House mouse *Mus musculus* eradication by aerial bait application on Adele, Tonga and Fisherman Islands, Abel Tasman National Park, New Zealand

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SUMMARY

Aerial application of cereal bait containing the poison brodifacoum was used to eradicate house mice *Mus musculus* from three islands in the Abel Tasman National Park, New Zealand, during July and August 2007. Poison bait was spread onto the islands by a helicopter using an under slung bait-spreading bucket and applied at a rate of 4 kg per hectare with a 50 % overlap in swath width. This gave an effective application rate of 8 kg per hectare. Bait was applied to the islands in two separate applications, 31 days apart. Monitoring for mice was carried out on all three islands for two years following the eradication attempt to determine the outcome. No mice or any sign of mice was detected. Eradicating mice from Tonga Island, Adele Island and Fisherman Island was the final step towards making the three islands free of introduced mammalian predators.

BACKGROUND

The exact date that house mice *Mus musculus* became established in New Zealand is unknown, but is assumed to be around the time that James Cook's first coastal charts of New Zealand were produced in 1769-70 (Searle *et al*. 2008). Mice thrive in both commensal and natural environments, and in most cases introduced populations having significant negative impacts on native biodiversity; New Zealand has been no exception. In New Zealand mice have been recorded killing native lizards (Whitaker 1978), suppressing regeneration in many plants (Badan 1979) and are known to eat bird eggs and young nestlings (Moors 1978). They also indirectly result in increased predation of native forest birds; during years of high mice numbers, stoats produce more offspring, this leading to higher stoat predation levels (Ruscoe & Murphy 2005).

The various prescriptions for eradicating non-native rats *Rattus* spp. from islands have been tested many times and some have proven to be very successful, however, operations targeting mice have achieved mixed results. Mice eradications have failed 38% of the time (MacKay *et al*. 2007) compared to just 5% of the time with Norway rat *Rattus norvegicus* eradications (Howald *et al*. 2007). The causes for failure in rodent eradications have been attributed to technical issues with bait application, insufficient bait, failure to follow protocols, bait competition by terrestrial invertebrates and lack of funding and public support (Howald *et al*. 2007). Possible reasons why the failure rate is higher with mouse eradications, compared to rat eradications, could be attributed to the much smaller home range of mice which means that even very small gaps in bait application may miss the territory of a mouse (Witmer *et al*. 2007). Other possible causes are behavioural differences in mice at the subspecies level which may cause failures (MacKay *et al*. 2007), aversion to cereals commonly used in poison baits (Humphries *et al*. 2000) or toxicant resistance where long term poisoning is taking place (Billing 2000). Recent trials have also found that mice can take up to 21 days to die from brodifacoum (G. Morriss, unpublished data), any females with young at this time would have a greater chance of survival.

The aim of this project was to eradicate mice from the three islands and to test a prescription for eradicating mice elsewhere. The islands were chosen because mice were the last introduced mammal on the islands, and are important locally as a representation of a native ecosystem. Size was also an important consideration in terms of cost, with the available budget sufficient to make an eradication attempt on these three islands, A key aim was to see if the procedure was successful on these islands and therefore could be expanded to larger islands i.e. practise on a smaller less expensive project. Careful planning and record keeping was essential to ensure the eradication succeeded but also to help identify where the weaknesses were should this operation have failed.

ACTION

Operation area: The mouse eradication took place on three small islands, Adele (87 ha), Fisherman (4 ha) and Tonga (8 ha) in the Abel Tasman National Park, lying off the northeast coast of South Island, New Zealand (Fig. 1). All three islands are uninhabited and are administered by the Motueka Area Office of the Department of Conservation.

Adele Island is located approximately 13 km north of the town of Motueka lying approximately 800 m from the mainland. Fisherman Island is located approximately 650 m to the south of Adele (about 800 m offshore). Tonga Island is located approximately 10 km north of Adele Island and again is approximately 800 m from the mainland. All three islands are fairly rugged, more-or-less pyramid shaped with moderate to steep narrow rocky ridges and numerous small bays and headlands with little flat ground. The rocks are Separation Point granite throughout and the soil is thin, friable and well drained. The highest point, 127 m a.s.l., is on Adele.

The vegetation on all three islands is heavily modified by past periods of burning and human occupation. The steep, drier, north facing slopes are predominately kanuka *Kunzea ericoides* and black beech *Nothofagus solandri* var. *solandri* with the occasional shallow gully of other hardwood tree species such as five finger *Psedopanax arboreus* and mahoe *Melicytus ramiflorus*. The more sheltered and less steep eastern faces are dominated by the broadleaf species of mahoe, five finger, kamahi *Weinmannia racemosa* and broadleaf *Griselinia littoralis* with a fern under storey. This also includes many frost tender species uncommon on the adjacent mainland, such as renga lily *Arthropodium cirratum* and large-leaved milk tree *Streblus banksii*.

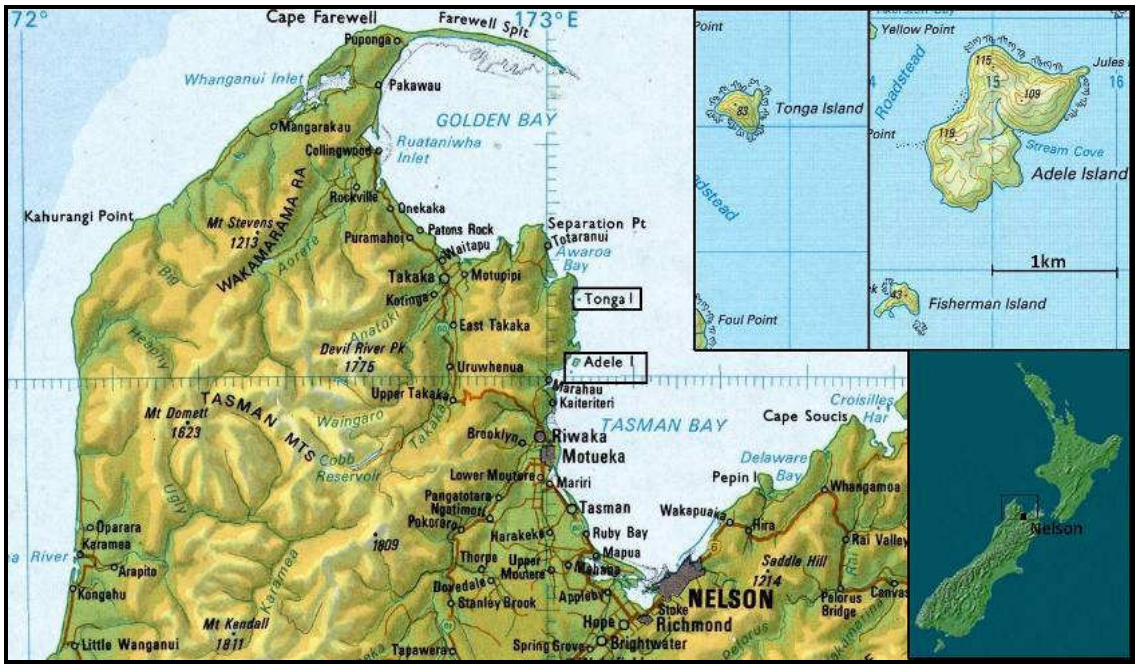

Figure 1. Location of Tonga Island, Adele Island and Fisherman Island, New Zealand.

Populations of native birds, including ruru or New Zealand owl *Ninox novaeseelandiae*, bellbird *Anthornis melanura*, tomtit *Petroica macrocephala*, kereru *Hemiphaga novaeseelandiae*, grey warbler *Gerygone igata*, variable oystercatcher *Haematopus unicolor* and spotted shag *Stictocarbo punctatus*. Spotted shags roost in large numbers on Adele Island. There have been records of Nelson green gecko *Naultinus stellatus* on Adele Island and common gecko *Hoplodactylus maculates* on both Adele and Tonga Island. Tonga Island also has a significant breeding colony of New Zealand fur seal *Arctocephalus forste*ri.

Eurasian stoats *Mustela ermina* were first observed on Adele Island in 1977. Two attempts have been made to remove stoats; the second successfully removing the last stoat in 2003. During this time no rats were caught or any sign observed. However, a diet study was conducted on stoats caught between 1980 - 1983 and one sample from Adele Island contained black (ship) rat *Rattus rattus* remains (Taylor & Tilley 1984). However, this was presumed to have been from a rat the stoat caught on the mainland.

Mice were recent arrivals on Fisherman Island (confirmed present in 2006) and Tonga (confirmed present in 2005), but had been known to be present on Adele for more than 25 years before the eradication programme. The closest distance to the nearest population of mice for all three islands is approximately 800 m. The islands are easily accessible to members of the public; it is therefore assumed that mice reached the islands by stowing away on boats/kayaks or in personal belongings bought ashore. Prior to this eradication operation, mice were the last introduced mammalian predator remaining on the islands. No attempt was made to assess the mouse population sizes prior to the eradication effort.

Treatment: The three islands were treated with two separate aerial applications of cereal bait containing brodifacoum poison. Pestoff 20R® (rodent bait), manufactured by Animal Control Products (New Zealand), was used. This bait and toxin has been used successfully for a large number of island rodent eradication programmes both in New Zealand and overseas. Pestoff 20R® is a 10 mm diameter (2 g minimum weight) cereal pellet dyed green (to reduce attractiveness to non-target species such as birds). The baits contained 20 ppm (0.02 g/kg) of brodifacoum and contained no lure or bitrex to eliminate the risk of these additives deterring mice from eating sufficient quantities.

The bait was applied aerially from a helicopter using a specially designed under slung bait-spreading bucket (Fig. 2). Prior to the operation the bucket was calibrated to spread bait at a rate of 4 kg/ha. These calibration trials used non toxic bait produced to the same specifications as the poison bait. Prior to bait application the boundaries of each island were flown and mapped using Differential Global Positioning System (DGPS) to ensure the entire area of each island was covered. The onboard GPS (AG-NAV® 2 GPS) was downloaded at the same time to ensure compatibility with mapping programmes.

Figure 2. Helicopter with bait spreading bucket being filled by loader.

Each island was flown with DGPS using parallel flight lines along the island with bait application (via the spreading bucket) sowed at a rate of 4 kg/ha with a 50% overlap in swath width giving 8 kg of poison bait per hectare on the ground. This was followed by one swathe following the coastline at a sowing rate of 4 kg/ha. The reasons for applying the bait with a 50% overlap were to minimise the possibility of gaps between the flight lines caused by small errors in satellite coverage of the DGPS, pilot error or by wind deflection of the bucket and the bait. Mice can have very small home ranges so 100% coverage of the island was essential. All offshore rock stacks around each island supporting possible mouse habitat were treated by spreading bait by hand from the helicopter.

The second application of bait was timed to take place at least 10 days after the first, and was carried out as previously described, but with the orientation of the parallel flight lines changed by about 90 degrees. The reasons for

applying the bait in two separate applications were to ensure complete coverage of the islands with bait, to minimise the risk of bad weather (i.e. rain) washing out both applications, to ensure the mice were exposed to bait for a long period of time and to ensure that any mice (e.g. young mice) that did not access bait from the first application were exposed to bait from the second.

Application dates: Timing of the bait applications was dependant on a suitable weather forecast. The first application took place during the first period of settled weather (a prediction of at least 4 days and 3 nights of consecutive fine, dry weather) after 1 July 2007. The second drop took place a minimum of 10 days after the first, depending on the suitability of the weather. The operation was also planned for this time of the year as it was the middle of the winter season when food availability for mice was considered to be lowest.

House mouse monitoring: Monitoring was carried out every three months, for a 2-year period, following the eradication attempt. This coincided with other research monitoring trips to the islands and field staff availability. Five different monitoring techniques were chosen as this was seen as the best approach, compared to using one monitoring technique only. These were as follows:

1) *Wax chew tags* - peanut butter flavoured wax tags were used to show sign of mouse teeth marks;

2) *Footprint tracking tunnels* - a network of tunnels were installed around each island with ink cards placed inside. Any mice walking through the baited tunnels leave footprints on the cards. These were active for 7-10 days every three months;

3) *Rodent motels* - a closed wooden box with four side entrances. Inside the box were traps and bedding material. Mice would either be caught in a trap or would leave sign (faeces) in the bedding. Traps inside these motels were active for the entire 2-year monitoring period;

4) *Rodent detecting dogs* - specially trained rodent detecting dogs were used on the islands to look for sign or the presence of mice;

5) *Mouse traps* - Victor® Easy Set mouse traps were set around the islands to catch any mice. These traps were set under covers to avoid non-target catch and were regularly set and inspected through the 2-year monitoring period.

Prior to the eradication, DNA samples were collected from 30 mice from each island. These were stored for analysis. If a mouse was found on any of the three islands following the eradication, the DNA could be compared with the samples to determine if the mouse was a survivor from the eradication or a new incursion.

Monitoring of non-target species: No formal monitoring of effects on non-target species was carried out; previous monitoring work during similar operations in New Zealand found that none of the species (birds or reptiles) present on Adele, Tonga and Fisherman, were considered to be at significant risk from brodifacoum poisoning. Following the two poison bait applications, monitoring was restricted to *ad hoc* searches on the islands while carrying out other work,

In the early stages of planning it was identified that bait application around coastal areas might pose some risk to the fur seal population on Tonga. Direct poisoning or secondary poisoning was considered to be very unlikely considering the large amounts of bait a seal would need to consume to elicit a harmful response.

However, at the time of the operation the fur seal population comprised predominantly females and pups, and disturbance by the helicopter was deemed a potential problem. Therefore, numerous experts were consulted. It was suggested that the seals would hold their ground until the helicopter got to with in a certain distance and then they would all stampede for the water, which could result in the potential trampling of the young seals and was therefore deemed the greatest threat. It was concluded that the best strategy was to approach Tonga from a distance and well above the height we would be spreading bait and then gradually reduce the altitude. Prior to the operation, the seals reaction to this approach was recorded.

Very little change in behaviour was recorded and, even at a height of about 50 m, the seals showed little sign of distress. The pilot suggested that it was important not to appear suddenly from over a ridge or around a corner, but to approach from a distance giving the animals plenty of time to observe the helicopter as it approached. These recommendations were based on the pilot's

previous experience when flying in the vicinity of other large mammals.

CONSEQUENCES

House mouse monitoring: There was too much ambiguity between insect damage and possible mouse teeth marks so it was decided to discontinue using chew tags after the second monitoring trip on April 2008. Due to the high cost of using a rodent detecting dog, this type of monitoring was only deployed briefly during the monitoring program. In April 2009 a rodent detecting dog and handler visited Tonga and Adele. During a two day period, the dog and handler traversed both islands and found no sign of mice.

At the conclusion of the 2-year monitoring period following the eradication attempt, no mice or any sign of mice was detected. Adequate post eradication monitoring (Table 1, monitoring effort) was deemed to have been carried out to confirm that the eradication of mice from all three islands was successful. No mice were detected using any of the monitoring techniques.

Non-target species monitoring: During the 8-12 day period following the first bait application, approximately 36 person hours were spent on Adele Island; no non-target species were found dead. Five days after the second application approximately 4 person hours were spent on Fisherman Island and Adele Island, again no non-target species were found dead. This time was not spent specifically searching for non-target species. While other field work was being carried out on the islands, staff were also observant for any non-target species they found dead, none were found.

Specific operation details

Bait application: The first drop took place on the 8 July 2007 and used 1,200 kg of bait. The second drop was on 22 August 2007 and used 1,300 kg of bait. Each application of bait to all three islands took approximately four hours to complete. One small rock stack on the northern end of Fisherman Island and one off the southern end of Adele Island were treated each time by throwing paper bags of bait out of the helicopter to give an application rate similar to that used on the main islands.

Application of bait using parallel flight lines with a 50% overlap in swath width was difficult to achieve in some parts of the smaller islands. Where this was not practicable, the island was flown with DGPS recording but using the pilot's judgement on direction to achieve full coverage with bucket sowing rate 4kg/ha. This was immediately followed by a repeat coverage in the same way, but choosing a different starting point and flying in a different direction. Completion of each island was confirmed by the immediate downloading of flight lines onto a computer, which ensured 100% coverage.

Weather: The first application of bait was on 8 July 2007. During the drop the weather was fine with no wind. On the second night, approx 12 mm of rain was recorded nearby on the mainland. The actual rain falling on the islands was considered to be a few millimetres less than this, as is normally the case when it rains in the area. The weather stayed fine for a further seven nights followed by a trace amount of rain on the 17 and 20 July. The second bait application was carried out on 22 August 2007. During the drop the weather was overcast with a light breeze (up to 6 knots at times). Some light afternoon spots of rain developed but barely wet the ground. No rain was recorded in the rain gauge. There was 3 mm of rain on the 29 August which was well after the recommended '4 days/3 nights' fine weather. Over the next week less than 10 mm of rain fell in the area.

Table 1. Post-eradication monitoring effort conducted on Tonga, Adele and Fisherman Islands, 2007-2009.

Island	Footprint tracking tunnel nights	Snap trap nights	Rodent motel snap trap nights
Adele (87 ha)	772	7,220	3,207
Tonga (8 ha)	123	1,086	2,352
Fisherman (4 ha)	123	1,359	1,122

Other observations

Bait: Three days after the first bait application, bait was still readily noticeable on the ground on Adele and less so on Tonga. On Fisherman Island there was still bait on the ground but it had to be searched for, even on the open forest floor. Trapping carried out to collect DNA samples prior to the eradication suggested high numbers of mice on Fisherman Island, although no density estimates were recorded. The rain that fell on the 9 July was not sufficient to wash away the bait. Most of the baits observed retained their shape and only a thin outer layer softened. Three days following the second application there was a noticeable amount of bait remaining on all three islands.

Seedling growth: In the summer following the eradication attempt there was anecdotal evidence of a significant increase in seed germination. One species in particular, *Streblus banksii*, which is uncommon on the nearby mainland, carpeted the forest floor with seedlings in some locations.

Conclusions and discussion: The aerial application of cereal baits containing brodifacoum at set rates proved to be effective at eradicating mice from these three islands. Mackay *et al*. (2007) showed that, globally, 17 previous mouse eradication attempts on 45 islands failed. It is suggested that the success of this project can be attributed to thorough planning, peer review of the operation procedure prior to the eradication action and following the prescription as planned. Planning for this operation took six months, carrying out the bait drops took eight hours. Though (Mackay *et al*. 2007) could not identify specific causes of failure to eradicate mice in previous attempts elsewhere, in this attempt it was ensured that all mice had access to quality bait. This was done by achieving excellent coverage of the islands, twice, during appropriate periods of fine weather.

It is considered unlikely that mice would be able to swim the distance to the islands. The most likely pathway for mice to return to the islands is via boats. A biosecurity program is in place to inform people about the risks of accidentally transporting mice and other unwanted pests to the islands, what they can do to prevent it and who to call if they encounter evidence of an incursion. Monitoring devices are permanently stationed on all three islands to detect any further incursions of rodents or stoats. A plan to provide a rapid response to any incursions detected or reported is now in place.

ACKNOWLEDGEMENTS

Thank you to the Department of Conservation staff from the Motueka Area Office and Nelson/Marlborough Conservancy who contributed to the success of this project. Thanks also to the New Zealand Island Eradication Advisory Group for technical advice and support for this project. Kerry Brown and Keith Broome provided useful comments on an earlier version of this manuscript.

REFERENCES

Badan D. (1979) *The ecology of mice (*Mus musculus *L.) in two forests near Auckland*. Unpublished M.Sc thesis, University of Auckland, NZ.

Billing J. (2000) The control of introduced *Rattus rattus* on Lord Howe Island. II. The status of warfarin resistance in rats and mice. *Wildlife Research*, **27**, 659-661.

Fitzgerald B.M., Karl B.J. & Moller H. (1981) Spatial organisation and ecology of a sparse population of house mice (*Mus musculus*) in a New Zealand forest. *Journal of Animal Ecology*, **50**, 489-518.

Howald G., Donlan C.J., Galvan J.P., Russell J.C., Parkes J., Samaniego A., Wang Y., Veitch, D., Genovesi P., Pascal M., Saunders A. & Tershy B.R. (2007) Invasive rodent eradication on islands. *Conservation Biology*, **21**, 1258-1268.

Humphries R.E., Sibly R.M. & Meehan A.P. (2000) Cereal aversion in behaviourally resistant house mice in Birmingham, UK. *Applied Animal Behaviour Science*, **66**, 323-333.

Mackay J.W.B., Russell J.C. & Murphy E.C. (2007) *Eradicating house mice from islands: successes, failures and the way forward*. In: *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.

Moors P.J. (1978) Methods for studying predators and their effects on forest birds. *In*

Dingwall, P.R. Atkinson, I.A.E., Hay, C. (eds.) The ecology and control of rodents in New Zealand nature reserves, pp. 47-56. *Department of Lands and Survey Information Series 4*.

Morriss G.A. (2007) *Susceptibility of Rangitoto and Motutapu house mice to 20R brodifacoum baits*. Landcare Research Report LC0607/155.

Ruscoe W.A. & Murphy E.C. (2005) House mouse *In* King C.M. (ed.), *The handbook of New Zealand mammals 2nd Edition*. pp. 204-221. Oxford University Press, Melbourne, Australia.

Searle J.B., Jamieson P.M., Gunduz I., Stevens M.I., Jones E.P., Gemmill C.E.C. & King C.M. (2008) The diverse origins of New Zealand house mice. *Proceedings of the Royal Society B.*, **276**, 209-217.

Taylor R.H. & Tilley J.A.V. (1984) Stoats on Adele and Fisherman Islands, Abel Tasman National Park, and other offshore islands in New Zealand. *New Zealand Journal of Ecology*, **7**, 139-145.

Whitaker, A.H. (1978) *The effects of rodents on reptiles and amphibians*. *In* Dingwall P.R., Atkinson I.A.E. & Hay C. (eds.) *The ecology and control of rodents in New Zealand nature reserves*. Pp. 75-86. *Department of Lands and Survey Information Series 4*.

Witmer G.W., Boyd F. & Hillis-Starr Z. (2007) The successful eradication of introduced roof rats (*Rattus rattus*) from Buck Island using diphacinone, followed by an eruption of house mice (*Mus musculus*). *Wildlife Research*, **34**, 108-115.