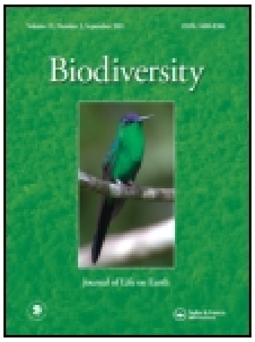

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Beyond Kapiti - A decade of invasive rodent eradications from New Zealand islands

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Abstract. New Zealand, an archipelago of more than 2000 islands, has a terrestrial fauna especially depauperate in native land mammals. Kiore (*Rattus exulans*) was the first of four rodent species introduced by people. A project to eradicate invasive rats from Kapiti Island in 1996, represented a turning point in the technology, complexity and scale at which managers of natural heritage on New Zealand islands could operate. This paper includes case studies of some significant projects targeting rodents, sometimes with other introduced mammals, undertaken in the 12 years following Kapiti. Details of the methods, costs, results and outcomes are provided for Kapiti, Whenua Hou, Tuhua, Campbell, Raoul, Hauturu, Taukihepa, and Pomona islands, collectively representing a total of over 23,000 ha of habitat cleared of introduced mammals. Research and trials undertaken in the Kapiti project provided the basis for future environmental risk assessments, allowing other projects to focus on knowledge gaps. New trends in invasive species eradication in New Zealand include more challenging multi-species eradication projects, some of which are undertaken by self- funded community groups. To summarise the lessons of the New Zealand experience: a programmatic approach is recommended which will fit each eradication within a context or framework of goals for those islands; address biosecurity issues at the outset; build capability to attempt the most challenging and rewarding projects; facilitate investment in monitoring and manage expectations of stakeholders to ensure their ongoing support. Success breeds success but is never guaranteed.

Keywords. New Zealand, islands, eradication, invasive alien species, island restoration.

INTRODUCTION

New Zealand, the last sizeable place humans colonised on earth, is an archipelago of more than 2000 islands with a terrestrial fauna especially depauperate in native land mammals (Diamond 1990). Polynesians, like other colonising people, carried commensal species to New Zealand that became invasive. The first of these was the kiore or Pacific Rat (*Rattus exulans)*, which arrived in about 1280 AD (Atkinson 1985; Wilmshurst *et al*. 2008).

Invasive species, particularly introduced mammals, impacted New Zealand ecosystems severely. Over half of the endemic bird species have disappeared since human arrival. Today threatened species of plants and animals number in the thousands (Anon. 2000). Management of invasive animals initially focussed on those species perceived to be particularly damaging to economic values (Parkes and Murphy 2003). Rodents, which largely affected biodiversity, were perceived as impossible to eradicate as recently as 30 years ago (Yaldwyn 1978). However, rat population control measures undertaken to protect seabirds on very small islands sometimes succeeded in eradicating the rats (Moors 1985).

Early attempts at further ground-based rodent eradications became more successful with the development of second generation anticoagulant toxicants (Thomas and Taylor 2002). The next shift in rodent eradication technology came with the use of aircraft to spread the poison bait. Navigational guidance followed, using a global positioning system (GPS) to enable aircraft to distribute poison bait over larger and more rugged islands without leaving gaps in the coverage (Towns and Broome 2003).

A project to eradicate invasive rats from Kapiti Island (1965ha) in 1996, represented a turning point in the technology, complexity and scale at which managers of natural heritage on New Zealand islands could operate (Towns and Broome 2003). Following Kapiti many other successful eradication projects have been completed. Here I present case studies of some significant projects targeting rodents undertaken in New Zealand during the period 1996 to 2007; how they were done, how each contributed to our knowledge and confidence to attempt more, and how each island has changed since rodents were eradicated. The case studies presented here are intended to complement and update earlier reviews (e.g., Thomas and Taylor 2002; Towns and Broome 2003; Howald *et al.* 2007) by providing more detail on individual project methods and outcomes.

ISLAND STUDY SITES

All of the projects described were successful at first attempt. Each project was planned with the help of people involved in previous eradication projects so that the collective experience and knowledge available to each project manager grew rapidly. Result monitoring was generally undertaken two years after the poison baiting. This in theory allows time for survivors to breed up to detectable numbers. Table 1 provides the details of the methods used in each project. Table 2 provides an estimate of the costs. These varied widely due to the variation in logistical constraints and supporting research, non-target mitigation and monitoring undertaken.

Kapiti - *Rattus norvegicus* and *R. exulans* eradication - 1996

Kapiti Island, at the western entrance to Cook Strait, is one of New Zealand's best known island nature reserves and has a long history of restoration and introduced animal removal since it was first reserved as a bird sanctuary in 1897 (Cowan 1992). Once trappers removed the last Possum (*Trichosurus vulpecula*) from Kapiti in 1986 only two species of introduced rats remained as invasive mammals (Ibid.). Forest vegetation began to recover but Norway Rats (*Rattus norvegicus*) in particular affected threatened birds such as Saddleback (*Philesturnus carunculatus*; Lovegrove 1996) and Kaka (*Nestor meridionalis*; Moorhouse 1991).

Kapiti was seven times larger than any previously attempted rat eradication in New Zealand although Norway Rats had been successfully eradicated from 3100ha on Langara Island in Canada in 1995 using bait stations (Thomas and Taylor 2002). Simultaneous eradication of two species of rats paved the way for subsequent projects with substantial monitoring of non-target forest bird species, captive management of Weka (*Gallirallus australis*) and Robins (*Petroica australis*), and monitoring of fish in the adjacent marine reserve. It also demonstrated that islands with several buildings and some permanent human inhabitants could be cleared of rats. Navigational guidance was an essential component in the technology deployed on the Kapiti project due to the size and terrain of the island.

Whenua hou (codfish island) -
***Rattus exulans* eradication - 1998**

Whenua Hou off the coast of Stewart Island was the next major step forward. Weka were eradicated by 1985 and Possums by 1987. Thirty endangered Kakapo (*Strigops habroptilus)* were moved to the island between 1987 and 1992 to avoid threats from feral cats, which devastated the Stewart Island populations (Kakapo Management Group 1996). By then the only remaining invasive mammal on Whenua Hou was Kiore which did not pose a great threat to adult Kakapo, but they were known to prey on eggs and chicks (Ibid.).

Critical risks and knowledge gaps had to be resolved before the eradication of rats could be safely attempted on Whenua Hou. One potential risk was to kakapo. These birds did not appear interested in the poison baits but due to their critically threatened status, no chances could be taken and they were moved to another island. The island was also a stronghold for threatened endemic lesser Short-tailed Bats (*Mystacina tuberculata*) which were potentially at risk from poisoning (Lloyd 2005). In order to mitigate the potential loss of bats from poisoning, about 400 were taken into captivity (Sedgeley 1998 in McClelland 2002). Short-tailed Bats had only rarely been handled and held in captivity for long periods. Captive facilities were established and techniques trialled before the eradication project went ahead.

An endemic sub-species of Fernbird (*Bowdleria punctata stewartiana*) occupied swampy habitat on the island and preliminary trials presenting baits to a closely related species on the mainland resulted in high mortality (McClelland 2002). Mitigation of detrimental effects of the rat eradication on Fernbirds was approached in three ways. Firstly the 37ha core area of Fernbird habitat was excluded from aerial baiting. Instead, once further testing illustrated that Fernbirds were reluctant to enter bait stations (Russell and Parker 1997 in McClelland 2002), these were established throughout the core area. Secondly, the feasibility of holding Fernbirds in captivity until the poison baits had disintegrated was trialled. However this study identified problems with holding large numbers of birds for the required length of time. Thirdly, new rodent-free habitat for Fernbirds was created by eradicating Kiore from the nearby island of Putauhinu (144ha) (McClelland 2002). An added precaution was the choice of bait formulation known as ‘Ag-tek’. This bait was known to break down more readily in rainfall than other types, thereby reducing the time it was available to non-target species.

Figure 1.
Campbell Island teal transfer, Southern Islands Area. Peter McClelland releasing two Campbell Island teal, September/ October 2004. Photographer: Gummer, Helen. Crown Copyright: Department of Conservation Te Papa Atawhai.

A further logistical obstacle was safe storage of the poison bait on site until fine weather allowed it to be sown. This problem was resolved with tents erected over the pallets of bait on the loading zone. Staff camped nearby as ‘bait minders’ ensured the weather tightness of the tents during bad weather and opened up the tent walls on fine days to reduce condensation and humidity.

Tuhua (mayor) - *Rattus norvegicus*
and *R. exulans* eradication - 2000

Tuhua Island is a basaltic volcano about 26km off the Bay of Plenty coastline. The island has forest, substrate and topography that resembles the more logistically challenging Raoul Island in the Kermadec group. For these reasons, Tuhua was used as a trial for eradication techniques proposed for Raoul. Like Raoul, Tuhua was inhabited by Norway Rats, Kiore and cats.

The key question for the Tuhua project to answer was: what effect would poisoning rats have on the cat population? Cats were known to die from secondary poisoning by eating poisoned rats and, in theory, survivors would become easier to trap once their rodent prey had gone. The population effect of secondary poisoning was unknown and therefore the scale of the follow-up trapping required to eliminate surviving cats on Raoul was difficult to estimate. A previous trial to answer this question had been confounded by rabbits present on the island (Dowding *et al*. 1999).

Table 1. Method detail for island eradication project.

Year of operation	Island (location)	Area	Target species	Bait[1]	Nominal sowing rate 1st application Kg/ha	Nominal sowing rate 2nd application Kg/ha	Swath overlap	Aircraft	GPS system used	Result	Comment
1996	Kapiti (40°51'S, 174°55'E)	1965	Norway rat & kiore	Talon 7-20 16mm	8kg/ha on 19/20 September 1996	8kg/ha on 16 October 1996	14% (20m)	1x Aerospatiale SA 315 'Llama'	Trimble (portable base station)	Eradication confirmed.	23ha spread by hand
1998	Whenua Hou (Codfish) (46°46'S, 167°38'E)	1396	kiore	Agtech 12 mm	8kg/ha on 18 August 1998	8kg/ha on 27 August 1998	20%	1x MD500D Hughes & 1 Bell 206 Jetranger. (2nd drop used 1 Jetranger)	Trimble (portable base station)	Eradication confirmed.	37 ha with bait stations. Extra bait spread on cliffs
2000	Tuhua (Mayor) (37°17'S, 176°15'E)	1277	Norway rat, kiore & cat	Pestoff 20R 12mm	8kg/ha on 10 September 2000	4kg/ha on 27 September 2000	22%	1x Bell UH1H Iroquois 1x Bell 206 Jet Ranger	Del Norte (portable base station)	Eradication confirmed.	Extra bait spread on cliffs. Paper bags of bait dropped on rock stacks
2001	Campbell (52°32'S, 169°12'E)	11300	Norway rat	Pestoff 20R 16mm	8kg/ha over 11 days 2nd to 22nd July 2001	No 2nd drop	50%	3x Bell 206 Jet Ranger AS350 Squirrel in support	Trimble (portable base station)	Eradication confirmed.	Extra bait spread on cliffs
2002	Raoul (29°16'S, 177°56'W)	2941	Norway rat, kiore & cat	Pestoff 20R 10mm	8kg/ha on 4th July 2002	5kg/ha on 8th July 2002	50% & 25%(2nd drop)	2x Bell UH1H Iroquois	Del Norte (portable base station)	Eradication confirmed.	Extra bait spread on cliffs
2004	Hauturu (Little Barrier) (36°12'S, 175°05'E)	3083	kiore	Pestoff 20R 10mm	8kg/ha on 8 & 9 June 2004	4kg/ha on 12 July 2004	50%	3x AS350 Squirrel	Trimble (portable base station)	Eradication confirmed	Extra bait spread on cliffs. Paper bags of bait dropped on rock stacks
2006	Titi Islands: Taukihepa (Big South Cape) Rerewhakaupoko, Putauwaka, Mokonui (47°14'S, 167°25'E)	939 26 3 66	Ship rat Ship rat Ship rat kiore	Pestoff 20R 10mm	8kg/ha on 14 July 2006	4.5kg/ha on 28 July 2006	50%	2x Bell 206 Jet Ranger	Trimble (portable base station)	Eradication confirmed.	3 of the islands within rat swimming range so treated as one unit.
2007	Pomona Rona (45°29'S, 167°32'E)	262 60	Ship rat, mice, possum, stoat & deer	Pestoff 20R 10mm	8kg/ha on 8 July	4.5kg/ha on 18 August.	50% & 25%(2nd drop)	1x Bell 206 Jet Ranger	Trimble (portable base station)	Eradication confirmed	Deer shot, stoats and possums trapped prior to rodent poisoning

[1] Trade names of the baits are given. All contain brodifacoum at 20ppm as the active ingredient.

Another logistical aspect to this operation was the lack of suitable bait loading sites on the island. The options for addressing this issue were:

- Clear an area of forest on the island to allow helicopters to land and load safely.
- Use a barge pulled up on the one beach as a loading platform.
- Load the helicopters and fly the 26km from the mainland with each bucket load.

Option 3 was chosen using Bell UH1H 'Iroquois' helicopters which could carry 1300kg payloads. Besides eliminating the need for forest clearance on the island this overcame any need to ship baits and allowed truck mounted machinery to efficiently load the large helicopter buckets. A loading site overlooking the coast meant the helicopters could take off with maximum payload.

The Tuhua project also included close community involvement. Although this approach is more common in New Zealand today, in the late 1990s eradication projects were more often attempted by the Department of Conservation (DOC) staff on island nature reserves that they administered. Tuhua is administered by the Te Whanau A Tauwhao ki Tuhua Trust Board. This meant that the eradication project and, more broadly, the restoration of the island biodiversity, was a partnership approach from its very inception. The Trust board was integrally involved in the planning and fieldwork associated with the project.

Campbell - *Rattus norvegicus* eradication - 2001

Planning for Campbell Island was undertaken concurrently with that for Tuhua. Campbell was a huge step up in the logistical difficulties of rat eradications but had comparatively fewer non-target issues to deal with than Kapiti or Whenua Hou. The primary challenges of Campbell were scale and weather. At four times the size of any island hitherto attempted for rodent eradication, Campbell was made all the more daunting because of its location in the Southern Ocean, 700km south of mainland New Zealand.

In order to avoid the summer breeding of seabirds on the island and to target the rats at a time of least alternative food sources, the operation was designed for late winter, a difficult time for helicopter operations. To meet the constraints of scale and weather the Campbell project team developed a multi-day baiting method. This allowed for weather delays, made efficient use of suitable weather when available, and required a realistic number of people and total time to complete the fieldwork. A non-toxic bait trial in 1999 played an important part in reducing uncertainties around the eradication design.

Large baits were used because these had longer life in damp conditions (see Table 1). The baits were spread in a single application, unlike on previous large islands which had two separate applications. To offset the risk of leaving gaps in the baiting coverage, the flight lines preloaded into the helicopter GPS were spaced closer than normal to allow an overlap in swath of fifty percent. This meant calibrating the sowing bucket to deliver 3kg/ha. After the second pass of the helicopter overlapped the first pass by 50% the required rate of 6kg/ha was laid on the ground. This comparatively low sowing rate was trialled using biomarker in non-toxic bait and found to have reached all rats examined in the 600ha trial area.

To make best use of available flying conditions the three helicopters worked from mobile loading sites to which bait was transported from a central supply as required by a fourth helicopter. The project team took any opportunity of suitable weather to lay bait. Whenever the edge of the baited area (the 'rolling front') remained static for more than two nights, extra bait was laid along the front of the previously sown area when flying resumed to mitigate against rats crossing the front into an area of weather-destroyed bait.

The storage and transport of bait was another challenge for the project. No suitable storage facilities were available on the island and tents such as those used on Whenua Hou would not last in the winter weather at 52˚S. Bait was packed into purpose built waterproof plywood boxes, each holding 750kg, which could be packed into the ship's hold efficiently and lifted by helicopter. They were used as a portable loading platform by strapping four together on site. Empty boxes could be collapsed and retrieved efficiently.

The Campbell project was unique for the interest it generated among government policy makers. DOC was given a 'Public Service Innovation' award for the project, although the project team felt that they were not doing anything untested or particularly new (Wright and de Joux 2003). Some team members felt the real innovation lay in their success in gaining the confidence of Government ministers and officials to fund the project.

Raoul - *Rattus norvegicus* and *R. exulans* eradication - 2002

Raoul Island is the largest of the Kermadec group. At 1050km northeast of the North Island it is the most remote New Zealand island. Restoration of Raoul Island nature reserve began with the eradication of goats from the island which was completed in 1984 (Parkes 1990). Several invasive plant species have been targeted for eradication for many years using DOC staff in partnership with a large group of volunteers (West 2002). With goats gone, an eradication project was designed to target the last three species of invasive mammals remaining (Norway Rats, Kiore and Feral Cats) in the winter of 2002.

The challenges for Raoul once again lay in the logistics of working on a relatively large and distant island. At 29˚S the weather on Raoul is less challenging than on Campbell in the Southern Ocean but there is no safe ship anchorage. Bait was loaded into steel shipping containers at the poison factory, trucked to the port of departure (Auckland), and loaded onto a 345 tonne motorised sand barge without need for further handling. This system ensured good weather protection on the voyage and reduced the biosecurity risk of introducing new pests to the island among the pallets of bait. On arrival at Raoul, unloading was achieved using a forklift to extract the 1100 kg pallets from the containers and helicopters to lift them ashore.

The eradication design specified that back up equipment should be available on the island to counter any equipment failure. This meant that a second helicopter was used even though the

Table 2. Island eradication project costs.

Island	Bait cost	Aircraft cost	Other costs	Comments	Total cost (actual)	Total cost 2009[1]	Cost per ha 2009 NZ$	Total cost 2009 USD[2]
Kapiti	110,000 (est [3])	31,000 (est)	395,000 (est)	Includes non-target mitigation & monitoring	536,000	714,500	$364	428,200
Whenua Hou (Codfish)	85,000	60,000 (est)	355,000 (est)	Includes non-target mitigation	500,000 (est)	646,500	$463	387,400
Tuhua (Mayor)	65,700	66,000	46,900	Includes salaries	178,600	227,700	$178	136,500
Campbell	336,000	1,000,000	1,184,500	Includes trial and result monitoring	2,520,500	3,118,000	$276	1,868,700
Raoul	210,000	376,000	613,000	Includes shipping and salaries	1,199,000	1,446,000	$492	866,600
Hauturu (Little Barrier)	210,000	88,000	452,000	Includes $200k consent costs	750,000	868,800	$282	520,700
Titi Islands Taukihepa (Big South Cape) Rerewhakaupoko, Pukeweka,Mokonui	66,000	37,500	146,000	Excludes Doc and owners' time	249,500	272,300	$258	163,200
Pomona Rona	23,500	13,000	25,000	Rodent component only. Includes monitoring	61,500	65,500	$203	39,200

[1] 2009 costs used NZ Consumer Price Indices to adjust actual costs www.statistics.govt.nz.
[2] Conversion to USD used the average exchange rate 1996 - 2009 NZ:US (0.6:1) www.treasury.govt.nz.
[3] Estimated values either used budgeted figures or extrapolated from quantities and approximate unit cost.

bait laying could have been achieved with one. Getting the two Bell UH1H Iroquois helicopters safely to Raoul required the fitting of long range fuel tanks and considerable planning to fly them there directly. This simplified the shipping requirements although it did raise concerns over the arrival time of the ship coinciding with that for the helicopters to allow efficient unloading.

The cat eradication component of the project was designed to capitalise on cat mortality caused by the rodent poisoning, which the Tuhua trial indicated would be substantial. Unlike on Tuhua, some cats survived the rat poison. A few probably succumbed to hand-laid cat baits containing 1080 and four were subsequently trapped over a long period, the last being in 2004. A dog trained to indicate the presence of cats was successfully used on two occasions and provided the impetus to continue the trapping effort when no other indications of remaining cats were evident.

A key aspect of the Raoul project was recognition that removing rodents might affect an ongoing weed eradication programme. A risk assessment identified that Wild Grape Vines (*Vitis vinifera*) at several locations on the island might produce viable seeds in the absence of rats, and be dispersed by birds. To eliminate this risk all known grape plants were removed.

Hauturu (Little Barrier) - *Rattus exulans* eradication - 2004

Hauturu or Little Barrier Island is, like Kapiti, a nature reserve island well known to New Zealanders as a refuge for rare native species. Feral cats were eradicated by 1981 (Veitch 2001) leaving Kiore as the remaining invasive mammal on the island. There was some evidence that the removal of cats had resulted in increased abundance of Kiore on the island which was affecting native species, particularly Cook's Petrel (*Pterodroma cookii*) (Imber *et al*. 2003; Rayner *et al*. 2007).

Hauturu is heavily forested and extremely rugged. Many of the techniques used successfully on previous eradication projects were incorporated into the design of the Hauturu project. For example, bait was containerised and barged as used for Raoul; bait was stored on the island under a tent as used for Whenua Hou; rock stacks nearby were treated using bait thrown from the helicopter by hand as used on several other projects. Steep slopes and the coastal margin were treated twice during each bait application, by this time considered standard practice.

Titi Islands (Taukihepa, Pukeweka, Rerewhakaupoko) - *Rattus rattus* and Mokonui *R. exulans* eradication - 2006

The Titi islands off the south western coast of Stewart Island were attempted in 2006 at the request of the local Maori owners who formed a trust 'Ka Mate Nga Kiore' (which roughly translates as 'death to the rats') to receive funding for the project from the 'Command' oil spill. On September 26, 1998, the tanker 'Command' released about 11,000 litres of fuel oil which washed ashore over 24km of California beaches, primarily in San Mateo County. Large numbers of seabirds were injured or killed including Sooty Shearwaters or 'titi' (*Puffinus griseus*) which migrate to California after breeding in New Zealand. One of the Sooty Shearwaters picked up was banded on Whenua Hou.

In 1999 the United States Attorney's Office announced it had agreed to settlement terms with those responsible for the spill. Over four million US dollars was paid in damages for natural resource injuries resulting from the incident. Approximately US$2,850,000 was identified for use on seabird restoration projects. The Titi islands project was one of those approved (http://www.darrp.noaa.gov/southwest/command/settle.html).

Taukihepa or Big South Cape Island, was invaded by Ship Rats (*Rattus rattus*) in the early 1960s. Wildlife biologists documented this event when visiting the island in 1964, soon after rats had arrived. Three species or subspecies of birds and one species of bat went extinct on the island as a consequence of the rat invasion (Bell 1978). Removing rats from the Titi islands would allow the restoration of the island as well as enhance the breeding success of nesting seabirds like the sooty shearwater. The project was notable not only for its unusual source of funds but also because its impetus came from local people with traditional titi harvest rights to the islands. DOC provided expertise to plan and implement the project.

A technical challenge in the design of the eradication was the small islands of Pukeweka and Rerewhakaupoko which are within swimming distance of Taukihepa and also had Ship Rats. To eliminate this obvious biosecurity risk the project included the eradication of rats from all three islands and the rock stacks associated with them. A fourth island Mokonui or Big Moggy was included as it had Kiore which were affecting the island ecosystem.

Another challenge was the large number of dwellings on the island used seasonally by the bird harvesters. Every structure had to be mapped and baited systematically by a ground-based team.

Pomona - *Rattus rattus* and *Mus musculus* eradication - 2007

Pomona Island in Lake Manapouri, is New Zealand's largest inland island. It formed the basis of a community-driven restoration project involving multiple pest eradications. Besides rodents, Stoats (*Mustela erminea*), Possums and Red Deer (*Cervus elaphus*) were targeted for eradication. By 2005, community led multi-species eradication projects were becoming popular on mainland sites which could be fenced from invasive animals. The Pomona Island Charitable Trust chose Pomona and nearby Rona Island to stage their biodiversity restoration efforts.

Pomona is 450m from the mainland at its closest point which is within swimming range of stoats and possibly two species of rats. This provided a new management challenge of detecting and eliminating individuals able to swim to the island in the years after the eradication was complete as well as implementing effective quarantine to prevent pests being taken to the (unrestricted access) island by visitors.

OUTCOMES

KAPITI

Saddlebacks were once widespread throughout New Zealand but declined quickly following the arrival of Europeans. This decline is attributed to their vulnerability to predation from introduced mammals, particularly Ship Rats, although Saddlebacks seem to have coexisted with Kiore for several centuries (Lovegrove 1996). North Island Saddlebacks were translocated to Kapiti in large numbers between 1981 and 1990 while Kiore and Norway Rats were present. However most of the 366 released had died out by the time translocations stopped in 1990 (Lovegrove 1996). Ten females may have been present on Kapiti by the time rats were eradicated in 1996. Monitoring showed no significant population decline of Saddlebacks over the period poison baits were on the island and numbers rapidly increased afterwards (Empson and Miskelly 1999; Miskelly and Robertson 2002). Casual observations of Saddlebacks on Kapiti in 2009 suggest that the population has continued to expand (C. Giddy pers. comm.).

North Island Kokako (*Callaeas cinerea wilsoni*) are highly vulnerable to egg and chick predation from Ship Rats. Small numbers of birds were translocated to Kapiti from remnant populations on the mainland from 1991 (Brown *et al*. 2004). By 1996 13 birds were able to be monitored. Two of these were presumed poisoned as they disappeared after the bait was laid (Empson and Miskelly 1999). The total Kokako population on Kapiti today is unknown and confounded by further translocations, but studies of nesting success between 1997 and 2002 recorded 29 fledglings from 40 nesting attempts (73%) (Brown *et al.* 2004). At least 16 pairs of birds were known by 2006 (www.kokakorecovery.org.nz).

Red-crowned Parakeet (*Cyanoramphus novaezelandiae*) are rare on mainland New Zealand yet abundant on many offshore islands lacking introduced predators (Greene 1998). Monitoring on Kapiti pre- and post-eradication in 1996 detected no significant population decline. Repeat monitoring undertaken between 1999 and 2002 showed a spectacular increase in abundance (or at least conspicuousness) compared with pre-eradication data with birds now commonly seen feeding on the ground (Miskelly and Robertson 2002).

Kaka (*Nestor meridionalis*) studied prior to the eradication often nested within one metre of the ground and half of the

Figure 2.
Giant Weta on a hand, Little Barrier Island, Photographer: Veitch, Dick. Crown Copyright: Department of Conservation Te Papa Atawhai.

monitored nests at these sites were destroyed by Norway Rats (Moorhouse 1991). A sample of 20 birds carried radio transmitters through the period of the eradication, four of which were known to have died. Kaka are now abundant on Kapiti and are seen in large flocks (C. Giddy pers. comm.).

The threatened Honeyeater Hihi or Stitchbird (*Notiomystis cincta*) had significantly higher survival rates in 1997 post-eradication than in the previous five years (Empson and Miskelly 1999). In the absence of rats, Lesser Short Tailed Bats were successfully translocated to Kapiti in 2005 (Ruffell and Parsons 2009).

Vegetation plots to monitor changes in seedling abundance two years before and two years after the rat eradication showed significant changes in almost all species measured but the lack of a non-treatment area hampered interpretation of results (Campbell 2002).

Whenua Hou

Before the eradication of Kiore in 1998, attacks on Kakapo chicks and eggs by rats were prevented only through intensive nest management.Management tactics included Kiore scaring devices deployed by nest minders who sat through the night watching video surveillance of nesting birds. All but two Kakapo were caught prior to the eradication and transferred to another island. The remaining birds survived unharmed (P. McClelland pers. comm.). Whenua Hou is now the centre of Kakapo recovery. In 1995 the total world population known stood at 51 birds. As of June 2009 there are 125 birds in existence, most of which live or have come from Whenua Hou.

Cook's Petrels on Whenua Hou were estimated to occupy more than 20,000 burrows in 1934 but were approaching extinction by 1982 (Imber *et al*. 2003). The sequential removal of Weka (1985), Possum (1987) and Kiore progressively lead to improved breeding success with more than 1000 breeding pairs by 2003 (Ibid) and an estimated 5000 breeding pairs by 2008 (Rayner *et al*. 2008).

Fernbirds appeared to suffer heavy mortality from the rat poisoning as few were recorded on the island in the two years following the eradication (McClelland 2002). However the population has recovered in the absence of rats and they now occupy all of their former range on the island and new sightings in tall forest (considered marginal habitat for this species) have lately been recorded. The birds translocated to Putauhinu Island have established and bred (P. McClelland pers. comm.).

Monitoring of the Lesser Short-Tailed bat population following the eradication showed no observable population effects from the poison baiting. Of the 400 animals held in captivity during the operation, 350 survived to be released back on Whenua Hou (Sedgely and Anderson 1998 in McClelland 2002).

Tuhua

The dawn chorus of birdsong on Tuhua is said to be "already returning" with North Island Robin, Kaka and Bellbird (*Anthornis melanura*) regularly seen and heard on the island. Many species rare on mainland New Zealand have been released on Tuhua with the support of the Tuhua Trust Board. Translocated species include North Island Brown Kiwi (*Apteryx mantelli*) in 2006 and again in 2009, and Pateke or Brown Teal (*Anas chlorotis*) (Department of Conservation 2009). Tuatara (*Sphenodon punctatus*: Sphenodontia) are medium sized reptiles (up to 1kg) that had not been seen on the island since the early 1900s. They were reintroduced in 2007 (Department of Conservation 2007).

Campbell

Campbell Island Teal (*Anas nesiotis*) were rediscovered on Dent Island (23ha) off the coast of Campbell Island in 1975 (Williams and Robertson 1996). Reintroductions of teal from both captive-bred and wild birds to Campbell Island following the successful eradication of Norway Rats have led to a viable breeding population requiring no further management.

In a similar situation to Campbell Island Teal, a genetically distinct species of Sub-Antarctic Snipe (*Coenocorypha* spp.) was discovered in 1997 on the (introduced) predator-free Jacquemart Island (19ha) which lies off the southern coast of Campbell Island. The first evidence of recolonisation by snipe was detected on Campbell two years after the 2001 rat eradication, likely from Jacquemart. A 2006 survey of 40ha on Campbell Island estimated at least 22 birds were present and breeding (Miskelly and Fraser 2006). Other observations recorded the recolonisation of Campbell by Auckland Island Pipit (*Anthus novaeseelandiae aucklandicus*) (Thompson *et al*. 2005) and Grey-backed Storm Petrels (*Garrodia nereis*) (Miskelly and Fraser 2006).

Raoul

The eradication of rats and cats from Raoul Island has lead to dramatic changes in the bird and plant life on the island. Compared with the nearby rat-free Meyer and Herald Islets (51ha) the fauna of Raoul was relatively depauperate with introduced Blackbirds (*Turdus merula*) and Native Tui (*Prosthemadera novaeseelandiae*) the most common birds recorded (Veitch 2003). Although collectively less than 2% the size of Raoul, birdlife of the Meyer and Herald Islets includes Masked Boobies (*Sula dactylatra*), White Capped Noddies (*Anous tenuirostris*), Red-tailed Tropicbirds (*Phaethon rubricauda*) and Kermadec Parakeets (*Cyanoramphus novaezelandiae cyanurus*), all of which were not recorded on Raoul in the decade before the eradication. Species observed on Raoul since the rat eradication include small breeding colonies of Wedgetailed Shearwaters (*Puffinus pacificus*), Black Winged Petrels (*Pterodroma nigripennis*) Red-tailed Tropicbirds and an abundance of Kermadec Parakeets. Within 18 months following the eradication, staff observed Kermadec Parakeets breeding on Raoul for the first time since 1836. This was confirmed by researchers in 2009 (Ortiz-Catedral *et al*. 2009).

Since 2002 the Tui population on Raoul has undergone a series of population booms followed by crashes as they have presumably outstripped their food supply (M. Ambrose pers. comm.). This phenomenon had not been recorded on Raoul previously but it may have been difficult to observe with rats scavenging Tui carcasses as they fell to the forest floor. Sooty Terns (*Sterna fuscata*) were historically abundant on Raoul with a breeding colony of several thousand birds recorded in Denham Bay by the 1967 scientific expedition to the island (Veitch *et al*. 2004). By the late 1990s the terns had all but gone but populations are now beginning to expand again (Ibid; C. West pers. comm.).

Vegetation changes following rat eradication have recently been studied. The most noticeable changes observed on the island are Kermadec Nikau (*Rhopalostylis baueri var cheesemanii*) seedlings which have increased 100 fold in one forest plot. Many plots recorded a more diverse forest floor with fungi, bryophytes and small ferns noticeably more common in 2008 than prior to 2002 (C. West pers. comm.).

Hauturu

Hauturu Island is the world's stronghold for Cook's Petrel. The only other significant population is on Whenua Hou. Cook's Petrel breeding success was studied on Hauturu between 1972 and 2007 (Imber *et al*. 2003; Rayner *et al*. 2007). Although cat predation was readily observable during the 1970s, there was little evidence of cats affecting the actual breeding success in comparison to losses of eggs and young chicks attributed to Kiore (Imber *et al*. 2003). Following the eradication of cats in the 1980s, Cook's Petrel breeding success actually declined slightly in the presence of Kiore alone (Rayner *et al*. 2007). At high altitude study sites breeding success averaged 0.05 chicks per burrow for two seasons immediately prior to the eradication of Kiore in 2004. However, it climbed significantly to an average of 0.59 chicks per burrow over the three breeding seasons 2005-2007 (Ibid.).

Tuatara failed to respond to the removal of cats from Hauturu in the early 1980s and by 1992 only eight adults could be found. These were all transferred into rat-proof pens on the island where they could breed, without predation of eggs by Kiore (Biodiversity Recovery Unit 2001). Since Kiore were eradicated, captive bred Tuatara have been released into the wild on the island and the breeding programme is no longer needed.

Vegetation monitoring undertaken on Hauturu before and after the Kiore eradication showed significant increases in abundance of seedlings for 13 species of native plant when compared with changes modelled from plots on islands where rodents remain (Campbell 2009). The most significant increase observed was for Parapara (*Pisonia brunoniana*) which had over 2000 seedlings recorded on one plot in 2008 compared with none recorded on this plot in 2004 (Ibid.).

Wetapunga (*Deinacrida heteracantha*) is the largest of the endemic Giant Weta in New Zealand. Although once thought to be widespread in northern New Zealand their contemporary range is restricted to Hauturu (Sherley 1998). Surveys undertaken prior to the rat eradication in 2004 found very few animals despite substantial search effort (Meads and Notman 1995). Monitoring of Wetapunga in the five years following the eradication has found a doubling of encounter rates since 2005 (C. Green pers. comm.).

Taukihepa

Changes on Taukihepa have not been recorded but Titi harvesters report a good season following the ship rat eradication in 2006 and a noticeable difference in the lack of nuisance rats infesting their houses and food supplies on the island (P. McClelland pers. comm.). Weka are known to be a significant predator of burrowing seabirds (Harper 2006). They are also vulnerable to the poison bait used to eradicate rats (Brown 1997; Empson and Miskelly 1999). However the mortality of Weka from poisoning during the Taukihepa rat eradication was unusually low, around 50% (D. Brown pers. comm.). This led to the abandonment of plans to eradicate Weka from Taukihepa immediately following the rat eradication project.

Pomona

The Pomona Island Trust have continued to maintain rat trapping on the island to intercept those animals swimming from the mainland. A decreasing number of rats have been trapped over the last three years. South Island Robins (*Petroica australis australis*) were successfully translocated to the island in 2009 and appear to have established. The Trust has future plans to release Saddlebacks and the endangered Mohua or Yellowhead (*Mohua ocrocephala*) (www.pomona-island.org.nz).

The Kiwi Recovery Group is using Rona Island as a crèche for Haast Tokoeka (*Apteryx australis lawryi*) an endangered sub-species of kiwi. Eggs taken from the wild are hatched in captivity and the offspring released on predator free 'crèches' until they grow to a size which allows them to defend themselves against predators and can be returned to their mainland habitat.

Figure 3.
Tuatara male, *Sphenodon punctatus*, on Cuvier Island, 1980s. Photographer: Veitch, Dick. Crown Copyright: Department of Conservation Te Papa Atawhai.

Figure 5. Cook's Petrel, *Pterodroma cookii*, Little Barrier Island, 1980s. Photographer: Veitch, Dick. Crown Copyright: Department of Conservation Te Papa Atawhai.

DISCUSSION

The New Zealand experience in island restoration through eradication of invasive rodents has been profoundly positive over the 12 years since completion of the Kapiti Island project. In 1996 Kapiti was nearly seven times larger than any New Zealand island previously attempted, and as such represented 'shifting gear' in the technology for environmental management in New Zealand. Positive changes in population sizes, recruitment of resident species and recolonisation have commonly been observed. Furthermore, islands cleared of invasive mammals have been used for successful reintroductions of threatened species of reptiles, birds and bats. Environmental impact studies of the methods deployed to achieve rodent eradication seldom showed unpredicted population effects.

The projects that followed over the decade since Kapiti showed that a corresponding 'gearshift' in the associated project management and organisational support was also necessary. DOC developed a programmatic approach to island rodent eradications whereby future projects were identified well in advance and project teams pooled experience so that each successive project could build capability. A specialist technical support group, the Island Eradication Advisory Group, was established specifically to foster this expanding expertise and to develop national best practice (Cromarty *et al*. 2002; Broome *et al*. 2005). Research and trials undertaken in the Kapiti project provided the basis for many future environmental risk assessments, allowing subsequent projects to focus on knowledge gaps rather than repeating the lessons of Kapiti.

With the benefit of hindsight, the programmatic approach worked well for knowledge- sharing among projects but could have worked better with earlier instigation and more strategic vision. Given these experiences, progress toward another leap in the scale of islands that could be attempted (islands in the 15-50,000 ha range), would need:

- Experiments on smaller islands to test ways of reducing the costs.
- Deployment of the best options on medium sized islands to prove the concept and fill information gaps.
- Progression to larger islands, beginning with those with fewest logistical and biological complications.

In reality almost every island eradication attempt over the last couple of decades has been pioneering a new scale or new logistical or biological challenge. This has led to a 'use what works' approach to the eradication design in order to minimise the risk of failure.

In recent years, the organisational confidence of DOC to attempt eradications has broadened to politicians and the wider community. This enthusiasm has led to new challenges when projects have high community and political support but also represent high risks of reinvasion or considerable ongoing maintenance costs. Examples include multi-species eradications on islands with open public access and within swimming range of some of those pests – exemplified by the Pomona project. In 2009 a multi-species eradication project began on Rangitoto and Motutapu Islands (3820 ha) close to Auckland city in the inner Hauraki Gulf (www.doc.govt.nz). This project takes all of the challenges of Pomona, increases the number of target pest species to seven, increases the scale by a factor of ten, and adds the complexities of 100,000 visitors per year and an operating farm park. Although very ambitious, each of the challenges taken in isolation has been overcome before on other sites and a comprehensive feasibility study preceded the decision to begin operational planning (Griffiths and Towns 2008). The results of this project will be known within the next few years.

The move toward treating islands where the biosecurity risks are high due to public visitation or where they are within swimming range of rats opens up new challenges and stretches the concept of eradication closer to the paradigm of mainland ongoing control. While these islands are undoubtedly less desirable than remote islands as eradication targets from a technical perspective, they do allow for more community involvement and an increased awareness of invasive species issues. They also present attractive alternatives to sustained mainland control which can be technically, logistically and politically difficult to sustain in the long term.

Despite the information provided in this paper and references cited, the outcomes for biodiversity as a result of removing the influence of invasive mammals have not been comprehensively measured for any of the case studies presented. Individual studies of the survival, breeding success or recolonisation of individual (usually threatened) species have been the priority. Social research on the changing perceptions and attitudes of stakeholders is also rare. Although limited resourcing for more comprehensive research is an obvious reason, it could be argued that a lack of clear, measurable goals for New Zealand islands is also a contributing factor (Towns *et al*. 2009). However limited monitoring and reporting of projects does not seem to be detrimental to political support for future projects. The relatively few concerns raised in public consultation are generally about direct impacts on non-target species.

RECOMMENDATIONS FOR FUTURE

If the New Zealand experience with rodent eradications on islands is to benefit other island management agencies, the following recommendations should be considered:

- The eradication of invasive species from islands should fit within a framework of goals for those sites. This would firstly provide context for the future management of biodiversity, biosecurity and human use and secondly establish incentives to measure progress toward those goals.
- The outcomes of each project and the whole programme should be monitored to allow the programme to adapt to new information. This knowledge should be freely shared to support other programmes.
- Biosecurity issues (e.g., reinvasion risks) should be addressed at the outset of the programme. This is the ongoing 'maintenance' cost which must be both efficient and effective in order to safeguard the 'capital investment' of eradication.
- A programmatic approach aimed at building capability should be developed. The most challenging and rewarding projects should be viewed as the final targets once capability is in place. This may mean that early in the programme, islands of low biodiversity significance are attempted as 'stepping stones' toward the higher priority islands. This development phase can be viewed as an overhead cost of the programme.
- Expectations of stakeholders should be managed to ensure their ongoing support. Success breeds success but is never guaranteed. The environmental impacts of the eradication must be weighed against the environmental benefits of success.

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Figure 6.
Helicopter bucket being loaded with Pestoff 20R poison bait at dawn? part of the Rat Eradication Programme, Campbell Island, 2001.
Photographer: Tyree, P. Crown Copyright: Department of Conservation Te Papa Atawhai.

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