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BRODIFACOUM RESIDUES IN TARGET AND NON-TARGET SPECIES FOLLOWING AN AERIAL POISONING OPERATION ON MOTUIHE ISLAND, HAURAKI GULF, NEW ZEALAND

Summary: Aerial poisoning using Talon® 7-20 baits (active ingredient 20 ppm brodifacoum) was carried out on Motuihe Island, Hauraki Gulf, during the winter of 1997. The operation aimed to eradicate Norway rats (*Rattus norvegicus*) and house mice (*Mus musculus*) and to reduce rabbit (*Oryctolagus cuniculus*) numbers significantly. We studied the diet of feral house cats (*Felis catus*) before the operation, then monitored the impact of the operation on them to determine whether secondary brodifacoum poisoning caused a reduction in their numbers. Large numbers of rabbits remained after poisoning; this and other observations suggested that insufficient bait had been applied to achieve the aims of the programme. Cat mortality, based on radio-collared animals, was 3/14 (21%). Cats on Motuihe Island appeared to eat rabbit muscle tissue in preference to internal organs; brodifacoum concentrations are lower in muscle than in liver and we suggest that rabbits may be a poorer vector than rodents for secondary poisoning of cats. We also confirmed the risk of an aerial brodifacoum application to a range of non-target bird species. Mortality of pukeko (*Porphyrio p. melanotus*) and paradise shelducks (*Tadorna variegata*) was 49% and 60% , respectively. No mortality of New Zealand dotterels (*Charadrius obscurus*) or variable oystercatchers (*Haematopus unicolor*) was detected. Twenty-nine individuals of 10 bird species (five indigenous and five introduced) were found dead after the operation and livers of all of them contained residues of brodifacoum; toxin levels averaged 0.84 μg g^{-1} (range 0.12-2.31 μg g^{-1}).

Keywords: Brodifacoum; Talon; secondary poisoning; cats; *Felis catus*; rabbits; *Oryctolagus cuniculus*; non-target, birds.

Introduction

Brodifacoum is a potent second-generation anticoagulant poison, widely used in New Zealand for the control and eradication of vertebrate pests, particularly brushtail possums (*Trichosurus vulpecula*[1]) and rats (*Rattus* spp.), but also rabbits (*Oryctolagus cuniculus*). Because it is insoluble in water and only slowly broken down by microbial action, brodifacoum persists in the environment and half-life in soil varies from 12-25 weeks (Haydock and Eason, 1997). It accumulates in vertebrate tissues and is particularly retained in the liver, with residues detectable after 16 weeks in sheep (Laas, Forss and Godfrey, 1985) and at least eight months in possums (Eason, Wright and Batcheler, 1996).

When poisoned animals (alive or dead) are eaten by carnivores or scavengers, secondary poisoning may occur. The potential of anticoagulants to cause secondary poisoning has long been recognised (e.g., Evans and Ward, 1967) but the risk from second-generation anticoagulants is particularly high because these compounds are not substantially metabolised before the vector dies (Haydock and Eason, 1997). In one New Zealand study, feral house cats (*Felis catus*), stoats (*Mustela erminea*) and ferrets (*M. furo*) died from eating rodents and rabbits poisoned with brodifacoum (Alterio, 1996). Deliberate secondary poisoning has been suggested as a potentially cost-effective means of controlling several carnivores which are conservation pests in New Zealand (Alterio, 1996; Brown, Alterio and Moller, 1998), but a number of questions about the efficacy and safety of the technique remain (Murphy *et al*., 1998).

Non-target animals are also at risk from both primary and secondary poisoning during control and eradication operations. Eason and Spurr (1995) noted that members of 10 species or subspecies of indigenous birds had been found dead as "a probable result" of eating baits containing brodifacoum and members of five species "probably as a result of secondary poisoning". Individuals of eight species of introduced birds had also been found dead, presumably as a result of eating baits (Eason and

[1]Nomenclature of mammals follows King (1990)

Spurr, 1995). Native birds most at risk from primary poisoning are those that are herbivorous or omnivorous, such as pukeko (*Porphyrio p. melanotus*[2]) and weka (*Gallirallus australis*); those most at risk from secondary poisoning are predators and scavengers, such as moreporks (*Ninox novaeseelandiae*), Australasian harriers (*Circus approximans*) and southern black-backed gulls (*Larus dominicanus*) (Eason and Spurr, 1995). Following poisoning operations in New Zealand, brodifacoum residues have been detected in liver tissue of dead birds of a wide range of species (e.g., Rammell *et al*., 1984; Ogilvie *et al*., 1997).

Brodifacoum has been used successfully in rodent eradication programmes on many New Zealand islands (e.g. Taylor and Thomas, 1989; 1993; Empson and Miskelly, 1999). In accordance with objective 21.7.4 of the Conservation Management Strategy for Auckland Conservancy (Department of Conservation, 1995), an aerial poisoning operation using brodifacoum was carried out on Motuihe Island in winter 1997. Motuihe Island has a limited suite of introduced mammalian pests, with brushtail possums, mustelids (*Mustela* spp.), ship rats (*Rattus rattus*), kiore (*R. exulans*) and hedgehogs (*Erinaceus europaeus*) being absent. Because of its distance from the mainland and other islands, natural invasion (or re-invasion) of Motuihe Island by mammalian pests is unlikely. The poisoning operation aimed to eradicate Norway rats (*Rattus norvegicus*) and house mice (*Mus musculus*) and to reduce rabbit numbers significantly. A follow-up ground operation was planned to complete the eradication of rabbits.

We studied the impact of the poisoning programme on the island's population of feral house cats, to determine whether secondary brodifacoum poisoning was a means of eradicating cats or reducing their numbers. This study was intended to provide information useful to other eradication projects on islands, and in particular to act as a trial for the proposed eradication of rodents and cats from Raoul Island in the Kermadec Group (Department of Conservation, 1995). We also studied the effects of the poisoning operation on non-target bird species on Motuihe Island.

Methods

Study area

Motuihe Island lies in the inner Hauraki Gulf at 36°49'S, 174°57'E, about 16 km east of Auckland city. It is 179 ha in area and is gazetted a recreation reserve, administered by the Department of Conservation. About 10% of the island is in bush or scrub, with most of the remainder in pasture. A wide range of techniques has been used in attempts to control rabbits, but no brodifacoum or other anticoagulants have been applied since 1987. Poisoning operations may have eradicated Norway rats in 1988 but they were definitely present at low densities (Dowding, *unpubl. data*) in 1997. Cats were reported as being eradicated in 1981 and subsequently re-introduced (John Allen, Department of Conservation, Auckland, *pers. comm.*). Domestic stock are normally present on the island but were removed on 26 June 1997 prior to the poison operation. On 25 July 1997, Talon® 7-20 baits (Wanganui No. 7 cereal baits containing 20 ppm brodifacoum and bitrex; Animal Control Products, Wanganui, New Zealand) were aerially applied over the island at a rate of 8 kg ha^{-1}, followed on 4 August by a second application at 3.5 kg ha^{-1}.

Cats

Cats were captured in soft-catch Victor 1.5 or wire cage traps baited with fish and were lightly anaesthetised by intramuscular injection of ketamine (10 mg kg^{-1} body weight). Fourteen cats were each fitted with a two-stage radio-transmitter on a leather collar and subsequently re-located using a Telonics TR4 receiver and a hand-held 3-element Yagi aerial. Cats were radio-tracked prior to the operation to determine home ranges and activity patterns (Dowding, *unpubl. data*.). Manipulation of cats was undertaken with the approval of the Department of Conservation's Animal Ethics Committee.

Cats found dead following the poisoning operation were examined for signs of external haemorrhage (mouth, nostrils and anus), then autopsied. The degree of internal haemorrhage (IH) was recorded in three broad categories (little or none, moderate, and extensive). Guts were removed and stored frozen. Between 4 and 12 May 1998 (approximately nine months after the operation), nine adult cats were trapped or shot. Liver samples from all cats were stored frozen until analysed for brodifacoum residues.

Diet analysis

Between 14 April and 25 July (before the poison operation), 61 cat scats were collected from all parts of the island and stored frozen until analysis. Scats were soaked overnight, washed through a 1.0 mm sieve and the resulting material sorted into broad categories (rabbit, invertebrate, bird, rodent, lizard

[2]Nomenclature of birds follows Turbott (1990)

and other). Gut contents of 9 cats found dead or collected after the operation were analysed in the same way. In some cases, identification of bird and rodent prey to species was possible by low-power microscopy and/or comparison with reference material. Results are expressed as percent frequency of occurrence.

Rabbits

Between 4 and 7 August (10-13 days after the first poison drop), samples of liver were collected from five rabbits found freshly dead. On 18 August, two weeks after the second drop, virtually no baits had been available to rabbits for 12 days and it was assumed that most animals that were going to die of poisoning would have done so. Four rabbits still alive at that time were shot and samples of liver were taken. All samples were stored frozen until analysed for brodifacoum residues.

Non-target bird species

Three groups of pukeko totalling 98 birds, and the flock of paradise shelducks (*Tadorna variegata*) in the central part of the island (totalling 52 birds immediately before the drop) were monitored following the poison drop. Four pairs of New Zealand dotterels (*Charadrius obscurus*) and seven pairs of variable oystercatchers (*Haematopus unicolor*) occupying breeding territories on South East Beach were also monitored.

Between 4 and 29 August 1997, 29 birds (of 10 species) found freshly dead on the island were collected. These were examined for signs of external haemorrhage (gape, nostrils and cloaca), then autopsied. The degree of internal haemorrhage was recorded in three broad categories (little or none, moderate, extensive). Liver samples were taken from all specimens and stored frozen until analysed for brodifacoum residues.

Brodifacoum analysis

Samples were analysed by the Toxicology Laboratory, Landcare Research, Lincoln, using high-performance liquid chromatography (TLM 009). The limit of detection was $0.01 \mu g\ g^{-1}$.

Results

Diet of cats

Results of the diet analysis are shown in Fig. 1. Rabbit made up the vast majority of the diet of cats on Motuihe Island; rabbit remains were the only remains in 41% of scats. Invertebrates were the second most commonly eaten prey class but were a relatively small component of the diet by weight, making up <5% of most samples in which they occurred. Birds in the diet identified to species were pukeko, song thrush (*Turdus philomelos*), goldfinch (*Carduelis carduelis*) and pied shag (*Phalacrocorax varius*). Remains of house mouse (two scats) and Norway rat (two scats) were identified.

On five occasions before the poison operation, radio-collared cats were seen eating rabbits. In all cases, the large muscle masses of the hind legs had been or were being eaten and in one case the muscle of the fore-limbs was also being eaten. The internal organs were not eaten in any of the five cases.

Gut samples from nine cats collected in May 1998 suggested little change in the diet of cats at that time. Remains of rabbit were present in nine samples (100%), invertebrates in two (22%) and birds and rodents in none (0%).

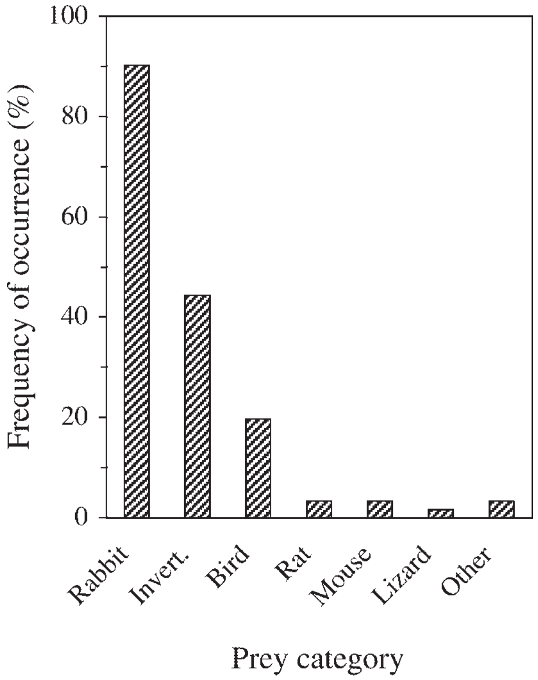

Figure 1: *Percent frequency of occurrence of prey in 61 cat scats collected on Motuihe Island, April-July 1997.*

Mortality of cats

Two cats (female 76 and male 82) died eight or nine days after the first poison drop. On autopsy, the stomach of 76 contained green dye (and rat fur), suggesting that she had either eaten bait directly or eaten the gut of an animal which had recently eaten bait. A third cat (female 86) was found dead in mid-September, and died about five weeks after the second drop. All three cats showed internal haemorrhage (extensive in the case of 76, moderate in the case of 86, little in the case of 82) and the livers of all three contained high concentrations of brodifacoum (Table 1). At the end of November (four months after the first drop), the remaining 11 cats carrying radio-transmitters were still alive. Mortality of radio-collared cats as a result of the poisoning operation was therefore 3/14 (21%).

Table 1: *Brodifacoum concentrations in livers of cats following the poison operation on Motuihe Island. Cats 76 and 82 were found dead in August 1997 and cat 86 in September 1997; remaining cats were caught or shot in May 1998. M=male, F=female.*

Cat number	Sex	Body wt. (kg)	Liver brodifacoum ($\mu g\ g^{-1}$)
76	F	2.30	0.98
82	M	2.55	1.38
86	F	2.70	0.91
70	M	4.40	0.93
01	F	2.45	0.46
90	F	3.05	0.75
02	M	4.20	1.01
03	F	3.15	0.48
04	M	5.05	0.90
05	M	2.20	0.02
62	M	3.80	1.10
06	M	4.90	0.81

Livers of all nine cats caught or shot in early May 1998 (nine months after the second poison drop) contained brodifacoum residues (Table 1).

Toxin levels in rabbit livers

Spotlight counts three weeks after the second poison drop (S. Mowbray, Department of Conservation, Auckland, *pers. comm.*) showed that rabbit numbers were still very high (a minimum of 60 rabbits per spotlight-km and a minimum of 2000 rabbits on the island). Livers of five rabbits found dead 10-13 days after the first drop all contained brodifacoum residues (0.54, 0.69, 0.05, 0.93 and 2.01 $\mu g\ g^{-1}$); in four of the five cases levels were high. Livers of four rabbits shot two weeks after the second drop also contained toxin residues (0.03, 0.42, 0.03, and 0.04 $\mu g\ g^{-1}$), but levels were low in three of them.

Mortality of non-target species

Two weeks after the second drop, mortality in the pukeko groups was 48/98 (49%) and in the paradise shelduck flock was 31/52 (60%). No mortality of New Zealand dotterels or variable oystercatchers was detected. No house sparrows (*Passer domesticus*) or goldfinches were found dead, but both species were seen eating baits and may have suffered some casualties.

Livers of all 29 birds of 10 species found dead between 4 and 29 August 1997 contained brodifacoum residues (Table 2); mean (±S.D.) concentration was 0.84±0.47 $\mu g\ g^{-1}$ and range was 0.12-2.31 $\mu g\ g^{-1}$. Only 3 of 29 (10.3%) birds found dead showed any external haemorrhage. There was no obvious relationship between the degree of internal haemorrhage observed and liver brodifacoum concentration. Mean (±S.D.)

Table 2: *Brodifacoum concentrations in livers of birds found dead on Motuihe Island following the poisoning operation, August 1997.*

Species	n	Brodifacoum concentration ($\mu g\ g^{-1}$)	
		mean	range
Paradise shelduck (*Tadorna variegata*)	4	0.56	0.24–0.80
Mallard (*Anas platyrhynchos*)	2	1.07	0.90–1.23
Grey duck (*A. superciliosa*)	1	0.91	
Australasian harrier (*Circus approximans*)	2	0.64	0.61–0.66
Pukeko (*Porphyrio p. melanotus*)	9	0.86	0.52–1.35
Southern black-backed gull (*Larus dominicanus*)	1	0.58	
Blackbird (*Turdus merula*)	2	0.67	0.56–0.78
Chaffinch (*Fringilla coelebs*)	3	1.43	0.12–2.31
Common myna (*Acridotheres tristis*)	3	0.80	0.54–1.27
Australian magpie (*Gymnorhina tibicen*)	2	0.70	0.40–0.99

brodifacoum concentrations (μg g^{-1}) for the three categories of IH were 0.56±0.28 (little IH, n=5), 0.95±0.63 (moderate IH, n=11) and 0.84±0.32 (extensive IH, n=12); there were no significant differences between categories (Student's *t*-test, little vs. moderate, t=1.3, d.f.=14, P=0.21; little vs. extensive t=1.7, d.f.=15, P=0.11; moderate vs. extensive t=0.53, d.f.=21, P=0.60).

Discussion

Secondary poisoning of cats

Several lines of evidence suggested that insufficient baits were laid on Motuihe Island to achieve all the aims of the project. First, rabbit numbers remained high after the aerial operation and the ground operation to eradicate them was abandoned. Second, few baits remained visible two days after the second drop, suggesting animals were still eating them at that time. Third, mortality of pukeko was about 50%; in similar operations elsewhere it was 90% or more (Eason and Spurr, 1995). Many rabbits probably ate little or no bait, so the project was unlikely to have provided a useful assessment of the potential of secondary brodifacoum poisoning to reduce cat numbers.

Where rabbits occur, they are a common item in the diet of feral cats in New Zealand (Fitzgerald, 1990) and were by far the commonest prey item of cats on Motuihe Island. Brodifacoum levels in different tissues of poisoned rabbits vary considerably, being high in liver and low in muscle; the average liver/muscle concentration ratio was 11:1 in one study (Rammell *et al.*, 1984). Cats on Motuihe Island appeared to eat the large muscle masses on the limbs of rabbits in preference to the internal organs, thereby ingesting little of the toxin.

Published LD_{50} values of brodifacoum for cats vary widely, from 25 mg kg^{-1} (Rammell *et al.*, 1984; Godfrey, 1985) to 0.25 mg kg^{-1} (Haydock and Eason, 1997). Assuming the lower value, a cat weighing 3.5 kg would need to ingest 875 μg brodifacoum. The mean liver concentration in five rabbits found dead on Motuihe Island was 0.84 μg g^{-1}, suggesting a muscle concentration of about 0.08 μg g^{-1} (Rammell *et al.*, 1984). Cats eating only muscle of dead rabbits would therefore need to have eaten about 11 kg of muscle to ingest 875 μg brodifacoum. The mean liver concentration in four rabbits collected alive on Motuihe Island two weeks after the second poison application was 0.13 μg g^{-1}; cats eating only muscle of surviving rabbits would need to have eaten in the order of 75 kg of muscle to ingest 875 μg brodifacoum. If the LD_{50} value of brodifacoum for cats is higher than 0.25 mg kg^{-1}, these quantities would be correspondingly higher. The combination of a high residual density of rabbits (suggesting a relatively low kill), low levels of toxin in many surviving rabbits and the apparent dietary preference of cats for rabbit muscle probably explains the low mortality of cats seen following the operation on Motuihe Island. Rabbits were also found to be an inefficient vector for secondary 1080 poisoning of ferrets (*Mustela furo*) (Norbury, Norbury and Heyward, 1998), possibly because levels of that toxin are also often lower in muscle than in internal organs (McIlroy and Gifford, 1992). The extent to which carnivores and scavengers will be affected by secondary poisoning will depend in part on which tissues and organs of poisoned animals they eat (McIlroy and Gifford, 1992). Rabbits appear to be a poor vector for secondary poisoning of cats (and possibly ferrets); in contrast, cats commonly eat entire rodents (Murphy, *unpubl. data*), which may be a better vector. The observation that one of the three cats (female 76) that died following the poisoning operation on Motuihe Island had rat fur in her stomach is consistent with this interpretation. Future eradication and control operations targeting cats and other carnivores through secondary poisoning may therefore need to take into consideration the relative abundance of prey (particularly rabbits and rodents) in each situation.

Another possible reason for the high survival of cats seen on Motuihe Island is that they detected poison-containing livers of rabbits and avoided them. However, cats were avoiding livers before the poisoning operation. In addition, three cats did die following the operation and all nine cats caught or shot nine months later contained brodifacoum residues. These facts suggest that most cats were not avoiding toxin-containing prey.

It seems likely in hindsight that Motuihe Island was not a good model for the proposed Raoul Island eradications. With rabbits absent (Gibb and Williams, 1990) and rodents their main prey (Fitzgerald, 1990), we suggest that cats will be affected differently by secondary poisoning on Raoul Island and that mortality will probably be higher than on Motuihe Island.

Our study shows that brodifacoum residues may remain in the livers of cats for at least nine months, and provides further evidence that this compound persists in living animals for long periods. Levels in some of the cats alive at that time were similar to levels in the three cats that died soon after baiting, raising the possibility that repeated exposure of cats to small doses of brodifacoum may result in tolerance to levels that are lethal when acquired from a single dose.

Non-target species

Birds of 10 species were found dead following the Motuihe Island operation and all contained toxin residues. There are difficulties in correlating mortality and liver brodifacoum concentrations in birds, because dead birds with low levels may have died of other causes, and birds collected alive may have been close to death. In addition, there are differences in primary toxicity of brodifacoum to different bird species (e.g., Godfrey, 1985), and in rats the toxin may also be present in liver without apparent effects on coagulation (Parmar *et al.*, 1987).

Overlap in brodifacoum levels in livers of birds found dead and those surviving poison operations are therefore not unexpected; data so far available suggest overlap occurs mainly in the range 0.2-0.6 $\mu g\ g^{-1}$. Thirty birds collected alive following two brodifacoum operations had liver toxin levels ranging from BDL (below detectable limit) to 0.61 $\mu g\ g^{-1}$, with 27 of the 30 (90%) below 0.2 $\mu g\ g^{-1}$ (Morgan, Wright and Spurr, 1996; Murphy *et al.*, 1998). The mean level in birds from Motuihe Island (0.84 $\mu g\ g^{-1}$), combined with the presence of moderate or extensive internal haemorrhage in 24 of 29 (83%) of them, suggests that most or all died as a result of brodifacoum poisoning. Results from the present study, combined with data from Rammell *et al.* (1984), Towns *et al.* (1994), Ogilvie *et al.* (1997) and Stephenson and Minot (1999), show that 37 of 42 birds (88%) found dead following brodifacoum operations in New Zealand had liver levels above 0.4 $\mu g\ g^{-1}$. Together these results suggest a threshold value of approximately 0.5 $\mu g\ g^{-1}$, above which most birds seem likely to have died of poisoning. Some individuals have almost certainly died with lower levels than this, but only few birds have been collected alive with higher levels. Our study also indicated that the degree of internal haemorrhage seen in birds was not necessarily a guide to liver brodifacoum level; some birds found dead contained elevated levels of brodifacoum, but showed little or no sign of internal or external haemorrhage.

Numbers of the various species found (Table 2) did not necessarily indicate the relative impact on each species. First, small passerines were probably under-represented in the sample of birds collected, partly because they are harder to find than larger birds and partly because it is easier for scavengers to remove them entirely. Second, mobility and status (resident or visitor) may have determined whether some birds died on Motuihe Island or elsewhere. Following the operation, large numbers of southern black-backed gulls visited Motuihe Island from nearby islands to scavenge dead rabbits, but only one was found dead. This species is highly mobile and some individuals may have died offshore.

Of the 10 species found dead (Table 2), one (Australasian harrier) is considered unlikely to consume baits but does scavenge rabbits, so was probably poisoned secondarily. Three species (southern black-backed gull, common myna and Australian magpie) are omnivorous (Heather and Robertson, 1996) and may have been poisoned primarily or secondarily (or a combination of both). The remaining species are known or considered likely to eat cereal-based baits (Eason and Spurr, 1995) and probably suffered primary poisoning. Our study confirms that among native birds pukeko are particularly at risk during aerial brodifacoum operations and indicates that anatids, particularly paradise shelduck, may also suffer high mortality, in spite of the high LD_{50} reported for this species (Godfrey, 1985). If rates of bait application had been high enough to eradicate rabbits, mortality of these and other species would presumably have been even higher.

There are costs and benefits associated with most eradication or control operations. Although individuals of non-target species often die, populations of these species usually recover either by breeding, re-invasion from surrounding populations, or re-introduction. Pukekos have re-populated Tiritiri Matangi Island after being reduced by at least 90% following a brodifacoum operation (Veitch, *unpubl. data*) and have increased on Motuihe Island in the year following baiting (Dowding, *unpubl. data*). In most cases, long-term benefits to threatened and endangered species from reduced predation rates probably outweigh short-term losses caused by poisoning operations (e.g. Taylor and Thomas, 1993; Eason and Spurr, 1995). However, conservation managers should continue to develop control and eradication techniques that minimise non-target deaths. It is also possible that non-lethal levels of brodifacoum reduce life expectancy and/or productivity of survivors, and research is clearly required on this topic.

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