A history of ground-based rodent eradication techniques developed in New Zealand, 1959–1993

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Abstract Eradicating rats from islands was for decades deemed highly desirable but considered practically impossible. This paper documents the development of ground-based rodent eradication techniques using bait stations in New Zealand up until 1993. The work culminated in a successful operation to eradicate Norway rats (*Rattus norvegicus*) from 3100 ha Langara Island in the Queen Charlotte Islands, Canada, in 1995.

Keywords Eradication; rat, *Rattus*; islands; bait station; rolling front.

INTRODUCTION

Introductions of rodents to new regions during centuries of exploration and colonisation around the globe are recognised worldwide as a major conservation problem (Atkinson 1985). New Zealand ecosystems developed without terrestrial mammalian predators, the only land mammals being native bats. The flora and fauna that evolved through long oceanic isolation during the Tertiary were vulnerable to the depredation of introduced mammals, and many of the extinctions that have occurred in this country can be attributed to the introduction of rodents (King 1984).

The first of the four rodent species introduced into New Zealand was the Pacific rat (*Rattus exulans*), which arrived with Maori, perhaps up to 2000 years ago (Holdaway 1996). This rat was transported widely around the Pacific by Polynesian peoples (Wodzicki and Taylor 1984) who utilised it as food. There were likely to have been intentional liberations that, along with natural dispersal, resulted in the species becoming widespread on the main New Zealand islands, as well as establishing on many offshore islands (Atkinson and Towns 2001).

One of the first documented records of Eurasian rodents in New Zealand is the account given by Anders Spaarman, a naturalist with Captain Cook, who described rats (probably Norway rats – *Rattus norvegicus*) coming ashore at Pickersgill Harbour when the *Resolution* was beached for careening in Dusky Sound, Fiordland, in 1773 (Rutter 1953). During the 19th century, the ship rat (*Rattus rattus*) and house mouse (*Mus musculus*) also became established in New Zealand (Atkinson 1973; Taylor 1975, 1978), probably accidentally as ship visits to the new colony of New Zealand increased in the mid-19th century.

The introduction of rodents has had a significant impact on native animal and plant species. What was accepted as unavoidable by colonisers of the day has been rued by naturalists, scientists, and conservationists ever since. In the 25 years since serious consideration was first given to the possibilities of rectifying this major ecological problem, eradication of rodents from islands has become an accepted conservation management tool – now used with much success in various parts of the world.

We describe here the history and development of ground-based, rodent eradication operations using bait stations in New Zealand, which led to the successful campaign to eliminate Norway rats from Langara Island in the Queen Charlotte Islands (Haida Gwaii) in Canada – at over 3100 hectares, the largest rat eradication achieved to date.

1959 TO 1976: TENTATIVE BEGINNINGS

With the establishment in New Zealand of various Government wildlife and science agencies in the mid-1900s, a better understanding of the distribution of rodents in New Zealand began to emerge (Wodzicki 1950; Watson 1956, 1961), together with a greater appreciation of the detrimental effect these predators were having in our ecosystems. A graphic example was the devastation and extinctions caused by ship rats on Big South Cape Island (Taukihepa), in the early 1960s where several locally endemic birds were extirpated (Bell 1978). Removal of rodents seemed insurmountable and understandably efforts were focussed on ongoing methods of control, rather than eradication.

For example, depredation of white-faced storm petrels (*Pelagodroma marina*) by Norway rats was noted in 1959 on Maria Island (1 ha) in the inner Hauraki Gulf (Fig 1). During the 1959 to 1961 breeding seasons, Mr A McDonald and other members of the Forest and Bird Protection Society, assisted in part by Don Merton and a £5.00 grant from Wildlife Service for poison, endeavoured to protect white-faced storm petrels on Maria Island and the adjacent David Rocks (less than 1 ha). This attempt used the warfarin-based rodenticide 'Rid-rat', which was distributed around petrel colonies (Merton 1961, 1962). From later visits in the mid-60s it appeared that rats had almost certainly been eradicated from each of these small islands (Moors 1985).

During the early 1970s, research on burrowing seabirds on Whale Island (Moutohora) in the Bay of Plenty included studies of the effects of Norway rats on grey-faced petrels

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(*Pterodroma macroptera gouldi*) and sooty shearwaters (*Puffinus griseus*) (Imber 1978). A rat control programme was carried out over a small, 6.3 ha area of low-density seabird burrowing on the island, in which 800 (4 oz) packets of the warfarin-based poison “Prodide” were distributed, reducing rats to low numbers. However, re-invasion from outside the study area soon began to occur (Bettesworth 1972; Imber 1978).

Similarly, Norway rats were believed to be having a detrimental effect on breeding sooty shearwaters and flesh footed shearwaters (*Puffinus carneipes*) on Titi Island (32 ha) in the Marlborough Sounds. In the belief that total eradication was unachievable, Brian Bell (1969) suggested to the Lands and Survey Department that a control programme be put in place to reduce rat numbers during the chick fledging period. In December 1970, Dick Veitch of the Department of Internal Affairs, Wildlife Branch, laid 310 4oz packets of “Prodide” at about 15 m intervals along or near the main ridge of the island. Subsequent checks indicated that the rat population had been significantly reduced (Veitch 1970, 1971). Follow-up was intermittent and rats continued to be recorded. There was further poisoning around the colonies in December 1973, but checks by Lands and Survey personnel in March 1975 indicated rats were still present. Another application of poison was undertaken in May 1975, but there was no follow-up monitoring until we visited in 1981–1982. Our intention was to use Titi for an experimental eradication of Norway rats, but after continuous trapping over a six month period (approximately 9000 fenn trap-nights) we found rats were no longer present (Gaze 1983).

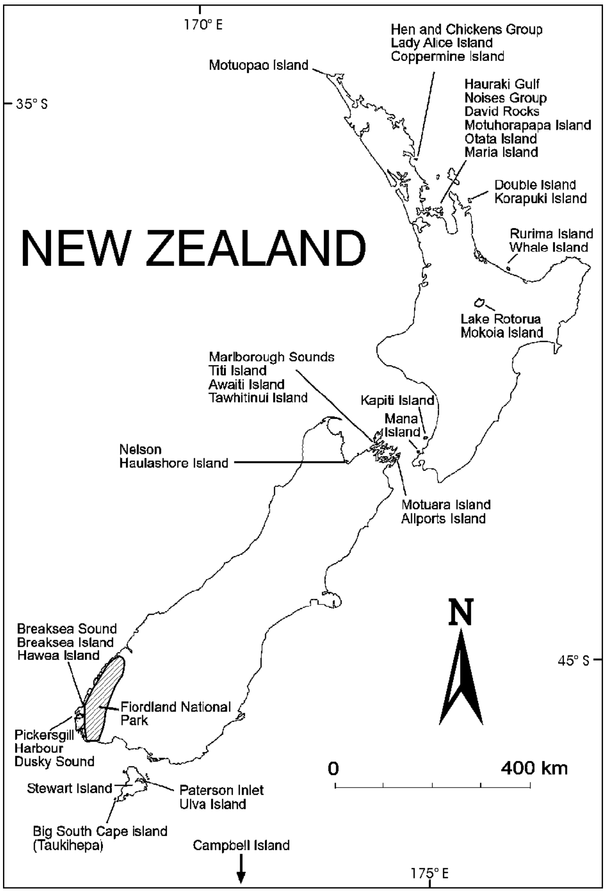

Fig. 1 Island localities mentioned in text.

Despite widespread concern at the possibility of rats reaching rodent-free islands, it was not until November 1976 that a concerted effort was made to address the problem. On advice from Ian Atkinson, Rowley Taylor and Brian Bell, members of the Outlying Islands Committee, and at the urging of John Yaldwyn (National Museum of New Zealand), a symposium on the ‘Ecology and Control of Rodents in New Zealand Nature Reserves’ was organised by the Department of Lands and Survey (Coad 1978). This conference brought together over 50 of New Zealand’s rodent researchers, wildlife practitioners and managers of island reserves – representing many government departments, research organisations, museums, and universities.

Presented papers and discussion ranged widely from the effects of rodents on ecosystems to the possibilities for control and eradication. It is indicative of general thinking of the day that despite a report of the apparent eradication of rats from Maria Island and the David Rocks (we did not know the outcome for Titi Island at this stage), in a final comment the Chairman, John Yaldwyn, concluded: “*We have control methods, and methods for reducing populations, but complete extermination on islands is remote or at least a very very difficult thing indeed.*”(Yaldwyn 1978). Nevertheless, the meeting overall provided the impetus for several individuals to pursue their ideas to develop methods for eradication of rodents.

1977 TO 1984: EARLY RESEARCH

Although most rodent research in New Zealand continued to be directed towards the distribution and ecology of rats and mice (Wildlife Research Liaison Group 1984), work now began on developing rat eradication techniques for islands. This was aided by the production of new and improved toxins in the form of second generation anticoagulants in proprietary rodenticides such as ‘Talon’ (brodifacoum) and ‘Storm’ (flocoumafen).

Recognising the difference in approach needed between eradication and control operations, Phil Moors of the New Zealand Wildlife Service began to test the feasibility of eradicating Norway rats from islands by undertaking differing poison trials on Motuhoropapa (9.5 ha) and Otata (21.8 ha) islands in the Noises Group (Moors 1978, 1979). It was thought eradication had been inadvertently achieved on Motuhoropapa in 1977–1978 as a result of his preliminary trapping study, and Moors postponed his planned poison programme to test this result. However, monitoring revealed that rats were still present in low numbers and the poison programme was reinstated in 1981. This involved a combination of compound 1080 (sodium monofluoroacetate)-impregnated grain, distributed in 75 plastic bait stations placed at 50 m intervals along existing tracks, plus 1080 paste spread in likely haunts around the coast and on the offshore stacks. A few months later, the 1080 baits were replaced with 0.005% brodifacoum ‘Talon’

WB 50 waxed baits and 0.01% brodifacoum paste (Moors 1985). Kill traps (over 1400 trap-nights) were also set. No rats or sign were found after February 1983.

In 1979, bait stations were established on Otata Island (21 ha) on a grid at 40 m spacings. Poisoning was undertaken in two stages, the first using Compound 1080 in a mixture of rolled oats and fish-flavoured cat food, little of which was touched. Single 'Talon' WB 50 baits (about 7500) were then placed at 10 x 5 m spacings over the island, but a second island-wide poisoning campaign was deemed necessary in September 1980 after rodent droppings were found (Moors 1985). Eradication was confirmed on both these islands in 1987 (Veitch and Bell 1990). Although this work eventually met with success, it required considerable time and effort and led Moors (1985) to recommend: "*use as many methods of killing rats as you can, and never rely on one weapon alone*".

Stemming from this work, Ian McFadden (1984) developed and tested bait stations, dispensing silos and various forms of baits and attractants on Pacific rats on Lady Alice Island. This technology was refined during eradication trials of Pacific rats in 1983–1984 on Rurima Island (6 ha) in the Bay of Plenty. After pre-feed trials, he used 1080-impregnated kibbled maize dispensed from 30 gravity-fed silos, but the rats did not take the bait (probably because of the taste of dyes used in manufacture). Subsequently, undyed kibbled maize impregnated with the anti-coagulant bromadiolone was used in an expanded array of silos (41 in total). Rodent feeding sign at the silos and monitoring using snap traps, indicated that eradication was probably achieved within three months of laying the poison (McFadden and Towns 1991).

This successful method was applied on Korapuki Island (18 ha), where McFadden improved his silo methodology and eradicated Pacific rats after just one application of bromadiolone-impregnated toxic kibbled maize (McFadden and Towns 1991). McFadden's next experiment on Pacific rats, on Double Island in 1989, compared the cost and effectiveness of bromadiolone-poisoned grain in silo bait stations on one half of the island against hand broadcast distribution of commercially-available flocoumafen-based "Storm" rodent pellets on the other half (McFadden 1992). Both techniques achieved successful eradication, but the cost of broadcasting baits was marginally cheaper. Because of potential cost savings McFadden explored the development of aerial broadcast technology in which poison is distributed from spreader buckets slung under helicopters (McFadden and Green 1994). It is an eradication technique now widely used in New Zealand that has proved especially effective in difficult terrain and/or isolated situations, and with which success is being achieved on larger and larger islands (Cromarty *et al.* 2002).

While Wildlife Service was undertaking their early work on northern islands, the Department of Scientific and Industrial Research (DSIR) Ecology Division, was engaged in a series of rodent distribution surveys – involving Bruce Thomas (BWT) and others – in the Nelson/Marlborough region under the leadership of Rowley Taylor (RHT). Through this work (Taylor 1984) links were developed with the Department of Lands and Survey, who in 1980–1981 were considering rat eradication trials on Campbell Island. RHT recommended that, given current knowledge, a more appropriate plan would be for Ecology Division to cooperate in trials of rat eradications on smaller, readily-accessible islands in the Marlborough Sounds.

In planning the trials, we adopted a different approach from that recommended by Moors (1985). We tested a single-hit, single-poison methodology, taking account of the known behaviour of rats. Our aim was to develop a system of dispensing a proven rodenticide into the territory of every rat on an island, in a way that would minimise non-target poisoning, and monitor the effectiveness of the campaign as it progressed (Taylor and Thomas 1989).

In a joint DSIR Ecology Division/Marlborough Sounds Maritime Park programme, David Taylor and two other Lincoln College students, under Rangers Dave Maizey and Bob Ryan, carried out the fieldwork for the first two trials. The initial experiment was against ship rats on Awaiti Island (2 ha). Simple bait stations with a top-loading access slot and a clip-in cover were made from 65 mm diameter plastic drainage pipe ('Novacoil'). About 120 bait stations were sited approximately 15–20 m apart over the island and a single 15 g "Talon WB 50" pellet containing 0.005% brodifacoum, a second generation anticoagulant rat poison, was placed in each tunnel. Pellets were replaced as necessary during weekly checks (i.e. up to five times between 10 March 1982 and 16 April 1982) – from which time no further baits were taken. Follow-up monitoring (kill traps and tracking tunnels) confirmed eradication had been achieved (D. Taylor 1983).

The second trial also targeted ship rats on the adjacent, forested, Tawhitinui Island (21 ha). A network of tracks was cut to give access to the coast at regular intervals from along the main ridges of the island. A total of 374 bait stations of 65 mm plastic drainage pipe were placed along these tracks, achieving a variable grid of 25–50 m. A single "Talon WB 50" bait was placed in each of the tunnels and checked and replenished weekly from 26 January 1983 until the poison-take stopped on 15 February 1983. Poison baits were left in place until February 1984 and the campaign was considered a success in August 1984 after follow-up monitoring (baited tracking tunnels and snap-trap lines) detected no further sign of rats (D. Taylor 1984).

About the same time, a review of Wildlife Service research priorities gave the highest priority rating for new predator projects to "*The development of eradication methods for use on small islands*" (Crawley 1983). We were already convinced of the potential to further develop bait station technology as a rat eradication technique for much larger islands, but a general scepticism of this methodology persisted amongst administrators, researchers and wildlife practitioners. For example, in a priority listing of 11 research topics on rodents, the Wildlife Research Liaison Group (1984) gave top priority to mapping rodent distribution. By comparison, 'methods of eradication or control' were placed low on the list at priority 9, with specific reference made only to possible biological methods. Despite our success in the Marlborough Sounds, the use of rodenticides in bait stations did not rate a mention. In 1983, influenced by the problems that Moors was encountering on the Noises Islands, Ian Atkinson voiced the then-commonly-held view that *"Once rats have established on an island, it is generally not feasible to remove them unless the island is very small."* (Atkinson 1986).

The Department of Lands and Survey was keen to continue its support for research aimed at rat eradication on Campbell Island, and in 1983 DSIR Ecology Division negotiated a research contract to further this objective. Graeme Taylor was employed to study Norway rats on the island to assist planning for an eventual eradication campaign. Key aspects of his research were rat distribution, density, breeding, food, habits, and home range size (Taylor 1986).

1985 TO 1988: THE BREAKSEA SOUND RAT ERADICATION CAMPAIGNS

Norway rats were confirmed present on Breaksea Island (170 ha) and the then unnamed Hawea Island (9 ha) during an ecological survey of islands in Breaksea Sound in 1974 (Thomas 1975). The possibility of eradicating Norway rats from Breaksea Island to create a predator-free environment in which to translocate the last few Fiordland kakapo (*Strigops habroptilus*) was discussed in depth by the team members during the survey. Enthused by the 'Rodents in Reserves' symposium, and encouraged by the success of the Marlborough Sounds trials, during subsequent work for the Fiordland National Park Board, BWT formulated ideas to undertake further development of bait station rodent eradication technology in Breaksea Sound (Taylor *et al.* 1986).

In April 1984 BWT, RHT and Fiordland National Park staff were joined by the director of Ecology Division on another ecological survey of islands in Breaksea and Dusky Sounds (Thomas and Taylor 1988). Our director was less than convinced with our proposal to eradicate rats from Hawea and Breaksea Islands, believing that eradication of rats from an island as large and rugged as Breaksea was not achievable – a sentiment echoed time and again from many quarters. Undaunted, and with the support of Department of Lands and Survey colleagues, we gained a small grant and an offer of logistical support from the Fiordland National Park Board. This enabled us to finalise plans to undertake an experimental eradication operation against Norway rats on Hawea Island, with the clear intention of expanding the programme to include Breaksea Island should we be successful.

We believed that the single best method available should be employed to achieve eradication in the shortest possible time. In undertaking the Hawea Island campaign we hoped to develop existing technology further to overcome problems such as bait station design, neophobia, bait avoidance and poison resistance, and monitoring success – all of which had compromised previous eradication operations to various degrees. With the help of Graeme Taylor and the voluntary assistance of several other people (Taylor and Thomas 1986), a track system and a preliminary programme to monitor ecological changes following rat eradication was completed on Hawea Island in 1986. Seventy-three 100 mm diameter plastic drainage pipe bait stations, each 400 mm long, were placed on a 40 m grid over the island three weeks before poisoning, to minimise neophobic avoidance by rats. From 11-22 April 1986, two "Talon WB 50" baits were placed in each tunnel and checked and replenished daily – a monitoring regime that enabled collection of precise data on rat activity. Eradication was accomplished in less than two weeks, and the system was self-monitoring and required no special effort to get the last rat (Taylor and Thomas 1989).

We could now recommend with confidence that a similar poison campaign be carried out on 170 ha Breaksea (Thomas and Taylor 1988). A project proposal submitted to DSIR gained research support for a Breaksea Island campaign for the period 1987–1989 (Ecology Division 1987). However, for the programme to go ahead it was essential that our draft work plan (Taylor and Thomas 1987) be accepted by the newly-formed Department of Conservation (DOC). The plan required an eight bunk hut and two bivvies to be built, hundreds of person-hours cutting tracks, the production of up to 1000 plastic drainage pipe bait stations, and 500 kg of "Talon 50 WB" rat poison – over NZ$50,000 for materials alone. The new managers we were dealing with were reluctant to commit resources, unconvinced that we could achieve eradication on such a large scale. By then, based on McFadden's work, conventional thinking was that *"rodent extermination on islands up to 40 or 50 ha might be possible."* (Towns 1988).

Two Te Anau DOC staff, Tom Paterson and Ron Peacock, shared our vision and were instrumental in the project being designated an official "Fiordland National Park Centennial Year Project". They secured some old Ministry of Works buildings, which provided the materials for the huts, successfully negotiated with ICI (Imperial Chemical Industries, now Zeneca) to donate the poison, and organised for the participation of "Operation Raleigh". A commitment by DOC was made to go ahead with the project, and Ian Thorne took responsibility for coordinating preparation of the island (Department of Conservation 1988). In 1987, several teams of young people from New Zealand and around the world, paying for an outdoor adventure experience with "Operation Raleigh", spent weeks under canvas in harsh conditions on Breaksea Island marking routes and cutting tracks, which were completed by DOC staff and voluntary helpers.

The Breaksea Island campaign was similar to the Hawea Island poison operation, but stations were more widely spaced (50 m apart) along contour tracks cut at 60 m vertical intervals from the coast to the summit. Thus, the surface distance between lines varied from about 30-100 m depending on the steepness of the terrain. Extra stations were installed at 25 m intervals along the main access ridges, with all 743 bait stations in place two months before poisoning. Six large weather-proof stations, each containing 50 "Talon WB 50" baits, were positioned by helicopter on inaccessible cliffs and offshore stacks. During the main poisoning operation (26 May to 16 June 1988), stations were loaded with two "Talon WB 50" baits and checked and replenished daily. Six poison operators, led by Ian Thorne, each had responsibility for a section of island. Bait-take was analysed daily to monitor the changing status of the rat population. As the operation progressed as predicted, even the sceptics in the team changed their views on our chance of success. On day 21, leaving the island loaded with four talon baits per station, we were confident that only two already-poisoned rats remained alive. Two years of post-poison monitoring confirmed our success (Taylor and Thomas 1993).

This created the largest predator-free island in Fiordland and advanced understanding of eradication technology. However, the most important outcome was improved confidence amongst administrators, conservation practitioners, politicians and the public alike, that eradication of rodents was achievable on a large scale – that money was not being squandered in attempting such operations. This was aided by raising awareness of the project through various media, the most important being the production of the Television New Zealand Wild South documentary 'Battle for Breaksea Island' (Natural History New Zealand Ltd 1990). This 26 minute television documentary, shown in New Zealand and overseas, has had a tremendous impact on predator eradication efforts.

1989 TO 1993: THE "ROLLING FRONT" AND OTHER CAMPAIGNS

The Breaksea Sound work was to us a preliminary step towards eradicating rats from Kapiti Island (Thomas and Taylor 1988), a 1970 ha island sanctuary of world renown and of particular importance to the conservation of several critically endangered bird species (Maclean 1999). Removal of feral stock had been achieved, and possums eradicated in 1986 (Cowan 1992; Maclean 1999). Pacific and Norway rats were the only introduced mammalian predators that remained and we felt the time was right to give consideration to their eradication. We prepared a discussion document proposing that because of the island's size a ground-based poison campaign be undertaken sequentially in three stages in what we termed a "rolling front" regime, and recommended that it first be tested elsewhere (Thomas and Taylor 1991). For reasons of size, shape, ease of access and the fact that it had Norway rats, we suggested that Ulva Island (270 ha) in Paterson Inlet, Stewart Island, would be the best place to undertake such trials. Southland Conservancy of DOC agreed that their existing programme for Ulva, based on methods used on Breaksea Island, should be modified and the island used to trial the rolling front on a "research by management" basis.

Responsibility for this project had been given to DOC officer Lindsay Chatterton who implemented the changes necessary to undertake the more complex "rolling front" programme. The island was divided into three blocks of 70–100 ha, which were to be poisoned sequentially. A total of 282 bait stations were placed along 47 lines to achieve a 100x100 m grid over the whole island. There were concerns about the possibility of unnecessary amounts of poison entering the food chain, and the effects of this on non-target species and the environment. To study optimum baiting levels, each block received a different loading of "Talon WB 50" poison, from an extremely low dosage in Block 1 to a dose somewhat less than we used on Breaksea Island in Block 3 (Fig. 2); and the check-replenishment regime was pulsed according to the particular stage of the campaign. Just before the poisoning began we learned that "Talon WB 50" baits had been in regular and widespread use on Ulva for rat control for over 10 years. This presented a possibility that the programme could be compromised by bait avoidance or poison resistance in the rat population (Taylor and Thomas 1989).

Poisoning began in Block 1 on 6 July 1992, with two Talon baits per station checked and replenished by two operators every two days. Three weeks later, poisoning started in Block 2 with four baits per station. A further four weeks later, in late August, eight baits per station were applied in Block 3. As the "rolling front" moved ahead into the next block, bait loadings were doubled and the frequency of checks reduced. On 24 October, all stations on Ulva Island were loaded with 10 baits and less frequent, but regular, checks continued until April 1993. Non-toxic indicator baits were also distributed over the island at this time and fenn traps set to monitor success and catch surviving rats. There were marked differences in results between blocks. Maximum daily bait-take peaked much earlier and declined more rapidly in high-dosage Block 3 compared with low-dosage Block 1, where the peak was delayed, the high bait-take period was protracted and the overall period of bait-take continued for longest.

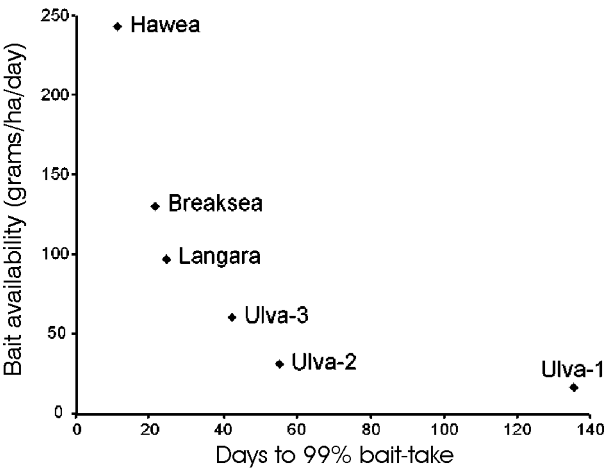

Fig. 2 Relationship between bait availability and duration of rat-eradication campaigns.

Our concerns at the possibilities of bait avoidance were also realised. A number of poison-resistant or bait-shy individuals survived on Ulva, after the rest of the rats had been poisoned. At least two females became pregnant several months after Talon bait was laid in their block, and one gave birth to at least three young before being finally trapped. Other trapped rats were found to have brodifacoum concentrations in their livers well in excess of that usually found in rats poisoned by Talon. The brodifacoum-resistant rats were detected through the monitoring regime, which included the use of non-toxic indicator baits as well as the self-monitoring nature of the bait-station method. Hotspots were eventually cleared by trapping (11 rats caught) and/or bromadiolone-poisoned crushed maize.

In response to concerns by some DOC staff that 100 m spacings of bait stations would be too wide, and to record responses of rats living adjacent to the poison fronts, 18 Norway rats were live-trapped in the vicinity of the poison fronts shortly before or during poisoning. Each rat was fitted with a radio transmitter, released and tracked. Of 11 transmitters used in the study, two failed after six and 18 days respectively and were never recovered, a male rat lost its transmitter after two days (probably through poor fitting), a female rat in poor condition was located dead the day after she was caught and, where appropriate, some transmitters recovered from poisoned rats were reused. Six of the transmitters had their aerials chewed off at the base but emitted strong enough signals for tracking to continue.

Rats were tracked for periods ranging from two to 69 days. Dens of marked rats were located daily and as many locality fixes as possible were obtained for each rat during their period of night-time activity. Single, linear movements of over 600 m in a night were recorded and all telemetered rats were recorded in the vicinity of one or more bait stations. As poisoning progressed and population pressure reduced, some rats moved up to 400 m into poison-activated areas from adjacent non-poison blocks. Most of the telemetered individuals died less than two weeks after Talon had been laid in their block, however, three of the study animals persisted for more than a month after baiting commenced. This pattern was quite different to what we had experienced in the Hawea and Breaksea campaigns, and a further indication that a percentage of the rat population on Ulva Island was either bait shy or poison resistant.

Concurrent with eradication operations on Hawea, Breaksea and Ulva Islands, important developmental work was also being undertaken in other areas by DOC workers. In 1989, Paul Jansen adapted the Breaksea Island work plan to eradicate Norway rats from Mokoia Island (135 ha) in Lake Rotorua (Veitch and Bell 1990). By 1990, bait station technology had been used to eradicate rodents from about 18 New Zealand islands, and a similar number had been cleared by hand broadcasting baits (Veitch 1994). Pacific rats were eradicated from Motuopao Island (30 ha), Northland, in 1990, and Motuara Island (59 ha), Marlborough Sounds, in 1991, with bait stations placed on a 50 m grid (McKenzie 1993; Cash and Gaze 2000). To address further the spatial requirement of bait stations for Pacific rats, an attempt was made to eradicate Pacific rats from Coppermine Island (80 ha) in the Hen and Chickens group using 100 m spacings. The operation failed but it was difficult to determine if this was because of the wider bait station spacing or the rugged topography of the island, which was later cleared of rats using aerial broadcast (McFadden 1997).

Spacing of bait stations was also a consideration on Allports Island (16 ha) in Queen Charlotte Sound in 1989, when Derek Brown (1993) successfully employed the Breaksea bait station system to eradicate mice using a 50 m grid. In exterminating mice from 217 ha Mana Island in 1989 a 25 m spacing of bait stations was used. However, an aerial application was also incorporated into this campaign and so a combination of factors brought about success (Hutton 1990; Hook and Todd 1992).

We felt throughout our trials that McFadden's concept of silo bait-dispensing technology was an alternative or adjunct to ground-based eradications (McFadden and Towns 1991) and we used "bulk bait stations" in the difficult areas at Breaksea. In 1991, the Nelson City Council approached us for advice on rats on Haulashore Island (6 ha), in Nelson Harbour. Index trapping indicated that this island had a population of approximately 300 ship rats, which we undertook to eradicate. This was a trial of low station density, with a weekly checking regime. Two steel 12 gallon drums placed on their sides were converted into simple poison stations by installing a hinged, lockable, access door on top, a 100 mm entry hole for rats 25 mm above ground level at either end, and a shallow wooden tray for holding baits. The drums were positioned about 250 m apart, each loaded with 100 "Talon WB 50" baits and checked and replenished weekly. In total, 755 baits were taken, about 2.5 baits per rat, and eradication was achieved over a period of 90 days with minimal operator input.

This approach worked on a temperate island with a simple habitat structure, where rats were scavenging for seasonal foods and beach flotsam. However, it is unlikely to be successful in complex habitats (i.e. tropical forests), with an abundance of year-round food. The results on Haulashore Island strongly suggested that ship rats, like Norway rats, were also susceptible to "peer pressure" in following each other to food sources, with the last rats extending their home ranges to encounter one or other of the two poison stations.

As a result of several years of trials and investigations into how best to deal with the presence of two rat species in a single eradication campaign, the Department of Conservation successfully eradicated Norway and Pacific rats from Kapiti Island in 1996 using helicopter broadcast of Talon 7-20 pollard baits. Offshore stacks were treated by either aerial or hand broadcast of baits and bait stations were used on three small adjacent Islands (Empson and Miskelly 1999).

1994 TO 2000: LANGARA ISLAND

With the more economical and simpler aerial poisoning operations gaining wider acceptance in New Zealand, opportunities for further testing the bait station approach were diminishing. However, ground-based rat eradication technology provided a viable alternative in situations where aerial broadcast was not feasible or actually prohibited by law. This assertion was tested in 1995 when the ground-based techniques developed in the Breaksea and Ulva Island campaigns were extrapolated to much larger Langara Island (3100 ha) in the Queen Charlotte Islands, British Columbia, Canada. The island had once been one of British Columbia's largest seabird colonies, with six species of burrow-nesting seabirds. Over a period of 30-40 years, Norway rats had exterminated five of these as breeding species and reduced the others from 200,000 to 14,600 breeding pairs (Harfenist 1994). Using funds from the litigation settlement following an oil spill from the tanker *Nestucca*, this project was managed by Environment Canada (Kaiser *et al*. 1997).

The Langara operation was huge, and new considerations such as different habitat type, vulnerable non-target species and the presence of permanent settlements on the island needed to be catered for (Taylor 1993). The island was divided into five working units, each with a camp, a supervisor, a cook, and a team of six bait station operators. With 100 x 100 m spacings, it required close on 4000 Breaksea-type bait stations to attain full coverage of the island. The whole island was poisoned simultaneously using a baiting protocol in which checks and replenishment of baits were undertaken every two days. Within 300 m of the shoreline, where concentrations of rats were greatest, tunnels were loaded with 12 baits per station. Stations over the rest of the island received six baits. Apart from a few "stragglers" in two areas of human habitation (one was trapped and the others quickly dealt with by providing extra baits), eradication of rats from Langara was essentially achieved in less than four weeks from the time the first bait was laid (Kaiser *et al.* 1997; Taylor *et al*. 2000).

DISCUSSION

The bait station rodent eradication technique is based on a strategy that takes into account the characteristics of second-generation anticoagulant poisons, the behaviour of the target rodents, and the island environment. It is designed to monitor its own progress, kill every rat or mouse within a selected timeframe, continually detect the presence of surviving rodents, limit the risk to non-target species, and overcome many of the problems often associated with "getting the last rat". This technique has led to many successes in rodent eradication, dealing with Norway, ship, and Pacific rats and house mice on scores of islands, up to 3100 ha worldwide. Experience shows that 100 m spacing between bait stations is adequate for Norway rats in temperate regions. In New Zealand, ship rats, Pacific rats, and mice have all been eradicated successfully using bait stations spaced 50 m apart. Not all operations have been straightforward, but most problems have been associated with human populations, non-target species gaining access to inadequately designed bait stations, and poison resistance. In a few populations where these poisons have been used for "controlling" numbers of rats and mice over a long period, poison resistance is continuing to be a problem – even with second generation anticoagulants - (Quy *et al*. 1995).

Considering all the campaigns in which we have been involved, from Awaiti Island (2 ha) in the Marlborough Sounds, New Zealand, to Langara Island (3100 ha) in Canada, it is evident that the under-pinning factor and key to success was the simplicity and self-monitoring nature of this ground-based technique. The duration of such eradications is related to bait availability in an exponential manner – the more bait available, the faster the rats are killed (Fig. 1). The scaling-up of the technique from Breaksea to Langara was straightforward and did not require any significant changes to the methodology. With such a large-scale operation, involving a great number of people, many inexperienced, there was plenty of potential for problems to arise on Langara. However, the success of the campaign within its predicted timeframe demonstrates the reliability and inherent robustness of the method.

Ground-based eradication techniques have an important part to play in many parts of the world, despite the present emphasis in New Zealand on aerial operations (Cromarty *et al.* 2002). In the United States, Canada, and some European nations, there is legislation regarding the use of rodenticides out-of-doors, and the broadcasting of vertebrate poisons from the air is prohibited. Already, there are limitations on the aerial sowing of anticoagulant rodenticides on the New Zealand mainland and on stocked islands. Such restrictions are likely to become more widespread in future. Most of the world's biodiversity occurs in tropical regions (Africa, Madagascar, Indo-Pacific, South America, etc.) where the indigenous inhabitants lack financial resources to fund aerial operations, whereas labour is less of a problem. Bait station techniques are also the only option on densely-populated islands. On sparsely-populated islands, or where very vulnerable non-target species have a proscribed distribution, a mix of both methods is often appropriate. There is a need for continued development of bait station design – in particular, improvements aimed at excluding non-target species and limiting the entry of toxins into the environment.

Island rodent extermination campaigns that 20 years ago were thought impossible are now being tackled with confidence – by both ground-based and aerial operations. Two important developments made this possible. First, the advent of new, potent and highly-palatable "second-generation" anticoagulant poisons, and second, the design of rodent eradication strategies to take advantage of these new poisons and our increasing knowledge of rat behaviour. However, one of the most important breakthroughs allowing eradication to progress has been psychological – the acceptance that the job can actually be done (Thomas and

Taylor 1988). It is perhaps ironic that eradication of Norway rats had been achieved unwittingly from 32 ha Titi Island during "rat control" operations that ceased in 1975, but through lack of monitoring this remained unknown for many years. If this success had been revealed earlier, especially at the time of the 1976 symposium, progress in the development of rat eradication techniques may have been accelerated. This highlights the need for adequate monitoring of control and eradication programmes.

Today, hundreds of rodent eradication campaigns have been carried out around the world, and others are in progress. Not all are successful. The main reasons for failure are that the best poisons are not always used, there is a super abundance of alternative foods, there are complications with non-target species, the effort is not sufficiently organised and sustained, or rodents are able to re-infest either from boats or by swimming. Before any campaign begins, the chances of re-infestation must be thoroughly assessed, and plans formulated and actioned to detect and counter future invasions.

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