Perspective

Received: 19 April 2013 Revised: 4 June 2013 Accepted article published: 13 August 2013 Published online in Wiley Online Library:

(wileyonlinelibrary.com) DOI 10.1002/ps.3627

# Innovative developments for long-term mammalian pest control

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## Abstract

**BACKGROUND: Invasive mammalian pests have inflicted substantial environmental and economic damage on a worldwide scale.**

**RESULTS: Over the last 30 years there has been minimal innovation in the development of new control tools. The development of new vertebrate pesticides, for example, has been largely restricted due to the costly and time-consuming processes associated with testing and registration.**

**CONCLUSION: In this article we discuss recent progress and trends in a number of areas of research aimed to achieve long-term population suppression or eradication of mammalian pest species. The examples discussed here are emerging from research being conducted in New Zealand, where invasive mammalian pests are one of the greatest threats facing the national environment and economy.**


**Keywords:** mammalian pest control; innovative developments; invasive species; vertebrate toxins and toxicants; resetting toxicant delivery; multidisciplinary approach

## 1 INTRODUCTION

Invasive species are a substantial threat to biodiversity, causing environmental degradation, modification and species extinctions throughout the world.[1–4] The effects of invaders on biodiversity and natural ecosystems range from direct impacts such as predation, competition and extinction, to complex indirect effects such as altering nutrient cycling within ecosystems.[3,5] Additionally, there are also social and economic costs in terms of damage to agricultural industries, the spread of new diseases and the costs associated with species management.[2,6]

Mammals represent some of the most damaging and widespread invaders. However, new developments in the field of mammalian pest control tools have been relatively slow to emerge, despite many currently employed methods (for example the use of anticoagulants) receiving increasing scrutiny related to humanness and risks to non-target species. Because of the heightened effects of mammalian pests on islands,[3,7–9] countries such as New Zealand have been working to develop novel control tools to address current issues and achieve long-term suppression in a cost-effective manner. This article presents an overview of the New Zealand problem and the novel solutions emerging in the field of mammalian pest control tools.

### 1.1 Mammalian pests in New Zealand

The oceanic archipelago of New Zealand has been geographically isolated for 85 million years, resulting in a unique flora and fauna that are particularly vulnerable to environmental change.[7,8] When humans first settled New Zealand in approximately AD 1280,[9] the only terrestrial mammals present were three species of bats.[10] Since then, 31 species of land mammals have become established through both deliberate and accidental transport,[11] with 25 of these now considered pests.[12] The arrival of these introduced mammalian species has been the main driver for the loss of over 40% of terrestrial bird species,[13] with over 40% of those remaining considered threatened, the highest proportion of any country in the world.[14]

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Around 30% of New Zealand is protected in National Parks and conservation areas, but the existence of invasive pests means these ecosystems continue to be degraded despite this level of legal habitat protection.[11] For example, endangered endemic birds such as kiwi (*Aptertyx spp.*) and mohua (*Mohoua ochrocephala*) are struggling to survive on the mainland of New Zealand due to predation by stoats (*Mustela erminea*), feral cats (*Felis catus*) and ship rats (*Rattus rattus*).[7,15] However, impacts of invasive mammals are not limited to direct mortality of endemic fauna; the brushtail possum (*Trichosurus vulpecula*) is irreversibly changing the composition of New Zealand's indigenous forests and in some cases causing canopy collapse through its extremely selective foraging behaviour.[16,17] Possums and ferrets (*Mustela furo*) are also a threat to agriculture as vectors for bovine tuberculosis (TB), posing a considerable risk to the national beef and dairy industry which accounts for 2.8% of New Zealand's gross domestic product (GDP), or five billion dollars.[18] Feral mammals are now found across the breadth of New Zealand landscapes, including production and conservation lands. This means that effective pest management depends on the adoption and use of best management practices by a range of stakeholders, and often means having to work in a co-ordinated fashion across landscapes managed by different stakeholders.

Driven by necessity, New Zealand has become a world leader in mammalian pest control. Initially, agricultural pests such as red deer (*Cervus elephas*) and rabbits (*Oryctolagus cuniculus*) were the focus of control, but as it became clear that populations of native species were dwindling on the mainland the focus broadened to include eradication of pest species from offshore islands.[11] Pest-free islands have been used as sanctuaries to house representative populations of indigenous species that are unable to survive on the mainland.[19] Work to date (with conventional control techniques) has resulted in over 180 populations of 14 mammals having been removed from over 100 islands, totalling 45 000 ha.[20] Notable eradication successes include removing Norway rats (*Rattus norvegicus*) from 11 300 ha Campbell Island[21] and a suite of nine mammalian pests from 3820 ha of very complex habitat on Rangitoto and Motutapu Islands in 2009.[20]

While these successes are by no means trivial, new concepts and approaches are necessary in order to try and successfully address mammalian pest control issues throughout the New Zealand mainland. Stoats on the mainland, for example, are largely controlled by traps, an approach which can be locally effective but logistically difficult and costly to implement at very large scales.[22] This results in a situation where native wildlife are protected in small pockets, but continue to decline over large unmanaged areas.[23] Re-invasion from surrounding areas is also a substantial issue, in some cases negating the effectiveness of control altogether. Therefore, operations need to be more cognizant of the movement of animals, and the development of long-term control tools which can be left *in situ* to prevent re-invasion are important.

In this paper we present an overview of novel, integrative and multi-disciplinary research being undertaken by a New Zealand Research Centre to development new vertebrate pest control methods that will allow long-term suppression or eradication of pest populations. Examples of recent advances include the development of new vertebrate toxicants; resetting long-life toxicant delivery devices for responsible toxicant use *in situ*; long-life bait coatings to address degradation issues and extend field deployment life; the use of new technologies for understanding animal behaviour; and the importance of collaboration as a key part of innovation and decision-making. These novel tools are paving the way towards a new era in vertebrate pest management. The research referred to here is characterized by a cross-organizational approach involving interdisciplinary researchers from four different universities (Lincoln University, Auckland University of Technology, Otago University and the University of Auckland), a Crown research institute (Plant and Food Research Ltd), and a commercial pest management partner (Connovation Ltd). An associated social and cultural team aims to identify integrative processes that help different groups to collaborate and act more collectively in pest management and two end-user advisory and advocacy groups also provide perspectives from industry and Māori (the indigenous people of New Zealand who play a key role in land management as Treaty partners, and are also often involved as stakeholders in their own right), respectively.

## 2 INNOVATIVE DEVELOPMENTS

### 2.1 New vertebrate toxicants

Until recently, the most effective method of controlling vertebrate pest populations over large areas of New Zealand has been aerially-applied sodium fluoroacetate (1080). Despite its effectiveness, the use of 1080 is becoming increasingly constrained by environmental, animal welfare and social pressures.[24] Similar issues exist around the world. In Australia, for example, opposition to the use of 1080 has resulted in the Tasmanian State Government phasing out its use by 2015,[25] a decision supported by an \$A4 million investment to assist with the development of alternatives.[24] The anticoagulant toxicant brodifacoum is widely used to eradicate rodent populations from islands[21] but it carries a high secondary poisoning risk,[26] has a moderate level of environmental persistence[27] and is considered inhumane.[26,28,29] Problems with over-reliance on these poisons can be compounded by the bait carriers used. Fragmentation of carriers such as the carrots or cereal bait used for 1080 in New Zealand, can lead to issues such as bait particle ingestion by native birds.[30] In conjunction with these issues, the expenditure required to meet growing compliance and consultation requirements continues to increase.[24]

This has led to a focus on new, improved, toxicants with humaneness and safety (such as readily available antidotes and increased levels of species specificity) as primary considerations. Para-aminopropiophenone (PAPP), a newly registered mammalian toxicant which became available in New Zealand in 2011, represents a new generation of vertebrate toxic agents which achieves these key primary considerations and does not bio-accumulate.[24] PAPP produces methaemoglobin, high levels of which reduce the capacity of red blood cells to carry oxygen to body tissues.[31] Affected animals become lethargic and fall to sleep before death, with no signs of discomfort such as writhing or vomiting.[24] An additional advantage of this new agent is the ready availability of an antidote (methylene blue).

The efficacy and efficiency of PAPP when dispensed in meat baits to stoats has been successfully demonstrated in both pen and field conditions.[32–34] The registration of PAPP has also fostered the use of baits to augment current trapping programmes to enhance the protection of native species. Unfortunately, despite the efficacy of PAPP to species like stoats, weasels and feral cats[33] it is not sufficiently toxic to control rodents. However, the mode of action of PAPP can be duplicated using other compounds and this opens a new avenue of research in vertebrate control agents.

Building on the platform created by PAPP development, a second red blood cell toxicant, sodium nitrite (SN), is also under investigation. SN is commonly used as a preservative in meat and fish products and, like PAPP, prevents red blood cells from carrying oxygen. Another advantage of SN is that it has the same antidote as for PAPP, methylene blue, in case of accidental poisoning. SN is showing very promising effectiveness for species such as brushtail possums and feral pigs. Initial results from small-scale possum field trials, for example, have demonstrated that possum abundance can be reduced by approximately 70 to 80% when using SN in a paste bait in bait stations.[35] The encapsulation technique used to coat the SN active is constantly being refined, and it is expected that the efficacy of this toxicant will continue to be further improved.

As an alternative option, toxins extracted directly from New Zealand plants are also being investigated as potential new tools.[36] For some plant species (e.g. tutu *Coriaria arborea*, karaka *Corynocarpus laevigatus* and kowhai *Sophora microphylla*), the toxicity to rodents, toxin extraction methods and the chemistry of the toxin have already been described. Māori community groups and scientists at Lincoln University are currently exploring the potential of natural New Zealand toxins, with a current focus on tutin, the active ingredient in tutu.[37] It has been shown that new growth parts of tutu contain the highest concentration of the tutin toxin and 100 g of this material contains enough tutin to cull around 3500 mice. Next steps include determining toxicity to rats and assessing tutin palatability for potential addition to bait material. This work provides a good example of how end-user groups can be involved in all aspects of the research process – as initiators of research ideas, as research partners and as end-users. This research is also being overseen by a national New Zealand group of expert Māori advisors, known as Ngā Matapopore (The Watchful Ones). By connecting with Ngā Matapopore, the research team has been able to ensure that pest control tools are produced that are both effective, and culturally acceptable to Māori communities. This has also allowed the research to integrate across traditional Māori knowledge (Matauranga) and science, an approach that is showing promise in the development of pest control technologies that are readily adopted by end-user communities.

We have also been extending the registration of existing products and active ingredients that are already approved. For example, since its registration in 1997, Feratox® has become the accepted method for cyanide baiting for possum control. Its use has strong community support and the registration has recently been extended to include control of Dama and Bennett's wallabies (*Macropus eugenii*, *M. rufogrisea rufogrisea*).[38,39] In Europe, cholecalciferol has been added to baits containing coumatetralyl (Racumin® plus) to overcome anticoagulant resistance in rats and mice.[40] Trials are currently underway to register the combined bait in New Zealand for possum and rodent control.

### 2.2 Resetting, long-life toxin delivery systems

New, less hazardous toxicants and toxins are, however, only part of the solution. Unless alternatives to current methods used to deliver toxicants can be provided, the majority of the benefits these new toxicants can deliver will not be realized. Current toxicant delivery methods in New Zealand mainly involve bait stations containing solid or paste baits, and the aerial delivery of 1080. Performance is often reduced through these delivery techniques due to influences such as bait degradation,[41,42] sub-lethal dosing,[43] induced toxicant or bait shyness[44,45] or other non-target species removing baits.[28] One other problem with these methods is the boom/bust cycle of pest populations that frequently results, and the consequent need for repeat application of baits at regular intervals to achieve biodiversity gains. If the low population threshold is not maintained, it will quickly recover, eventually to a point where conservation or agricultural benefits are lost.

These concerns have led to the development of resetting toxicant delivery systems to target several of the most destructive mammalian pest species in New Zealand, including stoats, feral cats, rats and possums. These devices aim to deliver a reliable, cost-effective and safe method for enabling a large number of individuals to be controlled (100–500 toxicant doses can be delivered by a single unit) in a manner that eliminates environmental and ecological problems and removes the need for costly repeated applications of bait. With this method, it will be possible to complement or replace wide-scale toxicant deployment and trapping as the only cost-effective methods of reducing pest populations over large areas.

Engineers, designers and ecologists have worked together to develop a device which can be left in the field for extended periods of time, with increased target specificity and reduced need for on-going maintenance. To take advantage of the natural grooming behaviour of mammalian pests, this system has been constructed to deliver a measured dose of a toxicant (such as PAPP) in a highly palatable carrier paste onto an animal's abdomen. The target animal then grooms off the paste and ingests the toxicant, leading to a rapid death. To increase target specificity, a system of triggers has been incorporated into the devices so that only those animals intended for control can activate the system. The device architecture and trigger systems have been customized according to the behaviour of the target species, as can be seen from Figures 1 and 2 illustrating the device design for targeting stoats and possums, respectively. Leaving devices operational *in situ* for several years would have the potential to reduce the fluctuations in pest numbers that can occur (such as the population explosions of rats and stoats which sometimes occur during mast seeding events),[46,47] for example by providing more rapid and sustained removal. Substantial advantages also exist through the provision of a single, measured dose of toxicant, which exposes target species to an amount known to be effective, reducing the possibility for sub-lethal doses.

Initial results from these systems are very promising. For example, enclosure trials for stoats and weasels dosed on the stomach with a paste containing PAPP demonstrated that both species groomed the paste off shortly after application, and death occurred within several hours.[48] Initial enclosure trials with brushtail possums demonstrated 100% efficacy when possums were dosed with a palatable, measured paste containing zinc-phosphide from these delivery systems (Blackie HM and MacKay JWB, unpublished observations). If these systems work successfully in upcoming field trials scheduled throughout 2013 we will have the capacity to signifcantly increase the harvest rate of the target animals compared with conventional methods.

### 2.3 Long-life bait coatings – addressing the issue of bait degradation

Previous research investigating Norway rat, ship rat and house mouse (*Mus musculus*) control methods has highlighted a need to develop more weather-resistant bait formulations to ensure on-going efficacy in situations where toxic hard-baits are deployed in bait stations.[41] This situation is particularly relevant for the control of Norway rats that quickly find weathered bait unpalatable.[42] An additional benefit of long-life baits is the increase in the period of

  


**Figure 1.** Resetting, long-life toxin delivery system for stoats, weasels and rats. Animals pass through the tunnel (A). If the animal successfully triggers the device a measured dose of toxicant paste fires out of the nozzle (B). The toxicant paste, the firing mechanism and the trigger electronics are enclosed in a lockable watertight box (C). The tunnel (A) can be removed and clipped on to the box (C) for transportation.


**Figure 2.** Resetting, long-life toxin delivery system for possums. The device is attached to a tree beyond the reach of native flightless birds. In order to trigger the device the possum must sit on the base plate (A) and reach up and touch the second trigger at the top of the device underneath the hood (B). If both triggers are activated toxicant paste is fired out of the nozzle (C). The two-stage trigger process ensures species specificity and that the possum is correctly aligned on the device for the spray to hit the abdomen. The toxicant paste, the firing mechanism and the trigger electronics are all enclosed in a lockable watertight container. The base plate (A) can be removed and the hood (B) folded back for transport.

time between servicing of bait stations thus reducing the overall cost of control.

Research undertaken in collaboration with specialists in advanced material development has investigated the efficacy of four novel long-life bait coatings for both Norway rats and house mice. Three out of four of these coatings actually increased initial bait palatability for Norway rats and two of the coatings remained palatable for six months when directly compared to fresh, uncoated bait (Sam S and Ross JG, unpublished observations). The results were more varied for mice; however, one of the new coatings also increased initial bait palatability and then remained palatable for two months. These new long-life coatings are now in the process of being approved as part of future bait recipes for registered toxicants by the New Zealand Environmental Protection Authority, and will provide improved longevity for current toxic hard-baits.

### 2.4 Increasing understanding of pest behaviour

A comprehensive scientific understanding of the behaviour of invasive species is essential for designing effective prevention and control techniques. Information on population biology is important for developing predictive models of invasions, and for creating optimal techniques for species management or eradication.[49] The behaviour of individuals in a population is closely linked to population density[50,51] and density-dependent behaviour (particularly behaviour at low population densities) is therefore an important aspect of pest management.[52,53] An increased understanding of the way dispersal, re-invasion and individual animal movements and interactions with devices change in response to control enables more effective management strategies to be developed.[54,55]

Understanding the way in which possums respond to control for example, is important to predict the spread of TB and determine the optimal placement of control devices in the landscape.[53] To obtain this information, research has involved experimentally reduced population densities[56] or removal of selected individuals,[57] with changes in movement behaviour following manipulation monitored using global positioning system (GPS) collars. These research findings suggest that home range use may increase in response to control, with subsequent increased risks of TB transmission through expanded ranging behaviour. This emphasizes the need for efficient initial control of pest populations to reduce populations to very low densities, plus the integration of tools (such as resetting toxicant delivery systems) which continue to suppress these populations once low density has been reached.

A key concern in the development of new long-life technologies is ensuring that the target animals find the devices and then interact with them in the correct way. Therefore, research continues into novel lure formulations and attractants to entice species such as possums, rats and stoats to control devices. In order to quantify the effectiveness of different lures in the field we have developed a novel proximity logger system. This system was specifically designed to monitor animal interactions with other individuals and 'base' stations left in the environment. The system combines Very High Frequency (VHF) and Ultra High Frequency (UHF) transmitters using a microprocessor, which allows the on board data derived from UHF to UHF interactions to be transmitted to a computer via remote download over the VHF tracking system of the transmitter. Each device can record up to 54 interactions recording the ID of the other device encountered, duration of encounter and a time stamp. These proximity loggers are currently being used to investigate how often possums interact with bait stations fitted with an auditory, an olfactory or a visual lure device. This new technology provides an enhanced method for examining the efficiency of different attractants and lures.

### 2.5 Collaboration and integration as a key part of innovation

Alongside novel developments in pest control tools, successful pest management requires the on-going participation of different stakeholders in all stages of the process from development to implementation. Many apparently successful innovations fail to scale up to operational level because of social and organizational constraints, and contemporary approaches to innovation recognize that it is important to involve the range of stakeholder groups in the development process.

The success of an integrated approach to research depends on strong stakeholder engagement. The approach used in these programmes builds on work we have been involved in through other research programmes in other natural resource management areas such as Integrated Catchment Management (ICM).[58] This highlights how the collaborative approach lends itself to focus on elements of problem-solving such as uncertainty, values and multiple social perspectives that tend to be neglected in traditional accounts of scientific practice. Our own experiences of working within a collaborative and interdisciplinary team point to the importance of building time into the programme to develop trusting relationships both between members of the research team and between the team and its wider stakeholders. We have found that this is best supported through offering both formal and informal forums for this engagement, and by inviting researchers and participants to actively reflect on this engagement. This collaboration allows different groups to contribute their local and traditional knowledge alongside scientific knowledge, to achieve better informed and more enduring solutions to contentious issues.

## 3 CONCLUSIONS AND PERSPECTIVES

Invasive mammalian pests continue to inflict profound damage throughout many ecosystems worldwide. However, development of innovative control tools has been relatively slow. For new vertebrate pesticides in particular, the necessarily comprehensive and expensive process of registration can substantially impede innovation. In spite of this, new toxicants with improved species-specificity and humanness as a primary factor are slowly moving through the pipeline. These new tools will assist in providing alternatives to sub-optimal toxicants which are frequently employed due to a lack of alternatives. While research into new toxicant developments occur, retaining and refining currently used tools will continue to be an important factor to ensure we can adequately mitigate the threats posed by these pests.

As research into improved control agents progresses, it is important that there is a parallel focus on delivering toxicants in a responsible and safe manner. Non-target kills or sub-lethal poisoning of target species are an issue of great concern in any control operation, and the use of species-specific delivery systems with measured doses will have substantial advantages. With the integration of new technological and engineering advances, resetting control systems offer the potential to 'set and forget' devices in the field for extended periods, allowing continued population suppression over longer timeframes, and an ultimate decrease in control costs.

In order to meet the challenges facing mammalian pest control, a strategic approach needs to be taken which integrates knowledge from a range of disciplines. Combining the skills of animal ecologists, toxicologists, social scientists and design engineers in a cohesive team can help provide novel solutions and fresh thinking which will ultimately lead to significant advances in our ability to control these pest species in a long-term and large-scale manner.

## ACKNOWLEDGEMENTS

Funding for this research is provided from the New Zealand Ministry for Business, Innovation and Employment, the Animal Health Board Ltd, the Department of Conservation and Connovation Ltd. We thank our associated research partners for their continued input into these research objectives including Plant and Food Research Ltd, Lincoln Agritech Ltd, Otago University, and the University of Auckland Chemistry Department. This manuscript was improved by comments from two anonymous reviewers.

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