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Authors
Broome, Keith
Murphy, Elaine
Cunningham, Celia
et al.

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New Zealand's Use of Brodifacoum in Eradication Efforts and Current Investigation of New Baits and Toxins

Keith Broome
Department of Conservation, Hamilton, New Zealand
Elaine Murphy
Department of Conservation, Christchurch, New Zealand
Celia Cunningham
University of Auckland, Auckland, New Zealand
Charles T. Eason
Department of Ecology, Lincoln University, Lincoln, New Zealand

ABSTRACT: Rodent eradication on islands has transitioned over 30 years in New Zealand through stages of initial scepticism, to early accidental and experimental successes, and now to the current bold large-scale aerial applications over increasingly large and complex island ecosystems. Starting in the 1970s and 1980s, gaining momentum in the 1990s, and continuing to the present day, islands once occupied by rodents are now being reclaimed. Until the mid 1980s, very few islands were entirely free of animal pests. Rodent eradication on islands, using bait in stations and baits applied from the air, has been spectacularly successful. To date, more than 90 islands around New Zealand have been cleared of rodents, and brodifacoum use has had an obvious benefit on valuable island ecosystems. The tactical use of toxic bait to protect island populations of indigenous birds, reptiles, and invertebrates endangered by rats and mice continues to be refined to enable larger and more complex islands to be cleared of rodents. New bait types that are especially attractive to mice as well as rats, long-life baits, new toxins, and tunnel delivery systems will augment existing bait types to aid future eradication programmes and help prevent re-invasions. New developments will need to be ethically and socially acceptable and demonstrate clear advantages in non-target impact as well as efficacy in achieving eradication. These endeavours are part of global efforts to eradicate invasives and manage islands to protect native birds and other important fauna and flora.

KEY WORDS: brodifacoum, eradication, invasives, island, new technologies, New Zealand, rodent control, rodents

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INTRODUCTION

There are four species of introduced rodents in New Zealand: kiore or the Pacific rat, (*Rattus exulans*), Norway rat (*Rattus norvegicus*), ship rat (*Rattus rattus*), and the house mouse (*Mus musculus*). The kiore is thought to have arrived in New Zealand around 1280 (Bellingham et al. 2010), whereas the other rodent species arrived with Europeans in the late 1700s to late 1800s (Atkinson 1973). Rodents can affect plant regeneration and consequently can change forest composition (Campbell and Atkinson 2002). On New Zealand's mainland, much of the native fauna and flora is threatened or has been greatly reduced due to the invasion of various mammals, including rodents (Towns and Broome 2003). Norway rats and ship rats have been responsible for reducing or causing local extinctions of seabirds (Bellingham et al. 2010), and there has been observed rat predation of eggs, chicks, and incubating adult birds (Towns et al. 2006). Rodents can also cause declines or extinctions in native invertebrates, lizards, and land birds (Towns and Broome 2003, MacKay et al. 2007).

Islands present a unique opportunity. If rodents can be eradicated from an island, native species can recover or be re-introduced to the area, and unlike the mainland, the likelihood of reinvasion is relatively small and controllable. This paper reviews the history of rodent eradications on New Zealand islands. New Zealand has gone through several phases over the decades, from initial scepticism about the possibility of even small-scale eradications in the pre-1970s (Clout and Russell 2006), to the successful eradications of rodents from large and complex islands in the 2000s. The four main phases are outlined in this paper, showing how the use of brodifacoum and other advancements have resulted in at least 90 successful island eradications in New Zealand to date (Table 1).

Table 1. Eradications of rodents from New Zealand islands up to 2007. Dates based on eradication completion or confirmation (Clout and Russell 2006, Broome 2009).

Decade	1960	1970	1980	1990	2000
House mice	0	0	1	11	3
Pacific rat	0	1	3	23	6
Norway rat	2	0	9	19	12
Ship rat	0	0	2	8	7
Total no.	***2***	***1***	***17***	***59***	***28***
Largest size (ha)	1	1	170	1,965	11,300
Technique	G	G T	G A	G T A	G A

G = Ground based poison, T = Trapping, A = Aerial spread

PHASE 1: SCEPTICISM

Wodzicki (1978) argued his belief that "possibilities for a complete extermination of New Zealand rodents by conventional control methods, even on islands, must be considered remote". The conventional control methods he referred to included first-generation anticoagulants such as warfarin and diphacinone, as well as trapping. This was an opinion generally shared by those working on rodent problems in New Zealand. At the closure of the 1978 Symposium on the Ecology and Control of Rodents in New Zealand Nature Reserves, Yaldwyn reiterated these sentiments, stating that "we have control methods for reducing populations, but complete extermination on islands is remote or at least a very very difficult thing indeed".

PHASE 2: EARLY EXPERIMENTAL AND ACCIDENTAL SUCCESS – THE TIPPING POINT

Despite sceptical attitudes towards rodent eradication still being prevalent in the late 1970s, there had already been successful eradications. The first recorded eradication of rodents in New Zealand was of Norway rats on Maria Island (1 ha) and the adjacent David Rocks Island (<1 ha), between 1959 and 1961, using a warfarin-based rodenticide. This eradication was not planned and was the unexpected result of attempts to protect white-faced storm petrels (*Pelagodroma marina*) on the island, using warfarin-based bait ground laid around petrel colonies (Moors 1985, Thomas and Taylor 2002, Towns and Broome 2003).

Anticoagulant rodenticides, such as the first-generation compound warfarin used on Maria and David Rocks Island, were deemed well suited for use in eradication attempts because symptoms do not occur until after many days of feeding. This reduces the chance of bait shyness and increases the chance that all rodents on the island will consume a lethal amount of toxin during the operation (Howald et al. 2007).

In the 1970s, Norway rats were eradicated on Titi Island and kiore eradicated on Lizard Island. Both eradications were the unexpected result of normal control

Table 2. Early, accidental and experimental rodent eradications on New Zealand Islands between 1960 and 1989. Data from Towns and Broome (2003) and Clout and Russell (2006).

Island	Start Date	End Date	Area (ha)	Species	Control	Comments
Maria	1960	1964	1	Norway	Hand laying of rid-rat warfarin baits	By-product of normal control
David Rocks	1960	1964	<1	Norway	Hand laying of rid-rat warfarin baits	Island adjacent to Maria, By-product of normal control efforts
Titi	1970	1983	32	Norway	Hand laying of prodide warfarin baits	By-product of normal control efforts
Lizard	1978	1978	1	kiore	Hand laying of commercial rat poison	By-product of normal control efforts
Motuhoropapa	1978		8	Norway	Snap-trapping	Reinvasion in 1979
	1981				1080 in oats & as paste, Talon 50 WB™ in bait stations & as 0.01% brodifacoum paste.	There have been five subsequent reinvasions, the last being in 2002 (Clout and Russell 2006)
Otata	1981		15	Norway	1080 in oats and cat food, 1080 as paste, brodifacoum as Talon 50 WB™	Testing eradication methods
Awaiti	1982	1983	2	ship	Talon 50 WB™ in bait stations	Reinvaded (Russell and MacKay 2005)
Tawhitinui	1982	1983	21	ship	Talon 50 WB™ in tunnels along tracks	Reinvaded (Russell and MacKay 2005)
Rurima	1983	1984	4.5	kiore	1080 & bromadiolone rodenticide in kibbled maize from bait silos	Testing eradication methods
Whenuakura	1983	1984	2	Norway, mice	Bromadiolone in bait stations	
Maukaha	1984	1984	0.2	Norway	Poison	
Hawea	1986	1986	9	Norway	Talon 50 WB™ in bait stations	Testing eradication methods
Motuterakihi	1985	1985	1	Norway	Poison	
Moutohora	1985	1986	143	Norway	Aerial spread of brodifacoum in Talon 20 P™ cereal baits	
Korapuka	1986	1987	18	kiore	One application of bromadiolone-impregnated toxic kibbled maize in silos	Improved on method used on Rurima
Takangaroa	1988	1988	6	Norway	Poison	
Breaksea	1988	1988	170	Norway	Talon 50 WB™ in bait stations, weatherproof bait stations positioned by helicopter on cliffs and offshore stacks	Improved confidence amongst administrators, conservation practitioners, politicians and the public" (Thomas and Taylor 2002)
Te Haupa	1989	1989	6	Norway	Poison	
Double	1989	1989	27	kiore	Poison	
Somes	1988	1990	32	ship	Poison	
Mokopuna	1988	1990	1	ship	Poison	
Mokoia	1989	1990	135	Norway	Poison	
Allports	1989	1991	16	mice	Brodifacoum Talon 50W™ bait	
Mana	1989	1991	217	mice	Bait stations on 25m grid and aerial application	(Thomas and Taylor 2002)
Rimariki	1989	1991	22	mice	Poison	
Motuopao	1989	1992	30	kiore	Bait stations on 50m grid	(Thomas and Taylor 2002)

efforts of rodents using hand-laid rat poison (Table 2) (Towns and Broome 2003). There was also an eradication of Norway rats from Motuhoropapa Island in 1978 using snap-trapping as part of normal control efforts, although this island was subsequently reinvaded (Clout and Russell 2006, Towns and Broome 2003)

Following these accidental eradications in the 1970s, a variety of successful eradications were deliberately planned and completed in the 1980s on small New Zealand islands (Table 2). Many of these operations used the newly available second-generation anticoagulant brodifacoum in bait stations (Towns and Broome 2003). While first-generation anticoagulant rodenticides (e.g., warfarin, pindone, diphacinone, and coumatetralyl) were developed in the 1950s and 1960s, second-generation anticoagulants (e.g., brodifacoum, flocoumafen, bromadiolone, difethialone) were not developed until the 1970s and 1980s.

Although brodifacoum was developed in the UK in the 1970s (Hadler and Shadbolt 1975), it was not registered in New Zealand until the 1980s. Brodifacoum, a second-generation anticoagulant rodenticide, is amongst the most potent of the anticoagulants (Hadler and Shadbolt 1975). Brodifacoum has advantages over first-generation anticoagulants at eradicating rodents, as individuals do not have to consume as much in order to receive a lethal dose (Howald et al. 2007, Taylor and Thomas 1989).

Brodifacoum was used in the successful eradication of ship rats on Hawea Island (9 ha) in 1986. The operation took two weeks using Talon 50 WB™ (brodifacoum) in bait stations (Taylor and Thomas 1989). There were about 20 other successful eradications of rodents from New Zealand islands that commenced during the 1980s. Most of these eradications used hand-laid brodifacoum or bromadiolone, although aerial spreads of poison were undertaken on Moutohora (1985) and Mana (1989) Islands. A helicopter was also used in the eradication of Norway rats from Breaksea Island (1988) to position bait stations on cliffs and on offshore rock stacks (Table 2). The successful eradications in the 1980s changed skeptical attitudes towards eradication efforts, and the methods used were seen as a huge advance for conservation efforts in New Zealand.

PHASE 3: NEW TECHNIQUES AND CHALLENGES

The successful eradications of the 1970s and 1980s were very encouraging, and in the 1990s and 2000s eradication methods were improved with the help of new technology. Whilst earlier attempts used mostly ground based techniques, the 1990s saw the use of aerial techniques and eradication attempts became more ambitious. The use of GPS navigational systems for aerial bait sowing was one of the biggest advancements in achieving rodent eradications from more complex islands (Tables 3, 4). Utilizing GPS systems allowed aerial drops of poison to be far more effective and efficient than in earlier attempts (Broome and Fairweather 2008).

On Kapiti Island (1,965 ha), a helicopter fitted with GPS navigational guidance was used to sow bait and eradicate Norway and kiore rats in 1996 (Table 4). The operation used brodifacoum (Talon®) in one application of 9kg/ha, and a second application of 5kg/ha. At the time, Kapiti Island was much larger (7 times) than any other island rodent eradication achieved in New Zealand (Broome 2009). GPS was vital in making this operation a success and demonstrated that eradication of rodents from larger islands was possible.

Another success of the 1990s was Fanal island (73 ha) in 1997. The eradication of kiore on this island involved a single aerial application of Talon® 7-20 at approximately 8kg/ha, again using a differential global positioning system (DGPS) to aid helicopter navigation lines. There was very heavy rain on the day following the application, which may have compromised bait, but despite this complication the eradication was successful. Altogether there have been around 49 successful island eradications that commenced during the 1990s (Tables 3, 4).

In 2001, Campbell Island was successfully rid of Norway rats (Table 5). Campbell Island is 11,300 ha, which makes this the largest island, not only in New Zealand, but the world, on which a successful eradication of Norway rats has been achieved. Campbell Island is also very isolated (700 km from the mainland). Brodifacoum bait was sowed aerially by DGPS-guided helicopter at 6 kg/ha over a period of 11 days (Broome 2009).

PHASE 4: FUTURE IMPROVEMENTS

The success of Campbell Island highlights how the use of bait and new technologies can facilitate the eradication of rodents on even large, complex, and remote land areas (Howald et al. 2007). Products used for rodent eradication have not changed much in the last few decades (Towns and Broome 2003), and there is room for improvements. Development of alternatives to anticoagulants would be valuable because of concerns regarding non-target species impacts.

In the medium to longer term, the preferred alternatives might emerge if they can be shown to be effective in eliminating rats from islands and offer advantages over brodifacoum. Examples of potential toxicants include: i) a novel humane red blood cell toxin (if it can be successfully developed), ii) diphacinone, iii) cholecalciferol in combination with coumatetralyl, and iv) cholecalciferol. *Para*-aminopropiophenone is being developed for stoat and feral cat control and the rodenticidal potential of this class of compounds will be determined in 2010/11. If a suitable new rodenticide is identified from this new class of red blood cell toxicants, then aerial bait containing a new toxin is an option for the future. Another possible alternative toxin is the rodenticide cholecalciferol (Baigent et al. 2007). Cholecalciferol, or preferably low-dose cholecalciferol in combination with coumatetralyl or diphacinone (which have a delayed onset of symptoms) represent low-risk toxins for control of rats and mice without secondary poisoning, and in aerial bait they would have lower risk to non-target bird species. The US EPA has recently registered diphacinone for aerial control of rodents for conservation purposes, although to date no large islands have been successfully cleared of rats using this method.

Other advances might include baits that are more attractive to mice, longer life baits, and new tunnel delivery systems to target re-invasions. Any new products or methods would have to show decreased or minimal non-target impacts, and similar efficacy in accomplishing eradication goals. Such advances would help future eradication attempts, as well as help to prevent rodent re-invasions. All these improvements are currently under active further development by the research team and offer hope for further effectiveness of island eradications of rodents in New Zealand.

What is the vision for the future? The eradication of rats on Stewart Island, third largest of the New Zealand islands (174,600 ha), has been scoped (Beaven 2008), but many issues (especially social) need to be addressed first.

CONCLUSIONS

Islands present a unique opportunity. If rodents can be eradicated from an island, native species can recover or be re-introduced to the area, and unlike the mainland, chances of reinvasion are relatively small and controllable. Rodent eradications have been part of a concerted effort, and by 2010, 115 populations of 13 species of vertebrates have been removed from at least 90 islands with a total area of 31,000 ha. Identified benefits to biodiversity were through *in situ* recovery and enabling the translocations of endangered species to newly secure environments.

Table 3. Successful rodent eradications on New Zealand islands between 1990 and 1994.
Data from Towns and Broome (2003) and Clout and Russell (2006).

Island	Start Date	End Date	Area (ha)	Species	Control	Comments
Taranaki	1990	1990	1	Norway	Poison	
Motiti	1990	1990	1	Norway	Poison	
Motutapu	1990	1990	1	Norway, mice	Poison	
Arch	1990	1991	1	kiore	Poison	
Burgess	1990	1991	56	kiore	Poison	
Flax	1990	1991	1	kiore	Poison	
Maori Bay	1990	1991	11	kiore	Poison	
Motupapa 'Stack C' **Stacks B-G,I,J** **Trig**	1990	1991	2 10 16	kiore	Poison	
Mokohinau islands	1990		0.1-73	kiore	Aerial spread of Talon 20 P™, follow up ground laying of Talon 50 WB™	Trial of helicopter to test bait
Motu-O-Kura	1990	1992	14	Norway	Poison	
Wainui	1991	1991	2	Norway	Poison	
Haulashore	1991	1991	6	ship	Poison	
Stanley	1991	1992	100	kiore	Poison	
Motuara	1991	1993	59	kiore	Bait stations on 50m grid	(Thomas and Taylor 2002)
Moturemu	1992	1994	5	mice	Poison	
Hauturu	1992	1994	10	Norway	Poison	
Middle Chain	1992	1994	23	kiore	Poison	
Red Mercury	1992	1994	225	kiore	Poison	
East & West Atoll	1992	1995	1	Norway	Poison	
SW Crater Rim	1992	1995	1	Norway	Poison	
Black Rocks **Little Rat** **Mouse** **Phil's Hat** **Rat**	1992	1995	1 1 1 1 2	ship, mice	Poison	
Ulva	1992	1996	259	Norway	Talon 50 WB™ in bait stations	Tested min. effective bait station density, min. bait loadings & rolling front approaches to bait application
Inner Chetwode	1993	1994	242	kiore	Poison, trapping, dogs, shooting	
Cuvier	1993	1995	170	kiore	Poison	
Enderby	1993	1995	710	mice	Poison	
Tiritiri Matangi	1993	1995	196	kiore	Aerial application of Talon 20P™ rodent bait	(Veitch 2002a)
Mauiroto	1993	1997	102	kiore	Poison	
Motutapere	1994	1996	45	mice	Poison	
Mauimua	1994	1996	155	kiore	Poison	

Table 4. Successful rodent eradications on New Zealand islands between 1995 and 1999.
Data from Towns and Broome (2003) and Clout and Russell (2006).

Island	Start Date	End Date	Area (ha)	Species	Control	Comments
Mou Waho	1995	1997	140	mice	Poison, trapping	
Mauipae	1995	1997	80	kiore	Poison	
Papakohatu	1996	1997	0.7	mice	Poison, trapping	
Kapiti	1996	1998	1965	Norway, kiore	Aerial spread of brodifacoum in Talon 7-20 cereal bait	Complex non-target issues
Tahoramaurea	1996	1998	1	Norway	Poison	
Matakohe	1996	1998	37	Norway	Poison	
Motungara	1996	1998	3	Norway	Poison	
Motuihe	1997	1999	179	mice	Poison	
Fanal	1997	1999	73	kiore	Aerial application Talon 7-20	(Veitch 2002b)
Motuihe	1997	1999	179	Norway	Poison	
Putauhinu	1997	1999	145	kiore	Poison	
Rarotoka	1997	1999	88	kiore	Poison	
Whangaokena	1997	1999	13	kiore	Poison	
Pakatoa	1998	1998	29	Norway	Poison	
Unnamed Cape Wiwiki A and B	1999	1999	2.2 1.2	Norway	Poison	

Table 5. Successful rodent eradications on New Zealand islands completed or confirmed in the 2000s.
Data from Towns and Broome (2003), Clout and Russell (2006), and Broome (2009).

Island	Start Date	End Date	Area (ha)	Species	Control	Comments
Browns	1995	2000	58	Norway, mice	One aerial application of bait loaded with bromadiolone	(Veitch 2002c)
Long	1997	2000	142	kiore	Poison	
Whenua Hou	1998	2000	1396	kiore	Aerial spread of brodifacoum in Agtech Talon 20 P™ cereal bait	Complex non-target and logistics
Koi	2000	2000	0.28	Norway	Poison	
Puangiangi	1999	2001	69	Norway	Poison	
Whakaterepapanui	1999	2001	74	kiore	Poison	
Tinui	1999	2001	95	Norway	Poison	
Mayor	2000	2002	1283	Norway, kiore, cats	Aerial spread of brodifacoum in Pestoff 20 R™ cereal bait	Tested effects of rat poisoning on cats
Tarahiki	2000	2002	5	Norway	Poison	
Mokoia	2000	2003	135	Mice	Poison	
Campbell	2001	2003	11300	Norway	Aerial spread of brodifacoum in Pestoff 20 R™ cereal bait	Largest successful island eradication, complex, new aerial spread technique used
Raoul	2002	2004	2941	Norway, kiore, cats	Aerial spread of brodifacoum Pestoff 20 R™ 10mm	
Quail	2002	2004	88	ship	Poison	
Rakino	2002	2004	148	Norway	Poison	
Iona	2004	2004	7	ship	Poison	
Hauturu (Little Barrier)	2004		3083	Kiore	Aerial spread of brodifacoum Pestoff 20 R™ 10mm	Paper bags of bait dropped on rock stacks
Taukihepa **Rerewhakaupoko** **Pukeweka,** **Mokonui**	2006 2006 2006 2006		939 26 3 86	ship ship ship kiore	Aerial spread of Pestoff 20 R™ 10mm	
Pomona **Roma**	2007 2007		262 60	ship, mice	Aerial spread of brodifacoum Pestoff 20 R™ 10mm	

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