Eradication of Pacific rats (*Rattus exulans*) from Whenua Hou Nature Reserve (Codfish Island), Putauhinu and Rarotoka Islands, New Zealand.

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Abstract Pacific rats (*Rattus exulans*) were eradicated from three islands in southern New Zealand in 1997 and 1998. In August 1998, two aerial applications (9.7 kg/ha and 9.4 kg/ha) of 2 g Agtech cereal pellets containing 20 ppm brodifacoum, were made over the whole of 1396 ha Codfish Island (Whenua Hou Nature Reserve) for the eradication of Pacific rats *(Rattus exulans)*. Preparation for the eradication included the eradication of Pacific rats from 144 ha Putauhinu in August 1997 so that a second population of a fernbird (*Bowdleria punctata wilsoni*) endemic to Codfish Island could be established there. A bait drop was also carried out on 88 ha Rarotoka (Centre Island) on the same day as Putauhinu, to eradicate Pacific rats as the first step in the restoration of that island. A single drop of 12 kg/ha of Talon 20P cereal bait containing brodifacoum at 20 ppm was used for the Putauhinu and Rarotoka eradications. To protect the fernbirds on Codfish Island which were at risk from the aerial bait drop, a ground bait station network on a 50 m x 25 m grid covering 37 ha was set up and operated in conjunction with the aerial drop. With no sign of rats having been detected for two years after the respective bait drops, the three eradications have been declared successful.

Keywords Pacific rat, kiore, *Rattus exulans*; eradication; brodifacoum; fernbird, *Bowdleria punctata*.

INTRODUCTION

Whenua Hou Nature Reserve (1396 ha), also known as Codfish Island, is located three kilometres west of Northern Stewart Island (Fig. 1). The New Zealand Department of Conservation (DOC) identified Codfish Island as a high priority site for the eradication of Pacific rat or kiore (*Rattus exulans*) prior to 1995, when planning for the eradication started. DOC managers had requested the eradication of Pacific rat as a further step in the ecological restoration of the island. Codfish Island is the largest island near the South Island and Stewart Island, which had such easily-realised restoration potential. The island has a diverse range of habitats typical of the Stewart Island area (Rakiura Ecological Region).

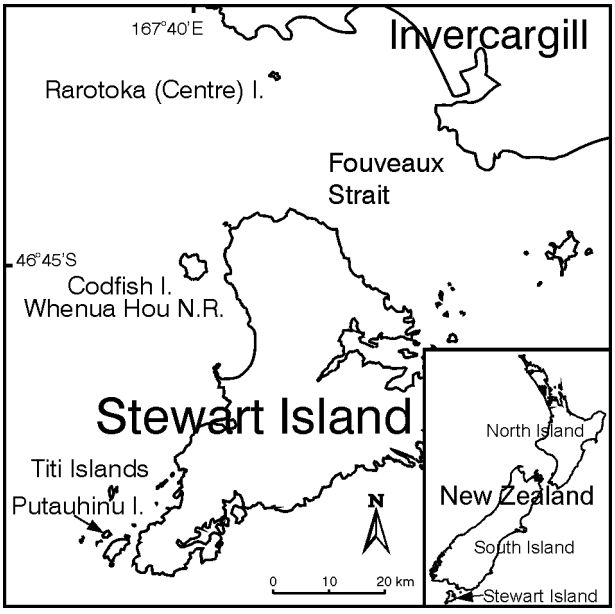

Fig. 1 The locations of Rarotoka, Putauhinu and Codfish islands.

Pacific rats are believed to have been introduced to Codfish Island by early Maori, possibly for use as a food source during their annual harvesting trips to the nearby Titi Islands. Like most New Zealand Maori, the local people consider Pacific rat a 'taonga' or treasure as they were introduced to New Zealand by the first colonists. However, muttonbirders, those Maori with inherited rights to harvest muttonbirds (young of sooty shearwaters (*Puffinus griseus*)), generally consider the Pacific rat as a pest to be removed, providing the species is safeguarded on some islands. For most local Maori the presence of Pacific rats on Stewart Island fills this requirement.

A range of trials was required prior to the rat eradication being undertaken on Codfish Island. Trials included: bait and toxin weathering; identification of non-target species at significant risk; and identification of the appropriate management techniques to minimise this risk. As a result of these trials, DOC determined that Pacific rat eradication was required on Putauhinu, a 144 ha island southwest of Stewart Island. This eradication was to prepare Putauhinu for the establishment of a second population of one of the non-target species at risk, the Codfish Island fernbird (*Bowdleria punctata wilsoni*).

Putauhinu is privately owned by Maori and is visited annually in autumn for up to two months by five families to harvest muttonbirds. For its size, Putauhinu contains a diverse range of habitats from tall rata (M*etrosideros*) forest to low flax (*Phormium* spp.) pakahi (wetland), but before the eradication, it had a very depleted fauna due to the presence of Pacific rats and cats (*Felis catus*). The cats

Pages 173-181 In Veitch, C. R. and Clout, M. N. (eds.). *Turning the tide: the eradication of invasive species*. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.

died out in the 1960s-1970s after some limited control by the muttonbirders (T. Davis pers. comm.).

The muttonbirders on Putauhinu first approached the DOC about removing Pacific rats from their island in 1994, in order to continue the restoration of the island to its former condition. Therefore, they were happy with DOC's proposal for the rat eradication and introduction of fernbirds to Putauhinu. Fernbirds had previously been on the island but had been exterminated by the rats and cats.

During the initial planning stages for the Putauhinu eradication the local Maori also suggested the possibility of eradicating Pacific rats from Rarotoka (Centre Island), an 88 ha island in Fouveaux Strait (Fig. 1). Rarotoka is a former lighthouse reserve which was cleared and intensively grazed for more than 100 years by sheep (*Ovis aries*) and cattle (*Bos taurus*) prior to being handed back to its original Maori owners. The rat eradication on Rarotoka was proposed as the first stage in the ongoing restoration of the island, which will include intensive plantings of native species.

METHODS

Putauhinu

The eradication operation on Putauhinu was carried out in August 1997 using a single aerial bait drop of 12kg/ha of Talon 20P bait (containing 20 ppm brodifacoum). The bait was loaded into the helicopter's spreader bucket directly off the deck of the boat which had been used to transport the bait to the island on the day of the drop. A second helicopter was used to transport fuel and personnel.

As the island has five dwellings which are occupied seasonally and rely on rainwater, a team was tasked with placing bait under and in all buildings and with disconnecting the water pipes to eliminate the risk of contamination.

Rarotoka

The eradication operation on Rarotoka was also carried out using a single 12kg/ha aerial drop of Talon 20P. Proximity to the mainland meant that it was more efficient to ferry the bait directly from there using a second helicopter, than to use a boat. Bait loading was carried out on the island with a single helicopter dropping the bait.

The relatively small size of Putauhinu and Rarotoka, and their proximity to each other, meant that eradication operations on them could be done cost effectively in the same day using the same helicopters and personnel.

As the risk that bitrex posed to the success of these operations (Veitch 2002) was not recognised at this stage the bait used for this drop did contain bitrex.

Codfish Island

Preparation for the eradication operation on Codfish Island began in 1992 with the commencement of a number of trials to gauge the likely effects of the operation on non-target species and to find the most suitable bait type.

Assessment of risks to non-target species

Fernbirds

Fernbirds had not previously been identified as a non-target species that would be affected by an aerial bait drop. However, this was based on toxins other than brodifacoum. As Codfish Island fernbirds are recognised as a separate subspecies, DOC staff decided it was necessary to quantify any possible risk. To this end the relevant permissions were obtained for a toxic trial at a mainland site. In 1993 toxic bait was dropped over 25 ha and the fernbirds monitored. Over 80% of the fernbirds in the area disappeared and one fledgling, which was found dead, was analysed and found to contain brodifacoum (Ranum *et al.* 1994). No birds in a neighbouring control block were lost, thereby showing that the proposed aerial bait drop on Codfish posed a significant risk to the fernbirds at a population level. In 1996 a repeat trial was carried out using bait stations (Russell and Parker 1997). The bait station trial had no observable effect on the fernbirds.

Also in 1996 a trial was carried out on the mainland to see if it was feasible to hold sufficient fernbirds to safeguard the subspecies in captivity for long enough to ensure that when they were released, they would no longer be at risk from residual baits. While birds could be successfully held in captivity, the territorial nature of the birds meant that it was not feasible to hold the required numbers as subordinate birds died apparently of stress-related causes.

Kakapo

Field trials using non-toxic bait were carried out on critically-endangered kakapo (*Strigops habroptilus*) which indicated that some birds might be at risk from eating the bait. At least one bird ate non-toxic bait when presented with it.

A non-toxic aerial bait drop on Codfish Island to determine risk to bats and kakapo was unsuccessful as the bait was washed out on the night of the drop by a heavy rain event.

Bats

To gauge the likelihood of secondary poisoning of short-tailed bats (*Mystacina tuberculatus tuberculatus*), brodifacoum cereal baits were fed to weta (*Hemiandrus* spp.), a large (20–40 mm) orthopteran that is part of the bats' natural diet. The weta were then assayed for the toxin. The assay showed that brodifacoum passed through a weta digestive tract in less than twelve days (Lloyd 1997). This meant that the likelihood of secondary poisoning to bats

was minimal, as a bat would need to eat a large number of invertebrates which had in turn each eaten a large amount of bait in the recent past.

Bait was presented directly to captive short-tailed bats but none was eaten (Lloyd 1997). However, as aerial bait drops had not been carried out on an island with bats before, DOC decided to hold a backup population in captivity and to monitor the wild population.

Fifty bats were transferred to nearby Ulva Island (40 km away) in the hope of establishing a backup population (Lloyd 1997). However, no bats were recorded after the "hard" release (i.e. the bats were released immediately on arrival at Ulva with no shelter or food provided) and much more work would have been required to make this technique work.

Trials were carried out to see if bats could be held in induced torpor, in a fridge, to reduce the feeding requirements during the period in captivity (Lloyd 1997). While the trial was successful it was not judged a practical option for the number of bats required (i.e. 300-400) to safeguard the population.

Other Species

The effect of an aerial brodifacoum drop on other non-target species had been noted during previous operations (e.g. kaka (*Nestor meridionalis*) on Kapiti, Empson and Miskelly 1999), and while some deaths were anticipated, any effect was expected to be on an individual (particularly juvenile birds), rather than population, level.

Bait Trials

DOC staff were concerned about the possible effect on non-target species of having bait available on the ground for a prolonged period; however to increase the chances of the eradication succeeding, the bait was required to be available to the rats for as long as possible. Therefore, trials were carried out to find the best compromise between the two conflicting issues.

Bait weathering

A comparison between Wanganui No. 7 and Agtech baits to test longevity of both baits under the climatic conditions found on Codfish Island was carried out in 1994. The longevity of Agtech bait was less than Wanganui No. 7 bait, but it could still handle at least 15 mm of rain. The longevity of the bait is, initially at least, based solely on precipitation levels; not on how long the bait is on the ground. Agtech was the preferred bait because, with reasonable weather, it would last long enough for all rats to have access to bait (minimum 3 nights), but would be unlikely to last for an extended period (i.e. over a month). The faster breakdown of Agtech bait reduced the length of time that bait would be available to the high-risk non-target species such as bats and fernbirds. The faster breakdown also reduced the risk to more common non-target species such as kaka, which Empson and Miskelly (1999) discovered could "learn" that the bait is food, the longer it is available. Faster bait breakdown also meant that kakapo and captive bats could be released on the island sooner, reducing both the stress on the individuals and the cost of holding them.

Toxin weathering

To find out at what point the bait was no longer likely to be lethal to rats and non-target species, bait was put out on Codfish Island under rat exclosures and samples analysed as it broke down. This showed that even when the bait appeared unpalatable (i.e. either mouldy or crumbled), it still contained the original toxic loading.

Selection of a quicker breakdown bait meant that the safety margin usually allowed for weather conditions in such an operation was reduced. This reduced safety margin meant that more emphasis was placed on accurate weather forecasting as >15mm of rain within three nights of the bait drop could have resulted in a failure of the entire operation.

Timing of operations

In New Zealand, rat eradications are undertaken in the winter when rat numbers are at their lowest (shown for Codfish by a three year, monthly trapping programme (DOC internal file REN 012)) and natural food is presumed to be in shortest supply. Also, in the winter rats are not breeding, therefore minimising the risk of any young rats being in the nest when bait is dropped and emerging once the bait has broken down.

A weather forecast for three nights without rain is also considered a requirement for all aerial bait drops. However, three consecutive fine nights is not always easy to obtain in southern New Zealand, particularly during an unsettled winter such as 1998.

Bait requirements

Well into the preparation for the Codfish Island operation DOC became aware that the toxin (brodifacoum) which was to be used contained bitrex, which has been incorporated into all Talon bait formulations (including the Agtech bait proposed for use in this operation), since late 1996. Bitrex was added to make the bait less palatable to humans, and the bait registrations had been altered accordingly, meaning that the selected bait could not be legally used without having bitrex in it. This additive had been put in the bait for previous operations without DOC's knowledge or approval despite requests being made for notification of any changes to formulation. While company trials had shown that bitrex may in fact act as an attractant to possums and some rodents (D. MacGibbon, ICI, pers. comm.), two out of four of the previous eradication attempts using bitrex had failed (I. McFadden pers. comm.), and the outcomes of the other two operations were unconfirmed at the time. In laboratory efficacy tests, involving bitrex in ICI rodenticidal formulations with albino rats and mice (20 animal groups, three-day choice tests),

three out of 60 rats rats did not eat sufficient bait to be killed (Kaukeinen and Buckle 1992). In tests on Pacific rats on Little Barrier Island, 12 of the 15 rats offered a choice of baits with (and without) bitrex, chose to eat significantly less of the bait containing bitrex (Veitch 2002). This was sufficient for DOC to stipulate that bitrex could not be present in the bait for this operation.

While most of the other specifications for the bait are standard (i.e. colour, moisture content, etc.). bait size was an important consideration. Twelve mm diameter baits (approximately 2 g), were selected as this gave the greatest number of individual baits per square metre, increasing the chance of each rat encountering bait.

Describing bait by weight/mass is in fact not appropriate, as bait production standards are given using diameter; in this case 12 mm. Depending upon factors on the day of manufacture such as humidity, etc., there can be a significant variance in the weight of each bait. Hence the cited weight of 2 g per bait should only be taken as a rough guide. In New Zealand, bait is available in 12, 16 and 20 mm diameters.

Bait storage

DOC staff decided that the bait should be stored on site until it was required, therefore temporary storage was erected using a pipe framed "Coverall" tent. This proved more than adequate but did require daily monitoring to ensure adequate ventilation and to avoid condensation falling onto the bait.

Helicopter operations

Due to uncertainty that a single helicopter could complete the drop in the time required (i.e. one day), two helicopters were arranged for the first drop along with a backup approximately one hour flying time away on the mainland. The island's boundary (i.e. the shoreline) and the core area (containing the fernbirds) that was to be treated using ground bait stations, were logged in with the GPS the day before the drop. These data were then stored in the helicopters' computers so that boundary logging did not need to be repeated for the second drop.

For safety, both to reduce the risk of collision and to speed up the operation (i.e. to reduce ferrying time from the loading site to the drop areas), the first drop was carried out using two loading sites. One site was at the bait storage area on the coast, and a second near the summit of the island. Bait was ferried to the top site by a third helicopter, which also transported personnel and the media representatives as required. The first drop showed that the island could be covered in one day by one helicopter, therefore the second drop was carried out by a single bait-drop helicopter operating from the top loading site, with a second helicopter ferrying bait to that site.

Each loading site had a platform made out of wooden pallets on which 12 opened bags of bait were placed so that loading could take place as quickly as possible. Having a raised platform allowed the bait loaders to tip the bait in quickly, rather than lifting each bag from ground level.

To monitor the bait coverage a Trimble GPS system, which recorded the lines that the helicopter had flown, was used. However, the pilot had to manually switch the tracking on while bait was flowing out of the bucket and switch the GPS off when bait flow stopped.

Bait drop

The Codfish Island bait drop was carried out to the formula (two bait drops, with a 20% overlap in flight lines for each drop) that had been used successfully elsewhere (I. McFadden pers. comm). The cliff areas (Fig. 2) were treated twice during each drop to allow for the increased planar area that had to be covered. This system ensured full coverage of the island and sufficient bait on the ground to ensure that every rat had access to a lethal dose.

The first drop was to be 8 kg/ha, followed by a second of 4 kg/ha. The first drop on 18 August 1998 ended up averaging 9.7 kg/ha due to the double-up on the cliffs, around the bait station area, and treating the rock stacks and small islets offshore, as the presence of Pacific rat on these could not be ruled out.

Because it rained the night of the first drop (5 mm) and again on the second day (7.1 mm), the DOC project team on the island decided to increase the second drop to 8 kg/ha due to concern about the possibility of the baits weathering. The second drop on 27 August 1998 averaged 9.3 kg/ha. The increase over the 8 kg/ha originally proposed was to ensure complete cliff coverage.

Bait was spread over the entire island, excluding the core fernbird area. This included the buildings, which had the water systems disconnected and were later washed down, and the bat aviaries, which were covered with polythene during the drop. No bait was dropped on the core fernbird area, but the perimeter of this area was flown with a double swath to ensure that the border between the two techniques was secure. The steep/cliff areas of the island were covered twice to ensure that they received the appropriate drop rate. Bait was also spread over all the islets and rock stacks adjacent to Codfish Island.

Accuracy of aerial bait spread

The basic requirement for the operation to succeed was that every rat had access to a lethal dose of bait (i.e. that bait was dropped into every rat's home range). To ensure that the bait drop covered the whole island a Trimble® second-generation differential global positioning system was used by the pilots to record the flight path of the helicopters. This allowed highly accurate bait placement on all parts of the island, including the steep coastal faces and adjacent rock stacks and islets. A map of the bait spread was available on a computer screen in the helicopter that could be viewed when required. This took place at least

every time the helicopters refuelled. The information was also downloaded after the drop and presented as a printed map. The map enabled the project manager to locate any possible gaps in the bait spread and get the pilots to cover those areas again. A print out of satellite flight paths was obtained prior to the drop to ensure that there was suitable GPS coverage.

Safeguarding kakapo

As a precautionary approach, all known kakapo on Codfish Island were removed to a safe island for the duration of the operation. One male who could not be found at the time of the transfer was located later, having been on Codfish Island for the duration of the operation, with no apparent ill affects.

Safeguarding fernbirds

Early trials confirmed that the endemic Codfish Island fernbird was likely to be seriously affected by an aerial drop of cereal bait, and that a ground bait station operation presented far less risk. A ground-based operation over the whole island was not deemed feasible as it would have had significant impacts on the wildlife and their habitats, including the cutting of many kilometres of track over fragile country. Further, using more ground bait stations would not guarantee exposing all rats to a lethal dose of bait.

It was therefore decided to use a two-pronged approach to protect the fernbirds:

Bait station network

A 37 ha block of the best fernbird habitat (Fig. 2), containing the densest population of fernbirds determined by a previous survey (G. Elliott pers. comm.), was set out with a total of 416 bait stations at 25 m intervals along parallel lines 50 m apart. Around the perimeter of the grid, the intervals between bait stations was reduced to 25 m x 25 m. Each bait station was loaded with 100 g of Agtech pellets on the day prior to the first drop to ensure that more than sufficient bait was available to the rats. After six days this was reduced to 10 pellets to enable easier monitoring of any bait take. After a further 31 days this was changed to a 28 g Contrac wax block containing 50 ppm bromadiolone in case of bait or toxin shyness (Table 1).

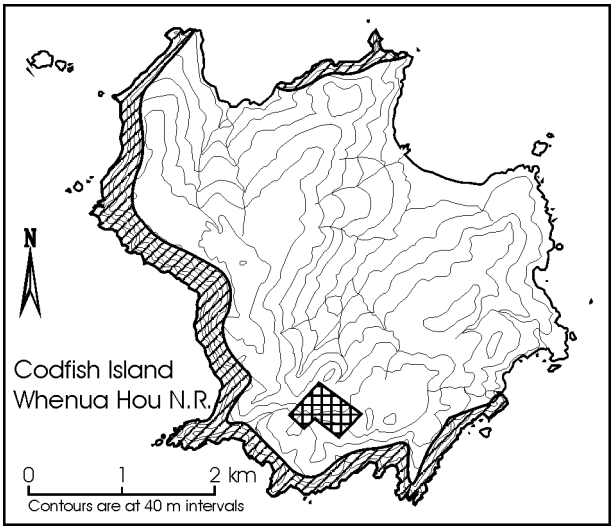

Fig. 2 Codfish Island showing the cliff areas (diagonal hatching) and core fernbird area (cross hatching) which were given specific treatments in the rat eradication programme.

The bait stations were made of 100 mm diameter Novacoil plastic drainage pipe, 450 mm long with a hatch in the middle for loading and checking bait. To help the helicopter pilots identify the boundary of the zone during the aerial application of bait, the perimeter was flagged using brightly coloured pennants at approximately 50 m intervals.

During both aerial applications the core area was excluded from any aerial poisoning. However in addition to the normal drop up to the boundary, two 60 m swaths were dropped around the entire boundary on both drops to reduce the possibility of rats moving in or out of the ground treatment area. The inner swath was centred on the perimeter flags, which meant that this bait dropped from the air penetrated 25–30 m into the grid from all boundaries, and a band of approximately 80–90 m immediately outside the grid received a double application of bait on both drops.

Fernbird transfers

In case the ground bait station network failed to protect the fernbirds, a second population was established on another island so that they could be re-introduced to Codfish Island if the Pacific rat eradication removed them from Codfish Island completely. The choices for islands were limited by the presence of either predators or other subspecies of fernbirds. Consequently the first transfer was to 12 ha Kaimohu Island south-west of Stewart Island. This transfer failed for unknown reasons, although it was thought

Table 1 Record of 416 bait stations on a 50m x 25m grid covering approximately 37 ha on Codfish Island.

Date of Check	No. of Stations Active ie bait still being taken.	% of Total Stations Active
17/8	416 bait stations loaded with 100 g Agtech pellets	
18/8	First Aerial drop	
18/8	65	15.6
19/8	90	21.6
20/8	111	26.6
21-22/8	111	26.6
23-24/8	19	4.5
23-24/8	Bait changed to 10 x 2 g baits	
25-26/8	20	4.8
27/8	Second Aerial drop	
28-29/8	10	2.4
30-31/8	0	0
Stations checked every 3 days until 24/9	0	0
24/9	Bait changed to 28 g “Contrac” wax block	

to be less than perfect prior to the introduction due to the island's size and vegetation types. As there were no other readily-available rat-free islands, the transfer team was then left with the only choice of preparing another island by removing predators from it.

The most suitable island for this was identified as Putauhinu (144 ha), which had a wide range of habitat including areas of pakahi (wetland scrub) similar to that preferred by the fernbirds on Codfish. This operation cleared the way for the transfer of 21 fernbirds from Codfish Island to Putauhinu in November 1997.

Safeguarding short-tailed bats

The other species identified as being at potential risk was short tailed bats. Various trials for both primary and secondary poisoning indicated that the risk was minimal although it could not be discounted entirely. Hence 50 bats were transferred to Ulva Island in an attempt to establish a second population of the bats. The transfer was not successful (B. Lloyd pers. comm.). Therefore holding sufficient bats in captivity for the duration of the project to safeguard the population was the only practical alternative.

Four purpose-designed "batteries" were constructed on Codfish Island and 386 bats were held for nearly three months. Only nine bats were lost up until the last week of the programme when 42 died in one event due to heat stress in one of the roost boxes. Even with this unfortunate event, the operation was still judged a major success by international bat husbandry standards. A team of 5-7 people was tasked solely with carrying out the bat protection and monitoring the wild population, and this investment of single task personnel is one of the main reasons for its success.

The wild population was also monitored during the operation using radio tracking and video monitoring of roosts.

RESULTS

Bait monitoring

The requirement for three fine nights following the bait drop was not met for this operation as there was 5mm of rain the night after the first drop. Despite this, the Agtech baits lasted longer than expected from the trials carried out in 1994 on Codfish Island. It was anticipated that most of the bait would have broken down/become unpalatable within about 20 days or 15 mm of rain, however baits in sheltered sites lasted several months and all the bait lasted long enough to do a more than adequate job. After the operation, bait was observed to breakdown at different rates in different habitats. The bait under the forest canopy broke down first, apparently because once it got wet it didn't dry out again very readily and so crumbled. However, the bait on the open pakahi areas lasted far longer, because even though it got wet more quickly, any wind or sunshine soon dried it out, forming a hard crust layer on the outside of the bait. This was particularly true for bait on moss, as the moss held the bait up slightly off the damper substrate.

Rat monitoring

There was minimal follow-up carried out after any of the three operations. Monitoring of Putauhinu relied largely on the muttonbirders, who spend up to eight weeks on the island each year and would soon have detected any rat sign if present. A trapping programme was put in place on Rarotoka with over 1000 trap nights not catching a single rat. This meant that in 1999 (after two years with no sign of rats), both islands were declared rat free.

On Codfish Island a student undertook a radio telemetry study of Pacific rat home range size and die-off during the eradication. Thirteen rats were radio collared and all were dead within seven days of the first bait drop. The information gained was useful to relay the timeframe of the die-off to senior managers and the media, but was not a guarantee of successful eradication.

For Codfish Island there was only one opportunity to carry out the eradication, due to the logistics of shifting kakapo, holding bats, and not having a budget for an immediate repeat. Intensive monitoring immediately post drop was neither feasible or warranted. Therefore there was no real advantage in spending a lot of money on learning the outcome (success or failure) straightaway as success could not be confirmed for two years anyway.

The initial proposal for post-operational monitoring for rats was to rely on the kakapo supplementary feeding stations that are scattered around the island – predominantly near the top of the island. These stations had acted as an attractant for rats in the past and there had been a trap network set up near them to reduce the interference from Pacific rats. The project team agreed that monitoring of these stations would be sufficient to monitor the success of the operation. However, after the return of the kakapo, the supplementary feeding was phased out temporarily by the kakapo management team. So a rat trapping programme was carried out in March 2000 with 180 traps being set in lines of ten, spaced around the island for a total of 1000 trap nights (I. McFadden pers. comm.). No rats were caught but the project team decided to wait until the kakapo supplementary feeding programme was re-started in September 2000 and monitor it for at least three months before declaring the eradication a success. This was done and the eradication was declared successful in December 2000.

There have been several possible, if unlikely, sightings of rats on Codfish Island since the eradication. Some of these have been discounted but others have required follow-up trapping which has not caught any rats.

Non-target monitoring

Bats on Codfish and fernbirds on both Codfish and Putauhinu were the only species actively monitored dur-

ing the eradication programmes on the three islands. The decision not to actively monitor other species was based on the observations made as part of previous island eradications including Kapiti (Empson and Miskelly 1999). Monitoring of the previous eradications had shown few detrimental effects for non-target species following aerial application of brodifacoum poison. In addition, ecological monitoring designed to accurately show the results of the Pacific rat eradication would have been a large undertaking and very likely cost more than the eradications themselves.

If the changes shown on other islands are replicated, what can be expected is an increase in the diversity and abundance of indigenous species recorded. This is already occurring and is most obvious with an increase in insects, small birds, lizards, and seedlings of several plant species.

Bats

Monitoring of both the wild population and released captive bats did not show any observable loss and it is believed that there were at worst minimal individual losses, and certainly no observable effect at a population level. This task has been reported separately (Sedgeley and Anderson 1998; Sedgeley 1998, pers. comm).

Fernbirds

In November 1997, 21 fernbirds were transferred to Putauhinu and confirmation of their breeding the following summer meant that the Codfish Island eradication could go ahead. Follow-up checks on Putauhinu have shown that the fernbird population has continued to increase and expand its range (P. McClelland pers. obs.).

While not quantified, it appeared that most of the fernbirds on Codfish Island were killed in the poison operation, with very few being recorded for two years after the drop. However enough have survived to allow the population to build up rapidly and expand into most of its former range (P. McClelland pers. obs.).

Table 2 Birds found dead following Codfish Island bait drops on 18/8/98 and 27/8/98.

Species	mg/kg brodifacoum	Death probably caused by toxin	Date collected
Tui (*Prosthemadera novaeseelandiae*)	0.32	Yes	18/09/98
Tui	<0.02	No	No date
Blackbird (*Turdus merula*)	0.87	Yes	27/08/98
Thrush (*Turdus philomelos*)	1.0	Yes	24/09/98
Morepork (*Ninox novaeseelandiae*)	0.78	Yes	24/09/98
Kakariki (*Cyanoramphus spp*)	<0.02	No	11/09/98
Kakariki	1.4	Yes	01/09/98
Kakariki	0.03	No	30/08/98

Other species

Following the two bait drops eight individual birds were collected and analysed for the presence of brodifacoum. This suggested that brodifacoum poisoning killed individuals of five different species (Table 2).

General observations

The recovery of vegetation and fauna on Putauhinu and Rarotoka has been dramatic, although significantly faster and more obvious on Putauhinu (P. McClelland pers. obs.), with its better seed source and greater species diversity. There have also been major increases in the numbers of invertebrates, especially weta on Putauhinu and stag beetles (*Hemidorcus* spp.) on Rarotoka (P. McClelland pers. obs.). On Putauhinu many native bird species, including saddleback (*Philesturnus carunculatus*) and parakeets (*Cyanoramphus novaezelandiae* and *C. auriceps*) as well as the numbers of lizards and invertebrates have increased in numbers dramatically (J. Lee pers. comm.). Since the eradication, Stewart Island robin (*Petroica australis rakiura*), another species eliminated from Putauhinu by cats, have been re-introduced to Putauhinu and have rapidly increased in numbers (J. Lee pers. comm.).

The many years of uncontrolled grazing on Rarotoka with sheep and cattle has meant that vegetation recovery is far slower with a dense grass sward stopping many seedlings. A significant planting programme will be required to revegetate the island prior to considering re-introducing many species (P. McClelland pers. obs.).

DISCUSSION

The eradication on Putauhinu and also Rarotoka both removed the introduced predators from these islands and provided a suitable site for the second fernbird population. These eradications also gave the Codfish Island eradication planning and operational team a test run for such things as consents, weather forecasting, loading team set-up, etc., which helped ensure that the latter operation went smoothly.

The longer lasting Wanganui No. 7 bait was suitable for Putauhinu and Rarotoka, with their limited non-target issues. The selection of the faster-deteriorating Agtech bait for Codfish Island was shown to be the correct choice, as all rats ate bait and non-target losses were minimal, even though the desired “three fine nights” after each bait drop did not eventuate.

While no quantifiable monitoring of the benefits of the eradications has been carried out, there have been a number of obvious benefits. These include finding invertebrates and lizards not previously recorded on those islands, noticeable increases in lizard numbers, and increases in numbers of some bird species.

The partial failure of the core area to protect all of the fernbirds it contained, is believed to be due to the bait lasting longer than expected. This meant that once any birds on the perimeter of the core area were killed by the bait, the birds in the centre expanded their territories into areas where bait was still available and were also killed. Whilst it was not possible to remove this risk, the impact may have been reduced by expanding the size of the core area, thus increasing the percentage of birds away from the perimeter. The partial failure of the core area to protect as many fernbirds as anticipated justified the additional costs involved in carrying out the eradication on Putauhinu, and the transfer of fernbirds to Putauhinu to establish a back-up population.

The three operations were successful largely due to the team approach used for the planning and field work, attention to detail by all personnel involved, forward planning, and using the information gained from previous eradications. The Island Eradication Advisory Group, a Departmental peer review group, ensured that these vital actions all occured.

The eradication of Pacific rat removes the last introduced predator on Codfish Island following the removal of Stewart Island weka *(Gallirallus australis scottii*) in 1984 and brushtail possum (*Trichosurus vulpecula*) in 1987 (A. Cox pers. comm.).

The removal of Pacific rats will allow greater regeneration of a number of trees, shrubs and herbs, including some rare species, which up until now were in part at least limited by rat predation of seed and seedlings (B. Rance pers. comm.). A range of both terrestrial and small seabirds will also benefit substantially from the removal of the sole remaining introduced predator, and it is predicted that their populations will increase significantly. Seabirds, eliminated by the rats and other predators, may naturally recolonise Codfish Island from neighbouring islands. Broad-billed prion (*Pachyptila vittata*) have been found in burrows on Codfish Island in 1999 (D. Scott pers. comm.), the first occurrence in over 60 years (M. Imber pers. comm.).

The removal of Pacific rats will allow the reintroduction of a number of terrestrial bird species presumed to have been eradicated by the rats, including robins (*Petroica australis*) and saddlebacks (*Philesturnus carunculatus*), and the introduction of other endangered species not previously found on the island but which require a safe haven, for example Campbell Island teal (*Anas nesiotis*). The removal of rats will also allow the resident impoverished invertebrate, reptile and small bird populations to recover. This programme has also created opportunities for introducing to Codfish Island threatened flora and fauna from other islands in the Titi Islands group, many of which hold remnant populations of threatened and endangered species (e.g. cloudy gecko (*Hoplodactylus nebulosus*)).

The next challenge is to ensure that these islands remain rodent free. Appropriate quarantine will require even more dedication than the eradications as it has to go on indefinitely with none of the glory or recognition of carrying out a successful eradication. The muttonbirders on Putauhinu have realised the value, both economically and to conservation, of having a rat-free island and are a leading example of rodent quarantine on a privately owned island. As Codfish is staffed and access is controlled by permit, quarantine is able to be strictly enforced, with strict standards being set for all visitors. Compared to Codfish, Rarotoka is relatively easy to access, is not inhabited, and hence presents a greater quarantine risk that will be managed by the owners with advice from DOC.

The eradication debriefs recommended that among other things:

1 The Department set up a national mechanism to record changes of bait and toxin formulation, so that managers can more readily attribute failure of any operation to a specific cause. This may be achieved by having a single national contact with toxin and bait suppliers and not accepting non-standard baits.

2 Managers do not set unrealistic goals as far as weather forecasting is concerned, as even Agtech bait lasted far longer than anticipated. However, there must be confidence that significant rainfall will not occur.

3 Detailed monitoring of potential non-target species in future operations should only occur when that species is at risk at population level and has not been monitored as part of a previous operation.

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