Current practices in sequential use of possum baits

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CONTENTS

Abstract

Many methods are currently used in sustaining control of possum populations. The effectiveness of these methods is likely to depend on: habitat; season; climate; topography and size of the ecosystem; the quality management systems used during planning; selection of baits; procedures used during implementation of an operation; and levels of residual shyness associated with previous sub-lethal poisonings. The use of some methodologies for control of possums are constrained because they present an unacceptable risk to non-target species, a risk to human health, or because of public dissent. This report reviews possum control methods as practised currently on conservation lands, and provides a literature review on control strategies. Long-term sustainable control is most cost-effective if initial kills of 95% (or a residual trap catch (RTC) <3%) are achieved by uniformly applying highly palatable baits of an appropriate size that contain recommended toxicant concentrations. If long-term sustained control of populations at low densities is required, then maintenance control is best initiated within 1 year if the RTC exceeds 5%. Thereafter population and / or ecosystem monitoring to establish times for maintenance control should be initiated at intervals of no more than 5 years. In small reserves, ongoing immigration will require managers to either establish a buffer zone around control areas or initially undertake annual control. In such areas, population and / or ecosystem monitoring to establish timing of maintenance control should begin 3 years after initial control (and follow-up operations). Optimal methods for the maintenance control of possums are dependent on the time elapsed since initial control, prevalence of residual shyness, costs of control, considerations of environmental safety, and public acceptance of the proposed method of control.

1. Introduction

Possum control has, for the past four decades, relied heavily on the aerial application of carrot or cereal baits containing sodium monofluoroacetate (1080) poison (Rammell and Fleming 1978). However, continuing public opposition to 1080, particularly when aerially applied (Eason 1995), has resulted in a shift towards increased use of ground-based operations using baits in bait stations (Thomas 1994), paste baits placed on the ground (Animal Health Board 1992), traps, and night-shooting. In recent years new poisons such as brodifacoum and cholecalciferol (Eason et al. 1993), new delivery systems such as toxin encapsulation (Warburton et al. 1996), new baits (Morgan & Henderson 1996, Morriss et al. 1997), and new types of traps (Warburton 1982, Warburton 1996) have been used to control possums. Despite these innovations and improvements to the quality of 1080 baits (Henderson et al. 1998) and their delivery systems (Morgan et al. 1996b), a significant proportion of possums still survive both initial and maintenance control (Spurr 1993a, Henderson et al. 1997). Such failures are thought to be due to: behavioural factors (Hickling 1994, Henderson & Hickling 1997); lower bait acceptance in some seasons (J.D. Coleman unpubl. data); inadequate distribution of bait (Morgan et al. 1996b); use of sub-standard baits (Henderson & Morriss 1996); sublethally poisoned possums developing a shyness to baits (Morgan et al. 1996a); or pest controllers using inappropriate methods during maintenance control of possum populations.

Advice on developing a programme for sustained control of possums is provided in this report in a three-step process (described in sections 5, 6, and 7) that addresses the following:

- What control methods are available and most appropriate? (Section 7)
- What are 'best current practices' for these methods? (Section 3)
- How can control methods be used optimally in sequence for sustained possum control? (Section 4)

Descriptions of the influence of past control and constraints on control options are detailed in Appendix 1.

2. Control methods

At present there are 16 commonly used methods for the control of possums. A summary description of these methods is given in Table 1. The table also refers to information in Appendix 1, explaining how the use of different methods is constrained by particular factors.

TABLE 1. SUMMARY OF CONTROL METHODS THAT USE A VARIETY OF BAIT TYPES AND TRAPS, WITH DETAILS OF SUPPLIERS AND COSTS OF MATERIALS. THE REQUIREMENT FOR A LICENCE AND THE MAIN ADVANTAGES AND DISADVANTAGES OF EACH METHOD OF CONTROL ARE ALSO LISTED.

METHOD OF CONTROL	BAIT OR TRAP TYPE (AND SUPPLIER)*	COST OF PRODUCT (EX GST)	LICENCE REQUIRED	ADVANTAGES OF METHOD	DISADVANTAGES OF METHOD (NUMBERS IN BRACKETS REFER TO 'CONSTRAINTS' SECTION IN APPENDIX 1.	
Aerial application (1080) bait	Carrot (contract) No.7 (ACP Wanganui) RS5 (ACP Waimate)	$100/tonne $1780/tonne $1313/tonne	Y	Control in remote areas; control in short time-frame; total coverage with GPS; kills most rodents and stoats.	Requires a forecast of dry weather; risks to non-target species; restricted use at many sites; public opposition; secondary poisoning of dogs.	(2.2) (2.3.1) (2.3.3) (2.2.1)
Paste baiting (1080 paste)	Pestoff ® paste (ACP) Wanganui)	$105/20 kg	Y	Low costs for control; lower environmental risk than aerial control; minimal risk of 1080 in waterways.	Requires fine weather; methodology not tested in deep forest; secondary poisoning of dogs; some ground-dwelling birds at risk.	(2.2.1) (2.2.2)
Hand broadcast (1080)	Carrot (contact) No.7 (ACP Wanganui) RS5 (ACP Waimate)	$100/tonne $1780/tonne $1313/tonne	Y	Bait applied to specific locations; birds in canopy not exposed to bait; minimal risk of 1080 in waterways.	Requires fine weather; some ground-dwelling birds at risk; operators exposed to 1080; secondary poisoning of dogs.	(2.2.2) (2.3.2) (2.2.1)
Bait stations (Continuous 1080 baiting for 5 weeks)	No.7 (ACP Wanganui) RS5 (ACP Waimate) Gel (Kiwicare Corp>)	$1780/tonne $1313/tonne	Y	Control in public water supply areas; avoids costs of pre-feeding; attracts few non-targets; unlikely to occur in drinking water.	Long baiting period, causing decreased bait palatability and total consumption; secondary poisoning of dogs; some rodents not killed.	(2.2.1) (3.3.3)
Bait stations (pre-fed 1080)	Apple (contract) Swede (contract) No.7 (ACP Wanganui) RS5 (ACP Waimate)	Variable Variable $1780/tonne $1313/tonne	Y	Reduces time toxic bait is in field; fewer bait stations required; pre-feeding and apple attracts possums; toxic baiting for only 5 days; more bait eaten; unlikely to occur in drinking water.	Labour intensive; non-target risks; secondary poisoning of dogs; some rodents not killed.	(2.2) (2.2.1) (3.3)
Maintenance control (1080 baits)	Paste (ACP Wanganui) Carrot (contract) No.7 (ACP Wanganui) RS5 (ACP Waimate) Gel (Kiwicare Corp.)	$105/20 kg $100/tonne $1780/tonne $1313/tonne	Y	Effective 4 or more years after initial control; lower costs of control; control over large areas.	Requires a forecast of dry weather; risks to non-target species; public opposition; reduced effectiveness for about 4 years.	(2.2)

METHOD OF CONTROL	BAIT OR TRAP TYPE (AND SUPPLIER)*	COST OF PRODUCT (EX GST)	LICENCE REQUIRED	ADVANTAGES OF METHOD	DISADVANTAGES OF METHOD (NUMBERS IN BRACKETS REFER TO 'CONSTRAINTS' SECTION IN APPENDIX 1.	
Bait stations (brodifacoum for initial control)	Talon® (ICI Cropcare) Pestoff® (ACP) Wax-coated Pestoff® Pest Management Services	$38/10 kg $35/10 kg $56/10 kg $33/10 kg	N	Unlikely to occur in drinking water; controls rats and mustelids; does not induce shyness; social luring of possums to stations; wax-coated baits more durable.	Extended control / high costs; Unsuitable for high-density populations; Possums eat >1 kg bait each; persistence in food-chain; high risks to non-targets; risks of residues in meat / liver; persistent in soils.	(11.2) (2.1.2) (2.2) (1.3.1) (2.1.1)
Bait stations (brodifacoum for maintenance control)	Talon® (ICI Cropcare) Pestoff® (ACP) Wax-coated Pestoff® Pest Management Services	$38/10 kg $35/10 kg $56/10 kg $33/10 kg	N	Suited to low-density populations; controls shy possums; controls many rats and mustelids; does not induce shyness; 'social luring' of other possums.	Long baiting period; persistent in soils; persistence in food-chain; high risks to non-targets; risks of residues in meat / liver.	(2.1.1) (2.1.2) (2.2) (2.3.1)
Bait stations (double strength Pindone)	Pest Management Services	$72/25 kg	N	Less persistent than brodifacoum; 'social luring' of other possums; suited to low-density populations.	Possums eat >2 kg bait, lower efficacy than brodifacoum; long baiting period.	
Bait stations (continuous Campaign® baiting for 5 weeks)	Campaign® (Key Industries) Pest Management Services	$43/kg	N	More cost-effective than brodifacoum; environmentally safe; low risk to non-targets; secondary poisoning unlikely; unlikely to occur in water.	Bait is expensive; Degrades in bait stations; use of sub-standard bait has caused low kills.	(11.2)
Bait stations (pre-fed Campaign®)	Campaign® (Key Industries) Pest Management Services	$43/kg	N	Reduces time toxic bait is in field; fewer bait stations required; increased kills.	Labour intensive; higher costs.	
Cyanide paste	ACP Wanganui Trappers Cyanide	$19/500 g $16/270 g	Y	Not persistent; secondary poisoning unlikely; recovery of furs possible; humane and low cost.	Not suited to humid conditions; kills fewer possums; risk to kiwi and weka Toxicant very hazardous.	(11.2) (2.2.2) (2.3.2)

METHOD OF CONTROL	BAIT OR TRAP TYPE (AND SUPPLIER)*	COST OF PRODUCT (EX GST)	LICENCE REQUIRED	ADVANTAGES OF METHOD	DISADVANTAGES OF METHOD (NUMBERS IN BRACKETS REFER TO 'CONSTRAINTS' SECTION IN APPENDIX 1.	
Encapsulated cyanide (Continuous baiting)	Feral control	$125/200 capsules $292/500 capsules	Y	Safer than paste and no aversive smell; secondary poisoning unlikely.	Possums may reject capsules increasing costs and decreasing control effectiveness; rats remove capsules from some feeders.	
Encapsulated cyanide (following pre-feed)	Feral control	$125/200 capsules $292/500 capsules	Y	Can be used in high humidity areas; humane; pre-feeding increases kills.	Peanut paste is attractive to non-targets; rats remove capsules from some feeders.	
Leg-hold traps (e.g. Victor No. 1, 1½ Bridgers BMI)	M. Woodcraft Ltd. Pest Management Services	Model dependent Approx. $17 each	N	Efficient at catching possums; recovery of furs; no toxic risks; no environmental residues.	Risk of non-target captures (e.g. kiwi, weka, cats); labour intensive.	(11.2)
Kill traps/devices	Timms (KBL Moulders Ltd.) Connibear (Woodcraft Ltd) Stinger (Bianca Stinger Co.) Electrostrike (Carlton-Taylor Industries)	$32 each $19 each $180 each $600 each	N	More target-specific than leg-hold traps; possums killed by trap; recovery of furs; Stinger and Electrostrike re-set automatically.	Not all are humane; limited number can be carried (except LDL 101); unit cost higher than leg-holds.	

3. Best current practice

Advice on best practices for current control methods is based on recent research and management information. Best practices are achieved mainly by attention to bait quality and delivery, and the avoidance of shyness. We therefore summarise the most important principles involved in these concepts before giving specific advice for each of the toxicants and traps currently in use by Department of Conservation (DOC) staff (Appendix 2). In conjunction with this report and any manuals produced from it, DOC pest managers are advised to familiarise themselves with the Vertebrate Pest Control Manual (Haydock & Eason 1997).

3.1 BAIT QUALITY

Bait of high quality is essential to consistently kill most (>85%) possums (Henderson & Morriss 1996). In cereal baits a concentration of 0.15% compound 1080, 0.8% cholecalciferol, or 0.002% brodifacoum should always be used. Before using baits in large control operations, toxicant concentrations should always be checked by sending samples to an analytical laboratory. Captive possums feeding *ad libitum* on baits are more inclined to be sublethally poisoned by baits of low palatability than by baits containing low concentrations of poison (Henderson et al. 1998). Bait palatability should exceed 30%, when tested in a standard choice test relative to non-toxic RS5 baits (where a value of 50% indicates equal palatability) (Henderson et al. 1998). The effects of various bait characteristics on bait palatability are detailed in Henderson & Frampton (1999). The hardness of bait affects how much is eaten by possums, and sublethal amounts of cereal bait are frequently eaten when baits are either very hard or are soft and crumbly (R. Henderson, AHB report). Under normal storage conditions baits that are hygroscopic will often become less palatable. Cereal baits with a moisture content ≥14% wt/wt frequently have a high mould and / or bacterial count within 2 months of manufacture, which reduces their palatability to possums). Palatability of stored baits is also likely to be reduced because some cinnamon is lost during storage, and this is likely to result in the 1080 in ‘aged’ baits not being adequately masked. Cereal-based baits should be stored in a cool, dry, locked storeroom, for no longer than 6 months, and should not be on-sold (Henderson & Frampton 1999). Carrot baits are more palatable to captive possums than cereal baits, and were more palatable to wild possums in 9 of 14 field trials (Morgan 1977). Because 1080 is leached only slowly from carrot during rain (Rammel & Fleming 1978, Bowen et al. 1995), it is also less likely to sublethally poison possums than cereal bait. Therefore, in many situations (particularly in ecosystems where high humidity is likely to cause cereal baits to rapidly lose palatability and 1080 concentration), carrot is likely to kill more possums than cereal baits.

Bait size in relation to possible non-target interference should also be considered (small pieces of carrot contain very high concentrations of 1080, and small pieces of both cereal and carrot bait are inclined to get caught in the canopy).

3.2 DELIVERY SYSTEMS

When bait is aerially broadcast it is essential that total coverage is achieved throughout the control area (Morgan et al. 1996b). Over large tracts of indigenous forest this will require the use of GPS (global positioning system), and baits that are unlikely to 'clump' leading to blockages in sowing equipment.

Replicated field trials have demonstrated that control using bait stations is reliant on an adequate bait station distribution and use of high quality baits. When control is reliant solely on bait stations distributed along a forest–pasture margin, stations may be required to be spaced as close as 50 m to expose all possums to baits (Hickling et al. 1990). When bait stations are distributed throughout forested areas, a spacing of 150 m is recommended for most situations when stations are pre-fed (Thomas et al. 1996) and 100 m when stations are not pre-fed (Henderson et al. 1994). Stations spaced wider apart than 100 m may not be encountered by a significant number of female possums (Hickling 1995, Henderson & Hickling 1997). This may cause low kills, a female bias in the sex-ratios of survivors (Hickling 1995), and higher intrinsic rates of increase than for populations with a 'normal' ratio of males and females (Coleman & Green 1984). Conversely, bait stations distributed at recommended rates kill 32% more females than males in 10 replicated field trials (Henderson & Hickling 1997), which is likely to slow population recovery. Although spacings closer than 100 m may expose a few more adult females that have very small (<0.5 ha) home ranges (Ward 1978, Jolly 1976, Brockie et al. 1987), the slight gain in percentage kill is not justified by the considerably higher costs.

Pre-feeding with a non-toxic bait is a common strategy in vertebrate pest control, which both attracts pests to baits by the 'socialisation' that occurs at bait stations (e.g. Hickling & Sun 1998) and then increases the consumption of toxic bait when it is subsequently applied. In possum control, prefeeding is generally used in 'bait station' operations (Thomas 1994) and this normally increases the percentage of possums killed when acute toxicants (i.e. 1080, cyanide, cholecalciferol) are then used (Thomas 1998). Pre-feeding is always advisable when bait stations are sited up trees (out of reach of ground-dwelling birds and livestock), as some possums may not randomly encounter the bait placed in elevated bait stations (Henderson & Hickling 1997).

3.3 MEASURING AND OVERCOMING SHYNESS

Most possums that eat only a sublethal quantity of bait will develop a learned shyness towards that type of bait (Morgan et al. 1996a, O'Connor & Matthews 1996). When shy possums are exposed to a choice of a familiar non-toxic bait (i.e. of the type last used during control) and a novel type of non-toxic bait, they feed selectively on the novel bait type. By contrast, naive possums feed randomly on the two bait types (Ogilvie et al. 1998). Managers can therefore test populations for 'shyness'. At least 20 pairs of bait stations should be established at 100 m spacings throughout a control area. The relative consumption of the familiar bait type (the bait previously used for control) and a novel bait type that is palatable to possums (palatability >30%) is then measured over 5 days. Very low consumption of the familiar baits (<20% of total bait consumption) indicates there is residual shyness in the population. Although further research is required to test the accuracy and precision of the methodology, results from field studies (Ogilvie et al. 1996, Ogilvie et al. 1998) show that possums display a strong behavioural aversion to bait types with which they have previously been sublethally poisoned.

Control of shy populations can be achieved in the short term (i.e. 3–12 months) by the use of brodifacoum baits (Henderson et al. 1997) or traps (this study; Appendix 1, section 2.2). In the medium term (i.e. 1–4 years) bait-switching and pre-feeding may also help to mitigate shyness, but these strategies need to be evaluated in the field (see Appendix 1, section 2.4).

3.4 1080

The use of compound 1080 is primarily constrained by: poor public acceptance, the risk that careless use could have serious consequences for human and environmental health, the fact that a licence is required for pest controllers to use it, and potential risks to some non-target species (e.g. dogs and robins). In areas where livestock, pets, and / or endangered fauna are likely to be at risk from either carcasses containing 1080 residues, or 1080 baits, managers are advised to control possums by using less hazardous poisoning methods (e.g. cyanide or cholecalciferol) or by use of traps.

3.4.1 Bait quality

- The 1080 concentration in all baits (cereal, carrot, or paste) should be 0.15% 1080 wt/wt (Henderson & Morriss 1996).
- Bait containing concentrations of 1080 that exceed 0.18% wt/wt may not be as palatable as 0.15% 1080 baits (Henderson et al. 1998).
- Bait must contain green dye to comply with legislation that is designed to avoid birds interfering with baits used during possum control (Caithness & Williams 1971). Baits should also contain 0.1% cinnamon (Udy & Pracy 1981).

3.4.2 Aerial delivery

- A minimum of 95% of baits used for aerial control should be in a range of 4–8 g, as baits smaller than this are likely to sublethally poison some possums (Frampton et al. 1998) and are likely to kill birds (Spurr 1993b).
- It is advisable to conduct either a poisoning trial, or a non-toxic rhodamine bait acceptance trial (Morgan 1982) (see Box 1) immediately before a major aerial operation to give a good indication of the likely level of success.
- Toxic bait should only be aerially broadcast when at least 2 nights of fine weather are forecast for the period immediately following bait application. Wet weather not only reduces the amount of activity on the forest floor by possums (Ward 1978, MacLennan 1984), but also causes 1080 to be rapidly leached from cereal baits (Bowen et al. 1995).

Box 1. Use of rhodamine dye.

During rhodamine trials, baits should be dyed with 0.1% wt/wt rhodamine B which is available as a 40% solution herbicide additive (i.e. 'Been There', FIL Industries Ltd, available from farm supplies retailers). Prepare a solution of Rhodamine B by mixing 60 ml 'Been there' with 1.44 L of water. Slowly add 1.5 L of this solution to 25 kg RS5 pellets in a concrete mixer to achieve an even surface-coating and lay out to dry. Distribute the baits aerially at 5 kg/ha over a block of at least 20 ha. After allowing possums 2 nights to feed on bait, capture a sample of possums by trapping and / or cyanide poisoning (only where bait is present) for up to 4 further nights. Assess the proportion of the population eating bait by inspecting the paws, mouths, and gut contents for evidence of the red dye. The levels of precision at various levels of bait acceptance is indicated in Table 2 for different sample sizes. Possums showing very insignificant traces of dye should not be regarded as bait-acceptors as it is likely that they may have either only nibbled at bait or trod on bait (feet-marking only) without eating it. The percentage of possums showing obvious traces of Rhodamine B dye is indicative of the percentage of possums likely to eat lethal amounts of bait during an aerial control operation.

TABLE 2. STATISTICAL PRECISION (BINOMIAL CONFIDENCE LIMITS) OF MEASURED BAIT ACCEPTANCE AMONG DIFFERENT SAMPLE SIZES OF POSSUMS.

NO. POSSUMS CAUGHT	MEASURED % BAIT ACCEPTANCE	95% BINOMIAL CONFIDENCE LIMITS AROUND % ACCEPTANCE
30	95	81.5–99.5
	90	73.5–97.9
	85	67.3–95.3
	80	61.5–92.3
50	95	84.9–99.1
	90	78.2–96.7
	85	72.1–93.5
	80	66.3–90.0
100	95	88.7–98.4
	90	82.4–95.1
	85	76.5–91.4
	80	70.8–87.3

- Use of carrot bait in conditions of high rainfall is recommended because carrots retain almost all the 1080 following 200 mm of rain (Bowen et al. 1995).
- Use of GPS is essential to ensure total bait coverage during aerial operations; poor coverage is a known cause of poor kills (Brown & Arulchelvam 1995, Morgan 1994a and b).
- Cereal baits applied at a sowing rate of 5 kg/ha or carrot applied at 10 kg/ha are generally appropriate to kill most possums, although lower rates than these can be effective (Morgan et al. 1997).

3.4.3 Bait station delivery

- Baits used in bait stations should weigh 1–2 g to avoid spillage (baits larger than these are often partially eaten and discarded; Henderson & Hickling 1997), and to enable them to 'flow' to the opening at which possums feed.

- Without pre-feeding, bait stations that are elevated up trees out of the reach of livestock are not used by some possums (Henderson & Hickling 1997).
- Pre-feeding bait stations may enhance kills (Thomas et al. 1996, Thomas 1998) through increased per capita consumption (R. Henderson, AHB report), and help prevent the development of shyness (Moss et al. 1998). Pre-feeding should be carried out using 3 'pulses' of bait (each using 2 kg of bait per station) over 2–3 weeks prior to the application of toxic baits. Pre-feeding also shortens the time toxic baits are needed in the field to 5 nights (Thomas et al. 1997).
- Toxic and non-toxic 1080 bait should not be mixed and presented concurrently in bait stations, as this is likely to result in many possums receiving sublethal amounts of poison (Hickling et al. 1991).
- Bait stations throughout forested areas that are pre-fed should be spaced on a 150 m grid (i.e. 1 per 2 ha: Thomas et al. 1996). Bait stations not pre-fed should be spaced within forested areas on a 100-m grid (1 per ha) and contain bait for a minimum of 35 days (Henderson et al. 1994). Along forest–pasture margins bait stations should be spaced at 50–100 m intervals and pre-fed (Hickling et al. 1990).

3.4.4 Ground baiting

There has been little research into best practice for paste baiting. Current practice is to pre-feed paste for 3–4 days on earth 'spits' or in bait stations (e.g. flower pots or Romark stations spaced 20–30 m apart). Toxic paste (0.15% 1080) is then presented for a further 3–4 days.

3.5 BRODIFACOUM

Brodifacoum use is constrained by high costs relative to other control methods, risks to non-target species, environmental persistence, and because it may need to be applied for 4 months irrespective of possum density (Henderson et al. 1997, Morriss et al. 1997, Thomas et al. 1997). Because brodifacoum accumulates in the livers and meat of pigs feeding on possum carcasses (Eason et al. 1999), managers should not use brodifacoum in areas where wild pigs are often harvested by recreational hunters. Department of Conservation managers issuing permits for pig-hunting on conservation lands are advised not to issue permits for areas where large amounts of brodifacoum bait have recently been used, and to inform hunters of the potential risks to their health (lesions and haemorrhage) from brodifacoum residues in wild pigs at other locations.

3.5.1 Bait quality

- Talon® 20p and Pestoff® 7/10 pellets nominally contain 20 ppm (0.002%) brodifacoum. Because some batches of commercial brodifacoum bait have had measured concentrations of brodifacoum as low as 11 ppm, brodifacoum concentration should be checked by sending samples to an analytical laboratory (Appendix 5) before planned operations likely to use large amounts of bait.

- Palatability of bait is affected by moisture absorption and subsequent growth of micro-organisms (R. Henderson, interim AHB report). A wax-coated Pestoff® bait is currently available that reduces the uptake of moisture by cereal pellets.

3.5.2 Bait delivery

- Brodifacoum should only be used in bait stations and only for control of low density populations (RTC<10%). Bait stations protect bait from rain and dew and reduce hazards to non-target species. In areas of high humidity the field life of baits that remain uneaten in bait stations may be prolonged by using brodifacoum baits with a wax coating.
- Pre-feeding does not appear to enhance kills with brodifacoum bait (Thomas et al. 1997).
- Bait stations should be spaced on a 150-m grid (1 per 2 ha).
- During initial and maintenance control brodifacoum baits should be either applied continuously for at least 4 months to kill most possums (Henderson et al. 1997), or 'pulse-baited'. Pulse-baiting is normally undertaken by placing at least 500 g of brodifacoum bait in each bait station at intervals of 2–4 weeks over a 12-month period.
- Brodifacoum is of greatest value in maintenance control when possum numbers are low, and should be used at least 3 months after use of acute poisons (cyanide, 1080, cholecalciferol) for control of residual populations of shy possums.

3.6 CYANIDE

Cyanide control is inexpensive, but is constrained because historically it has killed fewer possums than other poisons (probably as a result of inconsistent use and shyness (Warburton & Drew 1994); and it is known to have poisoned kiwi and weka (Spurr 1991).

3.6.1 Bait quality

- Cyanide is used for possum control as a 50–60% wt/wt formulation of sodium or potassium cyanide in paste or as 80 mg of potassium cyanide in Feratox® capsules.

3.6.2 Bait delivery

- Cyanide paste baits should be pre-fed for at least 2 nights by placing a mix of flour, icing sugar, and lure at intervals of 3–5 m along lines that are no more than 100 m apart before 'pea-size' cyanide baits are situated where lure has been interfered with by possums (B. Warburton pers. comm.). Several preferred lures (Morgan et al. 1995) may be used with cyanide, and although cinnamon is commonly used it is good practice to change the type of lure periodically (e.g. to aniseed, plum, cherry, orange, eucalyptus or curry) (Morgan et al. 1995) to avoid some possums developing an aversion to lures repeatedly used during sustained control of populations.

- Cyanide baits should be placed on a stone, a piece of wood, or in a small bait station (flower pot or Romark) to prevent contact with ground moisture and consequent loss of HCN gas. After 2 nights baits should be destroyed by overturning the stone or wood and forcing the bait into the ground.
- Cyanide is often used in combination with traps. Although best practice for the combined use of traps and cyanide has not been assessed, many operators use cyanide baits between traps.
- Encapsulated cyanide (Feratox®) is currently used for control of possums in areas where there is public opposition to 1080 poison and where 1080 may place non-target species at risk. Our recommendation based on research to date and manufacturers' instructions is that Feratox® should only be used in bait stations along with a prefeed (pellet or paste). Bait stations should be 50–100 m apart and either prefed for 1–2 weeks followed by toxic pellets for 1 week (Morriss et al. 1997). Alternatively, toxic pellets and prefeed should be simultaneously presented for 4 weeks (Morriss et al. 1997). To optimise the kills that are achieved with Feratox® it is important that the prefeed used is fresh and palatable. Best practice for use of encapsulated cyanide is being refined by the manufacturer in conjunction with end-users. A promising new strategy for Feratox® has been developed by the manufacturer. This involves placing the cyanide pellets in peanut paste in small plastic bags suspended from a rat-proofed stand.

3.7 CHOLECALCIFEROL

Cholecalciferol use is constrained because it is more expensive than 1080 and requires the use of prefeed to consistently kill most (>85%) possums (Wickstrom et al. 1997). However, environmental risks (i.e. risks to non-targets, persistence in soil and water; Appendix 1) are lower with cholecalciferol than other poisons currently used.

3.7.1 Bait quality

- Cereal baits should contain 0.8% cholecalciferol (Henderson & Morriss 1996) and be 1–2 g in size.
- The palatability of cereal baits containing cholecalciferol should exceed 40% relative to RS5 baits (1–2 g) that contain 0.5% cinnamon.

3.7.2 Bait delivery

- Campaign® should only be used in bait stations, which not only protect the bait from the weather, but also reduce the amount of interference by non-target animals.
- Campaign® can be either continuously baited for 35 days in bait stations sited at ground level spaced on a 100-m grid (Henderson et al. 1994, Campaign® information sheet), or applied for 5 nights in bait stations spaced 150 m apart (Thomas et al. 1996) after pre–feeding with RS5 bait (small size). Pre-feeding carried out using 2 'pulses' of bait (each using 2 kg of bait) during a 2-week period prior to the application of toxic bait often enhances the kills that are achieved (Wickstrom et al. 1997).

3.8 TRAPS

As yet procedures for best practices in trapping have not been formally documented.

- The Victor No.1 unpadded leg-hold trap weighs less than most other traps, is acceptably humane (Warburton 1982, Warburton 1992), is effective at catching possums, and is the most commonly used trap on conservation lands (Appendix 2).
- Fewer possums are injured during capture when soft-catch traps are used for control (Warburton 1992), but escape rates can be unacceptably high (Warburton 1998). Escape rates with soft-catch traps increase as the traps age, but escape rates can be reduced by fitting new (and more powerful) springs (Warburton et al. in press).
- Operators generally set 5 to 15 leg-hold traps per hectare for at least 3 nights on 'best sign' or 'possum runs' using a flour / icing sugar / lure mix as an attractant. Flour applied behind traps may contain a preferred lure (Morgan et al. 1995). However, if the traps are controlling bait-shy possums, the lure should not be the same as that in the pesticide bait which induced shyness.
- Where the risks to fauna from traps set on the ground are unacceptably high, traps must be set on platforms or leaning boards to exclude flightless birds (Thomson et al. 1996).
- The 'Timms' trap is the only kill trap routinely used at sites that are readily accessible.
- A recent evaluation of kill traps demonstrated that the LDL 101 (Canada) was effective at catching possums and was acceptably humane (Warburton & Orchard 1996). Because it is light (450 g) and compact it could potentially be used as a replacement for leg-hold traps.

4. Scenarios for sustained control

Areas where possum control is required will differ in terms of flora and fauna, patterns of public use, the extent of iwi involvement in land management, climate, topography, accessibility, local attitudes to control, and management objectives. There are therefore many different situations and hundreds of potential combinations of different methods that can be used for initial then maintenance control. At each location there will be a unique set of constraints (see Appendix 1) that limit the types of control possible. Consequently we suggest that computing software be developed to facilitate comprehensive decision making, as has been undertaken for Tb vector control (Bosch & Allen 1998). It is not possible to outline all options for sustainable control of possums in this report. Some of the more common situations are listed in Table 3. However, managers should follow through the flowchart (Fig. 1) and associated constraints (Appendix 1) to select the most appropriate control options for sustainable control of possums in their area.

TABLE 3. EXAMPLES OF SOME SCENARIOS FOR SEQUENTIAL BAIT USE FOR SUSTAINED POSSUM CONTROL. IN ALL CASES BEST PRACTICES FOR THE METHODS ARE ASSUMED WITH RESULTING LOW RTCS. TIME INTERVALS BETWEEN CONTROL OPERATIONS ARE BASED ON POPULATION MODELLING (SEE APPENDIX 3) AND LOW RTC (SEE APPENDICES 1 AND 2). ACTUAL OPTIMUM INTERVALS AT DIFFERENT LOCATIONS SHOULD BE DETERMINED BY MONITORING POSSUM POPULATIONS AND / OR ECOSYSTEM HEALTH.

AREA	MAJOR CONSTRAINTS	INITIAL CONTROL	TIME INTERVAL	1ST MAINTENANCE CONTROL	TIME INTERVAL	2ND MAINTENANCE CONTROL
Large (10 000 ha)	Inaccessible, remote, birds at risk	Aerial 1080 (RS5 cereal)	5–6 years	Aerial 1080 (Carrot)	5–6 years	Aerial 1080 (RS5 cereal)
	High rainfall area	Aerial 1080 (Carrot)	5–6 years	Aerial 1080 (No.7 cereal)	5–6 years	Aerial 1080 (Carrot)
Moderate (1500 ha)	Water catchment area, birds at risk	1080 bait stations	3–4 years	Brodifacoum	3–4 years	Cyanide and traps
	Pig hunting	1080 bait stations	3–4 years	Cyanide and traps	3–4 years	Campaign® or Feratox®
Small reserve (100 ha)	High public use, non-target risks	Campaign® in bait stations	1 year	Traps	3–4 years	Feratox®

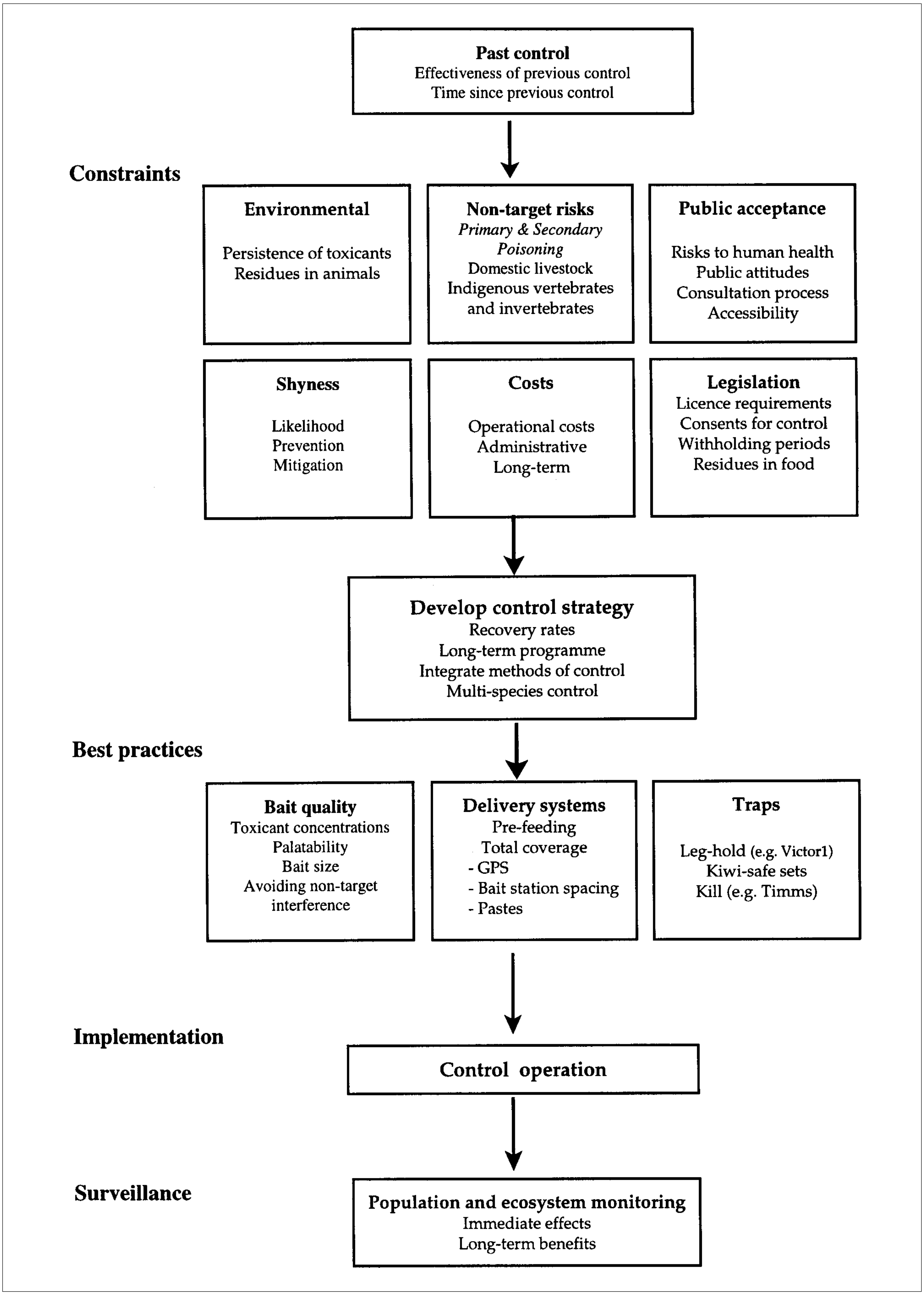

Figure 1. Flowchart outlining the considerations in determining best practices for sustained control. Information on 'past control' and 'constraints' is provided in Appendix 1.

5. Recommendations

Our review of current DOC field practice, presented in Appendix 2, has revealed areas where we believe some improvements could be made. For example, some methods are currently ineffective because they either consume too many resources or kill too few possums, and others that have been used may represent too high a risk to non-target species. We make the following recommendations:

- At most locations the **target density** of possums following initial control should be generally lowered to an RTC no greater than 3%, so that the optimal time intervals for sustained control are achieved. Managers may need to specify a lower RTC than this for protection of particular rare species.
- Managers should either implement systems of annual control (for up to 2 years) in **small reserves** or establish buffer zones around these sites to prevent reinvasion by immigrant possums.
- Effective **quality management** systems are required to ensure all control operations avoid sublethally poisoning possums and developing residual shyness.
- **Fast-acting (acute) pesticides** (1080, cholecalciferol, cyanide) should not be used within 12 months of each other. They can be effective for maintenance control 4 or more years after initial control with an acute pesticide.
- **Traps and brodifacoum baits** are, presently, the only proven means of controlling **bait-shy** possums. Brodifacoum is most effective if used no sooner than 3 months after an acute pesticide.
- Although predators are sometimes controlled by **secondary poisoning** with brodifacoum (Alterio 1996), the risks to other non-target species are not well researched. Until further research has better defined the environmental consequences of large-scale and prolonged field use of brodifacoum, usage of this pesticide should be limited to bait station control of low-density populations (i.e. RTC <10%).
- Managers should systematically **monitor possum populations and the ecosystems they are protecting,** to:
  —optimise the timing and frequency of control
  —minimise potential impacts on non-target species
  —measure the long-term benefits of pest control

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Appendix 1

Detailed information on the main factors influencing the development of a sustained control strategy[1]

The development of an optimal strategy for sustained control of possums in any particular area is influenced by many factors. Broadly speaking these fall into two categories. Firstly, the history of previous control must be known as this will influence both the selection of control method and the timing of operations. Secondly, the choice of particular control methods may be constrained by environmental considerations, non-target risks, public opinion, legislation, or by the cost of various options. We present a review of the most up-to-date information available on each of these subjects, which should be considered when planning sustained control of possum populations. The information is presented as a reference source to be used in conjunction with the 'best practices' advice given in the main body of this report.

1. PAST CONTROL

1.1 Effectiveness

The effectiveness of initial control not only determines how frequently maintenance control will be required, but also the extent of residual shyness during ongoing operations, and costs of control over the long term. The planning, quality of baits, systems for bait delivery, timing of an operation, and environmental factors (weather, habitat, possum 'condition') are all likely to influence the percentage of possums killed. To optimise kills and avoid possums being sublethally poisoned, best practices should be carried out as detailed in the report.

1.2 Timing

To conserve ecological diversity the density of possums should not exceed a maximum threshold for each type of ecosystem (Hickling 1995). In many cases these thresholds are not well understood. However, when endangered bird species are threatened by possum predation the threshold densities are very low (e.g. RTC <3%). To protect palatable sub-canopy species such as fuchsia from heavy browse the RTC should not exceed 10% (Pekelharing et al. 1998). To manage possum populations effectively therefore requires regular

[1] References to Appendices 1–3 are combined into Appendix 4.

monitoring of both possum abundance (Warburton 1996) and ecosystem health. When monitoring indicates that possums are at a density where they are likely to affect conservation values, then it is time for further maintenance control.

The times for maintenance control can only be accurately assessed by ecosystem and / or population monitoring. By contrast, the times when monitoring should be carried out (i.e. the approximate times of sequential control operations) can be determined by modelling rates of population recovery (Appendix 3). The time taken for possums to reach carrying capacity is determined by the residual density of possums that have survived previous control, the intrinsic rate of increase of a population (Caughley 1977, Hickling & Pekelharing 1989) and the carrying capacity. On small reserves (<500 ha) managers should be aware that rates of increase incorporate both births and immigration, so times for population recovery are shorter than when populations have been controlled over large areas (>1000 ha) (Appendix 3). These factors also determine the frequency with which maintenance control is required to sustain populations below thresholds, thus avoiding damage to flora and fauna. Theoretical rates of recovery of populations following initial control and the timing of maintenance control (Appendix 3) are summarised in Table A1.1. In these theoretical models of population recovery, the density at the time of initial control was assumed to be 7 possums per hectare, the carrying capacity of the habitat is assumed to be 10 possums per hectare, and percentage kills were either 'average' (i.e. 80% kill) or 'high' (i.e. 95% kill).

In small areas (<1000 ha), where rates of population recovery are confounded by immigration, managers may consider it appropriate to undertake an initial phase of annual control, or to establish a buffer zone (Fraser et al. 1998) around the reserve, in which possums are also controlled.

TABLE A1.1. PREDICTIONS OF THE TIME INTERVALS BETWEEN CONTROL OPERATIONS IN SMALL (<500 ha) AND LARGE (>1000 ha) AREAS BEFORE POSSUMS RECOVER TO WITHIN 5% OF CARRYING CAPACITY, OR BE MAINTAINED AT EITHER <1 OR <2 PER HECTARE, BASED ON MODELLING. THESE TIME INTERVALS WILL BE INFLUENCED BY POPULATION DIFFERENCES, RATE OF IMMIGRATION, AND ENVIRONMENTAL FACTORS AFFECTING SURVIVAL RATES. BOTH POPULATION AND / OR ECOSYSTEM MONITORING IS NECESSARY TO ESTABLISH CORRECT TIMES FOR CONTROL AT EACH LOCATION.

AREA	% KILL IN INITIAL CONTROL	TIME FOR POPULATION TO REACH CARRYING CAPACITY (YEARS)	MAINTENANCE CONTROL INTERVAL (YEARS)	
			MAINTENANCE OF DENSITY AT <1/ha	MAINTENANCE OF DENSITY AT <2/ha
Large	80%	11	4-5	5-6
Large	95%	17	5-6	7-8
Small	80%	7	3	4
Small	95%	11	4	5

2. CONSTRAINTS ON CONTROL OPTIONS

The **risk** of a vertebrate pesticide to human health, livestock, and non-target wildlife is determined by a combination of the toxicity of the pesticide to different organisms (i.e. **hazard**) and the potential for **exposure** of non-target species and humans (Eason et al. 1997). Therefore, in deciding on the types of control that are used, managers must not only comply with the Pesticides (Vertebrate Pest Control) Regulations 1983, but also weigh-up methods that are acceptable to the general public, that will optimise the potential for possums to be killed, yet cause negligible risk to human health, wildlife, and the environment.

A detailed description of poisons routinely used in New Zealand, their environmental fate, non-target effects, toxicology, pathology, signs and symptoms of poisoning, recommended treatments, and safety requirements during usage are included in the Vertebrate Pest Control Manual (Haydock & Eason 1997). Factors that constrain the use of some forms of pesticide bait are listed below.

2.1 Environmental

2.1.1 Persistence in water, soil, and plants

1080

Extensive research has demonstrated that 1080 is normally degraded in most moist soils over a period of 2 or more weeks by naturally occurring micro-organisms (*Pseudomonas, Fusarium*), although in climatic extremes (drought and extreme cold) the breakdown may take several months (Walker & Bong 1981, Wong et al. 1992, King et al. 1994, Parfitt et al. 1994, Walker 1994). Although it may be leached through some soils, **to date no detectable amounts of 1080 have been measured in water** that is reticulated to households following control operations (Parfitt et al. 1994).

After bait has disintegrated and 1080 is leached into soils there may then be an uptake of the toxin into terrestrial plants. Very low residues of 1080 (<0.08 ppm) were recovered from some plants in a laboratory study after 9 mg of 1080 (the amount in a 6-g bait) was watered in around their roots (Eason et al. 1998). Although uptake of 1080 by plants in the field is likely to be much lower, there is currently no data available on 1080 in plants after baits have been aerially broadcast. Extremely low 1080 concentrations in 1 or 2 isolated plants for only short periods of time are thought to present an extremely low risk to animal health.

Although **legislation requires that baits not be aerially broadcast within 100 m of streams**, there have been incidents where measurable amounts of 1080 have been detected in stream water (Eason et al. 1998a). However, the amounts recorded to date have all been less than 4 ppb and were only detected over short periods after aerial application of 1080. Although 1080 is not degraded in distilled water, the concentration of 1080 will decline in stream water, and these rates of degradation are about 60% higher when temperatures are increased from11°C to 21°C (Ogilvie et al. 1996). **Immediately following aerial control, the local Medical Officer of Health may require that samples of streamwater be sent to an approved laboratory for analysis**

of 1080 concentration as part of the 'Permit Conditions' (Ministry of Health 1995). This monitoring of water quality is routinely stipulated for catchments that are used as a public water supply.

Brodifacoum

Brodifacoum is extremely insoluble in water and is therefore unlikely to be detected in streams or groundwater. It is persistent in soils (Jackson & Hall 1992, Hall & Priestly 1992, Tasheva 1995), but no long-term effects of brodifacoum on invertebrate populations have been reported (Tasheva 1995, Spurr et al. 1997). The greatest risk to non-target species arises from the persistence of brodifacoum in the food chain of terrestrial animals (Eason et al. 1999a, Shore et al. 1999). Residues reported in several bird species after they had ingested brodifacoum (e.g. Morgan & Wright 1996, Ogilvie et al. 1997, Empson 1998, Dowding & Veitch 1999, Robertson et al. 1999, Stephenson & Minot 1998) are in many instances attributed to secondary poisoning. **Environmental contamination by brodifacoum can be minimised by using it only for control of low-density possum populations (RTC <10%), and by discrete application in bait stations.**

Cyanide

Cyanide paste is rapidly degraded by moisture and is therefore likely to **remain in the environment for a short period only**. Feratox® (encapsulated cyanide) may, however, persist for 2–3 months even when it is exposed to the weather (Warburton et al. 1996).

Cholecalciferol

Cholecalciferol is of low solubility in water and is therefore unlikely to be found in waterways. It is degraded by sunlight and is also slowly oxidised when exposed to air. There is no published information on the fate of cholecalciferol in soils.

2.1.2 Residues in animal tisues

1080

Residues of 1080 persist in sublethally poisoned mammals for up to 4 days before almost all is metabolised and excreted (Eason et al. 1996b). However, residues of 1080 will persist in the carcasses of dead animals for at least 80 days (Meenken & Booth 1997), and these are likely to be lethal to cats, dogs, rats (Hegdal et al. 1986, McIlroy & Gifford 1992), mustelids (Alterio & Moller 1998, Murphy et al. 1999), and possibly some omnivores (e.g. hedgehogs). Furthermore, some insectivorous birds that feed on insects and larvae on carcasses (Hegdal et al. 1986) may be exposed to hazardous residues. **In areas where domestic pets are likely to encounter carcasses, managers are advised to control possums by using less hazardous poisoning methods** (e.g. cyanide or cholecalciferol) or by use of traps.

Brodifacoum

During possum control, rats and mice also eat brodifacoum baits and many subsequently die (Gillies & Pierce 1998, Thomas 1998). Rodents become more susceptible to predation after eating brodifacoum baits and some die in the open (Cox & Smith 1992). Possum carcasses containing high concentrations of brodifacoum (Meenken 1999) are also scavenged by some birds and mammals that eat carrion. This has resulted in secondary poisoning of owls in New Zealand and overseas (Mendenhall & Prank 1980, Hegdal & Blaskiewicz 1984, Hegdal & Colvin 1988, Newton et al. 1990, Ogilvie et al. 1997, Stephenson & Minot 1998), other raptors (Radvanyi et al. 1988), domestic cats and dogs (Dodds & Frantz 1984, Marsh 1985, Du Vall et al. 1989, Hoogenboom 1994), and mustelids (Alterio 1996). In addition to the eight species of indigenous birds considered at risk from secondary poisoning with brodifacoum (Eason & Spurr 1995), residues have recently been identified in dead parakeets and kokako (C. Eason pers. comm.). As brodifacoum will persist in the meat and livers of sublethally poisoned sheep and possums for at least 6 months (Laas et al. 1985, Eason et al. 1996b), it is possible that many higher-order animals (including humans) may also be exposed to brodifacoum (Eason et al. 1999a). **Brodifacoum use should therefore be limited to bait station control of low-density possum populations so that non-target predators or scavengers are not placed at risk by eating animals containing residues.**

Cyanide

Cyanide is rapidly detoxified after it is ingested and the metabolites (which are of very low toxicity) are excreted over several days (Haydock & Eason 1997). **The risks to non-target species associated with cyanide control of possums are therefore mainly through primary poisoning.**

Cholecalciferol

Most cholecalciferol is partially metabolised in possums before they die, and although some metabolites (e.g. 25-hydroxycholecalciferol) are also toxic, the risks to dogs and cats by secondary poisoning is low when compared with 1080. Dogs that ate one or two carcasses of possums poisoned with cholecalciferol (Campaign®) exhibited no ill-effects, while dogs eating five carcasses over a period of 5 days showed mild clinical signs of poisoning, but recovered without treatment (Wickstrom et al. 1997a). Cats fed the carcasses of possums that had been killed by cholecalciferol had slightly higher serum calcium levels after eating possum meat for 5 days, but these returned to normal within a few weeks (Eason et al. 1996a). **Therefore, although there is a risk of secondary poisoning from cholecalciferol these risks are low compared to 1080, and multiple exposures over several days would be required to cause toxicosis.**

2.2 Risks to non-target species

2.2.1 Domestic livestock

1080

Of all animals so far exposed to 1080, dogs are the most susceptible (Eisler 1995). Residues in possum carcasses may be lethal to dogs for more than 80 days following 1080 poisoning (Meenken & Booth 1997). **Dogs should therefore be excluded from control areas where 1080 has been applied for possum control for at least 3 months from the date of application**. In areas frequently used by the public it may be necessary for managers to either caution dog owners about the need to fit muzzles to their dogs, or to use an alternative poison that does not present the same residue problems (e.g. cholecalciferol or cyanide). There have also been instances of livestock (e.g.

sheep, deer, cattle) being poisoned by baits or by scavenging (e.g. cats, mustelids, pigs) carcasses of animals that have been killed by 1080 (Gillies & Pierce 1998, Murphy et al. 1998). Most reported livestock deaths are a result of baits being unintentionally applied in the wrong place, or of inadequate withholding periods before stock are re-introduced into control areas.

Brodifacoum

The large amounts of brodifacoum bait currently used (>260 tonnes per annum; Innes & Barker 1999) suggests that **at some locations stock are likely to be exposed to bait**. Where bait stations are located along fencelines or in trees within the reach of animals, then some livestock (especially cattle) are inclined to rub against bait stations and dislodge bait which they then eat. Other domestic animals feeding on carcasses containing brodifacoum residues may ingest lethal amounts of brodifacoum through secondary poisoning (e.g. cats and dogs).

Cyanide

Cyanide is not a persistent toxicant, but there have been several reports of sheep, cattle, and dogs (Hughes 1994) ingesting lethal amounts of recently laid baits**. Paste baits should therefore be placed out of reach of these animals and destroyed after they have been in the field for 2 nights.**

Cholecalciferol

Cholecalciferol bait is likely to be lethal to domestic stock if they feed on it, and for this reason the manufacturer (AgrEvo Environmental Health, NSW) recommends controlled delivery of the pesticide in bait stations. However, **the risks of secondary poisoning are low compared with 1080**. Dogs and cats fed daily for 5 days on possums that had died after eating cholecalciferol baits developed mild clinical signs of calcinosis, but all recovered to normal health within a few weeks (Wickstrom et al. 1997a, Eason et al. 1996a).

2.2.2 Indigenous vertebrates

1080

The risk to non-target species during aerial control has been extensively studied (Spurr 1993a, Spurr 1994a, Fraser et al. 1995) and is being collated into a manual on risks to non-target species (E.B. Spurr & R.G. Powlesland, pers. comm.). Ongoing research is further evaluating species that may be at risk, and options that may further improve the safety of all possum control. Although most dead birds found following possum control have been exotic species (e.g. blackbird, chaffinch), native birds (e.g. whitehead, robin, tomtit, morepork) have also been killed (Spurr 1994a). The numbers of birds killed following aerial application of bait has declined since operators started routinely: screening carrot bait to remove highly toxic fragments (Spurr 1994a); adding green dye (Caithness & Williams 1971) and cinnamon (Udy & Pracy 1981) as bird deterrents; and reducing sowing rates (Morgan et al. 1997).

In areas where possum control is planned and threatened species are at risk (e.g. kaka, saddlebacks, etc.), the likely interference with non-toxic baits by that species should be first assessed in controlled experiments during the planning stages of the control operation (e.g. Spurr 1993b). The extent of non-target interference with baits in bait stations has not been well researched. Kaka may eat both plain cereal baits (Spurr 1993b) and baits dyed green and containing 0.1% cinnamon (Hickling 1997) when first exposed to them. However, cinnamon-lured baits are eaten less frequently and in significantly smaller amounts by kaka after they have been exposed to them two or more times (Hickling 1997). Kiwi may eat cereal baits (Pierce & Montgomery 1992) but not carrot (McLennan et al. 1992), but there have been no kiwi deaths reported following 1080 operations (Spurr 1994a).

Although rats and mice use bait stations (especially after pre-feeding, Thomas 1998) it is not known how many other species are at risk by primary poisoning. Possums and other non-target animals (e.g. rats) poisoned with 1080 are, in themselves, a hazard to other animals that predate or scavenge them.

Use of 1080 gel bait in purpose-designed bait stations presents low risk (relative to 1080 paste bait) to native vertebrates (Morgan 1999).

Brodifacoum

Brodifacoum is a potent second-generation anticoagulant that is toxic to many non-target species by both primary and secondary poisoning (Godfrey 1985, Eason & Spurr 1995). For example, most blackbirds on Red Mercury Island not killed by aerial application of brodifacoum baits were subsequently found to contain brodifacoum residues (Morgan & Wright 1996). A wide range of birds (e.g. saddleback, silvereyes, paradise shelduck, morepork, skua, robin and weka) have been found dead from poisoning after field use of brodifacoum in New Zealand (e.g. Taylor 1984, Williams et al. 1986, Taylor & Thomas 1993, Towns et al. 1993, Stephenson & Minot 1998). The manufacturer of brodifacoum concentrate (Zeneca, UK) recommends that the pesticide should not be aerially broadcast for the control of pests, and that systems for controlled delivery of baits should be used.

Further research in brodifacoum control areas is required to assess: the risks to insectivorous birds feeding on invertebrates; the risks to predatory (e.g. NZ falcon, morepork) and omnivorous birds; the risk to folivores and seed-eating birds that may eat baits (e.g. Ogilvie et al. 1997); and the impacts of an exposure to brodifacoum on the breeding success of selected bird species.

Cyanide

There are fewer reports of birds being killed by cyanide than by 1080 or traps (Spurr 1991). However, some ground-dwelling species are at risk, and unfortunately **in some regions there have been reports of weka and kiwi being killed**. For example, in 1984 some 66 hunters reported 37 kiwi poisoned by cyanide, about a quarter of the number caught in traps (Spurr 1991). In comparison, no kiwi have been reported poisoned after 1080 operations. The risks that discarded cyanide capsules (i.e. Feratox®) present to non-target species are not known.

Cholecalciferol

Cholecalciferol is much less toxic to birds than 1080 (Haydock & Eason 1997, Wickstrom et al. 1997a), and is therefore likely to kill few birds by either primary or secondary poisoning. Studies on captive mallard ducks showed most survived very high doses (2000 mg/kg) of cholecalciferol (Marshall 1984, Eason et al. 1994c), and only about half the canaries and chickens receiving the same dose subsequently died (Wickstrom et al. 1997a). The comparative acute toxicity of cholecalciferol to the brushtail possum (i.e. its LD50) is 16.8 mg/kg (Jolly et al. 1995). Use of cholecalciferol gel bait in purpose-designed bait stations presents low risk to native vertebrates (Morgan 1999).

2.2.3 *Invertebrates*

1080

There have been no significant changes in the relative abundance of different invertebrate taxa monitored before and after aerial poisoning that can be attributed to insect populations having been exposed to 1080 poison (Spurr 1994b, Spurr & Drew 1999). Residues of 1080 have been measured in some insects (e.g. weta and cockroaches) for up to 3 weeks following aerial application of 1080 baits (Eason et al. 1998a). Invertebrates with 1080 residues may present a risk to insectivorous birds (Hegdal et al. 1986). It has been shown that the addition of cinnamon to baits is a deterrent to some invertebrates (Spurr & Drew 1998). Ongoing research is further evaluating invertebrate species that may be at risk (Booth & Wickstrom 1999), and options that may further improve the safety of possum control.

Brodifacoum

Field studies have demonstrated that only a few (1%) invertebrates (e.g. slugs, weta) contained brodifacoum residues after Talon® 20P bait was aerially broadcast for rodent control (Morgan & Wright 1996, Ogilvie et al. 1997), and that there is no measurable change in abundance of invertebrates during such control (Spurr et al. 1997). Brodifacoum had no significant effect on weta when they were orally dosed (Morgan et al. 1996b). No data are available for other invertebrate species. The high survival of invertebrates exposed to brodifacoum may, in part, be due to the fact that they can metabolise and excrete the poison because they do not have the same blood-clotting systems as vertebrates (Shirer 1992). **The role of invertebrates as a vector in transferring brodifacoum from baits or carcasses to insectivorous birds is unknown.**

Cyanide

Although the effect of cyanide on invertebrate taxa in New Zealand has not been researched, it is lethal to aquatic invertebrates at relatively low concentrations (i.e. <200 ppb, Hone & Mulligan 1992). Although this indicates that **the hazards of cyanide to invertebrates may be high, the exposure of invertebrates to cyanide is minimal** (with only a few cyanide paste baits per hectare that are positioned on isolated spots of ground). The overall risks (i.e. hazard × exposure) of cyanide to invertebrates is therefore low.

Cholecalciferol

Few studies have assessed the risk to invertebrates from cholecalciferol baits. One trial on 18 captive weta indicated that they would eat cholecalciferol baits, but that the baits were not toxic to them (Ogilvie & Eason 1996). When cholecalciferol stock solution was administered to weta by oral gavage, they survived the highest dose volume (250 μg/g) given, suggesting **cholecalciferol is of low toxicity to at least this group of invertebrates** (Ogilvie & Eason 1996).

2.3 Public acceptance

2.3.1 *Risks to public health*

1080

The theoretical means by which the public may be exposed are either from: drinking contaminated water or milk, eating meat or honey that contains 1080 residues, locating baits and equipment not in safe storage, or entering a control area and either handling or eating baits applied for possum control. However, the potential for the general public to be exposed to 1080 is extremely low. Pesticides regulations place strict controls on: the broadcasting of 1080 baits in catchments used as public water supplies; the aerial broadcasting of bait within 100 m of rivers, application of baits on public roads, walkways, settlements, and camping grounds; and the storage of toxic baits. Aerial application of 1080 baits is prohibited during school and public holidays, and hunting permits must warn hunters that 1080 poisoning is planned for certain localities.

From 857 samples of stream water collected during 1990–97 shortly after the aerial application of 1080, residues of 1080 were found in only three samples with concentrations of 2–4 ppb (Eason et al. 1998a). These concentrations would now exceed the maximum concentration of 2 ppb permitted by the Ministry of Health. Long-term monitoring of water has shown the persistence of 1080 in stream water to be of a short duration, both in laboratory studies (Ogilvie et al. 1996, Parfitt et al. 1994) and in the field (Parfitt et al. 1994).

Because 1080 is metabolised and excreted within 4 days of an animal eating 1080 baits (Rammell 1993, Eason et al. 1996a), the risks of humans consuming meat containing 1080 residues is low. When sheep were administered a single sublethal oral dose and then slaughtered 2.5 hours later, the highest level in sheep tissue was 0.098 mg/kg (Eason et al. 1994a). Livestock exposed to 1080 should be withheld from slaughter for 10 days (Eason et al. 1994b).

To prevent both bee mortality and 1080 contamination of honey, the original 1080 paste that contained sugar was withdrawn from the market and replaced with a 'bee-safe' paste (BB3) (Morgan & Goodwin 1995) and legislation invoked that precludes control with pastes within 4 km of beehives (Ministry of Health 1995).

Legislation requires appropriate public notification of possum control, and for hazardous substances to be secured in safe storage while not in use (Hughes 1994). It is therefore unlikely that the public will be exposed to 1080 during pest control operations, but care is required to ensure that any chance of unauthorised persons being exposed to 1080 baits is avoided. To date there has been only one person killed (a suicide) in New Zealand from 1080 poisoning (Hughes 1994).

Brodifacoum

Brodifacoum is unlikely to contaminate stream water because it is recommended for use in bait stations. It is also extremely insoluble in water (Jackson et al. 1991). No brodifacoum residues were detected in water samples after control operations in which Talon® 20P was aerially broadcast at 15 kg/ha on Red Mercury and Lady Alice islands (Morgan & Wright 1996, Ogilvie et al. 1997).

Brodifacoum is a potent second-generation anticoagulant**. Humans could be exposed to brodifacoum by eating the meat (especially livers) of animals that have ingested the poison**. Animals may become contaminated with brodifacoum residues by eating baits, or by eating the carcasses of other animals poisoned with brodifacoum (e.g. wild pigs that have fed on possum carcasses; Eason et al. 1999a). Brodifacoum therefore represents a serious health risk to hunters who repeatedly eat the livers of wild pigs and / or wild pork from pigs shot in areas where brodifacoum has been extensively used for pest control (Eason et al. 1999a).

Cyanide

Although cyanide is a poison that is rapidly degraded after it is applied, **the public may encounter it on conservation lands where it is applied for control of possums**. Unless baits are unintentionally eaten, moved into vehicles on footwear (as was the case with one reported poisoning), or tubes of poison are not adequately secured during storage, then cyanide is unlikely to pose a significant health risk to the public.

Cholecalciferol

Cholecalciferol (vitamin D3) is most likely to be a risk to the general public if they eat pesticide baits. Cholecalciferol should not enter public water supplies because it is almost completely insoluble. It is also recommended for use in bait stations. The risks that residues in meat will affect public health are extremely low because when animals eat bait, cholecalciferol is rapidly absorbed and then converted to hydroxylated metabolites (e.g. 25-hydroxycholecalciferol; 1,25 dihydroxycholecalciferol), which are, in themselves, subsequently metabolised and excreted (Bahri 1990). The hydroxylated metabolites (which are also toxic) are retained mainly in the plasma, liver, heart, and adipose tissue of poisoned animals for about 4 weeks after cholecalciferol was first ingested (Wickstrom et al. 1997a). However, these toxic metabolites did not occur at high enough concentrations to have any measurable effects on dogs fed 1 or 2 possums, or have any lasting effects on the health of dogs that were fed five carcasses of recently poisoned possums (Wickstrom et al. 1997a).

2.3.2 Risks to pest controllers

Personnel regularly handling toxic baits or who are exposed to toxic concentrates must comply with label instructions and information supplied in material safety data sheets (MSDS). These persons are most at risk, not only because they have a high exposure to poisons, but they are frequently handling materials that are very hazardous. The relative toxicity of different pesticides when administered orally and dermally, and appropriate protective equipment, is discussed in the Vertebrate Pest Control Manual (Haydock & Eason 1997). Poisons may be ingested accidentally, resulting in a single sublethal exposure; or by ‘careless use’, which frequently results in repeated sublethal exposures.

1080

(a) A single sublethal exposure. A single sublethal exposure may cause 1080-induced myocardial lesions (Buffa et al. 1977), as observed in the cardiac muscle of sheep (Annison et al. 1960, Whitten & Murray 1963, Schultz et al. 1982, Wickstrom et al. 1997b). Large single doses (100 and 200 mg/kg) caused a reduction in plasma testosterone concentrations and degeneration of seminiferous tubules in skinks (Twigg et al. 1988). Single doses of 15 and 60 mg/kg resulted in damage to the kidneys of rats (Savarie 1984). Humans sublethally poisoned have on occasions had chronic cardiac dysfunctions or renal problems (Chung 1984). Sub-lethal exposures of 1080 also have neurophysiological effects, and a very large sublethal exposure caused permanent brain damage to a child (McTaggart 1970).

(b) Repeated sublethal exposure. Repeated sublethal exposure to 1080 has resulted in lower levels of spermatogenesis in rats (Sullivan et al. 1979, Miller & Philips 1955) and mink (Hornshaw et al. 1986). Foetal abnormalities were observed in rats after pregnant females were dosed with 0.33–0.75 mg/kg/day of 1080 from day 6–17 of gestation; and rats dosed for 14 days with 0.5–4.0 mg/kg/day had decreased testis weights and enlarged hearts (Eason et al. 1998b, Eason et al. 1999b). Sheep receiving repeated sublethal doses of 1080 had myocardial degeneration as well as necrosis of individual or small groups of myocardial fibres (Schultz et al. 1982). To date there is no evidence that 1080 is either a mutagen or carcinogen (Eason et al. 1998b, Eason et al. 1999b).

Brodifacoum

(a) A single sublethal exposure. Because brodifacoum is potent and persistent, a single exposure may alter clotting factors, resulting in haemorrhage (Pelfrene 1991).

(b) Repeated sublethal exposure. Brodifacoum persists in the liver and muscle of sublethally poisoned possums for more than 8 months (Eason et al. 1996b) and may similarly affect pest controllers who repeatedly ingest sublethal amounts. Long-term exposure to brodifacoum may also lead to an adverse effect on bone metabolism and the development of osteoporosis (Szulc et al. 1993). Repeated exposure to another anticoagulant warfarin (as a therapeutic agent) has also been linked with developmental malformations in pregnant women (Tasheva 1995). Although at this stage there is no evidence that brodifacoum is either a teratogen or mutagen, care should be taken to ensure that operators are not unnecessarily exposed to the poison.

Cyanide

(a) A single sublethal exposure. With appropriate treatment (amyl nitrite and sodium thiosulfate), patients will recover to full health (Laws 1991, Hayes 1991).

(b) Repeated sublethal exposure. Pest controllers who repeatedly ingest sublethal amounts of cyanide may suffer some lasting neurological effects (e.g. Parkinson's disease) from these exposures (Kanthasamy et al. 1994). Care should therefore be taken to avoid inhaling cyanide gas emitted from opened paste tubes and whilst laying paste baits.

Cholecalciferol

(a) A single sublethal exposure. No accidental human poisoning with cholecalciferol rodenticides is known to have been lethal (Pelfrene 1991). A single sublethal poisoning may result in soft tissue calcification, especially in the renal tubules, renal arteries, and aorta, with associated health problems (Pelfrene 1991).

(b) Repeated sublethal exposure. Since cholecalciferol (Vitamin D3) is a normal dietary constituent, anyone eating a normal balanced diet will be repeatedly exposed to sublethal amounts of cholecalciferol. However, long-term exposure to high sublethal doses of cholecalciferol results in hypervitaminosis whereby calcium mobilised from the skeleton may be deposited in many soft tissues (renal arteries and tubules, heart and coronaries, lungs, bronchi, and stomach). This can lead to fatigue, weight loss, headache, paraesthesia, depression, albuminuria and naematuria (Haydock & Eason 1997). Very high repeat doses of cholecalciferol may also cause foetal abnormalities, abortions, and fertility problems (Pelfrene 1991).

2.3.3 Public attitudes

A number of surveys have assessed public attitudes to the possum and to control technologies (Sheppard & Urquhart 1991, Fraser 1995, Fitzgerald et al. 1996). The surveys suggest a trend of increasing public awareness of the threats that possums present to indigenous bird life and native forests (95% of people now regard the possum as a pest); acceptance of the need to control possums (94% of people now feel there is a need for control); intolerance of the use of poisons for possum control (especially aerially broadcast 1080 where public approval was down from 44% in 1991 to 19% in 1996). In surveys throughout Australasia (Sheppard & Urquhart 1991, Fraser 1995, Fitzgerald et al. 1996, Johnston & Marks 1997) women are more opposed to the use of pesticides than men. These **objections to the use of poisons mainly arise from issues of humaneness and specificity**. Concerns that **1080 may endanger human health** is still also an issue with many people.

2.3.4 Consultation process

Resolution of people's perceived risks of control are unlikely to be achieved by 'merely hammering away at the scientific information' (Chess et al. 1989). **To develop control strategies that are publicly acceptable therefore requires managers to devise a two-way communication process and for community participation in decision making**. This is likely to require an investment of time by managers to develop a public understanding of the benefits of controlling possums, alongside the risks and costs of each type of control strategy. This dialogue is an essential prerequisite to any planned control, not only to ensure that control can be sustained over the long term, but also to enable community groups to facilitate their own control programmes (O'Brien 1998). The detailed procedures for public consultation are summarised by Hancox (1998).

2.3.5 Accessibility

The ability of ground hunters to control some possum populations is constrained by the topography of the land (e.g. steep, dissected hillsides) and the remoteness of some terrain. In very steep and isolated locations hunters will have difficulty in controlling possums with bait stations (or traps). In extreme situations hunters may also have difficulty in targeting all possums with hand-laid cyanide baits. **Where access makes it logistically very difficult for hunters to operate effectively, managers are reliant on aerial control**.

Where reserves and recreational areas are extremely accessible to the public (and / or dogs) it is important that managers are proactive in initiating consultation and in listening to concerns that people may have (see public acceptance). In these areas, control of possums by hunters using methods and materials that are least likely to have an impact on non-target species (e.g. cyanide or cholecalciferol baits) are the most prudent means of control.

2.4 Shyness in possums

2.4.1 Occurrence

Repeated exposures to pesticides often results in pests developing either a physiological resistance to the toxicants and / or a behavioural resistance to the toxicant or the bait.

Although it is not known whether possum populations repeatedly exposed to pesticide baits have become physiologically resistant to poisons, rats have developed a physiological resistance to 1080 (Kandel & Chenoweth 1952, Howard et al. 1973) and brodifacoum (Gill et al. 1992). Therefore, it is possible some possum populations that have been repeatedly poisoned may contain animals that are physiologically resistant to some poisons, but there are currently no empirical data to support this hypothesis.

Behavioural resistance may take the form of an 'innate' avoidance of baits and / or traps, or be 'conditioned' by animals surviving sublethal amounts of poison. One form of innate behavioural resistance is cautious feeding behaviour (neophobia), which has lead to significant numbers of rats and rabbits surviving control with toxic baits (Cowan & Barnett 1975, Oliver et al. 1982, Brunton & MacDonald 1996). Similarly, a few possums may be innately neophobic (Morgan 1982, O'Connor & Matthews 1996) and either refuse bait or eat negligible amounts of bait. Repeated exposures to baits (e.g. by pre-feeding) will help overcome neophobia (R. Henderson unpubl. data), but it is likely that a few possums will resist eating baits in most poisoning operations. Neophobia may result in as many as 5% of wild possums surviving control (Morgan 1982). Possums (and other species) may also be 'innately' averse to the taste and / or smell of toxicants such as 1080 (Morgan 1990) and cyanide (Warburton & Drew 1994) either because they are extremely unpalatable or because the animals have evolved in habitats where these toxins occur naturally.

Pesticide resistance is most frequently manifested in a 'conditioned' behavioural resistance to eating either the poison (e.g. Howard et al. 1977) or the bait (Morgan et al. 1996a) because animals associate the food (toxic bait) that was eaten with the trauma caused by a sublethal poisoning (see bibliography in Riley & Tuck 1985, Prakash 1988). Empirical studies have demonstrated that learned shyness develops in most (>60%) captive possums after they ingest sublethal amounts of 1080 (Morgan et al. 1996a, O'Connor & Matthews 1996, Ross et al. 1997), cholecalciferol (O'Connor et al. 1998), or cyanide (O'Connor & Matthews 1995). This shyness (to cyanide and 1080 baits) persists for at least 2–5 years in captive possums (Morgan & Milne 1997, O'Connor & Matthews 1997, O'Connor 1998).

Successful control of pests that survive poisoning therefore requires strategies that avoid re-exposing them to baits and toxins with which they are familiar, by carefully integrating systems used for the management of pests (Roush & Powles 1996). Possums with an existing behavioural resistance to baits, and which survive a further sublethal poisoning, develop an enhanced neophobia (O'Connor & Matthews 1996), which further exacerbates the difficulty in their control with other poisons (Hickling et al. 1998). In the wild, possums have also been demonstrated to generalise the aversions from an exposure to cyanide paste to other types of toxic baits (e.g. cereal baits containing 1080 and cholecalciferol) and these cross-toxin effects can severely constrain the effectiveness of other methods for controlling some populations (Hickling et al. 1998).

2.4.2 *Prevention*

The best way to prevent bait shyness is to ensure that baits are of a high quality (i.e. are of recommended toxicant concentration, palatability, and bait size) so that few, if any, possums are sublethally poisoned.

In addition, pre-feeding can be used to reduce the likelihood of shyness developing. Captive possums repeatedly exposed to a prefeed (containing dye and cinnamon) did not develop bait shyness after they were sublethally poisoned with the same bait type as the pre-feed (Moss et al. 1998). However, when non-dyed prefeed was used in one field trial possums still developed a shyness to toxic baits (C. O'Connor pers. comm.). This suggests that to prevent shyness developing, prefeed should not only be of the same type as the toxic bait that is subsequently applied, but should also be dyed green and cinnamon-lured.

Trials with captive rats have demonstrated that by incorporating neurotransmitter-inhibiting compounds in baits, rats were not able to form an association between the sublethal doses of the toxic bait and subsequent physiological trauma (Cook & Dean 1996). This technology has not yet been tested on possums, but may have potential for avoiding the development of bait shyness.

2.4.3 *Mitigation*

Research on captive possums has demonstrated that shyness to cyanide persists for at least 2 years (O'Connor & Matthews 1997), and shyness to 1080 may persist for 2–5 years (Morgan & Milne 1997, O'Connor 1998). In the wild, a gradual abatement of shyness at the population level is hastened by population turnover (i.e. births and deaths) so there are likely to be negligible levels of residual population shyness after 4 years (Hickling 1995). Repeat aerial operations 4 years apart have achieved a 0.2% RTC following maintenance control in one operation and a 83% kill following maintenance control in another operation (see Appendix 2). **Leaving at least 4 years between control operations is therefore likely to result in negligible levels of shyness in surviving possums**. However, shyness needs to be considered carefully if operations are scheduled more frequently than this.

The use of brodifacoum baits has proved effective for the control of 1080 bait-shy captive possums (Ross et al. 1997) and wild possums (Henderson et al. 1997a). Brodifacoum baits were more readily consumed and consequently killed more possums when applied 2 months after control with

1080 or cholecalciferol than when the use of the anticoagulant followed immediately after initial control (Henderson et al. 1997a). Current practices (Appendix 2) also suggest that control with brodifacoum is more effective several months after initial control with 1080 or cyanide, than when brodifacoum is used immediately after initial control. It is therefore **recommended that where maintenance control is required shortly after initial control, brodifacoum baits are applied, but no sooner than 3 months after control with 1080, cholecalciferol or cyanide**.

Shyness of captive possums to toxic baits has been partially mitigated during sequential use of toxic baits by changing the bait base and / or lure (Morgan et al. 1996a, O'Connor 1998). Further increases in the amounts of bait eaten and mortality of shy captive possums was facilitated by changing both the type of bait and the toxicant (Ross et al. 1997). Field trials on shy possums using non-toxic baits have similarly demonstrated that changing the bait matrix and lure causes wild possums to eat considerably more of a new bait type than a bait similar to that which induced 1080 shyness (Ogilvie et al. 1998). Other field trials have demonstrated that possums made shy by cyanide paste will eat more of a new non-toxic bait type (viz. carrot) than non-toxic paste (Henderson et al. 1997b). However, in four field trials, cyanide-induced shyness was not adequately mitigated by either bait-switching (i.e. using cereal baits instead of paste) or changing toxicants (using 1080 or cholecalciferol instead of cyanide) (Henderson et al. 1997b). These results suggest a generalised shyness to all bait types forms after sublethal cyanide poisoning but this requires further research.

The management of behavioural and physiological resistance to pesticides requires pest controllers to apply the concepts used in integrated pest management (IPM) (Roush & Powles 1996) to sustainably control possums. Hence **using a completely different approach to that of poisoning (e.g. traps) will optimise kills of possums that are neophobic or bait-shy**. Skilled trappers are able to achieve kills exceeding 80% (Montague 1997) and previous research has shown trapping is unlikely to induce shyness (Warburton & Hickling, 1992) but will control bait-shy possums (Appendix 1, section 2.2). Trapping is very labour-intensive though (Morgan 1998), and constrained if areas are not readily accessible.

2.5 Costs

2.5.1 Administrative

The administrative costs associated with successful control operations may be spread over a long period, and include costs associated with planning, compliance with legislation, public consultation, pre-poison assessments of possum abundance, implementation of the operation, and post-poison monitoring. To monitor the benefits of control there should also be monies allocated to ecosystem monitoring. The administrative costs incurred during a control operation may be as high as $21 per hectare in exceptional circumstances (Warburton & Cullen 1993).

2.5.2 *Operational*

The costs for each method of control per operation are summarised in Appendix 2. The costs of control presented are indicative, as they are based on a small number of operations. Also, costs at each location are likely to be dependent on a number of external factors (e.g. location, accessibility, weather, the professional skill and experience of staff, etc.).

Costs of control with acute poisons (cyanide, 1080, cholecalciferol) are on average lower than the costs of brodifacoum control. The costs of control with paste baits (cyanide, 1080) are on average lower than the costs of other methods of control. Paste baits are also likely to pose lower environmental risks than aerial control. This would suggest the way forward for ground control in terms of improved cost-effectiveness is through the use of pastes. Future research should explore strategies to optimise the effectiveness of paste, further improve the environmental safety of pastes (with bird repellents such as cinnamamide; Spurr & Porter 1998), and develop new paste products to provide baits suitable for different climatic conditions.

2.5.3 *Long-term*

Long-term programme costs are a result of the costs of each operation, the frequency with which control is necessary, and the percentage kills achieved. The costs of control increase as the number of operations required to reduce populations to lower and lower densities within a conservation area is increased (Cowan 1992, Thomas et al. 1995). For example, on Kapiti Island the first possum killed during an eradication programme cost $4.30, and the last possum killed cost $2750 (Cowan 1992). To undertake cost-effective possum control in the long term therefore requires each operation to be as effective as possible to reduce the frequency of operations required for sustained control.

Scenarios are presented in Table A1.2 for the costs of control during a 12-year period (over large areas and in conservation land) when management objectives require fewer than one possum per hectare. These costs are assessed following initial kills of 80% and 95%. From models of population recovery in areas with and without immigration (Table A1.1), the times when control is required to keep possums at or fewer than 1 per hectare can be predicted and these are used in Table A1.2. If the indicative, reported costs of control are used to estimate the hypothetical costs of control over a 12-year period (Table A1.2), it would seem that:

- Long-term costs are likely to be appreciably higher (by 19–52%) when immigration is confounding the rate of population recovery (as in the case of small reserves).
- Long-term costs are 28–38% higher when an 80% kill was initially achieved rather than a 95% kill.
- Long-term costs may be 40–88% higher if brodifacoum baits are used for maintenance control rather than ongoing aerial operations or the use of traps and cyanide.

To improve models of control economics, further research should sample a larger number of control operations and establish more reliable estimates of costs than those summarised in Table A1.2. As the costs and timing of sequential control are better defined, then costs of long-term control can be estimated as the discounted cost (Cullis & Jones 1992) incurred on an annual basis ($ per ha per year), which will enable reliable forecasting of budgets required for possum control.

2.6 Legislation

Certain possum control options require compliance with legislation, which can significantly increase operational costs. Nineteen different statutes that relate to the use of pesticides for control of possums are listed below. Details of how this legislation impinges on possum control are included in Nelson (1996), a Ministry of Health publication (1995), and a Ministry of Agriculture publication (1998).

TABLE A1.2. COSTS OF CONTROL ($ PER HECTARE), FOLLOWING INITIAL KILLS OF 80% AND 95%, THAT IS REQUIRED OVER A 12-YEAR PERIOD TO MAINTAIN DENSITIES BELOW 1 POSSUM PER HECTARE. COSTS ARE BASED ON DATA PROVIDED BY DOC PEST MANAGERS AND PRIVATE CONTRACTORS, AS SUMMARISED IN APPENDIX 2, AND ASSUMED TIME INTERVALS FOR CONTROL FROM MODELLING RATES OF POPULATION RECOVERY (APPENDIX 3).

METHODS USED SEQUENTIALLY	INITIAL CONTROL	YEARS AFTER INITIAL CONTROL IN WHICH MAINTENANCE CONTROL WAS UNDERTAKEN AND THE APPROXIMATE COSTS OF CONTROL ($)								TOTAL COST[2] AFTER 12 YEARS ($)
		<1	+3	+5	+6	+9	+10	+11	+12	
a) Control following an 80% kill (large areas)										
Aerial-Aerial	23	19[1]		23				23		88
Aerial-Traps and cyanide paste	23	19[1]		12				12		65
Aerial-Brodifacoum paste	23	29		29				29		109
b) Control following a 95% kill (large areas)										
Aerial-Aerial	23			23				23		69
Aerial-Traps and cyanide paste	23			12				12		47
Aerial-Brodifacoum paste	23			29				29		81
c) Control following an 80% kill (Reserves)										
Bait station (1080-Brodifacoum)	19	29		29		29			29	134
Bait stations-Traps and cyanide paste	19	19[1]		12		12			12	75
Traps and cyanide-Brodifacoum	18	29		29		29			29	133
d) Control following a 95% kill (Reserves)										
Bait station (1080-Brodifacoum)	19		29		29		29			105
Bait stations-Traps and cyanide paste	19		12		12		12			56
Traps and cyanide-Brodifacoum	18		29		29		29			104

[1] The costs of follow-up control ising traps.

[2] 'Accumulated' cost rather than 'discounted' cost (Cullis & Jones 1992).

Legislation relating to pesticide use includes:

- Civil Aviation Regulations 1953;
- Noxious Substance Regulations 1954;
- Health Act 1956;
- Agricultural Chemicals Act 1959;
- Dangerous Goods Act 1964;
- Standards Act 1965;
- Pesticides Act 1979;
- Toxic Substances Act 1979;
- Vertebrate Pest Control Regulations 1983
- Toxic Substances Regulations 1983;
- Resource Management Act 1991;
- Employment Act 1992;
- Biosecurity Act 1993;
- Health and Safety in Employment Act 1993;
- Hazardous Substances and New Organisms Act 1996;
- Agricultural Compounds and Veterinary Medicines Act 1997.

Legislation relating to residues includes:

- Meat Act 1981;
- Dairy Industry Act 1952;
- Food Regulations 1983;
- Vertebrate Pest Control Regulations 1983.

3. DEVELOPING A CONTROL STRATEGY

Having considered past control and the constraints that limit the choice of control options, managers should then develop a strategy for sustained animal control. This should involve consideration of whether the population is pre-peak or post-peak; the adoption of an approach that integrates different methods of control; and whether multi-species control is justified.

3.1 Irruptive cycles

When vertebrate pests are introduced into previously unoccupied habitat, they typically increase to a peak density and crash steeply to a considerably lower level in an 'irruptive oscillation' (Caughley 1976, Riney 1964, Thomas et al. 1993). This pattern of population change has been documented for several possum populations (Bamford 1972, Fraser 1979, Thomas et al. 1993), and is correlated with a significant modification of forest ecosystems (Pekelharing & Batcheler 1990, Rose et al. 1993). Controlling possums at near-peak or peak densities will merely pre-empt the population crash that is inevitably going to occur, and will be of negligible value in preserving conservation values. To be of most value control should therefore be scheduled before habitats are severely modified by possums, or during the period of post-decline stability when recovery of indigenous flora and fauna has begun.

3.2 Integrated management of possums

Integrating different methods during sequential control of possums avoids pesticide resistance (both physiological and behavioural) developing in populations that are repeatedly controlled by poisons (Posamentier 1988). This approach also avoids pests becoming shy of capture devices (e.g. traps). If the methods of control used sequentially are independent of each other (e.g. traps and poisons) then the fact that an individual survived an initial attempt at control is unlikely to influence the success of future control. Changing baits and / or poisons is also likely to enhance control of a pest species (Oliver et al. 1982, Morgan et al. 1996b), and minimise the risks of pesticide resistance (Prakash 1988, Roush & Powles 1996). Ultimately, programmes for integrated management of possums are also likely to include agents for biological control of possums (Cowan & Bayliss 1998). Long-term programmes for the sustainable control of possums should therefore include a mix of control strategies.

3.3 Multi-species control

Control that is targeted at a single species is also likely to change the local abundance of other pest species (Morgan 1993). Aerial control of possums with cereal baits containing 1080 is also likely to control most (>90%) rats (Warburton 1989) and most mustelids (Alterio & Moller 1998, Murphy et al. 1998) by either primary or secondary poisoning. The reduced impact of all predators (i.e. possums, rats, stoats, and ferrets) on populations of birds, reptiles, and invertebrates is likely to help restore ecological communities. Aerial control of possums also provides partial control (i.e. 30–60% kills) of deer (Daniels 1966, Parkes 1989, Fraser 1995), feral sheep (Parkes 1989, Parkes et al. 1997) and occasionally pigs or goats (Parkes 1989), which will reduce browsing of foliage in sub-canopy or ground-level plant species. Bait station control is unlikely to control as many predators as aerial control, because many rodents do not encounter or feed from bait stations spaced at 150-m intervals (Thomas 1998).

Ecosystem restoration is reliant on vegetation recovery and protection of native fauna from predation. Where vegetation recovery is a primary objective of control, managers should not only target possums (which browse canopy and subcanopy species) but also ungulates (which prevent forest regeneration by browsing ground-dwelling plants, seedlings, and subcanopy species) (Nugent et al. 1997, Parkes 1994).

Control targeted at a single species can potentially further endanger indigenous fauna if this results in 'prey-switching' by predators, or makes predators poison-shy and difficult to control thereafter. Examples of the counter-productive effects of single-species control include the control of rabbits causing increases in movements of mustelids (Norbury et al. 1998), more predation of birds (Norbury et al. 1997, Brown & Keedwell 1998), and bait-shyness in possums (Hickling et al. 1999). It is also possible that stoats and ferrets sublethally poisoned with 1080-contaminated carrion (viz. the carcasses of rats and possums that have eaten possum baits), will subsequently be more difficult to control with 1080-impregnated eggs (Spurr & Hough 1997). These scenarios suggest that in some situations control of predators would be more effective if it was implemented before control of possums (and rabbits).

Although many managers are currently using brodifacoum baits for multi-species control (i.e. control of possums as well as rats and mustelids), the risks to livestock and indigenous fauna from this practice is also high (e.g. Dowding & Veitch 1999, Eason et al. 1999a, Meenken 1999, Shore et al.1999, Stephenson & Minot 1999).

3.4 Long-term programme

Ecosystem restoration is reliant on a long-term programme of animal control that keeps predators at low densities and minimises the impacts of browsing animals on indigenous flora (Parkes 1994).

A long-term plan for animal control should avoid control methods that place endemic non-target species at risk; avoid, wherever possible, the repeated use of the same control methods; and ensure the proposed control methods are likely to be accepted by the local community. To ensure that pest control programmes are meeting their objectives, the manager should also periodically monitor wild animal populations and those key parameters within the ecosystem that they are attempting to preserve or restore. For example, monitoring of bird populations during a 2-year period after 1080 control in Waimarina forest (Oates 1997) and Pureora forest (Powlesland et al. 1999) has demonstrated significant increases (up to 225%) in abundance of indigenous birds (e.g. robin, tui, bellbird, fantail, tomtit, etc.) because of reduced predation by possums, mustelids, and rats. Allocation of times for monitoring should therefore also be an integral part of the plan.

It is likely that most successful long-term programmes of ecosystem management will successfully integrate control of predators (rats, stoats, ferrets, possums), folivores that reduce biodiversity (e.g. possums), and herbivores that prevent regeneration of seedlings (e.g. goats, deer, etc.) (Parkes 1994, Parkes & Nugent 1995).

Appendix 2

Review of current practice[2]

1. METHODS OF CONTROL

Questionnaires were circulated to DOC district managers and private contractors during 1994 and 1998 to assess the types of control used on conservation lands, and the effectiveness of these strategies. This provided 255 responses: 143 in 1994 and 112 in 1998.

The methods used to control possums on conservation land are influenced by the size of the control area (Table A2.1.). To control possums over large areas (>2000 ha) the most commonly used methods are aerially broadcast 1080 baits, the use of 1080 baits in bait stations, or a combination of traps and cyanide. Control in small reserves (<1000 ha) was normally undertaken using either bait stations (containing 1080, brodifacoum, cyanide, or cholecalciferol baits), traps and / or cyanide paste.

During the 1990s there have been changes in the methods used to control possums (Table A2.1). Since 1994 the use of aerial methods for initial control has declined and been replaced by an increased use of 1080 in bait stations. Although more 1080 bait is now aerially broadcast for maintenance control than during 1991–94, ongoing control of populations is mainly reliant on the use of bait stations containing brodifacoum baits or a combination of traps and cyanide. The advent of new products during 1995–98, such as Campaign® (used 5%) and Feratox® (used 2%), has largely replaced the use of cyanide paste in bait stations (used 6% in 1991–94 and 0% in 1995–98). Although brodifacoum baits were aerially broadcast in three operations before 1995 to control both possums and rats, because of risks to non-target species this practice has not been used for control of possums in recent years. Brodifacoum is, however, still broadcast on islands for rodent control (Empson 1998, Dowding & Veitch 1999, Stephenson & Minot 1999) after resource consents have been obtained for it to be used in this way. As the use of 1080 has declined, the use of ground-laid brodifacoum for pest control has increased (Table A2.1, Innes 1998). Since 1994 there has been a slight decline in the use of traps either alone or in combination with cyanide. The percentage of Lanes-Ace gin traps used during control has declined from 31% (8 of 26 respondents) during 1990–94 to 12% (4 of 34 respondents) during 1991–98 (see Table A2.5).

[2] References to Appendices 1–3 are combined intto Appendix 4.

2. COST-EFFECTIVENESS

The effectiveness of possum control was reported as either a percentage kill or residual trap catch (RTC). The highest average reported kill was for aerial control (Table A2.2). However, the subsequent success of aerially broadcast baits during maintenance control appeared dependent on the time that had elapsed since initial control, probably due to 1080 shyness problems. Operations 12 months after initial control killed 0% and 32% of possums, and 20 months after initial control killed 41% of possums. However, when 48 months had elapsed since initial control, maintenance control with 1080 killed 83% of possums in one operation and gave an RTC of 0.2% in another. This supports a hypothesis (explained in Appendix 1, section 2.4.3) that the effectiveness of 1080 for maintenance control is constrained by shyness until at least 48 months have elapsed since initial control.

Initial control using 1080 bait in bait stations produced average kills that were similar to those of aerial control, but the kills were more variable. This would suggest that operators were not using the same methodologies during control

TABLE A2.1. METHODS USED TO CONTROL POSSUMS BY THE DEPARTMENT OF CONSERVATION DURING 1991–94 AND 1995–98. THE TABLE LISTS THE PERCENTAGE OF RESPONSES TO METHOD USED FOR INITIAL OR MAINTENANCE CONTROL, WITH NUMBER OF RESPONDENTS IN PARENTHESES.

	MEAN AREA CONTROLLED IN HECTARES (95% C.I.)	1991–94		1995–98	
		INITIAL CONTROL	MAINTENANCE CONTROL	INITIAL CONTROL	MAINTENANCE CONTROL
Aerial (1080)	3043 (987)	32 (28)	2 (1)	21 (11)	14 (8)
Aerial (brodifacoum)	NR	3 (3)	0 (0)	0 (0)	0 (0)
Bait stations (1080 control)	2333 (2060)	2 (2)	4 (2)	25 (13)	7 (4)
Bait stations (brodifacoum)	611 (227)	5 (4)	46 (26)	9 (5)	39 (23)
Bait stations (other*)	811 (515)	7 (6)	11 (6)	9 (5)	8 (5)
Traps and cyanide	2453 (719)	36 (31)	20 (11)	32 (17)	17 (10)
Traps only	1666 (1437)	10 (9)	12 (7)	2 (1)	7 (4)
Cyanide only	3960 (848)	4 (3)	0 (0)	2 (1)	3 (2)
Ground baiting (1080 paste)	1473 (848)	1 (1)	5 (3)	0 (0)	5 (3)
Total	–	100 (87)	100 (56)	100 (53)	100 (59)

NR = Not Reported.

* Includes use of cyanide, cholecalciferol and pindone in bait stations.

TABLE A2.2. EFFECTIVENESS OF DIFFERENT METHODS OF CONTROL (MEASURED AS PERCENTAGE KILL OR RESIDUAL TRAP-CATCH) AND THE COST PER HECTARE OF EACH METHOD. THE COSTS FOR AERIAL CONTROL INCLUDE ADMINISTRATION OVERHEADS (PLANNING AND MONITORING), WHILE FOR GROUND CONTROL THE COSTS ARE CONTRACT PRICES PAID TO HUNTERS OR DEPARTMENTAL COSTS INCURRED DURING CONTROL (I.E. COSTS EXCLUSIVE OF ADMINISTRATION OVERHEADS).

METHOD OF CONTROL REPORTED	PERCENTAGE KILLS OR RESIDUAL TRAP CATCH (%) FOLLOWING INITIAL AND MAINTENANCE CONTROL ± 95% C.I. (NUMBER OF RESPONCES IN PARENTHESES)				COSTS PER HECTARE OF CONTROL IN 1988 $* ±95% C.I. (NUMBER OF RESPONSES IN PARENTHESES)	
	PERCENTAGE KILL		RESIDUAL TRAP CATCH		INITIAL	MAINTENANCE
	INITIAL CONTROL	MAINTENANCE CONTROL	INITIAL CONTROL	MAINTENANCE CONTROL		
Aerial	87.9 ± 4.4 (n = 15)	39.0 (n = 4)	2.2 ± 1.7 (n = 7)	2.9 ± 6.0 (n = 5)	$24.47 ± 5.54 (n = 25)	$18.60 ± 5.64 (n = 7)
Bait stations (1080) control	85.5 ± 19.3 (n = 6)	NR	3.3 ± 2.1 (n = 6)	NR	$18.90 ± 11.0 (n = 3)	NR
Bait stations (brodifacoum)	85.6 ± 10.1 (n = 5)	72.4† (n = 9)	1.3 ± 0.8 (n = 4)	1.8 ± 1.3 (n = 24)	$57.14 ± 31.30 (n = 5)	$28.77 ± 8.95 (n = 8)
Bait stations (cholecalciferol)	76.3 ± 8.0 (n = 3)	NR	NR	NR	$30.50 ± 6.12 (n = 10)	$34.67 ± 7.50 (n = 4)
Traps and cyanide	78.8 ± 7.1 (n = 13)	69.8 ± 17.1 (n = 5)	4.9 ± 1.2 (n = 31)	4.2 ± 1.5 (n = 9)	$18.04 ± 2.69 (n = 19)	$12.25 ± 5.03 (n = 9)
Traps only	79.2 ± 14.8 (n = 5)	78.6 ± 13.7 (n = 7)	5.1 ± 6.0 (n = 4)	3.3 ± 1.1 (n = 6)	$19.00 (n = 1)	NR
Cyanide only	70 ± 17.0 (n = 6) †	NR	NR	5.1 (n = 1)	NR	NR
Encapsulated cyanide	70 ± 0.5 (n = 3)	NR	7.2 ± 3.2 (n = 5)	NR	NR	NR
1080 paste	63.0 (n = 1)	NR	3.5 (n = 1)	4.1 (n = 3)	$10.61 (n = 1)	$10.73 ± 7.59 (n = 5)

* Includes costs previously reported by: Morriss & Henderson (1997), Montague (1997), Warburton & Cullen (1993), Thomas et al. (1995), Thomas et al (1996), and Henderson et al. (1997a).
† Includes trials undertaken by Landcare Research.
NR = Not Reported.

with 1080 in bait stations. Although brodifacoum baits consistently killed 76–95% of possums during initial control, costs were high ($57/ha). When brodifacoum baits were used for maintenance control the reported kills ranged from 0 to 93% and reported RTC from 0 to 16%, suggesting that in some cases baits were applied inappropriately and / or bait shyness may have affected kills. As explained in Appendix 1 (section 2.4.3), for best results brodifacoum baits should be applied a minimum of 3 months after control using 1080 or cyanide.

A combination of traps and cyanide was a cheap form of control, but the kills achieved were less than 80% during initial control (range = 62–95%, RTC = 1–15%), and the effectiveness was inconsistent when used for maintenance control (kills = 54–89%, RTC = 2–8%). Traps killed an average of 79% of possums and were equally effective on naive and shy possums, but are very labour-intensive (Morgan 1998), reliant on correct use by operators (Warburton 1982), and cannot readily be used at all locations (because of difficulties of access or risks to ground-dwelling birds).

Although the use of 1080 paste proved to be a cheap form of control in the limited number of operations reported, there were very few reports of its effectiveness.

3. SEASONAL CONTROL

Most aerial control is done during winter, and ground control during the summer months (Table A2.3). Too few data from control operations were obtained to test for seasonal differences in the kills achieved by aerial and ground control. The results suggest that there is no difference in the effectiveness of control during winter and summer. Although the reported kills during spring and autumn appear to be lower, they should be interpreted with caution until further data are reported for these times of year.

TABLE A2.3. PERCENTAGES OF DIFFERENT TYPES OF CONTROL UNDERTAKEN SEASONALLY, ± 95% CONFIDENCE INTERVAL AND THE OVERALL EFFECTIVENESS OF CONTROL IN EACH SEASON (IN OPERATIONS WHERE SHYNESS HAS NOT INFLUENCED CONTROL).

TYPE OF CONTROL AND MONITORING METHOD	SEASON (NUMBER OF RESPONSES IN PARENTHESES)				TOTAL (ALL SEASONS)
	SUMMER	AUTUMN	WINTER	SPRING	
Aerial (%)	11 (2)	6 (1)	72 (13)	11 (2)	100 (18)
Ground (%)	58 (60)	9 (9)	21 (22)	12 (13)	100 (104)
Percentage kill ± 95% C.I.	81.9 ± 5.3 (21)	59.0 ± 36.6 (3)	84.4 ± 4.3 (17)	76.8 ± 33.4 (6)	81.0 ± 2.8 (92)
Residual Trap-catch ± 95% C.I.	2.8 ± 0.9 (37)	3.0 ± 1.9 (6)	3.0 ±1.6 (9)	3.1 ± 1.8 (7)	2.9 ± 0.4 (105)

Research trials have shown that acceptance of aerially sown baits by possums indicated a high chance of effective control in three types of native forest during all seasons (Morgan et al. 1999). However, similar seasonal trials in a forest–farm edge habitat in Westland suggested that bait acceptance (and hence operational effectiveness) in such habitat may often be compromised by the availability of highly palatable and nutritious pasture species (Coleman et al. 1999).

4. SEQUENTIAL USE

The frequency with which poisons were used sequentially is shown in Table A2.4. Only about half the respondents using fast-acting acute poisons that can induce shyness (1080, cholecalciferol, cyanide) used brodifacoum baits during subsequent maintenance control. The remainder who followed an acute poison with another acute poison are likely to have had the effectiveness of their control compromised to some extent by residual shyness. Of the 17 reports of sequential use of acute poisons, further examination of the data showed little evidence of 'bait switching' to mitigate shyness (Morgan et al. 1996b) or operators leaving long periods between control so that shyness had time to abate (Hickling 1995).

The few operators that used brodifacoum baits for both an initial and subsequent maintenance control were undertaking control that would not only be very costly (Table A2.2), but would also present a significant environmental risk to non-target species (refer to constraints on control Appendix 1, section 2.2.2).

TABLE A2.4. PERCENTAGE OF OCCAISIONS ON WHICH POISONS WERE REPORTED AS BEING USED SEQUENTIALLY FOR AN INITIAL 'KNOCKDOWN' AND THEN MAINTENANCE CONTROL.

POISON USED FOR INITIAL CONTROL	PERCENTAGE OF OCCAISIONS DIFFERENT POISONS USED FOR MAINTENANCE CONTROL FOLLOWING INITIAL CONTROL WITH A GIVEN POISON (NUMBER OF RESPONDENTS IN PARENTHESES)				
	1080 PELLET	BRODIFACOUM PELLET	CYANIDE PASTE	CHOLECALCIFEROL PELLET	CYANIDE PELLET
1080	17 (3)	50 (9)	22 (4)	0 (0)	11 (2)
Brodifacoum	14 (2)	86 (12)	(0)	(0)	(0)
Cyanide paste	12 (2)	53 (9)	29 (5)	6 (1)	(0)
Cholecalciferol	(0)	33 (1)	(0)	33 (1)	(1)

5. APPLICATION RATES

Some respondents appeared to be using inappropriate numbers of bait stations, traps, paste baits, and pre-feeding regimes (Table A2.5). This either increases the cost of control or reduces its effectiveness. Examples of this included: 35% of respondents used more than 2 bait stations per hectare (cholecalciferol or 1080 baits), up to 9 bait stations per hectare with Talon®; 12% pre-fed Talon® when this practice has previously been demonstrated not to improve kills with brodifacoum (Thomas et al. 1997); pre-feeding over too short or too long a time-frame (2–28 days); using traps at extremely low or high densities (<1 to 25/ha); paste baits (1080 and cyanide) applied at 4–70 baits per hectare; and up to 19% of respondents (4/21) not using GPS (Global Positioning Systems) to ensure complete coverage when bait is aerially applied. Appropriate techniques are described in the best practices section.

TABLE A2.5. PROCEDURES APPLIED WHEN DIFFERENT METHODS WERE USED FOR CONTROL OF POSSUMS (NO. OF RESPONDENTS IN PARENTHESES).

METHOD USED FOR CONTROL	MEAN APPLICATION RATE (kg/ha[1]) ± 95% C.I.	PERCENTAGE USING PRE-FEED (NO. OF RESPONDENTS)	MEAN NO. DAYS PRE-FEEDING ± 95% C.I. (NO. OF RESPONDENTS)	TYPE OF PRE-FEED OR TRAP (NO. OF RESPONDENTS)
Aerial (1080)	5.9 ± 0.7 (38)	4 (24)	NR	NR
Bait stations	Bait stations/ha 1080: 1.8 ± 0.6 Talon®: 1.2 ± 0.4 Campaign®: 1 Cyanide: 3.8 ± 1.5	1080: 93 (14) Talon®: 12 (57) Campaign®: 43 (7) Cyanide: 86 (7)	1080: 10.8 ± 2.6 (33) Talon®: 6.4 ± 5.1 (7) Campaign®: 14 ± 0 (2) Cyanide: 3.8 ± 1.4 (9)	RS5: (9) No.7: (1) Cereal: (3) Ferafed: (1)
Traps only	Traps/ha 12.6 ± 2.3 (25)	67 (3)	NR	1990–94 Victor: (18) Gin: (8) 1995–98 Victor: (30) Gin: (4)
Cyanide only	Paste baits/ha 33.8 ± 9.0 (17)	98 (42)	3.4 ± 0.6 (n = 24)	Flour: (33) Cereal: (2)
1080 paste	Paste baits/ha 26.4 ± 6.3 (15)	NR	NR	NR

[1] Kilograms of bait broadcast per hectare.
NR = Not Reported.

Appendix 3

Modelling rates of population recovery[3]

The percentage kill and intrinsic rate of increase (r_m) of a population (Caughley 1977, Hickling & Pekelharing 1989) determine the frequency of maintenance control required to sustain populations below thresholds where they are not damaging flora and fauna or spreading disease. Provisional modelling to demonstrate theoretical rates of recovery of populations following initial control, and the timing of maintenance control, is summarised in Fig. A3.1 (based on criteria given by Efford 1991, 1992). Further research is planned to more accurately define the timing of maintenance control (J.P. Parkes & D. Choquenot pers. comm.). Managers are advised to use the suggested time intervals between control operations as the approximate times for population and / or ecosystem monitoring, which may trigger control if density is above a threshold required to protect conservation values. Actual timing of control at each location will be different, and can only be established by direct measures of animal abundance.

The residual densities of possums that survive control is dependent on the population density preceding control and the percentage kill. In the models presented, the density at the time of initial control was assumed to be 7 possums per hectare, the carrying capacity of the habitat is assumed to be 10 possums per hectare, and percentage kills were either 'average' (i.e. 80% kill) or 'high' (i.e. 95% kill). These parameters are typical of those reported in mixed hardwood forests where possums are a major pest (e.g. Coleman et al. 1980).

Differing estimates of population increase with 'normal' rates of fecundity have suggested intrinsic rates of increase (r_m) of 0.22 (Hickling & Pekelharing 1989) and 0.30 (Clout & Barlow 1982) after initial control, and 0.34 for a colonising population (Bamford 1972). In the models presented here it has therefore been assumed that populations recovering from control in a modified habitat have an r_m of 0.25.

There is a moderate (Efford et al. 1998) to large (Thomas et al. 1995) influx of immigrants into population 'vacuums' during the year following control, whereas in the second and subsequent years few immigrants repopulate areas of lower density (Efford et al. 1998). Therefore, where rates of population recovery are confounded by immigration, the increments to population numbers by births and immigrants are assumed to give an r_m of 1.0, and subsequent annual population increases are assumed to have an intrinsic rate of increase (r_m) of 0.3.

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[3] References to Appendices 1–3 are combined into Appendix 4.

Models presented demonstrate approximate times for maintenance control (with 75% kills) when management objectives require: (a) very low possum densities (i.e. an RTC of 5% or lower), (b) low densities (i.e. an RTC <10%), or (c) control to be undertaken every 5 years.

Control of large areas of conservation lands every 5 years (as recommended in the national possum control plan—DOC 1994), will cause possum densities to either progressively decline (following an 80% kill—Fig. A3.1 (a)) or be maintained at less than 1 possum per hectare (following a 95% kill—Fig. A3.1 (b)). However, when immigration exacerbates the rates of population recovery, 5-yearly control is unlikely to protect conservation values (Fig. A3.2 (a) & (b)).

High initial kills are advantageous in sustaining control of possums at low densities. Following an 80% kill, maintenance control every 5–6 years (without immigration) will at best maintain populations at less than 2 possums per hectare (Fig. A3.1 (c)). If, however, a 95% kill is initially achieved followed by 75% kills during maintenance control, then control every 5–6 years may keep densities below 1 possum per hectare (Fig. A3.1 (b) & (c)). Therefore, when an 80% kill is achieved, an immediate follow-up to further reduce densities to <0.5 possums per hectare is likely to ensure that control is only required every 5–7 years over large areas (Fig. A3.1 (c)) or 3–4 years in small reserves (Fig. A3.2 (c)) to maintain populations at less than 1 possum per hectare. **To make informed decisions on the success of initial control and the timing of maintenance control requires managers to regularly monitor populations using the trap-catch method (Warburton 1996) as an index of possum density.**

To overcome the effects of possums immigrating onto small reserves, managers may consider it appropriate to undertake an initial phase of annual control (using traps or brodifacoum baits), or alternatively to establish a buffer zone (Fraser et al. 1998) around the reserve in which possums are controlled to reduce immigration.

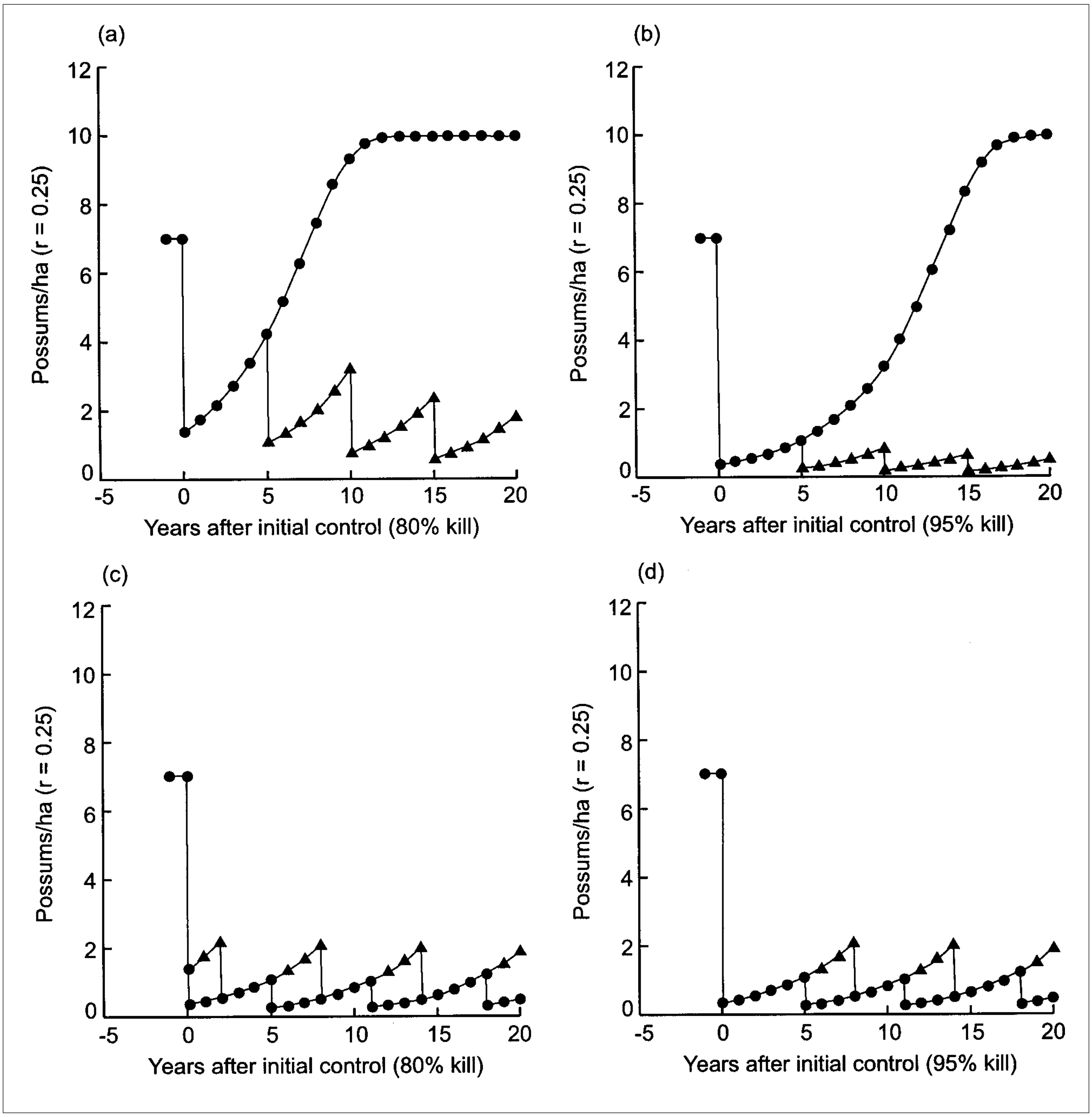

Figure A3.1. Theoretical rates of recovery of populations (assuming $r_m = 0.25$) after control over large areas following:

(a) an 80% kill with either no control (solid circles) or 5-yearly control (solid triangles).

(b) a 95% kill with either no control (solid circles) or 5-yearly control (solid triangles).

(c) an 80% kill with control when density first exceeds 1 possum/hectare (solid circles) or control when densities first exceed 2/hectare (solid triangles).

(d) a 95% kill with control when density first exceeds 1 possum/hectare (solid circles) or control when densities first exceed 2/hectare (solid triangles).

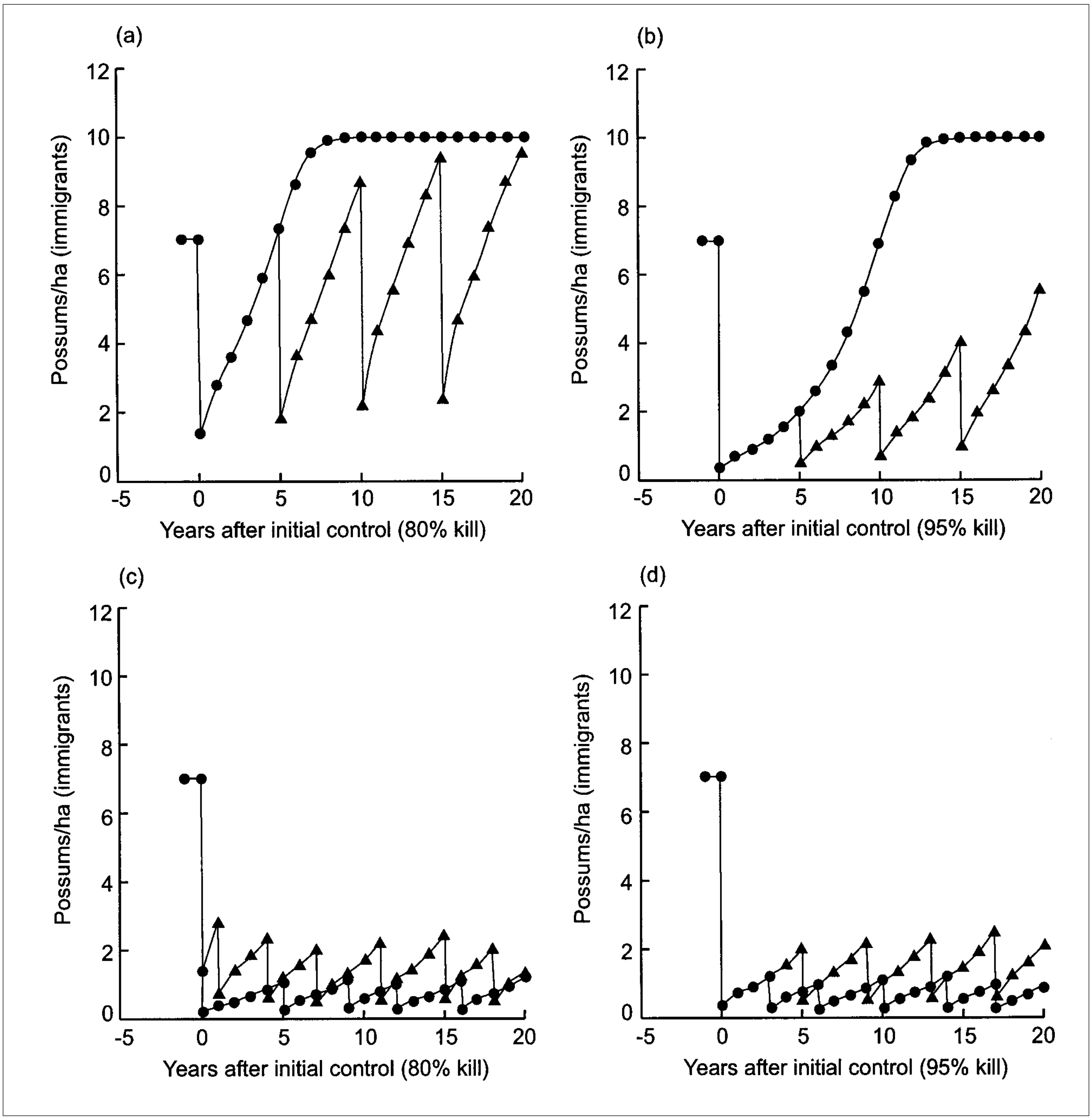

Figure A3.2. Theoretical rates of recovery of populations (assuming $r_m = 0.30$) after control in reserves (with an influx of immigrant possums in the first year ($r_m = 1.0$)) following:

(a) an 80% kill with either no control (solid circles) or 5-yearly control (solid triangles).

(b) a 95% kill with either no control (solid circles) or 5-yearly control (solid triangles).

(c) an 80% kill with control when density first exceeds 1 possum/hectare (solid circles) or control when densities first exceed 2/hectare (solid triangles).

(d) a 95% kill with control when density first exceeds 1 possum/hectare (solid circles) or control when densities first exceed 2/hectare (solid triangles).

Appendix 4

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Appendix 5

CONTACT INFORMATION

Suppliers listed in Table 1, page 7.

Animal Control Products

All baits including products containing 1080

Bill Simmons	Peter Thompson
101 Heads Road	10 Hayes Street
Wanganui	Waimate
Ph.06 344 5302	03 689 8367
Fax.06 344 2260	03 689 8804

Kiwicare Corporation

New Gel bait

John O'Brien
PO Box 15050
Christchurch
Ph. 03 389 0778
Fax. 03 389 0669

Cropcare Holdings Ltd

Talon®

Mike Shirer
25 McPherson Street
PO Box 3344
Richmond
Ph. 03 544 6096
Fax. 03 544 6105

Pest Management Services

All possum baits except gel and products containing 1080

11 Sunset Terrace
Waikanae
Ph. 04 293 1392
Fax. 04 293 1456

Key Industries

Campaign®

David Martin
PO Box 34373
Auckland
Ph. 09 483 5526
Fax. 09 483 9760

Trappers Cyanide

Cyanide paste

Rob Bushby
251 Styx Mill Road
Christchurch
Ph. 03 359 4150
Fax. 03 359 4150

Feral Control

Feratox®

Jeremy Kerr
PO Box 58613
Green Mount
Auckland
Ph. 09 273 4333
Fax. 09 273 4334

Maurice Woodcraft Ltd

All traps

128 Marine Parade
Mt Maunganui
Ph. 07 575 5920
Fax. 07 575 5920

KBL Rotational Moulders Ltd

Timms kill traps

Colin Barkwith
15 Keith Street
PO Box 827
Palmerston North
Ph. 06 358 6477
Fax. 06 355 4825

Bianca Stinger Co.

Stinger kill device

R.D.1
Warkworth
Auckland
Ph. 09 425 8401
Fax. 09 425 8401

Carlton-Taylor Industries Ltd

Electrostrike kill trap

46 Disraeli Street
Christchurch
Ph. 03 366 9064
Fax. 03 365 7975

Contact information on toxicology laboratories measuring toxin concentrations

Geoff Wright
Landcare Research
PO Box 69, Lincoln
Canterbury
Ph. 03 325 6701
Fax. 03 325 2418

National Chemical Residue Analytical Laboratory (NCRAL)
Wallaceville Animal Research Centre
Ward Street
PO Box 40 063
Upper Hutt
Ph. 04 528 0718
Fax. 04 528 1375

Animal Control Products
Private Bag 3018
Wanganui
Ph. 06 344 5302
Fax. 06 344 2260