Applied research to progress and support close-to-market pest control tools and their strategic application

Prepared for: New Zealand's Biological Heritage National Science Challenge

November 2017

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Contract Report: LC3051

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Summary

Project and client

Recent allocation of research funding from New Zealand's Biological Heritage National Science Challenge (NZBH-NSC) has focused on high-tech solutions for pest management in New Zealand. However, stakeholders have expressed concern about the lack of funding support for improving many of the currently available tools, which they are dependent on for the foreseeable future. To address this concern, NZBH-NSC has requested a review of the recently developed and close-to-market-tools, and identification of the key research required to support their incremental improvement. This review was carried out jointly by Manaaki Whenua – Landcare Research and Lincoln University between October 2016 and September 2017.

Objectives

- To provide a list of key research priorities for small-mammal pest-control tools and strategies, focusing on:
  - toxins (including residues, non-targets, cost-effectiveness)
  - monitoring
  - lures and baits
  - automated poison dispensers
  - traps (including non-targets, cost-effectiveness)
  - wireless trap monitoring
  - scaling up to regional operations
  - repellents.

Methods

- The review was developed by focusing on recent literature looking at existing pest control and monitoring methods, and new developments that have not as yet reached the market. This approach enabled the authors to determine gaps in current knowledge and research priority areas.
- The review focused on the three main predator species (possums, ship rats and stoats) that are encompassed by the Predator Free 2050 (PF2050) initiative. However, it is recognised that there are a wide range of other vertebrate pests (predominantly herbivores) that cause local if not national impacts.

Results

- The authors identified 34 priority areas needing further research. These were then reduced to 15 key research priorities. This final selection was based on current knowledge gaps, how close to market a tool is, the probability of success, and the likely size of benefits to PF2050 of the new tool becoming available.

- This final priority list now needs to be vetted and ranked by the stakeholders, who initially raised concerns regarding the lack of funding support for the currently available and close-to-market pest control tools.

Recommendations

The following recommendations are the top 15 key research priorities compiled by the authors. These are currently unranked and need to be both vetted and ranked from high to low priority by the stakeholders.

- Progress diphacinone + cholecalciferol (D+C) as an effective alternative to brodifacoum.
- Develop kill traps with improved capture efficiencies.
- Conduct comparative trials comparing the accuracy and precision of monitoring techniques, particularly camera traps, in direct relation to abundance and conservation thresholds.
- Advance our understanding of the need to include fat, protein and other additives in rat, possum, and (especially) stoat baits with the aim of developing standardised baits suitable for ground and aerial control.
- Investigate a combination approach to lures and determine the best mix of sensory attractants (e.g. sound and scent).
- Test wireless network reliability and cost-effectiveness across a range of trap network scenarios, including live and kill traps.
- Develop simulation tools for comparing the cost-effectiveness of competing scenarios for rolling out large-scale eradication programmes.
- Develop an attractive, long-life and standardised lure for the three target species to increase detection sensitivity.
- Develop new formulations of d-pulegone (to slow its decay) or new products that are effective at repelling kea.
- Conduct ground-based field trials comparing the efficacy and cost-effectiveness of all newly registered vertebrate toxic agents (VTAs) against current industry standards.
- Gain a better understanding of encounter and interaction rates for all three target species with monitoring and control devices.
- Test the capture efficiency and selectivity of the top five most popular kill traps for each target species, using both commonly used lures and baits and novel lures and sets, and then develop product information to enable purchasers of traps to make informed choices.
- Determine how to cost-effectively detect survivors of control.
- Conduct comparative trials using aerial 1080 with mixtures of sowing rates, new multispecies baits, and pre-feeding regimes to enable consistent high kills for all target species.
- Ascertain which prototype multi-kill poison devices have potential for field evaluation, and then run comparative field trials

1 Introduction

Recent allocation of research funding from New Zealand's Biological Heritage National Science Challenge (NZBH-NSC) for pest control technologies has focused on high-tech solutions to ensure the required 'science stretch' is achieved. However, stakeholders have expressed concern about the lack of funding support for incrementally improving many of the currently available tools, which they will be dependent on for the foreseeable future. As a consequence of this stakeholder concern, the NZBH-NSC requested a review of close-to-market-tools and the applied research required to support their incremental improvement. This review was carried out jointly by Manaaki Whenua and Lincoln University between October 2016 and June 2017.

2 Background

Introduced vertebrates have been managed in New Zealand for close to a century, with the earliest efforts to manage burgeoning rabbit and deer numbers starting in the early 1900s (McLean 1966; Caughley 1983), and the first aerial applications of poison baits to control possums in the 1960s (Warburton & Livingstone 2015). The control tools available for controlling vertebrate pests, especially the smaller forest-dwelling species such as brushtail possums (*Trichosurus vulpecula*), ship rats (*Rattus rattus*) and stoats (*Mustela erminea*), have not changed significantly for over 50 years, and their control is still reliant on aerial or ground application of poisons or the use of traps. Two exceptions are rabbits and deer: the former have had their numbers significantly reduced by the introduction of the biological control agent rabbit haemorrhagic disease (RHD; Parkes et al. 2002), and the latter by the development of a commercial deer harvesting industry (Warburton et al. in press).

The desire to save threatened species and ecosystems while protecting the health of our agricultural industry has driven the need for more specific targeting of pests, more humane methods, and greater operational efficiencies and effectiveness. Although traps and some poisons have been used for centuries, recent incremental improvements − both in the tools themselves and in their strategic application − have resulted in substantial pest-management gains, including eradication of pests from uninhabited islands and fenced sanctuaries, significant reduction in tuberculosis-infected herds through effective possum control, and large-scale threatened-bird protection through the Battle for Our Birds programme.

Despite these successes there has been an increasing desire by many stakeholder groups, such as community groups, pest control operators and conservation agencies, for fresh thinking and novel approaches to address pest control issues on the New Zealand mainland (Blackie et al. 2014). Notwithstanding the gains already achieved, there is still a general decline in the threatened status of many of New Zealand's endemic species, and it is believed that such trends will only be reversed by the development of new high-tech solutions, such as gene drives or other molecular-based technologies. Although the development of these new technologies will progress, it is inevitable they will take decades to develop and become operational. There is also a high risk that they will not deliver their promised solutions because of technical, biological or social acceptability issues. To ensure the pest-management gains achieved can be built on, it is critical that incremental improvement in low-tech tools and strategies continues in parallel with the development of high-tech solutions, at least until some of these deliver operationally effective solutions.

This report presents a review of recent literature on current pest control and monitoring methods, and new developments that have not as yet reached the market, to determine gaps in current knowledge and therefore research priorities to deliver cost-effective and safe environmental control of vertebrate pests.

The review focuses on the three main predator species that are encompassed by the Predator Free 2050 (PF2050) initiative (possums, ship rats and stoats). However, it is recognised that there are a wide range of other vertebrate pests (predominantly herbivores) that cause local if not national impacts (e.g. mice, deer, pigs, goats, wallabies, rabbits, chamois and tahr).

3 Objectives

To provide a list of key research priorities for small-mammal pest-control tools and strategies, focusing on:

- toxins (including residues, non-targets, cost-effectiveness)
- monitoring
- lures and baits
- automated poison dispensers
- traps (including non-targets, cost-effectiveness)
- wireless trap monitoring
- scaling up to regional operations
- repellents.

Best practice support for tool use is considered in each of the above topics.

4 Methods

The review of close-to-market tools and related applied research needs was based on recent literature and the expert knowledge of the two senior authors, both having in excess of 20 years' experience in vertebrate pest management research. Each priority area was divided into five sub-areas:

a **context:** briefly explains the current context the tools are used in and the likely short- to medium-term future needs

b **recent and current research:** provides a brief review of research related to the priority area

c **knowledge gaps:** identifies knowledge gaps based on reviewing the research and knowledge of operational needs d **market failures:** recognises that some failures to get new technologies or incremental improvements adopted are due to market problems (e.g. failure to obtain registration or develop best practice) rather than technology or operational problems *per se*

e **recommendations:** lists the recommended research or market needs that should be considered for support.

5 Related strategy and road map research priorities

The review also considered research priorities that had been identified in the regional councils' *Strategic Roadmap for Biosecurity and Biodiversity Research* (Byrom & Kavermann 2015), the Ministry for the Environment and Department of Conservation's *Conservation and Environment Science Roadmap 2017*, the Royal Society of New Zealand's *Challenges for Pest Management in New Zealand* (2014), and a recent survey of end-users carried out by D. Tompkins as part of the NZBH-NSC. The priorities and research recommendations most relevant to or within the scope of this review have been selected from the above strategies.

a The Regional Council's *Strategic Roadmap for Biosecurity and Biodiversity Research*

- Priority 1: scaling up
  - Develop novel tools and improve existing tools for cost-effective management of threats at a landscape scale.
  - Where eradication is not feasible, determine appropriate pest density impact thresholds.
- Priority 2: ecological monitoring and reporting
  - Develop monitoring tools, technologies and strategies that are cost-effective, simple to use, and sufficiently sensitive to changes in the resource indicators.
  - Develop monitoring protocols applicable to a range of taxa and ecosystems.
- Priority 3: surveillance and detection
  - Develop detection devices with appropriate sensitivity and specificity.
  - Calculate quantified detection probabilities for a range of devices and taxa.
  - Develop rapid in-field diagnostic techniques for new and emerging pests and diseases.
  - Develop surveillance and detection techniques applicable to a range of taxa and ecosystems nationally.
- Priority 4: novel tools, tactics and strategies for threat management and improvement of existing tools, tactics and strategies
  - Develop cost-effective, publicly acceptable tools for managing mammals. A priority is the development of humane methods to control invasive mammal species.
  - Manage multiple mammal pests using strategically integrated combinations of tools and strategies, both at small sites and on a landscape scale.
  - Develop biological control for priority mammal pests.

b The Ministry for the Environment and Department of Conservation's *Conservation and Environment Science Roadmap 2017*

- Theme: biosecurity
  - Improved and integrated detection and eradication or suppression tools and management systems for a range of current and potential biosecurity risks.
  - Disruptive tools, technologies or approaches that have the potential to radically change the paradigm for managing biosecurity risks.
  - Improved understanding of the behaviour of mammalian pests at low densities to enhance the success of eradication efforts and increase the success rate of early detection/prevention programmes.

c Royal Society of New Zealand's *Challenges for Pest Management in New Zealand*

- Emerging issues: vertebrate pests
  - The need for cost-effective, humane management of vertebrate pests at very large scales.
  - Keeping large areas free of mammal pests through effective monitoring, detection and rapid removal of invaders.
  - The maintenance of public support for pest control and eradication.
  - The need to address the extremely long time frame for the development of a product, its registration for field use, and becoming commercialised.

d D. Tompkins, NZBH-NSC

- Top priority species: rats (ship rats), mustelids (stoats), possums, mice, and cats (*Felis catus*).
- Favoured management goals: landscape-scale suppression, local/regional eradication, minimise or prevent reinvasion, increase populations of native species.
- Key needs to achieve successful management/eradication:
  - cost-effective tools for sustained control
  - tools for detecting and killing bait- or trap-shy individuals
  - socially acceptable tools for eradication
  - tools and strategies that can be sustained over extended periods and at scale
  - cheaper, self-resetting traps with proven efficacy
  - effective fence-exclusion systems for cats
  - more humane tools for control at scale
  - sustainable solutions that maintain pests below impact threshold levels
  - aerial application for new toxins.

6 Findings

6.1 Priority area: toxins

6.1.1 Context

Since the 1950s most new vertebrate toxic agent (VTA) registrations have been anticoagulants. However, recent concerns have been raised about their residues and the risks of secondary poisoning, environmental impacts and humaneness. Aerial application of sodium fluoroacetate (1080) continues to be the most effective means of controlling pest populations over large areas, but this toxin receives strong opposition from private individuals, groups and some political parties. This opposition has also driven the search for new toxins with low environmental impacts and improved humaneness. All of these concerns have led to new toxins such as para-aminopropiohenone (PAPP), sodium nitrate (ESN) and zinc phosphide (ZaP and MZP), which are the first new VTAs registered in New Zealand for over 30 years.

6.1.2 Recent/current research for compounds registered before 2010

Anticoagulant poisons

Brodifacoum

Brodifacoum is marketed worldwide as a very potent, second-generation anticoagulant against rodents. It was first registered in New Zealand in 1996 and has successfully been used in aerial applications for eradicating rodents from offshore islands (e.g. Kapiti Island, Enderby, Auckland Island) and fenced sanctuaries, and for possum/ rodent control on the New Zealand mainland using bait stations (Eason et al. 2002). Baits contain either 0.02 or 0.05 g/kg and are registered as Pestoff or Talon in cereal pellet and wax block baits. Other products containing brodifacoum can also be found on the domestic and commercial market under the trade names of Brigand (block), No Rats and Mice® (block), and Ratsak® (wax block).

Numerous cage and field trials have been undertaken on brodifacoum (Eason & Spurr 1995; Eason et al. 1999; Eason et al. 2002; Morgan 2004; Morriss et al. 2008; Silke 2008). Brodifacoum is a very effective single-feed toxin against rodents and possums, and it is the primary control method for large-scale possum operations that have recently been established by several regional councils. It is useful in situations where possum numbers are low and they are likely to be bait shy (Ross et al. 1997). However, because brodifacoum can persist in the food chain (e.g. in livestock and pigs) and in native species, and the high risk of primary and secondary poisoning of non-target species and its inhumaneness (Littin et al. 2004), its aerial application has been restricted to one-off eradication programmes on offshore islands (Veitch et al. 2011; Eason et al. 2015).

National Pest Control Agencies (NPCA 2015a, 2015b), Manaaki Whenua (Pest Decision Support System – PestDSS) and Orillion Ltd have extensive best practice documentation available. Best practice documentation for aerial application on offshore islands (Broome et al. 2014) and for ground-based use in possum control (Henderson et al. 1999) is available through the Department of Conservation (DOC). However, DOC's Pesticides Advisory Group recommended that brodifacoum only be used sparingly (i.e. restricted to one or two operations per lifespan for the longest-lived native animal species that were likely to be exposed) to avoid the build-up of the toxin within native species through repeated doses

Diphacinone

Diphacinone was registered as a rodenticide in 1984 and has also been incorporated into a fish-based bait for ferret control (Animal Control Products Ltd). New products such as Ramik Mini Bars® have recently been registered to Millychem Ltd (2013), as have Pestoff Rat Bait 50D® to Animal Control Products Ltd (2009), and D-Block Extreme® and RatAbate® paste and cereal bait to Connovation Ltd (2006−2014).

Trials have reported diphacinone to be less persistent but more potent than pindone, with a similar potency to coumatetralyl (Fisher et al. 2004; Eason & Ogilvie 2009). Palatability trials with diphacinone products found RatAbate® to be more palatable than Ditrac® (Fisher et al. 2004; Eason & Ogilvie 2009; Eason et al. undated). Connovation Ltd reported diphacinone to be economical for maintaining low-density populations. Diphacinone has a short elimination half-life in animal tissue (3 days, compared to 113 days for brodifacoum; Fisher et al. 2004), so there are minimal risks to native birds and a lower potential for secondary poisoning.

Eason et al. (undated) recommended using RatAbate® with either Feratox® or Feracol® for cost-effective control of possums and rodents. RatAbate® has a low secondary poisoning risk and no long-life residues. Eason and Ogilvie (2009) suggested the potential use of diphacinone for repeat aerial application, as it is already approved by the US Environmental Protection Agency for aerial control of rodents in Hawaii.

Connovation Ltd and Manaaki Whenua (PestDSS) have best-practice documents available on their websites, and because no controlled substances licence is required, baits such as RatAbate® can be used by both community and professional users.

Coumatetralyl

Coumatetralyl was developed in the 1950s and marketed internationally for rodent control as Racumin®, either as a tracking powder, wax block, cereal bait or paste (Eason & Ogilvie 2009). Racumin® was registered in 1999 in New Zealand for rodent control. Information about its general use is available on the manufacture's website (Bayer).

Cage trials in New Zealand carried out on rats found that coumatetralyl has low residue potential and therefore a lower risk of secondary poisoning (Fisher et al. 2004). Cage trials on mice (O'Connor & Booth 2001) found commercial bait to be less palatable than cereal-based baits used with brodifacoum, so increasing palatability would be required for effective mouse (*Mus musculus*) control.

Eason and Ogilvie (2009) suggested coumatetralyl could be used for aerial control of rodents. However, diphacinone has a similar potency, is less persistent, and is currently viewed as the preferred first generation option.

Pindone

Pindone was registered for use in 1992 and has mainly been used to control rabbits. Its use for rodent (*Rattus* spp.) and possum control has decreased since the introduction of brodifacoum (Eason et al. 2015). A controlled substances licence is not required for the use of pindone.

Silke (2008) showed that pindone is less potent than brodifacoum but poses a much lower risk of secondary poisoning. Silke's field studies reported good results for suppressing and maintaining low rat numbers. Eason and Ogilvie (2009) suggested pindone as a possible option for aerial control of rodents, although they stated that diphacinone would be a more effective first-generation anticoagulant.

A review of possum baits by Henderson et al. (1999) found that although pindone is less persistent than brodifacoum, possums must eat large amounts of bait to be lethal, they take 2 to 4 weeks to die, and there is a high risk of primary poisoning to non-target species. Henderson et al. reported that pindone is effective in areas where possum numbers are low or have developed bait shyness to acute-acting toxins. Optimal use for rabbit control has still to be determined, but this compound is currently not seen as an effective option for the control of rodents, possums and stoats.

National Pest Control Agencies (NPCA 2015a, 2015b) have included the use of pindone in their best practice documentation for possum control, safe use and handling. The purchase of pindone soluble concentrate requires a controlled substances licence and an approved handler certificate for use.

Warfarin

Warfarin, like pindone, belongs to the first-generation anticoagulants and is used overseas as an effective rodenticide. Although less persistent than brodifacoum, it is considered inhumane and is not registered in New Zealand. Fisher et al. (2004) suggested warfarin has lower efficacy and lower risk to non-target species such as birds than brodifacoum, and should be further evaluated. Eason and Ogilvie (2009) did not recommend it as a viable tool for the aerial control of rodents.

Bromadiolone

Bromadiolone is similar to brodifacoum, though less potent than the combination of brodifacoum and flocoumafen (Eason et al. 2015). Ready-to-use baits have been registered in New Zealand under the trade name Contrac® All- Weather Blox™, Maki® Block, Rid Rat® grain, Super Squeak® grain, and Tomcat® blocks containing 0.05 g/kg a.i. (active ingredient). The manufacturers report the bait to be palatable, durable for use in damp conditions, and less toxic to non-target animals than brodifacoum. Mortality occurs in 4–10 days after bait is consumed (Eason et al. 1999). Morriss et al. (2008), who conducted cage and field trials of bromadiolone on rats and mice, recommended Contrac® All-Weather Blox™ to be suitable for cost-effective, offshore island monitoring and protection due to the long life of the wax block baits. However, there is limited research on this compound in New Zealand.

Flocoumafen

Flocoumafen is a similar compound to brodifacoum in potency, persistence and secondary poisoning risks (O'Connor & Eason 2000; Campbell et al. 2015). Registered in 2003 under the name of Storm®, it is sold as ready-to-use bait blocks and mostly used as a commercial and agricultural rodenticide, especially for mice (Fisher 2005). Very little information is available on trials conducted in New Zealand. O'Connor and Eason (2000), referring to flocoumafen in their report on control in island situations, suggest it has the potential to cause primary and secondary poisoning of non-target species. Hook and Todd (1992) conducted mouse eradication on Mana Island using flocoumafen (Storm®), where baits were deployed aerially on steep cliff areas. Product information is available on the manufacturer's website.

Difethialone

Difethialone was registered as a rodenticide in 2013 by LIPHA Tech Ltd. It was included in a review of anticoagulant poisons on mice by Fisher (2005). There appears to be little information about difethialone other than the EPA application by LIPHA Tech Ltd, which suggests there may be a lower risk of primary and secondary poisoning as the baits only contain 0.025 g/kg, as well as being highly palatable and rapid acting for rodents. There is information about use of the product on the manufacturer's website, but there is limited research on this compound in New Zealand.

Acute poisons

Sodium fluoroacetate (1080)

The compound 1080 is a widely used, highly effective toxin for achieving rapid reduction of possums, rodent and stoats over large areas. It was re-registered in 2007 to meet more recent Environment Protection Authority requirements. Orillion supply a wide range of 1080 products for possum, rodent and rabbit control. The toxin is incorporated into cereal and paste baits or supplied as a concentrate to be applied to carrot baits.

A broad-spectrum toxin, 1080 has the advantage of targeting multiple pest species. It is the only toxin registered for aerial control on mainland New Zealand. However, its use can be controversial due to its toxicity to non-target species and the risk of secondary poisoning from possum carcasses. There are a large number of data from cage and field trials, including information on both aerial and ground applications of 1080. A review carried out by Fairweather et al. (2012) of intensive monitoring studies on native species suggested that although 1080 is toxic to native animals, field monitoring indicates there are no significant risks to native species at the population level. There is a high risk of secondary poisoning to domestic animals, particularly dogs (Fairweather et al. 2012). Eason et al. (2011) reported that although 1080 is not as humane as PAPP or cyanide, it is more humane than cholecalciferol and the anticoagulant poisons.

Morgan et al. (2015) and Nugent and Morriss (2013) identified the need to refine the use of 1080 to minimise cost and the amount of bait applied to the environment. For example, field trials that compared conventional aerial baiting with cluster baiting suggested the latter could significantly lower operational costs and reduce toxin usage (Nugent & Morriss 2013).

Morgan et al. (2015) also showed promising results by combining aerial pre-feeding of bait followed by ground baiting of smaller quantities of toxic baits.

Extensive best practice information is available through Orillion, Manaaki Whenua (PestDSS), NPCA (2015b) and DOC (Henderson et al. 1999). Operating procedures for aerial application are available from the NPCA (NPCA 2015c). A controlled substances licence and an approved handler certificate are required for its use.

Cholecalciferol

Cholecalciferol (vitamin D_3) was developed as a rodenticide in the 1980s (Eason & Ogilvie 2009). It was registered by Connovation Ltd in 1999 for possum control as a paste bait called Feracol®, containing 0.8% cholecalciferol (Eason et al. 2010). In 2008 the registration was extended to include rodents, and in 2009 a low-dose paste and pellet bait of 0.4% were developed.

Cage and field trials showed that cholecalciferol (0.8 %) effectively killed both rodents and possums (Eason et al. 2010; Morgan et al. 2013), has a low risk of toxicity to birds (Eason et al. 2000) and a low risk of secondary poisoning to domestic pets compared to 1080 (Eason et al. 2000). Also, cholecalciferol (0.9%) performed well in field trials using a long-life gel bait (Morgan 2006), and had a reported field life of 26 months. Successful cage and field trials of low-dose (LDC 0.4%) baits for multispecies control was undertaken by Hix et al. (2012). They suggested that the low dose further reduces the risk of primary poisoning of non-target species, but they recommended carrying out more field research.

Morgan and Milne (2002) and Hix et al. (2012) reported that possums generally die from heart failure in 4 to 7 days and therefore cholecalciferol is more humane than the anticoagulants (Eason & Ogilvie 2009). However, sub-lethal doses can lead to emaciation, and this has significant animal welfare impacts (Morgan & Milne 2002). Eason et al. (2010) reported that rats died in 4 days. NPCA (2015a) reported the toxin to be effective for reducing medium-to-high possum populations and is more cost effective in conjunction with a pre-feed bait.

Best practice documentation is available through NPCA (2015a, 2015b), Manaaki Whenua (PestDSS) and Connovation Ltd. Feracol® is available for use without a controlled substances licence. The long-life gel bait developed by Kiwicare® has been discontinued.

Sodium and potassium cyanide

Cyanide paste has been available for ground possum control in New Zealand since the 1960s. It is available as a formulation of sodium or potassium cyanide in a paste (e.g. Trappers Paste®) or more recently as potassium cyanide in Feratox® encapsulated pellets. Feratox® pellets were developed by Connovation Ltd in 1995 for use in bait stations to minimise the breakdown of cyanide paste in humid conditions, resulting in cyanide emissions that pose a hazard to operators and reduce bait palatability (Thomas et al. 2003). Native birds such as weka (*Gallirallus australis*) and kiwi (*Apteryx spp.*) are also at risk of primary poisoning when using the paste bait (Spurr 2000). More recently, Connovation Ltd developed and registered the Feratox Bio Bag in 2016 and a larger pellet to target wallabies. The Bio Bag product contains a non-toxic pre-feed along with one Feratox® (for possums) or Feracol® (rodents) pellet.

Cyanide is a very humane poison because it kills rapidly, causing unconsciousness within 6 minutes and death after 14 minutes (Gregory et al. 1998). Feratox® is cost effective for large-scale ground-based possum control operations in areas of medium to high possum numbers and is suitable for fur recovery (Thomas et al. 2003). Paste and pellets do not persist and pose no secondary poisoning risks (Henderson et al. 1999; Eason et al. 2015). If rats are present in high numbers, they can remove and cache capsules from bait stations and reduce overall control effectiveness (Ross & Sam 2014).

Best practice documentation is available from NPCA (2015a, 2015b), Connovation Ltd and Manaaki Whenua (PestDSS). Sodium and potassium cyanide require a controlled substances licence and an approved handler certificate for use and can be hazardous; antidotes are available.

Phosphorus paste

Phosphorus was first used for killing rabbits in the 1920s. It is available from Orillion as a fruit-based paste containing a flavoured lure for possum control. Phosphorus paste can be very effective, with kills of >90% in pastoral habitats (Landcare Research undatedb); however, efficacy is unproven in non-pastoral habitat. Cage trials by O'Connor et al. (2007) also questioned the humaneness of phosphorus paste, as it has a period of illness up to 18 hours and death after 25 hours, with unconsciousness occurring only 1 hour before death. This is a longer period of sickness than for 1080 and cyanide.

Phosphorus paste's environmental persistence and secondary poisoning risks are not well understood. It may persist for some time in the stomach and tissues of carcasses and cause secondary poisoning of birds (Sparling & Federoff 1997) and dogs (Gumbrell & Bentley 1995). DOC (2004) reported that it is known to kill birds that feed on carrion, although no dead non-target birds have been assayed.

Best practice documentation is available through Manaaki Whenua (PestDSS) and NPCA (2015b). It requires a controlled substances licence and an approved handler certificate.

6.1.3 Recent/current research on compounds registered after 2010

Para-aminopropiophenone (PAPP)

PAPP is the first new vertebrate toxin registered in 30 years in New Zealand (Dilks et al. 2011; Murphy et al. 2011), and the first targeted at stoat and feral cat control (Eason et al. 2014). Developed by Connovation Ltd, Lincoln University and DOC, PAPP was registered by the EPA in 2011 for stoat and cat control under the name PredaSTOP® and PAPP Paste Ready-to-use Bait (Eason et al. 2014). PAPP has recently been registered as a feral dog (*Canis familiaris*) bait in Australia, marketed as Dogabait®.

PAPP acts very rapidly and is considered a humane method to control stoats (Dilks et al. 2011). There is minimal residue risk to non-target species and low secondary poisoning risks.

An antidote is also available (Eason et al. 2014). Connovation Ltd report PredaSTOP® is cost effective, being a single-feed toxin, which is approximately 20% the cost of traditional trap-based methods.

Successful cage and field trials of toxicity on stoats were undertaken by Manaaki Whenua and Lincoln University (Fisher et al. 2005; Dilks et al. 2011). Cage studies showed some toxicity to birds but lower risk compared to other VTAs (Eason et al. 2013). PAPP analogues (PAVP) tested for rodent toxicity showed disappointing results (Quy et al. 2015; Rennison et al. 2013), although other synergists are being investigated (Eason et al. 2017).

There is a need to develop long-life PAPP baits and an effective low-concentration formulation. Research by DOC has progressed to pen trials in the development of palatable meat baits suitable for aerial application for feral cat and stoat control (Eason et al. 2015). No best practice documentation is available through the manufacturer (Connovation Ltd) or the NPCA. It requires a controlled substances licence and an approved handler certificate for use.

Sodium nitrate (ESN)

Sodium nitrate, a commonly used food preservative, is toxic at high doses. Developed and tested by Lincoln University and Connovation Ltd for ground control of possums and feral pigs (Shapiro et al. 2016a), it was registered by the EPA in 2013 under the name of Bait-Rite® paste. Connovation Ltd further developed the paste by encapsulating the sodium nitrate to improve palatability (Shapiro, Eason et al. 2016).

Encapsulated sodium nitrate was shown to be highly palatable and effective to possums in cage and field trials (Shapiro, Eason et al. 2016). Encapsulated sodium nitrate was found to be more effective than unencapsulated sodium nitrate (Shapiro et al. 2009). Sodium nitrate is biodegradable, with no persistent residues and a low risk of secondary poisoning (Shapiro, Eason et al. 2016). At high doses it is considered humane, with rapid death compared to 1080, brodifacoum and cholecalciferol (Shapiro, Eason et al. 2016). The bait is registered for use in bait stations.

Best practice documents are available through Manaaki Whenua (PestDSS), Connovation Ltd and NPCA (2015b). It requires an approved handler certificate for use but can be used without a controlled substances licence. EPA permission needs to be obtained before pig control operations are undertaken.

Microencapsulated zinc phosphide paste (ZaP)

Unencapsulated zinc phosphide has been used in the USA and Australia as a rodenticide, and in New Zealand a microencapsulated form has been developed as an alternative to 1080 for possum control (Eason & Ogilvie 2009). In pen and field trials, microencapsulated zinc phosphide paste(MZP) was more readily consumed and palatable than un-encapsulated zinc phosphide paste for possum ground control (Henderson et al. 2002; Ross & Henderson 2006; Shapiro, MacMarron et al. 2016).

Field trials undertaken by Ross and Henderson (2006) reported that zinc phosphide paste was very effective as it rapidly reduced possum numbers within 3 to 12 hours after the lethal dose was consumed. Non-target species such as birds are susceptible, but there is a comparatively low risk of secondary poisoning (Eason et al. 2013). Because of this successful research, zinc phosphide paste containing 1.5% microencapsulated zinc phosphide was registered by Connovation Ltd under the name of ZaP® for possum control in 2011.

There is currently no standard operating procedure or manufacturer's guidelines available. A best practice guideline for safe use and handling of VTAs is available through NPCA (2015b). Development of best practice needs to be further determined with more robust research, as reported by Shapiro, MacMarron et al. (2016). MZP requires a controlled substances licence and an approved handler certificate for use.

6.1.4 Recent/current research for non-registered experimental compounds

Cholecalciferol + coumatetralyl (C+C)

Research combining cholecalciferol and coumatetralyl as a multispecies bait (for possums and rodents) found the toxins have similar effectiveness as brodifacoum but are less toxic to birds, have a lower risk of secondary poisoning, and are considered more humane (Eason & Ogilvie 2009). Research was discontinued because the combination cholecalciferol + coumatetralyl was shown to be unpalatable, and combinations such as diphacinone + cholecalciferol (see below) are less persistent (Eason et al. 2015).

Diphacinone + cholecalciferol (D+C)

Research combining diphacinone and a low dose of cholecalciferol (0.03% and 0.06%, respectively) was shown to have a similar effectiveness as a second-generation anticoagulant (Eason et al. 2015). It is also considered more humane than brodifacoum (Littin et al. 2002, 2004).

Preliminary registration of a cereal bait formulation for use in bait stations was filed with the EPA and the Ministry for Primary Industries (MPI) in 2015 (Eason et al. 2015). Eason et al. reported that development and more research of the bait for aerial and ground control over 2016–19 will be required to support MPI and EPA registration.

Norbormide

Norbormide was developed in the 1960s as a rat-selective toxin, specifically toxic to Norway rats (*Rattus norvegicus*, Eason & Ogilvie 2009). It has never been commercially viable because of its poor palatability. Ship rats are less susceptible to norbormide and mice are resistant to this toxin (Eason & Ogilvie 2009). Norbormide is less toxic to non-target species such as birds and has lower secondary poisoning risk compared with 1080 (Campbell et al. 2015). Norbormide is acute acting, with deaths occurring within 8 to 24 hours. According to Eason and Ogilvie (2009) there are no long-term residue risks in sub-lethally exposed animals.

Norbormide is not registered in New Zealand or overseas, and Campbell et al. (2015) suggest that once laboratory and field trials are completed registration may occur in 5 years

(2019/20). However, Norbormide is not being produced commercially so currently the base material remains expensive.

Field trials were undertaken by Beveridge and Daniel (1966) on Norway rats on Mokoia Island. Rennison et al. (2013) and Jay-Smith et al. (2016) are undertaking trials investigating ways of overcoming taste aversion to norbormide.

CORMS

The University of Otago investigated the use of carbon monoxide releasing molecules (CORMs) that form with haemoglobin and produces carboxihaemoglobin in the gastro-intestinal tract of rats. Lincoln University (2012) reported that around 50% of haemoglobin needs to be converted to carboxyhaemoglobin in red blood cells to kill rats, and research indicated that this was not currently possible.

Tutin

Eason and Ogilvie (2009) investigated the potential of toxins derived from New Zealand native plants, primarily because 'natural toxins' were likely to be more acceptable to Māori. Eason et al. (2015) focused on tutin from tutu (*Coriaria arborea*) and found the toxin to have the highest concentration in new shoots. Toxicity trials found tutin to be toxic to rats, with female rats more susceptible than males (Eason et al. 2015). However, toxicosis was not immediate and animal welfare impacts were likely to be high unless a consistent high dosage of 55 mg/kg is consumed. Also, the development of tutin into a successful rodenticide in terms of toxicity, potency and humaneness may not be technically feasible (Ogilvie et al. 2017).

6.1.5 Knowledge gaps

- Despite refined best practice it is still not possible to consistently get 100% kills for multi-species (i.e. possums, rats and stoats) using aerial 1080, and research is required to identify the reasons for some individuals surviving and how to target them.
- There is a need to identify repellents or other mechanisms for reducing or eliminating non-target bird deaths, especially kea, following aerial 1080.
- There is a need for a suitably long-life bait for PAPP for both ground and aerial application to control stoats and feral cats.
- There is no chemical analogue of PAPP that is effective for multi-species control (i.e. rodents and possums).
- There is no effective alternative to brodifacoum for large-scale possum and rat control that does not pose residue risks.
- There is no best practice documentation for recently registered VTAs (i.e. PAPP, sodium nitrate, zinc phosphide). In particular, this relates to ground control and bait station spacing, and amounts of bait per application.
- There is a lack of information on the cost effectiveness of recently registered compounds compared with current industry standards.
- Newly registered VTAs (sodium nitrate, zinc phosphide) need development of a multispecies hard bait that could then be used for aerial control.

- Norbormide remains unpalatable and ineffective for ship rat control.
- Although D+C has been recently registered there is still a lack of information regarding efficacy and cost-effectiveness. There would also be questions regarding animal welfare, given that cholecalciferol is ranked as having poor welfare outcomes.

6.1.6 Market failures

- While there has historically been funding available to enable the registration of new VTAs, there are no additional sources of funding (or commercial interest) to develop and design best practice documents. So although end-users are keen to adopt new control options, they remain uninformed regarding optimal strategies and the relative cost effectiveness of the new tools compared with current industry standards.
- There is no funding to deal with new and current issues, even for industry standards. For example, more effective bird repellents need to be developed, particularly for kea. Non-target bird deaths threaten the future use of all VTAs in New Zealand.
- While we were able to locate many research articles on the various VTAs, there is no one website where end-users can locate up-to-date best practice for all registered VTAs.

6.1.7 Recommendations

There is a need to:

- conduct comparative trials using aerial 1080 with mixtures of sowing rates, new multi-species baits and pre-feeding regimes to enable consistent high kills for all target species
- conduct comparative, ground-based field trials comparing the efficacy and cost-effectiveness of all newly registered VTAs against current industry standards
- progress D+C as an effective alternative to brodifacoum
- conduct research to enable the registration of norbormide or its close equivalents as a rat-specific toxin
- develop an effective bird repellent for high-risk bird species (see section on repellents).

6.2 Priority area: monitoring

6.2.1 Context

Possums, rats and stoats are the most common pest species controlled to protect native biodiversity and prevent disease transmission. To manage pest species effectively, accurate, precise and cost-efficient methods for detecting and estimating pest abundance are needed.

Methods for detecting, monitoring and estimating possum population abundance include a range of trap-catch methods, bait interference (e.g. wax tags, chewcards), spotlight counts and faecal pellet counts. Common methods of detecting and indexing rodent population size include snap-traps and tracking tunnels. Due to the large sample error associated with estimating the population size of mustelids, and the high cost of undertaking robust surveys, mustelids have usually been indexed using catch data from trap lines deployed during control operations. More recently, camera traps coupled with occupancy modelling have been increasingly used to estimate abundance.

It is likely that an integrated approach for monitoring multiple species for simultaneous control and monitoring is the most beneficial way to effectively manage pest species in the future (Sam 2011).

The tools covered in this section, although focused on monitoring, can also be used for detection, a term more commonly used for monitoring the presence or absence of individuals in populations that are at very low densities.

6.2.2 Recent/current research

Tracking tunnels

Tracking tunnels for monitoring small mammal abundance were first described by King and Edgar (1977). The technique uses a run-through tunnel containing two pieces of paper either side of a sponge soaked with a tracking medium such as food colouring or black tracking ink (Pest Control Research Ltd). There are many tracking tunnels available, of varying sizes. Te Anau DOC provides a design to make your own. Gotcha Traps Ltd (Black Trakka™), Pest Control Research Ltd, and Philproof Pest Control Ltd (Philproof Monitoring Tunnel) are the main suppliers.

Pickerell et al. (2014) assessed tracking tunnels alongside eight other detection techniques in non-forest habitat and found detection rates of tracking tunnels too low when pest densities were low. They stated it is important to use more than one monitoring technique in the detection of a suite of pest species. Gillies and Williams (2013) report tracking tunnels to be more sensitive than snap traps at low rodent densities, and less labour intensive because the tunnels can remain *in situ* between monitoring sessions. Nathan et al. (2013) assessed the effectiveness of tracking tunnels and PCR WaxTags® for island surveillance and found that even at very low mice densities tracking tunnels were effective at detection.

Two studies in New Zealand have tested indices of small mammals against actual abundances. Brown et al. (1996) tested indices of ship rats and mice using tracking tunnels and removal trapping from a trapping grid to obtain density estimates. Blackwell et al. (2002) made comparisons of density indices of ship rats in mixed forest, comparing tracking tunnels, snap-catch and Fenn traps. Both trials indicated that tracking tunnels are generally correlated with trap catch rates, but the different methods did indicate different population trends, particularly when sampling low-density rodent populations.

Stoats, which occur at lower densities than other pest species, have also been indexed using tracking tunnels. However, due to the much lower densities and associated large sample error, monitoring is usually carried out using kill traps (King & White 2004). Brown (2001) investigated the field responses of stoats to the tracking tunnel design and suggested possible neophobia. Hegg (2006) reported that tracking tunnels failed to provide any useful information on the relative density of stoats in the Murchison Mountains, and suggested that when stoats are at low densities tracking tunnels with more attractive lures need to be developed. This conclusion is supported by a recent study where both cameras and artificial nests were more sensitive at detecting stoats in spring–early summer in alpine habitat (Smith & Weston 2017).

A national standard for using tracking tunnels to monitor rodents and mustelids is set out in *DOC Tracking Tunnel Guide v2.5.2*. Best practice documentation is available through DOC via four useful documents: a tracking tunnel calculator; a tracking tunnel guide (v2.5.2, Gillies & Williams 2013; Gillies 2013b); and a standard inventory and monitoring project plan (DOC 2008; Greene 2012). Land care groups also provide a best practice guide (NZLandcareTrust 2016). DOC and Manaaki Whenua provide guides to various small mammal prints (Cunningham & Moors 1983).

PCR WaxTags®

In an attempt to minimise risk to native birds such as weka and kiwi by using leg-hold traps for monitoring abundance of possums, and to overcome interference of lures by rats, non-invasive monitoring devices have been developed. Wax blocks (Thomas 1999) were initially deployed for monitoring rodents and possums, and these evolved into wax placed on a plastic tag nailed to a tree (Ogilvie et al. 2006). Using a coloured plastic tag increases visibility, and using bait or lures further enhances attractiveness (Thomas et al. 2006). Commercially available PCR WaxTags® were developed by Pest Control Research Ltd, and FORMAK offer instructions for how to make your own wax tags.

Thomas et al. (2006) assessed the accuracy of possum monitoring using PCR WaxTags® and reported them to be a lightweight, low-cost accurate method when compared to Residual Trap Catch Indices (TCI) estimates. Pickerell et al. (2014) reported that habitat heterogeneity may influence detection rates when using WaxTags. Nathan et al. (2013) also found tracking tunnels baited with peanut butter to be better at detecting mice than WaxTags baited with peanut butter.

Sweetapple and Nugent (2011) compared possum chew-track card indices (CTCIs – see below) with established trap catch indices, PCR WaxTags®, bite mark indices and faecal pellet indices; and rat CTCIs with tracking tunnel indices. Their research showed chewcards to be a sensitive and low-cost method of detecting small mammals, and concluded that they have a high potential to index low-density populations. Kavermann et al. (2013) reported chewcards to be more sensitive to possum presence than PCR WaxTags®, especially with the addition of peanut butter lure. Peanut butter-flavoured PCR WaxTags® are now available, although these have not been formally tested against other index methods (Kavermann 2013).

Best practice documentation is available through NPCA (2015d), FORMAK, and NZLandcareTrust (2016).

Chewcards

Chewcards were recently developed as an alternative to wax blocks and PCR WaxTags® for monitoring the relative abundance and distribution of small mammals (Sweetapple & Nugent 2011). Chewcards are easy to deploy in the field because they are small and lightweight compared to traps, and only two inspections are required. Unchewed chewcards are re-usable and have no impact on non-target species.

The cards are made of white corrugated plastic, with some flutes filled with peanut butter, aniseed or soft meat and nailed to trees or posts. Chewcards are commercially available (e.g. Connovation Ltd, Pest Control Research Ltd, Goodnature Ltd) and tooth marks on the chewcards are used to assess the presence and relative abundance of pest species (Jackson et al. 2016).

Ruffell et al. (2015) compared CTCIs of rat and possum abundance with a footprint tracking rate index of rat abundance and a wax tag bite rate index of possum abundance in 11 forest remnants that varied widely in rat and possum abundance. The CTCIs were strongly correlated with the bite rate and footprint tracking rate indices and showed little indication of saturation at high pest abundances. This research indicated that deployment of cards over a shorter time period helps to minimise issues of sensitivity and rat interference. The Cape to City project also uses chewcards to map predator distribution over large areas. They found that possum detections increased the longer the chewcards were deployed, which could indicate over-representation of abundance due to multiple interactions (Brown et al. 2016).

The attractiveness of baits and lures used in association with chewcards appears to be under-utilised. Jackson et al. (2016) demonstrated that the addition of fat to rat baits and protein to possum baits could improve attractiveness. Using chewcards combined with new combined olfactory and visual lures, Lure-it™ spray and flour blaze (LISB, Connovation Ltd) to monitor possums at low densities was investigated by Waters et al. (2017). Chewcards baited with LISB cinnamon or aniseed significantly increased possum detections compared to the standard flour/icing-sugar lure.

Best practice documentation is available for chewcard monitoring from NPCA (2015d), Goodnature Ltd, and NZ Landcare Trust. Landcare Trust groups also offer instructions on how to make your own chewcards. Guides for animal bite marks are available from Manaaki Whenua, and best practice for setting up monitoring projects is available from DOC (McNutt & Forsyth 2016).

Live capture traps (leg-hold and cage traps)

Live-capture traps can be used to trap pest species in situations where traps can be checked daily (Russell et al. 2008). Various designs are available depending on the target species, and they can range from leg-hold traps for possums, to wire-mesh-covered cage traps for rats and stoats (e.g. Tomahawk™, Holden Live capture trap). NPCA (2015e, 2015f, 2015a) gives a good overview of the live capture traps available, manufacture, costs, use, effectiveness and animal welfare concerns.

There are few studies of live trapping of rodents. However, in a recent study Nathan (2016) indicated major differences in detection rates for ship rats when comparing live trapping with other monitoring devices, such as camera traps, tracking tunnels, snap traps (see below) and bait stations. Also, Russell et al. (2008) suggest that Norway rats may avoid live traps. NPCA (2015e) reported that most research for live-capture traps had previously been done on ferrets and possums. The residual trap catch index (RTCI) was formalised by the NPCA (2015d) to provide a standardised method for estimating relative densities of possums.

As outlined by Glen (2014), leg-hold trapping is a useful monitoring method for possums where information is needed on decisions of possum control, the effectiveness of previous possum control, and trends in possum abundance over time. Many studies outline estimations of possum abundance in relation to leg-hold trapping (Batcheler et al. 1967; Warburton 1996; Thomas & Brown 2001; Warburton et al. 2004), and this research suggests that the relationship is non-linear (at low and high levels) and varies with season (Forsyth et al. 2005).

Due to concerns for native birds, DOC now requires that all leg-hold traps set on conservation land in areas inhabited by kiwi or weka be placed 70 cm above the ground. Field trials were conducted to compare capture rates of ground and raised leg-hold traps and found no significant difference in possum capture in forested sites (Thomas & Brown 2001); however, capture rates were generally lower for raised sets. Morriss et al. (2000) assessed the efficiency of leg-hold traps and reported that kill traps set above the ground were as effective as ground-set live-capture traps.

The National Animal Welfare Advisory Committee (NAWAC) have developed standards for testing traps in New Zealand, and NAWAC guidelines have set two categories for acceptable restraining traps such as cage and leg-hold traps (NPCA 2015e). NZ Landcare Trust provide a best practice guide, and there are numerous guides on the NPCA website for the use of traps for possums and ferrets (NPCA 2015e, 2015f, 2015a).

Snap traps

Snap traps are used as a surveillance, status and management tool to index the relative abundance of rodents. Traps are set over three nights to catch rodents, and the results are recorded as the number of rats or mice caught per 100 corrected trap nights (Gillies 2013c).

More recent research investigating rodent density, which compared indices from tunnels, snap traps and Fenn® traps, reported considerable differences between the methods (Blackwell et al. 2002). A potential new design of snap trap was also successfully tested by Thomas et al. (2011).

Best practice documentation on snap-trap guidelines and indices is available through DOC (Gillies 2013a, 2013c), as is an identification guide to rodents by Cunningham and Moors (1983). The DOC best practice guide recommends the use of traditional break-back snap traps.

Spot lighting

Systematic searches such as spotlighting can be used as a cheap, simple detection method for confirming the presence and relative abundance of small mammals. There is no recent literature covering the use of spotlighting for monitoring possums, rodents and stoats. However, the NPCA provides guidelines for spotlight monitoring of feral cats (NPCA 2015g) and rabbits (NPCA 2012). Also, Pickerell et al. (2014) compared spot lighting with eight other detection methods and suggested that large tracking tunnels and hair tubes for feral cats (*Felis catus*), large tracking tunnels for European hedgehogs (*Erinaceus europaeus*), and PCR WaxTags® for brushtail possums worked best.

DOC have best practice documentation for rabbit spotlighting, and the NPCA have information on the Modified McLeans Scale (2012), which is also used by regional councils

Faecal pellets

Faecal pellet counts can be used as a cheap, simple method for multispecies detection and as an index of abundance. These counts are more often used to measure relative abundances of deer in New Zealand, and there is a defined relationship between pellet frequency and deer abundance (Forsyth et al. 2011). Studies such as Sweetapple & Nugent 2011 have also assessed pellet counts as an index of possum abundance and found they are highly correlated with chewcards, PCR WaxTags® and leg-hold traps indices.

Best practice documentation on faecal animal counts is available through DOC (Smith 2012).

Radio tracking/GPS

Radio or GPS collars on animals have been used to determine home range sizes and monitor the spatial behaviour of pests (Recio et al. 2010; Glen et al. 2016). VHF mortality-sensing collars have been used to measure mortality (% kill) in field trials (Nugent et al. 2014; Blackie et al. 2016), but no best practice has been developed to guide their use for this purpose. VHF collars on goats, tahr, and recently possums (as 'Judas' animals) have also been used to increase the rate at which conspecifics can be found (Nugent et al. 2015).

DNA collection

Early attempts to monitor possums using DNA attempted to collect tissue from faeces and hair caught in traps. These attempts struggled to obtain high-quality DNA, and more recently researchers have been investigating the extraction of DNA from bitten chewcards or PCR WaxTags® (Dueñas et al. 2015). While the researchers were able to reliably obtain high-quality DNA, the high cost of DNA extraction limits the field use of this technique.

Hair traps were investigated by Brown (2001) and Horton et al. (2005) as a method to identify individual stoats. The method was developed to overcome the difficulties in analysing the relative abundance of stoats when at low numbers, and also to combat possible neophobia of stoats to tracking tunnels (see above). In this kind of trap, the hair is generally caught by glue (Domigan & Hughey 2008) and DNA is extracted from the hair follicle. In Hortons et al.'s (2005) trial, hair traps were visited by stoats. However, they had issues with contamination (mixed samples) and the high costs of DNA extraction (Gleeson et al. 2010).

No best practice is currently available, although Pickerell et al. (2014) referred to Manaaki Whenua protocols for designs for hair capture devices (Horton et al. 2005).

Species recognition device – PAWS

Lincoln Agritech have developed a prototype electronic surveillance device called PAWS (Print Application for Wildlife Surveillance) to detect pest species. PAWS uses an electronic pad that animals walk over, and the animal footprints, gaits, stride-lengths, etc. are used to identify the species.

Cage trials were completed in 2011 and a range of species have been successfully detected. Field trials were conducted in 2012/13 to test performance in field situations and to compare with traditional monitoring methods. Lincoln Agritech Ltd reported a high level of interaction and a more accurate rate of detection compared to the traditional monitoring devices (Lincoln Agritech 2017).

Although the devices will be more expensive than tracking tunnels, there is the advantage that the systems can potentially be left in the field for extended periods of time (over a year), can remotely transmit data, and can monitor many species. This makes this technology in the long term cost efficient in terms of labour.

No commercial product or documentation such as device cost or best practice is currently available.

Species recognition device – Scentinel®

The electronic 'smart' tracking tunnel called the Scentinel® was developed for small carnivore monitoring (King et al. 2007). This is an automated monitoring device using a 'smart' bait dispenser and a scent lure. It records date, time, weight and a digital photograph of animals visiting. The Sentinel® is programmed to ignore non-target species under a certain weight (<50 g).

King et al. (2007) successfully trialled the Scentinel® to compare it with standard tracking tunnel methods for routine monitoring. In contrast to tracking tunnels, which economically sample many sites over a short period of time, Scentinels sample fewer sites (due to the expense of the device) but record more detailed data over a longer period of time. King, McDonald, Martin, MacKenzie et al. field tested 24 Scentinel® units on farmland over 11 weeks, and the results indicated the Scentinels to be robust to operate in field conditions for extended periods of time.

No commercial product or documentation such as device cost or best practice is currently available.

Camera traps

Camera traps are being increasingly used for wildlife monitoring in New Zealand, after the introduction of inexpensive and lightweight cameras for deer hunters in the 1990s (Sam 2011). Detection of small mammals such as rodents and stoats is more challenging than the larger species the cameras were developed for (Glen et al. 2013). Although there is variation in commercially available camera traps, Glen et al.'s study suggested that camera traps are a promising, simple, low-cost tool for monitoring multiple species. Cameras can be used in conjunction with other devices as part of surveillance operations, and the data obtained can be used in a range of occupancy and density estimation models.

Sam (2011) suggested that camera traps can be useful for monitoring the bait station activity of possums and rodents. Sam's study compared two camera traps (infrared and white flash), and concluded that white flash camera traps do not influence behaviour and have the potential as a tool for recognising individuals for capture-recapture population estimates.

Camera trap specifications such as trigger speed, video vs still, and infrared vs white flash were studied by Glen et al. (2013) in pen trials. Glen et al. reported on camera traps' success in the capture of photographs of multispecies, but suggested a lure near the camera would encourage the animal to pause to increase the encounter rate and decrease the possibility of blurred photographs. They found placing two camera traps side by side increased success rate, and video footage achieved the same success rate as still cameras.

Field studies comparing camera traps with kill traps for detecting feral cats and stoats showed that cameras were sensitive at detecting both species (Glen et al. 2014). Recommendations for further research are to reduce false triggering of the cameras and test mounting cameras higher above the ground to increase the target zone (Glen et al. 2014; Nichols et al. 2017). Camera traps can be deployed in the field for long periods of time and operate in a wide range of weather conditions (Glen et al. 2016). However, we do not know how number of photos relates to population abundance. Also, the very high numbers of photos that can be recorded require a significant amount of time to view, and future electronic image recognition would be beneficial.

No best practice documentation is available. However, many recent research papers are indicating success for monitoring (Latham et al. 2012; Nichols et al. 2017), and some initial protocols have been developed by Manaaki Whenua (Morriss 2017). Also, some useful guides have been developed overseas for a range of pest and native species (Meek et al. 2012).

Detector dogs

Using detector dogs is relatively new for monitoring pest species in New Zealand, but it has been used overseas on carnivores (e.g. foxes in Australia; Brown et al. 2015). Trained dogs in New Zealand have mostly been used for locating threatened species (Dilks & Towns 2002). Using dogs for predator detection requires a lengthy and intense training period, and dogs need to be certified by DOC when working with protected species. The dogs are tested regularly to maintain their certification. Detector dogs in New Zealand are owned by DOC staff or several private operators.

Dogs can be highly sensitive and accurate at differentiating between target species and are trained to detect indirect (e.g. animal trails, scats) and direct (live animal) scents. Rodent detection dogs detect rodent scent from scent trails, including urine (Russell 2007; Russell et al. 2008). The success of trained dogs was demonstrated by Gsell et al. (2010) and Shapira et al. (2011) on low densities of Norway rats under experimental conditions. Glen et al. (2014) compared the cost effectiveness of camera traps and detector dogs for the detection of feral cats and reported that although comparable, dogs are a fast, reliable and inexpensive way of monitoring, and can help with catch and removal of pest species.

While dogs have considerable capacity for detecting scent, a future development in this area could involve the use of electronic noses (e-noses) with nanomaterial-based sensors. Recent research suggests that the detection of gas volatiles using e-noses will eventually be critical for environmental monitoring, chemical process control, agriculture, and even medical applications (Xu et al. 2017). Accordingly, the future ability to detect pests using e-noses in the field could provide a step-change in pest animal monitoring. Research is being carried out by Plant and Food (funded by NZBH-NSC) investigating the potential of using DNA-based detectors for environmental/pest monitoring.

Best practice is available through the DOC dog/handler team standard operating procedure. National standards and protocols exist for all conservation dogs and their handlers, whether they work on DOC-administered land, on private land where a DOC permit is required to handle protected species, or are looking for pests in areas where there are protected species.

6.2.3 Knowledge gaps

- For all devices we require more attractive, long-life and standardised lures.
- For all techniques, especially camera traps, we need a better understanding of the relationship between index values obtained from different devices and those indices and actual abundance.
- For techniques that require species identification, we need automated, accurate, species-recognition tools.
- For all techniques we need to determine relative cost effectiveness.
- For electronic techniques we need a better understanding of costs, field practicality and longevity.
- Current tools (with the possible exception of camera traps) are not sensitive enough to detect predators at low densities (e.g. stoats) in varying habitat conditions.
- To enable the use of DNA we need to develop techniques to reduce both field and extraction costs.
- VHF/GPS continues to be expensive and has animal welfare issues.
- To select from the range of tools for detection we need better estimates of their detection sensitivities.

6.2.4 Market failures

- Although there are many different monitoring tools, there is little, if any, information on the best lure type to use, or the relationship between the index and conservation or disease thresholds for species other than possums.
- More recent techniques such as camera traps have no best practice documentation and can have very high labour input requirements for the analysis of photos.
- Most cameras have been designed for hunters and security tracking. As such, they have not been specifically designed for monitoring small and fast-moving wildlife.
- There are few options available for rapid DNA extraction in New Zealand, and so the costs remain high.

6.2.5 Recommendations

There is a need to:

- conduct trials comparing accuracy and precision of monitoring techniques in direct relation to abundance and conservation thresholds
- develop an attractive, long-life and standardised lure for the three key target species to increase detection sensitivity
- better understand encounter and interaction rates for all three target species with monitoring and control devices
- test low-cost, disposable, drop-off mortality collars for all three target species
- explore the costs of off-shore or in-house DNA extraction.

6.3 Priority area: lures and baits

6.3.1 Context

Pest control, monitoring and surveillance operations require effective ways to attract animals to control devices. Current practice is to use primarily food-based or visual lures that attract target animals to control devices such as traps by using sensory cues (Clapperton et al. 2006). The lures can attract target animals from a distance (visual) and focus the animal's attention (food-based) on the control device (Clapperton et al. 2006). Baits are defined as edible materials and can also act as a lure, but are primarily designed for consumption by the target animal to deliver the toxin (Clapperton et al. 2006). Lures that are cost effective and long lasting have led to current research in scent, sensory and audio lures.

6.3.2 Lure and bait methods in use

Food-based baits/lures

A wide range of food-based lures and baits are used, depending on the target species. These range from fresh prey items (e.g. hen's eggs, fresh rabbit), to long-life/preserved material (e.g. freeze-dried rodents, salted rabbit), to commercial items (e.g. pet food, jerky, chocolate, peanut butter, cereal, flour, icing sugar, tallow (Dilks et al. 1996; Brown 2003; Clapperton 2006).

For stoats, cracked domestic hen's eggs, rodent and rabbit meat have been widely used in traps or to deliver toxins, and as an effective lure (Dilks et al. 1996; Spurr 1999; Montague 2002; Brown 2003). In cage trials by Clapperton et al. (2006) and field trials by Pierce et al. (2007), stoats were found to prefer fresh rabbit meat over long-life formulations such as freeze-dried rabbits and rodents, salted rabbit, synthetic extracts (e.g. anal sac glands), and commercial products such as human and pet food. However, fresh materials can rapidly deteriorate (Miller 2003), and can be attractive and a risk to non-target species, thus making bait replenishment costly and labour intensive (Jackson et al. 2016).

Although prey-based items are the most attractive to stoats, Pierce et al. (2007) suggested salted rabbit is a practical compromise. Community groups that have access to rabbit carcasses preferred salted rabbit to eggs and found it to be effective (Otanewainuku Kiwi Trust 2005). In situations where bait shyness may be an issue, Clapperton et al. (2006) suggested more expensive long-life bait options such as freeze-dried mice or wax/tallow rabbit baits could be used. NPCA (2015d) recommend a combination of uncracked hen's egg, with fresh, salted or dried rabbit to be best in traps.

For rodents, the most commonly used lure for rats is peanut butter. However, in field trials conducted by Jackson et al. (2016), fat-based products such as cheese, chocolate, Nutella® and walnuts were identified as more attractive to rats.

Current standard lures for possums are cinnamon and icing-sugar and flour mix (Warburton & Yockney 2009; Jackson et al. 2016). Flour and icing-sugar, although visibly distinct and attractive to possums, washes off quickly or gets eaten by rodents (Thomson et al. 2002; Ogilvie et al. 2006). In Jackson et al.'s (2016) field trials using almond, apricot, pineapple, raspberry, vanilla and walnut, all outperformed cinnamon, and these were recommended for further consideration. Sweetapple and Nugent's (2011) research on chewcards used peanut butter as a possum and rodent lure, and they commented that a mix of peanut butter, icing-sugar and ground-lucerne pellets was the best possum attractant tested.

Best practice information on the best baits/lures to use with which traps is available for stoats (NPCA 2015h, 2015i); possums (NPCA 2015h, 2015f, 2015d) and rodents (Gillies 2013c).

Commercial lures/baits

Numerous commercial lures, baits and pre-feeds have been developed from early trials on food-based baits and lures, such as Lure-It™ Salmon for mustelids (Connovation Ltd); Lure-It™ Possum Lure (aniseed lure by Connovation Ltd); Lure-it™ Peanut (rodents by Connovation Ltd); Stoat RM Formula (Goodnature Ltd); and Rat Lure (a chocolate-based polymer mix by Pest Control Research Ltd). Better ways of delivering the lure/bait have also been developed. For example, Connovation Ltd have developed ceramic lures that are soaked in a scent; Goodnature have lure bottles that attach to pumps; and Zero Invasive Predators have also investigated lures as part of their border security at their Bottle Rock field site.

Other research has tested three formulations (polymer, gel and paste) on captive stoats, and although fresh meat was more attractive, the stoats consumed enough of the polymer and paste bait to receive a fatal dose if toxin was present (Henderson et al. 2002). Clapperton et al.'s (2006) study on the palatability and longevity of fresh and commercial baits/lures for stoats included gelatine-injected, freeze-dried mice and a wax/tallow/rabbit meat mix, and reported these to be an attractive, long-lasting alternatives to eggs and salted rabbit. Meat polymer bait from Trappers Cyanide Ltd was compared to eggs in a 27-month trial at Lake Rotoiti and reported the bait to be as effective as fresh eggs at attracting stoats and rats. Also, researchers in Australia have developed a small meat-based sausage for feral cat control, called Curiosity® (Johnston et al. 2013).

More recently, Waters et al. (2017) conducted field studies on the new combined olfactory and visual lure, cinnamon/aniseed Lure-it® Spray and Blaze (Connovation Ltd) with the standard lure being a mixture of flour and icing sugar (1 part icing sugar: 4 parts flour). They reported Lure-it® Spray and Blaze to be long lasting and attractive to possums, increased effectiveness of monitoring possums, reduced rat interference, and recommend larger-scale field studies to be undertaken to test the preferences between lures.

Finally, Gould et al. (2007) compared a chemical lure (insect pheromone) to peanut butter and confirmed peanut butter to be the most effective lure for wild rats. However, Jackson et al.'s (2016) work on rodents' food preferences found fat-based products such as cheese, mild chocolate, Nutella® and walnuts to be successful for rats and possums.

Best practice documentation is available for Lure-it™ products by Connovation Ltd, such as Lure-it™ Salmon and Lure Pumps by Goodnature Ltd. Best practice is available for baits such as Eraz Paste Mustelid trap bait by Connovation Ltd (taking over the previous work by Henderson on Eraz formulations).

Sensory lures

To improve the efficacy of lures and baits, a limited number of trials have been undertaken by determining the sensory effect of colour, visual and movement cues of materials for stoats and possums. Warburton and Yockney (2009) conducted field trials assessing flour and icing-sugar lure on white backing boards. Visual cues such as tin foil have been reported to be traditionally used by trappers. Highly visible photo-luminescent tags that enhance the attractiveness of PCR WaxTags®, bait stations, traps and ground baits are available from Connovation Ltd (ConnoGlow Night Glow Lure) and Pest Control Research (GloTag). A field study by Ogilvie et al. (2006) assessed whether luminescent PCR WaxTags® were more attractive than plain PCR WaxTags® with a flour blaze and placement above the ground. In this study, possums favoured the flour blaze over the luminescent PCR WaxTag® and raising tags above the ground did not alter detectability.

Hamilton (2004) demonstrated brightly coloured trap covers to be more successful at trapping stoats when compared to duller colours, with yellow the most successful. However, Robbins et al. (2007) found captive stoats did not prefer one colour over another. Robbins et al. investigated a wide range of visual and movement cues of captive stoats and found visual cues such as mirrors, possum fur and prey-shaped bait to be cheap, practical attractants. Mirrors could increase entry rates into tunnels, and Robbins et al. suggested further investigation in field trials. Moving egg tunnels and swinging baits were also interesting to stoats and have the potential to attract stoats to traps.

No best practice documentation is currently available.

Audio lures

Although research using auditory lures was first investigated in 1995 for attracting stoats (Spurr & O'Connor, 1999), there is limited work on this topic. A sound lure could be used for several months without the problem of decaying, as with food-based lures, and could potentially attract target species from greater distances. Spurr and Connor (1999) used recordings of bird and mammal calls to determine if an electronically produced sound would be capable of attracting stoats. The research found digital recordings of chick, mouse and stoat calls were attractive, although further research on the quality, type, duration and frequency of the sounds was recommended. Kavermann et al. (2013b) suggested that audio lures increased detection rates of possums in low densities for both chewcards and PCR WaxTags®. The Cacophony Project (which is exploring digital sound and images on pest species and MD Lure by NovelWays) are at the stage of field testing an audio possum lure in Taranaki.

No best practice documentation is available.

Live lures

Limited research has been undertaken in this area. A trial to test the effectiveness of using live rodents for improving stoat capture rates was investigated by Lawrence (1999). In this situation it was found that live lures were labour intensive, with daily visits necessary, and it was suggested that nesting material may be more successful. Shapira et al. (2013) demonstrated the potential of using conspecific rats as lures. Norway rats were successfully lured and trapped by caged laboratory rats. In this situation, trapping rates were significantly higher when using live rats. Further research is recommended in conspecific attraction (see below) in other situations and in direct comparison with food-baited traps. The use of caged live Norway rats and bedding as lures in field trials significantly increased detection rates of wild rodents; wild rats were equally attracted to female and male scent and bedding (Gsell et al. 2014).

No best practice documentation is currently available.

Scent/odour lures

Many scent lures are in use to improve the efficiency of baits and traps used in monitoring and control. Manufacturers such as Connovation Ltd use cinnamon, aniseed and salmon in spray-on oils to attract possums and stoats, and cinnamon is now the most commonly used standard for possum control (Jackson et al. 2016). With the reduction of pest species due to improved control methods, attracting solitary animals like possums and stoats is difficult, especially when numbers are low or alternative food sources are abundant.

Many trials on non-food-based lures have been undertaken over the years. For example, the nectar of *Dactylanthus taylorii* flowers was investigated by Ecroyd et al. (1995) as a potential possum lure by extracting a synthetic nectar. However, cinnamon proved to be more effective as a lure. Clapperton et al. (1989), Spurr et al. (2004) and Clapperton et al. (1994) carried out studies of synthetic lures using anal sac components of ferrets and stoats. Ferrets demonstrated an increased interest in the lures, but stoats did not.

Clapperton et al. (2006) used captive stoats to test the efficacy of chemical extracts of prey items and anal sac secretion, but with little success. Wild rats were attracted to the scent of caged live Norway rats and bedding, and the need to investigate rat-scented monitoring stations was suggested by Gsell et al. (2014) and Shapira et al. (2013). A study using captive mice fed high- and low-protein diets found that mice preferred to be near the urine of other mice that ate high-protein diets (Shapira 2013).

More recently, scent lures containing urine odours (Linklater et al. 2013) or secretions from oestrus female or male stoats and possums have been being investigated for their reproductive secretion attractiveness by Victoria University, Manaaki Whenua and Lincoln University. Further research is currently underway to identify differences in the components of breeding and non-breeding females and males to develop synthetic formulations to attract possums. The use of body odour from a dominant predator (i.e. ferret) was field tested as a lure for pests (stoat, ship rat, hedgehog), and camera traps recorded increased observations of all three species, with a three-fold increase in stoat detections (Garvey et al. 2017).

No best practice documentation is currently available.

6.3.3 Knowledge gaps

- The inclusion of fat in rat baits and protein in possum baits needs to be further explored.
- We need to develop better long-life and standardised lures for predators.
- For all lures, we need to better understand interaction versus encounter rates.
- For all techniques, we need to determine relative cost-effectiveness and lure longevity.
- For all lures, we need to determine the optimal mix of different sensory lures.
- For scent-based lures, we need to identify the key chemical components of lures and synthesise artificial actives.

6.3.4 Market failures

As with monitoring tools, there are many different lure options, but there is no information on which lures work best or what combination of lures is most attractive for possums, stoat and rodent control.

The development of synthetic lures will require long-term funding commitment, with a multidisciplinary research team. This is unlikely to happen, with commercial developers working independently because the commercial market is too small.

6.3.5 Recommendations

There is a need to:

- conduct trials comparing the effectiveness, field longevity and cost-effectiveness of new commercial lures
- advance our understanding of the need to include fat, protein and other additives in rat, possum, and especially stoat baits with the aim of developing standardised baits suitable for ground and aerial control
- investigate a combination approach to lures and determine the best mix of sensory attractants.

6.4 Priority area: automated poison dispensers

6.4.1 Context

Trapping possums, rodents and mustelids is expensive because most traps only capture a single animal and require frequent checking to clear and reset. Also, single-capture kill traps can be set off by other pests and remain inactive until a trapper returns, sometimes weeks or months later. This is not desirable, particularly around beech masting events, when predator numbers can rapidly increase. Most poison dispensers have been designed to maintain predator numbers at low levels, and to prevent reinvasion by remaining active for long periods in the field. While multi-kill traps have also recently been developed that are multi-species (see below), the automated poison dispensers have generally been developed to be target specific, with triggering mechanisms developed to avoid non-target species. The poison dispensers could also be used to deliver species-specific toxins as they are developed and registered.

Felixer®: feral cats

Following previous unsuccessful trials on Kangaroo island using Cat Assassin tunnels (Ecological Horizons) and Spitfire tunnels (Connovation – see below) in 2013, the Felixer® (Ecological Horizons) fires sealed doses of PAPP gel at 60 m/sec at passing feral cats and can deliver up to 20 doses before servicing (Read et al. 2014). The device incorporates four rangefinder sensors, a programmable audio lure, a camera that photographs all activations and a solar-charged battery. Field trials at Venus Bay Conservation Park, Flinders Ranges National Park, and Arid Recovery in South Australia have several confirmed feral cat kills without being activated by non-target marsupials.

Pied Piper: rats

This device attracts rats using a bait station with pheromones (developed by Advanced Animal Technologies and a UK consortium). When the rat trips the movement sensor, the processor activates the aerosol spray containing cholecalciferol. A lethal dose of the chemical sprayed onto the rat's back is absorbed through its skin in 15 to 20 minutes. One device can kill up to 250 rats before servicing is required. No field trials have been run in New Zealand, but the agent is looking to register the device in New Zealand and Australia.

Spitfire: possums

This is a tree-mounted device, which requires a possum to stand on a weight-activated platform and simultaneously touch a lured upper trigger. When triggered, the device dispenses a measured dose of a palatable gel (5–100 doses) containing zinc phosphide onto the possum's abdomen. The possum then ingests this paste through grooming. The device is currently being field trialled in Project Janszoon (Blackie et al. 2016).

Spitfire: stoats

This device can be retro-fitted into a DOC200 trap box and works by firing PAPP paste onto the belly of a stoat as it passes through a tunnel and then resetting. Each Spitfire can deliver approximately 100 doses and is fitted with a counter and a delay mechanism. The device was field trialled in the Blue Mountains in 2012 using 65 units. The stoat tracking rate reduced from 100% to 27% within 2 weeks of deployment, versus a stable tracking rate in the non-treatment area (Elaine Murphy, DOC, pers. comm., 2017). Device reliability became an issue after 6 weeks in the field.

Spitfire: rats

As for stoats, but the device is filled with 1080 gel (0.55% wt/wt) to target rodents. In pen trials 15/15 wild Norway rats and 14/15 ship rats were killed. The device has been tested in the field and a significant reduction in tracking rates was observed. However, device reliability was again an issue.

6.4.2 Knowledge gaps

- There is limited information on efficacy, cost-effectiveness and field longevity.
- There is a need for information to better understand the relationships between pest density, number of potential kills, and required time between checks.

6.4.3 Market failures

- Development and commercialisation have been slow because of weak commercial incentives to fund the necessary R&D.

6.4.4 Recommendations

There is a need to:

- ascertain which prototype devices have potential for field evaluation and then run comparative field trials.

6.5 Priority area: traps

6.5.1 Context

In New Zealand, vertebrate pest control relies on traps, both for control and monitoring. For each of the key species targeted as part of PF2050 (possums, ship rats and stoats) there are live capture and kill traps available. Over the past 5 to 10 years there have been a number of traps developed or modified in New Zealand for these species, and users currently have a relatively large number to choose from (especially rodent traps). With the recent increase in the number of community groups involved in pest control there has also been an increasing demand for easy-to-use traps.

Leg-hold (foot-hold) traps are generally only used for possums, with both rats and stoats targeted with kill traps. In 2007 the Animal Welfare (Leg-hold Traps) Order 2007 prohibited the use of the larger leg-hold traps, with the No 1 sized double-coil spring traps now the most commonly used. Although kill traps that cause unacceptable pain and distress can also be prohibited, so far none have been. Regulations were also issued in 2009 under the Animal Welfare Act 1999 to restrict the sale and use of glueboard traps for rodents from 1 January 2015, except under ministerial approval.

Apart from the 2007 Leg-hold Trap Order and the 2009 glue-board regulations, any trap can be bought and used for trapping any species. The only other trap restriction relates to the checking time of restraining traps (leg-hold and cage traps). These traps must be inspected within 12 hours of sunrise the day after they were set or checked.

Although a variety of trap models are available for purchase, there is little, if any, information available on the animal welfare and relative capture performance of traps. In other words, for most traps the purchaser has no access to up-to-date information on which traps might have the highest capture rates, or which kill traps kill consistently and quickly, or best practice guidelines for using specific traps.

Operationally there has been a recent focus on multi-capture traps, using networks of traps for large-scale (regional) pest control programmes, coupled with wireless monitoring to make large-scale trap networks more cost-effective.

6.5.2 Recent/current research

Goodnature A12 and A24 kill traps

DOC have carried out extensive trials of these CO_2-powered traps, with the A24 used to target rats and stoats and the A12 to target possums. Early mixed results were believed to have been a result of either a reduction in the mechanical performance of the trap over time (e.g. loss of CO_2) or to improvements to lures in successive trials (Gillies et al. 2014). However, more recent trials using proven lures and more reliable versions of the A24 have resulted in successful reductions of rats (C. Gillies, DOC, pers. Comm. May 2017).

Trap network optimisation

Manaaki Whenua have been collaborating with Hawke's Bay Regional Council staff in their Cape to City project to determine the optimal layout of kill traps. This research has resulted in the development of a web-based app that enables operational staff to run simulations to determine trap spacings and checking frequencies that maintain trap network effectiveness but minimises costs.

Wireless monitoring of trap networks

See section below on wireless technology.

Multi-capture traps

Because multi-capture traps such as the Goodnature traps are relatively expensive (c. $170), and because they still need to be checked at 3–6-monthly intervals, there are questions about the cost-effectiveness of using such traps compared to using single-capture traps. To try to answer these questions, Warburton and Gormley (2015b) used an individual-based spatial model to estimate the number of animals likely to be caught in multi-capture traps and at sites that had increasing numbers of single-capture traps. For maintaining possums, stoats and ship rats at low densities, modelling indicated that two to three single-capture traps at an individual site could be more cost-effective than more expensive multi-capture traps. This result was based on a monthly trap-checking frequency, so longer periods between checks would increase the value of the multi-capture traps.

Capture efficiency

Manaaki Whenua carried out research funded by the Ministry of Business, Innovation and Employment that examined how different trap sets influence the encounter and interaction rates of possums with leg-hold traps. The data are still being analysed, but initial results suggest trap sets can be modified to increase capture rates. As a subset of this research, Manaaki Whenua also examined the use of oestrus female urine as a pheromone-based lure to increase capture rates of traps, and current work is now focused on developing a synthetic formulation as an easy-to-use trap lure. Victoria University has also been investigating the value of using pheromone lures to increase trap interaction rates (http://www.victoria.ac.nz/sbs/research-centres-institutes/centre-biodiversity-restoration-ecology/pdfs/Mammalian-pheromone-lures-Poster.pdf).

Low-cost rat and stoat trap

Because community groups are becoming increasingly involved in pest control, Manaaki Whenua worked with Pest Control Research Ltd to modify and test the Victor snap-back trap as a low-cost kill trap for stoats and rats. A plastic shroud that covers the trigger and bait was developed, along with a modification to the trap’s trigger. The trap passed the NAWAC trap-testing guidelines for both stoats and ship rats (Morriss & Warburton 2014).

Kill trap testing

Manaaki Whenua continues to test kill traps for their killing performance (using the NAWAC trap-testing guidelines) as a commercial service on request. Four new trap designs have been tested over the past 2 years.

6.5.3 Knowledge gaps

- There needs to be information on the cost-effectiveness of Goodnature traps for different target species, strategic fit and use at different pest densities.
- If traps are to be used in low-density maintenance situations or for eradication, there is a lack of long-life lures for each target species.
- There are few, if any, robust capture efficiency data for a range of kill traps used for each of the target species.

- Kill traps typically have lower capture rates than leg-hold traps, and kill trap designs need to be improved to increase kill trap capture efficiencies.
- There are few, if any, data on the killing (welfare) performance of most rodent kill traps.
- There are few data on how to maximise capture rates when using kill or leg-hold traps (i.e. what lures, baits, or setting method to use).
- There is a lack of information on the cost-effectiveness of using wireless monitoring or what systems are most appropriate.
- There is a market gap for kill traps that can target possums but exclude cats.
- There is potential for biodegradable trap designs that could be aerially applied for rats and stoats.

6.5.4 Market failures

- There is a lack of robust consumer information to help purchasers of traps make informed decisions. There are some NPCA guidelines that need updating, and DOC have a document on best practice use of Goodnature self-resetting traps.
- Because the Animal Welfare Act 1999 does not require traps to be approved before sale or use, there are few incentives for trap manufacturers to make traps than meet any minimum welfare performance standard. However, because some trap purchasers choose to buy traps that meet the NAWAC trap testing guidelines (e.g. DOC), there is positive market incentive for trap manufacturers/marketers to have traps tested.
- There is currently no website that trap users can use to find up-to-date information on traps.

6.5.5 Recommendations

There is a need to:

- test the capture efficiency and selectivity of the top five most popular kill traps for each target species using both commonly used lures and baits, and novel lures and sets, and then to develop product information to enable purchasers of traps to make informed choices
- develop best practice guidelines for using traps
- develop kill traps with improved capture efficiencies
- develop a range of long-life lures for use in kill traps (see section on lures and baits)
- seek ideas for development of a kill trap for possums that will exclude domestic (pit-tagged) cats
- seek ideas for development of biodegradable rodent traps for ground and aerial application
- determine the cost and benefits of using wireless networks for monitoring traps across a range of potential applications (see section on wireless trap monitoring).

6.6 Priority area: wireless trap monitoring

6.6.1 Context

Vertebrate pest control in New Zealand has been evolving over the last decade, from a paradigm of control applied periodically with intervening periods of no control, to essentially continuous control so that pest numbers are maintained at low levels (presumably below some threshold at which desired values are protected). There has also been a desire to increase the scale of control programmes, with some now covering hundreds of thousands of hectares. This evolution of control programmes has seen the increasing use of permanent networks of live- and kill-traps, with a wide range of setting and checking regimes employed. However, irrespective of the implementation details, a common outcome is that pest numbers are held at low density and, especially when having to check live-capture traps daily, the majority of traps checked have no captures. Once a trap network is established (i.e. the initial capital cost is committed), the main cost of running a network is staff or contractor time to check the traps.

Wireless systems have been developed recently to enable a wide range of environmental sensors to be monitored remotely and, if required, in real or close-to-real time. Traps, both live and kill traps, are set and checked in a wide range of scenarios, and the addition of remote monitoring using wireless systems might generate few economic benefits for some scenarios and potentially large benefits for others. At this stage of wireless network development and adoption there is little robust information available to inform land managers whether they should invest in such technology.

6.6.2 Recent/current research

Zero Invasive Predators (ZIP) has been monitoring leg-hold traps using a wireless mesh network within their barrier system at Bottle Rock. This system runs on a frequency of 2.4 GHz and requires nodes (traps) to be close (20–30 m) so they can communicate with each other.

Econode (https://www.econode.nz/), a remote sensing company, has developed a wireless trap monitoring system called TrapMinder. They are looking at using KotahiNet (a LoRaWAN, 'internet of things'- based system). An initial trial has been established in Glenfern Sanctuary (Great Barrier Island) to test it at a small scale, and then to consider how it could be practically implemented on a much larger scale (https://glenfern.maps.arcgis.com/apps/Viewer/index.html?appid=8da3b4403b7e4c7dba91f7425a192500).

Hawke's Bay Regional Council has been working with Encounter Solutions, who have developed a wireless trap monitoring system, Celium (http://www.encounter.solutions/celium/). Product development and its application are at an early stage, with some technical issues being addressed. An initial trial was used to monitor live-capture cage traps, and a second trial is being established to use the system for monitoring kill traps. This system communicates using 160 MHz, and each node (trap) communicates with a central hub (i.e. it is not a mesh network).

Manaaki Whenua have also been involved in assessing the potential economic benefits of using wireless trap monitoring and have identified a number of factors that can influence whether using such networks is cost-effective (see Jones et al. 2015; Warburton et al. 2015). Manaaki Whenua are currently carrying out an economic analysis of wireless trap data collected in the first Hawke's Bay Regional Council Cape to City trial.

6.6.3 Knowledge gaps

There is a need to know:

- what wireless monitoring technology is available (there are possibly other manufacturers/developers additional to those listed above)
- the technical dependability of the technology and the field-life expectancy of it – its dependability affects its use for restraining traps because the technology needs to meet MPI animal welfare guidelines
- the costs and benefits of using this technology.

6.6.4 Market failures

- There are no significant market failures, although not knowing the size of the potential market constrains how much risk developers are willing to take in scaling up. Unit price depends on the number of units manufactured/sold.
- MPI have been proactive in developing a guideline for the use of wireless networks for monitoring traps because of the requirements of the Animal Welfare Act 1999 to inspect restraining traps daily, and what 'inspect' actually means (i.e. does remote monitoring constitute an inspection?).

6.6.5 Recommendations

There is a need to:

- test wireless networks' reliability and cost-effectiveness across a range of trap network scenarios, including live and kill traps
- develop guidelines for using wireless networks for monitoring trap networks.

6.7 Priority area: scaling up to regional operations

6.7.1 Context

The size of control areas has always been, and still is, limited by control costs. Even so, there has been a recent desire to increase the area of control programmes. This has been especially prevalent in farm landscapes, where regional councils have developed large-scale possum and/or predator control programmes (e.g. the Hawke's Bay Regional Control Possum Control Area programme covers about 700,000 ha, and Horizons 1.1 million ha). For Crown lands, most large-scale programmes rely on aerial application of 1080 baits that target possums, ship rats and stoats. For example, as part of OSPRI's TBfree programme, a single operation covered about 90,000 ha, and a recent Battle for the Birds programme in 2016 covered over 800,000 ha.

Scaling up aerial operations is relatively simple because of the fixed costs associated with, and the standard methods used for, applying baits and the short time frames the control effort is actually applied. In contrast, ground-control operations are more challenging because of the need to get bait stations or traps into the home ranges of each of the different target species. This requires using a range of device spacings. Also, ground-control operations are generally more protracted, and costs per hectare can increase as the size of an area increases because of travel time.

In terms of PF2050, scaling up also requires a shift from what has essentially been limited to uninhabited areas to peri-urban and urban areas, and this shift poses additional challenges. A critical factor related to scaling up, especially if eradication is the goal, is to have effective perimeter control to prevent or significantly slow reinvasion.

6.7.2 Recent/current research

A key objective of the Zero Invasive Predators (ZIP) programme is to develop methods for protecting a control area perimeter without using expensive exclusion fencing (ZIP 2016). This work is still at an early stage, although initial results indicate that a high proportion of 'invaders' can be intercepted, albeit at a relatively high cost. They are also looking at developing improved methods for detecting survivors, and elimination (see section on monitoring and detection).

A key objective of Hawke's Bay Regional Council's Cape to City programme is to scale up predator control across non-Crown lands. A range of projects are underway to provide information on how to more cost-effectively scale up and how best to address social and community constraints. Some initial reports include Brown et al. 2016, Glen & Byrom 2014, and Warburton & Gormley 2015a.

Manaaki Whenua have been carrying out research funded by OSPRI looking at application strategies for reducing the costs of aerial 1080 operations. This has involved re-engineering fixed-wing aircraft, but because of market constraints (see below) adoption has been slow.

Glen et al. (2013) reviewed pest eradications from uninhabited and inhabited islands and reported that the presence of people creates regulatory, logistical and socio-political constraints. Real or perceived health risks to inhabitants, pets and livestock may restrict the use of some eradication tools, and communities or individuals sometimes oppose eradication.

6.7.3 Knowledge gaps

- What are the optimal spatial strategies for rolling out a large-scale eradication programme (i.e. do everywhere at once, have a rolling front, or have core areas that are expanded until they connect with neighbours)?
- If eradication is the management objective, then how is eradication reliably confirmed at large scales?

- How can we control rats (ship and Norway) cost-effectively across large areas of farmland where aerial application of poison baits is not an option?
- How do we best integrate control of multiple species across large areas? Are there some tools that are better at targeting multiple species than others?
- For large-scale maintenance control, what is the optimal trap/bait-station network design to provide the most cost-effective programmes?
- How do we achieve effective eradication of pests in an urban environment with rodents below ground (e.g. in sewers) and above ground (e.g. in high-rise buildings).
- What role can commercial pest control companies play in achieving PF2050?
- How are social/landowner/volunteer factors best accounted for or accommodated in effective large-scale control or eradication programmes? Are there tools (e.g. apps) that can assist with this?
- How can technology (e.g. wireless monitoring) best be used to assist with scaling up?
- What alternative tools are available for achieving effective control or eradication of pests in aerial 1080 exclusion zones?
- How do we cost-effectively detect residual individuals (see section on monitoring and detection)?

6.7.4 Market failures

- The market has failed to address the anticoagulant residue problem.
- The market has yet to respond to scaling up in terms of finding optimal large-scale, longer-term strategic approaches and pricing for carrying out control over large areas.

6.7.5 Recommendations

There is a need to:

- develop guidelines for using anticoagulants that minimise residue profiles in non-target species
- work with the Ministry of Health to develop tool applications that can potentially achieve eradication of pests in aerial 1080 exclusion zones
- develop ‘proof-of-eradication’ tools for use over large areas
- develop simulation tools for comparing the cost-effectiveness of competing scenarios for rolling out large-scale eradication programmes
- develop simulation tools for optimising large-scale trap and bait-station networks
- develop species-selective toxins that can be aerially applied across farm landscapes
- determine the effectiveness of current rodent control tools for achieving eradication in urban environments
- determine how best to cost-effectively detect survivors
- determine the cost-effectiveness of using wireless technology to enable the scaling up of control programmes (see section on wireless trap monitoring).

6.8 Priority area: repellents

6.8.1 Context

In the context of PF2050 there are two main needs for repellents:

- to protect non-target species (e.g. kea or deer) from poison baits
- to potentially repel immigrants from penetrating a perimeter barrier.

Most research carried out has focused on identifying chemical repellents (odour and taste) to repel non-target species. There has been very little research on the effectiveness of using either auditory or chemical repellents as spatial barriers.

Non-target bird deaths resulting from aerial 1080 operations have been a concern for several decades, but improvements in bait quality, reduction in bait sowing rates, and the use of cinnamon (primarily used to mask the taste of 1080 but with some minor bird repellency) has led to operations now causing very few bird deaths (Morriss et al. 2016). Kea, however, are an exception, with some recent 1080 operations killing an unacceptable number of these birds. As a consequence, recent research has focused on developing specific kea repellents.

Hunters have been and continue to be vociferous opponents of aerial 1080 operations, and considerable effort has been made to develop and test a deer repellent for 1080 baits (Morriss & Nugent 2008; Morriss & Nugent 2009). An effective product (EDR) was developed by EPRO Ltd, and was first trialled in 2002 (Lorigan et al. 2002). Subsequently, many 1080 operations have used EDR, with possum, ship rat, deer, and bird kills monitored (Morriss 2007; Nugent et al. 2012; Morriss et al. 2016).

However, there is a continuing operational reluctance to use EDR as a default additive because it doubles the price of the bait and causes significant logistical issues, with bait having to be transported to Taupō for coating before being re-routed to the operational area. The industry believes the current cost of adding EDR to bait is too high because there is no competitive product. Although other pest product manufacturers have potential deer repellent products, these have been slow to be commercialised because of the cost of registering a new bait formulation and entering what would be a competitive market with a limited New Zealand-only demand. For example, the initial trials and data collection required for registering EDR were mostly funded by OSPRI.

6.8.2 Recent/current research

Bird (kea) repellents

Recent research has focused on two repellents (d-pulegone and anthraquinone) as kea repellents. Trials have not been wholly successful, because d-pulegone dissipates too rapidly between the time of bait manufacture and operational use (Crowell et al. 2016), and anthraquinone is not adequately acceptable to rats (Cowan et al. 2015). Consequently, a review of possible alternatives was carried out, with tannic acid, ortho-aminoacetophenone and garlic identified as worthy of further investigation (Cowan et al. 2016).

Deer repellents

Recent research on EDR has been confirming its effectiveness for reducing by-kill on a wider range of ungulate species (e.g. sheep, fallow and sika deer) and assessing whether its effectiveness is reduced when baits are sown in clusters or strips compared to being broadcast (Morriss et al. 2016).

6.8.3 Knowledge gaps

- Can the decay rate of d-pulegone be reduced by encapsulation or some other method?
- Is tannic acid or another potential repellent a potentially better repellent than d-pulegone or anthraquinone?
- Can competitive deer repellents be developed, and will they reduce the market price of using them?

6.8.4 Market failures

- The potential market size for deer repellents is not large, and without agency funding individual pest product companies cannot afford to develop and register new products.

6.8.5 Recommendations

There is a need to:

- develop new formulations of d-pulegone (to slow its decay) or new products that are effective at repelling kea
- support the testing and commercialisation of competitive deer repellents.

7 Overall recommendations

The following recommendations are a prioritised list based on perceived market needs identified by the authors, and subject to external review by stakeholders. Priorities are based on knowledge gaps, how close to market a tool is, the probability of success, and the likely size of the benefits to PF2050 of the tool becoming available. The recommendations are grouped into priority areas and then ranked from high to low priority within each area. From each of these priority area lists we have then selected the top 10 overall priority research needs.

7.1 Priority area: toxins

- Conduct comparative trials using aerial 1080 with mixtures of sowing rates, new multispecies baits and pre-feeding regimes to enable consistent high kills for all target species.
- Conduct ground-based field trials comparing the efficacy and cost-effectiveness of all newly registered VTAs against current industry standards.
- Progress diphacinone + cholecalciferol (D+C) as an effective alternative to brodifacoum.

- Conduct research to enable the registration of norbormide or its close equivalents as a rat-specific toxin.
- Develop an effective bird repellent for high-risk bird species.

7.2 Priority area: monitoring

- Conduct comparative trials comparing the accuracy and precision of monitoring techniques in direct relation to abundance and conservation thresholds.
- Develop an attractive, long-life, standardised lure for the three key target species to increase detection sensitivity.
- Gain better understanding of encounter and interaction rates for all three target species with monitoring and control devices.
- Test low-cost, disposable, drop-off mortality collars for all three target species.
- Explore the costs of off-shore and in-house DNA extraction.

7.3 Priority area: lures and baits

- Conduct comparative trials comparing the effectiveness, field longevity and cost-effectiveness of new commercial lures.
- Advance our understanding of the need to include fat, protein and other additives in rat, possum and (especially) stoat baits with the aim of developing standardised baits suitable for ground and aerial control.
- Investigate a combination approach to lures and determine the best mix of sensory attractants.

7.4 Priority area: automated poison dispensers

- Ascertain which prototype devices have potential for field evaluation and then run comparative field trials.

7.5 Priority area: traps

- Test the capture efficiency and selectivity of the top five most popular kill traps for each target species using both commonly used lures and baits, and novel lures and sets, and then develop product information to enable purchasers of traps to make informed choices.
- Develop best practice guidelines for using traps.
- Develop kill traps with improved capture efficiencies.
- Develop a range of long-life lures for use in kill traps (see section on lures and baits).
- Seek ideas for the development of a kill trap for possums that will exclude domestic (pit-tagged) cats.
- Seek ideas for the development of biodegradable rodent traps for ground and aerial application.

- Determine the costs and benefits of using wireless networks for monitoring traps across a range of potential applications.

7.6 Priority area: wireless trap monitoring

- Test wireless networks' reliability and cost-effectiveness across a range of trap network scenarios, including live and kill traps.
- Develop guidelines for using wireless networks for monitoring trap networks.

7.7 Priority area: scaling up to regional operations

- Develop guidelines for using anticoagulants that minimise residue profiles in non-target species.
- Work with the Ministry of Health to develop tool applications that can potentially achieve eradication of pests in aerial 1080 exclusion zones.
- Develop 'proof-of-eradication' tools for use over large areas.
- Develop simulation tools for comparing the cost-effectiveness of competing scenarios for rolling out large-scale eradication programmes.
- Develop simulation tools for optimising large-scale trap and bait-station networks.
- Develop species-selective toxins that can be aerially applied across farm landscapes.
- Determine the effectiveness of current rodent control tools for achieving eradication in urban environments.
- Determine how best to cost-effectively detect survivors.
- Determine the cost-effectiveness of using wireless technology for enabling the scaling up of control programmes (see section on wireless trap monitoring).

7.8 Priority area: repellents

- Develop new formulations of d-pulegone (to slow its decay) or new products that are effective at repelling kea.
- Support the testing and commercialisation of competitive deer repellents.

7.9 Overall top priority research needs

This list of the top 15 research needs has been selected from the above priority area recommendations but has not been sorted into a final overall priority order. This will be done by stakeholder feedback. Once this feedback has been received the list will be updated.

- Progress diphacinone + cholecalciferol (D+C) as an effective alternative to brodifacoum.
- Develop kill traps with improved capture efficiencies.
- Conduct comparative trials comparing the accuracy and precision of monitoring techniques, particularly camera traps, in direct relation to abundance and conservation thresholds.

- Advance our understanding of the need to include fat, protein and other additives in rat, possum and (especially) stoat baits with the aim of developing standardised baits suitable for ground and aerial control.
- Investigate a combination approach to lures and determine the best mix of sensory attractants.
- Test wireless network reliability and cost-effectiveness across a range of trap network scenarios, including live and kill traps.
- Develop simulation tools for comparing the cost-effectiveness of competing scenarios for rolling out large-scale eradication programmes.
- Develop an attractive, long-life and standardised lure for the three target species to increase detection sensitivity.
- Develop new formulations of d-pulegone (to slow its decay) or new products that are effective at repelling kea.
- Conduct ground-based field trials comparing the efficacy and cost-effectiveness of all newly registered VTAs against current industry standards.
- Gain a better understanding of encounter and interaction rates for all three target species with monitoring and control devices.
- Test the capture efficiency and selectivity of the top five most popular kill traps for each target species, using both commonly used lures and baits and novel lures and sets, and then develop product information to enable purchasers of traps to make informed choices.
- Determine how to cost-effectively detect survivors of control.
- Conduct comparative trials using aerial 1080 with mixtures of sowing rates, new multispecies baits and pre-feeding regimes to enable consistent high kills for all target species.
- Ascertain which prototype multi-kill poison devices have potential for field evaluation, and then run comparative field trials.

8 Acknowledgements

We thank New Zealand’s Biological Heritage National Science Challenge for funding this project, all the stakeholders who participated in an initial workshop, and Patrick Garvey for reviewing the report.

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