Title: Innovative developments for long-term mammalian pest control in New Zealand

Running title: Innovative developments for mammalian pest control

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Abstract

Invasive species are a substantial threat to biodiversity, with mammals representing some of the most damaging and widespread invaders. In New Zealand, invasive mammalian pests have inflicted substantial environmental and economic damage, and are now found across a wide breadth of landscapes, including production and conservation lands. As a result, New Zealand has become a world leader in mammalian pest control, but fresh thinking and novel approaches are necessary in order to try and successfully address control issues throughout the New Zealand mainland. This paper presents an overview of novel, integrative and multi-disciplinary research being undertaken to achieve new developments in mammalian pest control that will allow long-term suppression or eradication of many pest populations on the mainland.

Keywords invasive mammalian pests; innovative developments; pest control; vertebrate toxins; resetting toxin 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 invasive species, and the impacts of invasive mammal species tend to be particularly accentuated on oceanic islands (3). Islands tend to have high levels of endemism and often there are no native mammals, putting native fauna and flora at high risk of damage from invaders (7-9). As a result of this, conservation managers around the world have worked to remove invasive mammal species from islands using eradication methods mainly pioneered in New Zealand (10).

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 particularly vulnerable to environmental change (11, 12). When humans first settled New Zealand in approximately 1280AD (13), the only terrestrial mammals present were three species of bats (14). Since then, 31 species of land mammals have become established through both deliberate and accidental transport (15), with 25 of these now considered pests (16). The arrival of these introduced mammalian species has been the main driver for the loss of over 40% of terrestrial bird species (17), with over 40% of those remaining considered threatened, the highest proportion of any country in the world (18).

Around 30% of New Zealand is protected in National Parks and conservation areas, but the existence of invasive pests means these ecosystems continue to degrade despite this level of legal habitat protection (15). For example, endangered endemic birds such as kiwi (*Apteryx spp*.) and mohua (*Mohoua ochrocephala*) are struggling to survive on the mainland of New Zealand due to predation by stoats (*Mustela ermine*), feral cats (*Felis catus*) and ship rats (*Rattus rattus*) (11, 19). 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 (20, 21). Possums and ferrets (*Mustela furo*) also pose 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 GDP or 5 billion dollars (22). 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 uptake of good practice 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. The initial focus has been on eradicating pest species from offshore islands to create sanctuaries to house representative populations of indigenous species dwindling on the mainland. 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 (23). Notable eradication successes include removing Norway rats from 11,300 ha Campbell Island (10) and a suite of nine mammalian pests from 3820 ha of very complex habitat on Rangitoto and Motutapu Islands in 2009 (23).

While these successes are by no means insubstantial, fresh thinking 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 (24). This results in a situation where native wildlife are protected in small pockets but continue to decline over large unmanaged areas (25). Reinvasion 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 consideration of corridors and buffers become more important – along with the need to integrate management across multiple stakeholder groups.

In this paper we present an overview of novel, integrative and multi-disciplinary research being undertaken by a New Zealand Research Centre to achieve new developments in vertebrate pest control that will allow long-term suppression or eradication of many pest populations. Examples of recent advances include the development of new vertebrate toxins; resetting long-life toxin delivery devices for responsible toxin 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, whereby permanent population suppression or local eradication on mainland environments becomes a distinct possibility. The research referred to here is characterised by a cross-organizational approach involving staff from four different universities (Lincoln University, Auckland University of Technology, Otago University and Auckland University), a crown research institute (Plant & Food Research Ltd), and a commercial pest management partner (Connovation Ltd). An underpinning 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[*]respectively.

2 INNOVATIVE DEVELOPMENTS

2.1 New vertebrate toxins

Until recently, the most effective method of controlling vertebrate pest populations over large areas of New Zealand has been aerially-applied sodium fluoroacetate (1080). However, despite its effectiveness, the use of 1080 is becoming increasingly constrained by

[*] Indigenous people of New Zealand. They play a key role in land management as treaty partners, and are also often involved as stakeholders in their own right.

environmental, animal welfare and social pressures (26). 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 (27), a decision supported by an $A4million investment to assist with the development of alternatives (26). The anticoagulant toxin brodifacoum is widely used to eradicate rodent populations from islands (10) but it carries a high secondary poisoning risk (28), has a high level of environmental persistence (29) and is considered inhumane (28, 30, 31). Problems with overreliance 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 (32). In conjunction with these issues, the expenditure required to meet growing compliance and consultation requirements continues to increase (26).

This has led to a focus on new, improved, toxins with humaneness and safety (such as readily available antidotes and increased levels of species specificity) as primary considerations. Para-aminopropiophenone (PAPP), a new registered mammalian toxin 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 (26). PAPP produces methaemoglobin which reduces the oxygen carrying capacity of red blood cells. Affected animals become lethargic and fall to sleep before death, with no signs of discomfort such as writhing or vomiting (26). An additional advantage of this new toxin 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 (33-35). The registration of PAPP has also allowed for these baits to augment current trapping programs to enhance the protection of native species. However, despite the efficacy of PAPP to species like stoats, weasels and feral cats (34) it is unfortunately not sufficiently toxic to rodents. Nonetheless, the mode of action of PAPP can be duplicated using other compounds and this represents another new avenue of research in vertebrate toxic agents.

Building on the platform created by PAPP development, a second red blood cell toxin, 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 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 shown that possum abundance can be reduced by approximately 70 to 80% when using SN in a paste bait in bait stations (36). The encapsulation technique used to coat the SN active is constantly being refined and it is expected that the efficacy of this toxin will continued to be further improved.

As an alternative option, toxins extracted directly from New Zealand plants are also being investigated as potential new tools. 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 toxicant have already been described. Māori community groups and researchers 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 3,500 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 real 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 toxins are, however, only part of the solution. Unless alternatives to current methods used to deliver toxins can be provided, the majority of the benefits these new toxins can deliver will not be realised. Current toxin delivery methods in NZ 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 toxin or bait shyness (44, 45) or other non-target species removing baits (30). 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 start to grow again, eventually to a point where conservation or agricultural benefits are lost.

These concerns have led to the development of resetting toxin delivery systems to target several of the most destructive vertebrate pest species in New Zealand, including stoats, feral cats, rats and possums. The development of these devices aims to deliver a reliable, cost-effective and safe method for enabling a large number of individuals to be controlled (100-500 measured toxin doses can be delivered by a single unit) in a manner that eliminates environmental and ecological problems, removes the need for costly repeated applications of bait. With this method, it will be possible to complement or replace wide-scale toxin 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 vertebrate pests, this system has been constructed to deliver a measured dose of a toxin (such as PAPP) in a highly palatable carrier paste onto an animal's stomach. The target animal then grooms off the paste and ingests the toxin, 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. Leaving devices operational *in-situ* for several years would have the potential to reduce the fluctuations in pest numbers that can occur by providing more rapid and sustained removal. One example of this is the population explosions of rats and stoats which sometime occur during mast seeding events in NZ (e.g. 46, 47). Substantial advantages also exist through the provision of a single, measured dose of toxin, which doses target species with a controlled amount known to be effective, reducing the possibility for sub-lethal doses occurring.

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 after an average of 42 minutes for stoats and 57 minutes for weasels (48). The applications of these resetting devices are now being extended for the control of brushtail possums, feral cats and rats. Initial enclosure trials with brushtail possums demonstrated 100% efficacy (n = 10) when possums were dosed with a palatable, measured paste containing zinc-phosphide from these delivery systems (Blackie HM and MacKay JWB, unpublished.). 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 (*R. norvegicus*), ship rat and house mouse (*Mus musculus*) control methods have 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, who quickly find weathered bait unpalatable (42). An additional benefit of long-life baits on the mainland is that this would increase the period of 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). 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 toxins by the NZ 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, for example, 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, reinvasion and individual animal movements and interactions with devices change in response to control enables more effective management strategies to be developed (54, 55). For example, understanding the way in which possums respond to control is important to reduce the spread of TB (53).

In an effort to understand the role that population density plays in the home ranges of individual possums we have fitted Global Positioning System (GPS) and Very High Frequency (VHF) collars to possums in high and low population density populations in both the North (MacKay and Blackie, unpublished data) and South (56) Islands of New Zealand. Additional studies experimentally reduced population densities (56) or removed selected individuals (57) and monitored changes in possum movement behaviour following these reductions. 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 emphasises the need for efficient initial control of pest populations to reduce populations to very low densities, plus the integration of tools (such as resetting toxin 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 a range of investigations 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 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 proximity collared possums interact with bait stations fitted with an auditory, an olfactory or a visual lure device.

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 organisational constraints and contemporary approaches to innovation recognise that it is important to involve the range of stakeholder groups in the development process.

The success of an integrated approach to the research as we are describing here depends on strong stakeholder engagement. The approach we have 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 findings echo those of other reviews in this collaborative space and point to the importance of building time into the programme to build a shared understanding of context and trusting relationships between the team (interdisciplinary) and between the team and its wider stakeholders (transdisciplinary), 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.

3.1 Conclusions and perspectives

Invasive mammalian pests continue to inflict profound damage throughout many ecosystems worldwide. However, innovations in control tools have been relatively slow. For new vertebrate pesticides in particular, the necessarily comprehensive and expensive process of registration can substantially suppress innovation. In spite of this, new toxins with improved species-specificity and humanness as a primary factor and slowly moving through the pipeline. These new tools will assist in providing alternatives to sub-optimal toxins which are frequently employed due to a lack of alternatives. While research into new toxin 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 progress into improved toxic agents continues, it is important that there is a parallel focus on delivering toxins in a responsible and safe manner. Non-target or sub-lethal kills are an issue of great concern in any control operation, and employing 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 (whether kill traps or modes of toxin delivery) offer the potential to 'set and forget' control 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 multi-disciplinary tactics, such as demonstrated here. Combining the skills of animal ecologists, toxicologists, social scientists and design engineers in a cohesive team can help provide novel solutions and fresh thinking to solve current problems.

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