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INVASIVE RODENTS ON ISLANDS

Prospects for the eradication of rats from a large inhabited island: community based ecosystem studies on Great Barrier Island, New Zealand

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Abstract Great Barrier Island (c. 27,400 ha) is the largest off-shore Island in New Zealand. Some of the most serious introduced mammalian pests of New Zealand are absent, but feral cats and rodents are present. Community based trusts are spear-heading ecological studies to support conservation and a pest eradication programme. Rodent numbers are greatest in late summer/autumn and lowest in winter/early spring. Maximum abundances were recorded in riparian and coastal vegetation, and in mature forest. Monitoring shows that trapping alone is not able to reduce rat numbers sufficiently for safety in avian re-introductions. A combination of trapping and strategically pulsed toxin baits, however, achieved low levels of rats. Ecosystem recovery is demonstrated by increases in key tree seedlings, large invertebrates and lizards in managed compared to unmanaged areas, and by the survivorship of translocated robins (*Petroica longipes*). The Great Barrier Island Charitable Trust is communicating these benefits, and associated risks, to the Island community, with a view to promoting pest eradication as a key component in an ecology-based economy, centred on eco-tourism.

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Introduction and background

New Zealand has no indigenous terrestrial mammals except for three rare species of bat, but over fifty introduced species occur wild or feral (King 2005). Collectively, invasive ungulates, mustelids and rodents have modified the natural vegetation and biota throughout the country, and caused extinctions in the avifauna (Atkinson 2006). Three species of rat (*Rattus exulans, R. rattus* and *R. Norvegicus)* are present throughout mainland New Zealand, and are considered to be the most detrimental of these invasive species (Atkinson 1985; Atkinson and Towns 2001; Innes 2001). Being omnivorous they are predators on birds, invertebrates, seeds and seedlings, thus causing ecosystem alteration at many points, often with cascading influences (Atkinson 1985; Towns et al. 2001; Campbell and Atkinson 2002). Rats are abundant in forest and scrub habitats, and on off-shore islands. Consequently much conservation management in New Zealand has concentrated on rodents, and methods for eradication on uninhabited islands are now well developed and generally successful (Clout and Vietch 2002). Such methods involve the aerial application of poisons, which are generally lethal to other mammals also. This has not been seen as a problem in conservation management because in most situations in New Zealand all terrestrial mammals threaten native ecosystems (Caut et al. 2007). However, there is strong opposition to the use of poisons from some quarters (e.g. deer-stalkers). Eradication of rodents from islands with substantial human communities, with mammalian pets and farm animals, has not yet been attempted.

Great Barrier is the largest off-shore Island in New Zealand, with a rugged mainly forested landscape covering c. 27,400 ha. The Department of Conservation administers 68%, but the remainder is mostly in private ownership. There are cleared areas around the four small townships and beaches, but much former farmland is now reverting to *Leptospermum scoparium* and *Kunzea ericoides* 'scrub'. The island is home to c.1,000 people, with at least as many landowners living off-shore. There are regular ferry and air services to the mainland.

Several endemic endangered New Zealand birds and lizards are present (Armitage 2004). Excepting rodents, feral cats, rabbits and pigs, significant vertebrate pests are absent. Ship rat (*R.rattus*), kiore (*R.exulans*) and mouse (*Mus musculus*) are the only rodents present. Their effects on indigenous birds are well recognised (Atkinson 1978, 1985), but they also have significant, but less understood, effects on forest regeneration (e.g. Dowding and Murphy 1994; Campbell and Atkinson 2002). Rats are also pests to humans, and island inhabitants spend considerable sums annually on their control.

Motu Kaikoura is a rugged island off the north-west coast of Great Barrier (Fig. 1). Rat eradication is planned for this island in 2009 (www.motukaikoura.org.nz). The island is uninhabited and the current proposal involves the aerial application of brodifacoum using established Department of Conservation protocols. This exercise, and the proposed predator-proof fence at Glenfern Sanctuary, on the main island nearby, will provide support for the total eradication of rodents on Great Barrier.

The Great Barrier Island Charitable Trust (GBICT: www.gbict.co.nz) was formed in 2002 with the aim of investigating the feasibility of the complete eradication of rodents, and other vertebrate pests, from Great Barrier Island. Linked with the existing scenic and ecological values of the island, the tourism potential of a rat-free status was seen by the foundation trustees as a strong economic incentive. The trust is currently presenting the ecological problems and uncertainties involved in aerial poison drops, and researching the potential economic benefits of a pest-free status. Research on the efficacy of trapping and poisoning for rat control has been carried out on Great Barrier by the Windy Hill Trust (www.gbict.co.nz/windyhillfacts.htm), Glenfern Sanctuary Trust (www.glenfern.org.nz) and Awana Catchment Trust (www.awana.co.nz)[1] since 1999. These three organisations are run by volunteer trustees, and financially supported by donations and grants from various local body and government sources. They currently provide part- or full-time income for at least sixteen people. However, eradication will require a much larger work-force, and long-term community support for conservation and biosecurity measures.

Fig. 1 Map of Great Barrier Island showing location of study sites. Inset, Great Barrier in relation to New Zealand

[1] Subsequently referred to as 'Windy Hill', 'Glenfern' and 'Awana', respectively.

In this paper we have two related goals. First we present data on rat trapping from the Awana Catchment and Windy Hill, and review unpublished data from Samaka (2004) and the Department of Conservation (Barker 1998, 1999). The efficacy of the long-term programme of rat trapping at Windy Hill, and ecosystem responses, are addressed. Secondly we discuss the role of community involvement in an eradication campaign, indicating some of the difficulties of rodent eradication on an island with multiple land-ownership titles, various controlling administrations and a population with disparate views on issues related to conservation, economy and development.

Methods

Study sites

The Awana study area contains coastal holiday homes and two farms, with areas of coastal flax (*Phormium tenax*), estuarine wetlands (mainly *Baumea* spp.), farmed paddocks, regenerating ‘scrub’ (*Letospermum scoparium* and *Kunzea ericoides*) and broadleaf forest communities in gullies (Ogden 2004). The total area in which trapping transects were set was c. 50 ha and the maximum altitude c. 20 m above sea level (asl). (Fig. 1)

The Windy Hill study area is predominately forested with kanuka ‘scrub’ (*Kunzea ericoides*). Broadleaf forest with a canopy of *Dysoxylum spectabile, Beilschmeidia* spp., and *Vitex lucens*, with *Rhopalostylis sapida* in the sub-canopy, occurs mainly on south-east facing slopes. Scattered *Dacrycarpus dacrydioides* occur in the gullies. The total study area comprises c. 450 ha and ranges in altitude from 100 to 300 m asl. Windy Hill is collectively owned, but there are only three occupied houses in the area. The trapped area includes the adjacent Benthorn Farm, which has rough grass paddocks with forest borders and a small macadamia nut orchard. The sites studied by Samaka (2004) were in mature kanuka scrub and forest, chosen for their similarity to sites at Glenfern Sanctuary.

At Okiwi, the area trapped by Barker (1998, 1999) was in the endangered brown teal (*Anas aucklandica*) habitat, comprising a mixture of estuarine wetlands (*Ampodesmia, Baumea* etc.) grazed and ungrazed paddocks, comparable with similar coastal vegetation at Awana.

Trapping

Rat trapping at Awana was intended to ascertain the annual pattern of abundance, and to investigate the relationships between the species and vegetation types, rather than to reduce rat numbers. Rats were trapped for 36 months from April 2001 until March 2004. Covered snap traps at ground level were used, baited with a paste of peanut butter and oats. Eight traps were maintained in each of five different vegetation types for three nights each month, giving 24 total trap nights for each vegetation type each month. Species, colour morph (for *R. rattus*: King 2005) age category, and sex were determined for each individual trapped. The rat-trap index was calculated to allow comparison between vegetation types and data from elsewhere. This index is a measure of rats caught per 100 trap nights, corrected for potential trap nights lost due to captures and sprung (empty or by-catch) traps (Cunningham and Moors 1996).

At Windy Hill, trap type, bait, layout and area covered changed during the growth of a rodent control and ecosystem recovery programme (Smit et al. 2002; Smit and Ferreira 2001), which is continuing. Since 2002 the recording methods have been standardised, with covered ground traps at 25 m intervals on tracks along the contours of the study area, and 12.5 m intervals around its periphery. Dense trapping has also been employed in the orchard and around farm buildings at Benthorn Farm. Traps were generally baited with macadamia nuts, peanuts or a cereal bait. Perimeter traps were monitored twice per week, and internal traps weekly to 3 weekly depending on the season. When an animal was caught its species (only) was recorded. Any ‘by-catch’ (birds) was also noted. If nothing was caught, the condition of the trap (set-off or still sprung) and bait (present or absent) was noted.

At Okiwi 50 terrestrial snap-traps were set in pairs at 25 locations and monitored for four nights each month from July 1998 to June 1999 (Barker 1998, 1999). The traps were caged to prevent by-catch and baited with peanut butter and oats.

Tracking tunnels

In order to support the translocation of robins (*Petroica longipes*) to Windy Hill and Glenfern the Department of Conservation requested data derived in a standardised manner from “tracking tunnels”

(Brown et al. 1996). Tracking tunnels have a food source at the centre and ink-pads at each entrance, so that rodents entering the tunnel for the food leave tracks on a recording sheet. The rodents are not killed, and the aim of the exercise is to get an independent estimate of rodent abundance. The track recording sheets are collected after one night and the percentage of tunnels with evidence of rats is obtained. Samaka (2004) also employed tracking tunnels to demonstrate the reality of differences between managed and control areas at Glenfern and Windy Hill.

In June 2004, 120 baited tracking tunnels were set out at 25 m spacing on two tracks at Windy Hill. The tracking exercise was run again in October 2004, and in January and April 2005. At the latter date 58 tunnels were also employed at Benthorn Farm, also on 25 m spacing. This programme is continuing, but spacing has been increased to 50 m to reduce the likelihood of one rat entering two or more tunnels in the same night. The earlier data have been adjusted by using only results from every other tunnel (i.e. 50 m spacing).

Poisons

Poison was not used at Awana or Okiwi. At Windy Hill the trapping regime was augmented with the seasonal 'pulsed' use of ferocol poison baits in 2006. Baits are put out close to the trap locations twice a year in June/July and December/January. They are left in place, attached to a tree at c. 30 cm height, for 5 or 6 weeks.

Monitoring/census techniques for native species (birds, lizards, invertebrates and plants)

A comprehensive system of bird monitoring has been in place at Windy Hill since 2001. Twelve transects each with four sample points are monitored seasonally, with six in valleys and six on ridges. A 3-minute bird count is carried out at each point 6 times ($6 \times 4 \times 12 = 288$ counts) each season. Since 2006, similar counts have also been made in an adjacent control (non-managed) area. Monitoring for invertebrates and lizards has also been carried out monthly in the control and managed areas; ten 'weta houses', comprising a strip of bamboo nailed to a tree are in place in each area, and the same number of 'lizard motels'. The latter are 5 layers of Onduline (corrugated card) c. 40 cm square, with the layers separated c. 0.7 cm by strips of bamboo. Invertebrates also inhabit these motels, and were counted. Seedlings of the important tree species whose seeds are known to be predated by rats (*Beilschmeidia taraire, Dysoxylum spectabile, Vitex lucens, Dacrycarpus dacrydioides* and *Rhopalostylis sapida*) are monitored in five 4 m^2 quadrats in each area. Similar methods, but using ten quadrats in each of two vegetation types (kanuka and broadleaf forest) were used to compare rat-managed and control areas at Glenfern and Windy Hill by Samaka (2004).

Statistical analyses

Population cycles are presented graphically. Differences between species, and between male: female and adult: juvenile ship rat abundance in different vegetation types at Awana were assessed using Chi squared tests on the assumption that no difference is expected. Linear regression lines were fitted to trends in ship rat index against number of traps over time at Windy Hill and Benthorn Farm. Seedling number differences between managed and unmanaged (control) areas were examined by separate t tests for each species. The data of Barker (1998, 1999) were plotted and the relationship between the numbers of rats and mice caught analysed using the correlation coefficient ('r').

Community outreach

Methods for rodent eradication used successfully on uninhabited islands—aerial poison drops—are difficult to apply on Great Barrier, due to multiple ownership of land, dispersed drinking water sources, problems with domestic animals and divergent community views on the subject. Recognising that community support was essential before the various agencies would take the case seriously, the GBICT embarked on a programme of community education and involvement. The Trust also encouraged local research on rodents and publicised the results on Great Barrier. The emphasis was initially on establishing credibility with funding bodies and administrative agencies, which often require scientific evidence, but later on community education. Part of the Trust's initial strategy to gain information on the level of community support was to run a questionnaire about researching rat and feral cat eradication.

The GBICT trust produces a quarterly newsletter. It has organised public lectures and workshops involving local and national experts, open-days at Windy Hill and Glenfern Sanctuary, and written letters to the local paper and items in national publications. More direct participation by local people has been achieved by organising quarterly bird counts, and (in 2006), running day excursions to Tiritiri Matangi Island—a nearby open-sanctuary maintained by the Department of Conservation, with an extensive community-led reforestation programme, and many indigenous birds formerly present on Great Barrier.

Results

Awana

Population cycles in different vegetation types

Although rat abundance apparently varied in different communities from year to year, there was a clear overall seasonal pattern (Fig. 2). Peak abundance was reached in late summer or autumn (March–May), while numbers were lowest in spring (September–November). This cycle was most evident where rats were most abundant: coastal flax (*Phormium tenax*) communities, riparian vegetation dominated by 'rushes' *(Baumea* spp.) and mature forest. The latter has a canopy dominated by *Beilschmeidia* spp., *Dysoxylum spectabile* and scattered large *Vitex lucens*. In contrast there was relatively less annual variation in pasture and scrub communities (mainly *Leptospermum scoparium* and *Kunzea ericoides*) where numbers remained low all year. Note that the spring low point was similar in all communities, except pasture, where rats were often apparently absent due to flooding in late winter.

Species, sex and age structure

Males were caught more often than females, with no significant difference between vegetation types (Fig. 3a). However, the relative proportions of juveniles and adults showed clear patterns, with significantly more juveniles in the riparian rushes, and more adults present in mature forest (Fig. 3b). The abundance of juvenile rats recorded in flax and riparian vegetation implies that these are important breeding sites, supporting the overall numerical increase in these

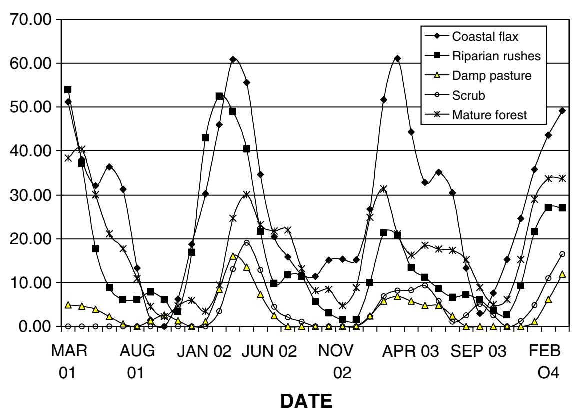


Fig. 2 Ship rat index over 3 years in various plant communities at Awana, Great Barrier Island

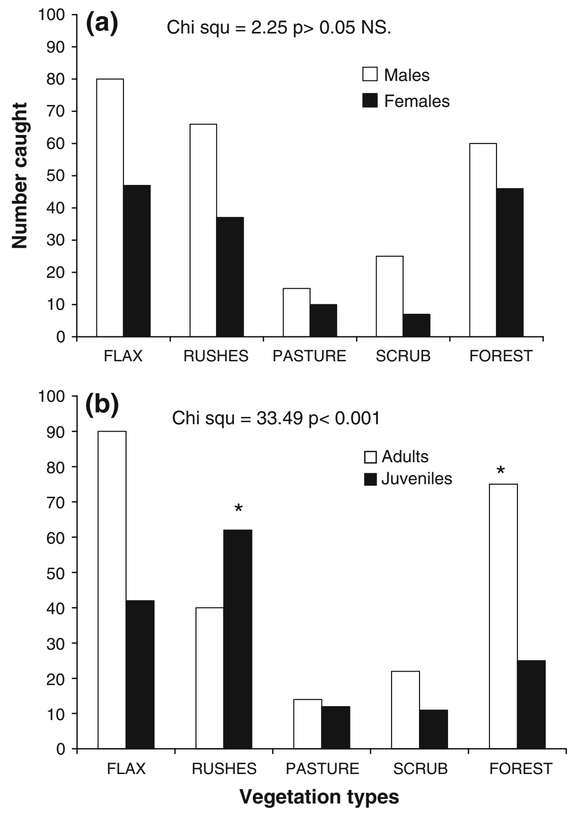


Fig. 3 **a** Relative proportions of male and female ship rats caught over 3 years in different vegetation types at Awana, Great Barrier Island. **b** Relative numbers of adult and juveniles caught in different vegetation types. *Asterisks* indicate significant differences between categories in vegetation types

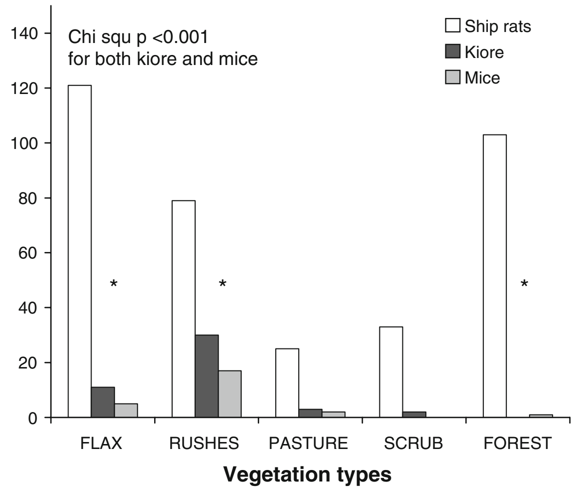


Fig. 4 Rats (*Rattus rattus*), kiore (*R. exulans*) and mice (*Mus musculus*) caught in different vegetation types over 3 years at Awana, Great Barrier Island. The differences between species are significant for the flax and rush dominated communities, and for the forest. *Asterisks* indicate significant differences between species within vegetation types

vegetation types over the summer. Significantly more kiore (and mice) were also caught in the riparian habitat, and significantly fewer in forest (Fig. 4).

Windy Hill and Benthorn Farm

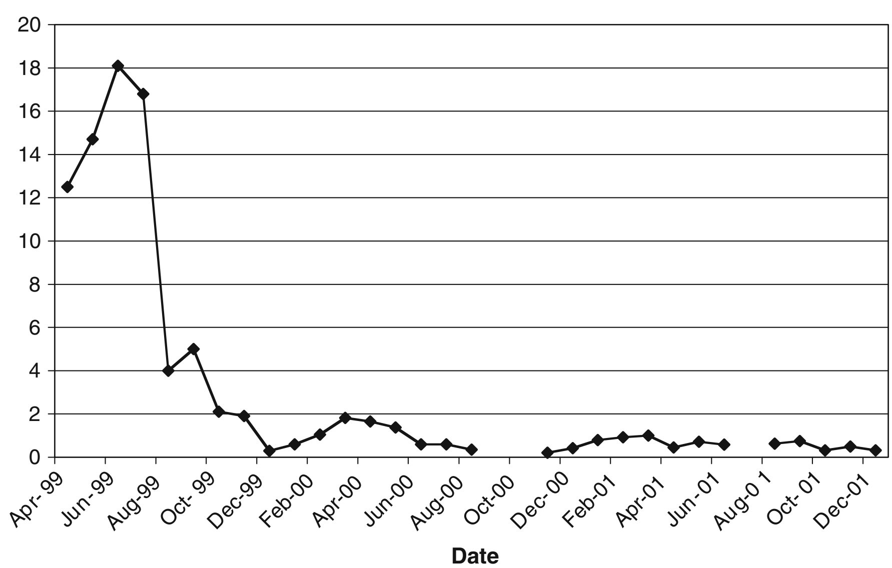
Seasonal changes in rodent numbers

Rat-trap indices were initially similar to those in similar vegetation at Awana, but declined markedly as trap numbers increased (Fig. 5). Indices in similar vegetation types in the same years at Windy Hill (with continuous large scale trapping) and Awana (with traps baited for only 3 days per month) were generally c. 10 times higher at the latter. However, ship rat numbers at Windy Hill and Awana, follow the same annual pattern, with peaks in March or April and low points during winter or spring (Fig. 6), confirming the island-wide nature of this cycle. The tendency for kiore peaks to be off-set with respect to ship rats, is confirmed also by unpublished data over the same period at Benthorn Farm where kiore and mice are much commoner than at Windy Hill (Table 1). A further trend noticed is that the month of peak abundance at Windy Hill has varied more as numbers have declined.

Trapping efficacy: index results and tracking tunnels

The efficacy of the trapping regime at Windy Hill and Benthorn Farm was initially assessed by examining the rat-trap index in April (peak numbers) and September (low numbers) in relation to the number of traps employed in different years (Fig. 7). This suggested that although the peak numbers declined with increased trapping effort, the winter surviving population remained unchanged. However, by 2004 the rat-trap index numbers were low throughout the year (generally <1.0), so the initial high tracking tunnel results were unexpected: the number of tunnels tracked by rats ranged from 30 to 78% in 2004 and

Fig. 5 Changing rat catch index at Little Windy Hill 1999–2001



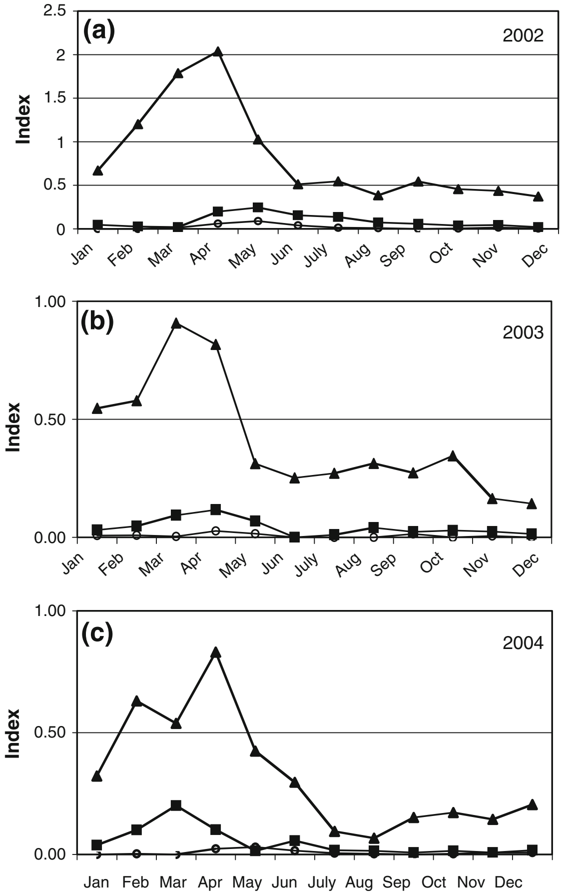


Fig. 6 The annual pattern of ship rat (*triangles*), kiore (*squares*) and mouse (*circles*) abundance at Windy Hill in **a** 2002, **b** 2003 and **c** 2004. Index is the corrected catch per 100 trap nights. Note that the kiore peak is off-set from the rat peak by 1 month after (2002, 2003) or before (2004)

2005. This was considered much too high: a figure of 5% had been set by the Department of Conservation as a guideline for bird reintroductions. As a consequence the trapping regime was augmented by the seasonal use of ferocol poison baits. In addition, an un-trapped/un-poisoned area was set up with tracking tunnels to act as a 'control'. The combination of trapping and 'pulsed poisoning' subsequently brought the tracking tunnel % down to <5%, while they remain at 70–80% in the control area (Fig. 8). The initial tunnel monitoring was monthly, but as it was suspected that individual rats were habituating to the monthly presence of a food source and setting territory boundaries accordingly, monitoring was reduced to 3-month intervals to mitigate this.

Okiwi

Interactions between rats and mice

Monthly rodent trapping by Barker (1998, 1999) at Okiwi demonstrates the annual population cycle and clear negative interactions between rats and mice. (Fig. 9).

Ecosystem level changes

Vegetation

Samaka (2004) carried out a small comparative study of seedling numbers in managed and unmanaged areas of kanuka (*Kunzea ericoides*) and broadleaf forest (*Dysoxylum spectabile,* and *Beilschmeidia* spp., canopy with *Rhopalostylis sapida* in the sub-canopy) at Windy Hill and Glenfern Sanctuary. He concluded that seedlings of large seeded tree species were significantly commoner in the treated than in the untreated areas. This was particularly clear for nikau palm (*Rhopalostylis sapida*), a species whose seeds are known to be eaten preferentially by rats (Campbell and Atkinson 2002) (Fig. 10). Comparison of seedling numbers in control and managed plots in November 2006 and April 2007 confirmed the greater abundance of nikau (*Rhopalostylis sapida*), puriri (*Vitex lucens*), kahikatea (*Dacrycarpus* dacrydioides) and tarairi (*Beilschmeidia tarairi*) in the managed area.

Birds

Samaka (2004) also counted birds in managed and unmanaged forest habitat. Kaka (*Nestor meridionalis*) and kereru (*Hemiphaga novaeseelandiae*) were both more abundant in the managed compared to unmanaged broadleaf forest, presumably reflecting the greater abundance of fruit in the managed stands. Small insectivores such as grey warbler (*Geregone igata)* and fantail (*Rhipidura fuliginosa*) were also generally more abundant in the managed kanuka stands than they were in the equivalent unmanaged vegetation.

At Windy Hill populations appear to have increased for most bird species since the commencement of rat control (Ferreira 2007a, b). The high fledging success rate of the translocated robins (*Petroica australis*) is further evidence of a very low rat population. Lack of any significant difference between the 2006 control

Table 1 Relative proportions of different rodents caught in three study areas 2001–2004

Site	Year	Trap no.[a]	Ship rat	Kiore	Mouse	Total rodent	Kiore % rats	Mouse % rodents
LWH forest[b]	2001	322	784	102	18	908	**11.5**	2.0
	2002	699	2,069	222	52	2,343	**9.7**	2.2
	2003	943	1,366	138	23	1,527	**9.2**	1.5
	2004	1,301	1,469	230	35	1,734	**13.5**	2.0
BHF pasture[c]	2001	NR	320	248	189	757	**43.7**	25.0
	2002	361	782	338	118	1,238	**30.2**	9.5
	2003	409	1,065	282	248	1,347	**20.9**	18.4
	2004	657	1,176	284	234	1,694	**19.4**	13.8
ACT flax	2002	40	46	4	2	52	**8.0**	3.8
	2003	40	45	5	1	51	**10.0**	2.0
ACT rushes	2002	40	34	10	7	51	**22.7**	13.7
	2003	40	19	12	8	39	**38.7**	20.5
ACT pasture[d]	2002–2003	40	17	3	0	20	**15.0**	0.0
ACT scrub[d]	2002–2003	40	25	2	0	27	**8.0**	0.0
ACT forest[d]	2002–2003	40	72	0	1	73	**0.0**	1.4

NR not recorded

[a] Median number of traps employed throughout the year at LWH and BHF; traps employed 3 days/month at ACT, for 12 months; 2001 and 2004 data excluded as full annual cycle not covered

[b] Mature forest, regenerating forest with kanuka, manuka on ridges

[c] Mixed farm with grassland, orchard and regenerating scrub

[d] Years combined due to absence of kiore or mice in most years

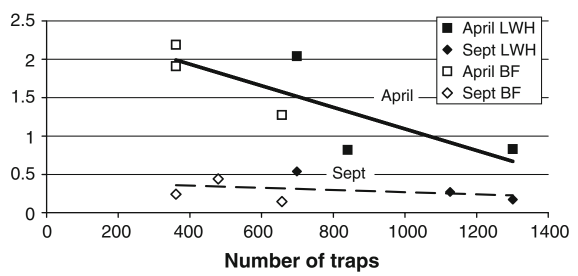


Fig. 7 Ship rat-index versus number of traps in use at LittleWindy Hill (LWH) and Benthorn Farm (BF), 2002–2004. *Squares* and *solid* line: indices at April peak; *diamonds* and *dashed line*, indices in September

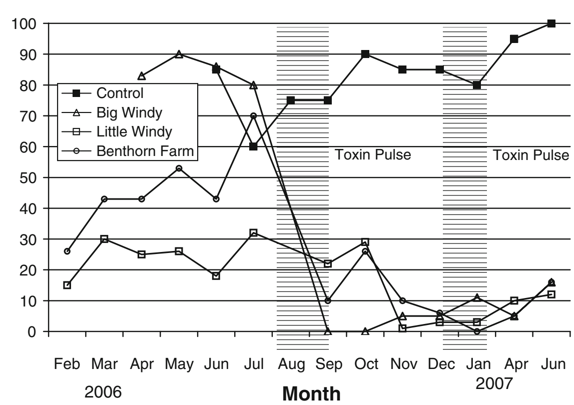


Fig. 8 Tracking tunnel results (% of tunnels with rat tracks) before and after ferocol bait exposure at two sites at Windy Hill (Little and Big Windy), Benthorn Farm, and an adjacent (un-trapped, un-poisoned) control area. Note the contraction of the *x* axis for the 2007 data, when tracking tunnels were monitored only in January, April and June

site and the managed area counts could possibly be because the study sites are too close together (c. 0.7 km apart), so that the control may benefit from a bird "spill-over" effect. However, numbers in the control were still lower on average for most species.

Invertebrates and lizards

The weta and lizard results illustrate the severe impact of rats in the unmanaged area (Table 2), where only one weta was recorded over the year. In contrast, up to 40% of the weta houses in the managed area were occupied, commencing immediately. Lizard motels showed equally dramatic differences, with one, two or three ornate skinks (*Cyclodina ornata*) present under the Onduline in the managed area every month except

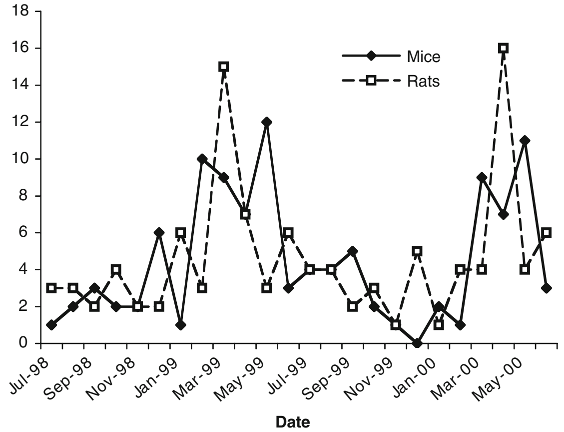


Fig. 9 Mouse (*Mus musculus*) (*filled diamonds* and *solid line*) and rat (*R.rattus*) (*open squares* and *dotted line*) over two annual cycles (July 1998–May 2000) at Okiwi, Great Barrier Island. Modified after Barker (1998, 1999). If the data are standardised to remove the annual cycle the correlation (r) between mouse and rat abundance is -0.583 ($n = 24$; $P < 0.01$)

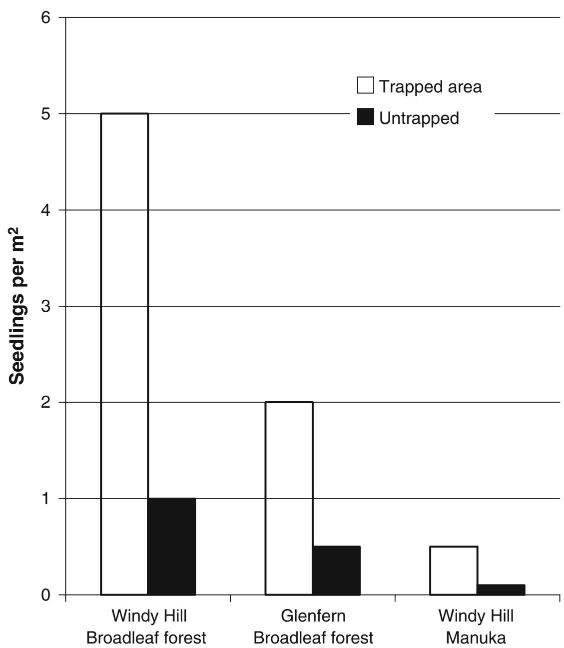


Fig. 10 Nikau (*Rhopalostylis sapida*) seedling abundance in trapped and un-trapped areas. Modified after Samaka (2002). All differences significant at $P < 0.05$

the first, but none recorded in the control area. However, the 12-month totals for insects, amphipods, spiders and slugs counted under the Onduline did not show a significant difference between the two study sites and in fact there was a slight excess in the control areas for all groups except the rare paua slug, which was confined to the managed area. These results indicate a need for caution in drawing generalisations from the weta and lizard results.

By-catch

By-catch was monitored at Windy Hill and Awana. Dead bird by-catch was <1% of the rodents trapped (Ogden and Gilbert 2005). The only indigenous bird with conservation value caught was banded rail (*Rallus philippensis*), and modification of the trap covers has prevented this. Otherwise all birds caught were introduced passerines with high reproductive rates—blackbird (*Turdus merula*), song thrush (*Turdus philomelus*), dunnock (*Prunella modularis*), silvereye (*Zosterops lateralis*) and finches (Fringillidae).

Community support

Our initial questionnaire demonstrated strong support for our aims, with over 90% of 558 respondents supporting continued research on rat and feral-cat eradication.

Since then our support base has grown among off-island organisations, and possibly locally. Open-days and bird counts were well supported, with 60–70 people at the former and 36 people volunteering a day (or more) for the latter. Evening lectures by 'experts' on rat ecology (John Innes) and island eradication methods (Alan Saunders) were not well attended. Part of the Trust's research on the technical feasibility of eradication involved the relative merits of various types of toxins and methods of application, and a study of successful and less-successful rodent eradications elsewhere. Papers and information relating to this topic were placed in a box in the local library and discussed in our Newsletter. However, in 2006 a segment of the population, supported by antagonistic editorial comment in the local paper, thought that the trust was advocating stricter controls on personal freedoms and the use of aerial poison drops, and signed a petition against continued research.

Despite this set-back, and the acknowledged difficulty of measuring support, community awareness of the fragile status of some of the currently endangered birds on the island appears to be growing, and is being translated into pest control in some areas.

Table 2 Comparison of LWH and control area using weta (*Hemideina* spp.) and skinks (*Cyclodina ornata*) as indicators of ecosystem health

Date	Number of weta houses occupied LWH[a]	Number of lizard motels with skinks present LWH	Number of weta houses occupied in control area	Number of lizard motels with skinks in control area
Jul-06	3	0	0	0
Aug-06	4	1	0	0
Sep-06	3	1	0	0
Oct-06	3	3	0	0
Nov-06	4	3	0	0
Dec-06	1	2	0	0
Jan-07	3	1	0	0
Feb-07	4	2	1	0
Mar-07	2	1	0	0
Apr-07	3	1	0	0
May-07	4	2	0	0
Jun-07	2	1	0	0

[a] Ten houses and motels in each area

After 5 years of activity the Trust has established a 'local identity', and is now working within a more informed and sympathetic societal framework than that in which it started.

Discussion

Rodent population ecology and trapping

The studies reported here had varying degrees of planning by professional scientists, but they were mostly carried out by individuals with little training in experimental design or statistical rigour. Due to practical or logistic considerations, standardisation of methods throughout a study, randomisation of treatments and proper replication were not always possible. These criticisms do not apply equally to all the studies, but even the 3-year study at Awana was (strictly) pseudo-replicated, rendering 'treatment' (vegetation type) comparisons statistically questionable. Basic skills such as species identification were often learned during the course of a monitoring programme: kiore (*R. exulans*) can be readily confused with juveniles of the '*alexandrinus*' morph of *R. rattus*, and if these have been confused both species composition and age structure are in doubt. However, these problems were recognised and have been addressed during the analyses presented. The Windy Hill studies in particular are based on large amounts of data, replication over years, and cross-checking between observers, giving confidence in the results.

At Awana, all three rodent species were most abundant in lowland riparian and coastal flax (*Phormium tenax*) vegetation. The abundance of juvenile rats recorded in these vegetation types implies that these are important breeding sites, resulting in the numerical increase in them over the summer. In contrast, while ship rats may be seasonally very abundant in mature forest also, the other species are not—at least in the presence of ship rats. Presumably the more arboreal nature of ship rats allows them to take advantage of fruit crops while they are still on the tree. An important conclusion—supported by observations at Windy Hill—is that rodent numbers are generally lowest in manuka (*Leptospermum scoparium*) and kanuka (*Kunzea ericoides*) scrub or forest. Together these constitute the predominant vegetation cover on Great Barrier, including most of the Department of Conservation estate. Thus, areas with high rodent populations are predictably located within a generally lower background population for much of the island. Also, the annual population cycle is similar in different years, locations and vegetation types, reaching its lowest in late winter or spring. These two results have implications for both the spatial and temporal aspects of control or eradication.

When they are numerous, ship rats appear to exclude kiore from forest habitats, restricting them to rough grassland or riparian vegetation. Where both species are present, ship rats invariably predominate. Mice are commoner in grassland (e.g. at Benthorn Farm) and riparian rushes (e.g. at Awana) and only occurred in forest at Windy Hill when rat numbers were much reduced. The off-set peak in abundance shown by kiore in relation to ship rat trap captures may indicate that the latter exclude kiore from food sources. This situation is even more marked between rats and mice, which seem to be negatively correlated in abundance. The results imply that were rats (only) to be removed, the mouse population could explode, at least in farmed land and riparian vegetation. The implication of a dominance hierarchy: *R. rattus* > *R. exulans* > *M. musculus* is not unexpected based on respective weights, but has important implications for their control (Caut et al. 2007).

At Windy Hill an intensive trapping programme apparently reduced rat numbers to very low levels compared to those existing before trapping, and compared to those in equivalent vegetation types at Awana. However, this reduction was largely in the late summer peak, rather than the over-wintering population, so that the potential to increase rapidly, should trapping cease, remained. Moreover tracking tunnels indicated that low rat-trap indices did not necessarily reflect low rat numbers; apparently several years of trapping had selected for a trap-shy population. The Windy Hill monitoring has shown that trapping alone is not able to reduce rat numbers to levels at which robins (*Petroica longipes*) are likely to survive, but trapping combined with toxin pulses at bait stations can do so. The rat population at Windy Hill is now clearly very low, whatever measure of abundance is used. The challenge is to obtain sufficient funding to maintain this situation.

Most of the forest vegetation at Awana, Windy Hill and Glenfern is regenerating forest following cessation of farming in c. 1940. The ridges have reverted from grassland to manuka and/or kanuka 'scrub', in some cases over the last 10 years (personal observations). Rates of change are probably greatest in the mid-slope kanuka stands, which are being invaded by (mainly) hardwood forest species, which form the canopy in adjacent gullies (Ogden and Perry 2005). In the mature forest areas the monitoring results indicate that reducing rats to rat-trap index levels <2, and tracking tunnel percentages to c. 5%, has had a beneficial effect on ecosystem processes. This is demonstrated in the vegetation by an observed increase in fruit- and seed-fall, and by the monitored seedling survivorship. Seedlings of large seeded canopy tree species appear to be more abundant, and frugivorous birds commoner, in the managed areas. Although these results are based on small-scale field studies, they are in line with those of Campbell and Atkinson (2002). We conclude that rat reduction will facilitate the transition from kanuka to broadleaf forest on mid-slope sites. Relatively uncommon tree species with palatable seeds (eg. *Pittosporum eugenioides, Melicope ternata*) may also be benefiting. Abundant ripe fruit on nikau palms (*Rhopalostylis sapida*) is the clearest indicator of forest recovery.

The Windy Hill monitoring work demonstrates also increased survivorship of large invertebrates (eg, wetas) and skinks in the managed areas. Small insectivorous birds may also be doing better, as indicated by Samaka's results and the success of the translocated (insectivorous) robins.

However, all these changes represent an increase in potential food for rats, and increase the likelihood of rapid population growth should control be relaxed. Moreover, as there are fewer occupied territories close to the margin of the control area, boundary invasion remains a constant threat.

The possibility of a mouse 'explosion' following rat eradication has already been raised. But all introduced mammals and many native birds on Great Barrier interact through competition and predation in a trophic web, and the consequences of removing any one of them cannot be readily predicted. For example, feral cats prey mainly on rabbits, but rats comprise an unknown proportion of their diet. Rabbits have recently been reduced by an outbreak of rabbit haemoragic (colesi) virus. Consequently, elimination of rats could well bring greater predation pressure from feral cats on endangered reptiles and ground nesting birds, such as brown teal (*Anas aucklandica*), black petrel (*Procellaria parkinsoni*) and New Zealand dotterel (*Charadrius obscurus*). Even with this over-simplified analysis it is clear that pest species inter-interactions, and their potential effects on endangered native species, pose a problem for any planned rat elimination. The obvious solution is to eliminate or severely control all the mammalian pests simultaneously, but this poses huge technical problems (for mice) and social problems in the case of cats and rabbits. The former are often regarded as harmless or even beneficial by cat-lovers, while the latter are a significant food source for some members of the community.

Community outreach

In all cases in which rodents have been eradicated from large *uninhabited* Islands the method has been aerial application of poison baits (Clout and Vietch 2002). Great Barrier Island is larger than any island from which rats have been eliminated to date (Campbell Island: 11,300 ha), and has a human population employed in farming, tourism and other commercial activities. This means that methods employed successfully elsewhere cannot be simply up-scaled; a different approach is required, both to eradication and to subsequent bio-security. Community support is vital, because without it access to private property may be denied or the project sabotaged in other ways.

Most people on Great Barrier are supportive of the GBICT's rat eradication campaign, but do not believe it will succeed, and do not support aerial application of toxins. Also, many islanders do not see any link between rats and the local economy, except in the context of being a nuisance around houses. Feral cats, and other ecosystem interactions, are seen as irrelevant by some and as insurmountable problems by others.

The GBICT planned to investigate the boost to the local economy that could follow if unequivocal support for a rat and feral cat eradication programme was forthcoming from the community. There are indications that the new Community Board[2] is more aware of the objectives of the trust, and recognises the potential advantages of a pest-free status to eco-tourism and the island's economy.

The ideal of a "bottom-up" approach to rodent eradication, led by the local community, is difficult to achieve because (1) there is a general lack of appreciation of the ecological damage done by rodents and consequently low priority placed their elimination; (2) community members advocating conservation measures affecting everyone's land and Island-wide biosecurity may be treated with suspicion; (3) there is no clear pathway through the plethora of regulatory barriers, which must be addressed. There are numerous points at which "top-down" regulatory authorities such as the Department of Conservation or the Regional and City Councils can delay decisions, especially those which relate to matters for which they have no clear mandate. All of these factors have been at play in the case of Great Barrier Island.

An important lesson learned from the work at Windy Hill is that rodent control (and, by extension, rodent eradication) is most effective if a variety of techniques are employed in a planned sequential manner. It is apparent that rodent numbers vary through the season and that species composition varies spatially, implying that control methods should take account of these facts. Community views indicate that overall application of a toxin, at least near dwellings, is unacceptable. These considerations immediately suggest that multiple methods for rodent mortality will be required; toxins must be only part of the approach to eradication on Great Barrier Island, applicable in some areas only. However, the details of any methodology will change as new, more specific toxins become available. The relative inefficiency of trapping indicates that a major effort in this regard will also be required in selected non-toxin zones, probably mobilising a considerable proportion of the population. The detailed planning required far exceeds anything yet attempted in pest eradication.

Science tends to be communicated to scientists. When results are disseminated to less critical audiences many of the caveats are discarded, giving them a false aura of certainty. Striking the balance between clear, honest explanation and acknowledged uncertainty is often difficult, especially where emotional issues such as the broadcasting of mammalian toxins, are involved. Community education, consultation and involvement are at the core of any large-scale pest control operation in inhabited areas.

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[2] The Community Board is an elected statutory body advising to the Auckland City Council.

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