Aerial 1080 operations to maximise biodiversity protection

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ABSTRACT

The Department of Conservation (DOC) uses different control methods and frequencies of aerial 1080 operations to control possums. We have identified important aerial 1080 strategic and operational issues to maximise biodiversity protection. Firstly, we suggest that biodiversity objectives should be clearly defined and that changes in possum abundance and biodiversity 'health' should be used to determine control return times. Currently, most operations are based on a regular return cycle irrespective of possum abundance and impacts. Secondly, we suggest that an adaptive management approach should be used to test whether aerial 1080 operations can enhance and maintain forest bird communities. Forest birds are vulnerable to ship rats, possums and stoats. These pest animals can be controlled over large areas of rugged terrain using aerially applied 1080. Regular three-yearly operations using pre-feed, 12 g cereal baits and 0.15% toxic loading are likely to be of benefit to forest structure, forest birds, vulnerable plants, and other biodiversity. Large-scale, ground-based stoat control may be required in addition to aerial 1080 operations to protect species such as kiwi (*Apteryx* spp.), kakariki (*Cyanoramphus* spp.) and kaka (*Nestor meridionalis*).

Keywords: aerial 1080, predator control, possum control, native birds, biodiversity objective

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1. Introduction

Introduced mammalian predators are the main cause of forest bird extinctions and ongoing decline (Innes & Hay 1991). Most New Zealand mainland forests have lost bird species and have greatly reduced forest bird abundance (Heather & Robertson 1996). Ship rats (*Rattus rattus*), possums (*Trichosurus vulpecula*) and stoats (*Mustela erminea*) are the most important predators of New Zealand forest birds (Clout et al. 1995; Brown 1997; Innes et al. 1999; Dilks et al. 2003; Moorhouse et al. 2003; Powlesland et al. 2003; Innes et al. 2004). Mainland ecological restoration at key sites aims to increase bird abundance (through pest control) and diversity (through translocations) (Clout & Saunders 1995; Saunders & Norton 2001). Ground-based techniques (poisoning and trapping) are mostly used to control predators on the mainland (Saunders & Norton 2001).

Aerial 1080 operations have been used to control possums for over 50 years (Rammell & Fleming 1978). The Animal Health Board (AHB) currently controls possums on about 4.6 million ha in an attempt to eradicate bovine tuberculosis (Tb) to protect our meat export industry. The Department of Conservation (DOC) controls possums on about 1 million ha to protect forests (Green 2003b).

Aerial application of toxin is currently the most cost-effective strategy for the control of possums (Speedy 2003). Aerial application of brodifacoum is the main tool used to eradicate mammalian predators on islands. Aerial 1080 operations (in association with ground-based control) have also been used to enhance forest bird abundance (Innes et al. 1999). Though an important possum control tool, aerial 1080 operations have not been used systematically to control predators (ship rats and stoats). Yet 1080 is a very effective means for controlling these predators (Innes et al. 1995; Gillies & Pierce 1999; Henderson, O'Connor et al. 1999; Murphy et al. 1999; Alterio 2000).

Possum percentage kills and cost-effectiveness have increased significantly in the last 5–10 years as sowing rates have decreased, bait palatability has increased and 0.15% toxic loading (for cereal bait) has become standard practice. Twelve gram baits and pre-feeding also probably increase effectiveness but are not universally accepted at present. Opportunities exist to improve aerial 1080 operations and to optimise timing to maximise biodiversity protection.

2. Objectives

The objective of this review is to identify the best way to maximise biodiversity protection using aerial 1080 operations.

3. Methods

Wellington Conservancy initiated a review of its aerial 1080 practice in July 2003 (Brown & Urlich 2004). This document is an extension of that review.

The review process involved:

- A workshop with Wellington Conservancy animal pest management staff.
- A literature review.
- Discussions with external experts and DOC pest management staff nationally.
- Interrogation of Pestlink (DOC's animal pest operations database).
- Use of DOC best practice (for aerial application of 1080 for rat control and draft for possum control).
- Peer review from pest management experts.

4. Variation in aerial 1080 practice

4.1 NATIONAL VARIATION IN AERIAL 1080 PRACTICE BY DOC

The aerial application of 1080 bait is a cost-effective method for controlling possums and ship rats over large areas of rugged terrain. Methods have evolved over 50 years and, although reliable, they differ nationally (Table 1), e.g. in the use of increased bait size and pre-feeding, which have not been universally accepted but appear to achieve improved kills. Improving aerial 1080 cost-effectiveness has been largely ad hoc despite being underpinned by considerable research. A national database that records key operational details could be used to identify the most effective operational specifications, and a systematic adaptive management approach could be used to test how well operations meet biodiversity objectives.

Different conservancies use different bait types, toxic loading, bait size and return times, and some use pre-feed. In some conservancies (e.g. Tongariro / Taupo and Waikato), aerial 1080 return times are guided by possum trend monitoring that predicts when possums will reach pre-determined target densities. Elsewhere, possum operations are carried out on a regular cycle, ranging from 3 to 7 years (e.g. Wellington and Wanganui) (Table 1). Auckland, East Coast / Hawkes Bay, Canterbury and Otago do not currently carry out aerial 1080 operations.

Biodiversity objectives for aerial 1080 control vary nationally. These include the protection of: tree fuchsia (*Fuchsia excorticata*), northern rata (*Metrosideros*

TABLE 1. VARIATION IN 1080 BAIT SPECIFICATIONS AND TACTICS BY DOC.

CONSERVANCY	TOXIC LOADING (%)	BAIT TYPE	BAIT SIZE (g)	PRE-FEED AND TOXIC (kg/ha)	RETURN TIME (years)
Northland	0.15	No. 7 cereal	12	2; 3	First operation since 1994
Auckland*	N/A	N/A	N/A	N/A	N/A
Waikato	0.08	Carrot	9–13	2–5; 3–8	4–5
Waikato	0.15	No. 7 cereal	12	2; 2–3	4–5
Tongariro / Taupo	0.15 and 0.08	Carrot	6 and 9–13	2–3; 3–5	3–5
Tongariro / Taupo	0.15	No. 7 cereal	12	2–3; 3–5	3–5
Bay of Plenty	0.15	No. 7 cereal	12	NIL; 7	First operation
East Coast / Hawkes Bay*	N/A	N/A	N/A	N/A	N/A
Wanganui	0.15	No. 7 cereal	6	NIL; 3	7
Wellington	0.15	No. 7 cereal	6 and 12	NIL; 3	7
Nelson / Marlborough	0.15	RS5 cereal	12	NIL; 3	6
West Coast	0.15	No. 7 cereal	12	NIL–2; 2–4	3–5
Canterbury*	N/A	N/A	N/A	N/A	N/A
Otago*	N/A	N/A	N/A	N/A	N/A
Southland	0.15	No. 7 cereal	6	NIL; 3–5	4

* Conservancy does not currently carry out aerial 1080 operations.

robusta), southern rata (*Metrosideros umbellata*), mistletoe (*Peraxilla* spp.), forest canopy, beech (*Nothofagus* spp.) forest ecosystems, rata / kamahi (*Weinmannia racemosa*) ecosystems, *Powelliphanta*, kiwi (*Apteryx* spp.) and various other forest birds. The frequency of control and methods used will change with the biodiversity objective and target pest. Rat target densities are not usually declared, yet rat and stoat kills are frequently seen as a positive spin-off of aerial 1080 control. In some cases, effective rat control is needed to achieve biodiversity objectives.

4.2 DOC WELLINGTON AS A CASE STUDY

Aerial 1080 operations to control possums are currently carried out by DOC Wellington Conservancy, over 66 800 ha in the Tararua Ranges on a 7 year return time (Table 2, Appendix 1). This will be changed to a 6 year return from 2006/07. The Tararua Range scored highly when Wellington Conservancy ranked management units for conservation value and vulnerability to possums (DOC 1994; Sawyer & Brady 1998). Ground-based possum control operations (including Chatham Island) are carried out by Wellington Conservancy on approximately 5750 ha (Brown 2004). Large areas of DOC-administered lands in the Wellington region do not receive possum control or are treated by Greater Wellington Regional Council (GWRC) (e.g. Rimutaka Forest Park and Aorangi Forest Park).

TABLE 2. DOC TARARUA AERIAL 1080 POSSUM CONTROL BLOCKS AND YEARS OF TREATMENT.

AREA OFFICE	OPERATIONAL AREA	YEAR	AREA (ha)
Wairarapa	1. Upper Waiohine / Upper Waingawa*	1994; 2001	7 300; 9 500
	2. Mid Waiohine / Upper Tauherenikau	1995; 2002	7 600
	3. Lower Waiohine / Tauherenikau	1998/99	8 000
	4. Northeast Tararua	1999	9 600
Kapiti	5. Ohau / Mangahao	2001	10 500
	6. Lower Otaki / Waiotauru	1997; 2004	8 600
	7. Upper Otaki†	1996; 2003	9 500; 13 000
	Current 7 year rotation total		66 800

* In 2001 the upper Ruamahanga was included, extending the area controlled from 7300 ha to 9500 ha.

† In 2003 the Upper Otaki operation was enlarged to 9500 ha plus a biodiversity bid of 3500 ha, and renamed Otaki.

Brady & Field (1993) identified a 5 year return time as being optimal for ecological benefit based on modeling presented in DOC's National Possum Control Plan 1993–2002 (DOC 1994). The approach suggested in the national plan aimed to reduce possum numbers through time. The plan's model assumed an original possum abundance of seven possums/ha and an initial 80% kill followed by ongoing 80% kills every 5 years (maintenance control). This approach would drive the population down through time. Possum target densities and 'ecological damage thresholds' (Moller 1989) were not set or known (see 5.2.5).

The original Wellington Conservancy Possum Control Plan specified treatment of 17 800 ha (Brady & Field 1993). The total treatment area was increased as more resources became available. However, available resources dropped dramatically in 1998. The current budget is $175 000/annum. Under this regime, Wairarapa Area Office treats 34 700 ha and Kapiti Area Office treats 32 100 ha. Wellington Conservancy responded to the reduction in resources in 1998 by extending the return time to 7 years. This decision was made so that the planned treatment area could be retained, despite the recognition that this would probably result in reduced ecological benefit (Phil Brady, pers. comm.).

Wellington Conservancy has since reviewed the Tararua possum control programme (Brown & Urlich 2004). Consequently, possum control operations have been reconfigured to increase biodiversity protection. In 2006/07, return times will be reduced from 7 to 6 years using cereal baits (no pre-feed) over c. 55 000 ha in six canopy protection zones. A 4000 ha biodiversity zone has been created to protect lowland bird and plant communities in the Otaki catchment using pre-feeding and a 3 year return frequency. The extent of the Tararuas receiving possum control has been reduced by c. 7800 ha.

4.2.1 AHB operations in Wellington Conservancy

GWRC and Horizons Manawatu / Wanganui Regional Council (HRC) have carried out aerial 1080 operations in the Tararua range since 1994 (Appendix 1, Table 3). GWRC treats areas on a 3–4 year rotation. Operations are carried out on behalf of AHB to eradicate bovine Tb from possum populations (GWRC is the main AHB operator in Wellington Conservancy). AHB operations are also carried out elsewhere on DOC-administered lands (e.g. Rimutaka Range, Rocky Hills Reserve and Aorangi Range).

4.2.2 Operational differences in Wellington Conservancy

Pre-feeding and 3–4 versus 7 year return times are currently the main differences between GWRC and DOC operations. Cinnamon loading and bait size vary between the Kapiti and Wairarapa Areas (Table 4).

TABLE 3. AERIAL 1080 OPERATIONS CARRIED OUT BY GWRC AND HRC IN THE TARARUA RANGE FROM 1994 TO 2003.

REGIONAL COUNCIL	OPERATIONAL AREA	YEAR	AREA (ha)
GWRC	1. Mt Bruce–Mikimiki Crown	1995; 1998; 2002	5 286
	2. Holdsworth–Woodside Crown	1995; 1999; 2003	9 344
	3. Featherston Crown	1996; 2000	3 673
	4. Featherston–Waiorongomai Crown	1995; 1998; 2002	11 647
HRC	1. Panatewaewae / Waitohu	1996	2 979
	2. Lower Ohau / Waikawa	1996	2 358
	3. Ngapuketurua / Makahika	1994; 2000	6 484
		Total =	41 771

TABLE 4. DIFFERENCES IN DOC AND GWRC AERIAL 1080 OPERATIONS AS ILLUSTRATED BY THREE RECENT OPERATIONS.

SPECIFICATIONS	WAIRARAPA AREA Mid Waiohine / Upper Tauherenikau (2002)	KAPITI AREA Otaki (2003)	GWRC Holdsworth / Woodside Crown (2003)
Area (ha)	7600	13 000	9300
Toxic loading (% wt/wt)	0.15	0.15	0.15
Cinnamon loading (% wt/wt)	0.15	0.3	0.3
Bait type	Wanganui No. 7	Wanganui No. 7	Wanganui No. 7
Bait size	8 g (16 mm)	12 g (20 mm)	12 g (20 mm)
Pre-feed	No	No	Yes
Sowing rate (kg/ha)	3	3	1.5 and 1.5
Return time (years)	7	7	3
RTC (%)	1.2	2.2	0.1

4.2.3 Comparison of GWRC and DOC trap-catch results

The trap-catch method is the standardised method for estimating relative possum population densities (NPCA 2004). Over 30 successive operations, GWRC achieved a mean post-control residual trap catch (RTC) of 0.83 ± 0.1% from a mean pre-control RTC of 15.0 ± 1.5% (Table 5). These results may be biased, as GWRC obtains RTCs soon after control operations, which may overestimate possum kill (see 6.10). Over ten successive operations, DOC achieved a mean post-control RTC of 1.7 ± 0.3% from a mean pre-control RTC of 14.7 ± 3.4% (Table 6). Therefore, GWRC operations appear to have been significantly more effective, having an average RTC that was half that of DOC. The use of pre-feeding and 12 g baits is the most likely reason for the higher kills achieved by GWRC (Graeme Butcher, pers. comm.).

TABLE 5. TRAP-CATCH RESULTS FROM 30 CONSECUTIVE GWRC AERIAL 1080 POSSUM CONTROL OPERATIONS (1998/99–2003/04) USING 20 mm NO. 7 PELLETS, PRE-FEED AND 0.15% 1080 (DATA COURTESY OF GRAEME BUTCHER).

SITE	YEAR	PRE-FEED RATE (kg/ha)	TOXIC RATE (kg/ha)	PRE-CONTROL RTC (%)	POST-CONTROL RTC (%)
Wainuiomata	98/99	3	3	18.3	1.1
Owhanga	99/00	2	2	22	1
Pukunui	99/00	1.2	2	23.4	0.5
Bideford	99/00	2	2	7.4	0
Tinui	00/01	2	2	12.5	0.3
Otaki Crown	00/01	2	2	24.9	1.7
Te Wharau I	00/01	2	2	–	0.7
Te Wharau II	00/01	2	2	–	0.4
Tinui	00/01	2	2	–	1.4
Tinui	00/01	2	2	–	0.6
Whakatikei	00/01	1	2	11.5	0.9
Featherston	00/01	2	2	13.4	0.8
Te Wharau III	00/01	2	2	–	0.7
Rocky Hills	01/02	2	2	–	1.7
Te Awaite	01/02	2	2	–	0
Castlehill / Bideford	01/02	2	2	7.4	0.8
Owhanga	01/02	2	2	5.9	0.9
Akatarawa Valley	01/02	2	2	19.3	2.3
Mt Bruce / Miki Miki	01/02	1	1	15.6	1.5
Mt Bruce / Miki Miki	01/02	2	2	15.6	0.9
Featherston / Waiorongomai	01/02	2	2	13.6	0.6
Featherston / Waiorongomai	01/02	1	1	13.6	1.4
Mangaroa / Kaitoke	02/03	2	2	–	0.7
Mangaroa / Kaitoke	02/03	1	1	–	1.0
Bideford	02/03	1	1	–	0.5
Homewood / Riversdale	02/03	2	2	–	0.2
Haurangi Crown	02/03	1.6	1.6	–	0.4
Featherston / Waiorongomai	02/03	1.5	1.5	8.4	1.2
Hutt Catchment	03/04	2	2	23	0.5
Holdsworth / Woodside	03/04	1.5	1.5	–	0.1
Mean ± SEM				15.0 ± 1.5	0.83 ± 0.1

TABLE 6. TRAP-CATCH RESULTS FROM TEN CONSECUTIVE DOC AERIAL 1080 POSSUM CONTROL OPERATIONS IN THE TARARUA RANGE (1994–2003).

SITE	YEAR	AREA (ha)	TOXIC RATE (kg/ha)	PRE RTC (%)	POST RTC (%)
Upper Waingawa	1994	7 300	5	6.9	0.3
Mid-Waiohine	1995	7 600	6	10.4	0.7
Upper Otaki	1996	9 500	4	7.3	1.4
Lower Otaki	1997	8 600	4	–	0.7
Tauherenikau	1998	8 000	4	36.2	2.6
NE Tararua	1999	9 600	4	18.7	3.0
Ohau / Mangahao	2001	10 500	3	17.6	2.9
Upper Waingawa	2001	7 300	3	10.6	2.0
Mid-Waiohine	2002	7 600	3	–	1.2
Otaki	2003	13 000	3	9.7	2.2
Mean ± SEM				14.7 ± 3.4	1.7 ± 0.3

4.2.4 Biodiversity protection by GWRC and DOC

Tree fuchsia protection was identified as the biodiversity objective of possum management in the Tararua Range. Fuchsia monitoring to determine the effectiveness of possum control at protecting fuchsia commenced in 1994 (Urlich & Brady in press). Plots were established from 1994 to 1997 in upland forests of the main range. However, important lowland plots (Lower Waiohine / Tauherenikau, Northeast Tararua and Ohau / Mangahao) were not established as monitoring resources were withdrawn in 1998.

Urlich & Brady (in press) found that Wellington Conservancy protected fuchsia in upland areas treated with aerial 1080. However, it is unlikely that fuchsia was protected in lowland areas where possum abundance is higher (cf. Sweetapple et al. 2002). The Tararua Range has suffered a dramatic loss of forest bird diversity and abundance (Moffat & Minot 1994). Despite the lack of formal monitoring, there is no evidence that the aerial 1080 control (7 year return) protected forest bird communities.

Possum population recovery is slowed and biodiversity protection is increased when fewer possums survive operations. Protection is further enhanced by return operations every 3–4 years rather than every 7 years. GWRC aerial 1080 operations are correlated with the greatest abundance of mistletoe (*Peraxilla tetrapetala* and *P. colensoi*) in the Holdsworth Valley and Blue Range areas. This distribution suggests that GWRC's regular effective aerial operations are providing some protection to threatened plants, while less frequent DOC operations may not have protected mistletoe (see 5.2.5). Though untested, it is probable that GWRC possum control operations also benefited forest bird populations.

5. Aerial 1080 strategic issues

5.1 DEFINING BIODIVERSITY OBJECTIVES

Well-defined biodiversity objectives are required if we are to achieve DOC's Statement of Intent outcome of 'Halt the loss of natural heritage' (DOC 2004a).

Historically, the biodiversity objectives of aerial 1080 have focused on killing possums to protect forest canopies or individual tree species (e.g. tree fuchsia in Wellington Conservancy). However, aerial 1080 operations can also enhance biodiversity by killing possums, ship rats and stoats over extensive areas. Aerial 1080 can therefore potentially provide a very cost-effective tool for biodiversity protection. The biodiversity objectives selected will determine the appropriate frequency, intensity and timing of aerial 1080 operations.

5.2 FREQUENCY OF CONTROL

The frequency of control will vary depending on the recovery rates of the target pest species and the reduction in pest population size required to achieve biodiversity objectives.

5.2.1 Possum control to protect trees

DOC operations to control possums vary in their frequency from 3 to 7 years (Table 1). Some conservancies carry out control on a regular rotation (e.g. every 7 years) whereas others use possum abundance (see 6.10) and biodiversity 'health' (see 6.12) to determine control return times. Protection of different tree species (e.g. mahoe (*Melicytus ramiflorus*), kohekohe (*Dysoxylum spectabile*), kamahi, Hall's totara (*Podocarpus hallii*), pate (*Schefflera digitata*), tree fuchsia, northern rata and wineberry (*Aristotelia serrata*)) require different return times, but these are not clearly understood (Green 2003a).

5.2.2 Possum control to eradicate Tb

AHB operations that aim to eradicate bovine Tb repeat control every 3–5 years. An optimum threshold RTC of 5% (maximum of 10%) is used to trigger control operations with targets of < 2% RTC.

5.2.3 Possum, rat and stoat control to protect forest birds

Aerial 1080 operations can effectively kill possums, ship rats and stoats (Innes et al. 1995; Brown et al. 1997; Henderson, Frampton et al. 1999; Murphy et al. 1999; Alterio 2000).

Ship rats are the most important predators of forest birds in mixed broadleaf forest (Brown 1997; Innes et al. 1999; Powlesland et al. 1999; Innes et al. 2004). Rat populations recovered within 2–5 months after aerial 1080 control in

Waikato and Bay of Plenty podocarp / broadleaf forests (Innes et al. 1995), after 18 months at Pureora (Powlesland et al. 1999), and after 2 years at Whirinaki (Powlesland et al. 2003). Therefore, operations targeting ship rats can provide forest birds with at least one breeding season's protection. Variability in rat kill has been recorded. The reasons for this are not clear but are currently being researched (Ian Flux, pers. comm.). Ship rats are very neophobic. They prefer cereal bait over carrot (see 6.1) and can detect cinnamon (see 6.5). Pre-feeding should mitigate most neophobia to bait (see 5.5) and ensure that the majority of ship rats ingest lethal amounts of toxic bait (Ray Henderson, pers. comm.).

Possums and stoats are also important predators of forest birds (Brown et al. 1993; Innes et al. 1999; Moorhouse et al. 2003; Greene et al. 2004; Innes et al. 2004). Stoats reinvade within 4–5 months of aerial control (Brown et al. 1998; Murphy et al. 1999). Stoat predation of kiwi and kaka (*Nestor meridionalis*) is particularly problematic. Unfortunately, kiwi chicks are vulnerable to stoats for approximately 6 months (until about 1 kg in weight). An experiment is underway at Tongariro forest to determine whether aerial 1080 operations can provide kiwi chicks with protection from stoats (Peter Morton, pers. comm.). Results from an aerial operation in 2001 indicated that some protection was achieved, but sample sizes were small (Peter Morton, pers. comm.). The next operation, in which it is hoped to have 30 radio-tagged chicks, is planned for 2006.

Kaka are vulnerable over the nesting (3–4 months) and post-fledging (3–4 months) periods (Greene et al. 2004). Kakariki (*Cyanoramphus* spp.) are also vulnerable to stoats (and ship rats) for most of the year, as they can breed all the year round. Therefore, aerial 1080 operations are unlikely to provide protection from stoats for all birds because stoats reinvade within periods of vulnerability. Large-scale stoat kill trapping in association with 1080 operations may be needed to recover a wider range of forest birds (see 5.8).

Aerial 1080 operations increased the breeding success of kokako (*Callaeas cinerea*) (Innes et al. 1999) and tomtit (*Petroica macrocephala*) (Powlesland et al. 2000). Pulsed pest control is probably the most cost-effective means of restoring bird populations (Basse et al. 2003). Forest birds are capable of producing many young in a season per pair: tomtit—18; grey warbler (*Greygone igata*)—10; whitehead (*Mohoua albicilla*)—8; fantail (*Rhipidura fuliginosa*)—15; wax-eye (*Zosterops lateralis*)—15; kereru (*Hemiphaga novaeseelandiae*)—3; bellbird (*Anthornis melanura*)—5; and tui (*Prosthemadera novaeseelandiae*)—4 (Heather & Robertson 1996). Individuals can live for a number of years: tomtit—10+; grey warbler—10+; whitehead—8+; fantail—10; wax-eye—11+; kereru—10+; bellbird—8+; and tui—12+ (Heather & Robertson 1996). Therefore, one successful breeding season in three may result in a dramatic increase in forest bird abundance over time.

Kereru, kokako, kakariki and kaka all have 'good' and 'bad' breeding years in response to food availability (mast fruiting and flowering). Pest control operations that target 'good' years would provide the most cost-effective protection (Powlesland et al. 2003). Indicators (e.g. annual phenology monitoring) are needed to identify 'good' years so that managers have enough time to plan and implement pest control. A flexible financial system would be required to support such an approach. Pest control aimed at protecting insectivores (most small forest birds) would not need to coincide with 'good' fruiting and flowering years.

5.2.4 Possum, rat and stoat control to protect mistletoe

Regular aerial 1080 operations (e.g. three-yearly) targeting possums, ship rats and stoats could be used to protect vulnerable plant species such as mistletoe (Sweetapple et al. 2002; Green 2003a). The distribution of mistletoe in the Tararua Range strongly correlates with AHB possum control operations that achieve high kills and are repeated on a 3–4 year cycle (see 4.2.4). Regular aerial operations would provide relief from possum predation and would protect mistletoe pollinators (e.g. bellbird and tui) through reduced rat and stoat predation.

5.2.5 Ecological damage thresholds

Determining the most appropriate frequency of control to protect a range of biodiversity values is complex. Knowledge of the pest densities that negatively impact on native species (ecological damage thresholds) is needed (Moller 1989). The correlation between pest densities and damage has been calculated for some species. Possum trap-catch rates of < 5% and rat tracking rates of < 5% are needed to restore kokako (Innes & Flux 1999) and kereru (Norbury & Innes 2002; Powlesland et al. 2003; Innes et al. 2004) populations. Possum trap-catch rates need to be < 5% to protect kaka (Greene et al. 2004), < 3% to protect mistletoe (Sweetapple et al. 2002) and < 2.5% to protect *Dactylanthus* (DOC Waikato, unpubl. data).

There are several approaches to determine the optimum frequency of return to meet biodiversity objectives at a particular site. Firstly, pest abundance monitoring (result and trend monitoring: see 6.10, 6.11) can be used to intervene when a pest reaches a predetermined abundance. Secondly, the monitoring of a biodiversity value (outcome monitoring: see 6.12) can be used to intervene when that value sustains a predetermined level of damage. Both these approaches assume that the damage threshold is known. Thirdly, an adaptive management approach can be used to determine optimal return times by testing and refining return times (see 5.9).

5.2.6 Pest recovery rates

Possum (and rat and stoat) survival rates, immigration rates and intrinsic rates of increase (births minus deaths) will determine rates of recovery after control (Henderson, O'Connor et al. 1999). Immigration rates are significantly less for large forest blocks (Cowan 2000). Possum control operations that achieve *very high* (99%) possum kills are significantly more cost-effective than those that achieve *high* (95%) kills (Ross in Speedy 2003). Modeling of possum control return rates has been carried out based on RTC data (e.g. DOC 1994; Henderson, O'Connor et al. 1999; Speedy 2003). However, modeling of possum, rat and stoat control return rates based on real animal recovery rate data from multiple sites is much needed. Knowledge of pest recovery rates (associated with trend monitoring) would allow managers to predict when and where limited resources should be spent.

5.3 TIMING OF CONTROL

The timing of control is very important because it can remove predators over the breeding season, maximising bird-breeding success. Forest bird breeding seasons vary, but most have begun by 1 September (e.g. tomtit, grey warbler, whitehead, fantail, wax-eye, kereru, bellbird and tui) (Heather & Robertson 1996). Aerial 1080 operations in late August to early September should maximise bird breeding success by killing most stoats (Murphy et al. 1999), possums (see 5.3.1) and rats (see 5.3.2).

5.3.1 Possum control

Traditionally, possum control has been carried out in winter (because carrot bait is more available, possums are in poor condition and possums were thought to be hungriest). Veltman & Pinder (2001) found that possums were most susceptible to 1080 in colder weather (i.e. winter). Henderson, O'Connor et al. (1999) ranked seasonal variation in possum control efficacy as winter > summer > spring > autumn. Spring operations need to be conducted in early September, as operations in October and November give poorer kills (Ray Henderson, pers. comm.). However, GWRC has carried out successful possum control in spring and summer using pre-feed and 12 g baits (see 5.5).

5.3.2 Rodent control

Gillies et al. (2003) found that ship rats were more likely to take bait in winter and spring operations than in autumn and summer. Rat numbers are lowest in spring and early summer and peak in autumn (Innes 1990). Rat eradications from islands are attempted in late winter and early spring when rat populations are thought to be most vulnerable. Mice are more likely to take bait in winter and summer (Gillies et al. 2003). Mouse populations recover quickly after 1080 possum operations (Innes et al. 1995).

5.4 SIZE OF OPERATIONAL AREAS

Aircraft type and weather strongly influence the size of operational area that can be treated. A weather window of three to four consecutive fine nights / days is required to carry out aerial possum control operations. Baits must be applied in the first 2 days to maximise results. Two day operations would probably be restricted to areas of 15 000 ha or less over winter months when daylight hours are limited. However, larger areas could be treated if operations occurred in late winter or early spring, or if fixed wing aircraft were used.

Fixed wing aircraft are more cost-effective than helicopters and should be used in preference to helicopters whenever possible (Warburton & Cullen 1995). However, helicopters should be used to treat boundaries. Larger operational areas are more cost-effective and provide greater protection because pests are slower to reinvade.

5.5 COSTS AND BENEFITS OF PRE-FEEDING

Pre-feeding with non-toxic bait is a common strategy in vertebrate pest control as it increases the consumption of toxic bait when it is subsequently applied (Henderson, O'Connor et al. 1999). In an analysis of 163 operations, Henderson & Frampton (1999) found that pre-feeding significantly increased the amount of bait eaten from bait stations, reduced neophobia and significantly increased kills with aerially broadcast carrot. Although their pellet operation data was limited, it suggested that the same was true for pellets. Subsequent operations by GWRC have achieved consistently high possum kills using pre-feeding (Table 5).

Pre-feeding also significantly reduces the likelihood of 1080 shyness occurring, because possums are less likely to eat a sub-lethal dose (Moss et al. 1998; Ross et al. 2000). Ship rats are very neophobic and pre-feeding is probably necessary to achieve good rat kills (Innes et al. 1995). Ship rats can detect cinnamon (used to mask 1080 from possums), so when ship rats are the main target, cinnamon levels should be kept low (see 6.5). Using cinnamon lure with pre-feed and toxic baits could potentially maximise rat and possum consumption whilst minimising non-target risks. Landcare Research NZ Ltd is currently carrying out paired trials on the efficacy of pre-feeding aerial 1080 operations (Jim Coleman, pers. comm.). Pre- and post-operation measures of possum and rat abundances are being collected.

Several bird populations have been monitored through pre-feed aerial 1080 operations. These operations did not negatively impact on populations of kokako (Bradfield & Flux 1996; Innes et al.1999), kaka (Powlesland et al. 2003), kereru (Powlesland et al. 2003), and tomtit (Westbrooke & Powlesland in press), or robin, morepork (*Ninox novaeseelandiae*), kakariki and weta (Andrew Styche, pers. comm.). Other native species, such as bats, should also be monitored during pre-feed operations (Lloyd & McQueen 2000). Bird populations on islands were at low risk of poisoning by aerial operations (cereal baits loaded with brodifacoum) targeting ship rats (Greene & Dilks 2004). Tomtits appear to be more at risk from carrot than cereal pellet operations (see 6.1.1).

The effect of pre-feeding pests wears off over time, so that toxic operations could be less effective if delayed (e.g. by bad weather). GWRC carries out most toxic operations approximately 7–10 days after pre-feeding, once pre-feed is no longer detectable. However, high possum kills have been achieved up to 50 days after pre-feeding (Graeme Butcher, pers. comm.).

Pre-feeding is more expensive than using toxic bait alone. For example, if we compare the estimated cost of the Waiotauru (10 950 ha) operation (3 kg/ha toxic) with a hypothetical pre-feeding operation (2 kg pre-feed and 2 kg toxic) over the same area, the 3 kg toxic operation costs $16.30/ha whereas the 2 kg × 2 kg operation costs $19.26/ha (Table 7). Operational costs and possum and vegetation monitoring costs are included.

Pre-feeding can result in a reduced area of land receiving possum control due to the greater cost/ha. However, pre-feeding also results in a higher number of possum kills, enabling return times to be extended with medium to long-term cost savings and / or increased biodiversity protection. Less toxic bait is used

TABLE 7. THE COSTS OF THE WAIOTAURU AERIAL 1080 POSSUM CONTROL OPERATION AND A HYPOTHETICAL PRE-FEEDING OPERATION.

ITEMS	WAIOTAURU (3 kg/ha)	HYPOTHETICAL PRE-FEEDING OPERATION (2 kg × 2 kg/ha)
Bait and transport	$75 250	$41 768 + $49 450 = $91 218
Helicopter	$49 275	$65 700
Possum and vegetation monitoring; bait clearance; advocacy	$53 990	$53 990
Total	$178 515 ($16.30/ha)	$210 908 ($19.26/ha)

(potentially reducing the risk to non-target species) and the risk of poison shyness is reduced (as possums are more inclined to eat enough bait to kill them), making pre-feeding a highly desirable strategy.

5.6 COORDINATING WITH AHB AND REGIONAL COUNCILS

AHB Tb operations make a major contribution to biodiversity protection nationally. They maintain low possum abundance by treating vast areas of DOC-administered and non DOC-administered lands regularly (three- to five-yearly). The area of DOC-administered land controlled by AHB will potentially decrease through time as either Tb is eliminated or a vaccine is developed. The impact of such change on biodiversity protection should be assessed and management strategies should be developed to maximise biodiversity protection.

In Wellington, DOC operations are carried out independently of GWRC and occur at different times. There are also some areas of land between DOC and Regional Council operations that are not treated (e.g. Kapakapanui catchment). Better coordination of Regional Council and DOC operations (through time and space) would slow rates of possum reinvasion, achieve greater biodiversity gains and potentially assist in the elimination of Tb.

5.7 1080 OPERATIONS AND DEER

The New Zealand public has two polarised views on deer: deer are considered either a pest or a resource (Nugent, Fraser et al. 2001).

5.7.1 Deer as a pest

Deer (*Cervus* spp., *Dama dama* and *Odocoileus virginianus*) are ecological pests (DOC 2001). Their impacts include: local extinction of palatable understorey plants, alteration of forest structure, reduction of fruits and seed sources for birds, and alteration of soil nutrient cycling due to the loss of species diversity. Even at very low densities, deer can prevent regeneration of preferred plant species (Coomes et al. 2003). The deer kills achieved with aerial 1080 operations are not sufficient to control deer at the very low densities needed to protect biodiversity values. Other tools (e.g. helicopter and ground hunting, and / or targeted poisoning) would probably be needed to protect biodiversity values (i.e. maintain deer at levels below ecological damage thresholds).

Deer hunters are concerned that aerial 1080 operations target deer and kill large numbers. As stated above, aerial 1080 operations targeting deer are not an effective means of achieving biodiversity objectives. Deer percentage kills are variable, ranging from 5% to 93%, but are mostly 30–57% (Fraser & Sweetapple 2000; Meenken & Sweetapple 2000; Nugent, Fraser et al. 2001). Nugent, Fraser et al. (2001) found no clear correlations between bait type, toxic loading, sowing rate and percentage deer kill.

Deer size and density and ground cover density are likely to affect percentage kills. A recent aerial 1080 operation in the Blue Mountains was estimated to have killed 66–75% of the fallow deer population (Nugent & Yockney 2004). Fallow deer are smaller than reds, and fawns were most at risk. Deer in areas of dense ground cover were less likely to be killed. The population was higher than normal because of hunting block closure: this may have resulted in increased hunger, making them more susceptible to poisoning. The exact causes of variation in deer mortality are still not clear.

5.7.2 Deer as a resource

DOC also has a mandate to facilitate recreational hunting. It is therefore desirable that hunters are well informed of why and where DOC is carrying out pest control operations. Likewise, DOC needs to take into account hunters' opinions. For example, DOC possum control operations in the Tararua Range purposely avoid the Roar (20 March – 20 April). Operations are run in winter so that baits and possum carcasses break down after 300 mm rain and 6 months respectively. The Roar could still be avoided if operations were run in spring (September), allowing 6 months for bait to break down.

DOC is establishing a Natural Heritage Management System (NHMS) that aims to define where DOC will carry out management (DOC 2004b). This is likely to result in integrated pest management areas within which a wide range of pests would be controlled intensively to levels below damage thresholds. This system should also clearly identify where DOC does not carry out management (e.g. deer control). A clear understanding of where deer are, and are not, controlled should result in more surety and better relations between DOC and hunters.

An alternative approach is to reduce deer by-kill by reducing the attractiveness of toxic bait to deer. Trials have shown that deer repellent in carrot baits effectively reduced deer mortality, but did not significantly affect possum kills (Morriss et al. 2003; Nugent et al. 2004). High rat kills have also been achieved where it has been used (Cam Speedy, pers. comm.). The use of deer repellent in 1080 baits has resulted in support for 1080 operations on land where deer are managed as a resource (Cam Speedy, pers. comm.). Deer repellent costs an additional $6–7/ha to apply and has not been successfully applied to cereal bait. DOC does not currently support the use of deer repellent on DOC-administered lands.

5.8 GROUND-BASED VERSUS AERIAL CONTROL

Ground-based control of pests provides an alternative to aerial 1080 operations. Morgan & Warburton (1987) compared the effectiveness of possum hunting and aerial 1080 at reducing possum numbers. They found that hunters and aerial 1080 control achieved similar kills (80%), but that hunters required considerable management. Further work in 1993 suggested that ground-based hunting was as cost-effective as aerial 1080 operations in small areas of relatively flat terrain (Warburton & Cullen 1995). Kills achieved (83%) were similar to those in 1987. Corson (1999) found that ground control ($50.33/ha) was considerably more expensive than aerial 1080 control ($18.49/ha) when reducing possums to below 5% RTC.

In a recent trial, aerial application of 1080 was found to be the most cost-effective method when compared with four currently used ground-based control methods. A 99% reduction in possum numbers was achieved for $20.25/ha (excluding the cost of deer repellent). The ground-based methods were significantly more expensive, were more time consuming and / or achieved poorer and less consistent results. Modeling suggests that aerial 1080 had a discount cost of $55/ha over a 10 year period. The most cost-effective ground-based control was $128/ha over a 10 year period. In addition, the aerial 1080 operation achieved high rat kills with the associated added ecological benefit (Speedy 2003).

Aerial 1080 operations will not provide a panacea for pest control nationally. There will be many instances where ground-based techniques will be more appropriate to address socio-political concerns but still meet biodiversity objectives. Likewise, aerial 1080 operations may need to be combined with ground-based techniques (e.g. large-scale stoat kill trapping) to meet biodiversity objectives (Brown 2003). Ground-based multi-species pest control can be expensive, ranging from $40 to $135 per hectare per year (Clapperton & Day 2001). Combining aerial 1080 operations with ground-based control may prove very cost-effective for meeting biodiversity objectives at some sites.

5.9 ADAPTIVE MANAGEMENT APPROACH

'Adaptive management combines research and action. Specifically, it is the integration of design, management and monitoring to systematically test assumptions to adapt and learn' (Salasky et al. 2002). Adaptive management aims to learn from past actions to improve future management. An adaptive management approach was used to determine the causes of North Island kokako decline and to identify potential management action for kokako recovery (Innes et al. 1999). The lessons learnt have been applied to recover North Island kokako populations (Innes & Flux 1999).

An adaptive management approach could be used to test the hypothesis that aerial 1080 operations using pre-feed and carried out in spring on a 3 year cycle will protect a wide range of biodiversity. Managers would need to monitor operational specifications (e.g. bait size, type, coverage, hardness and mould growth, and lure concentrations and toxic loading), operational cost, pest abundance, post RTC timing, and the abundance of native forest birds, native invertebrates, such as stick insects, weta and cicadas (Atkinson et al. 1995), bats (Lloyd & McQueen 2000) and indicator plant species at a number of sites. The knowledge gained could then be applied to direct future management.

5.10 IMPROVING PUBLIC PERCEPTIONS OF 1080 OPERATIONS

Fitzgerald et al. (2000) surveyed public opinion of possums and possum control technologies. They found that 'poisoning was the least favoured control method, with aerial application of 1080 poison particularly unacceptable', despite people recognising that 1080 is the most effective form of possum control currently available in New Zealand. People's opinions were strongly influenced by their perceptions of risk, including to non-target native species.

Fitzgerald et al. (2000) suggest that public perception can be changed most effectively by engaging in two-way communication discussing the risks of possum control technologies. We suggest that public perceptions of and support for aerial 1080 could be changed dramatically. Improved monitoring of forest bird abundances and forest health associated with regular aerial 1080 operations could be used to change negative public perceptions. Easy public access to sites where biodiversity has been enhanced would further facilitate a positive change in perceptions.

6. Aerial 1080 operational issues

Operational issues are varied, complex and interdependent. Kills of 80% were the norm in the 1990s. Reasonably successful possum control operations (> 90% kills) are now the norm. Improvements in bait palatability, toxic loading, pre-feeding and bait size are probably responsible for increased kills (Henderson & Frampton 1999). We believe that there is further room for improvement nationally. Pre-feed operations using 12 g cereal baits with 0.15% toxic loading are achieving even more successful operations (> 95% kills). Below we discuss methods that we believe will maximise the likelihood of high kills.

6.1 BAIT TYPE

Three types of bait are used for aerial application nationally: carrot (6 g and 12 g), Wanganui No. 7 (16 mm— 6 g and 20 mm—12 g) and RS5 (6 g and 12 g).

6.1.1 Carrot bait

The application of carrot bait is more specialised than the application of cereal bait, requiring more skill, specialised equipment and more labour. However, over 100 000 ha/annum are currently treated with carrot (Cam Speedy, pers. comm.). Carrot bait (with deer repellent) may be the only acceptable option for landholders concerned about deer kills.

Good-quality carrots improve palatability (Henderson & Frampton 1999). Sharp knives are needed to reduce chaff to < 1.5%, reducing the risk to non-target species. Only contractors with a proven record in the use of carrot-cutting equipment should undertake carrot operations (Alastair Fairweather, pers. comm.).

There is a risk that carrot bait will be unusable if an operation is delayed by rain, as carrot has a short shelf life. However, carrot is more rain resistant than cereal baits (Bowen et al. 1995) and therefore is the preferred bait when many large-scale operations are planned (Cam Speedy, pers. comm.). Carrot is more expensive to fly than cereal because it is usually applied at higher sowing rates (2–3 kg pre-feed and 5 kg toxic).

Tomtits are at risk from carrot baits both at high (Powlesland et al. 1999) and low (Westbrooke & Powlesland in press) sowing rates. However, the results obtained at low sowing rates may be biased, as they were obtained at the beginning of the tomtit breeding season when individuals may be less conspicuous. Despite the potential loss of a few individuals (when carrot sowing rates are low), it is likely that tomtit populations would increase where carrot baits are used due to the removal of ship rats during the tomtit breeding season (Powlesland et al. 2000). However, the efficacy of carrot baits at achieving consistently high rat kills needs to be tested.

Epro Limited has achieved high possum kills using carrot (6 g baits, pre-fed, 0.08% toxic loading; cinnamon is only used for DOC contracts) (Table 8). Carrot is the preferred bait (20% of operations are cereal) used by Epro because its water resistance enables operations to occur when weather conditions would prevent cereal operations. Carrot bait also offers a cost-effective alternative to cereal bait when treating bait-shy pest populations (O'Connor & Mathews 1999).

We suggest that further refinement of carrot baits (e.g. use of cinnamon, larger baits and 0.15% toxic loading) could result in higher kills. GWRC has achieved consistently higher kills using 12 g cereal baits, pre-fed at 0.15% toxic loading and 0.3% cinnamon (Table 5).

TABLE 8. EPRO LIMITED AERIAL 1080 CARROT OPERATIONAL RESULTS (2003 AND 2004) (DATA COURTESY OF CAM SPEEDY, EPRO LTD, TAUPO, NEW ZEALAND). REGIONAL COUNCILS ARE ABBREVIATED AS FOLLOWS: HAWKE'S BAY (HBRC); ENVIRONMENT WAIKATO (EW); AND ENVIRONMENT BAY OF PLENTY (EBOP).

OPERATION (CLIENT)	DATE	SIZE (ha)	SOWING RATE (kg/ha)	TOXIC LOADING (%)	POST RTC (%)
Mohaka Forest (HBRC)	May 2003	15 500	5	0.08	0.70
Tongaporutu (EW)	June 2003	13 500	10	0.08	2.26
Clements Road (EW)	June 2003	1 000	5	0.08*	0.17
Tarawera Nth (HBRC)	August 2003	3 579	5	0.08	0.80
Te Awahohonu Forest (HBRC)	August 2003	7 875	5	0.08	1.10
Wairapakau (EBoP)	August 2003	8 000	3	0.08	0.50
Te Awa (EBoP)	September 2003	19 100	3	0.08	1.40
Kakanui (EBoP)	September 2003	850	5	0.08	0.10
Wakeman's (HBRC)	July 2003	1 700	5	0.08*	0.67
Pohokura (HBRC)	October 2003	11 821	5	0.08*	1.10
Hauturu / Honokiwi (DOC)	April 2004	11 000	5	0.08	2.88
Te Tapui (EW)	July 2004	2 018	3	0.08*	4.67†
East Taupo EW)	August 2004	31 252	3	0.08	0.33
Tataraakina / Ngatapa HBRC)	September 2004	12 120	5	0.13*	1.51
Total		c. 140 215			
Mean ± SEM					1.29 ± 0.3

* Deer repellent applied.

† Poison-shy population following failed ground contract by another contractor.

6.1.2 Cereal bait

RS5 is suited to drier climates whereas Wanganui No. 7 is suited to wetter climates. However, DOC Nelson / Marlborough Conservancy has achieved very high possum kills in high rainfall areas using RS5 (without pre-feeding) (Mike Hawes, pers. comm.). High palatability of bait is critical to the success of possum control operations, and RS5 provides the national standard for palatability (Henderson, Frampton et al. 1999). The palatability of Wanganui No. 7 bait has improved in recent years through changes in formulation and a reduction of moisture content (Ray Henderson, pers. comm.).

Wanganui No. 7 bait has been the bait of choice in Wellington Conservancy because it is more likely to remain intact when wet. Wanganui No. 7 ($2132/tonne) is more expensive than RS5 ($1808/tonne), but RS5 freight costs are higher for Wellington Conservancy ($220/tonne versus $60/tonne for Wanganui No. 7) because it is manufactured in the South Island.

6.2 TOXIC LOADING AND BAIT SIZE

6.2.1 Toxic loading

At least 8 g of bait (0.15% 1080) is needed to administer 4 mg/kg of 1080 to a 3 kg possum (Eason & Wickstrom 2001). Therefore, large possums need to eat more than one 6 g bait to kill them. However, possums can detect 1080 and stop eating bait within 12 minutes of commencing bait consumption (Henderson, Frampton et al. 1999). Therefore, Henderson, O'Connor et al. (1999) recommend that 'Cereal bait containing a concentration of 0.15% compound 1080 should always be used'. Concentrations of 0.08% should not be used (at least for cereal baits) because fewer possums are killed and shyness often results (Henderson, O'Connor et al. 1999). Epro have achieved high possum kills using 0.08% (carrot at 5 kg/ha), but not as high as GWRC using 0.15% (cereal at 2 kg/ha). Concentrations greater than 0.15% may not be adequately masked, resulting in 20–24% of possums eating sub-lethal amounts of bait (Henderson & Frampton 1999). High percentage kills of ship rats have been achieved using 0.15% 1080 in cereal bait (Innes et al. 1995).

6.2.2 Bait size

For a large possum, 12 g baits are required to administer a lethal dose of 1080 (Henderson, O'Connor et al. 1999). GWRC achieves very high possum kills using 12 g baits with pre-feed (Table 5). Twelve gram baits include less dust and fragmentation, reducing the risk to native birds. In addition, they are more rain resistant, lure is retained longer, suppliers prefer them, they enable a better spread of bait at low sowing rates, greater swath widths can be achieved (reducing flying costs), and they are easier to clear from tracks (due to greater visibility and lower numbers). Use of 12 g baits may be more important at low sowing rates to ensure that all possums have access to enough toxic bait to kill them.

Twelve gram carrot baits are more expensive because they result in a lot of waste and, due to their larger size, they are more likely to block sowing buckets, potentially leaving gaps (Cam Speedy, pers. comm.).

6.3 SOWING RATES

A number of factors can influence sowing rate. Possum and rodent density and the presence of other animals that will consume bait (e.g. deer and pigs) should be considered. Higher sowing rates may be necessary when possums are at high density because ship rats will compete for baits with possums (Gillies et al. 2003). Pre-control monitoring of possum and rat abundance can be used to guide sowing rates and help interpret the results of control. Increased sowing rates should also be considered when thick ground cover, steep slopes and / or boulder fields are present.

DOC operations using 1080 cereal baits applied at rates of 3–6 kg/ha have achieved high percentage kills of possums (Table 6). The standard GWRC operation is 2 kg/ha pre-feed followed by 2 kg/ha toxin (Table 5). Pre-feeding at 1.5 kg/ha is also used by GWRC (Graeme Butcher, pers. comm.). Lower sowing rates increase the risk of gaps in spread because helicopters need to fly faster to facilitate bait spread (e.g. 70 knots rather than 40 knots) (Keith Broome, pers. comm.). However, GWRC has achieved excellent possum kills with toxic sowing rates as low as 1 kg/ha following pre-feeding (Table 5; Graeme Butcher, pers. comm.). Potential benefits of reduced sowing rates include: less toxin introduced into the environment, reduced risks to non-target species, and reduced operational costs (aircraft, storage, labour, bait and cartage).

Spread quality is determined by bucket design. A review of bucket designs and spread quality is being undertaken by Andy Cox, DOC Southland (Alastair Fairweather, pers. comm.). Bait sowing rates and spread should be calibrated prior to application (Cam Speedy, pers. comm.). A low-sow bucket is available and technically good, but is very expensive (Ray Henderson, pers. comm.).

6.4 BAIT PALATABILITY / QUALITY

Bait quality is the most important factor in determining the success of 1080 operations (Henderson, O'Connor et al. 1999). Possums are more likely to be sub-lethally poisoned because bait is of low palatability than because it contains low concentrations of poison (Henderson, Frampton et al. 1999). Cereal 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). Quality specifications are described in Appendix 1 of Eason & Wickstrom (2001). Measures of 1080 content, cinnamon content, mould growth and bait hardness should be undertaken prior to all operations.

6.5 LURE / MASK

Cinnamon concentrations should never be < 0.1% or > 0.5% wt/wt (Eason & Wickstrom 2001). Possums can detect 1080 when baits contain < 0.1% cinnamon, but the palatability of baits is reduced at cinnamon concentrations > 0.5% (Henderson & Frampton 1999). Kapiti Area and GWRC use 0.3% cinnamon (double standard of 0.15%) to reduce the risk of the cinnamon dissipating over time in storage. Single cinnamon (0.15%) only lasts 6 weeks in storage. The additional cost of using 0.3% is minimal.

Ship rats are deterred by cinnamon, so only low concentrations should be used in fresh bait (i.e. 0.1% in bait < 1 month old; 0.15% in bait 1–2 months old) when ship rats are the primary target (Ray Henderson, pers. comm.). The use of cinnamon in pre-feed is likely to mitigate taste and / or smell aversions to cinnamon by ship rats, but this has not been tested (Ray Henderson, pers. comm.).

Carrot baits absorb 1080 into their vascular tissue making it less detectable. This may explain the relative success of Epro carrot operations that do not use cinnamon. Where possums are likely to have learnt to avoid cinnamon-lured bait due to failed operations, alternative lures could be used. Waikato Conservancy has also used orange lure / mask for variety. Cinnamon (0.3%) is the lure most frequently used by DOC nationally.

6.6 GREEN-DYED BAIT

Green dye is used to deter birds from eating toxic bait. However, green dye is not used in pre-feed bait so that human operators can distinguish between toxic and non-toxic bait. This practice could increase the risk to birds from pre-feeding, if birds are first attracted to un-dyed bait. Birds are less inclined to eat blue-coloured food than green (Hartley et al. 1999; Hartley et al. 2000) and possums readily accept blue bait (Day & Mathews 1999). Brodifacoum baits have been dyed blue to make them distinguishable from 1080 baits (Graeme Butcher, pers. comm.).

Research is required to determine whether pre-feed baits should be dyed (green or blue) and whether toxic baits should be blue rather than green. This is a DOC strategic science need.

6.7 BAIT AVERSION

Bait-shyness can last for at least 3 years after a failed operation (O'Connor & Mathews 1999). Henderson, O'Connor et al. (1999) recommended a minimum return time of 4 years to reduce the risk of bait-shy possums remaining. However, we believe that a 3 year return time should be tested due to benefits to biodiversity. Warburton & Thomson (2002) found that 'repeat aerial control did not appear to become less effective when the bait type was changed and pre-feed used'.

Maximising possum kills should also reduce the risk of bait-shyness in possums. Possums that have been sub-lethally poisoned associate ill-effects with the bait. Switching baits and to a lesser extent lures (e.g. cinnamon to orange) are likely to be the best methods to overcome bait aversions (O'Connor & Mathews 1999). Bait-shyness can be tested in the field prior to operations to determine the appropriate bait to use (Morgan 1982; Henderson, O'Connor et al. 1999; Ogilvie et al. 2000). Possums that are not bait-shy but occur at low abundance (so that plenty of natural food is present) will take bait (Warburton 1996).

6.8 TEMPERATURE

Possums are more susceptible to 1080 at lower temperatures (Oliver & King 1983). Veltman & Pinder (2001) found that nights colder than 9ºC were needed to achieve > 90% kills (using 6 g cereal baits (0.08% and 0.15% toxic loading) without pre-feeding). Temperature is probably important when possums only consume small amounts of 1080 at the threshold of a lethal dose. Use of the methods proposed in this document should ensure that possums take large amounts of 1080, potentially eliminating the importance of temperature. GWRC has achieved very high kill rates on nights when temperatures were greater than 9ºC (spring and summer operations) using pre-feeding (Graeme Butcher, pers. comm.). It is likely that pre-feeding and the use of 12 g baits ensures that possums eat enough bait to die, even at temperatures greater than 9ºC.

6.9 DGPS AND BAIT COVERAGE

Total bait coverage is needed to achieve high possum and rat kills. Even small gaps in bait coverage enable those possums with small home ranges and ship rats to survive (Cowan 2000). Bait can be applied accurately and good coverage can be achieved using differential global positioning systems (DGPS) (Morgan 1994). DGPS is more effective in helicopters than fixed-wing aircraft because of their lower air speed. Squirrel helicopters deliver 160 m wide swaths and Hughes 500 helicopters deliver 120 m swaths. Bait coverage should be tested in the field (Morgan 1994).

Operational boundaries need to be clearly defined to minimise the risk of bait being spread beyond boundaries. This is an offence under the HSNO Act 1996. DOC has developed a boundary Standard Operating Procedure to minimise such risk (Alastair Fairweather, pers. comm.). Helicopters using a boundary bucket with a 40 m swath can be used to accurately spread bait along boundaries. A second helicopter (e.g. with a 120 m swath) can be used to spread bait elsewhere in the block. Trickle feeding bait alongside waterways may be the only pragmatic means of ensuring that there are no large gaps in spread. Computer equipment is now available to check the accuracy of spread on-site to ensure that gaps are identified and filled. Boundaries with many corners should be avoided to prevent overloading the DGPS.

6.10 POSSUM TRAP-CATCH AND TREND MONITORING

Trap-catch, using leg-hold traps, is the method used nationally by DOC and AHB for monitoring possum abundance (National Possum Control Agencies 2004). Trap-catch can be used to measure the effectiveness of control (i.e. pre- and post-control) and to measure possum population trends (e.g. repeated measures of the same lines every 2–3 years). Some conservancies carry out control on a time based rotation (e.g. every 7 years) while others initiate control once possum target densities are reached (measured using trap-catch).

Possum target densities and recovery rates in different habitats can be determined using trend monitoring. Possum ecological damage thresholds can also be determined when possum density (trap-catch results) is linked to possum damage (outcome monitoring) (see 6.12). Trap-catch does not provide an absolute measure of possum density but rather an index.

Unfortunately, trap-catch under-estimates possum abundance (and over-estimates kills) immediately after control (Nugent, Whitford et al. 2001). Why possum abundance is under-estimated is not clear. Possums may become more wary of traps following sub-lethal poisoning and / or when large numbers of their social group are killed. Female and juvenile possums in particular are under-represented immediately after control (Henderson et al. 2004). A delay in post-operational trap-catch of at least 4 months would provide more accurate measures of operational success. Wellington Conservancy waits 4 months before carrying out trap-catch. However, AHB operations are monitored (e.g. GWRC) directly after control operations so that contractors can be paid if they have achieved the required performance target. This could potentially result in an over-estimation of possum kill.

6.11 RAT AND MUSTELID TRACKING

The DOC rat and mustelid tracking protocol (Gillies & Williams 2003) is used to measure change in rat abundance. Variable kills have been achieved by aerial 1080 operations. The reasons for this are not clear, but preference trials are underway to determine which bait characteristics are most favoured by rats (Ian Flux, pers. comm.). Tracking tunnels can be used to measure the effectiveness of aerial operations at killing ship rats and stoats. They could also provide a pre-treatment estimate of rat abundance that could be used to guide sowing rates.

6.12 OUTCOME MONITORING

Outcome monitoring is needed to determine the effectiveness of management aimed at protecting biodiversity (Urlich & Brady 2003). It also improves our ecological understanding of the systems being managed.

Potential outcome monitoring methods that could be used include:

- Five-minute bird counts (Dawson & Bull 1975) to measure long-term changes in forest bird communities.
- Tomtit transect counts (Westbrooke et al. 2003; Westbrooke & Powlesland in press) to measure changes in tomtit, grey warbler and rifleman abundance.
- Northern rata view method (DeMonchy et al. 2000) to measure possum impacts on rata.
- Mistletoe foliar browse (Payton et al. 1999) to measure possum impacts on mistletoe.

6.13 IMPROVING COST-EFFECTIVENESS

Warburton et al. (1992) and Cowan & Pugsley (1995) identified the need for improved reporting of DOC pest control operations. DOC has subsequently set up a Quality Conservation Management animal pest framework that identifies different planning phases and tasks. However a pre-operational plan is not required for large-scale animal pest control projects. In addition, DOC's post-operational pest reporting system (PestLink) lacks room for comprehensive discussion and does not set useful criteria for comparing expenditure between operations. We believe that further improvements to DOC reporting systems are needed if operations are to be compared.

A national database that records key operational details, bait specifications, bait quality and monitoring results (Henderson 1999) is essential. Such a database would provide reliable data for modeling and continued improvement. Accurate measures of financial costs and ecological benefits are also needed to improve cost effectiveness and meet biodiversity objectives.

7. Conclusions

1. Aerial application of 1080 is the most cost-effective way of controlling possums, ship rats and stoats over large areas of rugged terrain.
2. Three-yearly aerial 1080 operations using pre-feed, 12 g cereal baits and 0.15% toxic loading would probably protect most forest bird populations and a wide range of other biodiversity (including forest structure and vulnerable plants). Large-scale stoat kill trapping in association with aerial 1080 operations may be needed to recover some species (e.g. kiwi).
3. An adaptive management approach should be used to test the ability of three-yearly aerial operations at protecting biodiversity.
4. Improvements in forest bird populations and forest health associated with regular aerial 1080 operations should be monitored. This information would help to change negative public perceptions of aerial 1080 operations.
5. The initiation of aerial 1080 operations should be triggered when possum numbers reach predetermined thresholds (below which biodiversity values are protected) rather than at set return times (e.g. seven-yearly).
6. The operational specifications that constantly achieve high rat kills need to be determined.
7. There is considerable variation within DOC and between DOC and AHB aerial 1080 operational practice. A national database that records key operational details, such as bait specifications, bait quality and monitoring results, should be established to help refine best practice and improve aerial 1080 operational cost-effectiveness.
8. AHB Tb operations make a major contribution to biodiversity protection nationally. Management strategies are needed to maintain biodiversity protection if or when AHB operations decrease or cease. DOC and AHB operations should be integrated as much as possible.

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Appendix 1

DOC AND AHB AERIAL 1080 OPERATION BLOCKS IN THE TARARUA RANGE