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SECONDARY POISONING OF MAMMALIAN PREDATORS DURING POSSUM AND RODENT CONTROL OPERATIONS AT TROUNSON KAURI PARK, NORTHLAND, NEW ZEALAND

Summary: A poison baiting operation at Trounson Kauri Park in Northland, New Zealand using first 1080 and then brodifacoum targeted possums (*Trichosurus vulpecula*) and rodents (*Rattus rattus*, *Rattus norvegicus* and *Mus musculus*). Predatory mammals were monitored by radio telemetry during the operation. All six feral cats (*Felis catus*), the single stoat (*Mustela erminea*) and the single ferret (*Mustela furo*) being monitored at the beginning of the operation died of secondary poisoning following the 1080 operation. A further two cats and four stoats were monitored through the ongoing poisoning campaign using brodifacoum in a continuous baiting regime. None of these radio tagged carnivores died of secondary poisoning. However, tissue analysis of additional carnivores trapped at Trounson found that cats, weasels (*Mustela nivalis*) and, to a lesser extent, stoats did contain brodifacoum residues. The duration that the radio-tagged predators were alive in and around Trounson Kauri Park suggests that the secondary poisoning effect was much reduced under the continuous baiting strategy compared to the initial 1080 poison operation.

Keywords: cats; stoats; ferrets; weasels; mustelids; 1080; sodium monoflouroacetate; brodifacoum; conservation.

Introduction

The acute toxin compound 1080 (sodium monoflouroacetate) is widely used in New Zealand to control the brushtail possum (*Trichosurus vulpecula* Kerr) and rabbits (*Oryctolagus cuniculus* L.) (Livingstone, 1994). The second-generation anticoagulant brodifacoum is now also being used in New Zealand forests to control possums and rodents (Innes *et al.,* 1995). Field and laboratory research has illustrated the potential risks to wildlife through secondary poisoning from 1080 (Hegdal, Gatz and Fite, 1981; McIlroy and Gifford, 1991) and from anticoagulant rodenticides (Evans and Ward, 1967; Mendenhall and Pank, 1980; Merson, Byers, and Kaukeinen, 1984; Townsend *et al*., 1984; Hegdal and Colvin, 1988; Shore *et al*., 1996).

The possibility that mustelids (and cats) may be affected by secondary poisoning following 1080 operations to control rabbits or possums in New Zealand has been suggested by several researchers (Marshall, 1961; Richardson, 1995; Moller, Showers and Wright, 1996; Norbury and McGlinchy, 1996). High non-target kills of carnivores have been recorded overseas following 1080 baiting campaigns (Hegdal *et al.,* 1981; McIlroy and Gifford, 1991), but until recently few incidental carnivore kills in New Zealand following 1080 operations have been reported (Norbury and Heyward, 1997) or were not confirmed as the result of secondary or direct poisoning (Moller *et al*., 1996).

Recent studies in New Zealand have shown that cats and mustelids are susceptible to secondary poisoning when rabbit and rodent pest species are controlled using brodifacoum (Alterio, 1996; Alterio, Brown and Moller, 1997; Brown, Alterio and Moller, 1998; Murphy *et al*. 1998a). These studies raised the possibility that secondary poisoning may provide conservation managers with an efficient multi-species tool for controlling mammalian pests. The current method of controlling mustelids and feral cats in New Zealand is trapping, which is time consuming, costly, subject to seasonal limitations (Alterio, 1996) and does not always significantly reduce predation pressure on threatened species (Peters, 1997).

Trounson Kauri Park in Northland is being managed by the New Zealand Department of Conservation (DOC) as a "Mainland Island" where mustelid, cat, possum and rat numbers are intensively controlled. The aim is to reduce these introduced mammalian pests to such a level that would restore the kauri (*Agathis australis* Salisbury) forest ecosystem, to allow reintroduction of locally or regionally extinct fauna and allow recovery of those native species still present in the park (McClellan, 1997). Possums and rodents (*Rattus rattus* L., *Rattus norvegicus* Berkenhout and *Mus*

musculus L.) were targeted at Trounson Kauri Park initially using cereal based pellets laced with 1080 poison in bait stations. This operation was followed by continuous baiting with brodifacoum-laced pellets. The aim of the research described here was to monitor the impact of the possum and rodent control operations on the survival of radio-tagged cats and mustelids. Rat and mouse abundances were measured in order to determine which were likely vectors of the poison to the predators.

Study Area

Trounson Kauri Park comprises 450 ha of mixed kauri-podocarp hardwood forest, situated on a southerly aspect (140-320 m a.s.l.), surrounded by grazed pastureland and bordered by the Waima River on its south-western edge (Fig. 1). The park is located south of the Waipoua Forest and about 36 km north of Dargaville on the west coast of the North Island, New Zealand (35º44´S, 173º38´E).

Methods

Pest Control

Possum and rodent pest control was carried out using toxic baits fed from bait stations. The bait stations ("Philproof" feeders, Phil Thomson, Taupiri, New Zealand) were set out in the forested areas of the park at a density of one station ha^{-1} (Fig. 1). The initial phase of the poison operation (Table 1) used "Wanganui No. 7" cereal-based baits (Animal Control Products, Wanganui, New Zealand) laced with 1080 at 0.15% concentration, dyed green and flavoured with cinnamon. Four "pre-feeds" with non-toxic baits were carried out to lure target animals to the bait stations prior to the poison operation. The toxic baits were removed from the stations after 18 days. The second phase of the pest control operation (Table 1) involved continuous baiting with either "Talon® 20P" (ICI Crop Care, Nelson, New Zealand) or "Pest off" (Animal Control Products, Wanganui, New Zealand) cereal-based

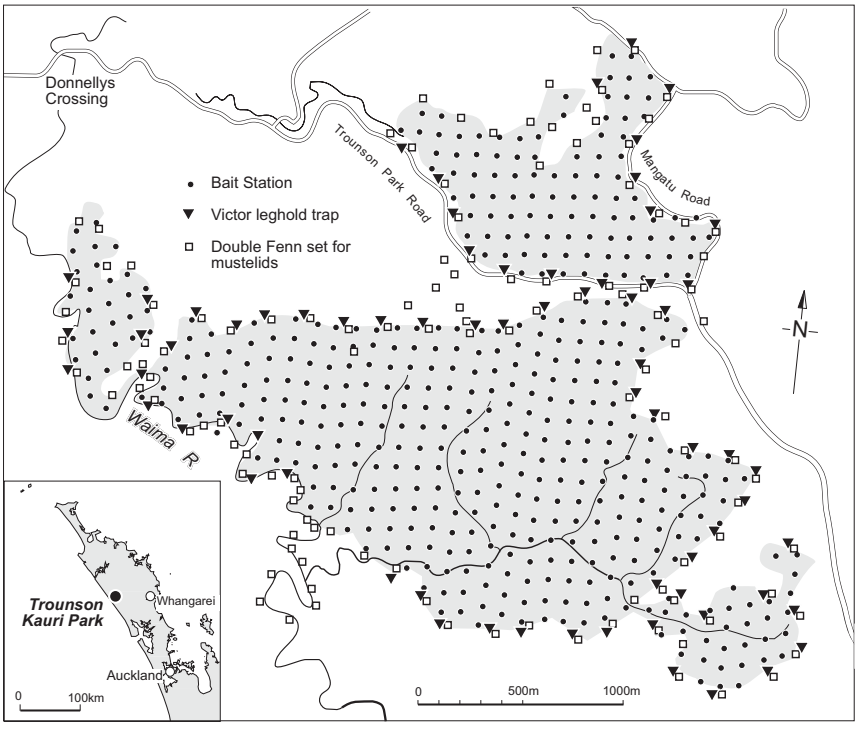

Figure 1: *Map of Trounson Kauri Park showing trapping and bait station layout in the study area (all bait station and trap locations on this map are approximate. Some trap sites along the Waima River 1 km south of the park are not shown).*

Table 1: *Timetable of pest control work carried out at Trounson Kauri Park between June 1996 and September 1997.*

Pest control work	Date
1080 poison operation	10 June 1996
Brodifacoum poison operation started	16 July 1996
Predator trapping started	August 1996
Brodifacoum baits replaced in stations	September 1996
Brodifacoum baits replaced in stations	November 1996
Brodifacoum baits replaced in stations	February 1996
Brodifacoum baits replaced in stations	April 1997
Brodifacoum baits replaced in stations	July 1997
Brodifacoum baits replaced in stations	September 1997

pellets laced with the anticoagulant brodifacoum (20 ppm). The objective of this saturation baiting technique (Eason and Spurr, 1995) was to maintain possum and rodent numbers at the low levels achieved using 1080.

Predator control was carried out by trapping around the forest margins and along the Waima River (Fig. 1). Mustelids were targeted using Mk 6 Fenn traps (FHT Works, Worcester, England) in double sets placed under wooden tunnels and feral cats were targeted using "Victor" soft catch leg-hold traps (Woodstream Corporation, Lititz, U.S.A.) set above ground on ramps to avoid non-target animals. Periodic night shooting was also carried out for additional control of possums and cats.

Radio telemetry

The fates of individual predators were directly monitored using radio telemetry during periods when poison baits were laid. Predators were live captured in cage traps (Veitch, 1985; Harding and Veitch, 1992) and "Edgar" treadle traps for mustelids (King and Edgar, 1977) set around the margins of the park and along roadsides leading to it. All traps were checked daily and some were checked twice daily.

All trapped cats, stoats or ferrets were anaesthetised, weighed, sexed, their colour and general condition noted and sequentially numbered eartags fitted for identification purposes. Each subject was fitted with a collar-mounted two stage radio transmitter (Sirtrack, Havelock North, New Zealand), and released. Six of the cat collars were fitted with mortality transmitters which increased the signal pulse rate from 40 pulses per minute to 80 pulses per minute if the animal did not move for seven hours, indicating it had died or shed its collar. The expected battery life was 4 months for stoat transmitters and 15.4 months for the cat and ferret transmitters.

Secondary Poisoning

The survival of all radio tagged animals (except for those cats fitted with mortality transmitters) was determined by physically locating the subject daily after the commencement of the 1080 operation. All radio tagged predators recovered dead whilst the 1080 was in bait stations were immediately stored in a freezer (-18° C) to prevent further breakdown of any 1080 residues within the tissues. Sections of skeletal muscle were later removed from one hind leg of each specimen and frozen separately to be analysed for 1080 residues. Care was taken to prevent cross contamination between specimens by washing dissection equipment and changing gloves after each muscle sample was removed.

All predators killed in traps or by shooting at Trounson Kauri Park were collected for autopsy. The livers of any predators killed after 16 July 1996 were removed and frozen at -18° C for later analysis of brodifacoum residues. Some predators especially during summer months were too decayed when found; the livers of these animals were not removed.

Analysis for 1080 residues was initially carried out by the toxicology laboratory of Landcare Research, New Zealand Ltd, Lincoln. Tests for 1080 were carried out using TLM 005, 1080 measurement in tissue by gas liquid chromatography. The limit of detection in tissue was 0.005 $\mu g\ g^{-1}$. Subsequent analyses for 1080 residues and all analyses for brodifacoum residues were carried out by the National Chemical Residue Laboratory, Ministry of Agriculture, Wallaceville Animal Research Center, Upper Hutt, New Zealand. The tests for 1080 used method 1080Tox.v2 (Hoogenboom and Rammell, 1987) which can detect residues to a minimum of 0.1 mg kg^{-1}. Analysis for brodifacoum residues was carried out using method anticoag.v2 (Shell Research Limited, Kent, England). The minimum detectable levels of brodifacoum for liver samples from the first batch of predators (killed between 9 August 1996 and 19 January 1997) was 0.05 mg kg^{-1}. For the second batch (killed between 21 January 1997 and 5 September 1997) of liver samples the minimum detectable level of brodifacoum was 0.01 mg kg^{-1}.

Chi-squared tests of independence were used to test for significant differences in the number of livers that contained brodifacoum residues between predator species and predator sexes Where the observed frequencies were low, Fisher's Exact test was applied (Seigel, 1956).

Rodent surveys

As part of the ecosystem recovery plan for Trounson Kauri Park the Department of Conservation

conducted regular rodent monitoring. Rodent snap trapping to estimate indices of rodent abundance was carried out at Trounson in May 1996 prior to pest control work. Rodent trapping was repeated during July, August and October 1996 and January and April 1997. Five trap lines each with 20 trap sets spaced at 20 m intervals were run from random start points. Each set consisted of one "Ezeset Supreme" break back rat trap and one plastic "Better mouse trap" (Intruder Incorporated Australia) snap trap, set under natural cover. Mouse and rat traps were spaced at far enough apart (*c*. ≥ 30 cm) at each set to prevent interference between traps by captured animals. Trap lines were run for three consecutive nights in periods of clear weather. Trap catch data was corrected for sprung traps and converted to an index of abundance expressed as the number of rats or mice caught per 100 corrected trap nights (Nelson and Clark, 1973).

Results

Secondary poisoning from 1080

Twenty cats, two stoats, and one ferret were captured and fitted with radio transmitters between the 18th of January 1996 and the 10th of June 1996. Prior to the poison operation, seven of the cats died from various causes, we were unable to locate three animals, one was removed from the survey for humanitarian reasons and one stoat shed its transmitter. Three male cats were outside the treatment area for the duration of the 1080 operation in June 1996, but one of these may have moved through the treatment area two nights after the toxic baits were loaded into the stations. Six radio-tagged cats, one stoat and one ferret were present in the treatment area at the commencement of the 1080 operation. After the start of the poison operation all of the radio-tagged cats in the treatment area, the stoat and the ferret died or were found dead within 5, 10 and 21 days respectively. 1080 residues were detected in the skeletal muscle of all of the radio-tagged animals that were recovered (Table 2). Two additional cats (not study animals) were found dead near the treatment area (within 100 m of the nearest bait station) after the start of the poison operation. 1080 residues were detected in the skeletal muscle of one of these (a female), found three days after the operation began. Residues were not detected in the muscle tissue of the other cat (also female), discovered 27 days after the operation began.

Secondary poisoning from brodifacoum

Two cats and four stoats were monitored using telemetry between July 1996 and May 1997 (Table 3). None of these predators died of secondary poisoning. However, the livers of the two cats and two of the stoats contained brodifacoum residues (Table 3). The transmitter expired on the fourth stoat.

Table 2: *1080 residues in skeletal muscle of predators found dead during the 1080 operation at Trounson Kauri Park in June 1996. All the animals except the last two cats were radio-tagged. The limit of detection of 1080 was 0.005 μg g^{-1} except for the last cat and the ferret for which it was 0.01 mg kg^{-1} * = animal possibly dead earlier than this. † = carcass inside large tree stump and could not be recovered.*

Species	Days from bait application to death	1080 residue (μg g^{-1})
cat	1	0.57
cat	2	1.06
cat	2	1.24
cat	2	0.24
cat	3	0.43
cat	5†*	not tested
cat	3*	0.21
cat	27*	not detected
stoat	10	0.079
ferret	21*	13

Table 3: *Concentration of toxin in the livers and fate of predators monitored through the brodifacoum poison operation at Trounson Kauri Park, July 1996 to May 1997. Duration monitored refers to the length of time the animal was monitored by radio telemetry. * = stoat 842 monitored in park for 107 days before transmitter failed. † = poisoned area not in core of territory (Gillies,* unpubl. data*).*

Species, sex	Date captured	Concentration of brodifacoum (mg kg^{-1})	Duration monitored (days)	Cause of death
cat, m	21 Apr 1996	0.13	91 †	shot
cat, m	12 May 1996	0.25	212 †	shot
stoat, m	20 Jan 1997	0.08	227*	Fenn trap
stoat, f	14 Jan 1997	not tested	110	fate unknown
stoat, m	17 Jan 1997	0.36	4	Fenn trap
stoat, f	13 Jan 1997	not detected	5	died in live trap

Brodifacoum residues

The livers of 19 cats, 19 stoats and 13 weasels were analysed for brodifacoum residues (Fig. 2). The proportions of residues detected varied significantly between species ($\chi^2 = 11.309$, d.f. = 2, $P = 0.004$).

One of the cats killed in a trap was a domestic animal belonging to a neighbouring landowner. This animal had been sighted in the park on two occasions over six months prior to its capture and contained a relatively low concentration of brodifacoum residues in its liver.

Only a small number of female predators was captured during the study period. Similar proportions of male and female cats contained brodifacoum residues (Table 4). The level found in the single female weasel was within the range of the values found in male weasels. The single male ferret liver that was tested did not contain brodifacoum residues.

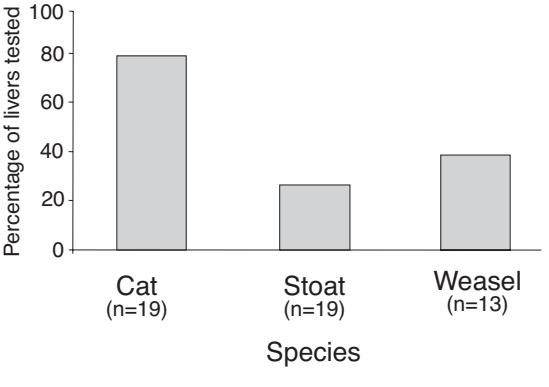

Figure 2: *Percentage of predators killed at Trounson Kauri Park between July 1996 and September 1997 that contained detectable levels of brodifacoum in their livers.*

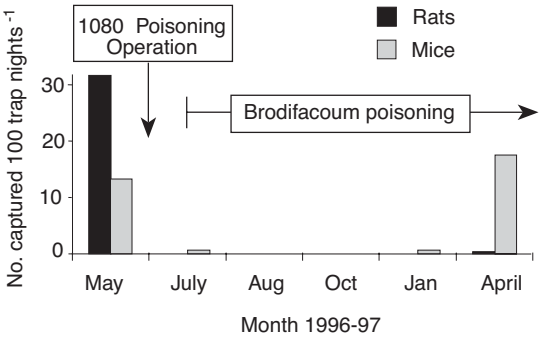

Figure 3: *Rodent snap trap capture rates at Trounson Kauri Park, (before and during poison operations to control possums and rodents), expressed as the capture rate for 100 trap nights, corrected for sprung traps (Nelson and Clark, 1973).*

Rodent indices

Snap trap indices indicated that the initial June 1080 poison operation reduced the numbers of rats to non-detectable levels (Fig. 3). Mouse numbers also appeared to be greatly reduced. The indices also suggested that the ongoing poison campaign using brodifacoum may have suppressed rats continuously and mice at least until the autumn of 1997.

Discussion

Secondary poisoning following the 1080 operation

All of the radio tagged predators in Trounson Kauri Park died soon after the 1080 baits were put into the stations. The occurrence of 1080 residues in the skeletal muscle of these predators strongly suggests that poisoning was the cause of mortality. Autopsies of the gut contents of the Trounson predators that

Table 4: *Percentage of livers of male and female predators kill trapped during the brodifacoum operation at Trounson Kauri Park, July 1996 to September 1997, that contained detectable brodifacoum residues, corresponding probabilities for Fisher's exact test for male female comparisons and mean (± S.E.) concentrations of toxin detected.*

Species	Sex	Percentage of livers containing brodifacoum	n	Fisher's exact test probability (P)	Mean concentration of brodifacoum (mg kg^{-1})
Cat	M	87	13		0.40 (± 0.17)
	F	50	2	0.178	0.88 (± 0.83)
Stoat	M	36	5		0.28 (± 0.1)
	F	0	0	0.257	
Weasel	M	36	4		0.6 (± 0.1)
	F	50	1	0.462	1

contained 1080 residues in the tissues, did not reveal any traces of bait or dye. Dyed cereal bait was found in the guts of one cat, but this was inside a mouse the cat had eaten. The guts of these animals contained remains of rodents and/or possums, one also contained a small passerine (C. Gillies, *unpubl. data*). The predators probably died from secondary poisoning as a result of eating 1080-poisoned prey, or scavenging the carcasses of poisoned animals. Both of the two radio-tagged mustelids were found in burrows along with dead rats that contained dyed cereal bait in their guts. In both cases the mustelids had only partially consumed their prey. Another recent New Zealand study at Waimanoa, in Pureora Forest in the central North Island has also shown that a large proportion of stoats can die following an aerial sown 1080 operation (Murphy *et al.,* 1999). The results from this and the Waimanoa study suggest that secondary poisoning may have potential as a useful mammalian carnivore control technique, particularly if the poison operations are timed to coincide with vulnerable periods (e.g., just before bird breeding times) for threatened species. The question remains as to why the incidental carnivore kill following a 1080 operation was so high in these two studies compared to other New Zealand studies.

Secondary poisoning during the brodifacoum operation

High incidental kills of predators have been recorded following three brodifacoum poisoning operations to target other pest mammals in the South Island (Alterio, 1996; Alterio *et al*., 1997; Brown *et al*., 1998). In the central North Island, stoat capture rates were reported to have dropped (possibly due to secondary poisoning) after successful brodifacoum poison operations (Murphy *et al*., 1998b). However, none of the radio-tagged predators at Trounson died from brodifacoum secondary poisoning.

Attempting to determine the efficacy of secondary poisoning by brodifacoum as a potential technique for controlling predators was confounded by the intense predator trapping and control methods being carried out. However the period over which two of the cats and two of the stoats were monitored, combined with the analysis of 52 liver samples, enable us to make some interim conclusions regarding secondary poisoning. Brodifacoum residues were found in the livers of carnivores trapped and shot at Trounson, despite the fact that none of the radio-tagged animals actually died from secondary poisoning. The levels of brodifacoum found in cats and stoats from Trounson were low when compared to those found in the predators that died of secondary poisoning in the South Island studies (Alterio, 1996; Alterio, *et al*., 1997; Brown *et al*., 1998). Although the mean residue level found in the weasels sampled from Trounson was similar to that found in the single weasel killed at Maruia (Alterio, *et al*., 1997), it was lower than the mean residues detected in weasels trapped at Mapara (Murphy *et al*., 1998 b).

No differences were detected between predator sexes at Trounson, either in the proportions of livers containing brodifacoum or in the mean concentrations of toxin detected. This could be a result of the sample size for each of the predator species, particularly the low number of females captured. A higher proportion of female stoats were found to contain brodifacoum residues than males at Mapara, although the mean residue levels did not differ between sexes (Murphy *et al*., 1998 a). Comparison of brodifacoum concentrations detected in predator livers may, however, be of limited value as there are few toxicological data available to link residue levels with mortality and sub-lethal effects (Shore *et al*., 1996).

There is also the problem that most of the samples taken from Trounson were from predators caught in kill traps, and the time spent by each animal in the treatment area prior to capture is unknown. Mean brodifacoum residues in stoats increased with time at Mapara, suggesting that there is a cumulative effect from continuing to eat poisoned prey (Murphy *et al*., 1998a). Some predators might eventually have died of brodifacoum poisoning given the cumulative nature of this toxin (Eason and Spurr, 1995). Although brodifacoum residues were detected in many of the predator livers in the present study, the time that the radio-tagged animals were alive in (or near) the treatment area suggests that the secondary poisoning effect was much reduced and perhaps of limited conservation value, especially when compared to the initial 1080 operation at Trounson, and the South Island brodifacoum operations where the carnivores died soon after the poison application (Alterio, 1996; Alterio *et al*., 1997).

Comparison between secondary poisoning effects after the 1080 and brodifacoum operations

High secondary kills of carnivores have occurred with both an acute toxin, 1080 (this study) and with an anticoagulant toxin, brodifacoum, (Alterio, 1996; Alterio *et al*., 1997, Brown *et al*., 1998, Murphy *et al.,*1999). This suggests that the differing nature of the toxins is unlikely to be the reason for the reduced secondary poisoning effect on predators with brodifacoum at Trounson. A more likely explanation is that the reduced number of toxic prey

at Trounson could mean that the carnivores were exposed a lower risk of brodifacoum poisoning.

Rats may be one of the key vectors of toxin to predators (Alterio *et al*., 1997; Murphy *et al*., 1998a). Rodents form an important component of the diet of cats and stoats in Northland forests (C. Gillies, *unpubl. data*) and other New Zealand habitats (Fitzgerald and Karl, 1979; King and Moody, 1982; King, 1990; Langham, 1990; Murphy and Bradfield, 1992). Rats can live for 3-5 days after consuming fatal doses of brodifacoum (Hooker and Innes, 1995). High concentrations of brodifacoum were found in dead (Alterio *et al*., 1997) and live rats (Murphy *et al*., 1998a) following poison operations. Alterio *et al*. (1997) also suggest that that the ingestion of only a few poisoned ship rats can kill stoats and therefore secondary poisoning may occur at low prey densities. Brown *et al*.(1998) confirmed that secondary poisoning by brodifacoum still occurred when mouse numbers were low, but carnivores took longer to succumb to the effects of the poison.

It is difficult to assess the impact of the 1080 operation on rats in this study due to the lack of adequate non-treatment comparisons prior to pest control. Infra-red video footage taken during the pre-feed phase of the 1080 operation showed that rats were frequently visiting the bait stations and taking baits (C. Gillies and R. Pierce, *pers. obs*.). The rodent survey results suggest that rat numbers at Trounson were reduced considerably following the 1080 operation. Rats however, have continued to be caught in the Fenn traps around the perimeter of the park (McClellan, 1997), which shows that they were still present, albeit in low numbers. The carcasses of these rats (and any possums caught) were generally discarded near the trap (C. Gillies, *pers. obs*.) and therefore could still be scavenged by predators.

Mice could also have been a potential vector for brodifacoum poisoning of carnivores (Alterio, 1996). Indices of mouse abundance increased at Trounson following the commencement of poison operations. This increase in mouse numbers, following successful poisoning operations has been recorded in forests elsewhere in New Zealand (Innes *et al*., 1995). There was however, no increase in the occurrence of brodifacoum in predator livers which coincided with the increased mouse abundance. Also, of two stoats that were being monitored over the period when mouse indices at Trounson were high, neither died (C. Gillies, *unpubl. data*). No toxin analysis was carried out on mouse carcasses from Trounson so it is unclear to what extent they may be acting as a vector of brodifacoum. The increase in mouse numbers suggests that the bi-monthly pulse baiting strategy had a limited effect on the population of this rodent.

Possum numbers were reduced by 90 % at Trounson following the 1080 operation (McClellan, 1997). Within two or three days after the 1080 operation, possum carcasses (and to a lesser degree rat carcasses) were abundant on the forest floor at Trounson (C. Gillies, *pers. obs*.). No possums were caught in the June 1997 survey trap lines (McClellan, 1997). This suggests that the possum numbers have been further and more heavily suppressed as a result of the brodifacoum operation. The high availability of toxic prey following the initial 1080 operation at Trounson may explain the high incidental kill of the carnivores. In South Island studies potential mammalian prey (of the carnivores) were significantly reduced and also found dead or dying in the respective study areas following the poison operations (Alterio, 1996, Alterio *et. al*., 1997, Brown *et al*., 1998). Murphy *et al*. (1998b) report that it was the successful (high rat kill) anticoagulant operations which resulted in lower stoat capture rates. Recently, cats were monitored using telemetry throughout two brodifacoum campaigns targeting rats and rabbits on Motuihe Island in the Hauraki Gulf, New Zealand. Only a small number of these cats died, probably because the operations failed to reduce the rabbit population (J. Dowding, *pers. comm*.; P.O. Box 36-559 Northcote, Auckland, N.Z..).

At Trounson there was also the possibility that an increased availability of rabbits may have provided a sufficient non-toxic prey "buffer", particularly for the cats. Rabbits can be an important prey species of feral cats in New Zealand forest (Fitzgerald and Karl, 1979). Rabbit counts at Trounson in 1997 (C. Gillies, *unpubl. data*) supported suspicions that rabbit numbers had increased noticeably over the year since the operation began. Some bait stations were located near the margins of the forest, so rabbits may have had access to baits. No toxin analysis was carried out on rabbit carcasses from Trounson, so the potential for them to act as brodifacoum vectors is unclear. No cereal bait was ever seen or recorded in the guts of rabbits shot or caught in Fenn traps, suggesting that they were not taking toxic baits. By comparison, cereal bait was found in approximately half of the possums caught in the cat traps, especially shortly after station refills (S. Theobold, *pers. comm*.; Department of Conservation, Northland, N.Z.). Alterio (1996) and Norbury and Heyward (1997) report that poisoned rabbits were an important source of toxin for predators. In both of those studies rabbits were targeted in the poison operations and had a high likelihood of consuming toxic baits.

Differences in proportions of brodifacoum detected between carnivore species

One reason for the higher number of cats containing brodifacoum residues compared to the stoats and weasels could be a result of the reinvasion patterns of these predators at Trounson. The peak capture rates for stoats (in both live and kill traps) occurred during December 1996 and January 1997 (McClellan, 1997; C. Gillies, *unpubl. data*), when rodent numbers were still low. Peak captures for cats occurred through the winter months of 1997 (C. Gillies, *unpubl. data*), when the incidental catches of rats in Fenn traps were high (McClellan, 1997) and mouse numbers had increased. Weasel capture rates in kill traps were more consistent over the study period. It appears more weasels captured in late winter 1997 contained brodifacoum residues than during other periods, but this could possibly be due to the lower sensitivity of the second set of toxin analyses. The differences in sensitivity between the two sets of toxin analyses may also explain the differences between cats and stoats, but the majority of residues found in cat livers were above the minimum detectable level for both tests.

The reason fewer stoats contained brodifacoum residues than did cats or weasels could also be due to differences in dietary habits. Birds were found to be the most important prey of stoats in three New Zealand forest studies (King and Moody, 1982; King, 1990; Murphy and Dowding, 1994). It is possible that stoats at Trounson could have switched diet from rodents (particularly rats) to birds following the poisoning operations as found at Mapara (Murphy and Bradfield, 1992; Murphy *et al.,* 1998b). It is also possible that cats directly consumed baits (Morgan *et al.,* 1996), which are believed to be unpalatable to mustelids (Richardson, 1995).

Implications for conservation

In New Zealand, the secondary poisoning effect on mustelids and cats has conservation benefits. However, this research also highlights the potential risk to carnivores of secondary poisoning elsewhere in the world. In Britain, polecats (*Mustela putorius* L.), other native mustelids and even farmyard cats are likely to be exposed to second-generation rodenticides currently in widespread use there (Shore *et al.,* 1996).

The high incidental kill in mammalian predators with the initial poison operation at Trounson, at Waimanoa (Murphy *et al.,* 1999) and on the South Island (Alterio, 1996; Alterio *et al*., 1997), highlights the potential for multi-species control using secondary poisoning in New Zealand. These recent findings have been heralded by several conservation managers as "the breakthrough" that will allow efficient multi-species pest control in mainland ecosystems. Certainly, the results found when carnivores have been monitored have generally been quite dramatic. However, secondary poisoning of predators must have been occurring, at least to some degree, for as long as 1080 and brodifacoum have been used (for rat and possum control) in this country, yet predators are still a conservation problem. There is good potential for secondary poisoning to be used as a predator eradication tool on off-shore islands where predator re-invasion is unlikely. At Trounson, re-invasion of predators began soon after the initial knockdown (McClellan, 1997; C. Gillies, *unpubl. data*). The reduced effect of the ongoing poisoning operation on predators at Trounson however, demonstrates the need for more research into the mechanisms by which the secondary poisoning effect is achieved. The reduced effect at Trounson and the low impact on cats at Motuihe (J. Dowding, *pers. comm*.), also demonstrate that it is not yet a proven method by which carnivores can be controlled on a sustained basis. Conservation managers in New Zealand should not rely on secondary poisoning as the sole way to manage introduced carnivores in mainland habitats.

If secondary poisoning is to be used as a multi-species management tool, a greater understanding of which prey species are important and the densities required to achieve a useful incidental kill in carnivores is required. Vector prey such as the ship rat can pose a serious conservation risk (Innes *et al.,* 1995). Any benefits achieved by secondary poisoning would also have to be gauged against the possible risks associated with allowing the vector prey species to recover to sufficient levels. The vulnerable periods of threatened native species would need to be assessed and the tolerable densities of potential "vector prey" species (e.g., rats or possums) determined before any poison pulsing regime could be designed to achieve the best incidental carnivore kill.

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References

Alterio, N. 1996. Secondary poisoning of stoats (*Mustela erminea*), feral ferrets (*Mustela furo*), and feral house cats (*Felis catus*) by the anticoagulant poison, brodifacoum. *New Zealand Journal of Zoology 23:* 331-338.

Alterio, N.; Brown, K.; Moller, H. 1997 Secondary poisoning of mustelids in a New Zealand *Nothofagus* forest. *Journal of Zoology, London 243:* 863-869.

Brown, K.P.; Alterio, N.; Moller, H. 1998. Secondary poisoning of stoats (*Mustela erminea*) at low mouse (*Mus musculus*) abundance in a New Zealand *Nothofagus* forest. *Wildlife Research 25:* 419-426.

Eason, C.T; Spurr, E.B. 1995. Review of the toxicity and impacts of brodifacoum on non-target wildlife in New Zealand. *New Zealand Journal of Zoology 22:* 371-379.

Evans, J.; Ward, A.L. 1967. Secondary poisoning associated with anticoagulant-killed nutria. *Journal of the American Veterinary Medical Association 151:* 856-861.

Fitzgerald, B.M.; Karl, B.J. 1979. Foods of feral house cats (*Felis catus* L.) in forest of the Orongorongo Valley, Wellington. *New Zealand Journal of Zoology 6:* 107-126.

Harding, D.; Veitch, D. 1992. Demonstration of predator management methods. *In:* Veitch, D.; Fitzgerald, M.; Innes, J.; Murphy, E. (Editors), *Proceedings of the National Predator Management Workshop, Craigeburn, Canterbury, N.Z. 13-16 April 1992. Threatened Species Occasional Publication No. 3:* 67-72. Department of Conservation, Wellington, N.Z.

Hegdal, P.L.; Gatz, T.A.; Fite, E.C. 1981. Secondary effects of rodenticides on mammalian predators. *In:* Chapman, J.A.; Pursley, D. (Editors), *Proceedings of the First Worldwide Furbearer Conference, Frostburg, Maryland, U.S.A. 3-11 August 1980,* pp. 1781-1793. Worldwide Furbearer Conference Inc., Frostburg, U.S.A.

Hegdal, P.L.; Colvin, B.A. 1988. Potential hazard to eastern screech-owls and other raptors of brodifacoum bait used for vole control in orchards. *Environmental Toxicology and Chemistry 7:* 245-260.

Hoogenboom, J.J.L.; Rammell, C.G. 1987. Determination of sodium monoflouroacetate in tissues and baits as its benzyl ester by reaction-capillary gas chromatography. *Journal of Analytical Toxicology 1:* 140-143.

Hooker, S.; Innes, J. 1995. Ranging behaviour of forest dwelling ship rats, *Rattus rattus*, and effects of poisoning with brodifacoum. *New Zealand Journal of Zoology 22:* 291-304.

Innes, J.; Warburton, B.; Williams, D.; Speed, H.; Bradfield, P. 1995. Large-scale poisoning of ship rats (*Rattus rattus*) in indigenous forests of the North Island, New Zealand. *New Zealand Journal of Ecology 19:* 5-17.

King, C.M. 1990. Stoat. *In:* King, C.M. (Editor), *The handbook of New Zealand mammals*. pp. 288-312. Oxford University Press, Auckland, N.Z. 600 pp.

King, C.M.; Edgar, R.L. 1977. Techniques for trapping and tracking stoats (*Mustela erminea*); a review, and a new system. *New Zealand Journal of Zoology 4:* 193-212.

King, C.M.; Moody, J.E. 1982. The biology of the stoat (*Mustela erminea*) in the National Parks of New Zealand II. Food habits. *New Zealand Journal of Zoology 9:* 57-80.

Langham, N.P.E. 1990. The diet of feral cats (*Felis catus* L.) on Hawke's Bay farmland, New Zealand. *New Zealand Journal of Zoology 17:* 243-255.

Livingstone, P.G. 1994. The use of 1080 in New Zealand. *In:* Seawright, A.A.; Eason, C.T. (Editors), *Proceedings of the science workshop on 1080. The Royal Society of New Zealand, Miscellaneous Series 28:* 1-9.

Marshall, W.H. 1961 (unpublished). Ecology of mustelids in New Zealand. *Animal Ecology Division, Information series No. 1.* Department of Scientific and Industrial Research, Lower Hutt, N.Z. 24 pp.

McClellan, R. 1997 (unpublished). *Trounson Kauri Park scenic reserve. Mainland Island Restoration. Annual report 1996-1997.* Unpublished internal report to Northland Conservancy, Department of Conservation, Whangarei, N.Z. 57 pp.

McIlroy, J.C.; Gifford, E.J. 1991. Effects on non-target animal populations of a rabbit trail-baiting campaign with 1080 poison. *Wildlife Research 18:* 315-325.

Mendenhall, V.M.; Pank, L.F. 1980. Secondary poisoning of owls by anticoagulant rodenticides. *Wildlife Society Bulletin 8:* 311-315.

Merson, M.H.; Byers, R.E.; Kaukeinen, D.E. 1984. Residues of the rodenticide brodifacoum in voles and raptors after orchard treatment. *Journal of Wildlife Management*. 48: 212-216.

Moller, H.; Showers, J.; Wright, M. 1996. Sodium monoflouroacetate (1080) poisoned jam bait

laid for brushtail possums (*Trichosurus vulpecula*) also kills ferrets (*Mustela furo*). *New Zealand Journal of Zoology 23:* 135-141.

Morgan, D.R.; Innes, J.; Ryan, C.; Meikle, L. 1996. Baits and baiting strategies for multi-species pest control and feral cats.. *Science for Conservation 40*. Department of Conservation, Wellington, N.Z. 27 pp.

Murphy, E.; Bradfield, P. 1992. Change in diet of stoats following poisoning of rats in a New Zealand forest. *New Zealand Journal of Ecology 16:* 137-140.

Murphy, E.C.; Clapperton, B.K.; Bradfield, P.M.F.; Speed, H.J. 1998a. Brodifacoum residues in target and non-target animals following large-scale poison operations in New Zealand podocarp-hardwood forests. *New Zealand Journal of Zoology 25:* 307-314.

Murphy, E.C.; Clapperton, B.K.; Bradfield, P.M.F.; Speed, H.J. 1998b. Effects of rat-poisoning operations on abundance and diet of mustelids in New Zealand podocarp forests. *New Zealand Journal of Zoology 25:* 315-328.

Murphy, E.C.; Dowding, J.E. 1994. Range and diet of stoats (*Mustela erminea*) in a New Zealand beech forest. *New Zealand Journal of Ecology 18:* 11-18.

Murphy, E.C.; Robbins, L.; Young, J.B.; Dowding, J.E. 1999. Secondary poisoning of stoats after an aerial 1080 poison operation in Pureora Forest, New Zealand. *New Zealand Journal of Ecology 23:* 175-182.

Nelson, L.; Clark, F.W. 1973. Correction for sprung traps in catch/effort calculations of trapping results. *Journal of Mammalogy 54:* 295-298.

Norbury, G.; McGlinchy, A. 1996. The impact of rabbit control on predator sightings in the semi-arid high country of the South Island, New Zealand. *Wildlife Research 23:* 93-97.

Norbury, G.; Heyward, H. 1997 (unpublished). *Impact of rabbit control on predator ecology*. Landcare Research contract report LC9697/138, Landcare Research, Alexandra, N.Z. 26 pp.

Peters, D. 1997. Kiwi research at Waikaremoana. *In:* Sim, J.; Saunders, A. (Editors), *Proceedings of the National Predator Management Workshop 1997, St. Arnaud N.Z. 21-24 April 1997* pp. 15-17. Department of Conservation, Wellington, NZ.

Richardson, J.S. 1995 (unpublished). *The susceptibility of ferrets (Mustela furo) to primary and secondary poisoning, and their ability to develop aversions to compound 1080 under laboratory conditions*. BSc Hons. dissertation, University of Otago, Dunedin, N.Z. 45 pp.

Seigel, S. 1956. *Nonparametric statistics for the behavioural sciences*. McGraw-Hill Kogakusha, Limited. Tokyo, Japan. 312 pp.

Shore, R.F.; Birks, J.D.S.; Freestone, P.; Kitchener, A.C. 1996. Second generation rodenticides and polecats (*Mustela putorius*) in Britain. *Environmental Pollution. 91:* 279-282.

Townsend, M.G.; Bunyan, P.J.; Odam, E.M.; Stanley, P.I.; Wardall, H.P. 1984. Assessment of secondary poisoning hazard of warfarin to least weasels. *Journal of Wildlife Management 48:* 628-632.

Veitch, C.R. 1985. Methods for eradicating feral cats from offshore islands in New Zealand. *In:* Moors, P.J. (Editor), *Conservation of Island Birds. Case studies for the management of threatened island species,* pp. 125-141. International Council for Bird Preservation Technical Publication No. 3. Cambridge, England.