

1 **Alternatives to brodifacoum for possum and rodent control - how and why?**

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10

11 **Abstract:** The risks of vertebrate pesticides to non-target animals are determined by intrinsic
12 susceptibility, the toxicokinetics of the compounds used, and the degree and frequency of
13 exposure. Metabolism and persistence studies coupled with field surveys have provided us with
14 an improved understanding on the toxicokinetics and non-target effects of different
15 anticoagulants. This has enabled improved choice of tools for island versus mainland use in
16 New Zealand, and has stimulated the development of low-residue tools. Brodifacoum is a potent
17 second generation rodenticide used worldwide for commensal rodent control, and has been
18 widely used to eradicate rodents from islands. The risks associated with “one-off” application of
19 baits containing second-generation anticoagulants for rodent eradication on islands are
20 considered to be outweighed by the potential benefits to their ecosystems. Possums are
21 susceptible to bait containing brodifacoum, but not to first generation anticoagulants, hence
22 brodifacoum has been the only alternative to 1080 that effectively targets both possums and
23 rodents. On the mainland, contamination of wildlife and game species and secondary poisoning

1 of non-target species has been substantial where brodifacoum has been used repeatedly. We are
2 extending the current range of low residue alternatives to reduce reliance on brodifacoum.

3

4 **Keywords:** vertebrate pesticide, anticoagulants, rodenticide, secondary poisoning

5

6 **INTRODUCTION**

7

8 The risk to non-target wildlife, livestock, pets or humans from baits containing vertebrate
9 pesticides will be determined in part by the animal's intrinsic susceptibility, the properties of the
10 poisons used (such as their toxicokinetics), bait design and deployment methods, and the site-
11 specific complexities of the food webs in the areas where they are used, which may limit or
12 exacerbate the exposure of non-target species. In New Zealand, we have been heavily reliant on
13 anticoagulants and sodium fluoroacetate (compound 1080) for broad-scale pest control; however,
14 public support for 1080 poisoning has declined and alternatives used for field control of pests
15 (e.g. second-generation anticoagulants) have resulted in wildlife contamination (Eason et al.
16 2002) in New Zealand and internationally (Young & de Lai 1997; Stone et al. 1999).

17

18 In the 1990's a need was identified to select suitable toxicants for field use that are effective but
19 less persistent than second-generation anticoagulants, and therefore likely to be less hazardous to
20 non-target bird species (Eason et al. 2002). The tendency for anticoagulants to persist in
21 mammalian liver tissue is influenced by the magnitude of the dose ingested and the relative
22 affinity of the compound for receptors in the liver, which determine the hepatic elimination half-
23 life and the proportion of the dose retained (Parmar et al. 1987). Accordingly, liver tissue has

1 been the focus for most investigations of anticoagulant persistence, although there were few data
2 on the comparative hepatic persistence of anticoagulant rodenticides in mammals, where either
3 compounds or species have been compared. In this paper, we review the science rationale
4 behind the development of low-residue poisons, and report on recent developments. In the next
5 section, we initially focus on the pharmacokinetics of non-anticoagulant rodenticides, and then
6 review the persistence of anticoagulants before describing new developments.

7

8 **Comparative pharmacokinetic - basis for improvements**

9

10 Concentrations of cyanide, even in the carcasses of poisoned animals, declines very rapidly in
11 the first 48 hours after ingestion (table 1), and residue concentrations are negligible after one
12 week (Morriss et al. 2003). In New Zealand, hunters skin possums killed with cyanide and
13 sometimes feed the carcasses to their dogs with no ill-effects. Zinc phosphide breaks down in
14 the stomach and its decomposition products are absorbed both as phosphine and as phosphide.
15 Excretion occurs as exhaled phosphine from the lungs, and other metabolites, including
16 phosphoric acid and phosphate, are excreted in urine and faeces (WHO 1976). In possum
17 carcasses, concentrations decline rapidly and a half-life of 6.7 days in vomit and 3.4 days in
18 stomach contents has been calculated for residues after poisoning (Brown et al. 2007). In sub-
19 lethally poisoned animals, elimination processes for cyanide and zinc phosphide are likely to be
20 much quicker, with elimination half-life values likely to be less than 12 hours (table 1).
21 Compound 1080 is rapidly absorbed into the blood and distributed through the soft tissues and
22 organs. Highest concentrations of 1080 occur in the blood, and most residues of 1080 or its
23 metabolites will be eliminated 1 - 4 days after a sub-lethal dose. The elimination half-life in

1 blood is 11 hours or less (table 1) in sheep (*Ovis aries*), goat (*Capra hircus*), rabbit (*Oryctolagus*
2 *cuniculus*), mouse (*Mus musculus*) and possums (*Trichosurus vulpecula*) (Eason et al. 1994).
3 Like other compounds in this group, 1080 will not readily bioaccumulate, but in contrast to
4 cyanide and zinc phosphide, it can persist in carcasses at hazardous concentrations that remain
5 lethal to dogs and other avian or mammalian scavengers for several months (Meenken & Booth
6 1997).

7
8 The hepatic half-life of brodifacoum in sub-lethally dosed animals has been reported as 130-350
9 days in rats (Parmar et al. 1987; US EPA 2002), 252 days in possums (Eason et al. 1996a), and
10 >250 days in sheep (Laas et al. 1985). Thijssen (1995) estimated an hepatic half-life of 7-10
11 days for warfarin in rats, while residues in the liver of pigs that survived a dose of warfarin had
12 declined to near the analytical limit of detection by 30 days (O'Brien et al. 1987). The
13 persistence of pindone in mammalian liver has been described for dogs (Fitzek 1978) and sheep
14 (Nelson & Hickling 1994). Bullard et al. (1976) reported that cows sub-lethally dosed with
15 diphacinone had detectable liver residues 90 days after dosing. None of these previous studies
16 allow the accurate definition of persistence of any of the anticoagulants in tissues for
17 comparative purposes and selection of tools for best management practice.

18
19 Comparative pharmacokinetics is an important basis for assessment of risk to non-target species.
20 The hepatic persistence of second-generation anticoagulants, such as brodifacoum in the liver of
21 mammals, was well characterized in comparison to first-generation anticoagulants, although
22 estimates of plasma retention for the latter group are available in the literature.
23 Recommendations of preferred anticoagulants for field use in New Zealand were made on

1 estimates of their persistence in the liver of a range of mammalian species, based on relatively
2 few published studies. This literature suggests low-single-dose-potency anticoagulants such as
3 warfarin and pindone persist in the liver for 0.5-1 month; moderate-single-dose-potency
4 anticoagulants such as diphacinone and coumatetralyl persist in the liver for approximately six
5 months; and high-single-dose-potency anticoagulants such as bromadiolone, brodifacoum and
6 flocoumafen can persist in the liver for more than 12 months (Eason 1999).

7
8 The persistence of sublethal (approximate LD_{15}) oral doses of brodifacoum, warfarin, pindone
9 and diphacinone in the livers of laboratory rats was comprehensively compared more recently to
10 determine whether earlier recommendations were appropriate. At one end of the spectrum,
11 retention of brodifacoum in liver was characterized by a relatively long half-life of 113.5 days,
12 compared with half-lives of 26.2 days for warfarin, and three and two days for diphacinone and
13 pindone respectively (Fisher et al. 2003). These results suggest that the indandinone
14 anticoagulants diphacinone and pindone present a shorter-term and, therefore, reduced risk of
15 secondary poisoning to predators and scavengers than the coumarin anticoagulants warfarin and
16 brodifacoum (Fisher et al. 2003). This allows for more confident recommendations and selection
17 of less persistent anticoagulants and alternatives for field use.

18

19 **Appropriate use “patterns” of anticoagulants**

20

21 Rodent eradication has transitioned over 30 years in New Zealand, through stages of initial
22 scepticism, to early accidental and experimental successes, and now the current bold large scale
23 aerial applications over increasingly large islands (Townes & Broome 2003). Starting in the

1 1980's, gaining momentum in the 1990's, and continuing to the present day, islands once
2 occupied by rodents are now being reclaimed through robust, meticulous planning (Broome et al.
3 2005) and continual improved effectiveness of pesticide use and biodiversity management
4 (Broome & Fairweather 2008). Until the mid-1980's, very few islands were entirely free of
5 animal pests. Rodent eradication on islands, using bait in stations and baits applied from the air
6 has been spectacularly successful (Taylor & Thomas 1989, 1993; Towns et al. 1993; Empson &
7 Miskelly 1999). To date more than 90 islands around New Zealand have been cleared of
8 rodents, and brodifacoum use has had an obvious benefit on valuable island ecosystems (Towns
9 & Broome 2003).

10

11 Over the last twenty years, the tactical use of pesticides to protect island populations of
12 indigenous birds, reptiles and invertebrates endangered by rats and mice has continued to be
13 refined, with improved effectiveness enabling larger islands to be cleared of rodents (Broome &
14 Fairweather 2008). Improved effectiveness has also meant increasingly complex habitats have
15 been able to be tackled, where terrain is rugged and steep, numerous native species are present,
16 or the island is occupied by human inhabitants e.g. Kapiti Island (Towns & Broome 2003). The
17 continued eradication of already established rodent populations and the prevention of re-invasion
18 to rodent-free islands (island biosecurity) must now be considered part of the management plan
19 for future eradication operations (Broome 2007). Although aerial operations are extremely
20 successful in removing rats from islands, mice still cause some problems (Towns & Broome
21 2003). Diphacinone and cholecalciferol have been recommended as an alternative to
22 brodifacoum for use against rats in island conservation (Donlan et al. 2003). As such, new bait
23 types are currently being developed that are especially attractive to mice as well as rats, long-life

1 baits, new toxins and tunnel delivery systems, showing clear advantages in non-target species
2 impacts and efficacy in achieving eradication, to compliment existing bait types to aid future
3 eradication programmes and help prevent re-invasions.

4

5 In parallel to its use to eradicate rats from islands, there was an increased use of brodifacoum
6 baits delivered from bait stations for possum and rodent control on mainland New Zealand
7 (Eason & Spurr 1995; Innes & Barker 1999), raising concerns about contamination effects on
8 other fauna. Although second-generation anticoagulants, such as brodifacoum, are used
9 extensively throughout the world, they are mostly employed for the control of commensal
10 rodents (i.e. those living in close association with man and his domestic animals) (Colvin et al.
11 1991). While primary exposure of non-target fauna may be reduced by the use of effective bait
12 stations, secondary exposure is more difficult to manage. We detected brodifacoum residues in
13 game animals such as pigs and deer (*Cervus* sp.), and a range of avian species including weka
14 (*Gallirallus australis*), morepork (*Ninox novaeseelandiae*), harrier (*Circus approximans*),
15 pukeko (*Porphyrio porphyrio*), grey duck (*Anas superciliosa superciliosa*), mallard duck (*Anas*
16 *platyrhynchos*), black-backed gull (*Larus dominicanus*), robin (*Petroica australis*), saddleback
17 (*Philesturnus carunculatus*), chaffinch (*Fringilla coelebs*), mynah (Family Sturnidae), magpie
18 (*Gymnorhina* sp.) and blackbird (*Turdus merula*) (Eason et al. 2001). Of less concern was the
19 detection of brodifacoum in cats (*Felis catus*) and stoats (*Mustela erminea*), introduced species
20 regarded as pests and largely responsible for the decline of native birds, such as kiwi (*Apteryx*
21 sp.). Because of the potential for contamination of wildlife, broadscale field use of brodifacoum
22 in New Zealand was discontinued in the late 1990's. Nevertheless, limited use of brodifacoum
23 baits in bait stations is extremely valuable for controlling localised populations of possums that

1 have entrenched bait shyness. This sometimes occurs where acute pesticides (1080, cyanide or
2 cholecalciferol) have been used ineffectively due to poor bait quality, climatic effects, and/or
3 “bait-shyness” caused by repeated usage of the same bait type. The bait shyness is overcome
4 when the pest animal initially samples a small quantity of bait containing an anticoagulant,
5 experiences no ill-effects, and continues to consume baits, eventually ingesting a lethal quantity
6 (Morgan & Ross 2001).

7

8 Switching from brodifacoum to alternative second-generation anticoagulants with similar
9 toxicokinetic profiles, with hepatic half-lives >100 days (US EPA 2004) would not significantly
10 reduce the risk of exposure and bioaccumulation in non-target species, although the risk of
11 toxicoses might be less (dependent on the potency of the alternative rodenticide, the amount of
12 active ingredient in bait types, the amount of bait eaten, or the amount ingested by scavengers
13 eating poisoned carcasses).

14

15 In summary, brodifacoum has an unusual persistence (Fig. 1) compared to other second
16 generation anticoagulants. Persistent organic compounds (POCs) e.g. DDT and brodifacoum,
17 bioaccumulate along terrestrial food chains, and repeated field use of POCs, including second
18 generation anticoagulants, is unwise and discouraged (see US EPA Rodenticide Mitigation –
19 Decision May 2008). Brodifacoum residues have been found in pigs and weka, morepork,
20 harrier, pukeko, grey duck, robin, and saddleback many months after possum control, and
21 bioaccumulation to lethal concentrations occurs in non-targets from repeated use.

22

1 First-generation anticoagulants (which are less persistent), alone or in combination with
2 cholecalciferol, Feratox® (an encapsulated cyanide pellet) and traps, are a rational choice to
3 avoid food web contamination, and new low-residue alternatives are being developed.
4 Toxicokinetic assessments and food–web considerations provide a science base for an increased
5 understanding of the suitability of different poisons.

6

7 **Improved choice for ground control**

8

9 Ideally a single bait will be capable of killing possums, rats and mice, and baits must include
10 toxins that have a relatively low environmental persistence (see table 2). Different types of toxic
11 baits should include either fast or slower acting poisons. Slow-acting toxic baits produce better
12 results for bait shy individuals or low density populations, whereas fast-acting toxic baits work
13 best for high density populations.

14

15 Humane fast-acting poisons such as cyanide have many advantages (Gregory et al. 1998);
16 however pastes used in the early 1990's liberated cyanide gas, which deterred possums and was
17 hazardous to operators. The development of Feratox® in 1997, an encapsulated cyanide pellet
18 for possum control (Gregory et al. 1998), helped to overcome this problem, and greatly enhanced
19 ground control of possums. Much of the public disapproval of 1080 resulted from the accidental
20 poisoning (primary and secondary) of dogs, an unfortunate consequence of dogs being 25 times
21 more sensitive to 1080 than possums (Eason & Wickstrom 2001). In the early 1990's, there
22 were intense efforts to identify safer alternatives to 1080 (Eason 1991; Eason et al. 1993).
23 Determination of the risks presented to dogs through use of cholecalciferol, showed that it was

1 much lower to pets and birds (Eason et al. 1996a, b), and this underpinned the development of
2 cholecalciferol baits that can be preferentially used close to habitation where dog risks are
3 higher. Feratox[®] has provided a low-residue humane alternative for >10 years for possum
4 control for licensed professionals. In July 2008, cholecalciferol paste (Feracol[®]) was registered
5 for rodents as well as possums. In June 2008, a product license application was filed for micro-
6 encapsulated zinc phosphide paste for possum control. New data is being generated to extend
7 this registration to rodents and possums. Registration dossiers on low-dose cholecalciferol with
8 coumatetralyl (C+C) as a slow acting alternative are being finalised for submission in 2010/11.
9 Zinc phosphide and C+C have a low risk of secondary poisoning, and C+C has the potency of
10 brodifacoum without the extreme tendency to bioaccumulate.

11

12 **CONCLUSION**

13

14 In this paper we have summarized details of our improved understanding of the importance of
15 toxicokinetics, and the rationale for the choice of anticoagulants and alternatives for different
16 uses. Brodifacoum has been the only alternative to 1080 registered for both possum and rodent
17 control. This is no longer the case. Alternatives are currently being registered, which will be
18 effective against both possums and rodents. There are no “silver bullets” and different tools have
19 advantages and disadvantages. Traditional and alternative baits and traps should be integrated to
20 meet site – specific needs to achieve eradication or sustained control.

21

22 Improved formulations and choices are now becoming available for possum and rodent control.
23 These are just some of the examples that have enabled improved delivery and more effective pest
24 control of the highest standard, delivering disease control and conservation outcomes with

1 minimal side-effects. There are opportunities for the development of useful products based on
2 past research on alternatives to 1080 (Eason et al. 1993), and more recent work that has enabled
3 us to be more selective in our choice of anticoagulants (Fisher et al. 2003). Further research is
4 underway to improve target specificity, provide more species-specific baits and poisons, and to
5 decrease costs associated with aerial and ground control.

6

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8

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10 Department of Conservation, and the Foundation for Research, Science and Technology.

11

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1 **Table 1.** Summary of vertebrate pesticide half-lives and expectation for persistence of
 2 residues in sub-lethally exposed target or non-target species (adapted from Eason et al. 2008).

Compound	Half-life values in tissue or blood	Likely persistence of residues after sub-lethal exposure
Cyanide	+	12 to 24 hours
zinc phosphide	+	12 to 24 hours
1080	< 11 hours	7 days
Pindone	2.1 days	4 weeks
Diphacinone	3 days	6 weeks
Cholecalciferol	10-68 days	12 weeks
Coumatetralyl	50-70days	12-16 weeks
Brodifacoum	130-300 days	24 months or longer
Bromodiolone	170 days	24 months or longer
Flocoumafen	220 days	24 months or longer

3 + no published value but likely to be < 12 hours

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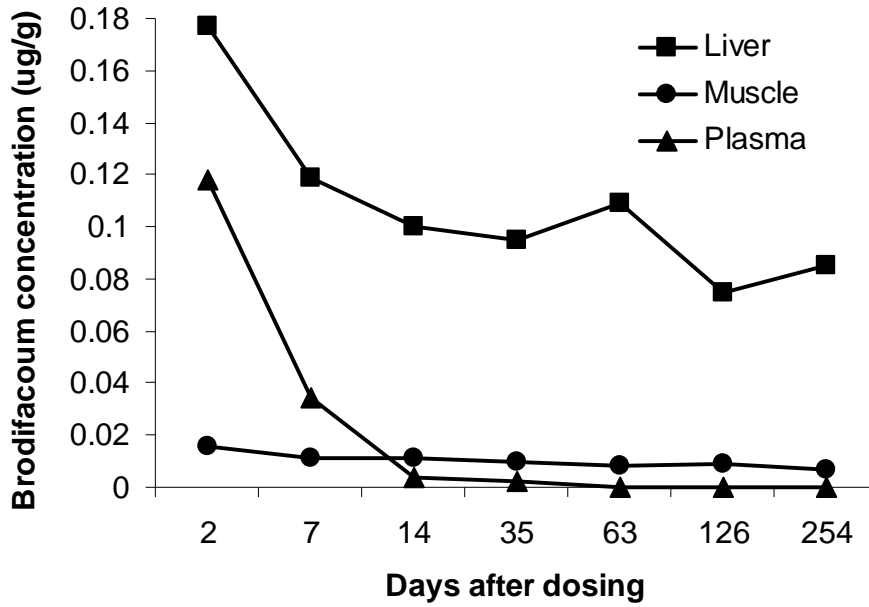
1 **Table 2.** A summary of key characteristics of low residue alternatives to brodifacoum

Compound	Species	Fast or slow in onset	Persistence	Relative humaneness vs. brodifacoum	Comment
Cyanide pellets Feratox®	p	fast	low	high	Most humane.
Zinc phosphide paste	p+r	fast	low	Mod	Fast acting –product registration filed June 08.
Cholecalciferol Feracol®	p+r	mod	mod	mod	Registered for rodents and possums
Low dose cholecalciferol +coumatetralyl	p+r	slow	mod	mod	Dossier in prep for registration
Diphacinone	r	slow	low	mod	Least persistent anticoagulant
Brodifacoum	p+r	very slow (in possums)	extreme	poor	Very effective but not intended for repeated field use.

2 Key p= possums; r=rodents
3 (Eason et al. 2008).

4

1 **Figure 1.** Typical persistence profile after sub-lethal dosing in possums (*Trichosurus vulpecular*) with (0.1
2 mg/kg) brodifacoum, which would be similar in game or birds.



3
4 Adapted from Eason et al. 1996b