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Abstract: Invasive pest eradication is an increasingly viable management option for conservation and wildlife managers all over the world. The list of successful rodent eradications from isolated islands continues to grow globally. Now, with the development of effective pest exclusion technologies, the opportunities for eradicating multiple species of vertebrate pests from progressively larger fragments of habitat in mainland situations are also increasing. Attempts at eradicating up to fifteen separate species of pest mammal from indigenous forest fragments protected by Xcluder™ pest proof fencing have been made on the main islands of New Zealand. These include various assemblages of multiple species of deer (*Cervidae*), feral pig (*Sus scrofa*), brushtail possum (*Trichosurus vulpecula)*, lagomorphs, rodents and a range of other predators. At some sites, individual species remain, while at others, complete eradication of a full suite of previously present pest species has been achieved. Using the 3,400 ha Maungatautari Project as a case study, we explore critical issues associated with successful pest eradication and reinvasion management in habitats protected by pest proof fencing, including eradication methods, finding and removing survivors, monitoring and surveillance, and the behaviour of reinvading pests. The transfer of the techniques successfully developed in New Zealand to other parts of the world is likely to depend as much on the regulatory environment at the management site as on the pest species present.

Key Words: anticoagulant, brodifacoum, eradication, house mouse, invasive species, *Mus musculus*, pest-proof fencing, *Rattus rattus,* reinvasion, rodent.

Managing Vertebrate Invasive Species: Proceedings of an International Symposium (G. W. Witmer, W. C. Pitt, K. A. Fagerstone, Eds). USDA/APHIS/WS, National Wildlife Research Center, Fort Collins, CO. 2007.

INTRODUCTION

Since the 1970s, introduced, invasive rodents have been eradicated from an increasing number of islands around New Zealand and, more recently, elsewhere in the world (Veitch and Bell 1990, Taylor et al. 2000, Towns and Broome 2003). Using these island techniques, there has been an increasing focus in New Zealand since 1999 to remove multiple species of pests from progressively larger fragments of mainland habitat. This approach has been encouraged primarily by new pest-proof fencing technologies that stop pests from reinvading (e.g., Day and MacGibbon 2007). While there are a number of independent projects underway in New Zealand, such as the Karori Wildlife Sanctuary, the Xcluder™ Pest Proof Fencing Company specifically has completed more than 20 fencing projects ranging from <1 ha to 3,400 ha. Of these, 11 projects have eradication of all pest species present inside the fenced area as one of the primary goals. A list of these projects, the techniques used to eradicate the pest species present and current project status in terms of pest eradication success within pest-proof fenced areas appears in Table 1. Figure 1 shows the location of the projects described.

Each of the projects detailed in Table 1 is run independently by different community groups or agencies using a variety of methods, service delivery contractors and/or pest eradication approaches. In this paper, we provide an overview of the Maungatautari Project (www.maungatrust.org), which has been the largest and most complex project to date and focus on important lessons learned to date from this ambitious project.

BACKGROUND

Maungatautari is a highly eroded, andesitic volcanic cone in the central Waikato in the North Island of New Zealand. Although surrounded by farmland, the mountain itself (300-800 m asl) is mostly forest-covered, with about 3,400 ha (8,400 acres) of dense, primary, podocarp-broadleaved

Table 1. Summary of current pest-proof fencing projects in New Zealand where multi-species eradication has or will soon be attempted.

Project Site	Size (ha)	Date Eradication Began	Methods*	No. of Pest** Species Present Originally	Pest Species Remaining at July 2007
Karori (not Xcluder™ fence)	250	September 1999	- Aerial bait - Trapping - Ground bait - Bait stations	10	- Mice
Warrenheip	16	November 1999	- Trapping - Bait stations	11	- Mice
Rapanui Point	1	June 2003	- Trapping - Ground bait	7	- Nil
Riccarton Bush	7	July 2004	- Trapping - Bait stations	7	- Nil
Maungataurai (2 x Pilot Exclosures)	100 (35 & 65)	September 2004	- Aerial bait - Trapping - Ground bait - Bait stations	11	- Nil
Tawharanui	660	September 2004	- Aerial bait - Trapping - Ground bait - Bait stations	11	- Mice
Young Nicks Head	30	July 2005	- Trapping - Ground bait - Bait stations	7	- Mice (reinvasion)
Bushy Park	98	August 2005	- Aerial bait - Trapping - Bait stations	11	- Nil
Macrae's Flat	22	August 2006	- Trapping - Ground bait	7	- Mice
Horseshoe Bay, Stewart Island	160	September 2006	- Trapping - Ground bait - Bait stations	7	- Ship rats - White-tailed deer
Maungatautari (Main Mountain)	3,300	November 2006	- Aerial bait - Trapping - Ground bait - Bait stations	15	- Mice - Goats - Hares - Rabbits
Lake Rotakare	227	August 2007	- Aerial bait - Trapping - Ground bait - Bait stations	12	Eradication not yet undertaken
Orokonui	248	August 2007	- Aerial bait - Trapping - Ground bait - Bait stations	12	Eradication not yet undertaken

* Aerial baiting includes helicopter application of brodifacoum cereal pellets. A wide range of traps and toxins are also registered for use in New Zealand.
** Refer to Table 2 for a list of typical pest species found in New Zealand project areas.

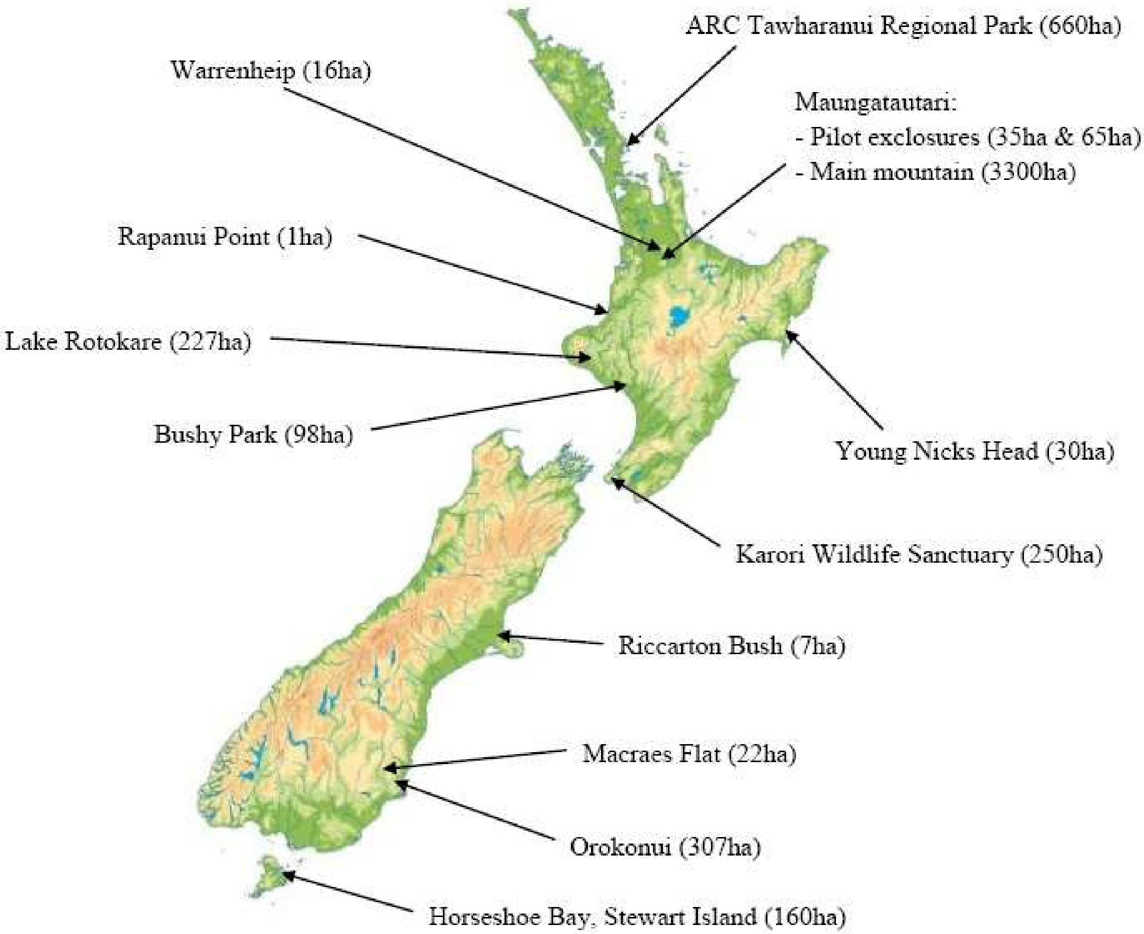

Figure 1. Current pest-proof fencing projects in New Zealand where multi-species eradication has or will soon be attempted ([Xcluder™ 2006], also refer to Table 1).

native forest. The Maungatautari Ecological Island Trust has a vision to: "...remove, forever, introduced mammalian pests and predators from Maungatautari, and restore to the forest a healthy diversity of indigenous plants and animals not seen in our lifetime..."

The Trust's approach has been to completely ring fence the mountain with 47 km of Xcluder™ pest-proof fence and then attempt to eradicate 15 species of pest mammal species (Table 2) within the 3,400 ha fenced area. Once this is achieved, ecological recovery of the mountain is anticipated and a wide range of pest-vulnerable indigenous species, now extinct on the mountain, can begin to be reintroduced.

As a pilot for the larger mountain, two smaller exclosures were constructed protecting 35 ha (Northern Exclosure) and 65 ha (Southern Exclosure) respectively (Figure 2). Eradication began in the two pilot exclosures in September 2004. Information gained from the eradication attempts within the pilot exclosures has formed the basis for a larger scale eradication attempt on the main mountain, which began in 2006.

ERADICATION METHODS

The primary tool used to eradicate most small mammal pest species on Maungatautari has been the aerial application of cereal pellets containing the anticoagulant toxin brodifacoum at a

Table 2. Species list of typical vertebrate pests present in pest-proof fencing project areas of New Zealand.

Common Name	Latin Name
Cat	*Felis catus*
Fallow deer	*Dama dama*
Ferret	*Mustela furo*
Goat	*Capra hircus*
Hare	*Lepus europaeus occidentalis*
Hedgehog	*Erinaceus europaeus occidentalis*
Mouse	*Mus musculus*
Norway rat*	*Rattus norvegicus*
Pig	*Sus scrofa*
Possum	*Trichosurus vulpecula*
Rabbit	*Oryctolagus cuniculus cuniculus*
Red deer	*Cervus elephus*
Ship rat	*Rattus rattus*
Stoat	*Mustela erminea*
Weasel	*Mustela nivalis vulgaris*

* not confirmed but present near-by

concentration of 20 ppm, marketed by its New Zealand manufacturers, Animal Control Products Ltd, as “PestOff Rodent Bait 20R”. However, the registration for this product using aerial application methods is very restrictive due to the residual nature of the toxin in the food chain. A special Code of Practice (CoP), which complied with the New Zealand Government's Agricultural Compounds and Veterinary Medicines Act (1996), had to be developed to ensure the risks of livestock contamination and other human health risks were satisfactorily managed, before the New Zealand Food Safety Authority would approve aerial application of PestOff Rodent Bait 20R for use in mainland situations. A copy of the CoP is available from the Animal Control Products website at www.pestoff.co.nz. The Maungatautari aerial bait application operations also required a Resource Consent under the Resource Management Act (1991) which set out strict conditions for the discharge by air, of a contaminant to land or water. These conditions included stakeholder consultation, extensive water monitoring and non-target impact reporting (Environment Waikato 2004, 2006).

In previously successful offshore island rodent eradications, two applications of brodifacoum bait have been routinely used, with bait sowing swathes being overlapped by 50% to ensure complete bait coverage. Bait application is typically timed for the late winter/early spring period when bait acceptance is highest (Gillies et al. 2003), and rodent numbers are lowest after winter mortality and before spring-summer breeding (Innes et al. 1995, Innes 2005, Ruscoe and Murphy 2005). On Maungatautari, there were a number of variations to the standard island rodent eradication bait application technique:

1. In both pilot and main mountain eradication attempts, there was a significant increase in bait sowing rates from the typical 8 kg/ha and 4 kg/ha for the initial and follow-up operations to 15 kg/ha and 10 kg/ha respectively, due to the presence of a large number of pest species that would find the baits highly palatable. While the list of pest species included ship rats (*Rattus rattus*) and house mice (*Mus musculus)* that would eat few baits, the slow acting nature of the toxin combined with the presence of the larger brushtail possums, hedgehogs (*Erinaceus europaeus occidentalis)*, hares (*Lepus europaeus occidenalis)*, rabbits (*Oryctolagus cuniculus cuniculus)* and pigs meant bait could quickly be consumed from more favourable habitat sites, resulting in some pests being unable to access bait, or receiving sub-lethal exposure. Ensuring adequate bait penetration through a dense, complex forest vegetation cover on the mountain was also a consideration in increasing bait sowing rates.

2. For standard island rodent eradications, the second aerial bait application is typically less than 10 days after the first application based on a time to death of 3 to 7 days for rodents. The average time to death after consuming a lethal dose of brodifacoum for the range of animals present on Maungatautari ranges from 5 days (rodents) to 22 days (possums) (Eason and Wickstrom 2001), so the second aerial bait application for both pilot and main mountain eradications occurred six weeks after the first, to allow larger animals that had consumed bait a chance to die before the second aerial bait application occurred.

3. For the main mountain, a third aerial bait application targeting surviving mice proved necessary the following winter (June-July 2007, 6 months after the second operation), again at a sowing rate of 10 kg/ha.

4. All aerial bait applications were accompanied by hand-broadcast bait application immediately inside the fence to reduce the chances of bait being

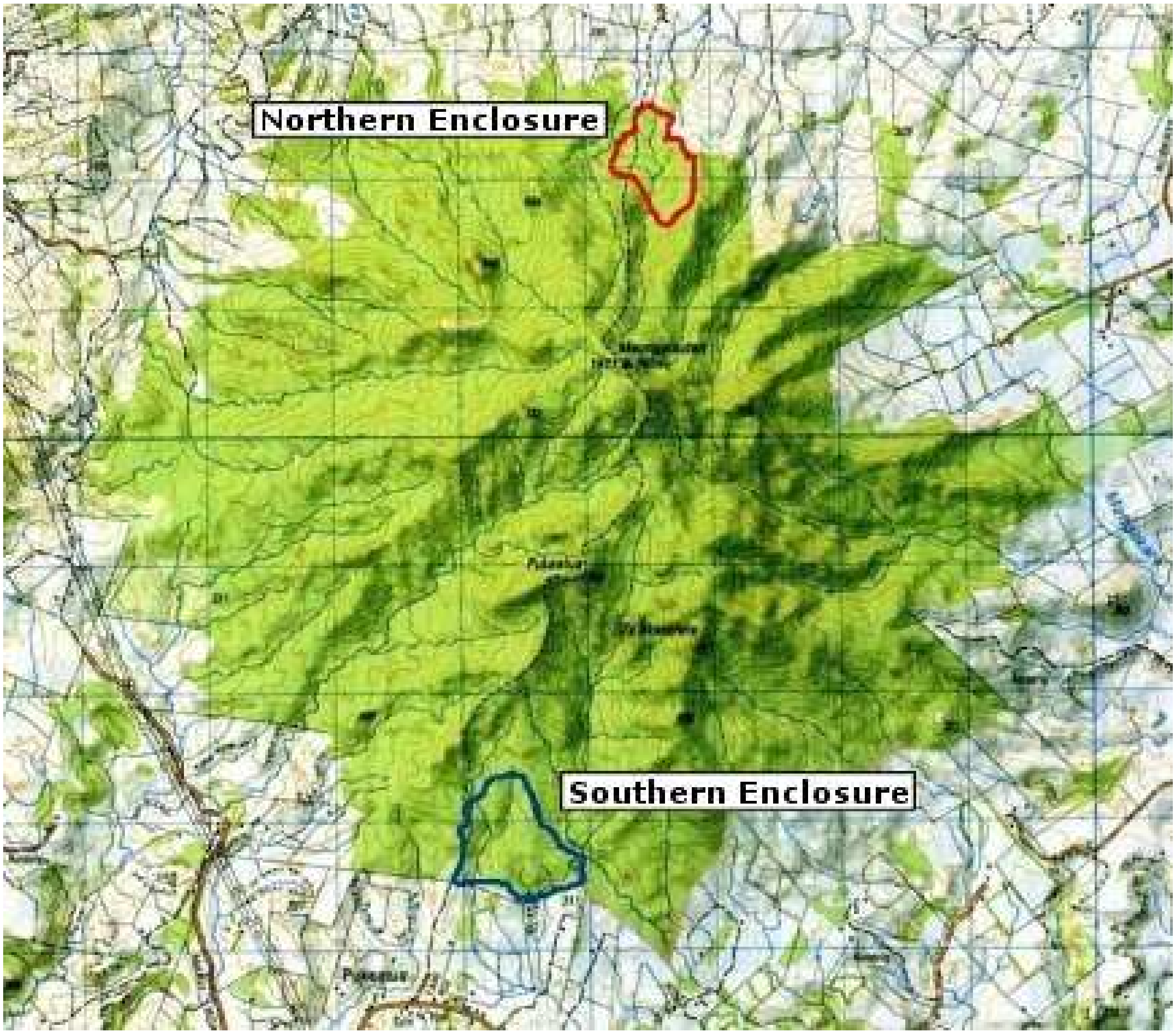

Figure 2. Map of Maungatautari Project area.

over-flown from the helicopter onto adjoining grazing land, and to ensure complete bait coverage.

Secondary poisoning has been well documented for predators feeding on the carcasses of other pests that have been poisoned as primary targets in New Zealand pest control operations using brodifacoum and mono-sodium fluoroacetate (1080) (Alterio 1996, Alterio et al. 1997, Alterio and Moller 2000, Department of Conservation 2006). While it was anticipated that the impact of the aerial bait applications on prey species would seriously impact predators through secondary poisoning, follow-up trapping and or poisoning was anticipated for most pest species, to be guided by the results of post aerial bait application monitoring.

Pigs, goats (*Capra hircus*), and deer (*Cervus elephus and Dama dama*) evacuated the pilot treatment areas during fence construction so no information about these pests was available for the main mountain from the pilot eradication attempt. However, effective goat and deer eradication techniques are already well developed in New Zealand (Parkes 1990), and these species were not considered a major issue. Pigs were considered to be extremely vulnerable to brodifacoum poisoning.

TARGET PEST MONITORING

Pilot Exclosures

The use of ink-tracking tunnel networks (King and Edgar 1977, Ratz 1997) for monitoring small pest mammal populations has been critical for both the pilot and main mountain eradication attempts on Maungatautari.

The relatively small, accessible nature of the pilot exclosures allowed tracking tunnel grids of 25 m x 25 m and 50 m x 50 m to be established in the 35 ha and 65 ha Northern and Southern exclosures respectively, to detect surviving pests. The 25 m x 25 m tracking tunnel grid was originally thought to be particularly important to detect surviving mice. Some sampling using these networks occurred prior to any bait application to help train personnel and to provide some assessment of pre-operational pest presence/densities.

After the second aerial bait application, all tracking tunnels were monitored weekly for the first year, then monthly until six months of zero mammal tracking was achieved. Tunnels were serviced by teams of volunteers who replaced cards to allow expert interpretation of any tracking, and re-baited tunnels with fresh peanut butter. Once eradication was confirmed, clean cards and fresh peanut butter has been placed for one 7 to 10 day period every three months before cards are uplifted for interpretation. Fence breach monitoring and surveillance protocols have also been established for situations where tree falls or other fence damage, or a range of other scenarios, result in the opportunity for pest reinvasion.

When a ship rat, house mouse or hedgehog was detected on the tracking tunnel grids, it was targeted with snap traps set in the tracking tunnels using peanut butter on the trigger plate for rodents, or Mark IV Fenn traps baited with canned cat food for hedgehogs.

Starting six months after the second aerial bait application, a biomarker (rhodamine B) was distributed on non-toxic cereal pellets around the outside of the pilot exclosures to bio-mark the resident rodents. This was undertaken in an attempt to help definitively distinguish any animals caught on the inside of the pilot exclosures as either reinvaders or survivors. These pellets were distributed at 6-8 week intervals for 18 months.

Following increased house mouse tracking in the Southern Exclosure in March 2006, bait stations containing poison blocks with 20 ppm brodifacoum were deployed at all sites that tracked mice, until tracking stopped. Some of these bait stations were lured with mouse urine.

Reinvasion Risk Assessment

To begin understanding the risk of pest animals reinvading after damage to a pest-proof fence (e.g., a tree fall), research to quantify the detection and use of fence breaches by pests resident outside the fence was initiated. Using a 10 km section of the larger Maungatautari pest proof fence where eradication had not yet begun, 25 artificial holes (to simulate fence mesh damage) and 25 artificial ramps (to simulate a fallen tree branch leaning on the fence) were created along the fence. Unbaited tracking cards were placed at each artificial breach in such a way that all use of the breaches by pest animals from outside the fence could be detected and the species identified. The artificial breaches were then inspected for pest activity daily for the first 4 days and once after 4 weeks.

Reinvasion Behavior Research

To further understand the behaviour of potentially reinvading rodents, and to help develop effective reinvasion response plans, a small research programme was begun following removal of what was thought to be the last surviving rat from inside the Southern Exclosure. Six ship rats, caught against the outside of the fence, were radio collared and released into the rat-free exclosure during April-September 2006. Ship rats were selected because they are common outside the fence (probably 3-7 per ha), arboreal, active all year round and highly exploratory, and, therefore, one of the most likely species to reinvade. Only adult, territorial males were used and the animals were not de-sexed to allow for as natural behaviour as possible. The rats were released next to their existing home ranges, thus mimicking the most likely natural invasion via a fence breach or a falling tree. Rats were introduced sequentially so that only one translocated rat was ever present in the exclosure at any time. Key objectives were to describe the movement and denning behaviour of such invasives, and to see if the standard invader detection system (the 50 m x 50 m tracking tunnel grid) detected the rats. Our intention was to track each rat until its movements stabilised, when it would be removed, although in practise rat movements within the exclosure did not stabilise. We tracked the rats nightly, from evening for about 5 hours, for a week after release, then more sporadically but at least every few days.

Main Mountain

On the main mountain, perimeter access track networks and cut ridgeline/valley transects allowed for the establishment of over 1,700 tracking tunnels spaced at 100 m intervals across the mountain. If each tunnel can attract and record a mammal within a 100 m radius, then this network provides coverage of 57% of the project area. Some transects within a representative range of habitats across this network were assessed prior to the start of the eradication attempt to help understand pre-operational rodent densities.

Since the second aerial bait application, this network has been monitored on a two-monthly cycle where clean cards and fresh bait (both peanut butter and minced rabbit meat) are placed for one 7-10 day period before cards are uplifted for reading.

Likely pig survival was indexed using six young (18 to 25 kg) wild pigs, carrying radio-transmitter ear tags with a mortality function. The pigs were released onto the mountain 4 months prior to any aerial bait application and were located weekly until the first bait application, then daily after that.

RESULTS

Pilot Exclosures

House mice were virtually undetectable in the exclosures prior to aerial bait applications, with just 4% tracking in the Northern Exclosure and no detections in the Southern Exclosure. Ship rat density was extremely high with pre-operational tracking rates of 98% and 96% in the Northern and Southern exclosures, respectively. Possums, hares and rabbits were present in low numbers but no carnivores (mustelids or cats, *Felis catus*) were detected. It is possible that these animals emigrated over the fence in the months between fence closure and the beginning of the eradication (6 months and 2 months in the Northern and Southern exclosures, respectively), and that their absence boosted ship rat numbers. Both mustelids and cats were tracked immediately outside the exclosure fences at the time of these eradication attempts.

A total of 7 ship rats, at least 5 house mice and 1 hedgehog were detected and removed by trapping in the 20 months following the second bait application in the two pilot exclosures, although further mice were almost certainly poisoned by brodifacoum baits in bait stations deployed in the Southern Exclosure starting March 2006 to specifically target increasing mouse detections. No other species are known to have survived the two aerial bait applications, although a single hare was seen once within two weeks of the first bait application, but subsequently disappeared.

All animals trapped after aerial bait application were necropsied to provide information on sex, age, reproductive status and toxin residues. Table 3 details all animals removed by follow-up trapping in the pilot exclosures post aerial bait application.

Some surviving ship rats were detected almost immediately and were relatively easy to catch at tracking tunnels once they had tracked. However, some rats remained undetected for up to 18 months before being tracked and then trapped. Rat home ranges appeared to increase significantly over time with earliest rat detections covering 2 to 3 ha (based on tracking tunnel detections) while in the last detection, a female covered almost 20 ha.

Surviving mice did not show up in the pilot exclosures until 6 months after the second aerial bait application (and then only in the Southern Exclosure). Home ranges of surviving house mice post eradication ranged from 2-6 ha, much larger than ranges in higher density mouse populations (Ruscoe and Murphy 2005).

The single surviving hedgehog tracked tunnels over 10.5 ha before being caught.

Several lines of evidence lead to the conclusion that these animals were all survivors and not reinvaders, despite the sometimes long period (up to 18 months) before detection. No Rhodamine B dye was present in any of the animals trapped within the Southern Exclosure; all animals trapped in both exclosures had brodifacoum residues and no females were lactating or pregnant, despite being of mature age and in good condition.

Two possible reinvasion events within the Southern Exclosure were detected where rat prints were found within a few days of a tree fall on the fence. In both cases, despite reinvasion responses by project staff, the rats were subsequently neither trapped nor tracked. It is possible that they emigrated back outside the fence, as did most of the experimentally translocated ship rats (see below).

Based on movements of the animals we detected, the intensive 25 m x 25 m tracking tunnel grids did not prove necessary to detect even mice surviving the aerial bait applications, with 50 m x 50 m spacings proving more than sufficient to detect all rat, mice and hedgehog survivors. In fact, a tracking tunnel layout on a 100 m x 100 m grid system is likely to have been sufficient to intercept the home ranges of all animals caught subsequent to the aerial bait applications in the pilot

Table 3. Summary of mammals trapped from Maungatautari pilot exclosures - post aerial bait application (Sept/Oct 2004).

Site/Species	Timing	Sex	Range	Reproductive Status	Rhodamine' B'?	Toxin Residue?
35 ha (Northern) Pilot Exclosure:						
Ship rat	Nov 2004	Female	2.5 ha	Never bred	N/A*	Positive
Hedgehog	Dec 2004	Female	10.5 ha	Never bred	N/A*	Positive
Ship rat	Jan 2005	Male	5.0 ha	Testes abdominal	N/A*	Positive
Ship rat	Apr 2005	Female	3.0 ha	Never bred	Negative	Positive
65 ha (Southern) Pilot Exclosure:						
Ship rat	Nov 2004	Female	3.0 ha	Never bred	N/A*	Positive
Ship rat	Nov 2004	Female	2.0 ha	Never bred	N/A*	Positive
Ship rat	Jan 2005	Female		Never bred	N/A*	Positive
Mouse	Apr 2005	Male	3.0 ha	Testes descended	N/A*	Positive
Mouse	Sept 2005	Male	6.0 ha	Testes descended	Negative	Positive
Ship rat	Mar 2006	Female	19.5 ha	Never bred	Negative	Positive
Mouse	Apr 2006	Female	1.0 ha	Pregnant – 7 embryos	Negative	Positive**
Mouse	May 2006	Male	1.5 ha	Testes descended	Negative	Positive**
Mouse	May 2006	Female	1.0 ha	Juvenile	Negative	Not tested**

* Rhodamine B baiting outside pilot exclosures began May 2005.
** Brodifacoum present in bait stations from April 2006.

exclosures and a 100 m x 200 m layout would have detected the majority.

Both pilot exclosures are now considered completely pest free, the Northern Exclosure since April 2005 and the Southern Exclosure since July 2006.

Reinvasion Risk Assessment

Of 50 artificial breaches placed along a 10km section of pest proof fence, 4 (8%) were used within the first 24 hours (brushtail possums over 2 ramps; mice through 2 holes). The exact time of use was not determined. Over the following 3 days, 11 (22%) of the 50 breaches were used, with 8 of these breaches used on at least 2 nights. Cats, brushtail possums and rats (species not determined) crossed the fence via ramps and mice and rats used the artificial holes. After 4 weeks, 32 of 45 breaches (71%; some tracking cards were missing from breaches so were not included in the data) were used. Possums, cats, rats and mice used the artificial ramps. Mice, rats, hedgehogs and rabbits were tracked using the artificial holes in the fence. Although mustelids (ferrets *Mustela furo* and stoats, *Mustela erminea*) were observed and trapped along the fence line during the period of this experiment, none were detected on the tracking cards to be using the artificial ramps or holes.

Reinvasion Behaviour Research

Table 4 details the time spent inside the exclosure, the maximum distance travelled, the number of tracking tunnels used and the fate of the six male ship rats released in April-October 2006. Unexpectedly, four of the six rats sooner or later climbed over the fence and returned to their original home ranges. The remaining two were eventually killed by brodifacoum poison laid for mice. The rats that did move considerably inside the exclosure all showed a similar pattern to each other. They stayed within 100 m of the release point for about 3 days, usually denning at the same place, but we cannot tell if this was related to recovery from anesthesia and radio-collaring, or

Table 4. Summary of the behaviour of six radio-collared, adult, male ship rats released within the 65 ha (Southern) Maungatautari exclosure.

Rat No.	Time In Exclosure	Tracking Tunnels Tracked	Largest Distance Travelled From Release Point	Fate Of Animal
1	7 days	2	650 m	Died within exclosure from brodifacoum laid for mice
2	31 days	7	1000 m	Died within exclosure from brodifacoum laid for mice
3	3 days	0	20 m	Trapped outside exclosure in original home range
4	7 days	8	600 m	Returned to original home range outside exclosure; final fate never verified.
5	< 24 hrs	0	20 m	Returned to original home range outside exclosure. Verified dead after first main mountain aerial poison drop
6	< 6 hrs	0	20 m	Returned to original home range outside exclosure; final fate never verified.

reflected true behaviour of a cautious rat invading new territory. They then gradually made bigger movements into the exclosure, eventually changing den sites as well. Movements were undeniably much larger that those usually made by ship rats in normally structured NZ populations. They used similar routes on consecutive nights, and the same dens, perhaps implying that they were using scent trails. Only three of the six rats tracked were detected at any tracking tunnels at all. The rat that stayed longest (31 days) in the exclosure tracked at only seven tunnels.

Main Mountain

Rats were detected at 48% of the sample tracking tunnel transects across a representative range of habitats prior to the start of the eradication attempt, while house mice were detected at 18% of the tracking tunnels sampled, mostly in habitats with dense ground cover (grass, gorse, windrows) where rat tracking was very low or zero. Very limited tracking of other pest mammals was detected with isolated possum, cat and stoat tracks observed. This does not mean that these species were scarce, however, since the tracking tunnels used were baited with peanut butter to primarily target rodents. Hedgehogs hibernate in winter which is when these assessments were made.

Rats were first seen dead after day three of the first aerial bait application on the main mountain. The first radio-tagged pig died on day seven and all six tagged pigs were dead by day eleven. All pigs had significant brodifacoum residues in their livers. The first dead cat was found at day eleven but this animal had been dead for several days. A live possum was observed about 5 weeks after the first aerial bait application suffering severe toxicosis and was euthanised. There were also reports of live cats, a single live hedgehog, numerous rabbits and at least two hares up to five weeks after the first aerial bait application.

The need for suitable weather conditions meant that the second aerial bait application occurred six weeks after the first. Isolated sightings of rabbits, hares and cats continued inside the perimeter fence around the mountain, even after the second bait application.

The first tracking tunnel assessment across the main mountain was undertaken one month after the second bait application. This assessment detected house mice on 0.92% of tunnels, at three locations. Cats were detected on 3.8% of tracking tunnels, at two broad locations, though both appeared to be covering large ranges along several kilometers of the internal perimeter of the pest-proof fence. Two male cats were subsequently trapped at these locations and tracking stopped.

Additional rabbit poisoning, using hand laid 20 ppm Pindone pellets (a low-toxicity, first generation anticoagulant specially formulated in cereal pellet form and marketed for rabbit control in New Zealand by Pest Management Services Ltd.), was undertaken at four sites where rabbits continued to be seen. One hare was shot, but hares continued to be seen at two locations. Mouse trapping began at all three detection locations and mice were caught at all sites. However, in the subsequent tracking tunnel assessment in March 2007, while no other mammal detections were recorded, mice were detected at 7.28% of tunnels and large-scale hand spreading of PestOff Rodent Bait 20R was undertaken at a range of these sites. By the May 2007 tracking assessment, 4.93% of tunnels across the mountain were still detecting mice, although the lack of other mammal detections continued.

A third aerial bait application targeting mice is planned for winter 2007 across the whole mountain at a sowing rate of 10 kg/ha. The results of that aerial third aerial bait application remain unknown at the time of writing this paper.

DISCUSSION

The Maungatautari eradication case study, together with evidence from a range of other pest-proof fence project sites in New Zealand, shows that multi-species pest mammal eradication can be achieved behind pest-proof fences in mainland situations, at least on small to medium landscape scales. The aerial application of brodifacoum-based cereal pellet baits, if well planned and conducted, provides an important 'first shot' that can lay the foundation for a successful eradication. Issues such as the suite of pest species present, their density and interspecific relationships, the nature of the habitat, timing, bait sowing rates and bait coverage are all important planning issues to be carefully considered for aerial bait applications.

Even with a well planned aerial bait application, small numbers of survivors, particularly house mice, should be anticipated. It is not clear from the existing attempts exactly why mice have been successfully eradicated in some projects and not in others. However, the common survival of mice is seemingly a result of dense habitat types; e.g., long grass which may restrict access to bait, but it is also likely to be behavioural, related to the presence of ship rats. Ship rats appear to act as both predators and competitors of mice and, as such, often mask the presence of mice, especially when rats occur at high density within project areas. Mice may not appear in any significant numbers, or at all, until ship rats are reduced to extremely low (near zero) levels or even removed completely. Careful planning is required where these two species are known to co-exist, but additional research is still badly needed to refine the menu of most effective tools and approaches for removing small, residual pockets of house mice.

Perseverance is critical in removing the last few individuals. Increasingly intensive monitoring is required as pest density approaches zero, although home range expansion of survivors at very low density can be expected. A range of eradication tools is required to target animals that survive the use of primary tools such as aerial bait application and follow-up trapping. Management agencies should have an expectation that a long-term commitment must be sustained and funded to ensure eradication is achieved, and to avoid projects being abandoned too early. In even small project areas, total eradication of a full suite of mammalian pest species may require intensive effort over a period of years before it is successfully achieved.

Reinvasion remains an ever present risk for pest-proof fence project areas. Monitoring and surveillance regimes are a critical part of ongoing management of such areas. Reinvasion response planning, preparedness and response capability are especially important due to the potentially rapid nature of reinvasion as a result of a fence breach.

Our initial pest reinvasion risk research at Maungatautari suggests that fence breaches need to be identified and rectified inside the first 24 hours if pest invasion events from multiple species are to be minimized. For projects where daily physical inspection is unachievable (such as the 47 km fence around Maungatautari), remote fence surveillance technology becomes an important additional management tool (Day and MacGibbon 2007). Ongoing research is now underway to better determine reinvasion risk for different pest species and identify suitable invasion risk management options for Maungatautari and other projects.

Our initial research with ship rats suggests that reinvaders of this species may spend at least the first few days at the entry point, again reinforcing the need for rapid response as such animals are easier to target in a more confined area at this early stage. The use of established scent trails by reinvading animals suggests that dogs could play an important role in reinvasion response. We are pursuing this line of research at Maungatautari.

The regulatory environment in New Zealand currently allows for the use of aerial application of brodifacoum bait subject to adherence to a strict Code of Practice and to Resource Consent conditions. The unique situation within New Zealand where there are no vulnerable, ground dwelling native mammals, is a key part of this regulatory environment. The presence of native mammals or other wildlife vulnerable to brodifacoum is likely to restrict such tools in many parts of the world, unless careful cost-benefit analysis can show overwhelmingly positive outcomes for the indigenous ecology from the use of such tools, to eradicate serious pest mammals.

CONCLUSION

- Aerial application of brodifacoum provides a broad-spectrum pest mammal eradication tool, if used in conjunction with follow-up monitoring, trapping, shooting and poisoning to remove the limited numbers of survivors that may remain.
- A range of site specific variables must be considered when planning such aerial bait applications to maximize their effectiveness.
- Of the introduced mammal species we have worked with in NZ, house mice are the hardest to eradicate and can remain almost undetectable until ship rats have been removed or reduced to near zero density.
- Perseverance is critical in removing the last few individuals. Management agencies should have an expectation that a long-term commitment must be sustained and funded to ensure eradication is achieved.
- Rapidly identifying and rectifying breaches, coupled with reinvasion surveillance and monitoring are critical aspects of post eradication management. While baited tracking tunnels have been critically helpful at Maungatautari, little is known about the actual probabilities that they will detect all survivors or invaders of various species.
- We are now experimentally researching the comparative effectiveness of dogs and tracking tunnels at locating single survivors or invaders.
- The transfer of the techniques successfully developed in New Zealand, to other parts of the world, are likely to depend as much upon the regulatory environment at the management site as on the pest species present.

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