#33
MAY 2020

Manaaki Whenua
Landcare Research

Kararehe Kino

ANIMAL PEST RESEARCH

Max Harvey

In this issue

Predator-free New Zealand

Cover photo: Grant Morriss and a sedated ship rat with radio collar attached, Lake Alabaster, Fiordland.

Editorial: Research towards achieving a predator-free New Zealand

New Zealand's mission to eradicate rats, stoats (shorthand for all mustelids) and possums from New Zealand by 2050 has raised eyebrows, enthralled or angered people and kick-started a number of new predator control and eradication projects across the country. Whatever your perspective, the bar has been set very high, and consequently many people have engaged in the thinking, planning and on-the-ground action to achieve this national goal.

This is one of the most exciting times in New Zealand's history to be either managing or studying predators. The challenge is huge, and the opportunities tremendous, but we won't get there unless we address a number of important knowledge gaps. Manaaki Whenua is one of many New Zealand research providers helping to fill these gaps. Starting eight years ago with the landscape-scale predator control project at Poutiri Ao ō Tāne in Hawke's Bay, and more recently at Cape-to-City, Manaaki Whenua scientists are now also helping Predator Free Taranaki, Predator Free Wellington, and Predator Free Dunedin with their research needs.

Achieving eradication of predators at a national scale requires quantum leaps in pest management. There are four key areas that need attention: (1) new tools and strategies for removing predators and defending against reinvasion; (2) more accurate methods of detecting predators at very low abundance; (3) statistical methods for declaring probability of success; and (4) public co-operation and involvement in the programme. This edition of *Kararehe Kino* addresses the technical aspects of predator eradication (1-3). Our social research on understanding and facilitating (4) will be featured in a future edition.

Dan Tompkins from Predator Free 2050 Ltd begins by setting the science scene and outlining the national research strategy that underpins the big research questions. An eradication strategy using dual 1080 bait switching is explained by Graham Nugent and Bruce Warburton. They found that two applications of 1080 bait in quick succession using different bait types has the potential to eliminate possums. The ability to defend eradicated areas by identifying reinvasion routes is addressed by Audrey Lustig and Simon Howard by modelling possum reinvasion between eradication zones on the Māhia Peninsula in Hawke's Bay.

Andrew Veale's article considers how to detect stoats at very low abundance using motion-triggered cameras. Provided adequate numbers of cameras are used and set correctly, cameras are a viable method for detecting residual stoats. Cameras have the advantage of not requiring predators to interact with them, so they have greater detection probability than many other devices. However, their disadvantage is the time they require to process thousands of images. Fortunately, artificial intelligence is coming to the rescue. Al Glen discusses new software that automatically culls out images with no animals, and learns to identify species when they are present. This will be a huge cost saver.

Managers aim to ultimately detect no predators so that they can declare eradication. But zero detections do not necessarily mean zero predators if the array of detection devices and checking frequencies are insufficient to detect a predator that is present. Andrew Gormley and colleagues explain the statistical framework and software that allows managers to design robust detection networks, and to declare success with a given level of probability. A potential problem with applying this and other pest management software is that the essential animal behaviour parameters, such as interaction rates with devices, are not well quantified. Giorgia Vattiato and Rachelle Binny have reviewed what we already know about these parameters and, importantly, where the knowledge gaps lie. Much research is required in this area to constantly improve the models' accuracy.

Finally, the lessons we can learn from fenced and unfenced ecosanctuaries, where predators have already been eradicated or suppressed over large scales, are discussed by John Innes and colleagues. They list seven key lessons relevant to achieving the PF2050 vision, one being that different native species are vulnerable to different mammals, and when one mammal (such as possums) is controlled, there is often an increase in another (such as ship rat). These two factors suggest that there will be more benefit for broad biodiversity recovery if multiple, rather than single, mammal pests are controlled at a site.

Finally, I'd like to thank our collaborating partners: Predator Free Hawke's Bay, Hawke's Bay Regional Council, Maungaharuru Tangitū, Whakatipu Māhia, Department of Conservation, Taranaki Regional Council, Taranaki Mounga Project, Predator Free Wellington, Greater Wellington Regional Council, Predator Free Dunedin, and Dunedin City Council for engaging with us in these fascinating areas of research. We are all on an exciting learning journey.

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Building the Predator Free 2050 Limited Research Strategy for 2020-2024

Predator Free 2050 Ltd (PF 2050) was established in November 2016 with two aims: (1) to supercharge local and regional efforts to scale up predator suppression and eradication, working closely with community groups and regional and city councils, and (2) to focus research efforts to achieve a breakthrough science solution capable of eradicating at least one small mammal predator by 2025.

The inaugural PF 2050 Limited research strategy, consisting of projects running from January 2018 to June 2020, was designed to complement existing efforts to give the best chance of achieving an interim goal of achieving a breakthrough science solution by 2025 that is capable of eradicating at least one small mammal predator (see *Kararehe Kino* 31). The strategy, now nearing completion, has made strong advances through four programmes – 'Environment & Society', 'Best Use of Existing Approaches', 'Exploring New Approaches' and 'Modeling and Data Sharing'.

A highlight of the research programme has been the building of capacity to achieve and maintain national possum eradication (see https://pf2050.co.nz/funded-projects/ for all project details and outcomes).

Construction of the second PF 2050 Research Strategy is now underway, to guide funding investment from July 2020 to June 2024. To better focus efforts on achieving the breakthrough science solutions needed, the new strategy will be based on a more fundamental understanding of which predators in which contexts need the most research support, beyond incremental and business-as-usual development, to enable eradication.

Strategy development is based on addressing three key questions for PF 2050's target predators (possums, rats and mustelids): (1) For what spatial scale of achieving eradication is research support most needed? (2) For what spatial scale of maintaining eradication is research support most needed? (3) For which predators in which landscapes is research support most needed?

The 'achieving and maintaining eradication' questions are informed through consideration of current and near-future predator management tools and approaches; the spatial scale at which they are applicable for the achievement and maintenance of possum, stoat and rat eradication; and how this may increase over time through business-as-usual and incremental development, or targeted investment into underfunded avenues. This consideration is illustrated in Figures 1 and 2, underpinning the conclusions that research support is most needed to give more options for achieving and maintaining landscape-scale eradication.

The 'which predators in which landscapes' question is informed through consideration of the different life-history characteristics of the PF 2050 target predators, which have consequences for the effort, tools and approaches that will be required for their eradication at large spatial scales. This also has consequences for the current and predicted near-future state of play of projects attempting their eradication in urban, rural and backcountry landscapes.

This consideration is illustrated in Figure 3, underpinning the conclusion that new research focus is now most needed on enabling landscape-scale rat and mustelid eradication in New Zealand's backcountry.

This synthesis clearly shows that while the research and development to enable national possum eradication is well underway, business-as-usual and incremental development alone is not going to enable Predator Free 2050's goals of national predator eradication.

Capability building that enables trans-disciplinary approaches is needed for breakthroughs to overcome current barriers to scaling up. Ongoing conversations on social, cultural, ethical and policy acceptability will be essential for guiding the application of current and new tools.

The complete draft high-level strategy document is available at https://pf2050.co.nz/funded-projects/, alongside a request for review feedback (and a form with which to do so). Also available is a form for researchers submitting funding applications for projects that will initiate in the new strategy timeframe, to request PF2050 Ltd Research Strategy co-funding.

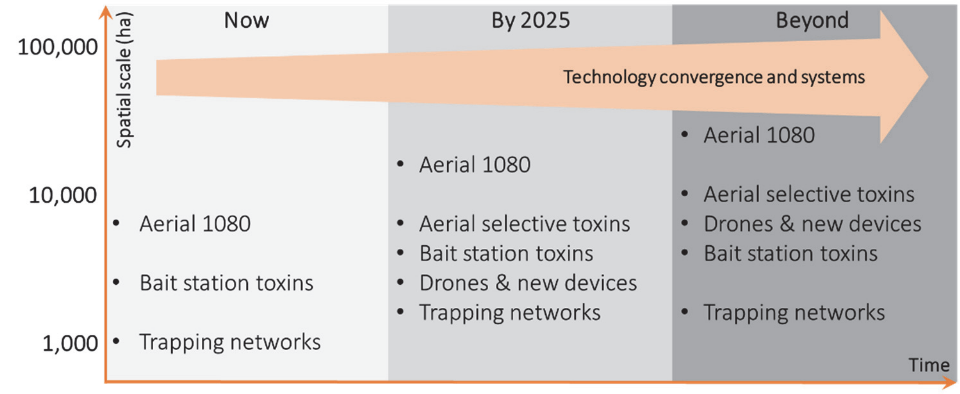

Figure 1: Spatial-scale applicability of current and near-future tools and approaches for achieving eradication

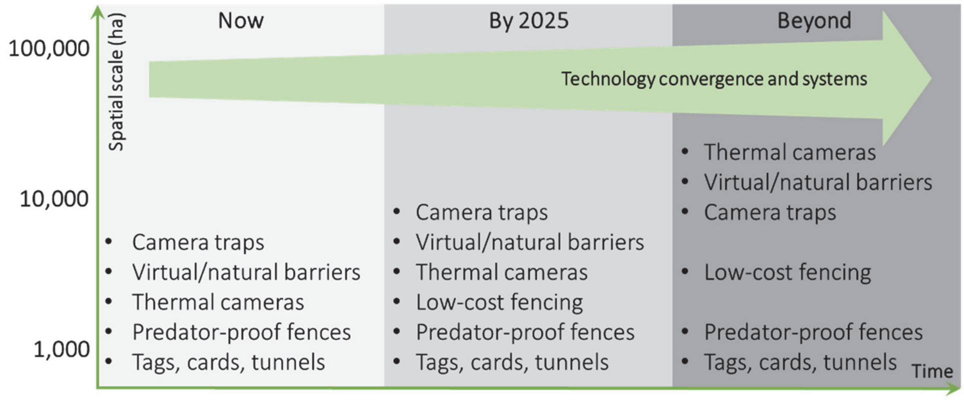

Figure 2: Spatial-scale applicability of current and near-future tools and approaches for maintaining eradication

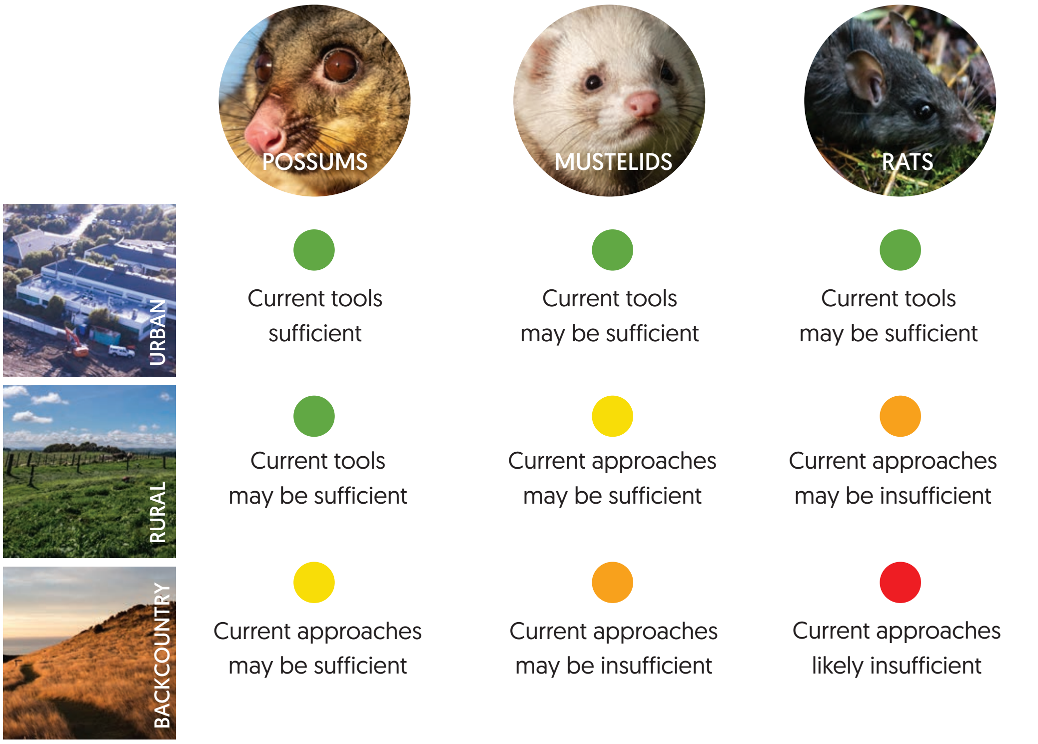

Figure 3: How applicable are current and near-future tools and approaches for PF2050 target predators?

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Predator Free NZ: how will we know?

As part of our national bid for a predator-free New Zealand by 2050, numerous predator eradication projects continue to pop up around the country. Yet the question remains: how will we know when we have successfully eradicated the last predator?

To declare an area free from predators requires some degree of certainty, which is critical to determine when the focus of predator management can be shifted from 'remove' to 'defend'. Best practice data gathering involves surveillance of predators across an eradication zone (e.g. using trail cameras or live ground traps) in an attempt to detect any individuals that may have slipped through the eradication net. If no predators are detected during surveillance, then either they have been eradicated or they have not been detected by any of the surveillance devices used.

Ecological models also have an important part to play in predator eradication. Models are used to simulate theoretical surveillance scenarios (e.g. different layouts of devices) to help design and optimise surveillance operations. If no predators are detected during surveillance, models can also provide a probability of eradication, enabling a threshold level of certainty to be applied to an area to declare it predator-free. However, to be reliable, such models require inputs describing the 'detectability' of the target pest by whatever surveillance methods are used. To complicate matters, this detectability varies for different pest species, pest densities, surveillance device types, seasons and habitats. While some detectabilities are known from field studies for some species by some device types, the picture is incomplete. In addition, there is no easily accessible central database for these values; instead, they are dispersed across numerous published papers, contract reports and unpublished works.

To tackle these problems of data inconsistency, Giorgia Vattiato and Sam Davidson from the University of Canterbury, in collaboration with Rachelle Binny from Manaaki Whenua, have done a literature review of all known predator detectability parameters and identified key knowledge gaps where future studies are needed. Giorgia and Sam's thorough stocktake has yielded 16 New Zealand studies and

Left: Tracking cards are often used as a first detection method. Animals cross the inky section of the card, leaving their footprints behind.

Below: Lake Alabaster, Fiordland: Small cage traps baited with peanut butter are used to catch rats alive. They are then sedated, weighed, measured, and tagged and/or radio collared, before release.

Max Harvey

one unpublished dataset, reporting a total of 123 detectability values for possums, rodents, mustelids and cats. The studies used a range of traps, including live ground traps, tracking tunnels and, in one instance, camera traps, but the results were patchy; not all devices had been used to detect all species in all habitats.

Possum and house mouse detectability was the most widely studied parameter, largely using live ground traps. After values were pooled across all studies, Giorgia and her colleagues found a seasonal trend, with house mice easier to detect in autumn-winter than in summer. Of all predators studied in New Zealand, stoats, studied mainly in beech forest and alpine grassland habitats, were the most difficult to detect. Next to nothing is known about the detectability of weasels and kiore, or of any predator species in wetland or urban environments. The team found only one published study reporting detectability with camera traps. The costs of trail cameras are high, although their popularity as a detection device is likely to increase in the coming years.

Giorgia is now preparing a review paper for publication that will pull together these findings, highlight any trends that emerge when detectability values are aggregated across many different sources, and make recommendations to direct the focus of future detection experiments. This work will make it significantly easier for modellers and pest managers from different organisations around New Zealand to access this information. It will also improve consistency in the way detectability values are applied in models, and increase transparency of the reliability of model predictions given the uncertainties in these parameters.

This work was co-funded by the University of Canterbury's Summer Scholarship programme and Manaaki Whenua.

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Rachelle Binny

Use of cameras and artificial intelligence to monitor wildlife

Motion-triggered cameras ('camera traps') can be an effective tool for monitoring wildlife, especially animals that are rare or secretive. Although camera traps can collect large volumes of useful data, processing the images can be time-consuming and expensive. For example, cameras are often triggered by non-target animals (e.g. livestock) or by vegetation moving in the wind, creating many thousands of superfluous images. Until recently these images have been processed manually by human annotators, but developments in the field of artificial intelligence are set to revolutionise camera trapping.

Image recognition software has the potential to automate the processing of photographs, making camera trapping much more time- and cost-effective. Al Glen and colleagues have used software developed for Australian animals and adapted it to identify species found in New Zealand. Using a machine-learning approach known as Deep Metric Learning, they 'trained' computer models to identify camera trap images of stoats, cats, hedgehogs, livestock, kiwi and other birds. The models were initially trained using a few hundred sample images of each species and achieved up to 75% accuracy with independent test data. With help from collaborators around New Zealand, Al's team is compiling much larger numbers of sample images to improve the accuracy of species recognition. They aim to collect over 10,000 images of each species and anticipate that accuracy will reach well over 90%.

The list of species that the software will recognise is growing longer. Driven partly by the Predator Free 2050 objective, two high priorities are to train the software to identify rodents and possums, and to investigate whether artificial intelligence can reliably distinguish between rats and mice. Other species to be added include ferrets, rabbits, hares, pigs and dogs.

The software first identifies whether an animal is present in each image. This is challenging due to extreme variability in background and lighting conditions when monitoring wild animals. Sample images therefore include a wide variety of backgrounds (e.g. pasture, forest, tussock) and lighting conditions (e.g. bright light, low light, dappled shade).

If an animal is present, the software produces a copy of the image with a box drawn around the animal, a label (e.g. cat or stoat) and a confidence rating for the identification. The software can also identify more than one animal in the same image. The images are then sorted into folders according to species, and a spreadsheet is produced showing the species identified in each photograph.

Processing speed will vary depending on the computer used, the speed of the internet connection, and the size of the image files. In early trials with large numbers of photographs, processing speeds between 10 and 30 times faster than manual image processing have been achieved.

When the artificial intelligence software identifies an animal in a photograph, it draws a box around the animal, labels it by species and gives a confidence rating for the identification. This helps the user to check the accuracy of identifications. 'Clean' copies of each image are saved into folders according to species, and a spreadsheet is produced showing the species identified in each image.

In collaboration with Groundtruth Ltd, Al and his colleagues also plan to develop a user interface to allow the image recognition software to be used by conservation organisations, community groups and researchers throughout New Zealand. The software will be made freely available for wildlife researchers and practitioners through Trap.NZ (www.trap.nz). Users will be able to upload their camera trap images and have animal species automatically identified and tagged by artificial intelligence.

A number of questions and approaches need further investigation. At what confidence rating should a species identification be considered reliable? For example, managers may use manual processing to check any images with a confidence rating below a certain threshold. Future work will also improve the software's ability to identify animals in images with different backgrounds (e.g. grassland, shrubland, etc.).

With further development, artificial intelligence will make camera trapping achievable and cost-effective at the large scales required for Predator Free 2050.

This work was funded by MBIE under the Kiwi Rescue Endeavour Programme, and by PF2050 Products to Projects funding.

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Knowing when to walk away: tools for proving eradication success

A common feature of all the current Predator Free New Zealand 2050 projects is attempts at regional-scale eradication of at least one species of pest. For example, Hawke's Bay Regional Council (HBRC) is currently eradicating possums from Mahia Peninsula, while Predator Free Wellington is targeting mustelids and rats on Miramar Peninsula.

An important phase of any pest eradication programme is surveillance to try to find any survivors. This can be done using a variety of methods, including trail cameras, tracking tunnels and/or bite-mark devices (e.g. WaxTags® or chew cards). If there is evidence of survivors, then eradication has been unsuccessful and cannot be declared. This decision may lead to mop-up control, total recontrol, or reassessment of the feasibility of control.

If, however, there is no evidence of survivors, then the conclusion is less certain. The targeted species may have been successfully eradicated, but it is also possible that surviving animals are present but not detected. What, then, is the decision if there are no detections? Is the species absent or not?

The conclusion ultimately depends on the answers to three questions:

1. How confident in eradication were managers before undertaking surveillance?
2. How hard did managers look for any pests that may have survived the eradication programme?
3. How confident do managers want to be when declaring eradication?

These three factors can be related by an equation called Bayes' theorem:

$$PoA = \frac{Prior}{1 - (SSe \times (1 - Prior))}$$

The 'Prior' is the probability that eradication was successful before any surveillance was carried out and reflects how good the control programme was thought to be. This may be based on expert knowledge, outcomes of similar eradications, simulation modelling, or some combination of these factors.

The system-level sensitivity (SSe) is the probability of detecting the species if it is still present, and reflects how good the detection network is at finding pests. This is calculated from the spatial arrangement of devices, how long they have been deployed, how good they are at detecting the species, and its home range size.

Bayes' theorem therefore updates prior knowledge (Prior) with data (SSe) to give the posterior probability of absence (PoA). PoA increases with more surveillance, as long as no targeted pests are detected during surveillance: if they are, then eradication was unsuccessful and PoA = 0.

Depending on the value of PoA, a management decision is made to declare the species absent and eradication a success, or to carry out more surveillance (i.e. increase the overall SSe until a value of PoA is reached that the manager is happy with). Because managers can never be 100% sure of success, the target value for declaration of eradication is set to reflect an acceptable failure rate: too low and managers risk incorrectly declaring success and having to incur expensive recontrol or loss of support; too high and managers will have overspent on unnecessary surveillance.

This PoA framework was developed by Dean Anderson and others for OSPRI to process surveillance data used to help make decisions about declaring areas free of bovine TB. It has more recently been modified by Dean to help make decisions about attempts to eradicate invasive species.

Predator Free 2050 in New Zealand and the Centre for Invasive Species Solutions in Australia (CISS) were keen to make the surveillance framework easier to use, and so they funded the development of a tool to allow managers to process their surveillance information consistently. Audrey Lustig, working with Pascal Omondiagbe from the Informatics team at Manaaki Whenua, embedded Dean's framework in a web-based user platform.


An example of a tracking card.

A two-day user workshop was held in October 2019 and hosted by Manaaki Whenua researchers from the newly formed Centre for Applied Ecological Modelling (CAEM). Twenty-five participants attended from Predator Free 2050, CISS, HBRC, Taranaki Regional Council, Predator Free Dunedin, Predator Free Wellington, and Biosecurity Queensland.

On day one the principles of surveillance to prove absence were presented, covering topics such as how to specify a Prior, calculating surveillance sensitivity, and how to know when to declare success. This was followed on day two by user testing of the PoA software with their own surveillance data, as well as a demonstration of the JESS4Pests app, which is used for calculating how much surveillance is required (see https://landcareshinyapps.io/JESS4Pests).

The workshop was a great opportunity to ensure the software met the needs of the end-users, as well as providing the end-users with the information required to understand the process and framework. As a result of the workshop, the PoA software will be further refined to add more functionality.

Feedback was overwhelmingly positive, with one manager stating that

> *We got a lot of value from better understanding the model, its parameter inter-relationships and the operational implications of these. In addition, we were able to run the model with our data which gave us some really valuable operational and risk insights and will lead to changes in what we are doing. The discussion on the model helped us change our thinking on how we are framing the results around eradication, PoA etc for our stakeholders and community. Finally we were able to wrap up by exploring some of the real life challenges we have around eradication, PoA, risk and operational expenditure. With the collective science / research-based expertise we charted some useful solutions to future challenges we may face.*

This process of development and engagement is a great demonstration of the benefits of working closely with stakeholders and end-users to ensure outputs are tailored to their needs and to help them deliver their outcomes.

This work was supported by Strategic Science Investment Funding from the New Zealand Ministry of Business, Innovation and Employment, the Centre For invasive Species Solutions, Australia, and Predator Free 2050.

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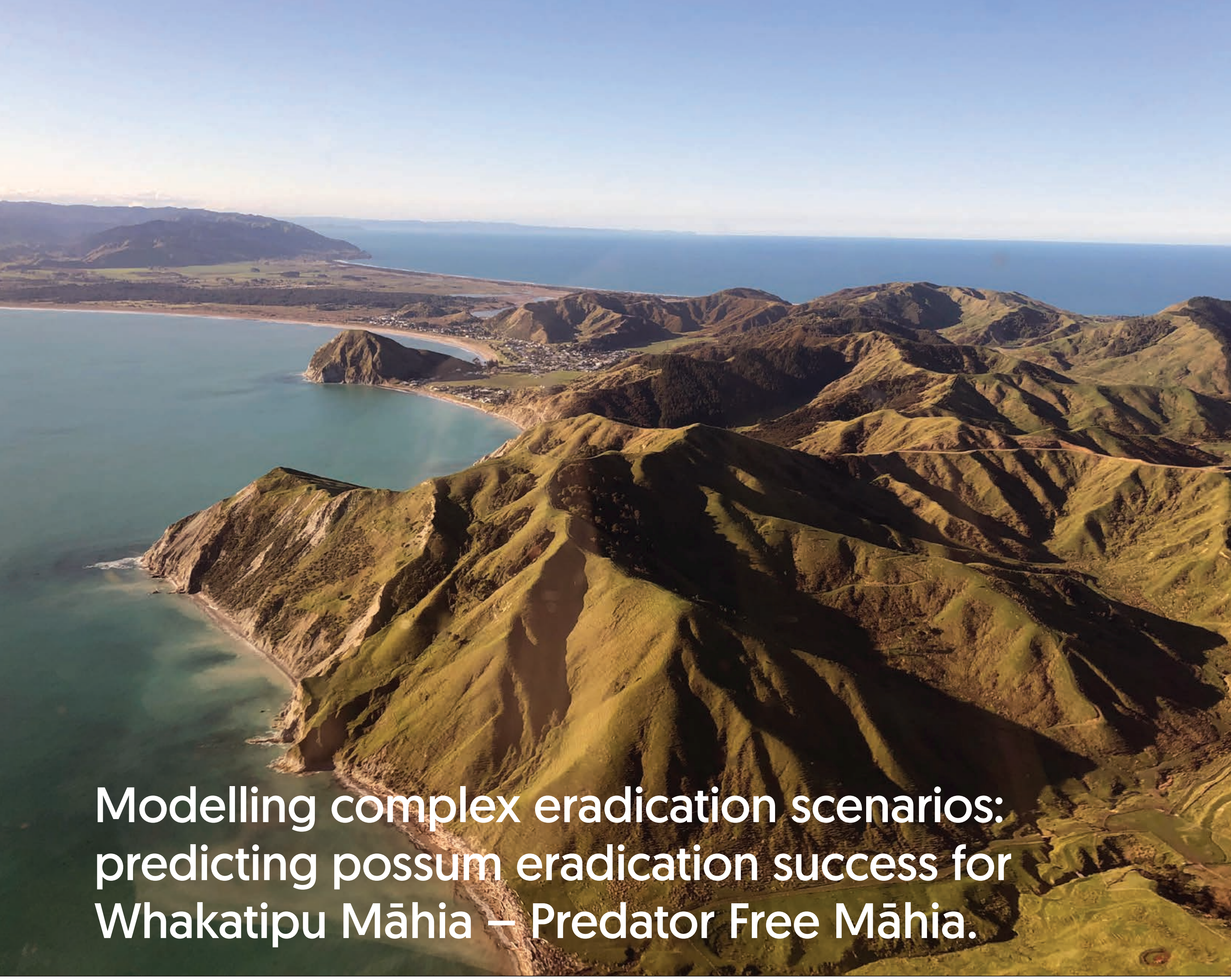
Dean Anderson, Audrey Lustig, Pascal Omondiagbe, Simon Howard, Rachelle Binny, Cecilia Latham



Modelling complex eradication scenarios: predicting possum eradication success for Whakatipu Māhia – Predator Free Māhia.

A view of Māhia Peninsula

Predator Free 2050 has the goal of eradicating possums, rats, and mustelids from New Zealand by 2050. Outside conservation areas, responsibility for pest management often falls on local government agencies, and many regional councils have adopted the Predator Free 2050 goal, establishing pest eradication projects alongside partner organisations.

However, given the range of tools available to managers, one-size-fits-all eradication plans are difficult to design. Managers need to be able to adapt plans to take advantage of local geography and emerging technologies, and make the best use of available resources. Therefore, managers require flexible tools that can test proposed eradication programmes and determine the likelihood of eradication success.

Predator Free Hawke's Bay (https://www.hbrc.govt.nz/environment/pest-control/predator-free-hb/, Hawke's Bay Regional Council, HBRC) released an operational plan, launched as Whakatipu Māhia, for eradicating possums from 14,500 ha on Māhia Peninsula. The project has the goal of eradicating possums over Māhia Peninsula and maintaining them at zero density by the end of 2021. The project aims to take advantage of the Peninsula's geography, using a rolling front of treatment blocks starting at head of the Peninsula to reduce reinvasion rates, and create an immigration barrier across the neck of the Peninsula to prevent reinvasion from uncontrolled areas. The benefits of using the geography are contingent on preventing reinvasion, so an assessment of the effectiveness of the rolling fronts was undertaken by Manaaki Whenua.

The wildlife ecology team at Manaaki Whenua has several tools that managers can use to test these types of questions. The first tool, TrapSim (an online tool to help managers decide on a trapping regime, *Kararehe Kino* 32; https://landcare.shinyapps.io/TrapSim/) is a hands-on 'ready reckoner' that managers can use to test eradication programmes, by altering trap numbers, trap spacing, duration and effectiveness. TrapSim is especially useful for quickly assessing the trapping effort proposed to achieve eradication within each treatment block and for confirming that the proposed trap spacings and trap nights can achieve eradication. However, the TrapSim model simulates single treatment areas that are closed to migration, making it less suitable for modelling multiple treatment areas with mobile animals. An improved tool, the Agent Based Model (ABM), developed by Audrey Lustig during her postdoctocal research with the University of Canterbury, is designed to model migration between treatment areas, and differing control methods and timing between areas. The ABM model simulates spatially explicit sub-populations, including birth, death and migration processes to more fully represent population responses to control. This makes the model well suited to simulate scenarios like the Whakatipu Māhia project.

The ABM was applied to the control scenarios proposed for the Whakatipu Māhia project using existing estimates of current possum densities, carrying capacity and home range parameters, and each scenario was run for 500 simulations. A no-control scenario was simulated to establish a baseline for the possum population. A total carrying capacity of 21,105 possums (1.44 per hectare) was estimated for the eradication area, and simulations showed that without control possums could readily spread between habitat patches across the area.

Under the control scenario, the ABM estimated strong declines in possum abundance, including eradication in over 90% of simulations for the first phase of the project covering 5,500 ha at the southern end of the peninsula. Importantly, the ABM estimated that possum eradication during the second phase of the project (a 9,000 ha area) was highly unlikely. Modelling was able to identify control blocks likely to contain remaining possums after treatment, and a scenario which doubled the effective traps nights in these blocks, from 28 to 56, estimated further reductions in the possum population but little likelihood of achieving eradication.

The ABM simulates each sub-population over time, which means it can track which sub-populations are likely to remain after control and where these animals are likely to spread. In Whakatipu Māhia, this revealed that population recovery after failed eradication was predicted to follow a consistent pattern. Dispersal from adjacent non-controlled blocks facilitated the recovery of recently controlled areas. However, this exchange between blocks was spatially limited and suggested that dispersal between control blocks could be managed, for example by using a buffer of traps or bait stations while eradication was underway.

Based on these results the HBRC approached Manaaki Whenua to further develop possum eradication prediction to guide the development of a control network that could achieve eradication across the entire Peninsula. Control-to-zero density of possums was feasible if buffers of bait stations around high-density possum control blocks and across the neck of Māhia Peninsula are used to limit immigration from untreated areas. The model also showed that possum density at the edge of the eradication area has a very low effect on the suppression of possums in the eradication area and did not compromise the effectiveness of the eradication programme. This is not surprising as the eradication area

TrapSim model: an online tool to help managers decide on trapping regime (trap numbers, trap spacing, trapping duration and effectiveness).

takes advantage of the geography of the Mahia Peninsula, with a lagoon and settlement at the neck of the peninsula creating an effective natural barrier to pest immigration from uncontrolled areas. Reinvasion is likely to occur in the three years following suppression in the absence of an immigration barrier at the neck of the Peninsula.

The trappability parameters (probability of detection/capture and spatial decay in the probability of detection/capture) appear to be particularly important in determining the level of trapping effort (trapping duration and strategy) needed to achieve eradication. In particular, small inter-individual variation in the detection/capture probability can quickly hinder the efficacy of the management scenarios tested. Passive control that relies upon possum investigation and contact with the control device may fail to sample individuals that are less active or too wary to approach such devices. Active control methods (such as that proposed in stage 2 of the Whakatipu Māhia eradication programme) may be particularly useful to target survivors with a low trappability.

This work was supported by funding from the Strategic Science Investment Fund, Ministry of Business, Innovation and Employment, Predator Free 2050, and Predator Free Hawke's Bay.

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For more information visit: https://www.hbrc.govt.nz/environment/pest-control/predator-free-hb/

Lessons from ecosanctuaries – already Predator Free!

The vision to be predator free by 2050 has been greatly enhanced by successful achievements in previous decades of numerous smaller predator-free visions in diverse ecosanctuaries around New Zealand.

Inspired by successful offshore island eradications, the Department of Conservation established several 'Mainland Islands' during 1995-96. Multiple mammal pests were targeted in these unfenced sites, some of which (Trounson, Boundary Stream, Rotoiti) are still closely managed today. Around the same time, trials with pest fencing enabled fenced ecosanctuaries such as Zealandia in Wellington and Maungatautari in the Waikato to completely eradicate key mammal pests inside the fences and keep reinvaders out.

There are currently seven large ring-fenced ecosanctuaries in New Zealand and numerous smaller ones, and a similar number of fenced peninsulas, although pests can reinvade the latter around the ends of fences.

Today there are at least 80 sanctuaries around New Zealand larger than 25 ha implementing multi-species pest mammal control for ecosystem recovery objectives, and all have substantial community involvement. Most of these are unfenced.

For the past 15 years John Innes, Neil Fitzgerald and Corinne Watts have hosted an annual workshop for ecosanctuary practitioners and have maintained a database of ecosanctuary attributes, while Rachelle Binny and colleagues have collated a vast database (1 million-plus records) of biodiversity outcomes from 27 ecosanctuaries of different kinds.

So, what are the key lessons from ecosanctuaries that may be relevant to the 2050 vision of a predator free New Zealand?

1. Pest-fences work. In the words of Elton Smith, manager at Orokonui Ecosanctuary near Dunedin, they "keep out most mammals most of the time". Of course, mishaps with fences and associated gates and culverts sometimes let reinvaders in, but these are usually rapidly detected and removed.
2. There is a gradient of increasing reinvasion of cleared areas by pest mammals: least on offshore islands, then progressively more on nearshore islands, ring-fenced mainland sites, fenced peninsulas, and finally unfenced ecosanctuaries. The risk of mammal reinvasion at any site is never zero, even on remote islands, as visiting boats may carry mammals as inadvertent passengers.

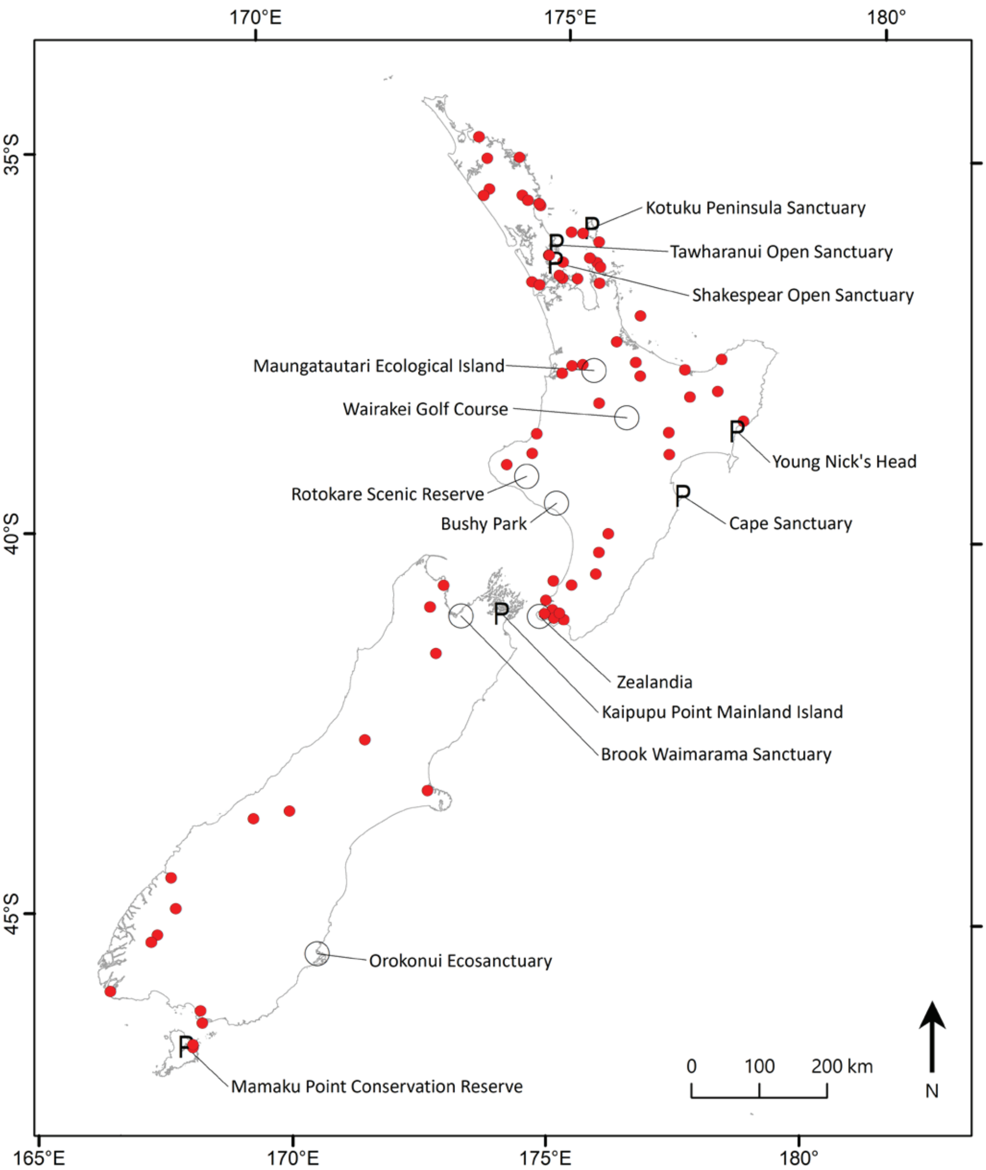

Figure 1: Ecosanctuaries throughout New Zealand. Ring-fenced ecosanctuaries are shown with a circle and fenced peninsula ecosanctuaries with a P. The unfenced sites (red dots) are a large sample of all such sites rather than a complete listing.

Neil Fitzgerald

House mice frequently survive eradication attempts in mainland ecosanctuaries, and so may become abundant if a predator free New Zealand is successfully achieved.

Neil Fitzgerald

The pest-fenced peninsula Cape Sanctuary in Hawke's Bay is 2,500 ha and has hosted the return of kiwi, toutouwai (robin), tīeke (saddleback), pāteke (brown teal) and tītipounamu (rifleman) among others to this mainland site.

3. Different plant or animal species respond to pest mammals in different ways. Some birds, such as North Island kōkako, robins, North Island brown kiwi and tūī, increase in unfenced reserves with control of pests by trapping and poisoning, and zero pests are not necessary for such bird populations to recover. However, sensitive species like tīeke and hihi need zero or near-zero pest mammals for their populations to recover, and then they do so only in pest-fenced or marine island ecosanctuaries. Detailed monitoring in ecosanctuaries can therefore help guide future pest control by identifying threshold pest levels above which native species will not recover.

4. So-called 'deep endemic' bird species that have evolved for a long time in New Zealand seem to rapidly outcompete the introduced and more recent colonising bird species when mammal predators are removed. In other words, ancient New Zealand bird species are particularly vulnerable to pest mammals, but once freed from them may be more efficient foragers in New Zealand's native environments.

5. Different native species are vulnerable to different mammals, and when one mammal (such as possum) is controlled, there is often an increase in another (such as ship rat). These two factors suggest that there will be more benefit for broad biodiversity recovery if multiple mammal pests are controlled at a site, rather than just one pest.

6. The mammal pest that is most likely to remain (and increase) after others are removed is the humble house mouse. Nearly all pest-fenced ecosanctuaries have struggled to remove all individuals of this small omnivore, and they rapidly become abundant when their predators and competitors (ship rats, Norway rats, stoats, weasels and cats) are removed.

7. There is an increasing need for large pest-free areas on the New Zealand mainland. Takahē were recently established at a new site in Kahurangi National Park, but large areas of suitable habitat for takahē are scarce. Similarly, the recent huge breeding season of kākāpō has created a challenge to find large, pest-free sites where this iconic parrot can safely breed.

While ecosanctuaries of different kinds have enabled some insights into biodiversity recovery that can be expected when different pest control regimes are undertaken, there is no clear biodiversity vision associated with Predator Free New Zealand projects. What has been learned in ecosanctuaries can help decision-makers decide what level of pest control to implement at different sites.

Ecosanctuaries have always been made as large as possible. However, at unfenced sites, ship rats in particular demand intensive control year after year as they reinvade and breed rapidly after control. This has limited the area of sustainable mainland ecosanctuaries to about 3,000 ha, although most are smaller.

As predator-free sites, ecosanctuaries are potentially valuable research sites for predator-free studies, such as finding ways to detect and remove invaders when they are at very low density. And clearly, Predator Free New Zealand research can hugely help New Zealand mainland restoration by deriving new tools that cost-effectively control key pest mammals (stoats, possums, ship and Norway rats) over very large areas (10,000+ ha). The two very different approaches have much to offer each other.

This research is supported by Strategic Science Investment funding from the Ministry of Business, Innovation and Employment.

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Camera trapping and occupancy models to measure residual stoat populations

In pest control, it isn't the number of animals you remove that matters. It's the number that remain. Monitoring the level of these residual pests in controlled areas is vital to the optimisation of trapping regimes and to determine whether each programme is meeting its pest reduction goals. In order to do this, conservation managers need reliable, accurate, and timely measurements of the abundance of their target species.

Predator Free Dunedin hopes to remove >90% of stoats within the Halo region, an unfenced but highly trapped area surrounding the Orokonui pest-free sanctuary north of Dunedin. This ambitious reduction in stoat abundance should result in significant ecological benefits, but how do you measure stoat population density? There is no standard measure of stoat abundance, and all mustelids are cunning and cryptic, making them difficult to detect. When stoats invaded Kapiti Island they were undetectable using baited tracking tunnels, and currently very few stoats are detected within the Halo region using these methods. Baited camera traps have been suggested as a way to measure stoat abundance, but the ideal number and distribution of cameras, and the statistical power of these networks to detect population changes, requires investigation and refinement.

Each camera was focused on a lure of fresh rabbit meat, Erayz lure, and ferret bedding lure, a mixture particularly attractive to stoats. Each camera was set to record three photographs in succession when triggered by movement, allowing each animal to be identified to the species level. The researchers then created indices of abundance for each species based on the number of encounters per 1,000 camera hours, and did spatially and temporally related occupancy modelling for the target species. Occupancy modelling uses repeated observations, either through spatial replication (multiple cameras close to each other) or temporal replication (the number of time periods in which a species was detected versus time periods without detection) to assess both the detectability of each species, and the proportion of the landscape occupied by the species. This kind of modelling can discern whether low detection rates are because of low species abundance or difficulty in detecting a species even when it is present.

Over 70,000 photographs were taken during the study period, with some cameras taking more than 6,000 images and others taking only hundreds. Over 1,000 encounters with animals were recorded by the cameras; encounters were defined as detections separated by at least 30 minutes from previous detections of that species at that site. This filtering process removed repeated photographs of individuals foraging around the camera. Rats were the

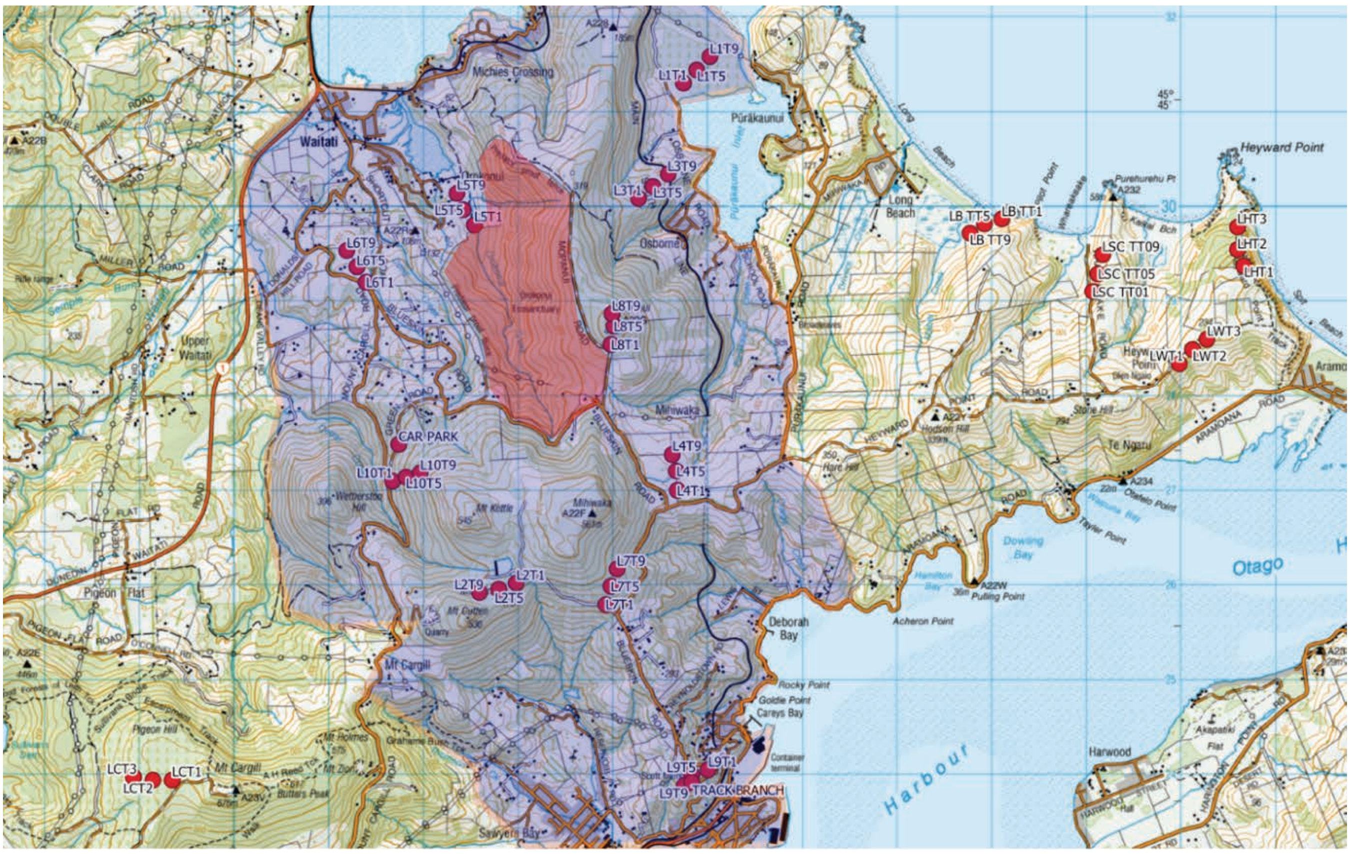

Figure 1: Map of camera trapping network. Each camera is labelled, the Halo region is shaded purple/violet, and the Orokonui fenced sanctuary is shaded red.

Left: One of many Australasian harrier hawks that attempted to remove the rabbit lure.

Below: Examples of pictures of stoats captured from the pilot stoat monitoring programme in the Halo region.

most recorded pest species (303 encounters), with cats the most encountered carnivore (48 encounters), then stoats (15 encounters), ferrets (13 encounters) and weasels (one encounter). Stoats were more active during the day, but were also recorded at night.

Rabbits, hares, possums, mice, pigs, goats and sheep were also detected. Birds were encountered 278 times, including several endemic species such as bellbirds, rifleman, kākā, and tomtits, along with some Australasian harrier hawks that tried to eat the rabbit lure.

Pleasingly, bird encounters were significantly more common in the Halo region than outside it. Occupancy estimates for each pest species (which varied depending on the parameters used) were stoats 56–99%, ferrets 34–39%, cats 63–70%, rats 85–95%, mice 80–90%, and possums 69–87%.

The reason why few stoats were encountered despite the high occupancy estimates is that even where stoats are present, there is a low probability of them being detected by a camera on a given night, despite the best-practice lure being used, because the population density is low compared to that of other species, and the home ranges are comparatively large.

All cameras placed in grassland had frequent false triggering due to grass movement in the wind, shadows, and interference by livestock. The camera memory cards became filled with these images, limiting the collection of usable data. No mustelids were detected by cameras in grassland (although they were detected on cameras placed in small bush patches adjacent to farmland). The extremely high numbers of false triggers in open grassland settings, along with the lack of mustelid detections in these settings, indicate that cameras are not an effective tool for mustelid detection there. Additional expense is incurred in the time required to process the images.

From this study, Andrew Veale and his colleagues found that camera trapping is a viable method for monitoring mustelid abundance and presence, although a reasonable number (30+ inside the Halo region, 30+ outside) of cameras are required due to low mustelid detectability. Both occupancy models and camera trap indices may be useful to monitor relative changes of abundance in mustelids (and other pest species). This work will contribute towards a nationally applicable best-practice method for monitoring mustelid abundance and will better quantify and improve the ever-increasing effort to control these predators.

This work was funded by Predator Free 2050, supported by funding from the Strategic Science Investment Fund, Ministry of Business, Innovation and Employment, and Predator Free Dunedin.

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Trail camera-monitoring for bait aversion. The possum is investigating but not eating a non-toxic cereal bait nailed to a tree.

Bait switching: a pathway to possum freedom using 1080?

Since about 2005, Graham Nugent, Bruce Warburton and others have been trying to locally eliminate possums using aerial 1080 baiting. Back then, Residual Trap Catch Indices (RTCIs, a measure of possum relative abundance) of zero were sometimes recorded after 1080 operations. The initial work was funded by New Zealand's bovine tuberculosis (TB) management agency (now called OSPRI) and sought to determine whether it was feasible to reliably achieve 100% kills of possums within an area. For OSPRI, that would have immediately eliminated TB infection in possums. Once TB freedom had been achieved, management would no longer need to maintain zero possum density (by preventing re-invasion). The term 'local elimination' was therefore coined to distinguish the 'temporary reduction to zero density for TB freedom' from true eradication, which requires not only achieving zero density but also preventing any reinvasion.

By 2010 it had become clear that it was much harder to achieve zero possum density with a single application of 1080 bait than previous monitoring results had suggested; the 0% RTCIs from the early 2000s appeared more likely to have been low-precision sampling errors rather than true zero densities. At large scales there were always some surviving possums, even with double pre-feeding with non-toxic bait, improved bait quality and size, and (by modern standards) high sowing rates.

New work on local elimination began in about 2015, initially again by OSPRI for TB eradication but then also by Zero Invasive Pests (ZIP) and other groups involved in managing pests as part of the burgeoning Predator Free 2050 initiative. The new idea was to use two applications of 1080 bait in quick succession rather than just one (called '1080 to zero' by ZIP and 'dual 1080' by Manaaki Whenua). A small-scale 2016 field trial by Graham, Bruce, and Grant Morriss at New Creek on the West Coast showed that possums that survived an initial 1080-baiting with standard RS5 cereal baits were all likely to have developed a learned and generalised aversion to anything that looked like a cereal bait As a result, a second application of 1080 with a slightly different cereal bait killed only some of the survivors, despite the area being pre-fed twice with the different form of non-toxic bait. Possum survivors of dual 1080 baitings have also since been detected in large-scale operations in 2019 in the Kaitake Range (Taranaki Mounga) and in the Perth River (ZIP, Westland).

Although the survivors at New Creek were shy of cereal bait, many of them did eat peanut butter that had been deployed in chewcards used to monitor their abundance. That prompted Graham and Bruce to explore whether switching to a completely different bait base for the second application of 1080 bait might achieve local elimination – specifically, a peanut butter paste (PBP) bait deployed in paper bags nailed to trees. At a site near Rotorua, possums in three blocks were radio-collared and a different dual 1080 treatment was applied to each.

Two blocks were pre-fed with non-toxic PBP. All three blocks were then poisoned with RS5 cereal 1080 bait. Subsequently one of the PBP pre-fed blocks was pre-fed a second time with more non-toxic PBP, and the remaining block was pre-fed for the first time with non-toxic PBP. Lastly, all three blocks were poisoned again, this time with PBP 1080 baits.

The initial RS5 1080 baiting killed 81% of the 134 radio-collared possums present (75-87% depending on block). Trail cameras deployed after the 1080 baiting to monitor possum interactions with a non-toxic cereal bait nailed to a tree recorded 31 visits by radio-collared possums. No cereal bait was eaten during those visits by radio-collared possums, confirming that most, if not all, survivors had eaten cereal bait but survived through a learned aversion to that bait type. The second 1080 baiting, this time with PBP, killed 22 (92%) of the remaining 24 possums. This included all of the 14 possums in the two blocks pre-fed with non-toxic PBP before the first (cereal) 1080 baiting. However, two of the 10 possums in the block that was pre-fed with PBP only after the first 1080 baiting survived. That result suggests that familiarising possums with the second form of 1080 bait before they encounter the first 1080 bait type is important – where that was done, 100% of radio-collared possums (n = 89) were killed. This suggests that dual 1080 baiting with different bait types has the potential to locally eliminate possums.

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Bruce Warburton

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Contacts & Addresses

Key contacts are included at the end of each article.

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Editor: Jim Coleman

Published by: Manaaki Whenua
PO Box 69040
Lincoln 7640, New Zealand
ph: +64 3 321 9999

ISSN 1175-9844 (Print)
ISSN 1170-3016 (Online)

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