Kararehe Kino

Vertebrate Pest Research

Issue 21 / January 2013

HOW SCIENCE CAN CONTRIBUTE TO A PEST-FREE NZ

Landcare Research
Manaaki Whenua

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Photo Credits:
Front cover: Burgess Island, Mokohinau Islands, situated 110 km north east of Auckland. A lighthouse was erected on the island in 1883 and since then stock and fire have reduced its natural vegetation to remnants along cliffs. Stock have now been removed and kiore (introduced by Polynesians) were eradicated in the early 1990s. Photo by Neil Fitzgerald
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Pg 4: Black browed albatross chicks on the Kerguelen Islands by Hélène De méringo

Pg 18: Australasian harrier with rabbit, photo courtesy of Nga Manu Images
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Pg 20: Cat photo by Patrick Garvey

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ERRATUM – ISSUE 20

There was an error in printed copies of Kararehe Kino, Issue 20, Community Conservation. On page 15 the key to Fig. 3 should have shown the orange dots inside the rodent control area and the black dots outside the rodent control area. Our apologies for any confusion caused with this error.

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In this issue...


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Hélène de Meringo

Eradicating invasive species on big inhabited islands

One legacy of the New Zealand physicist Sir Paul Callaghan was his vision of a pest-free New Zealand. John Parkes has been investigating whether such a vision will divert pest managers from practical solutions and waste a lot of money, or whether it is in fact feasible. All pest eradication projects face this question and there are two ways of answering it – by looking at precedents (who has done it before under similar circumstances) and by analysing the general obligatory rules and particular constraints affecting projects and determining whether they can be met or overcome.

Precedence

Most of the 31 species of exotic mammals but only a few of the exotic birds, invertebrates and weeds that occur on the main islands of New Zealand have been individually eradicated from some smaller islands (Table). For mammals, the question is whether these successes could be scaled up to deal with one or more species across the larger islands of New Zealand – D'Urville (16,782 ha), Great Barrier (28,510 ha), Chatham (90,650 ha), Stewart (173,500 ha), and the North (11.3 million ha) and South Islands (15 million ha).

Some of the constraints

Scale is a problem for the eradication of some species. What is unclear is whether factors (e.g. topographic complexity, habitat and natural foods, and the size of the target population that might allow for individuals with odd behavioural or physiological characters to avoid being killed) that correlate with scale increase the risk of failure. Scale also means very big islands have to be treated in some sort of 'rolling front' strategy with increased risks of reinvasion of cleared areas and increased costs to detect and deal with immigrants. This risk of backfill probably determines the time frame over which any large-island eradication must take place, as the cost cannot be spread over decades without a huge increase in the risk of failure. Thus scale, and things that correlate with it, makes eradication difficult but not intrinsically impossible.

Tools such as aerial baiting with an anticoagulant can put all rodents at risk in one event, but no method exists that reliably kills 100% of populations of other pest species in a single application. For possums, cats, rabbits and stoats, some animals survive each control event and have to be killed, usually by applying other methods, until the last event kills the last animal.

Table. *Large islands in New Zealand and overseas from which the 'target' pest species have been eradicated.*
[1] Eradication pending but stoats are likely to reinvade even if they are eradicated. [2] To be confirmed. [3]Eradication pending.

Species	Largest island in New Zealand	Area (ha)	Largest island elsewhere in the world	Area (ha)
House mouse	Rangitoto/Motutapu	3820	Macquarie (Australia)[3]	12 785
Ship rat	Rangitoto/Motutapu	3820	Macquarie (Australia)[3]	12 785
Norway rat	Campbell	11 200	Saint Paul (Kerguelens, France)	800
Kiore	Raoul	2938	Vahanga (Tuamotus, France)	382
Possum	Rangitoto/Motutapu	3820		
Stoat	Resolution[1]	20 860		
Cat	Rangitoto/Motutapu	3820	Marion (South Africa)	29 000
Goat	Great Barrier	28 510	Isabela (Galapagos, Ecuador)[2]	500 000
Pig	Kapiti	1970	Santiago (Galapagos, Ecuador)	58 465
Rabbit	Rangitoto/Motutapu	3820	Macquarie (Australia)[3]	12 785
Hedgehog	Rangitoto/Motutapu	3820		

Costs make many operations impractical. The Campbell Island rat eradication cost $220 per hectare so a rough estimate to aerially bait all of New Zealand to eradicate rodents is $6 billion, assuming a perfect kill. What is not known is the cost to remove other pest species that require some sequence of control. The cost to eradicate the suite of mammal pests from Rangitoto/Motutapu islands was about $3.5 million or $914 per hectare, and that did not include the earlier costs of removing possums and wallabies. Judging by this case, the cost to remove a similar suite of pests from New Zealand would be at least $24.6 billion! This is a minimum figure as managers of Rangitoto/Motutapu islands did not have to spend much money to mitigate non-target effects, manage people, or deal with reinvaders in the short term.

The presence of people poses problems for most eradication projects. There are all sorts of smart tools these days to target sustained control of pests but none (by themselves) are remotely likely to kill 100% of a population, especially of rodents. For that, toxins are essential and aerial baiting will be required in most areas. What an urban human population would think of aerial baiting in their vicinity or how such a technique could be imposed on, for example, organic farmers hardly bears thinking about.

What about just some species?

If just one pest could be eradicated from large islands, which one would be picked? If possums were chosen, a plague of rats and stoats would likely follow; if rabbits were chosen, an increase in hares is likely; if ship rats, a plague of mice is likely. The Animal Health Board would be likely to pick possums, DOC might pick rats, and Otago sheep farmers might nominate rabbits.

The positive solutions

John believes a pest-free New Zealand would be wonderful but in this case 'perfect' is the enemy of the 'good'. The 'good' is practical and includes (a) doing rigorous feasibility plans on one or more small islands with human inhabitants, (b) choosing the best places to protect the most valued assets (how much of this can be done depends on the national budget, and national optimisation depends on trade-offs between individual, regional and national priorities (who pays?), (c) improving efficiency by developing new tools and better ways to intervene with current tools, and better ways to monitor effects, (d) investing in research to find out why some individuals of some species always survive our best efforts, and (e) ensuring that the capacity to deliver action is accepted not just as a job for government but is sustained by landowners and the community.

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Will reinvasion stymie large-scale eradication of invasive mammals in New Zealand?

So far, eradication of invasive species has mostly been achieved in relatively small areas. For terrestrial invasive species, the coast of a small island or the fence around a reserve is often used to set the spatial limit to eradication, but these boundaries are just special cases of a more general selection of areas, including portions of large land masses, where managers might decide to aim for eradication. So, is eradication of invasive mammals, such as possums, mustelids and rodents, over very large areas of New Zealand just a matter of scaling up from what has been achieved on near-shore islands or in fenced sanctuaries?

If a control programme is rolled out across the country, the problem of pest reinvasion will become a more important issue than that encountered in local eradication programmes for two reasons. Firstly, the boundary between treated and untreated areas is likely to be very long and will often not coincide with a physical barrier (such as a river or the ocean) expected to block or slow dispersing animals. This means there will be a large pool of potential invaders immediately outside treated areas. Secondly, it will be difficult to confirm that all individuals of an invasive species have been removed from a large treated area. In such a case, it may not be obvious whether any resurgence of a pest population is due to recruitment from survivors or from immigration, and sometimes determining the source of reinfestation might be impractical or too costly.

Peter Banks and Chris Dickman from the University of Sydney, with Andrea Byrom and Roger Pech from Landcare Research, have been examining how the problem of 'reinvasion' can differ from an initial invasion by an exotic species, and why this might matter. They defined reinvasion as: 're-establishment of a species in a location it had previously invaded, but was controlled or eradicated to manage unwanted impacts'. Essentially three factors can change the management of reinvasion, compared to in an initial invasion. These are (1) changes in the invader itself, (2) changes in the invaded environment, and (3) interactions among invaders and with other local species. These three factors are illustrated with the following examples.

Changes in the invader: Various pest control techniques have had a long history of use in New Zealand and susceptibility of invasive mammals to these techniques can change over time, as for example through development of resistance to poisons or disease. There is some evidence of this in the declining effectiveness of rabbit haemorrhagic disease as a biocontrol agent (Bruce Warburton et al; Kararehe Kino, Issue 18) and with the use of sodium monofluoroacetate (1080) for rabbits in parts of Australia. Also individuals that survive a control programme may be bait-shy or trap-shy. Consequently new methods of control may be required to manage reinvasion due either to in situ recruitment from survivors or immigration from outside populations that have a history of exposure to conventional control techniques.

Changes in the environment: Many exotic plants have become established in New Zealand since the first introductions of rodents (kiore, ship rats, Norway rats and house mice). Grant Norbury and colleagues have shown that in the grasslands of the central South Island, mouse populations are generally larger in areas with introduced pasture grasses that regularly produce high volumes of seed compared with populations in indigenous tussock lands that mast less frequently (Fig; see also Kararehe Kino, Issue 18). Clearly these dryland environments have changed in a way that benefits rodents, which will increase the likelihood of populations resurging after control.

Fig. *Grasslands dominated by introduced pasture species (above) provide a more reliable supply of seed for mice than those dominated by indigenous tussock (below).*

Species interactions: There is now substantial evidence that interactions among invasive species need to be taken into account in control programmes. For example, in North Island forests control of ship rats leads to greatly increased abundance of house mice (Ruscoe et al., Kararehe Kino, Issue 13). And Chris Jones and colleagues have shown that stoats are specialist predators of mice, which suggests that with high mouse populations following local eradication of rats and mustelids, conditions are likely to be ideal for re-establishment of stoat populations through reinvasion.

These examples illustrate why managing reinvasion could be more difficult than dealing with an initial invasion. However, Peter and his colleagues note that in many cases better knowledge of the biology of invasive species and their impacts should increase the ability of managers to block reinvasion. The review has highlighted some key areas of research that would improve the chances of achieving large-scale eradication of invasive mammals across New Zealand. These include understanding: the population dynamics of reinvaders at ultra-low population density; genetic changes in invader traits; how to exploit changes in ecological processes such as predation, competition and disease; biophysical factors that enhance or suppress reinvasion; and interactions between reinvasion and other drivers of global change such as climate change and land-use change.

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Peter Banks, Chris Dickman and Roger Pech

Measuring progress and declaring 'success' in broad-scale eradications of wildlife pests and disease

Tom Fraser

Broad spatial-scale eradications are necessarily broad temporal-scale operations because large areas occupied by wildlife pests or diseased animals cannot all be treated at one time. This makes the process logistically complicated and expensive, if not prohibitive. A quantitative method for assessing progress and success is required to justify ongoing investment. However, these methods have yet to be developed. A case in point is New Zealand's attempt to eradicate bovine tuberculosis (TB) from wildlife and livestock. This is an ambitious goal requiring decades of investment, but an analytical framework for assessing success at regional and country-wide scales that incorporates rigorous probability theory, epidemiology, possum biology and bio-economics has not yet been developed. This is a disease example but the same analytical principles, basic data requirements and spatio-temporal complexities apply to a growing list of vertebrate-pest-eradications: foxes on Tasmania and vertebrate pests on Stewart Island to name just two.

In broad-scale eradication operations such as these the targeted area is subdivided into zones, across which pest or disease control is organised in a spatio-temporal fashion, using strategies such as a 'rolling front' (*Fig*.). To assess (1) the progress and (2) success of such a strategy, Dean Anderson and colleagues are developing a two-stage analytical process that incorporates probability theory, biology, and economic and political constraints.

Stage one operates at a relatively fine-spatial scale and follows control in a given zone (*Fig*.). The aim is to quantify the probability the zone is free of pests or disease, which influences the decision to advance the control to new zones. This probability can be obtained in two ways. The first and inexpensive way is to use precedence, or the proportion of times that previous similar control efforts have succeeded. While this may appear risky, if the economic and political cost of being wrong is low, then this may be the optimal decision (i.e. low cost to re-control). If prior information on the probability of freedom in the zone does not exist, then surveillance data should be collected to calculate the sensitivity.

Surveillance sensitivity, or the probability of detecting the agent in the targeted area given that it is present, is the essential element for using surveillance data to quantify a probability of freedom from the pest or disease. Importantly, a probability of freedom for an area cannot be calculated using surveillance data without a sensitivity of detection. Intuitively and quantitatively, surveillance sensitivity increases with increasing search effort.

The objective in stage two is to provide a probability of ongoing freedom from pests or disease (given no detection) in the area no longer under active control. As in stage one, this requires a measure of surveillance sensitivity over the corresponding area.

Ongoing surveillance over all previously controlled areas is critical in broad-scale eradications because of the unavoidable risk of reintroduction through 'backfill' (dispersal into a treated zone from an untreated adjacent area). This process continues until all control has been completed in all zones and the target probability of freedom for the entire area has been reached.

Stage-two surveillance to detect pests or disease in previously controlled areas, conducted over multiple zones, must be very inexpensive. A novel and important area of research is the development of surveillance models that are capable of incorporating multiple sources of low-cost detection data, as well as biology and epidemiology (in the case of diseases), to quantify zone-level sensitivities. These are then aggregated statistically for calculating the probability of freedom for the entire area. While low-cost and broad-scale-surveillance data may result in low zone-level sensitivities immediately following control, the modelling approach results in increasing sensitivities over the course of eradication operations.

To illustrate a hypothetical eradication of TB from possums in the South Island, a sensitivity measure would be calculated for all zones following the end of control in 2028 (*Fig.*). Intuitively, the most risky zones are those last controlled in 2010 because of elapsed time and the potential for reintroduction. However, the modelling approach incorporates the expectation that the possum population has recovered, and if TB was present a decade previously, it would be easily detected through surveillance of TB in livestock, captured sentinel species (e.g. pigs or ferrets) or direct surveillance of possums.

It is possible that it could take several years of low-cost and broad-scale surveillance following control to reach a target probability of freedom of a pest or disease for the entire area. The continuation of low-cost surveillance beyond control will be a small fraction of the total financial and political investment in the eradication programme. Further, the modelling approach can be used to predict, prior to the eradication effort, the amount of low-cost surveillance that will be required throughout and after control ends.

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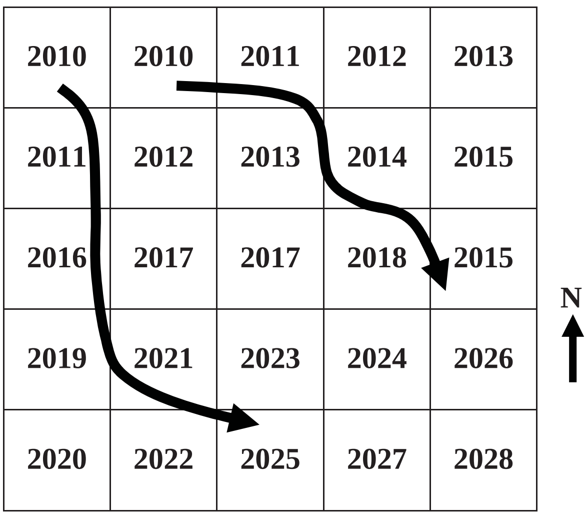

Fig. *The spatiotemporal progression of a hypothetical broad-scale eradication operation that begins in the north-west in 2010 and finishes in the south-east in 2028. Confirmation of eradication may extend well beyond 2028.*

An ecological game to enhance the pest-free New Zealand debate

The goal of creating a pest-free New Zealand, whether aspirational or real, will inevitably lead to heated debate, with both proponents and opponents using facts and figures to strengthen or weaken support for such a goal. Eradicating invasive species is a complex challenge, not only because of technical issues, but because of necessity it will involve many people and communities. As soon as the public becomes intimately involved, the complexity of the challenge increases considerably, and the issue becomes a 'wicked problem'. This is because interest groups with differing values will see the problem differently and are unlikely to agree to whatever solution is proposed. Thus, individuals or groups with entrenched interests (e.g. protection of biodiversity vs protection of the lives of animals, or your pest vs my resource) raise different values, and will protest every choice suggested by managers from multiple value and scientific perspectives.

Given the significant challenge that wicked problems pose, one potential contribution to assist discussion and resolve conflict is to ensure participants are as well informed as possible about the complexities of the ecological issues of invasive species and the impacts they have on New Zealand's indigenous species and ecosystems. As well, participants need to be informed about the complexities of managing invasive species including control effectiveness, perverse outcomes, non-target and environmental risks, and costs.

Communicating science information, especially complex issues, is difficult because the public have limited access to scientific journals and, even when they can access them, are not always familiar or comfortable with such media. In reverse, ascertaining stakeholders' goals and objectives is also difficult because communication between individuals and scientists and managers is limited, and assessing which opinions come from an informed point of view or which are pure rhetoric is also difficult.

Pen Holland and Bruce Warburton, in collaboration with Hazel Bradshaw (Human Interface Lab, Canterbury University) and Julian Looser (Dried Frog), have been developing a novel approach to better inform individuals and increase communication between science and the public using a computer game based on possum interactions with forest, choices for managing possums, and the consequences of such choices. Players will learn about known, science-based interactions between pests and forest ecosystems, and the management choices and their consequences, while their preferred strategies and attitudes to the available management tools can be captured and analysed. This will, for the first

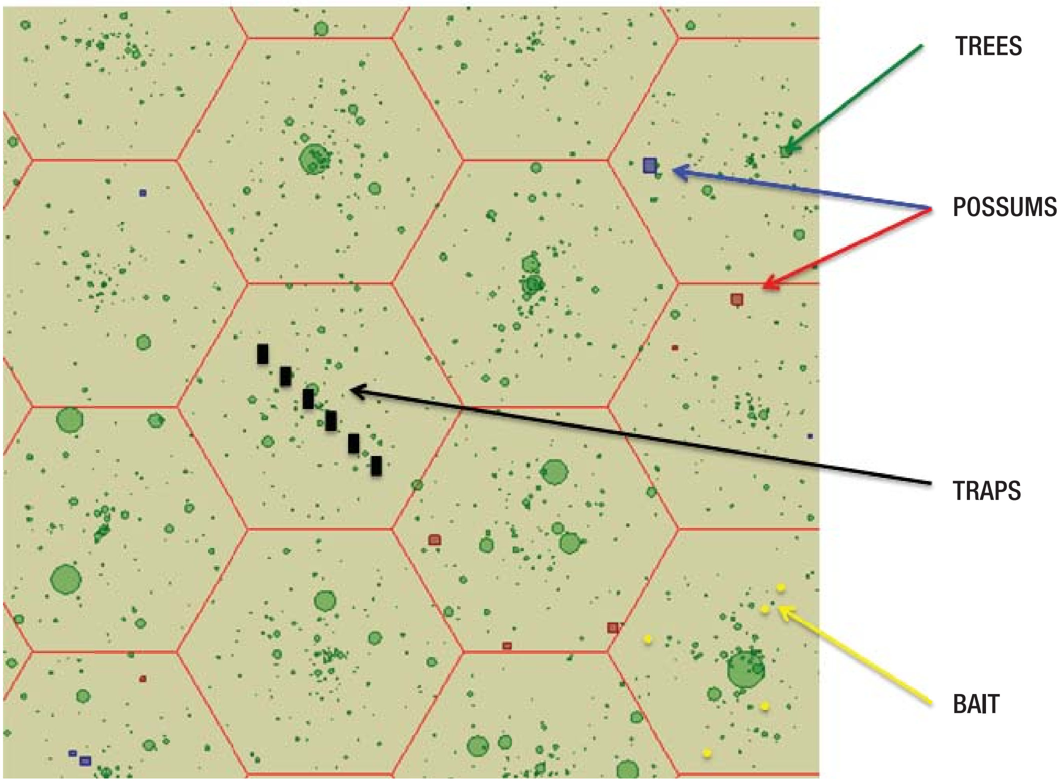

Fig. 1 *The Graphical-User-Interface that underpins the game includes forest and possum population dynamics and some control options.*

Fig. 2 *The game environment that players interact with.*

time, enable crowd sourcing (i.e. seeking solutions by online outsourcing) to be used for generating possible management strategies, assessing public perceptions on a large scale, and ascertaining whether and how perceptions change if more information is provided in an engaging way.

To underpin the development of the game, a model of the best available knowledge is required. Although many separate models have been developed to address individual components of possum control (such as possum dynamics, bait consumption, or browse-induced tree mortality rates), decision-making for the whole problem requires an integrated model of all of these. Pen has developed a 'whole-of-system' simulation model of interactions between possum management and tree condition (*Fig. 1*). The foundation of the model is a virtual landscape created using digital elevation and forest composition data derived from real locations. A population dynamics module (based on data about individual possums) sits in the landscape, simulating birth, death and dispersal processes in response to available food (calculated from the relative palatability of individual, simulated trees within possum home ranges). Management tools such as traps, bait stations or bait can be placed into the landscape via ground or aerial control operations, and possums then interact with these tools, and may subsequently die. In addition, repeat tree monitoring may be simulated by tagging individual trees and recording canopy health. The costs of control and monitoring operations are calculated from the cost of equipment and deployment (e.g. ground-based contractors transport and remuneration), so that control effort (cost/time) versus benefit (e.g. kills/ increased tree health) can be estimated for a given monitoring and management strategy.

Ultimately the game will be released over the Internet, as a source of both entertainment and scientific information (*Fig. 2*). Players' actions and winning strategies will be analysed to get feedback on how perceptions differ, and to find publically acceptable solutions to pest control problems. Computer games can provide an accessible, fun way to engage the public in complex problems and to motivate people to rise to challenges and develop new skills by harnessing their innate curiosity. This can be used for learning by carefully embedding learning outcomes into gameplay goals, which hides the overtly educational content from the player. Hopefully, such an initiative will ensure participants that get involved in the debates that will inevitably arise around the goal of pest-free New Zealand do so as informed participants rather than misinformed supporters of entrenched positions.

This work was funded by the Ministry of Business, Innovation and Employment.

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Landscape influences on *possum dispersal*

Dispersal of possums into new territory is a key issue for possum management, resulting in the spread of bovine tuberculosis (TB) and rapid recolonisation of controlled areas. Landscape features act to limit possum dispersal but just how is not fully understood. Knowing how these features influence dispersal is important for large-scale possum control programmes, especially since they affect potential possum dispersal back into areas under management.

Tom Etherington, a PhD student at The University of Auckland and Landcare Research Joint Graduate School in Biodiversity and Biosecurity, is currently trying to identify the main landscape features that influence possum dispersal at large regional scales.

Collecting sufficient information on individual possum dispersal across large regional areas would be very costly. Instead Tom is using a 'landscape genetics' approach to provide an indirect measure of connectivity between possum populations across a landscape (*Fig. 1*). The assumption is that possum populations that are more closely related are likely to be more geographically connected. The Figure shows that such genetic connectivity is clearly not a simple function of how close or far apart possum populations are in the landscape as the 'crow flies', and that other variables must also be acting to influence possum dispersal.

To identify what landscape features may be limiting possum dispersal, Tom is analysing the landscape genetics data using a geographic information system (GIS) approach called 'least-cost modelling'. Cost refers to the energy needed to get around particular topographic features (e.g. steep hills), behavioural preferences (e.g. forest remnants) and mortality risk (e.g. crossing rivers or roads). Using this information, least-cost modelling can find pathways between pairs of locations that represent the most efficient route of dispersal by balancing the distance travelled with the cost to traverse that landscape. The total cost associated with each least-cost pathway is then taken as a measure of connectivity.

A large number of scenarios, in which different combinations of landscape features have different costs, are being analysed and compared with the genetic data to identify what landscape features are important in limiting possum dispersal. Preliminary results suggest that large improvements in understanding the connectivity of possum populations across landscapes can be achieved by accounting for the costs of dispersal associated with certain landscape features (*Fig. 2*). The analyses indicate that the main factors restricting possum dispersal are the size of major rivers, followed by the absence of tree and scrub landcover.

Once the analyses are completed, GIS maps that represent the landscape in terms of costs to possum dispersal will be produced. These 'cost maps' will then be used as inputs to further analyses that will enable large-scale suppression programmes to tailor management of possums based on whether parts of a landscape are more or less isolated, or are more or less likely to act as dispersal pathways.

The collection of genetic data was undertaken under contract to the Animal Health Board (Project R-10625). The analysis was funded by the New Zealand Government through an International Doctoral Research Scholarship.

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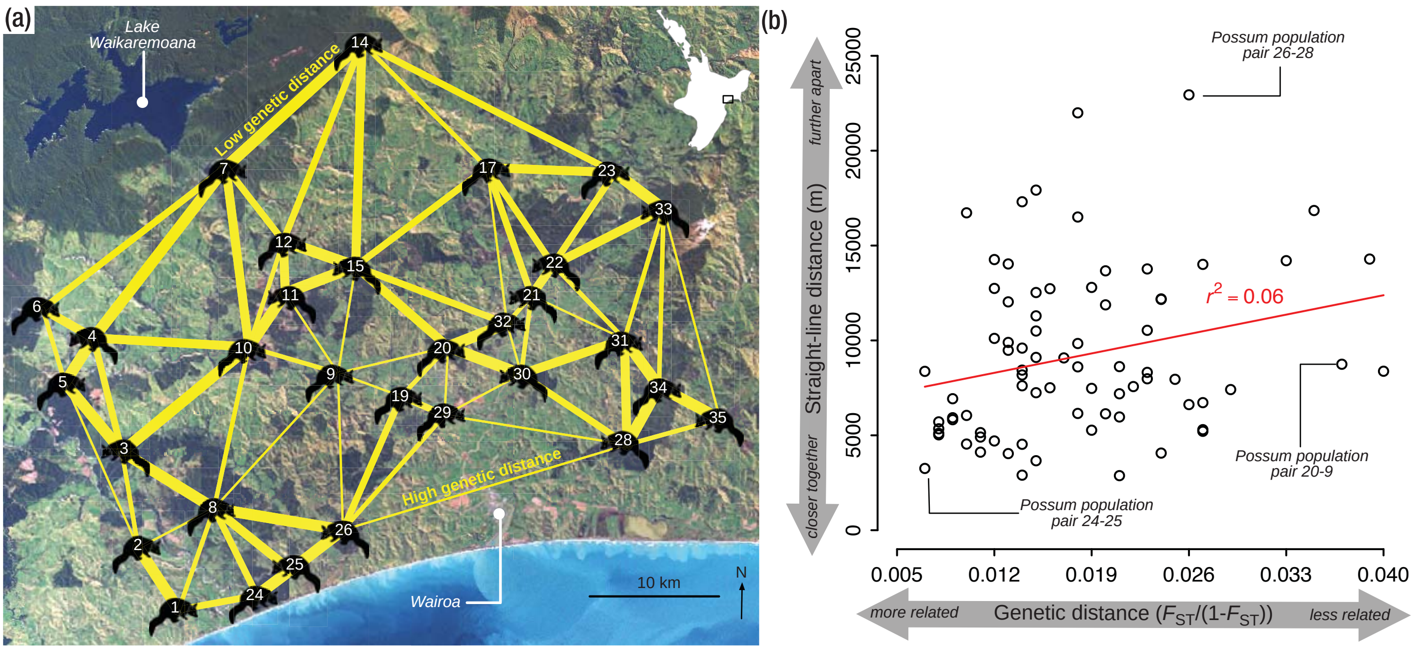

Fig. 1(a) *The location of possum populations for which genetic data have been collected, with neighbouring possum populations connected to form a network. Thicker lines indicate more closely related possum populations with lower genetic distances.*
*(***b)** *A correlation between genetic distance and straight-line distance, where each point represents a neighbouring possum population pair. If the landscape does not affect dispersal then possum populations that are closer together should be more related, and possum populations that are further apart should be less related. The poor correlation suggests that landscape features must be affecting possum dispersal.*

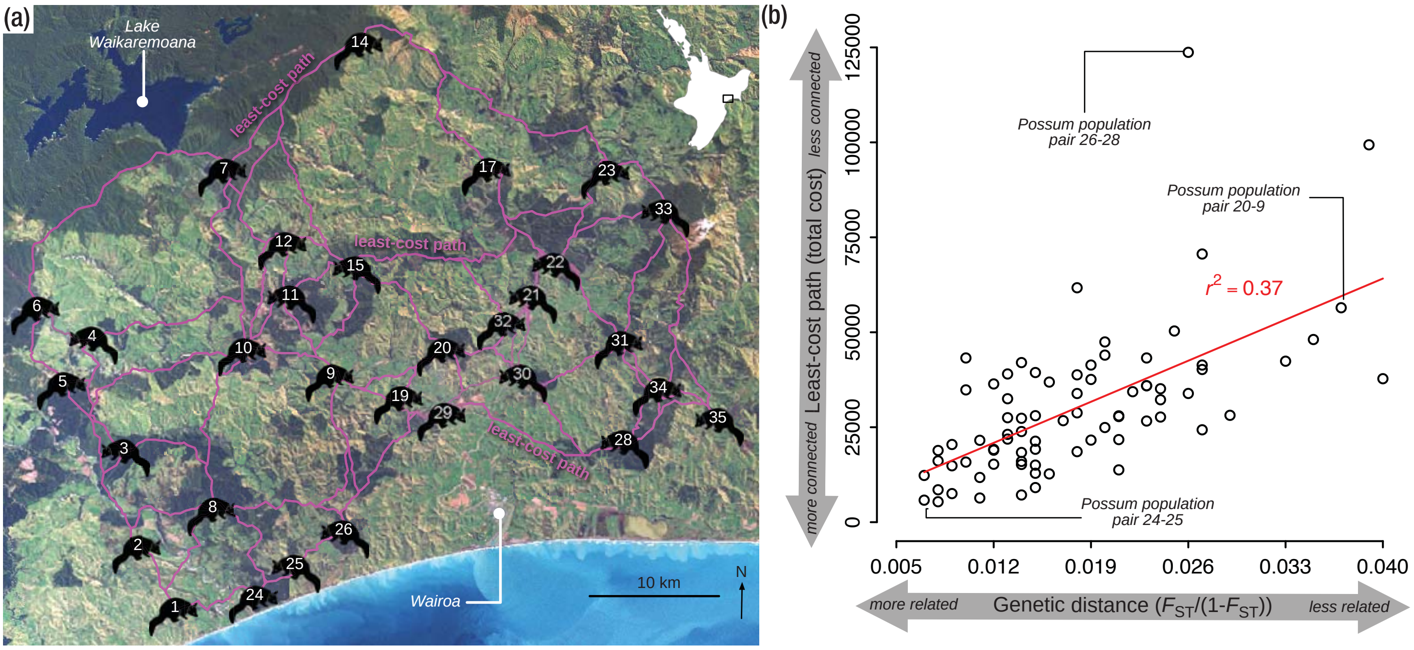

Fig. 2(a) *Preliminary results from the least-cost modelling have identified pathways that are a more realistic representation of connectivity between neighbouring possum populations.*
(b) *A correlation between genetic distance and least-cost-path total cost, where each point represents a neighbouring possum population pair. If the landscape does affect dispersal then possum populations that are more connected should be more related, and possum populations that are less connected should be less related. The reasonable correlation suggests that landscape features do affect possum dispersal.*

Spillover and edge effects in pest control

Clearly, native biodiversity benefits when invasive predators are controlled. However, the spatial extent of these benefits is poorly understood. For any given area under pest control, both edge effects and spillover effects are likely. Edge effects occur when the control area closest to the boundary (the edge) receives a lower level of benefit than areas closer to the centre of the control area (the core) (*Fig. 1*). Edge effects may occur if pests from the surrounding uncontrolled area reinvade the edges of the management area and adversely affect the biodiversity there. Conversely, spillover effects may occur when the area directly outside the boundary of the control area receives some level of biodiversity benefit due to the proximity of pest control. Spillover may occur if native plants and animals that benefit from the pest control are also present in the surrounding area, or if linked to the surrounding area via processes such as seed dispersal. Edge effect and spillover effect are not mutually exclusive concepts and may or may not be observed at individual pest control areas.

Knowing the spatial extent of edge and spillover effects in regard to pest management goals and conservation outcomes is important but the effects are not well understood. Edge effects could reduce the actual area receiving biodiversity benefits to only part of the entire area being managed, In such situations, a 'buffer zone' of pest control surrounding the managed area may be necessary to protect the whole area as intended. On the other hand, if significant biodiversity spillover effects occur outside the managed area, it may not be necessary to actively manage pests over the entire area in order to achieve beneficial outcomes.

Mustelids and rodents are two groups of predators that have had particularly severe impacts on, and continue to devastate, New Zealand's native animals, plants and ecosystems. As a result, these pests are targeted in many areas of high conservation value around the country. One such area is the Ark in the Park Open Sanctuary Project, a 2300-ha area in the forested Waitakere Ranges Regional Park west of Auckland City. There, rodents and possums are poisoned and mustelids are trapped.

In the Ark in the Park area, Eru Nathan of the University of Auckland has established transect lines 1200 m long, 600 m within the pest control boundary and 600 m beyond in untreated parkland. At 200-m intervals along these lines, Eru records several easy-to-measure biodiversity indicators that are representative of the range of local biodiversity. These indicators are bird counts, occupancy rates of gecko and skink artificial refuges and of weta 'motels', counts of ground invertebrates, seedlings on seedling density plots, and counts of rodent and mustelid tracks in tracking tunnels.

Although the fieldwork is continuing, preliminary analyses of the tracking tunnel data suggest that both edge and spillover effects are occurring at this site (*Fig. 2*). At 200–400 m outside of the control area, pest numbers are lower and weta numbers higher than at 600 m beyond the boundary, suggesting that some level of spillover benefit is occurring outside the management area. Conversely, from the control boundary to 200 m inside the management area, pest numbers are higher and weta numbers lower than at the core of the area, suggesting that an edge effect is also occurring at this site.

Given the heavy use of pest control for conservation benefits in New Zealand, better knowledge of the spatial extent of control benefits could potentially be used to make pest management more time- and cost-efficient, and allow for better allocation of conservation resources overall.

This work is funded by the University of Auckland and Landcare Research and is supervised by Margaret Stanley and Al Glen.

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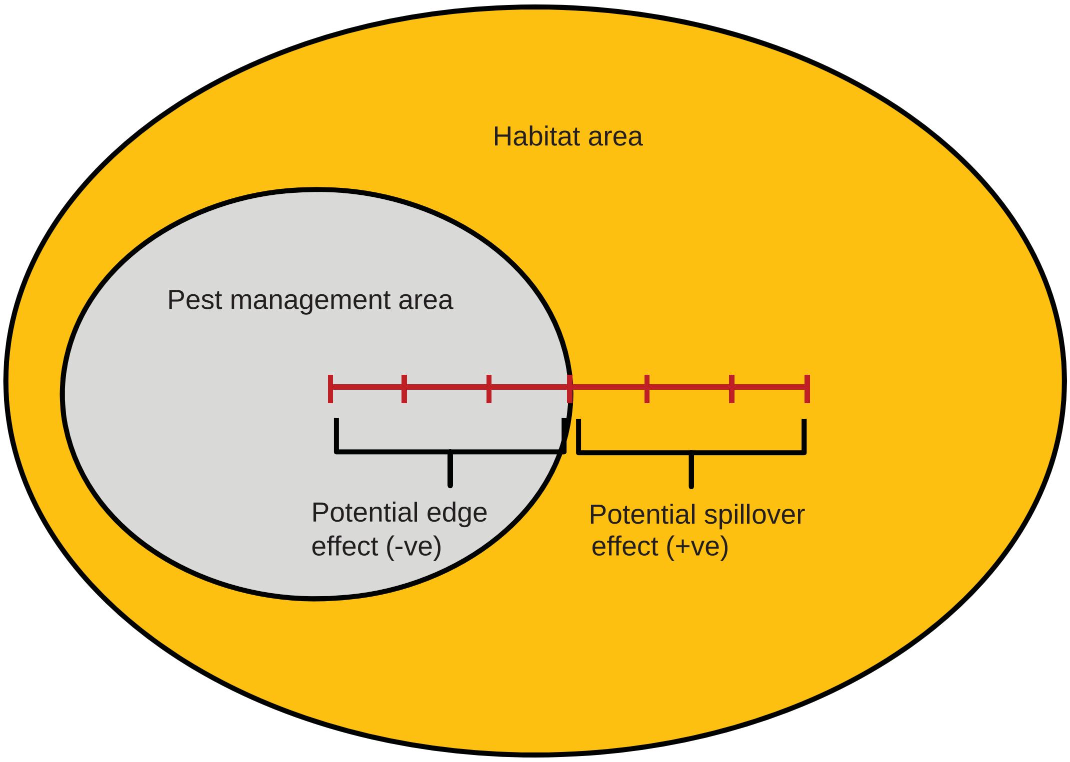

Fig. 1 *Diagram representing transect set-up and demonstrating potential edge and spillover effects.*

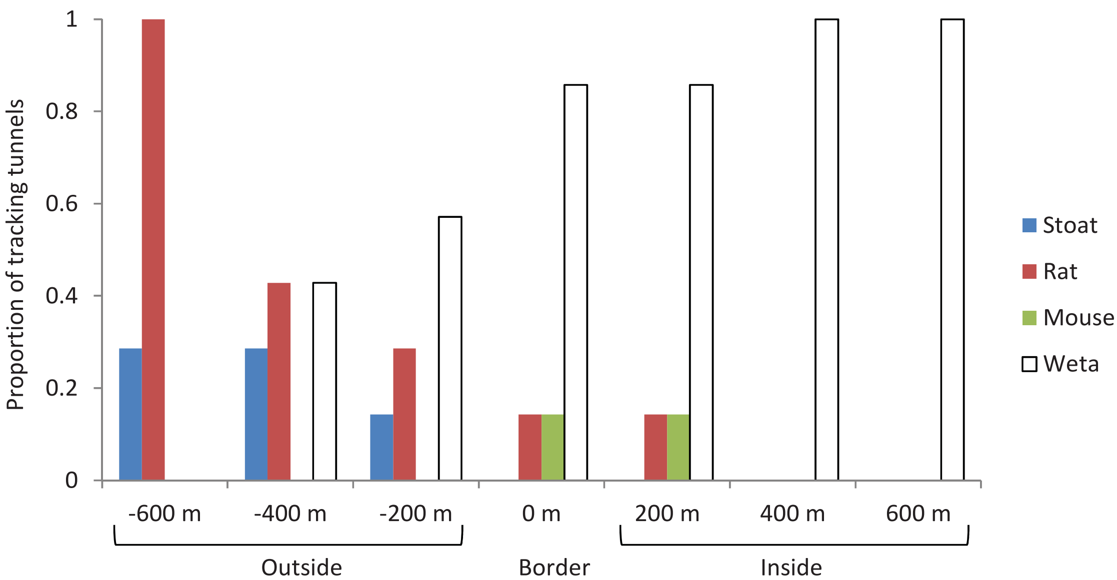

Fig. 2 *Proportion of tracking tunnels visited by pests and weta by distance from the border of pest control.*

Pest control across boundaries

Project Kaka is large-scale (22,000 ha) ecological restoration initiative undertaken by the Department of Conservation (DOC) in Tararua Forest Park. DOC's aim is to suppress possum, rat and stoat populations via 3-yearly aerial application of 1080 to allow the recovery of native vegetation, and invertebrate and bird communities. Control outcomes will be monitored to improve understanding of the value, safety and efficacy of large-scale pest control. The project has provided Mandy Barron and colleagues with the opportunity to test ideas about where and when to apply pest control. Mandy's team has set up biodiversity monitoring complementary to DOC's to test whether the area protected by pest control is larger or smaller than the area poisoned (a 'core effect' vs. 'halo effect') and whether the size of the protected area varies for different native species such as weta (an iconic invertebrate) and native vegetation.

To investigate the spatial extent and benefits of pest control, two survey lines (Totara Flats and Waitewaewae) have been set up perpendicular to the control boundary and extending 2.5 kilometres into and out of the control zone (*Fig. 1*). Devices to measure the relative abundance of pests (rodents, mustelids, and possums) have been set up along the lines. Resource availability (seed fall), the relative abundance of native invertebrates and tree health are also being measured to see if the benefits of pest control change with increasing distance into and out from the control zone. The duration of pest control benefits will be measured by repeated monitoring over the next 3–5 years to assess how quickly pest populations reinvade or recover to pre-control levels.

The first aerial 1080 control in Project Kaka was done in November 2010 and to date seven monitoring sessions have been completed, including one before control was applied. Not surprisingly, rats have been the species that responded most rapidly. Their tracking rates, revealed in tracking tunnels, were reduced to near-zero in the treatment zone following control but recovered to pre-control levels within 9 months (*Fig. 2*). By comparison, at DOC's monitoring sites near the centre of the treatment area, rat abundance has not recovered as fast or to the same level as at our survey lines, which are both closer and more accessible to a source population from untreated parts of the Tararua Range (*Fig. 1*), indicative of a core effect of control on rat abundance. Possum numbers, indexed using WaxTags, have been slower to recover, although effective control across the line at Totara Flats was not achieved until August 2011. Despite this, a reduction in possum browse on kāmahi along the controlled part of this line was apparent 3 months after control, while possum browse on the entire Waitewaewae line has remained negligible. Tree weta numbers, as indicated by their occupancy of wooden shelters, have been increasing over time,

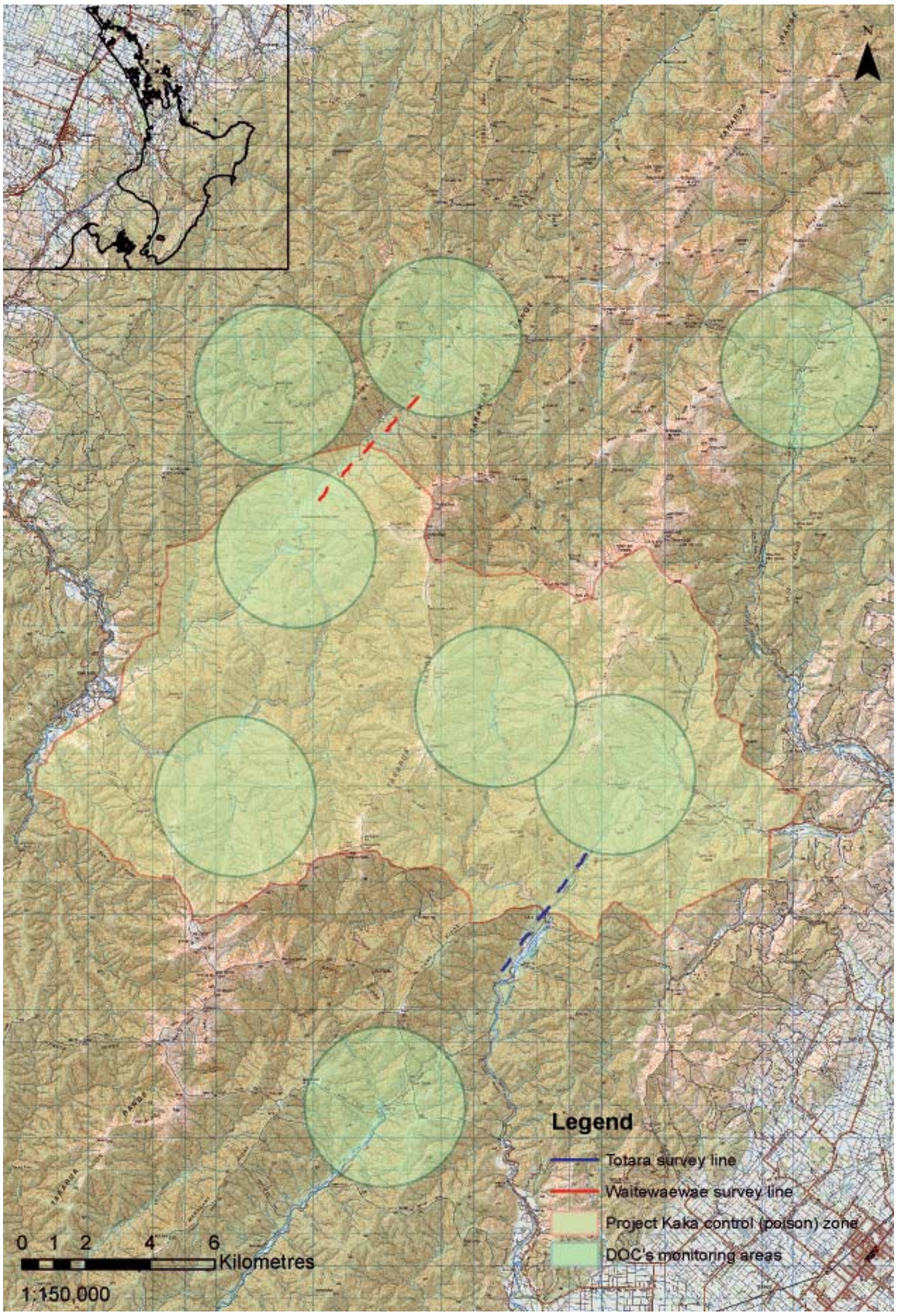

Fig. 1 *Location of the two survey lines set up in Tararua Forest Park for Project Kaka.*

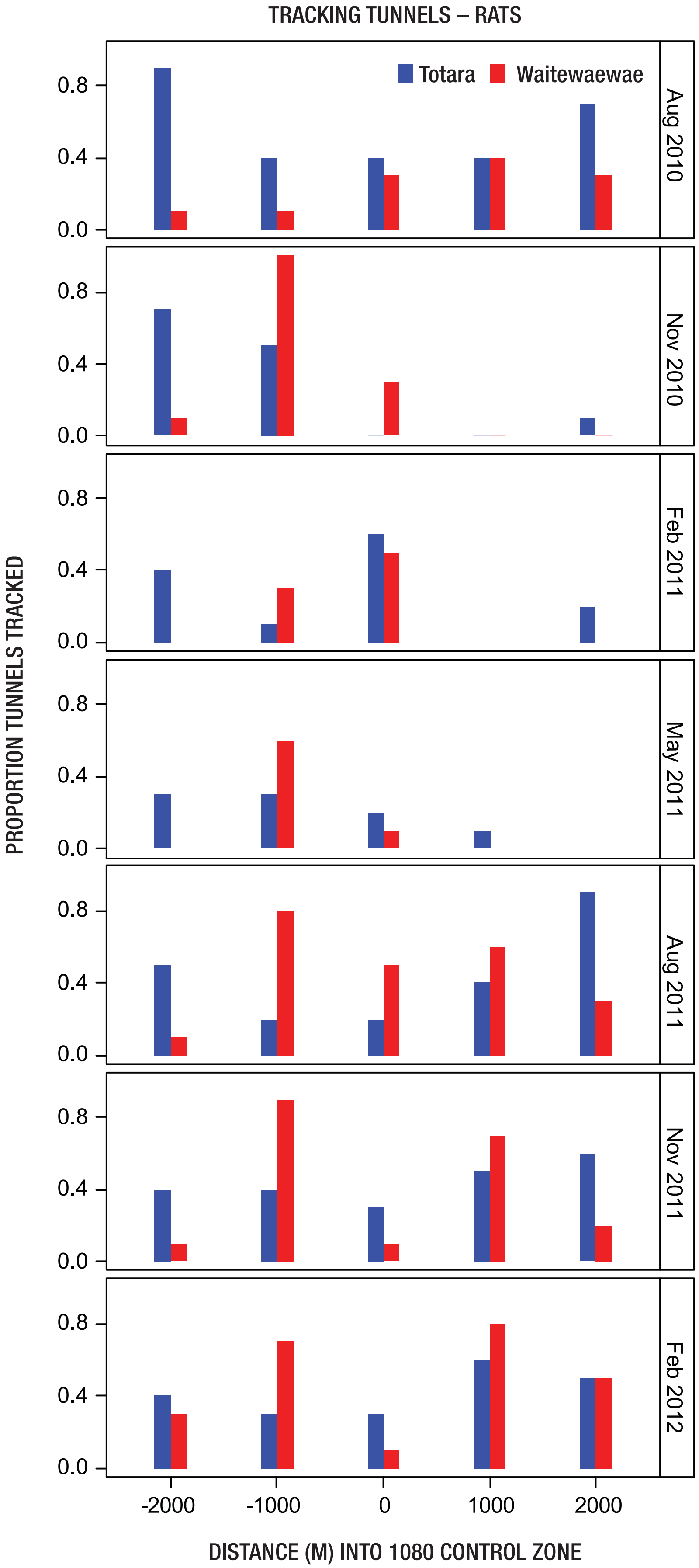

Fig. 2 *Indices of rat numbers with distance into the control zone in Project Kaka.*

averaging 34% when last checked in February 2012. There appears to be no trend in weta occupancy with respect to distance into/out of the control zone, which probably reflects the rapid recovery of rat populations across the control boundary.

To improve monitoring of the effects of predator control on native biodiversity along the survey lines, Peter Sweetapple has developed a method for indexing the abundance of native stick insects, weta and cockroaches by counting frass pellets (insect faeces) or eggs in litterfall traps. Peter has recorded variation in both measures between litterfall trap locations, with stick insect frass and eggs more common under rimu (compared with kāmahi and toro) and tree wētā frass more common in traps positioned near tree trunks compared with those under the canopy.

To investigate whether the browsing choices of possums can be explained by leaf chemistry, Hannah Windley, a PhD student at the Australian National University, has sampled foliage extensively along the monitoring lines for available nitrogen (measured in vitro; AvailN). In addition, Hannah has completed captive feeding trials to assess possum tolerance to plant secondary metabolites (anti-feedants), and how the AvailN of the foliage offered to possums influences their intake. Preliminary analysis has shown that there is a large effect of tannins on AvailN in kāmahi leaves and this resulted in possums eating more kāmahi foliage when the tannins were experimentally deactivated.

Collectively the various Project Kaka monitoring projects aim to measure the impact of pest control on both pests and native biodiversity over space and time, plus identify and explain the processes producing those impacts. The next Project Kaka control operation is scheduled for November 2013.

This project is funded by the former Ministry of Science and Innovation (contract no. C09X0909 Invasive Mammal Impacts on Biodiversity) and core funding to Landcare Research.

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Wendy Ruscoe, Dean Clarke, Pen Holland, Mike Perry, Peter Sweetapple and Caroline Thomson

Scaling up pest animal control with aerial baiting – what's your poison?

The feasibility of creating large pest-free areas will always be hampered by limited resources. This makes aerial application of toxic bait a practical choice for initially reducing populations of pests such as possums and rats to low levels on a large scale. After this, other more expensive tools (such as trapping, detector dogs, shooting or ground baiting) can be used to mop up the survivors. A combination of methods will be needed, but using aerial baiting raises questions about the environmental effects of the toxins. Objective information about the toxins likely to be used is needed to underpin discussion of the benefits and risks of striving to be pest-free.

Two toxins can currently be applied aerially in New Zealand under specific circumstances – sodium fluoroacetate (1080) and brodifacoum. It is important to distinguish between them when scoping the risks and benefits of their use as they differ significantly in their mode of toxic action and pathways through which each can be transferred to, and degraded in, natural environments.

Brodifacoum is an anticoagulant, one of a 'family' of such compounds used worldwide as rodenticides. Bait formulations of several anticoagulants, including brodifacoum, are widely available to the New Zealand public for rodent control around houses and farms (just have a look at the label next time you buy rodent bait!) Anticoagulants act by preventing blood from clotting effectively, so that death in mammals normally eventuates through internal haemorrhage after a few days. Anticoagulant poisoning can be treated successfully by administration of Vitamin K1. Anticoagulants are not water-soluble, and persist for various times in liver tissue (less so in muscle and fat) of animals that eat a sub-lethal dose. Brodifacoum is one of the most persistent anticoagulants so it poses a secondary exposure hazard to any wildlife that scavenge carcasses or prey on rodents and possums. Anticoagulant residues have been reported in birds of prey in many countries, including Australasian harriers in New Zealand. Aerial application of brodifacoum bait is less common than ground application and has much stricter regulation. It is an important conservation tool in the eradication of introduced rodents from large offshore islands or fenced sanctuaries, where complete removal of introduced pests (and their ongoing exclusion) has major biodiversity benefits for island ecosystems and endemic wildlife.

1080 is an acute toxin and its use in New Zealand is also tightly controlled – it requires a licence to use, and its aerial application is subject to stringent regulatory controls and reporting requirements. 1080 is a metabolic energy inhibitor, causing death through cardiac or respiratory failure usually within 24 hours. Treatments for accidental 1080 poisoning have been described, but their success generally depends on early intervention. Aerial application of 1080 for possum and rat control on mainland New Zealand attracts a wide spectrum of positive and negative perceptions, even though from a toxicological and environmental risk assessment context, 1080 is the best researched and described vertebrate pesticide currently in New Zealand use. It is water-soluble, biodegradable in natural water and soil, and does not persist for more than a few days in living animals.

Both brodifacoum and 1080 can cause secondary poisoning of non-target wildlife that scavenge carcasses or prey on poisoned animals. The benefits where feral cats, ferrets or stoat numbers are reduced through secondary poisoning need to be weighed against the secondary hazard to native wildlife scavengers, such as weka, as long as carcasses retain residual concentrations of the toxin.

Penny Fisher recommends continuing to apply the food-web approach suggested by John Innes and Gary Barker to investigate toxin movement and persistence in natural environments, and to assess net outcomes at the ecological community level of using toxins for pest control. This approach is readily applicable to the concept of whether significant areas of the mainland or inhabited islands of New Zealand could feasibly be made pest-free. Penny believes public concern and media attention are likely to focus on the potential risks of using aerial baiting to achieve this, and that this will result in increased publication of both factual and inaccurate information about different toxins. A trusted source of objective and clear information will be needed because 1080 and brodifacoum are already known to have different effects on non-target wildlife, different fates in the environment, and different potential to contaminate human food. Such information will be essential in discussions about balancing the benefits and risks of attempting to achieve pest-free status using either toxin as part of an overall strategy.

This work was funded by the Ministry of Business, Innovation and Employment through core funding to Landcare Research.

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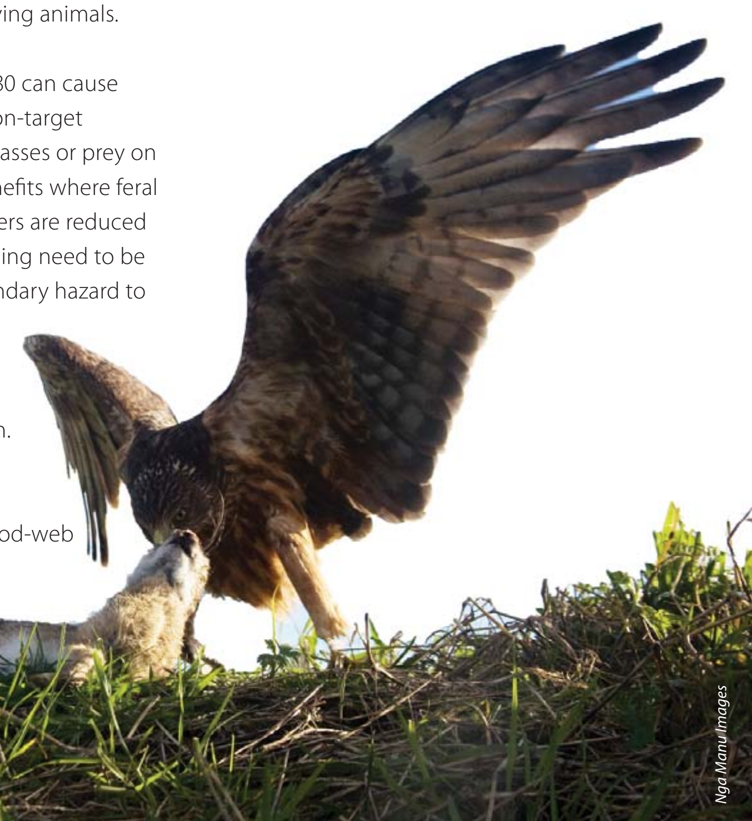

Nga Manu Images

The increasing problem of rabbits

Rabbits have been introduced to more than 800 islands around the world, including mainland New Zealand and many of its inshore and subantarctic islands. Rabbits significantly modify indigenous ecosystems and threaten the financial and ecological sustainability of agricultural and horticultural properties. Various control combinations of poisoning, trapping, dogging and shooting have successfully removed rabbits from over 18 New Zealand islands ranging in size from 1 to 3820 hectares and from many other islands worldwide. Currently Australian agencies are in the final stages of a programme to eradicate rabbits from the 12,785 ha Macquarie Island using aerial baiting, shooting, detector dogs and a biocide based on rabbit haemorrhagic disease (RHD). Broad-scale eradication on the mainland of New Zealand has never been attempted and it is not known whether the necessary conditions for successful eradication or long-term control of mainland populations can be met. For example, for successful eradication, all rabbits must be put at risk and killed faster than they can be replaced by natural births, and immigration must be prevented. Additionally, the benefits of eradication should outweigh the costs and be socially acceptable. There are many questions yet to be answered. It is clear, however, that successful and affordable control is more likely to be achieved if the effectiveness of the existing biological control agent, rabbit haemorrhagic disease (RHD) virus, can be regained and maintained.

Following its introduction to New Zealand in 1997, RHD spread rapidly, causing high mortality (often >90%) and greatly reducing the use of toxins, the costs of pest control to farmers, and the degradation of land in rabbit-prone areas. However, in most areas, secondary follow-up control was not undertaken and rabbit numbers have increased, as the effectiveness of RHD has decreased due to the high proportion of rabbits having antibodies that make them immune to circulating strains of RHD virus (RHDV). Rabbits can acquire these protective antibodies following exposure to RHDV early in life or possibly from infection with a closely-related but benign form of rabbit calicivirus (RCV) that may have been present in rabbits when they were first released in New Zealand 150 years ago. Researchers in Australia have shown that since RHD release, wild strains of RHDV in some areas have become more virulent, killing a high proportion of rabbits more quickly. They have also discovered a benign RCV, that is closely related to RHDV but is non-lethal and that infection with the benign RCV provides 30–40% protection against pathogenic RHDV strains. Janine Duckworth and her colleagues involved in the Rabbit Biocontrol Initiative project are now trying to find out whether variations in the effectiveness of RHDV throughout New Zealand are due to differences in the virulence of the virus across the country and whether any benign RCVs exist in New Zealand that may protect rabbits against RHDV infection.

Janine and members of the Rabbit Biocontrol Initiative are seeking samples of New Zealand field strains of RHDV from farmers, contractors and land users to identify RHD outbreaks. RHDV recovered from freshly-dead wild rabbits will be screened through challenge trials of naïve captive-bred rabbits to identify the most potent wild viral strains for further selection on virulence. As part of this study, the team will use molecular techniques to identify any benign RCV present and determine whether exposure to this virus protects rabbits against subsequent RHDV challenge (including the most virulent RHD strains identified in the survey). In the future, high-virulence strains of NZ-sourced RHDV will be made available to land managers to maximise the benefits of rabbit control in New Zealand and will be a key tool supporting long-term control and any attempts at regional eradication of feral rabbits.

This work is funded by the Ministry for Primary Industry's Sustainable Farming Fund (12/055) and the Australian Invasive Animal Co-operative Research Centre.

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RHD outbreaks – virus sample collection

- Samples of rabbits are sought from throughout New Zealand for genetic analysis and to identify differences between strains of RHDV that are killing rabbits in different regions of the country.
- Of most interest are carcasses from 1–4 rabbits that have recently died from RHD. Fresh carcasses are best but any relatively intact carcass up to 7–10 days old is acceptable. Please label any carcasses with your contact details and the location where the rabbits were found and freeze them until Janine arranges their collection.
- RHD outbreaks can be difficult to detect as rabbits often die underground and any above-ground carcasses can quickly be scavenged by hawks. Lots of hawks circling may be the indication of an RHD outbreak. The best time to look for rabbit carcasses is early in the morning before they are scavenged and the best place to look is near the entrance to burrows.
- So please keep a look out for any RHD-killed rabbits and let Janine know.

Contact: Janine Duckworth, Landcare Research, Gerald Street, Lincoln to tell her of any active RHD outbreak, or to arrange collection of any samples, or if you have any questions.

Email: RHDBio@landcarereseach.co.nz or phone 03 321 9999 or 0800 743 246

Can rabbit control reduce feral cat numbers at a regional scale?

One of the most important factors affecting the abundance of predators is the availability of their prey. In New Zealand, introduced rabbits support populations of introduced predators, including feral cats. The abundance of rabbits may therefore affect the level of predation by cats on native birds, lizards and invertebrates.

Previous research by Grant Norbury and colleagues suggested populations of predators can be controlled by reducing the abundance of their introduced prey. However, the strength of this relationship is unclear because accurately measuring the numbers of rabbits and cats is expensive and time-consuming. Mark–recapture and/or radio-telemetry studies have been used, but such methods are too expensive to be applied routinely or at regional scales. An alternative is to use a relatively inexpensive measure such as spotlight counts to produce indices of pest abundance. However, these counts are imprecise, and predictions based on them may be unreliable.

Al Glen and colleagues took advantage of a new modelling approach that allows the abundance of rabbits and cats to be estimated explicitly from spotlight counts. Staff from Otago and inland south Canterbury (Mackenzie Basin) regional councils conducted spotlight counts of rabbits and cats along 66 transects between 1990 and 1995 (*Fig. 1*). Spotlighting was conducted on two (usually consecutive) nights for at least two sessions per year on each transect. The data were allocated to summer (September–February) and winter (March–August), corresponding approximately to the breeding and non-breeding seasons for cats. Repeated sampling within these seasons allowed detection probabilities to be estimated for both species. With this information, spotlight counts were then used to estimate abundance of rabbits and cats each season, and these estimates were used to model the response of cats to fluctuations in rabbit numbers.

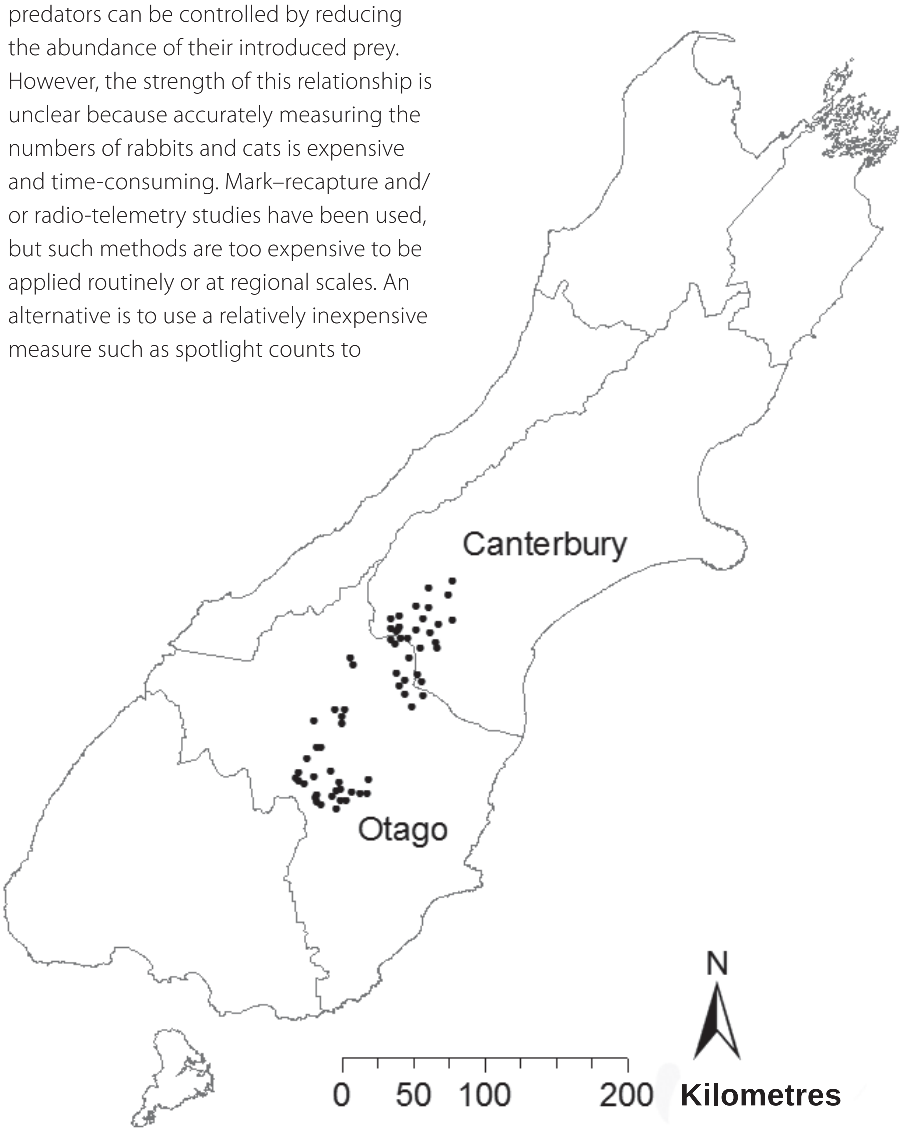

Fig. 1 *Location of the spotlight transects in South Island dryland pastoral areas.*

The abundance of both rabbits and cats fluctuated seasonally, being highest in winter and lowest in summer, partly due to rabbits and juvenile cats becoming more detectable by spotlighting in early winter (*Fig. 2*). In addition, the abundance of cats was strongly influenced by rabbit numbers in the previous season (*Fig. 3*). Although past work has suggested that cat populations are influenced by the abundance of rabbits, the strength and generality of this relationship was previously unknown.

These results confirm that rabbits contribute to inflated numbers of feral cats at a regional scale in the South Island. By supporting high numbers of feral cats, rabbits might indirectly intensify cat predation on native species: a process known as hyperpredation. Thus, rabbit control may not only directly reduce the damage rabbits cause to pasture and native vegetation, but may also indirectly reduce cat predation on native fauna. However, some caution is required with this approach. Sudden reductions in rabbit numbers can increase predation on native species in the short term. Faced with a shortage of rabbits, cats may simply eat more native prey. Because such prey are generally less abundant than rabbits, cat numbers will eventually decline, but not before they have eaten many native animals. To avoid this possibility, rabbits should not be controlled in isolation, but rather cats should be controlled at the same time.

So, why not simply control cats and ignore rabbits? There are two main reasons. Firstly, if rabbits are plentiful, cat numbers can recover rapidly after control, so any benefits may be short-lived. Secondly, rabbits are themselves harmful to native ecosystems and agriculture, so reducing their numbers has direct benefits in addition to helping suppress the numbers of feral cats.

Al and his colleagues are not the first to suggest that rabbit control could be used to reduce the abundance of feral cats in New Zealand. Their models confirm previous observations that cat populations are strongly influenced by rabbit abundance and show that this relationship holds across most pastoral areas of Otago and the Mackenzie Basin. By adopting a multi-species approach, in which rabbit and cat populations are targeted simultaneously, they suggest that both species can be supressed over large areas for long periods. This should have considerable benefits for pasture and for native vegetation and fauna.

This work was supported by core funding to Landcare Research from the Ministry of Business, Innovation and Employment. Spotlight count data were collected by Otago and Canterbury regional councils for the Rabbit and Land Management Programme.

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Jennyffer Cruz and Roger Pech.

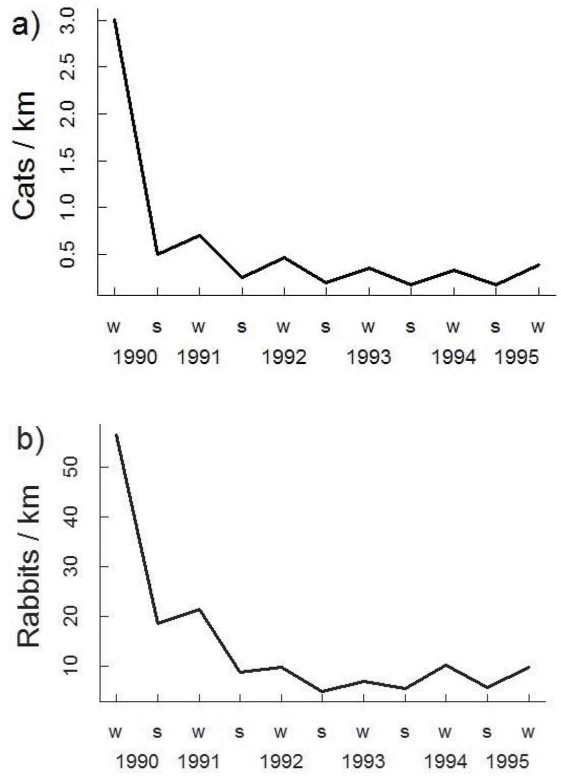

Fig. 2 *The estimated mean abundance of feral cats (a) and rabbits (b) across the Mackenzie Basin and Otago. Following broad-scale rabbit control in 1990-91, estimates of both cats and rabbits fluctuated seasonally, with values highest during March – August ('winter': w) and lowest during September – February ('summer': s). These seasonal changes are due partly to rabbits and juvenile cats becoming detectable by spotlighting in autumn.*

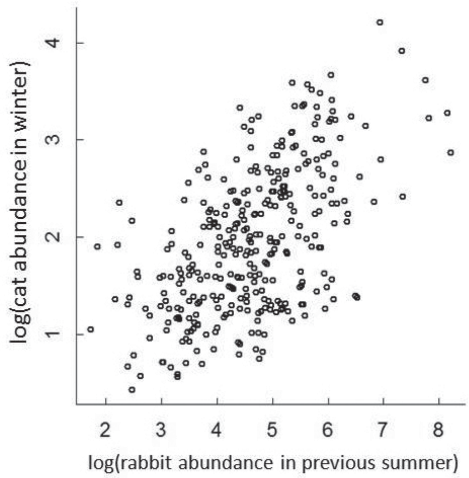

Fig. 3 *Cat abundance over the 6 months March to August plotted against the abundance of rabbits during the previous 6 months (September to February).*

Local elimination – a necessary stepping stone to dreams of national freedom from vertebrate pests

The vision of a pest- or predator-free New Zealand has focused attention on the key differences between eradicating pests from islands and eradicating them from large parts of mainland New Zealand. Eradication on the mainland has so far only been achieved in small areas and then only by using fences to prevent reinvasion – one of the obligatory rules of eradication. To achieve eradication over large areas of New Zealand without using fences will require either scaling up operations to cover an entire island in one operation or finding a way to progressively 'rollback' pest populations. Scaling up is a plausible option for eradicating pests from Stewart Island, but currently would seem to be an unaffordable option for controlling pests across all of the North or South Islands. That leaves some form of progressive rollback as the only option, with prevention of reinvasion without fences being the key new tool or tactic needed.

Graham Nugent, Bruce Warburton, Dave Morgan, Peter Sweetapple, Grant Morriss and others have been exploring the concept of 'local elimination' of pests since 2006. Their research has had three main aims: (1) to find ways of achieving near zero density within infested areas, (2) to develop tools for cheaply detecting survivors and/or invaders, and (3) to find affordable ways of reducing reinvasion.

Graham's team focused first on improving the aerial delivery of toxic bait used for 'initial knockdown'. Aerial baiting is currently by far the most affordable approach for the control of small mammals in areas on mainland New Zealand that are difficult to traverse on foot, and has been widely used for eradication of rodents from islands. Trials in 2006 and 2007 using aerial 1080 baiting against possums, rats, and mice showed that the number of non-toxic prefeeds was ultimately more important in increasing the kill than either sowing rate or sowing pattern, especially for rats. More importantly, these and other trials identified that because a few of the baits sown were not lethal to large possums, sowing rates had to be set at levels that permitted possums multiple encounters with bait. That insight led to development of new strip and cluster sowing strategies for aerial baiting. In the few operational trials completed using these strategies, control efficacy has not been as consistent as that achieved using current 'best practice' (the culmination of decades of research and development). However, in the best result to date, near total reductions in possum, rat, and mouse populations were achieved using sowing rates of 167g/ha (i.e. 95% lower than normal). This achievement indicates that there is potential for substantial reductions in the cost and amount of 1080 used per operation, which would make it more feasible to reduce populations over very large areas.

The second aim, cheaply detecting survivors or invaders, was progressed by the development of a low-cost high-sensitivity detection device and strategy-of-use that could be deployed over entire control areas and used to either map where survivors were (so they could be targeted) or confirm the area as being pest free. Peter Sweetapple and Graham successfully developed chewcards for this purpose, i.e. small sheets of core-flute plastic (with a peanut-butter-based attractant) that pests bite and leave identifiable evidence of their presence. The cards require only two visits by observers, and can detect multiple species. Chewcards are now being used widely, particularly as part of surveillance undertaken by the Animal Health Board to 'prove' areas controlled for possums have very low possum populations and consequently likely freedom from TB.

The third aim, affordably reducing invasion, was attempted for possums in an area near Lake McKerrow, South Westland, using several lines of lethal long-life baits (a gel containing cholecalciferol) placed in parallel along the boundary of an area (i.e. 'perimeter control') within which the possum population was heavily reduced. Chewcard monitoring and trapping within the 'cleared area' showed a rapid build-up of possum numbers, indicating low effectiveness of such perimeter control. The reasons for the failure are unclear – one possibility is that dispersing possums arriving in a new area could be wary of unfamiliar objects such as baits.

Overall, the 'Local Elimination' programme and related research indicate that rollback eradication of pests will be difficult – not so much because of difficulties in achieving zero density locally at an affordable cost or in identifying where animals remain, but more because of the difficulties of preventing reinvasion without using fences. However, other strategies for perimeter control may become feasible when working at landscape scales – most notably the use of buffers tens of kilometres wide in which control is frequently repeated. Such buffers could be successively expanded as the areas inside them are progressively cleared.


Graham Nugent

This work was funded by the Ministry of Business, Innovation and Employment and the Animal Health Board.

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Bruce Warburton, Dave Morgan, Peter Sweetapple and Grant Morriss

Applying the seven rules for eradication to *pest-free New Zealand*

A key challenge for pest-free or predator-free NZ (PFNZ) will be to decide whether mammal pests can be eradicated or, if not, whether biodiversity goals can be achieved by suppression. As progress is made towards a zero or low predator/herbivore environment, managers of large areas of New Zealand or some of our largest inhabited islands may well tackle eradication of selected pests, or local elimination with management of reinvasion.

Achieving eradication from very large islands such as Stewart, Chatham or Great Barrier or defendable areas of the mainland such as Banks Peninsula will require systematic planning. Fortunately, there is a framework of seven 'rules' that we can apply, summarised here by Andrea Byrom and John Parkes. Rules 1–3 are regarded as critical, i.e. unless met, eradication cannot proceed. Rules 4–7 are desirable, i.e. eradication can still proceed even if they are not strictly met.

Rule 1: All animals must be put at risk. Usually, this rule is applied to one species at a time, and there are numerous examples of single-species eradications worldwide. Some species can be removed with a single method applied once (e.g. aerial baiting of rodents); others require a series of control events, often changing methods to get the last pest (e.g. ground and helicopter hunting of ungulates). Multi-species eradications have been achieved at small scale in New Zealand (e.g. in fenced sanctuaries such as Maungatautari).

Rule 2: Pest species must be killed at rates faster than their rate of increase. Intuitively, this rule makes sense for pests that require a series of control events. New Zealand has made huge strides in very large scale suppression of possums and for species such as goats, where control methods are deployed sequentially. Attempting eradication on the scale of PFNZ will challenge this rule for species with fast rates of increase like mice.

Rule 3: The risk of recolonisation must be zero. It's easy to envisage this rule working for islands with water barriers that prevent or slow the movement of animals (e.g. Tiritiri Matangi). However, when considering large areas of the mainland such as Banks and Otago peninsulas (suggested as first steps for mainland eradication), preventing recolonisation will be challenging.

Rule 4: Social and economic conditions must be conducive to meeting the critical rules. A range of stakeholders have an interest in the outcome of any eradication programme; communities always have a range of values and aspirations. However, when eradication is the aim, only some control methods can meet the critical rules – anticoagulant aerial baiting will need to be used to eradicate rodents on big islands despite people being present. Others oppose the killing of animals on ethical grounds, and some value some pests as a resource. The hard fact is that as managers work towards PFNZ they will be confronting the public with techniques that will cause angst and objections.

Rule 5: Where the benefits of management can be achieved without eradication, discounted future benefits should favour the one-off costs of eradication. In other words, if the benefits can be achieved more cheaply by suppressing pest animals in perpetuity, then it's a better option. This is a simple calculation when the benefits have monetary value, but it is more complex when the value of biodiversity or other non-monetary values are considered.

Rule 6: Animals surviving the campaign should be detectable and dealt with before numbers can increase. Detection of pests is a growing field in the management of invasive species internationally and is often regarded as easy, but it is not! Detection is both a technical problem (which devices are most suitable?) and a statistical problem, because managers must put a probability on their belief that no pests are present when they cannot find any. Scaling up to large areas of the New Zealand mainland will pose an even greater challenge, especially for cryptic species like mice and stoats.

Rule 7: There must be no net adverse effects. The method chosen to eradicate a pest must not affect valued species (unless the latter can be replaced) or permanently damage the environment. Less clear are the problems of removing some pest species while leaving others. New Zealand's mammal pests interact, so removing possums alone may lead to an increase in rat (and stoat) numbers, such that threats to plants are reduced but threats to birds may increase.

These 'seven rules' provide an excellent framework that can help us work towards PFNZ. However, they will need to be applied to multiple species simultaneously; pest species that cannot be removed in one hit have rapid rates of increase at low densities; recolonisation will be an ongoing challenge; some methods of control will generate public debate; even if eradication is a more logical option than sustained control, the one-off costs may still be too high; managers need to get smarter in detecting re-emerging pests; and removal of an individual pest species may have adverse ecological consequences. Nevertheless, the rules will keep managers grounded in reality as they begin to think about local elimination of multiple pests at very large scales on mainland New Zealand.

Andrea Byrom and John Parkes

This article was funded by the Ministry of Business, Innovation and Employment (contract C09X0909).

Some recent vertebrate-pest-related *publications*

Brown S, Warburton B, Fisher P, Bunt CR 2012. Optimising the palatability and longevity of stoat baits. *New Zealand Journal of Zoology 39: 229*–243.

Fisher P, Funnell E, Fairweather A, Brown L, Campion M 2011. Accidental discharge of brodifacoum baits into a freshwater lake: a case study. *Bulletin of Environmental Contamination and Toxicology 88:* 226–228.

Forsyth DM, Gormley AM, Woodford L, Fitzgerald T 2012. Effects of large-scale high-severity fire on occupancy and abundances of an invasive large mammal in south-eastern Australia. *Wildlife Research 39:* 555–564.

Gormley AM, Holland EP, Pech RP, Thomson C, Reddiex B 2012. Impacts of an invasive herbivore on indigenous forests. *Journal of Applied Ecology 49:* 1296–1305.

Jones C, Barron M, Warburton B, Coleman M, Lyver P, Nugent G 2012. Serving two masters: reconciling economic and biodiversity outcomes of brushtail possum (*Trichosurus vulpecula*) fur harvest in an indigenous New Zealand forest. *Biological Conservation 153:* 143–152.

Latham ADM, Nugent G, Warburton B 2012. Evaluation of camera traps for monitoring European rabbits before and after control operations in Otago, New Zealand. *Wildlife Research 39:* 621–628.

Lim ML, Brady H, Hambling T, Sexton K, Tompkins D, Slaney D 2012. *Rickettsia felis* infections, New Zealand. *Emerging Infectious Diseases 18:* 167–169.

MacLeod CJ, Blackwell G, Benge J 2012. Reduced pesticide toxicity and increased woody vegetation cover account for enhanced native bird densities in organic orchards. *Journal of Applied Ecology 49:* 652–660.

MacLeod CJ, Blackwell G, Weller F, Moller H 2012. Designing a scheme for monitoring changes in bird abundance in New Zealand's agricultural landscape. *New Zealand Journal of Ecology 36:* 312–323.

MacLeod CJ, Drew KW, Coleman M 2011. Radiotracking small farmland passerines: tradeoffs in study design. *Notornis 58:* 113–123.

Morgan DR, Scobie S, Arthur DJ 2012. Evaluation of Zoletil and other injectable anaesthetics for field sedation of brushtail possums (*Trichosurus vulpecula*). *Animal Welfare 21:* 457–462.

Nugent G, Twigg LE, Warburton B, McGlinchy A, Fisher P, Gormley AM, Parkes JP 2012. Why 0.02%? A review of the basis for current practice in aerial 1080 baiting for rabbits in New Zealand. *Wildlife Research 39:* 89–103.

Nugent G, Warburton B, Thomson C, Cross ML, Coleman MC 2012. Bait aggregation to reduce cost and toxin use in aerial 1080 baiting of small mammal pests in New Zealand. *Pest Management Science 68:* 1374–1379.

Paterson RA, Townsend CR, Poulin R, Tompkins DM 2011. Introduced brown trout alter native acanthocephalan infections in native fish. *Journal of Animal Ecology 80:* 990–998.

Stokes V, Banks P, Pech R 2012. Influence of residency and social odors in interactions between competing native and alien rodents. *Behavioral Ecology and Sociobiology 66:* 329–338.

Tompkins D 2012. Introduction to the special issue on advances in tools for bird population monitoring in New Zealand. *New Zealand Journal of Ecology 36:* 267**.**

Warburton B, Tompkins D, Choquenot D, Cowan P 2012. Minimising the number of individuals killed in long-term vertebrate pest management programmes, and the economic incentives to do so. *Animal Welfare 21:* 141–149.

Young LJ, Cross ML, Duckworth JA, Flenady S, Belov K 2011. Molecular identification of interleukin-2 in the lymphoid tissues of the common brushtail possum, *Trichosurus vulpecula. Developmental and Comparative Immunology 36:* 236–240.

For further reading on the topic of pest suppression, we recommend the two excellent IUCN proceedings summarising papers presented at the international conferences on island invasives and published in 2002 and 2012 respectively.
The most recent volume is available online at: http://www.issg.org/pdf/publications/Island_Invasives/IslandInvasives.pdf