldfinch	15 g
		Pheasant	1100 g
	Omnivore	Kea	800–1000 g
		Waxeye	13 g
		Black-backed gull	850–1050 g
		Mallard duck	1100–1300 g
Reptiles		Skinks / Geckoes	5-50 g
Invertebrates		Ants, beetles, bees	<1 g

5.1.1 1080

There is a relatively large body of data regarding the oral toxicity of 1080 to many species (Appendix 1, Table A1), providing reasonable confidence in theoretical estimates of non-target risk. Table 2 shows the risk rankings for primary poisoning in non-target animals, assuming they would readily ingest the different bait types (carrot, pellet, oat or paste) used to deliver 1080 to rabbits. Overall there is a high to very high primary poisoning risk to mammals and birds that eat these bait types and from those bait types with higher 1080 concentrations e.g. paste bait, present a greater hazard. There is sparse information regarding the uptake of rabbit bait types by non-target wildlife, although carrot and oat bait at least are likely to be acceptable to the species listed in Table 2. For example, the acceptability of paste bait to non-target animals (apart from possums) is not well known. The relatively low use of oat bait for rabbit control is presumed due to the likely high acceptance of oats by herbivorous (granivorous) birds and subsequent high to very high risk (Table 2).

Table 2 Rankings of primary poisoning risk to non-target wildlife, from ingestion of 1080 bait used for rabbit control. 'Very high' risk is where an amount of toxic food less than 1% of an animal's bodyweight is likely to be lethal, 'high' risk 1–5% of bodyweight, 'medium risk 5–10% of bodyweight and 'low' risk greater than 10% of bodyweight

		Risk category		
Group/diet	**Species**	**0.02% 1080 carrot bait**	**0.04% pellet or oat bait**	**0.06% paste bait**
Mammals	Mouse	High	High	High
Onmivore	Black rat	Very high	Very high	Very high
	Norway rat	Very high	Very high	Very high
	Hedgehog	Very high	Very high	Very high
	Pig	High	High	Very high
Mammals	Hare	Very high	Very high	Very high
Herbivore	Possum	Very high	Very high	Very high
	Sheep	Very high	Very high	Very high
	Fallow deer	Very high	Very high	Very high
	Red deer	Very high	Very high	Very high
	Cow, horse	Very high	Very high	Very high
Birds	Paradise shelduck	High	Very high	Very high
Herbivore	Canada goose	High	Very high	Very high
Birds	Blackbird	High	Very high	Very high
Herbivore + Insectivore	California quail	High	High	Very high
	Goldfinch	High	Very high	Very high
	Pheasant	High	High	Very high
Birds	Kea	High	Very high	Very high
Omnivore	Waxeye	High	High	High
	Black-backed gull	High	Very high	Very high
	Mallard duck	High	Very high	Very high
Reptiles	Skinks	Low	Low	Low
Invertebrates	Ants	Low	Low	Medium
	Others	Medium	High	High

There have been very few field assessments of non-target risks from 1080 rabbit baiting. In North Canterbury some incidental kill of possums occurred as the result of rabbit control using aerial 0.02% carrot bait (Hickling et al. 1999). A study to assess the impact of carrot baiting on population of California quail in Central Otago had inconclusive results (Evans & Soulsby 1993). In recent 1080 carrot baiting trials in Otago, the carcasses of a fallow deer, one blackbird and two dunnocks (*Prunella modularis*) were opportunistically observed the day after bait application (D. Latham, Landcare Research, pers. comm). The deer was confirmed by residue testing as poisoned but the birds were not tested.

The largest overall potential for primary non-target poisoning is associated with aerial application of 0.02% 1080 carrot bait because that is by far the most commonly used bait formulation for rabbit control. Factors that influence whether a non-target animal might ingest a lethal amount of carrot bait include the size and toxic loading of carrot pieces (how many pieces of bait represent a lethal exposure?), the application rate of bait (how likely is the animal to encounter and consume a lethal quantity of bait?) and the rate at which bait is removed or degraded after application (how long is the bait available and toxic?).

Size and toxicity of 1080 carrot bait pieces

The National Pest Control Agencies (NPCA) provides bait preparation and application guidelines (NPCA 2012), with a target size for carrot baits of 6 g mean, with 95% of baits weighing 3–9 g where bait is to be aerially distributed. A 16-mm screen is recommended to reduce the production of chaff. However, the Environmental Protection Authority (EPA) currently stipulates that the average size of the carrot pieces used for rabbit baiting after screening must be >6 g with <1.5% chaff (ERMA 2007), so there is room for greater consistency and tightening of the specifications for carrot bait used against rabbits in New Zealand.

Recent field assessment has shown considerable variability in the size and quality of carrot bait applied (Nugent et al. 2012). Monitoring of bait during two rabbit-control operations in 2010 showed the mean weight of screened diced carrot pieces after aerial sowing ranged from <0.5 g to 13.2 g, with 32–55% (by number) of the bait pieces <1 g, so that the mean weight was only 1.7–2.5 g. Fewer than 17% of the number of bait pieces were in the 4–6 g range. Similar findings from New Zealand rabbit baiting operations were reported in 1982 (Fraser 1985). The concentration of 1080 within individual carrot pieces also varies widely (see review by Nugent et al. 2012) due to relative amounts of epidermis and parenchyma cells in the chopped carrot and differences in size and shape of carrot pieces. Where there are increased w/w concentrations of 1080 with decreasing size of bait (e.g. Batcheler 1982), non-target risk is increased because less bait is required for a lethal exposure. Nugent et al. (2012) reported that the majority of baits in 2010 operations contained <0.3 mg of 1080 each – which is likely to be a lethal amount for some dogs, some small birds and rodents.

Poorly prepared carrot bait is well recognised as likely to decrease the efficacy of rabbit control but current manufacturing and distribution practices can still produce large numbers of small carrot fragments that are sublethal to rabbits. Such practices also increase the risk of unwanted non-target mortality – chaff pieces may be sublethal to rabbits but potentially lethal to animals that are highly sensitive to 1080, e.g. dogs and also animals that are small (<50 g) in size. Nugent et al. (2012) suggest the production of uniformly sized toxic baits in the range of 4–6 g should lead to significant and immediate improvement in the efficacy of rabbit baiting programmes. That is also likely to reduce primary poisoning risk to non-target species that may feed on small chaff pieces of 1080 carrot bait.

Aerial application rates of 1080 carrot bait

The NPCA (2012) recommends aerial application rates of 20–40 kg bait per hectare, depending on the density of the rabbit population to be controlled. In 2011, 1080 was aerially-applied for rabbit control over approximately 10 000 ha (2.6% of the extremely rabbit prone land) in Otago and Canterbury, at rates varying between 8 and 30 kg of bait per hectare (EPA 2012). High broadcast coverage of 1080 bait is intended to maximise the rates at which rabbits encounter and consume bait, but will have the same effect for non-target wildlife that find carrot acceptable. However, there is no information about the extent to which wildlife (including invertebrates) in New Zealand contributes to the removal of carrot bait from an operational area after aerial application, and whether this results in non-target mortality that is significant at a population level.

Degradation of 1080 carrot bait in field conditions

The acceptability of carrot bait to rabbits is maximised when the carrot is good quality and freshly prepared but decreases rapidly as the carrot degrades or dehydrates in field conditions (Allen & Fisher 1999). This may also hold true for acceptance by some non-target wildlife; but other species may also accept degraded carrot bait, especially small pieces that rabbits generally would reject.

Once applied, removal of some bait through ingestion by rabbits reduces potential availability to non-targets. Once rabbits start dying (generally within 24 h of a lethal exposure), remaining bait is a non-target hazard until toxic concentrations decline through biodegradation by microorganisms, leaching through exposure to moisture, or dehydration. These processes may also change (decrease or increase) the acceptability of bait to non-target wildlife.

Carrot bait in the field can rapidly dehydrate in dry, hot conditions. This will incidentally increase the weight:weight toxic concentration of each piece of bait because as water (weight) is lost through evaporation, the amount of 1080 in the bait remains the same. Chopped carrot may also blacken and shrivel in frosty conditions, and it is not known how this might affect the 1080 concentration. Blackening may make remaining bait less visible to human observers (as it loses the green dye over orange colour of freshly prepared bait) and perhaps give a misleading impression of high bait uptake by rabbits. A study of leaching of 1080 from carrot baits for possum control containing 0.08% 1080 using simulated rainfall (Bowen et al. 1995), found carrot baits were highly water-resistant and showed no decline in 1080 concentration after 200 mm of rain. There has been no equivalent assessment of leaching of 1080 from 0.02% carrot bait for rabbits; early research (Staples 1968) found that while rainfall was an important factor in the degradation of carrot bait, it was not possible to determine appropriate periods to withhold livestock from treated areas. The selection of a 0.02% toxic loading for 1080 in carrot bait for rabbits appears to be based on concerns regarding potential risks to domestic livestock from uneaten bait (Nugent et al. 2012) and minimising the period until baited areas could be restocked.

We could not find any formal field assessments of the degradation of 0.02% carrot bait under a range of environmental conditions, nor assessments of the uptake of carrot bait (as applied for rabbit control) over time by both rabbits and non-target wildlife, including invertebrates. Such information would increase the certainty around estimates of non-target risk.

5.1.2 Pindone

Compared with the available toxicity information for 1080 there are relatively few estimates of pindone toxicity (Appendix 1, Table A2) and many of these have low precision. Accordingly, many of the risk rankings for primary poisoning for various non-target animals (Table 3) are based on LD_{50} values extrapolated from another species, which further increases the uncertainty of the risk estimates.

Table 3 Rankings of primary poisoning risk to non-target wildlife, from ingestion of pindone bait used for rabbit control. Risk was ranked against single or multiple daily exposures to freely available bait, indicated as the number of days' exposure in brackets. 'Very high' risk was where an amount of toxic food less than 1% of an animal's bodyweight is likely to be lethal, 'high' risk 1–5% of bodyweight, 'medium risk 5–10% of bodyweight and 'low' risk greater than 10% of bodyweight

		Risk category	
Group /diet	**Species**	**0.025% pellet bait (number of daily exposures)**	**0.017% carrrot bait (number of daily exposures)**
Mammals Onmivore	Mouse	Very high (5 days)	Very high (5 days)
	Black rat	High (5 days)	Medium (5 days)
	Norway rat	High (5 days)	Medium (5 days)
	Hedgehog	High (5 days)	Medium (5 days)
	Pig	Very high (5 days)	Very high (5 days)
Mammals Herbivore	Hare	High (1 day), Very high (7 days)	Medium (1 day) Very high (7 days)
	Possum	Low (1 or 5 days)	Low (1 day), Low (5 days)
	Sheep	Medium (7 days)	Medium (7 days)
	Fallow deer	Medium (7 days)	Medium (7 days)
	Red deer	Medium (7 days)	Medium (7 days)
	Cow, horse	Medium (7 days)	Medium (7 days)
Birds Herbivores	Paradise shelduck	High (7 days)	High (7 days)
	Canada goose	High (7 days)	High (7 days)
Birds Herbivore + Insectivore	Blackbird	Very high (4 days)	High (7 days)
	California quail	Very high (4 days)	High (7 days)
	Goldfinch	Very high (4 days)	High (7 days)
	Pheasant	Very high (4 days)	High (7 days)
Birds Omnivore	Kea	High (5 days)	High (7 days)
	Waxeye	Very high (4 days)	High (7 days)
	Black backed gull	Very high (4 days)	High (7 days)
	Mallard duck	High (7 days)	High (7 days)
Reptiles	Skinks	Medium (1 day)	Medium (1 day)

Rabbits appear relatively susceptible to pindone in comparison with other mammals (Appendix 1, Table A2). An important difference from the primary risk profile of 1080 is that animals are generally far more susceptible to repeat doses of pindone than single doses, and so most of the available LD_{50} estimates are based on multiple-daily exposures for a nominated number of days. Accordingly, risk rankings shown in Table 3 are based on the number of days' exposure for which the underpinning LD_{50} value was estimated. In general, the amount of pindone ingested in a single exposure causing mortality is relatively much larger than the total quantities ingested over a number of days.

While no LD_{50} data for invertebrates were found, early research suggests that pindone and structurally similar compounds are toxic to some insects. Isomeric valeryl-1,3-indandiones exhibited strong insecticidal properties against houseflies (Kilgore et al. 1942). 2-pivalyl-1,3-indandione (pivalyl) showed toxic effects against body lice (Eddy & Bushland 1948), and 0.025% pivalyl cereal baits applied in field trials for rodent control also had insecticidal properties (Crabtree & Robinson 1953). There have been no assessments of the uptake and toxicity of pindone bait to New Zealand invertebrates, representing a significant information gap such that non-target risk to invertebrates cannot currently be estimated.

There are a small number of field observations and residue tests to indicate primary poisoning of some non-target birds, hedgehogs and reptiles. Birds found dead following pindone operations (no specifications on application available) include: plovers, rail, wrybills (*Anarhynchus frontalis*), waxeyes, grey warblers and Southern black-backed gulls. However, none of these were tested for pindone residues to confirm whether exposure had occurred, except three black-backed gulls that had liver pindone concentrations of 4.3–11 mg/kg (Fairweather & Fisher 2010). Liver from a live-sampled chaffinch (*Fringilla coelebs*) that was seen feeding on pindone bait (operation in Pukaki Flats, 2007) had liver concentrations of 3.5 mg/kg (Fairweather & Fisher 2010). More recently, liver pindone residues of 4.1 µg/g were measured in a hedgehog found dead after a 2011 pindone operation in Canterbury (Landcare Research unpubl. data).

A moko skink found dead following handlaying of pindone rabbit pellets as 3.3 kg/ha in Whangapoua Conservation Area, Great Barrier Island, in 2007 contained liver residues of 19 µg/g, and one of two green geckos found dead during pindone pellet (0.5 g/kg pindone) bait station operations at Boundary Stream, Hawke's Bay, in 2002/03 contained a whole body residue of 0.52 µg pindone per gram bodyweight (Fairweather & Fisher 2010).

Size and toxicity of pindone bait

Pindone pellet baits at manufacture are assumed to have high uniformity in bait size and toxic concentration, maintained by quality assurance procedures of the manufacturer. A laboratory trial of bait-weathering tested pellet baits (Agtech) that nominally contained 0.25 g/kg pindone and found a slightly higher concentration of 0.326 g/kg (Booth et al. 1999). Fragmentation of pellets during transport or aerial application may produce small bait pieces that are more easily ingested by smaller non-target bird species, but the extent to which such fragmentation occurs operationally is not known.

Because of the higher concentration of pindone used (Table 3) and greater potential variability in manufacturing procedures, chopped carrot bait has a higher theoretical primary non-target risk than pindone pellets. Chopped carrot baits must have a mean weight of 4 g or more, contain less than 5% (by weight) 'chaff' pieces weighing less than 0.5 g and contain no pieces with any dimension less than 16 mm (NPCA 2012). Pindone solution is sprayed onto chopped carrot bait, along with a green dye solution, to produce a toxic concentration of 0.17 g/kg (0.017% w/w). As for carrot bait containing 1080, poor preparation of pindone carrot bait not only decreases the efficacy of rabbit control but can also increase primary non-target risk.

A field assessment of freshly prepared carrot bait (July 1994, Wither Hills, south of Blenheim) measured a toxic concentration of 0.185 g/kg pindone, slightly higher than the nominal 0.17 g/kg (Boswell 1995). No other information was found regarding how well operationally-prepared pindone carrot bait meets requirements in terms of uniformity of bait size, chaff content and toxic concentration.

Application method and rates of pindone bait

Pindone baits (usually pellets) in bait stations are generally used where rabbit control is required close to human habitation, e.g. on lifestyle blocks. Use in bait stations prevents livestock and domestic animals from accessing toxic bait. Stations may also restrict access by some non-target wildlife but are unlikely to prevent invertebrates or rodents from accessing bait. Bait station applications are probably a minor use of pindone for rabbit control, with broadcast bait applications having higher potential for primary poisoning of non-targets because of the increased distribution and availability of toxic bait.

Aerial application of pindone carrot or oat baits is done by either the Department of Conservation, a regional council or other unitary authority. This restriction does not apply to pindone pellets (NPCA 2012). Aerial application rates specified on the label for pindone bait are 12–18 kg/ha, and current practice for aerial pindone baiting appears to be typically one prefeed followed by two toxic applications 3 to 7 days apart. As for aerial application of 1080 carrot bait for rabbit control, there is no information about the extent to which wildlife (including invertebrates) in New Zealand contribute to the removal of pindone bait (carrot, oat or pellets) from an operational area after aerial application, and whether this results in significant non-target mortality.

Degradation of pindone bait in field conditions

Pindone occurs in acid and salt forms, with the latter having higher water solubility. Carrot and oat baits manufactured by adding a solution made from pindone liquid concentrate (the salt form) are expected to leach more readily under wet conditions than pellet baits, which are manufactured using the less soluble pindone acid form.

In a laboratory study, Agtech pindone pellets exposed to simulated heavy rainfall (20 mm per hour) crumbled quickly and lost their shape after 300 mm rainfall. From an initial pindone concentration of 0.326 g/kg, the toxicity of the pellets declined to 0.279 g/kg after 100 mm of rain and then very slowly to 0.24 g/kg after 400 mm of rainfall (Booth et al. 1999). So even after substantial exposure to simulated rain, these pellet baits retained concentrations of pindone representing a primary non-target hazard. Following a 2007 baiting operation at Pukaki Flats, pindone rabbit pellets (0.25 g/kg) still contained 0.091 g/kg, 60 days after being laid (Fairweather & Fisher 2010). This suggests pindone pellet baits may remain sufficiently toxic for weeks, especially under dry conditions, to pose a non-target risk.

Pindone carrot baits appear to detoxify more quickly than pellet baits after broadcast application. Boswell (1995) reported that in freshly prepared carrot bait, the initial concentration 0.185 g/kg pindone declined to 0.108 g/kg after 1 day in field conditions and to 0.088 g/kg after 2 days. After 11 days and 26 mm rain, pindone concentration in the baits was 0.071 g/kg.

We found no formal assessments of the field uptake of pindone bait (carrot, pellet or oat) by both rabbits and non-target wildlife, including invertebrates. Such information would increase certainty around estimates of primary non-target risk.

5.2 Secondary poisoning risk

Non-target animals that may have secondary exposure to 1080 or pindone as the result of rabbit baiting are summarised in Table 4. All are known to or may scavenge rabbit carcasses and some are also known to prey on rabbits. Factors that influence whether a non-target animal undergoes secondary lethal exposure of 1080 and pindone through ingestion of tissues from poisoned rabbits include the residual concentration of 1080 or pindone in rabbit tissues and the availability/accessibility of contaminated live rabbits or the carcasses of poisoned rabbits.

Table 4 Non-target animal species that may or are known to prey on or scavenge rabbits and be secondarily exposed to 1080 or pindone. Weight ranges for mammals were obtained from King (1998), and for birds from Heather & Robertson (1996), with the author's own estimates of weights for invertebrates

Group	Diet category	Representative species	Weight range
Mammals	Carnivore	Stoat	200–350 g
		Ferret	400–1500 g
		Cat	1.5–4.0 kg
		Dog	5.0–50.0 kg
	Omnivore	Mouse	15–20 g
		Rat (black, Norway)	55–200 g, 100–350 g
		Hedgehog	300–1300 g
		Pig	40–200 kg
Birds	Omnivore	Kea	800–1000 g
		Black-backed gull	850–1050 g
	Raptor	Australasian harrier	650–850 g
		New Zealand falcon	300–500 g
Invertebrates	Omnivore	Ants, beetles	< 1 g

5.2.1 1080

We found no previous measurements of 1080 residues in rabbit carcasses recovered after baiting operations in New Zealand. An Australian study using ten rabbit carcasses collected after a baiting operation using 0.03% 1080 carrot bait (McIlroy and Gifford 1992) measured residual 1080 in samples of muscle, organs and stomach contents of the poisoned rabbits. In general, stomach contents (mainly masticated carrot bait) and liver contained the highest concentrations, followed by stomach, kidney, heart and muscle. The total amounts of 1080 in each of the ten rabbits are shown in Fig 1 as a summary of the relative secondary hazard of different tissues, e.g. although 1080 concentrations in muscle were lower than in other types of tissue, muscle represents a greater proportion of a carcass than the other tissues and is therefore a higher hazard to scavengers. Some rabbit carcasses were more hazardous than others due to variability in the residual concentrations of 1080 in different tissues, with total 1080 in carcasses ranging from 3.25 to 15.15 mg (Figure 1).

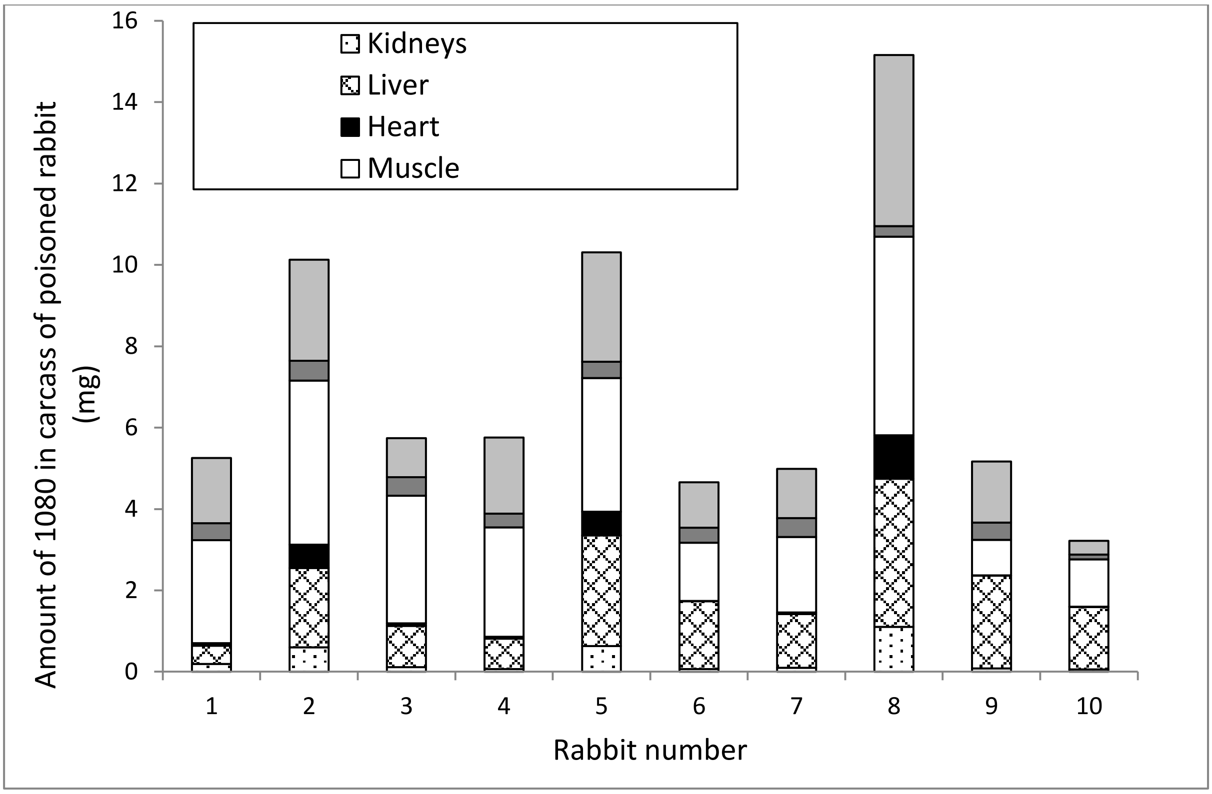


Figure 1 Total amounts of residual 1080 in the carcasses of poisoned rabbits (data from McIlroy & Gifford 1992).

Estimates of the mean (±SE) wet weight residual concentrations of 1080 were 6.1 ± 0.9 in rabbit muscle, 23.2 ± 4.2 in viscera and 22.3 ± 1.8 in stomach and contents (McIlroy & Gifford 1992). These mean values were used to rank secondary poisoning risk to predators and scavengers consuming rabbit muscle, viscera or stomach and contents (Table 5). This theoretical assessment is a general evaluation based on mean concentrations of 1080 rabbit carcasses, and not on the wide range of concentrations measured. Overall, mammalian carnivores, particularly dogs, are at high to very high risk of secondary poisoning particularly if they eat the viscera or stomach/contents of rabbit carcasses. Secondary risks to birds and invertebrates are low.

Table 5 Rankings of secondary poisoning risk to non-target wildlife, from ingestion of tissues from the carcasses of 1080-poisoned rabbits. ‘Very high’ risk was where an amount of toxic food less than 1% of an animal’s bodyweight is likely to be lethal, ‘high’ risk 1–5% of bodyweight, ‘medium risk 5–10% of bodyweight and ‘low’ risk greater than 10% of bodyweight

		Risk category	
Group/diet	**Species**	**Muscle**	**Viscera/Stomach and contents**
Mammal Carnivore	Stoat	Medium	High
	Ferret	Low	Medium
	Cat	High	High
	Dog	Very high	Very high
Mammal Omnivore	Mouse	Low	Low
	Black rat	Low	Medium
	Norway rat	High	Very high
	Hedgehog	High	Very high
	Pig	Low	Low
Bird Omnivore	Kea	Low	Low
	Black-backed gull	Low	Low
Bird Carnivore	Australasian harrier	Low	Low
	New Zealand falcon	Low	Low
Invertebrate Omnivore	Ants, beetles	Low	Low

New Zealand field studies have shown that ferrets are secondarily poisoned following rabbit control with 1080. Heyward and Norbury (1999) used radio-telemetry and residue testing of ferret carcasses to estimate that 7–15% of monitored ferrets apparently died of secondary 1080 poisoning in the two months following rabbit baiting. Secondary poisoning of cats also occurred, but mortality rates were not measured (Heyward and Norbury 1999).

The availability of rabbits to predators and scavengers following a 1080 baiting operation is likely to vary considerably, with increased risk where many rabbits die above ground e.g. where there are not extensive warrens. Moller, Clapperton *et al.* (1997) estimated that nine per cent of rabbit carcasses from 1080 poisoning operations in the Mackenzie Basin had been partly eaten by predators. Residual 1080 concentrations in degrading rabbit carcasses have not been measured, but are expected to be similar to those in degrading of possum carcasses, which have been more extensively investigated in the context of secondary poisoning risk. While warm and moist conditions favour relatively rapid degradation of 1080 in carcasses (e.g. Meenken and Booth 1997), the worst case scenario for duration of secondary hazard should assume residual 1080 persist in rabbit carcasses for months at low ambient temperatures and dry conditions – noting that many rabbit baiting operations are undertaken in winter.

5.2.2 Pindone

Recent research has documented residual concentrations of pindone in 24 rabbit carcasses collected after baiting operations in Tekapo, Wanaka and McLeans Island in the South Island of New Zealand (Table 6). The highest mean concentrations of pindone in rabbit liver, muscle and fat (from the McLeans Island sample) were used to rank secondary poisoning risks shown in Table 7. Currently, no data are available regarding the concentrations of pindone in stomach contents of poisoned rabbits, but residual concentrations ranging from 0.26 to 6.98 µg/g have been detected in caecal contents of rabbits during a week over which they ingested a lethal amount of pindone bait (Landcare Research, unpubl. data). These concentrations represent the latter stages of food (bait) digestion so are likely to be lower than pindone concentrations in rabbit stomach contents (representing masticated bait). For the secondary risk rankings across non-target animals consuming rabbit gut contents, the highest reported residue concentration of 6.98 µg/g was used.

Table 6 Pindone concentrations (wet weight) measured in liver, muscle and fat of rabbit carcasses collected after pindone baiting operations in 2011

	Mean (range) pindone concentration (µg/g)		
Field location	Liver	Muscle	Fat
Tekapo (*n*=12)	8.73 (2.6-1.5)	0.76 (0.4 -1.5)	5.54 (3.2-13.7)
Wanaka (*n*=9)	10.58 (3.14 – 17.1)	2.66 (0.59-4.62)	4.76 (<MDL-7.25)
McLeans Island (n=3)	23.00 (20.7 -25.8)	3.03 (1.86-4.04)	19.33 (14.2-27.5)

The estimated high secondary risk to dogs from feeding on gut contents, liver and/or fat of pindone poisoned rabbits is supported by research showing mortality of dogs fed over multiple days on the carcasses of nutria (*Myocastor coypus*) that had died of pindone poisoning (Evans and Ward 1967). While we found no confirmed instances of pindone poisoning in New Zealand dogs, there are numerous reports of anticoagulant poisoning and successful veterinary treatment in domestic dogs where clinical differentiation of the causative anticoagulant compound (including rodenticides) and confirmation of the exposure source was not undertaken. Thus instances of secondary pindone poisoning in dogs, particularly in farm dogs with access to rabbit carcasses, cannot be discounted.

The estimates of medium to high secondary risks (Table 7) of pindone to ferrets, cats, black-backed gulls and Australasian harriers have some substantiation in a small number of reports describing individuals of these non-target species found dead following rabbit control operations, where residue testing confirmed the presence of pindone in liver samples from the carcasses (Fairweather & Fisher 2010).

Table 7 Rankings of secondary poisoning risk to non-target wildlife, from ingestion of tissues from the carcasses of pindone-poisoned rabbits. Risk was ranked assuming multiple daily exposures to freely available poisoned rabbit/carcasses, indicated as the number of days' exposure in brackets. 'Very high' risk was where an amount of toxic food less than 1% of an animal's bodyweight is likely to be lethal, 'high' risk 1–5% of bodyweight, 'medium risk 5–10% of bodyweight and 'low' risk greater than 10% of bodyweight

		Risk category		
Group /diet	**Species**	**Muscle**	**Gut contents**	**Fat / Liver**
Mammal Carnivore	Stoat	Low (4 days)	Medium (4 days)	Medium (4 days)
	Ferret	Low (4 days)	Medium (4 days)	Medium (4 days)
	Cat	Low (4 days)	Medium (4 days)	Medium (4 days)
	Dog	Low (1 day), Medium (5 days)	Low (1 day), High (5 days)	Low (1 day), High (5 days)
Mammal Omnivore	Mouse	Low (5 days)	Low (5 days)	Medium (5 days)
	Black rat	Low (5 days)	Low (5 days)	Low (5 days)
	Norway rat	Low (5 days)	Low (5 days)	Low (5 days)
	Hedgehog	Low (5 days)	Low (5 days)	Low (5 days)
	Pig	Low (5 days)	Low (5 days)	Medium (5 days)
Bird Omnivore	Kea	Low (5 days)	Low (5 days)	Low (5 days)
	Black-backed gull	Low (4 days)	Low (4 days)	Medium (4 days)
Bird Carnivore	Australasian harrier	Medium (5 days)	High (5 days)	High (5 days)
	New Zealand falcon	Medium (5 days)	Medium (5 days)	Medium (5 days)

6 Discussion and conclusions

This report focuses only on mortality through poisoning as the ultimate 'risk' to non-targets. Sublethal effects of exposure to 1080 or pindone on long-term survival or reproductive fitness of non-target wildlife was not considered. Risks of primary or secondary poisoning outlined for domestic dogs, cats and livestock appear well enough described and understood to enable their effective management through current recommendations and regulations around toxic baiting for rabbit control, e.g. through destocking periods for treated grazing areas, adequate notification and signage around application areas, muzzling or confinement of dogs, etc.

There is a significant lack of toxicological and field-evidence data available for pindone. Far more specific information was available with which to assess non-target risks from 1080 exposure, with relatively less known about pindone and hence greater assumptions and extrapolation required in estimating risks. While 1080 receives greater public interest, community concern, and research and monitoring with regards to non-target risk than pindone, for some non-target wildlife (e.g. Australasian harriers) secondary risks are theoretically similar between the two toxins. Perceptions that pindone always has lower non-target risk than 1080 need to be assessed by addressing the identified information gaps for pindone.

Exposure of wild animals to toxic bait or poisoned rabbits is difficult to manage and whether the theoretical risks translate to population-level effects in operational settings of rabbit control can only be determined by operational monitoring of non-target species. For some non-target wildlife (e.g. reptiles, black-backed gulls and Australasian harriers), there is limited field evidence of individual non-target mortality from pindone use. For other wildlife (e.g. New Zealand falcon, invertebrates) there is a theoretical risk of poisoning but no field-based information to substantiate it. In the absence of population studies, any non-target mortality caused by rabbit control using 1080 or pindone is assumed to be compensated by increased productivity or survival after rabbit numbers are reduced. This may not be the case, especially in local populations of non-target species for which rabbits are an important food item rather than a competitor.

Incidental secondary poisoning of mustelids or feral cats as the result of rabbit baiting appears to be largely regarded as a benefit in terms of reducing local numbers of introduced predators. Again there is little information on the extent of such reductions and the associated ecological effects. For example, a potential downside to a sudden and significant decrease in local rabbit populations (through any effective form of rabbit control such as baiting, fumigation or shooting) is 'prey switching' behaviour by predators of rabbits, to alternative available prey such as birds, reptiles or invertebrates (Norbury 2001).

Increased application of 1080 and pindone is anticipated in areas with rabbit problems, particularly through aerial baiting. Greater field-based evidence to support best practise for minimising risks to non-target wildlife, particularly for pindone, will enable managers to better justify ongoing use of this technique for broad-scale rabbit control and current baiting practices.

7 Recommendations

- Estimates of the annual usage of pindone and relative use of carrot, pellet and oat baits for rabbit control across New Zealand would help to prioritise areas where primary risk to non-target animals is likely to be highest.
- Field-prepared samples of both 1080 and pindone carrot bait should be monitored for size distribution, chaff content and toxic loadings of bait size classes to check whether primary risk is being minimised by current best practice.
- The rates at which toxic baits are removed, and by which animals, after aerial application for rabbit control should be assessed across a variety of field situations. Evaluation of the associated degradation / detoxification rates of uneaten bait would further assist in characterising the extent and duration of primary non-target hazard.
- Similarly, field assessments of the availability of rabbit carcasses to scavengers following 1080 or pindone baiting, and the rates at which carcasses degrade under various environmental conditions would provide increased certainty around secondary non-target risk.
- The suite of non-target animals potentially affected by rabbit baiting operations will vary with location. Rabbit areas that also have relatively high diversity of native wildlife species, (particularly where high profile native birds such as the New Zealand falcon or kea are present) should be considered as sites for formal monitoring of impacts on non-target populations, with a focus on detection and confirmation of the extent of mortality attributable to non-target poisoning.

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Appendix 1 – Oral toxicity values

Table A1 Oral toxicity values for sodium fluoroacetate (1080) used to estimate risks of non-target mortality. Where available, 95% confidence intervals are shown in square brackets

Species	Oral toxicity as LD_{50} value (mg/kg)	Reference
	Mammals	
House mouse (*Mus musculus*)	8.3	McIlroy (1982b)
Black rat (*Rattus rattus*)	0.72	McIlroy (1982b)
Norway rat (*R. norvegicus*)	0.22	Dieke & Richter (1946)
Hedgehog (*Erinaceus europaeus*) *use value for Norway rat	None found 0.22	 As above
Stoat (*Mustela erminea*)	0.49 [0.29-0.70]	Spurr (2000)
Ferret (*M. furo*)	1.41	Tucker & Crabtree (1970)
Cat (*Felis catus*)	0.35	Eason & Frampton (1991)
Dog (*Canis familiaris*)	0.06	Chenoweth (1949)
Pig (*Sus scrofa*)	4.11 [3.02 – 5.34]	O'Brien (1988)
Hare (*Lepus europaeus*) * use value for rabbit (*Oryctolagus cuniculus*)	None found 0.42	 McIlroy (1982a)
Possum (*Trichosurus vulpecula*)	0.79	Bell (1972)
Sheep (*Ovis aries*)	0.25	Jensen et al. (1948)
Red deer (*Cervus elaphus*)	0.5	Rammell & Fleming (1978)
Fallow deer (*Dama dama*) *use value for red deer	None found 0.5	 As above
Cow (*Bos taurus*)	0.211 [0.149 – 0.327]	Robison (1970)
Horse (*Equus caballus*)	0.32	Atzert (1971)
	Birds	
Mallard duck (*Anas platyrhynchos*)	3.7	Hudson et al. (1972)
Paradise shelduck (*Tadorna variegata*) * use value for mallard (*Anas platyrhynchos*)	None found 3.7	 As above
Canada goose (*Branta canadensis*) * use value for mallard	None found 3.7	 As above
Black-backed gull (*Larus dominicanus)* * use value for mallard	None found 3.7	 As above
Spur-winged plover (*Vanellus miles*) * use value for mallard	None found 3.7	 As above
California quail (*Callipepla californicus*)	4.6	Hudson et al. (1984)
Blackbird (*Turdus merulus*) * use value for Brewers' blackbird	None found 3.0	 Atzert (1971)

(*Scolecophagus cyanocephalus*)		
Goldfinch (*Carduelis carduelis*)	3.5	McIlroy (1984)
Pheasant (*Phasinaus colchicus*)	6.46	Tucker & Crabtree (1970)
Kea (*Nestor notabilis*) *use value for sulfur-crested cockatoo (*Cacatua galerita*)	None found 3.5	 McIlroy (1984)
Waxeye (*Zosterops lateralis*)	9.25	McIlroy (1984)
New Zealand robin (*Petroica australis*) * use value for house sparrow (*Passer domesticus*)	None found 3.0	 Tucker & Crabtree (1970)
Fantail (*Rhipidura fuliginosa*) * use value for house sparrow	None found 3.0	 As above
Grey warbler (*Gerygone igata*) * use value for house sparrow	None found 3.0	 As above
Australasian harrier (*Circus approximans*) * use value for marsh hawk (*Circus cyaneus*)	None found 10.0	 Atzert (1971)
New Zealand falcon (*Falco novaeseelandiae*) * use value for marsh hawk	None found 10.0	 As above
Reptiles and invertebrates		
New Zealand skink species * use value for shingle-backed lizard (*Tiliqua rugosa*)	None found 206.0	 McIlroy et al. (1985)
Ant (*Huberia striata*)	42	Booth & Wickstrom (1999)
Honey bee (*Apis mellifera*)	8.0 (estimate)	Booth & Wickstrom (1999)
Other invertebrates, e.g. beetles, flies * use value for honey bee	 8.0	 As above

Table A2 Oral toxicity values for pindone used to estimate risks of non-target mortality. Where available, 95% confidence intervals are shown in square brackets. Single-exposure toxicity estimates are expressed as mg/kg and multiple-exposure toxicity values are expressed as mg/kg × number of daily exposures.

Species	**Oral toxicity as LD_{50} value (mg/kg or mg/kg x number of days)**	**Reference**
	Mammals	
House mouse (*Mus musculus*)	1.19 × 5 [0.67-2.00]	Ashton et al. (1987)
Norway rat (*R. norvegicus*)	12.80 × 5 [1.73-84.8]	As above
Black rat (*Rattus rattus*) * use value for Norway rat	None found 12.80 × 5	 As above
Hedgehog (*Erinaceus europaeus*) *use value for Norway rat	None found 12.80 × 5	 As above
Dog (*Canis familiaris*)	75 4[a] 0.3 × 5	Beauregard et al. (1955) Fitzek (1978) Twigg et al. (1999)
Cat (*Felis catus*)	1.0 × 4	Twigg et al. (1999)
Stoat (*Mustela erminea*) * use value for cat	None found 1.0 × 4	 As above
Ferret (*M. furo*) * use value for cat	None found 1.0 × 4	 As above
Pig (*Sus scrofa*) * use value for dog	None found 1.3 × 5	 As above
Hare (*Lepus europaeus*) * use value for rabbit (*Oryctolagus cuniculus*)	None found 13 0.52 × 7	 Twigg et al. (1999) Oliver & Wheeler (1978)
Possum (*Trichosurus vulpecula*)	>100 51.0 × 5	Eason & Wickstrom (2001) Jolly et al. (1994)
Sheep (*Ovis aries*)	>12.0 × 7	Oliver & Wheeler (1978)
Red deer (*Cervus elaphus*) * use value for sheep	None found 12.0 × 7	 As above
Fallow deer (*Dama dama*) *use value for sheep	None found 12.0 × 7	 As above
Cow (*Bos taurus*) *use value for sheep	None found 12.0 × 7	 As above
Horse (*Equus caballus*) *use value for sheep	None found 12.0 × 7	 As above
	Birds	
Mallard duck (*Anas platyrhynchos*) * use value for grey duck (*Anas superciliosa*)	None found 5.0 × 7	 Twigg et al. (1999)
Paradise shelduck (*Tadorna variegata*)	None found	

* use value for grey duck	5.0 × 7	As above
Canada goose (*Branta canadensis*)	None found	
* use value for grey duck	5.0 × 7	As above
Black-backed gull (*Larus dominicanus)*	None found	
* use value for chicken (*Gallus gallus*)	2.5 × 4	As above
Spur-winged plover (*Vanellus miles*)	None found	
* use value for chicken	2.5 × 4	As above
California quail (*Callipepla californicus*)	None found	
* use value for chicken	2.5 × 4	As above
Blackbird (*Turdus merulus*)	None found	
* use value for chicken	2.5 × 4	As above
Goldfinch (*Carduelis carduelis*)	None found	
* use value for chicken	2.5 × 4	As above
Pheasant (*Phasinaus colchicus*)	None found	
* use value for chicken	2.5 × 4	As above
Kea (*Nestor notabilis*)	None found	
*use value for Port Lincoln parrot (*Barnadius zonarius*)	5.0 × 5	As above
Waxeye (*Zosterops lateralis*)	None found	
* use value for chicken	2.5 × 4	As above
New Zealand robin (*Petroica australis*)	None found	
* use value for chicken	2.5 × 4	As above
Fantail (*Rhipidura fuliginosa*)	None found	
* use value for chicken	2.5 × 4	As above
Grey warbler (*Gerygone igata*)	None found	
* use value for chicken	2.5 × 4	As above
Australasian harrier (*Circus approximans*)	None found	
* use value for wedge-tailed eagle (*Aquila audax*)	0.25 × 5	As above
New Zealand falcon (*Falco novaeseelandiae*)	None found	
* use value for wedge-tailed eagle	0.25 × 5	As above
Reptiles and invertebrates		
McCann's skink (*Oligosoma maccanni*)	> 15	Freeman et al. (1996)
Invertebrates	None found for any species	

[a] Note large difference in two available estimates of oral toxicity of pindone to dogs. Larger value (i.e. less toxic) estimate used because it is more consistent with other single-exposure toxicity estimates for mammals, and because there is no other evidence suggesting that dogs are relatively more susceptible to pindone than other mammals.