Seedling recovery on Hauturu/Little Barrier Island, after eradication of Pacific rats *Rattus exulans*

DOC RESEARCH & DEVELOPMENT SERIES 325

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DOC RESEARCH & DEVELOPMENT SERIES 325

Published by
Publishing Team
Department of Conservation
PO Box 10420, The Terrace
Wellington 6143, New Zealand

DOC Research & Development Series is a published record of scientific research carried out, or advice given, by Department of Conservation staff or external contractors funded by DOC. It comprises reports and short communications that are peer-reviewed.
This report is available from the departmental website in pdf form. Titles are listed in our catalogue on the website, refer www.doc.govt.nz under *Publications*, then *Science & technical*.

ISSN 1177-9306 (web PDF)
ISBN 978-0-478-14911-1 (web PDF)

This report was prepared for publication by the Publishing Team; editing by Sue Hallas and layout by Lynette Clelland. Publication was approved by the General Manager, Research and Development Group, Department of Conservation, Wellington, New Zealand.

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Seedling recovery on Hauturu/Little Barrier Island, after eradication of Pacific rats *Rattus exulans*

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ABSTRACT

Pacific rats (*Rattus exulans*, kiore) eat seeds and seedlings of native plants. Seedlings of selected woody plants on Hauturu/Little Barrier Island were counted in 18 linear plots twice before rat eradication in 2004, and again 4 years after. All seedlings ≤30 cm tall were measured and grouped into 5-cm classes. The same species were counted at the same time on rat-inhabited Taranga Island and Great Barrier Island (Aotea Island), and the ratios of post-eradication to pre-eradication seedling numbers on the control islands were used to predict likely post-eradication seedling numbers on Hauturu. Post-eradication numbers of 14 species increased more on Hauturu following rat eradication than on the control islands, listed here in descending order of increased abundance: *Pisonia brunoniana*, *Coprosma macrocarpa*, *Ixerba brexoides*, *Knightia excelsa*, *Rhopalostylis sapida*, *Phyllocladus trichomanoides*, *Nestegis lanceolata*, *Dacrycarpus dacrydioides*, *Ripogonum scandens*, *Hedycarya arborea*, *Dysoxylum spectabile*, *Pittosporum umbellatum*, *Macropiper excelsum* and *Corynocarpus laevigatus*. Five species had fewer seedlings: *Agathis australis*, *Beilschmiedia tawa*, *Beilschmiedia tarairi*, *Vitex lucens* and *Prumnopitys ferruginea*. Small seedlings of 11 other species, not systematically counted previously, were searched for in 2008 and 2009. Seedlings of *Coprosma arborea*, which was not monitored, were very abundant in 2009. Several less-common, rat-affected species have not yet responded. Early changes in seedling abundance indicate that rats have influenced the vegetation composition of the modified part of the island. No evidence was found for any suppression of the spread of kauri (*Agathis australis*) into kānuka (*Kunzea ericoides*) forest, but Pacific rats had inhibited the spread of some bird-dispersed species into kānuka forest.

Keywords: nature reserve, rat effects, rats, juvenile recruitment, indigenous forest, island restoration, New Zealand

Campbell, D.J. 2011: Seedling recovery on Hauturu/Little Barrier Island, after eradication of Pacific rats *Rattus exulans*. *DOC Research & Development Series 325*. Department of Conservation, Wellington. 53 p.

1. Introduction

The Pacific rat or kiore (*Rattus exulans*) is now considered to have arrived in New Zealand with Polynesian migrants c. 1280 AD (Wilmshurst et al. 2008). Pacific rats became widespread on the New Zealand mainland and reached most offshore islands that Māori inhabited or visited regularly except for a few islands, most of which had poor anchorages for canoes (Atkinson 1986). The consensus opinion in the late 19th century was that the Pacific rat was a 'harmless vegetarian species' (Colenso 1891; White 1895), but little was known then about the Pacific rat's diet, let alone any effect that it may have had on any of its varied food species. Until the middle of the 20th century, it was considered that the Pacific rat had little effect on either New Zealand's native fauna or flora (Wodzicki 1950). Research since the mid-1960s has progressively redefined the severity of the impact of the Pacific rat on many groups of native animals and plants, including birds, reptiles, arthropods, molluscs and vegetation (Campbell & Atkinson 1999, 2002; Atkinson & Towns 2005; Towns et al. 2006). In particular, it has been shown that Pacific rats, through destroying seed and eating seedlings, depress juvenile recruitment and influence forest regeneration (Campbell 1978; Campbell et al. 1984; Campbell & Atkinson 2002). This is consistent with other parts of the world, where small mammals have influenced forest succession and canopy composition by eating seeds and seedlings (Crawley 1990, 2002).

For almost 600 years, the Pacific rat was the only introduced mammal that could have directly affected the regeneration of any plants in the New Zealand flora: the question arises of how much influence this rat exerted on the composition of mainland forests. Because mainland New Zealand now has other rodent species, and a suite of other introduced mammalian herbivores, the role of the Pacific rat in forest regeneration has become difficult to isolate from numerous other factors. Fortunately, New Zealand has the unique distinction of having pioneered successful methods of ridding islands of rats (Taylor & Thomas 1993; Thomas & Taylor 2002; Towns & Broome 2003). As a result, various islands that previously had Pacific rats are now clear of them. Regeneration of tree species on these islands can be compared with that on islands that had never had these rats, as well as that on islands where Pacific rats were still present (Campbell & Atkinson 2002). Rat-proof exclosures on islands that have rats can be used to investigate the effect of rats on individual species, either by measuring differences in seedling establishment from natural seed fall (Campbell 1978), or by using added seed and comparing seedling establishment with that of nearby control areas (Campbell & Atkinson 2002).

Evidence gleaned from husking station studies and other field observations (Campbell 1978; Campbell et al. 1984; Bunn & Craig 1989) has established a partial list of plant foods of Pacific rats, that has a bias towards species that have durable seeds. Other studies have gradually extended this list of plant foods (Campbell & Atkinson 1999, 2002; Campbell 2002). Exclosure trials and comparisons of tree populations on islands of differing rat status (Campbell & Atkinson 2002) have confirmed the negative effects of Pacific rats on seeds and seedlings on some species (Campbell 1978; Campbell et al. 1984; Campbell & Atkinson 2002), and have shown that they inhibit regeneration of many forest trees. In these exclosure trials, and in the post-eradication tree populations on other islands, rat effects on seedlings could not be separated from their effect on seeds. Other studies in New Zealand have investigated forest regeneration and seedling changes after Norway rat (*Rattus norvegicus*) eradication (Allen et al. 1994), and the effects of possums (*Trichosurus vulpecula*) and ship rats (*R. rattus*) on seedling populations (Wilson et al. 2003).

It is not known exactly when Pacific rats became established on Hauturu/Little Barrier Island (hereafter Hauturu), but a very early arrival is indicated by the absence of coastal maire (*Nestegis apetala*)[1] and milk tree (*Streblus banksii*); species that have a widespread coastal distribution on other northern islands[2] and are very susceptible to seed consumption by Pacific rats (Campbell & Atkinson 2002). Two rat-proof exclosures were constructed on Hauturu in 1996 because the island was one of a few remaining sizable islands upon which Pacific rats were still found. Seedling establishment in exclosures that received added seed of selected species was compared with that of control areas open to rats, to determine the magnitude of differences in establishment success when rats were excluded (Campbell & Atkinson 2002). Most of these exclosure trials determined whether Pacific rats affected seedling establishment of tree species that were widespread on other islands so that results from exclosures could be compared with seedling response after rat eradication. Cumulative frequency curves of size classes were used to compare tree populations on Hauturu and other islands on which the rat status differed, to determine whether juvenile recruitment had been affected (Campbell & Atkinson 2002).

Using the above techniques, reduced seedling abundance and depressed juvenile recruitment in the presence of Pacific rats had been demonstrated for at least 23 species and at least eight others also appeared to be affected (Campbell & Atkinson 1999, 2002; Campbell 2002). Specifically, post-rat eradication increases in the number of seedlings had been confirmed for 11 rat-affected species: coastal karamū (*Coprosma macrocarpa*), coastal māhoe (*Melicytus novae-zelandiae*), coastal maire, karo (*Pittosporum crassifolium*), kohekohe (*Dysoxylum spectabile*), milk tree, nīkau (*Rhopalostylis sapida*), parapara (*Pisonia brunoniana*), taupata (*Coprosma repens*), tawāpou (*Pouteria costata*) and white maire (*Nestegis lanceolata*) (Campbell & Atkinson 2002). Post-rat eradication increases in seedling numbers had been recorded for populations of some other species, including fivefinger (*Pseudopanax arborea*), houpara (*P. lessonii*), karaka (*Corynocarpus laevigatus*), māhoe (*Melicytus ramiflorus*) and pūriri (*Vitex lucens*), but the effects of rats on these species, as well as seedling recovery following rat eradication, were less clearly defined (Campbell & Atkinson 2002). Seedlings counted on Kapiti Island after rat eradication showed a post-eradication increase compared with pre-eradication counts for aruhe (*Coprosma areolata*), hīnau (*Eleaocarpus dentatus*), mataī (*Prumnopitys taxiflolia*), passion vine (*Passiflora tetrandra*) and supplejack (*Ripogonum scandens*) (Campbell 2002).

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[1] Scientific and common names are provided when a plant species is first mentioned; thereafter, common names only are used. For a complete list of scientific and common names used for plants in this report, see Appendix 1.

[2] See detailed distributions in Appendix 2.

Although the Hauturu exclosures tested seedling establishment of lowland species, including those that were also found on smaller islands, they were unsuitable for testing rat effects on species that were restricted to wetter, higher altitude parts of Hauturu—species that were not found on smaller islands. Neither was is possible to test species that were rare on Hauturu, such as coastal māhoe, matai or ngaio (*Myoporum laetum*) because of the difficulties of obtaining seed for trials.

In 2003, the Department of Conservation (DOC) initiated planning to rid Hauturu of Pacific rats. Notwithstanding the substantial conservation benefits of a rat-free island of Hauturu's size and species richness, the decision to eradicate Pacific rats was opposed by the local iwi who wanted Pacific rats retained on cultural grounds, and by groups objecting to the use of pesticides for their eradication. These obstacles were resolved and rats were eradicated in 2004. Since rat eradication presented an opportunity to quantify the magnitude of the adverse effect of Pacific rats on seedlings of trees and vines on Hauturu, permanently marked plots were established on Hauturu 2 years ahead of the planned eradication to monitor numbers and sizes of seedlings of selected species. Marked plots were also established on Taranga Island and Great Barrier Island (Aotea Island) (hereafter Great Barrier Island). These islands were used as scientific controls because climatic conditions were similar to those of Hauturu and rat numbers were to remain unaltered. Seedlings of the same tree species were counted in appropriate plots on Hauturu and on the control islands before rat eradication and again 4 years after eradication. Seedling counts on the control islands where rats were not managed were intended for use in predicting the likely post-eradication seedling numbers expected on Hauturu, as well as the relative magnitude of differences between species.

Most plots were established to document changes in numbers of seedlings of individual tree species that previous work suggested were affected by Pacific rats, but the plots also targeted some tree species found on Hauturu that could not be studied in exclosures. Some plots were established to document seedling changes in specific forest types, such as kānuka (*Kunzea ericoides*) or kauri (*Agathis australis*) forest, to test the hypothesis that Pacific rats may have slowed the spread of kauri into kānuka-dominated forest on the lower ridges. Others were sited to determine whether rats could have been influencing the rate of forest succession by restricting the establishment of seedlings of some bird-dispersed species into regenerating kanuka forest.

The objectives of the study were to:

- Compare post-eradication changes in seedling numbers on Hauturu with changes in seedling numbers on nearby controls islands, using seedling numbers on the control islands to determine the numbers that should have been expected on Hauturu if rats had not been eradicated.
- Compare pre-eradication and post-eradication seedling numbers on Hauturu of other species that, because of their distribution or abundance, could not be studied on the control islands, with the aim of identifying other species that responded to rat eradication.
- Test the hypothesis that Pacific rats may have influenced forest succession by slowing the spread of kauri.
- Test whether Pacific rats may have influenced forest succession by eating seed that had been carried by birds into kānuka forest.
- Make preliminary predictions of possible changes in species composition in some Hauturu forests from the seedling response data.

2. Methods

2.1 STUDY AREAS

2.1.1 Hauturu/Little Barrier Island

Hauturu/Little Barrier Island (2817 ha) is midway between mainland Northland and Great Barrier Island (Aotea Island) (Fig. 1). The island (an extinct volcanic cone) is roughly circular, and is rugged and deeply dissected. The old central cone is surrounded by planeze[3] slopes formed from volcanic debris that, in places, have eroded into narrow ridges. The planeze slopes and ridges, separated by deeply dissected ravines, radiate from the central Mt Hauturu (723 m a.s.l.) to end in high coastal cliffs—most with boulder beaches at their bases. The boulder-bank flat on the southwest of the island (Te Maraeroa) is geologically very recent, and the alluvial soils of the flat were cultivated by Māori, who occupied the island. At the time of purchase as a sanctuary in the mid-1890s, the southwest part of the island had been burnt and logged for kauri and the area currently supports regenerating forest dominated by kānuka. Elsewhere, the island is unmodified and densely forested.

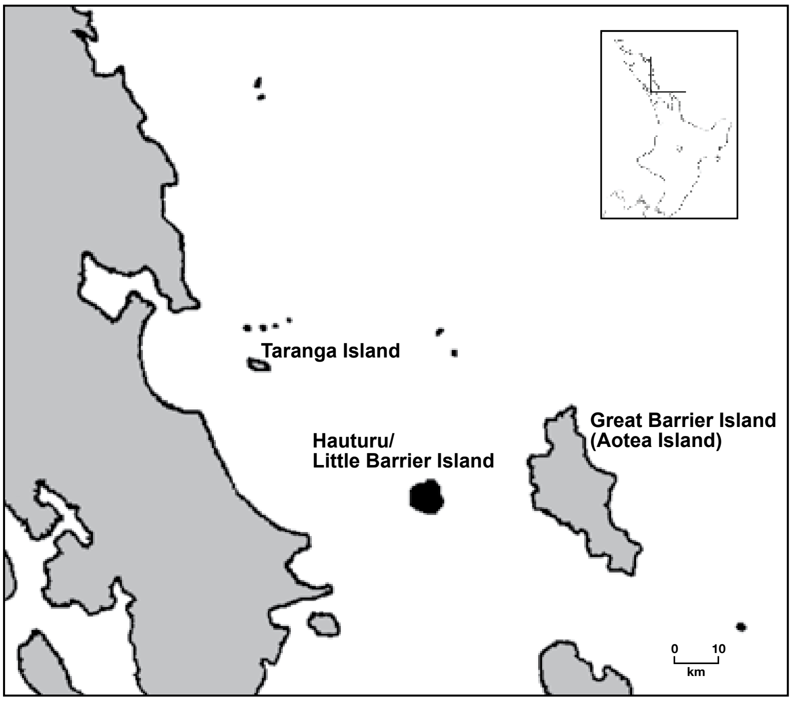

Figure 1. Location map: Hauturu, Taranga and Great Barrier Islands.

The coastal cliffs and seaward-facing talus slopes of the island are fringed with pōhutukawa (*Metrosideros excelsa*) forest with other salt-hardy coastal trees. Unmodified valley floors have mixed lowland forest dominated by northern rātā (*M. robusta*), pūriri, taraire (*Beilschmiedia tarairi*) and tawa (*B. tawa*), with kohekohe and nīkau as understorey trees. Valley floors that had been modified have regenerated into kānuka forest. Kauri forest dominates infertile ridges derived from the planezes of the old volcano; occasional patches of forest on these ridges contain hard beech (*Nothofagus truncata*), rewarewa (*Knightia excelsa*) and tānekaha (*Phyllocladus trichomanoides*) often in the understorey or co-dominant in the canopy. Higher on the slopes of the old central cone, the mixed hardwood forest is often cloud covered, and both the trees and ground are densely covered with mosses, lichens and ferns. This mixed forest has hinau, pigeonwood (*Hedycarya arborea*), rewarewa, tawa and tawhero (*Weinmannia silvicola*) as canopy trees. Major components of the forest at higher altitudes are: tāwari (*Ixerba brexoides*), tāwheowheo (*Quintinia serrata*) and southern rātā (*M. umbellata*) together with miro (*Prumnopitys ferruginea*), neinei (*Dracophyllum latifolium*) and thin-barked tōtara (*Podocarpus hallii*).

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[3] A planeze is a triangular landscape facet at the base of a volcano formed from volcanic debris, and is usually dissected by radial streams.

Other than the Pacific rat, the only introduced mammal to become established on Hauturu was the feral cat (*Felis cattus*). Cats were probably taken to the island c. 1870, and remained feral until they were exterminated in 1980 (Veitch 2001). Pigs (*Sus scrofa*) and cattle were kept on the island by Māori before its purchase (Watson 1961). Pigs were removed before they became feral, but Boscawen (1895) reported that cattle were destructive and 'travelled far' in forest.

2.1.2 Great Barrier Island (Aotea Island)

Great Barrier (Aotea Island) (28 500 ha) lies 18 km east of Hauturu. The central part of the island near Port Fitzroy is formed from volcanic rock that has weathered to produce deep ravines, steep bluffs and pinnacles. The area is very rugged, with steep ridges that rise to the highest peak, Mt Hobson (Hirakimata) (621 m a.s.l.). Several rivers, terraced in their lower reaches, drain this part of the island and flow through small lowland flats at the bay heads.

Kauri forest dominated the lowlands before the forest was logged in the late 19th century. Some forest still contains large kauri but, generally, the forest is regenerating through tall kānuka or mixed hardwood forest that contains kohekohe, hīnau, miro, nīkau, pūriri, rewarewa, tānekaha, taraire and tawa.

As well as the Pacific rat, Great Barrier Island has several other introduced mammals that eat seeds or seedlings, including ship rats, mice (*Mus musculus*) and pigs.

2.1.3 Taranga Island

Taranga Island (formerly Hen Island), of the Hen and Chickens Islands, lies 38 km northwest of Hauturu and 12 km off the coast of mainland Northland. The island is 500 ha in area, 6 km long and has an average width less than 1 km. It is the remnant of an ancient volcano, dominated by a rocky ridge that is over 400 m a.s.l. at the highest point.

Māori occupied and cleared most of the island. Forest has regenerated after their departure c. 1820 (Cranwell & Moore 1935). The forest canopy is now mostly composed of karaka, kohekohe, nīkau, pūriri, rewarewa, taraire and tawa, but tall kānuka is common in forest on the upper parts of the island, and old pōhutukawa trees persist in mixed forest on former cultivation terraces. Kōwhai (*Sophora chathamica*), *Xeronema callistemon* and *Astelia banksii* are common on the south-facing inland cliffs, and pōhutukawa forest fringes the coastal cliffs and shoreline talus slopes.

The Pacific rat is the only introduced mammal on Taranga Island.

2.2 SELECTION OF SPECIES TO MONITOR

Species chosen for monitoring met one or more of the following criteria: (1) they were known to be eaten by rats but the effects on juvenile recruitment were, for most, not clear; (2) it was suspected from the fruit characteristics and/or from adult abundance that the species was affected; (3) previous work indicated that seedling numbers were not affected (i.e. taraire and tawa); or (4) they were either important or rare in the Hauturu vegetation (Table 1) (Campbell 1978; Campbell et al. 1984; Campbell & Atkinson 2002).

TABLE 1. PLANT SPECIES MONITORED ON HAUTURU AND CONTROL PLOT(S), OR JUST HAUTURU ALONE, AND THEIR STATUS AT THE START OF THE STUDY. A = SPECIES MONITORED ON HAUTURU AND ONE OR BOTH CONTROL ISLANDS; B = SPECIES MONITORED ONLY ON HAUTURU.

A

SPECIES	STATUS*	COMMON NAME	REFERENCE
Agathis australis†	U	Kauri	Campbell & Atkinson 2002
Beilschmiedia tarairi		Taraire	Campbell & Atkinson 2002
Beilschmiedia tawa		Tawa	Campbell & Atkinson 2002
Clematis paniculata	U	Puawhananga	
Coprosma macrocarpa†	U	Coastal karamū	Campbell & Atkinson 2002
Coprosma repens		Taupata	Campbell & Atkinson 2002
Corynocarpus laevigatus		Karaka	Campbell & Atkinson 1999
Dacrycarpus dacrydioides†	U	Kahikatea	Colenso 1880
Dysoxylum spectabile	U	Kohekohe	Campbell & Atkinson 2002
Elaeocarpus dentatus		Hīnau	Campbell 2002
Hedycarya arborea†	U	Pigeonwood	Campbell 1978
Knightia excelsa	U	Rewarewa	Campbell 2002
Macropiper excelsum†	U	Kawakawa	Campbell 1978
Melicytus ramiflorus†	U	Māhoe	Campbell 1978
Nestegis lanceolata	U	White maire	Campbell 2002; Campbell & Atkinson 2002
Phyllocladus toatoa	U	Toatoa	
Phyllocladus trichomanoides	U	Tānekaha	
Pisonia brunoniana		Parapara	Campbell & Atkinson 2002
Podocarpus sp.‡	U	tōtara	
Pouteria costata		Tawāpou	Campbell & Atkinson 2002
Prumnopitys ferruginea†	U	Miro	Colenso 1880; Campbell 1978
Rhopalostylis sapida		Nīkau	Campbell & Atkinson 2002
Ripogonum scandens		Supplejack	Campbell 2002
Toronia toru	U	Toru	
Vitex lucens	U	Pūriri	Campbell & Atkinson 2002

B

SPECIES	STATUS*	COMMON NAME	REFERENCE
Alseuosmia macrophylla	U	toropapa	
Brachyglottis kirkii	U	Kirk's daisy	
Corokia buddleoides	U	korokio	
Ixerba brexoides	U	tāwari	
Myrsine salicina	U	toro	
Nothofagus truncata†	U	beech	Meeson 1885; Rutland 1890
Pittosporum tenuifolium	U	kōhūhū	
Pittosporum umbellatum	U	haekaro	
Pseudopanax crassifolius†	U	lancewood	

* U indicates species for which it was not known whether Pacific rats (kiore) affected seedling abundance.

† Recorded as eaten by Pacific rats (kiore) but effects on seedling abundance were unknown.

‡ Thin-barked tōtara (*Podocarpus hallii*) was monitored on Hauturu, whereas tōtara (*P. totara*), a similar species, was counted on Great Barrier Island.

Species in the first group were coastal karamū, karaka, kauri, kawakawa (*Macropiper excelsum*), kohekohe, miro, pigeonwood, pūriri, rewarewa, supplejack and white maire, and five species known to be severely affected by rats: hīnau, nīkau, parapara, taupata and tawāpou. (For example, Pacific rats eat the seed, bark (Campbell 1978) and, probably, seedlings of taupata.) The second group included haekaro (*Pittosporum umbellatum*), hard beech, kahikatea (*Dacrycarpus dacrydioides*), kōhūhū (*Pittosporum tenuifolium*), lancewood (*Pseudopanax crassifolius*), korokio (*Corokia buddleoides*), tānekaha, tāwari, thin-barked tōtara, toatoa (*Phyllocladus toatoa*), toro (*Myrsine salicina*), toropapa (*Alseuosmia macrophylla*) and toru (*Toronia toru*). Most species that were monitored had large fruit or fruit that was aggregated into clusters that rats could efficiently exploit, as many species with these characteristics had been shown to be affected by Pacific rats (Campbell & Atkinson 2002). A few species were added to this group because seedlings were known to be eaten (e.g. māhoe; Campbell 1978) or suspected to be eaten (Kirk's daisy (*Brachyglottis kirkii*) and puawhananga (*Clematis paniculata*)). Species that met the fourth criterion were kauri and tānekaha (importance) and kahikatea (rarity).

Overall, the monitored species formed two groups: those for which the post-eradication seedling response on Hauturu could be compared with that on one or more control islands, and those monitored only on Hauturu and for which it was not possible to exclude a climatic influence on the response of seedlings to rat eradication (Table 1). As many species as possible were monitored but, in part, whether a species was monitored depended on whether mature trees could be located either on Hauturu and one or both control islands. Several species, especially those that remained relatively common on rat-inhabited islands and for which the magnitude of the effects were either unknown or not clear (kauri, karaka, kohekohe, pigeonwood, pūriri, rewarewa, tānekaha, taraire and tawa) were, if possible, monitored on multiple plots on all three islands (Table 2 lists which species were monitored on which plots). Because the numbers of seedlings of the target species that would establish after rat eradication were unknown, the number of species recorded at each plot site was restricted to six or fewer where possible (but 12 species were searched for and counted in plot 15 on Hauturu (Table 2)). This made the counting of the target species quicker and more accurate, and made it possible to count seedlings on a larger area within a uniform habitat type, and sample a greater range of micro-habitats. This approach also allowed a large area of potential seedling environment near seed trees to be efficiently searched for seedlings.

As well as the species that were sampled before and after rat eradication on fixed plots, seedlings of an additional 11 species was searched for widely on Hauturu during post-eradication surveys to check for evidence of a flush of small seedlings in the mixed seedling population. These 11 species were bush lawyer (*Rubus cissoides*), coastal māhoe, fivefinger, houpara, karo, maire (*Mida salicifolia*), native broom (tainoka) (*Carmichaelia cunninghamii*), ngaio, passion vine, patē (*Schefflera digitata*), tītoki (*Alectryon excelsus*) and wharangi (*Melicope ternata*). Suitable sites near trees of coastal māhoe, ngaio and karo were searched for seedlings.

TABLE 2. PLOTS ON WHICH SPECIES WERE SAMPLED PRE- AND POST-RAT ERADICATION ON HAUTURU AND CONTROL ISLAND(S).

SPECIES	COMMON NAME	PLOTS ON WHICH EACH SPECIES WAS SAMPLED PRE- AND POST-ERADICATION		
		HAUTURU	TARANGA ISLAND	GREAT BARRIER ISLAND
Agathis australis	Kauri	3, 7, 8, 14		2, 3, 8
Alseuosmia macrophylla	Toropapa	3		
Beilschmiedia tarairi	Taraire	9, 10–12, 15	1, 7	8, 11, 12
Beilschmiedia tawa	Tawa	9, 12, 15, 17	3, 7, 8	3, 8, 11, 12
Brachyglottis kirkii	Kirk's daisy	2		
Clematis paniculata	Puawhananga	9	3, 8	
Coprosma macrocarpa	Coastal karamū	6, 15	3, 5, 8	6, 9, 14
Coprosma repens	Taupata	15	5, 8	14
Corokia buddleoides	Korokio	3, 6		
Corynocarpus laevigatus	Karaka	9, 10, 12, 15	1, 3, 4, 7, 8	8, 9, 13
Dacrycarpus dacrydioides	Kahikatea	5		2, 13
Dysoxylum spectabile	Kohekohe	5, 9–12, 15	1, 3, 4, 7, 8	1–4, 6, 8, 9, 11, 12
Elaeocarpus dentatus	Hīnau	5		8, 11
Hedycarya arborea	Pigeonwood	9–13, 15, 17, 18	1, 6, 7	2–4, 6, 8, 9, 11–13
Ixerba brexoides	Tāwari	16		
Knightia excelsa	Rewarewa	1–8, 10, 11, 14, 15, 17, 18		1–3, 8, 9, 11, 12
Macropiper excelsum	Kawakawa	6, 9, 12	3, 8	9
Melicytus ramiflorus	Māhoe	9	1, 3, 6, 7, 8	
Myrsine salicina	Toro	9, 16		
Nestegis lanceolata	White maire	1–4, 6–12, 14–18		1–3, 8, 11
Nothofagus truncata	Beech	3, 7		
Phyllocladus toatoa	Toatoa	14		7
Phyllocladus trichomanoides	Tānekaha	1, 3, 10, 14		1–3, 7, 9, 11
Pisonia brunoniana	Parapara	6	2, 4	
Pittosporum tenuifolium	Kōhūhū	8		
Pittosporum umbellatum	Haekaro	7, 8		
Podocarpus sp.*	Tōtara	17		2, 7
Pouteria costata	Tawāpou	6	1	
Prumnopitys ferruginea	Miro	3, 13, 16		1, 2, 7, 8,
Pseudopanax crassifolius	Lancewood	3, 8		
Rhopalostylis sapida	Nīkau	6, 9–12, 15, 18	6, 8	1–3, 4, 8, 12
Ripogonum scandens	Supplejack	6, 9, 10–13, 15, 17	6,	2, 3, 6, 8, 9, 11, 12
Toronia toru	Toru	3		5
Vitex lucens	Pūriri	10–12, 15	8	2, 8, 11–13

* Thin-barked tōtara (*Podocarpus hallii*) was monitored on Hauturu, whereas the related tōtara *P. totara* was monitored on Great Barrier Island.

2.3 SELECTION OF PLOT SITES

See Table 3 for a summary of the numbers of plots, species and sampling period for each island, as well as numbers of seedlings.

The study design aimed to avoid problems that can bedevil the interpretation of monitoring data for post-eradication changes in populations of rat food species on a single island (e.g. Kapiti Island, Campbell 2002). Furthermore, because flowering, fruiting and seedling establishment can be influenced by many factors besides climate, comparisons between islands can present other problems. Issues

TABLE 3. SAMPLING PERIODS, NUMBERS OF PLOTS, SPECIES AND SEEDLINGS MEASURED, BY ISLAND.

	HAUTURU*	CONTROL ISLANDS	
		GREAT BARRIER ISLAND	TARANGA ISLAND
Sampling periods	Nov 2002	Feb 2003	Feb 2003
	Nov 2003	Feb 2004	Jan 2004
	Jan 2008	Feb 2008	Mar 2008
Interval between last and previous sampling	4 years, 2 months	4 years	4 years, 2 months
Plots			
Latitude, longitude	36°13′S, 175°03′E†	36°10′S, 175°22′E	35°58′S, 174°43′E
Total number	18	14	8
Total area sampled	> 10 400 m^2	3610 m^2	1890 m^2
Plants sampled			
Total number of species	34‡	22	21
Total number of seedlings	14 977	6169	3775

* Rat eradication was completed on Hauturu in 2004.

† Except for three plots sited at higher altitudes on the Thumb Track, all plots were located in the modified southwest quarter of the island (Appendices 3 and 4).

‡ A further 11 species were not systematically counted on the seedling plots, but small seedlings were searched for in 2008 and 2009.

related to pseudo-replication of sample sites were addressed, where possible, by locating the sample sites near seed trees of monitored species, in sites where seedlings were already present. The main species of interest were sampled on multiple sites on each island, to ensure that the samples were representative of seedling populations of the species on a given island.

Plots were sited within 20 m of mature trees of the selected species and had to contain seedlings or juveniles of the target species, or the site was judged to be suitable for those seedlings to establish (see Appendix 3 for the rationale behind each plot location on Hauturu). With dioecious species, the plot was sited near at least one female tree, whose presence was confirmed from fallen fruit or from durable endocarps beneath the tree. Each plot was confined to a single landscape-site type and vegetation type to ensure the plots sampled consistently suitable habitat for the target seedlings. Appendix 3 lists altitude, GPS co-ordinates, topography, species sampled and vegetation of each island's plots, and Appendix 4 indicates the position of each plot on topographic maps.

Most of the monitored species found below 100 m a.s.l. on Hauturu could be monitored on both control islands (Table 2), but some that introduced animals had suppressed on Great Barrier Island were monitored only on Taranga Island. On the other hand, some species from mid-altitude (c. 400 m) kauri forest on Hauturu were found on Great Barrier Island but not Taranga Island. It was not possible to exclude a climatic influence on any post-eradication seedling response on species found at higher altitudes on Hauturu that could not be compared with populations on either control island (Tables 1 & 2).

Plots were not intended to sample every species found on Hauturu, because of the possible confounding effects of climatic influences on post-eradication responses when scientific control areas are not used (Campbell 2002). Neither were the plots intended to systematically sample the different types of vegetation found on the island, or to measure long-term changes in vegetation. However, to test the hypothesis that rats may have slowed the rate of spread of kauri from the margins of existing stands, some plots were established on ridges on Hauturu at the lower edge of kauri distribution on the Waipawa, Thumb and Hamilton tracks (plots 4, 7, 8, 14). To assess whether rats may have affected the spread, into kānuka forest, of kauri and species with bird-dispersed fruit (by eating seed, including that already carried to a site by birds), two plots (10, 12) were established in kānuka forest on river terraces in the Waikohare and Turikikawa Valleys. Seedlings of some additional bird-dispersed species were monitored on other sites where seed trees of the species were not evident in the canopy of the forest at these sites (see section 3.5).

Canopy cover conditions were similar on all surveys on each site, except when an occasional canopy tree fell over a plot, or if a track had been upgraded, which was always a risk since most plots ran along the sides of tracks. However, only one plot on Great Barrier Island had to be abandoned, after a major upgrade of the track, and a few metres of another plot were affected when a track was re-routed.

2.4 SEEDLING COUNTING METHODS

Each seedling plot was a 2-m-wide strip that ran parallel with the edge of a track, or, in a few cases, parallel with a tape stretched between permanent markers. Plots varied in length from 150 m to 250 m, giving an area of 300–500 m^2, but usually seedlings were counted on both sides of the track, thus doubling the plot area. A few plots were even larger, having an area of 1200 m^2, whilst a few plots narrowed in places (e.g. if a track fell away steeply at the edge of a stream terrace or ridge). During each survey, numbers and heights of the same species of seedlings were counted and measured over the same length (and area) of plot notwithstanding any variations in sample width.

Seedling height was measured with a 2-m pole made from 1.5-cm-diameter aluminium tube and marked with tape at 10-cm intervals. The pole was collapsible and held together with a tension cord with enough slack to allow the lowermost 50-cm segment to be dis-articulated and drop vertically. This facilitated the measurement of seedling height, especially at the far side of the plot. To ensure that seedlings were not trampled during counting, all counts were made from outside a plot, either from the edge of the track or from one side of a tape. When seedlings were being searched for, ground vegetation such as ferns, taller seedlings and twiggy litter was lifted or pushed to one side with the measuring pole.

Seedlings $\leq$ 30 cm in height were measured, assigned to the nearest 5-cm size class (size class boundaries: 10, 15, 20, 25 and 30 cm) and counted. Seedling height was measured to the apical bud rather than the uppermost leaves. Cotyledon-stage seedlings were often difficult to see and, for some species (such as fivefinger and *P. discolor*), differentiate, so they were not used for comparisons between surveys, but data for any such seedlings that were abundant before eradication were recorded as part of the baseline information. In contrast, because cotyledon-stage seedlings of pūriri and rewarewa are distinct and unambiguous, these were counted on all surveys. Nīkau seedlings were recorded as 'two leaf' for young seedlings (which rats eat (Campbell & Atkinson 2002)) or 'four leaf' for older ones, while those with leaves > 30 cm long were ignored.

Seedlings growing on logs or moss-covered stones were included, even if they were unlikely to survive in those situations. Some seedlings growing at the edge of the track had been cut to a height of < 30 cm during track maintenance: they were ignored if originally they had been taller than 30 cm. Seedlings growing on the track were not counted but, if the track was banked, the visible area was searched to 2 m from the edge of the track including any drainage gutters.

Ground vegetation was very dense on parts of a few plots, obscuring seedlings at the far side of the plot. In these situations, seedlings were counted from the centre line of the 2-m-wide transect. All seedlings in all surveys were identified, measured and counted by the author. It was assumed that the visibility of seedlings, including their contrast against the litter, did not differ between surveys. Twelve plots were sampled twice or more during the same survey: six plots (3, 4, 7, 8, 9, 18) on Hauturu and six (2, 3, 3, 8, 9, 11) on Great Barrier Island. Total numbers of seedlings of each species counted were found to vary within ± 10%.

2.5 ANALYSIS OF DATA AND STATISTICAL METHODS

Species with 20 or fewer seedlings over all plots on Hauturu and the control islands were eliminated from further analysis (Table 4). Kirk's daisy was not analysed further, although 24 seedlings of Kirk's daisy were recorded after rat eradication compared with six before eradication. The species was monitored in a single plot, and there was no marked response of small seedlings.

For each of the 19 species with more than 20 seedlings (Table 4), a Generalised Linear Model (GLM) was fitted to the count data using a log link function and Poisson error. The model tested for differences between islands, years, height classes and their interactions, and plots within islands. If there were real changes in species prevalence on Hauturu in 2008, compared with those on Great Barrier and Taranga Islands, particularly in newly established seedlings following rat eradication, this would show up as a significant island by height class by year interaction. The graphs in section 3 show this interaction. There were generally also significant main effects, always including highly significant plot within island effects. The GLM allows a test of the validity of applying the Poisson model to the data, and this application was generally supported by the analysis. Because the Poisson model was found to be valid, the square root of the count was used as an estimate of the standard error of the count.

Pooled size-class data for seedling numbers of the 19 most abundant species on Hauturu before and after rat eradication were compared with equivalent seedling counts for the same species on the control islands. Data were log-transformed and the log ratios of data for Hauturu, Taranga and Great Barrier Islands were plotted for the species and expressed with 95% confidence intervals calculated as ± 2 standard deviations (SD), using a Poisson distribution. On the log ratio graph, a ratio of 0 indicated no change in seedling numbers, a negative ratio indicated a decrease and a positive ratio, an increase.

TABLE 4. SEEDLING TOTALS OF MONITORED SPECIES ON HAUTURU AND CONTROL ISLAND(S) RECORDED BEFORE AND AFTER RAT ERADICATION. SPECIES WITH SUFFICIENT SEEDLINGS FOR STATISTICAL COMPARISONS ARE IN BOLD TYPE.

SPECIES	COMMON NAME	CONTROL ISLANDS					HAUTURU		
		TARANGA ISLAND		GBI*					
		BEFORE	AFTER	BEFORE	AFTER	RATIO BEFORE/ AFTER	BEFORE	PREDICTED NUMBER	AFTER
Agathis australis	Kauri			127	112	0.8824	498	439	457
Alseuosmia macrophylla	Toropapa						17		0
Beilschmiedia tarairi	Taraire	208	207	122	356	1.7061	396	676	271
Beilschmiedia tawa	Tawa	74	64			0.8750	82	72	51
Brachyglottis kirkii	Kirk's daisy						6		24
Clematis paniculata	Puawhananga	0	0				0		1
Coprosma macrocarpa	Coastal karamū	108	117	57	56	1.0485	19	20	827
Coprosma repens	Taupata	10	11				0		4
Corokia buddleoides	Korokio						3		5
Corynocarpus laevigatus	Karaka	248	335	6	3	1.3508	242	327	384
Dacrycarpus dacrydioides	Kahikatea			4	10	2.5000	19	48	95
Dysoxylum spectabile	Kohekohe	294	349	229	254	1.1530	248	286	530
Elaeocarpus dentatus	Hīnau			2	6		0		1
Hedycarya arborea	Pigeonwood	50	41	128	264	1.7135	87	149	270
Ixerba brexoides	Tāwari						5	5	127
Knightia excelsa	Rewarewa			307	300	0.9772	25	24	372
Macropiper excelsum	Kawakawa	23	12			0.5217	42	22	91
Melicytus ramiflorus	Māhoe	11	19				1		1
Myrsine salicina	Toro						4		0
Nestegis lanceolata	White maire			76	189	2.4868	15	37	315
Nothofagus truncata	Beech						4		4
Phyllocladus toatoa	Toatoa			40	34		0		0
Phyllocladus trichomanoides	Tānekaha			43	32	0.7442	83	62	390
Pisonia brunoniana	Parapara	17	14			1.6667	2	2	2289
Pittosporum tenuifolium	Kōhūhū						1		0
Pittosporum umbellatum	Haekaro						303	303	367
Podocarpus sp.	Tōtara			3	6		2		0
Pouteria costata	Tawāpou								
Prumnopitys ferruginea	Miro			54	59	1.0926	28	31	18
Pseudopanax crassifolius	Lancewood						2		3
Rhopalostylis sapida	Nīkau	4	24	102	235	2.4434	51	518	2233
Ripogonum scandens	Supplejack	5	7	64	170	2.5652	47	244	447
Toronia toru	Toru			5	8		3		6
Vitex lucens	Pūriri	6	110	33	190	7.6923	15	115	110

* GBI = Great Barrier Island.

The ratio of post-eradication to pre-eradication seedling numbers on the control islands was used to predict the numbers of seedlings that could have been expected if rats had not been eliminated from Hauturu, and these predicted numbers were plotted against the actual numbers counted after rat eradication. Pre-eradication seedling totals of the two species that were monitored on only Hauturu were plotted against post-eradication numbers. Predicted numbers were plotted against actual numbers on logarithmic scales, where a line with a slope of 1 indicates that predicted and actual numbers are equal. Points that fall above the line are of species that had more seedlings than predicted, while species farthest from the line had substantially more seedlings on Hauturu after rat eradication compared with natural variation in numbers on the control islands. Species that fall below the line had fewer seedlings after rat eradication than on the control islands.

Seedling size-class totals for the 19 most abundant species were graphed for all plots on which the species was sampled for each of the three surveys for the islands on which the species was found. 95% confidence intervals were calculated using a Poisson distribution.

3. Results

Post-eradication numbers of seedlings of 45 species were monitored on Hauturu, with 34 species being monitored on fixed plots (species monitored in particular plots are listed in Table 2). Almost 25 000 seedlings of 34 species were identified on Hauturu and the two control islands, but only 19 species of these had more than 20 seedlings on Hauturu or the control islands and were used for further analysis (species in bold in Table 4). Two of these 19, tāwari (*Ixerba brexoides*) and haekaro (*Pittosporum umbellatum*), were monitored only on Hauturu. Qualitative results for the 15 species with fewer than 20 seedlings over all islands are presented in section 3.3.

3.1 EARLY TRENDS IN SEEDLING RESPONSE ON HAUTURU COMPARED WITH CONTROL ISLANDS

Changes in seedling numbers on Hauturu after rat eradication and on the control islands were plotted (Fig. 2) using log ratios (post-eradication/pre-eradication numbers, with 95% confidence intervals). In 2008 (post-eradication), there were more seedlings on Hauturu of all except 4 of the 19 species (there were fewer kauri, taraire, tawa and miro). Species that showed a significant increase in seedling numbers on Hauturu relative to changes on one or both of the control islands were coastal karamū, karaka, kohekohe, pigeonwood, rewarewa, white maire, tānekaha, parapara, nīkau and supplejack (Fig. 2). Tāwari and haekaro (the species monitored only on Hauturu) showed significant increases in seedling numbers. Fewer kawakawa seedlings were recorded in 2008 on Taranga Island compared with a significant increase on Hauturu. Although kahikatea did not show a significant increase, seedlings counted in 2008 were mainly <5 cm in height, indicating a positive response to rat eradication. Numbers of pūriri seedlings did not show a consistent pattern over the 3 years of the survey (Fig. 2). Details of these 19 species are given below (section 3.1.1).

Seedling numbers on the control islands were used to predict the likely number of post-eradication seedlings on Hauturu (Fig. 3) and those species that had many more seedlings than predicted were coastal karamū, nīkau, parapara and rewarewa. Species, such as parapara, that lay near the y-axis exhibited the greatest difference in counts between Hauturu and the control island(s).

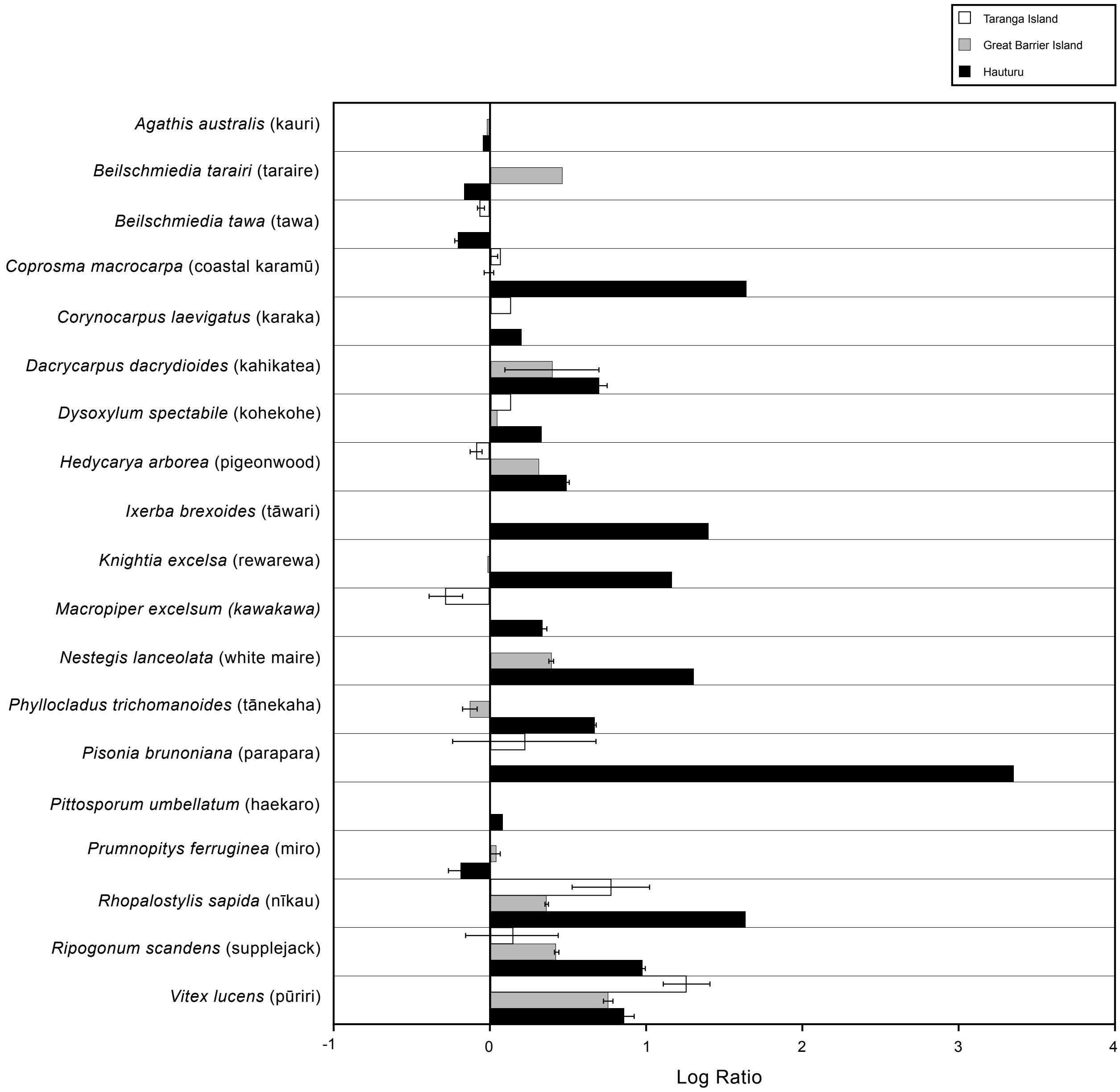
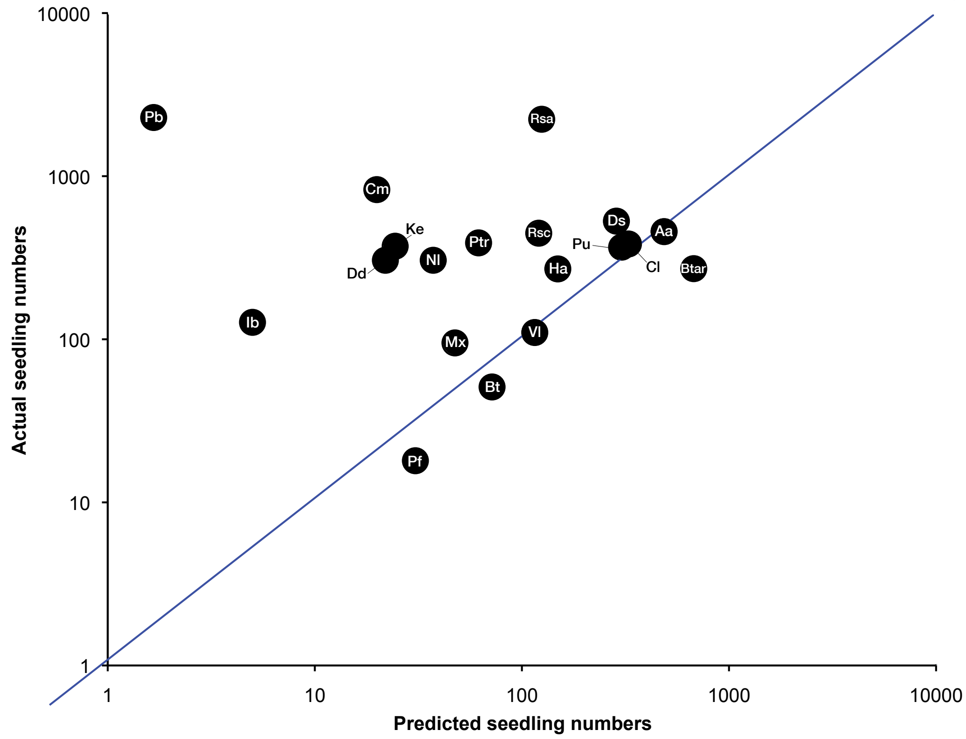


Figure 2. Log ratios of seedling numbers before and after rat eradication on Hauturu compared with those on control islands. Log ratios of < 0, 0 and > 0 indicate seedling counts that decreased, remained the same or increased, respectively. Seedling data are from Table 2, with 95% confidence intervals.

3.1.1 Seedling demographic responses on Hauturu and the control islands

Agathis australis (kauri)

Slightly fewer kauri seedlings were counted on Hauturu in the four plots checked after rat eradication. However, the decrease was smaller than that observed in the three plots on Great Barrier Island (Table 4). In 2008, there was a slight but significant increase in seedlings in the 10-cm size class on Hauturu (Fig. 4). Fewer seedlings were recorded in 2002 for Hauturu because one less plot was monitored. Only a few kauri trees have been seen on Taranga Island; these were not monitored during this study because of their location.



Aa	kauri	*Agathis australis*	**Mx**	kawakawa	*Macropiper excelsum*
Btar	taraire	*Beilschmiedia tarairi*	**Nl**	white maire	*Nestegis lanceolata*
Bt	tawa	*Beilschmiedia tawa*	**Pt**	tānekaha	*Phyllocladus trichomanoides*
Cm	coastal karamū	*Coprosma macrocarpa*	**Pb**	parapara	*Pisonia brunoniana*
Cl	karaka	*Corynocarpus laevigatus*	**Pu**	haekaro	*Pittosporum umbellatum*
Dd	kahikatea	*Dacrycarpus dacrydiodes*	**Pf**	miro	*Prumnopitys ferruginea*
Ds	kohekohe	*Dysoxylum spectabile*	**Rsa**	nīkau	*Rhopalostylis sapida*
Ha	pigeonwood	*Hedycarya arborea*	**Rsc**	supplejack	*Ripogonum scandens*
Ib	tāwari	*Ixerbia brexoides*	**Vl**	pūriri	*Vitex lucens*
Ke	rewarewa	*Knightia excelsa*			

Figure 3. Logarithmic plot of predicted post-eradication seedling numbers on Hauturu compared with numbers counted. Predicted numbers were calculated from the post-eradication/pre-eradication ratio of seedling numbers on control islands (data in Table 2). The line indicates the position where the predicted number of seedlings equals the number counted.

Beilschmiedia tarairi (taraire)

Taraire seedlings were counted in five plots on Hauturu before and after rat eradication (Table 4). In 2008, significantly fewer taraire seedlings were recorded (271 compared with 396 counted in 2003; Table 4) (Figs 2 & 4). Seedling numbers were stable over the same period in the three plots on Taranga Island, and numbers increased in the three plots monitored on Great Barrier Island (Figs 2 & 4), mainly on plot 11 where pigs had been controlled.

Beilschmiedia tawa (tawa)

Tawa seedlings were counted in four plots on Hauturu, four on Great Barrier and three on Taranga Island before and after rat eradication (Table 4). Significantly fewer tawa seedlings were recorded for Hauturu in 2008 (51 compared with a mean of 82 recorded for the two earlier surveys; Table 4). Only a few seedlings were recorded for Great Barrier Island, and fewer still were recorded for Taranga Island in 2008 compared with 2003 (Figs 2 & 4).

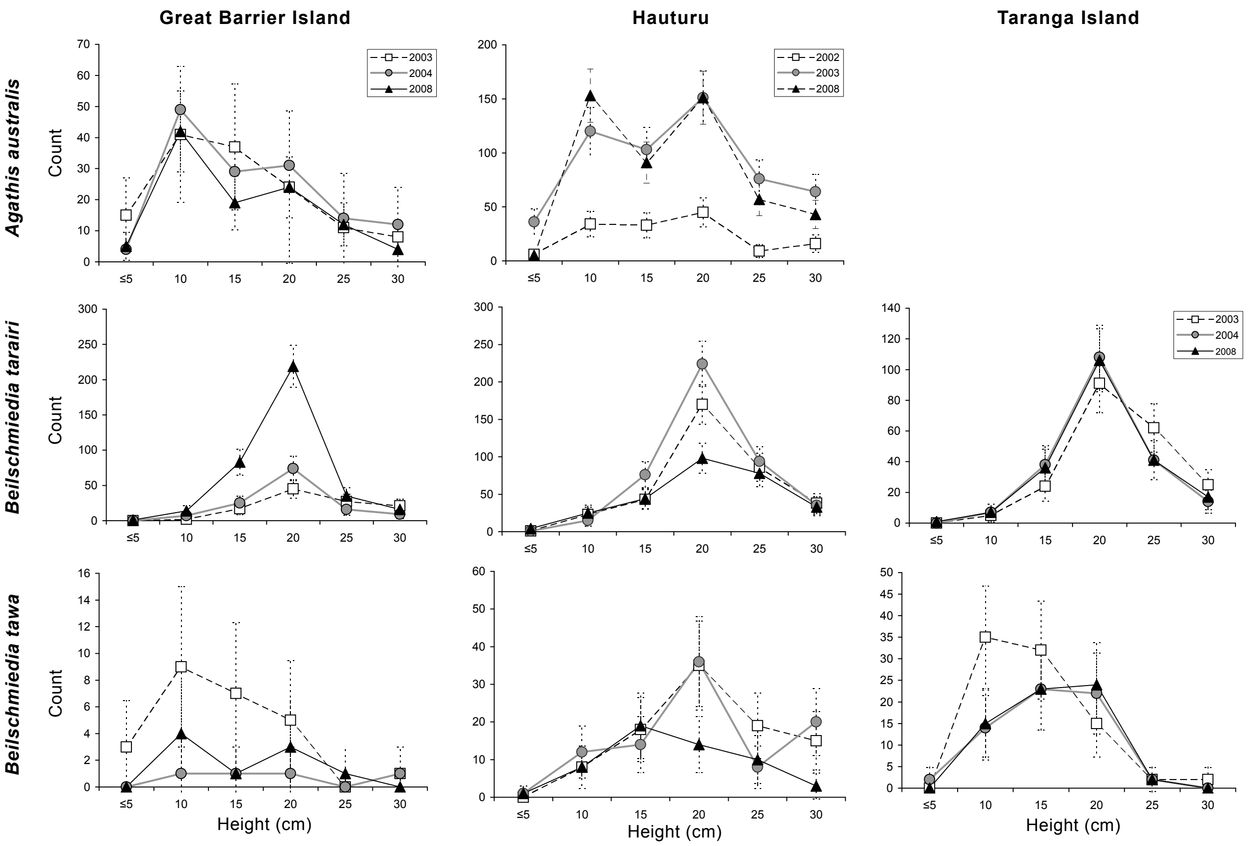


Figure 4. Numerical changes in seedling size classes, pre-eradication and post-eradication, for Hauturu and the control islands of *Agathis australis* (kauri), *Beilschmiedia tarairi* (taraire) and *B. tawa* (tawa). Error bars show 95% confidence interval. Note: there is no *A. Australis* plot for Taranga Island.

Coprosma macrocarpa (coastal karamū)

Before rats were eradicated, only 18 and 19 seedlings of coastal karamū were present in plot 15 on Hauturu in 2002 and 2003, respectively, and seedlings were evenly distributed between all size classes (Fig. 5). Numbers recorded in 2008 for the three plots monitored on each of Taranga and Great Barrier Islands (Tables 2 & 4) had not changed significantly from those of the earlier surveys (Figs 2 & 5), but in Hauturu plot 15, the numbers of coastal karamū seedlings >10 cm in height had risen to 288 seedlings, with another 301 seedlings in the <10-cm size class. That same year, in Hauturu plot 6, seedling numbers reached 237 for the <10-cm size class and only 23 in the 10-cm class. Small seedlings were very abundant in many sites in both 2008 and 2009.

C. repens (taupata)

Taupata was monitored on one plot (15) on Hauturu and a total of three plots on the control islands (Table 2). No seedlings were seen on Hauturu before rat eradication, but four were recorded in 2008.

Corynocarpus laevigatus (karaka)

Karaka was monitored on four plots on Hauturu, five on Taranga Island and three on Great Barrier Island (Table 2). Seedling numbers increased on both Hauturu and Taranga Islands during the study, with the increase after rat eradication on Hauturu being significantly greater than on Taranga (Table 4; Figs 2 & 5). However, increases in the numbers of karaka seedlings were small compared with some other species (Fig. 2). Karaka was very uncommon on Great Barrier Island.

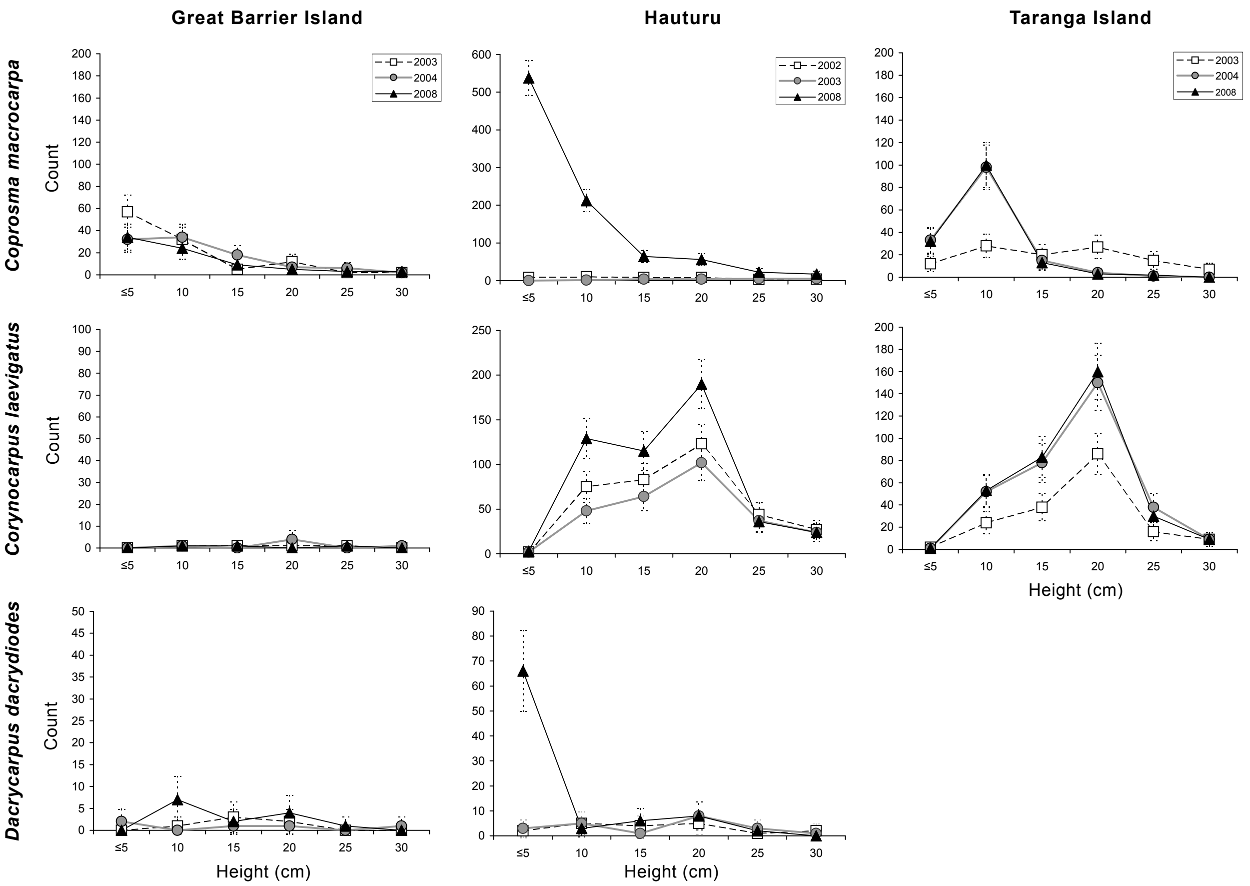


Figure 5. Numerical changes in seedling size classes, pre-eradication and post-eradication, for Hauturu and the control islands of *Coprosma macrocarpa* (coastal karamū), *Corynocarpus laevigatus* (karaka) and *Dacrycarpus dacrydioides* (kahikatea). Error bars show 95% confidence interval. Note: there is no *D. dacrydioides* plot for Taranga Island.

Dacrycarpus dacrydioides (kahikatea)

In the plot sited near a single mature kahikatea tree on Hauturu (plot 5), numbers of seedlings 10 cm high or taller did not change over the study period, but numbers of 5-cm-high seedlings increased significantly from two and three in 2002 and 2003, respectively, to 66 in 2008 (Fig. 5). Although there was no similar increase in small seedlings on Great Barrier Island (two plots sampled; Table 2), data limitations meant that the differences between the islands were not significant (Fig. 2). Kahikatea is not found on Taranga Island.

Dysoxylum spectabile (kohekohe)

Following rat eradication, numbers of kohekohe seedlings in the six Hauturu plots (Table 2) were almost double the pre-eradication numbers, but similar increases were not seen on Taranga (five plots) and Great Barrier Islands (nine plots) (Tables 2 & 4; Figs 2 & 6). Although kohekohe was common on Hauturu, rats appear to have severely affected seedling numbers (Fig. 6).

Hedycarya arborea (pigeonwood)

Pigeonwood seedlings were counted on eight seedling plots on Hauturu, three on Taranga Island and nine on Great Barrier Island (Table 2). There were significantly more pigeonwood seedlings on Hauturu following rat eradication, and while there were also more on Great Barrier Island, the increase was much less (Table 4; Figs 2 & 6). On Great Barrier Island in 2008, 10-cm-high pigeonwood seedlings were more common on three plots that had been pig rooted in 2004. Numbers on Taranga Island decreased between 2003 and 2008 (two plots)

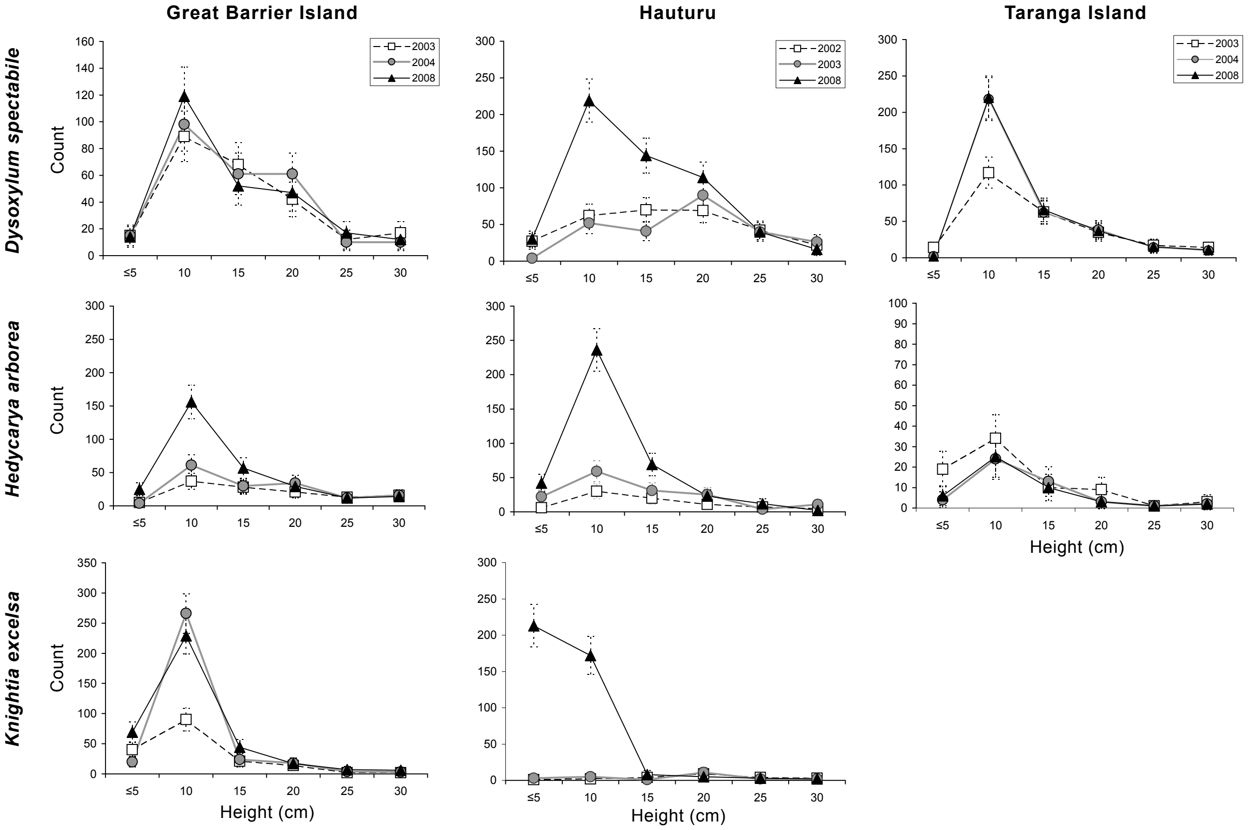


Figure 6. Numerical changes in seedling size classes, pre-eradication and post-eradication, for Hauturu and the control islands of *Dysoxylum spectabile* (kohekohe), *Hedycarya arborea* (pigeonwood) and *Knightia excelsa* (rewarewa). Error bars show 95% confidence interval. Note: there is no *K. excelsa* plot for Taranga Island.

(Table 4; Figs 2 & 6). Although there were more seedlings in 2008 on Great Barrier Island, numbers on Hauturu after rat eradication were significantly greater than predicted (Figs 2 & 3).

Knightia excelsa (rewarewa)

Significantly more rewarewa seedlings were recorded on Hauturu after rat eradication (Table 4; Figs 2 & 6), and small seedlings were found on 13 of the 14 seedling plots monitored. In 2008, 372 seedlings were in the 5- and 10-cm height classes, compared with only 16 recorded for the 15–30-cm classes. Although large mature rewarewa trees were common on rat-inhabited Taranga Island, seedlings and saplings were rarely seen. Seedlings were searched for, both on the plots and more widely, but none was recorded during the three surveys. Seedling numbers did not change on the seven plots on Great Barrier Island over the duration of the study (Table 4; Figs 2 & 6) (note that one plot fewer was sampled in 2003).

Macropiper excelsum (kawakawa)

Kawakawa was recorded for three plots on Hauturu, two on Taranga Island one on Great Barrier Island (Table 2). Adequate seedling numbers for comparisons were recorded for Taranga Island and Hauturu (Table 4; Fig. 2). Significantly more seedlings were recorded after rat eradication on Hauturu (Fig. 7).

Nestegis lanceolata (white maire)

Small seedlings of white maire were rare on Hauturu when rats were present (Fig. 7), and saplings were uncommon. In 2008, following rat eradication, seedlings were found on all except two of the 18 plots, and although there were

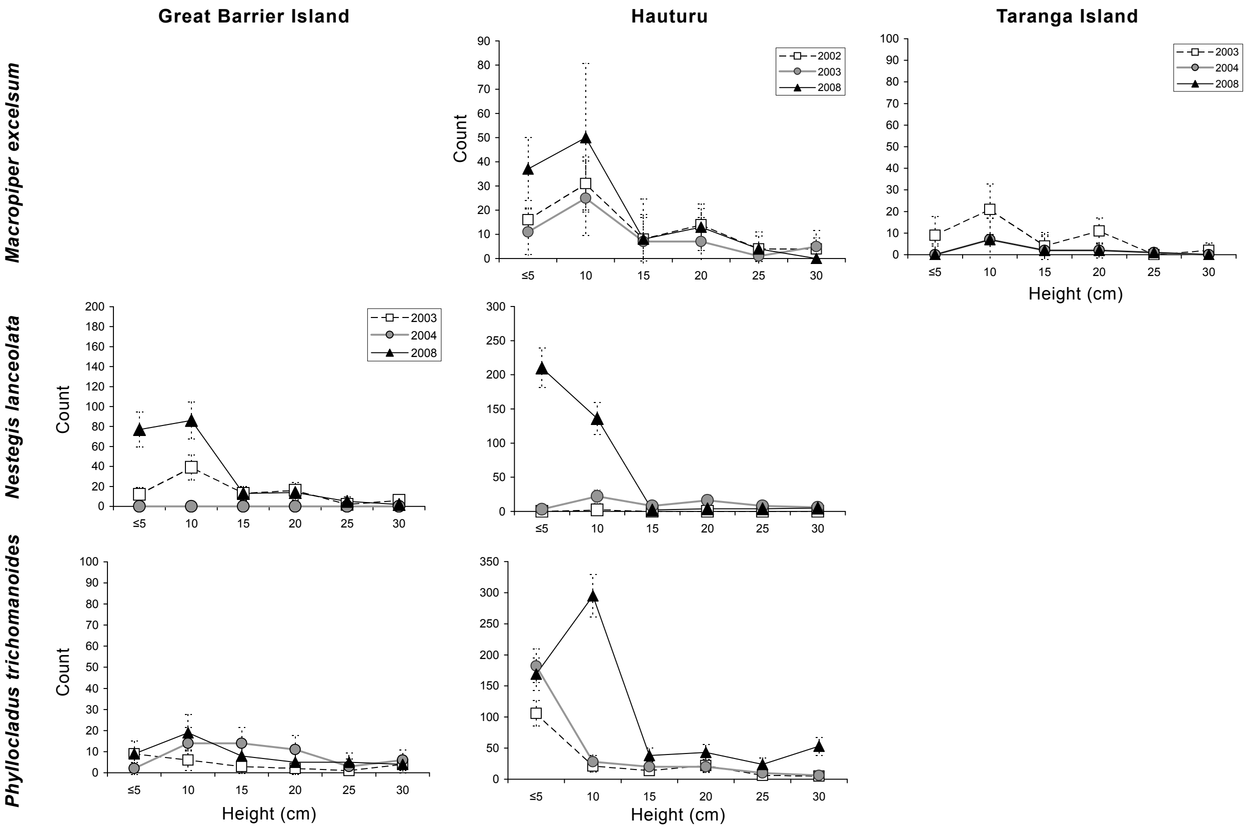


Figure 7. Numerical changes in seedling size classes, pre-eradication and post-eradication, for Hauturu and the control islands of *Macropiper excelsum* (kawakawa), *Nestegis lanceolata* (white maire) and *Phyllocladus trichomanoides* (tānekaha). Error bars show 95% confidence interval. Note: there is no *M. excelsum* plot for Great Barrier island or *N. lanceolata* and *P. trichomanoides* plots for Taranga Island.

more small seedlings on both Hauturu and Great Barrier Islands at that time, the increase was significantly greater on Hauturu (Table 4; Figs 2 & 7). A total of 305 seedlings were recorded for the 5- and 10-cm height classes, compared with only 10 seedlings counted for all other size classes (Table 4; Fig. 7). On Great Barrier Island, 159 seedlings were recorded for the 5- and 10-cm size classes but larger seedlings were three times more common there than on Hauturu. No seedlings were seen on Taranga Island. The plot of predicted versus actual seedling numbers on Hauturu (Fig. 3), shows a large increase in seedlings over predicted numbers, despite there being a significant increase on Great Barrier Island in the presence of seed predators.

Phyllocladus trichomanoides (tānekaha)

Tānekaha is found on Hauturu and Great Barrier Island but not on Taranga Island. In 2008, slightly fewer seedlings were recorded for Great Barrier Island compared with the earlier surveys, whereas almost five times more seedlings were counted on Hauturu than before (Table 4; Figs 2 & 7). On the four Hauturu plots for which seedlings were monitored over all surveys (and a further four added in 2008), 464 seedlings were counted for the 5- and 10-cm size classes, compared with 81 seedlings in the 15- and 20-cm size classes (Fig. 7).

Pisonia brunoniana (parapara)

While Pacific rats were on Hauturu, two parapara seedlings were recorded in the one plot where parapara was monitored. After rats were eradicated, seedlings became very abundant; 2289 seedlings were recorded, with only 412 of them in the 10-cm height class (Table 2; Figs 2, 3 & 8; note the difference in scale

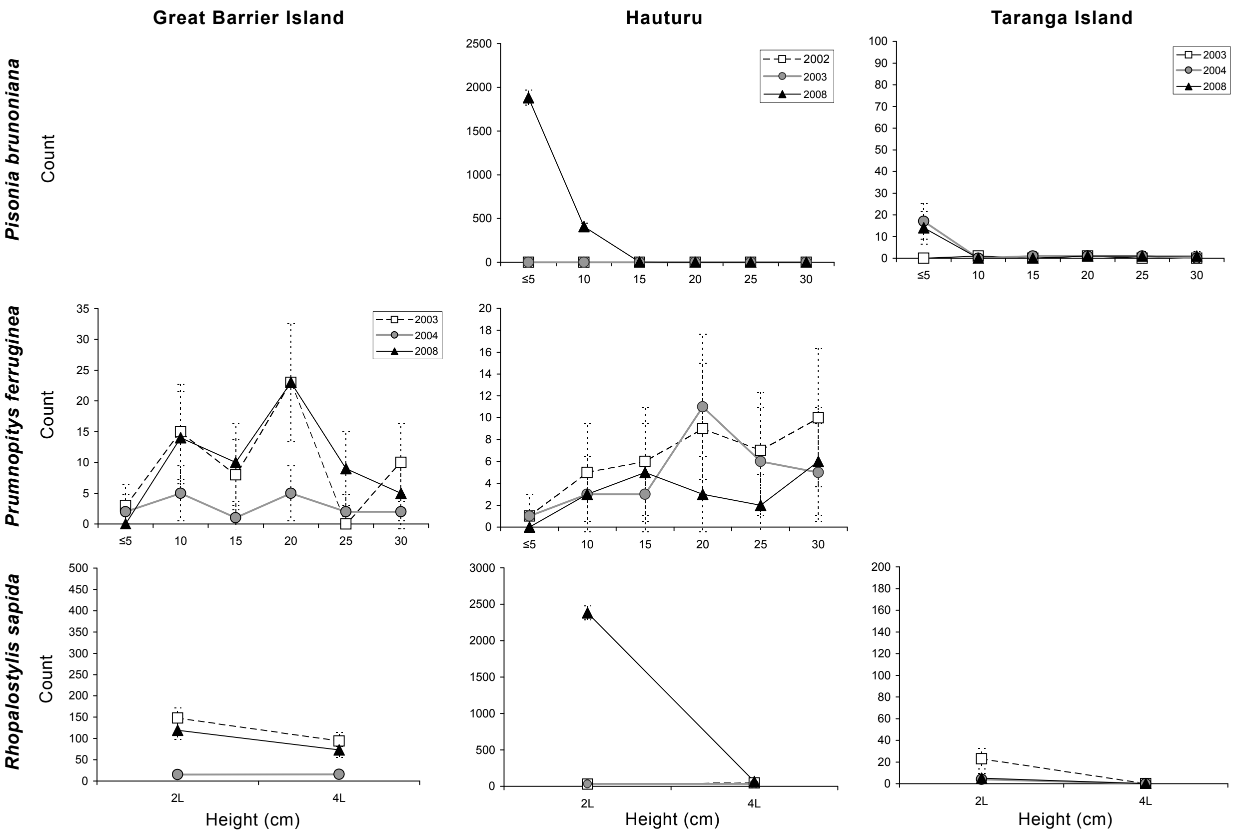


Figure 8. Numerical changes in seedling size classes, pre-eradication and post-eradication, for Hauturu and the control islands of *Pisonia brunoniana* (parapara), *Prumnopitys ferruginea* (miro) and *Rhopalostylis sapida* (nikau). Error bars show 95% confidence interval. Note, for *Rhopalostylis sapida*, 2L = two leaf and 4L = four leaf, and there is no *P. brunoniana* plot for Great Barrier Island or *P. ferruginea* plot for Taranga Island.

on Fig. 8). On rat-inhabited Taranga Island, no seedlings were found beneath 12 trees, and under another tree that was growing on a stony substrate where a few seeds could escape rats, 17 seedlings were recorded in 2004 and 14 were present in 2008 (Fig. 8).

Prumnopitys ferruginea (miro)

Miro seedlings were searched for on three plots on Hauturu and on four on Great Barrier Island (Table 2). There was a decrease in the numbers of seedlings recorded for Hauturu, while over the same period seedling numbers increased on Great Barrier Island (Table 4; Figs 2 & 8). This inter-island difference appeared to be significant (Fig. 2), but numbers were relatively low and the data on size classes are more difficult to interpret. Miro is not known from Taranga Island.

Rhopalostylis sapida (nikau)

Small, two-leaf seedlings (< 1 year old) of nikau were uncommon on Great Barrier and Taranga Islands (Fig. 8). After rat eradication, significantly more seedlings were in the seven plots checked on Hauturu (Table 2) compared with the numbers recorded for both control islands over the same period (Table 4; Figs 2 & 8). On Hauturu, the increase was greatest in the small, two-leaf size class (Fig. 8).

Ripogonum scandens (supplejack)

Significantly more supplejack seedlings were recorded for Hauturu after rat eradication compared with numbers for 2008 on Great Barrier and Taranga Islands (Tables 2 & 4; Figs 2 & 9). However, the only noteworthy change in numbers on Great Barrier Island over the study period was on plot 11, where

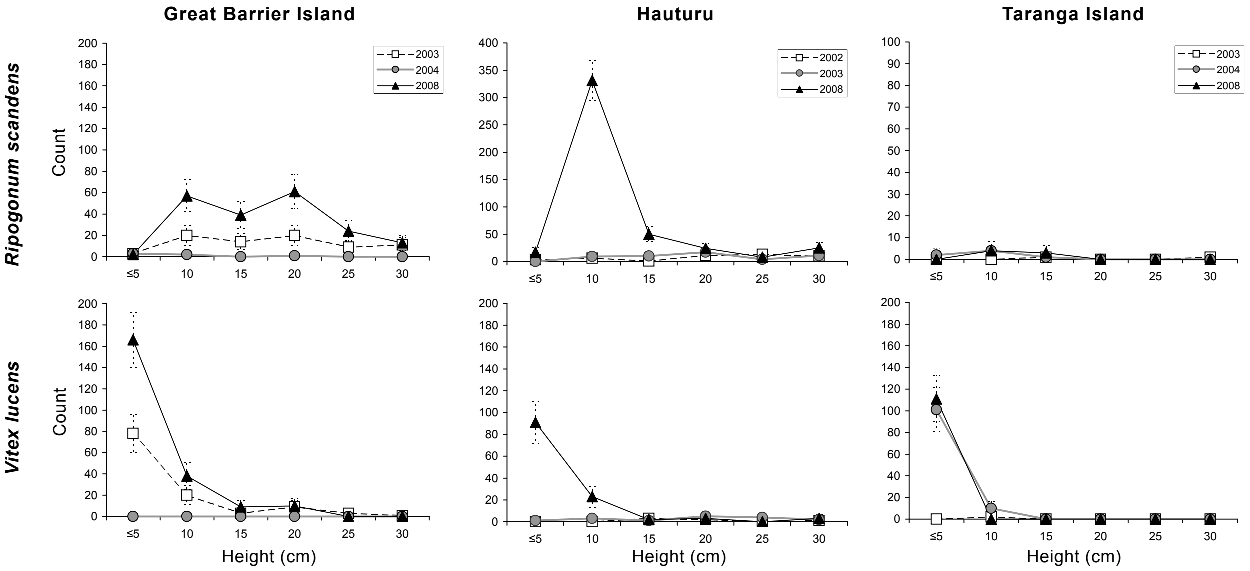


Figure 9. Numerical changes in seedling size classes, pre-eradication and post-eradication, for Hauturu and the control islands of *Ripogonum scandens* (supplejack) and *Vitex lucens* (pūriri). Error bars show 95% confidence interval.

rat numbers had been controlled. Increases on Hauturu were greatest (up to ten times more seedlings) after rat eradication (Fig. 9) in moister mid-altitude plots (13, 15, 18), where mature vines were more common initially. Considerably more post-eradication seedlings were recorded than predicted (Fig. 3).

Vitex lucens (pūriri)

Over the study period, pūriri seedlings increased on all three islands (Table 4; Figs 2 & 9). Seedling numbers in the 10-cm size class on four plots on Hauturu doubled after rat eradication, but changes on individual plots varied greatly, with many more seedlings on two plots (10, 15), and no change on two (11, 12). In 2008, one plot on Taranga Island (8), one on Great Barrier Island (11) and one on Hauturu (15) had many more seedlings in the 5-cm size class than previously. The variable number of seedlings on the control islands influenced the predicted post-eradication numbers on Hauturu (Table 4; Fig. 3).

3.2 SPECIES MONITORED ONLY ON HAUTURU

Two of the nine species monitored only on Hauturu (Table 1), tāwari and haekaro, had substantially more seedlings after rat eradication and were included in the analysis, with the assumption that pre-eradication seedling numbers on Hauturu were equivalent to seedling counts from surveys undertaken before 2008 on the control islands. The remaining seven species counted only on Hauturu each had fewer than 20 seedlings and all were eliminated from further analysis.

Ixerba brexoides (tāwari)

A single plot (16) was established at 560 m a.s.l. on Hauturu to monitor tāwari. From 2003 to 2008, numbers of seedlings >10 cm tall did not change, but over the same period, seedling numbers in the 5-cm class increased significantly from 1 to 93, and those in the 10-cm class rose from 0 to 32 (Fig. 10). On Great Barrier Island, tāwari grows on the wetter upper slopes of Mt Hobson but was not monitored. It is not found on Taranga Island.

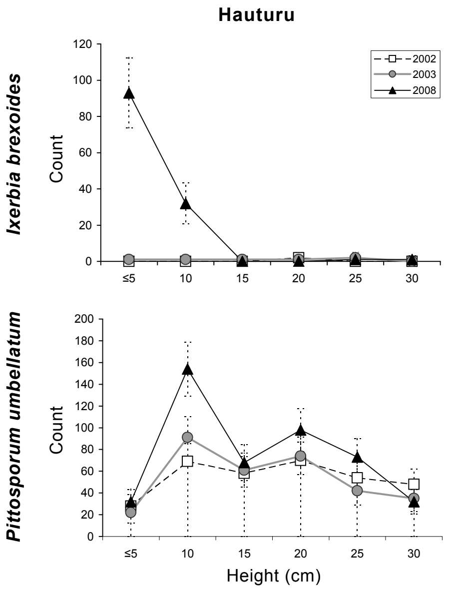


Figure 10. Numerical changes in seedling size classes, pre-eradication and post-eradication, for Hauturu only of *Ixerba brexoides* (tāwari) and *Pittosporum umbellatum* (haekaro). Error bars show 95% confidence interval.

Pittosporum umbellatum (haekaro)

Haekaro seedlings were monitored on Hauturu on two plots (7, 8) at c. 100 m a.s.l. on the Thumb and Hamilton tracks. The species is not found on Taranga or Great Barrier Islands. Assignment of seedlings to size classes was sometimes difficult because often taller seedlings had died back and re-sprouted, so that some seedlings were older than their height suggested. After rat eradication, seedling numbers in the 10-cm size class, where dieback was not a problem, increased significantly from 91 in 2003, to 154 in 2008, an increase of 1.6 times (Table 4; Figs 2 & 10). Overall, however, the increase in seedlings was only slightly more than predicted from the pre-eradication numbers (Table 4; Fig. 3).

3.3 MONITORING OF OTHER SPECIES ON HAUTURU

Of the 15 species listed in Table 4 that were not analysed further, seven species were monitored only on Hauturu: hard beech, Kirk's daisy, kōhūhū, korokio, lancewood, toro and toropapa. Kirk's daisy, kōhūhū and toropapa were monitored in a single plot, while hard beech, korokio, lancewood and toro were monitored on two (Table 2). Six of the 15 species were monitored on Hauturu and one control island: *Clematis paniculata*, hīnau, toatoa, tawāpou, toru and tōtara (*Podocarpus hallii* on Hauturu and *P. totara* on Great Barrier Island). Taupata and māhoe were monitored on Hauturu and both control islands.

Extensive searches for small seedlings of these species in the fixed plots and more widely on Hauturu during the post-eradication survey and during the visit in 2009 did not detect a post-eradication flush of seedlings. However, as taupata and tawāpou have had their adult abundance greatly reduced by Pacific rats (Campbell 2002; Campbell & Atkinson 2002), a large increase in seedling numbers was not expected. By 2009, a few taupata seedlings < 5 cm in height were seen in coastal forest near plot 6. Small seedlings of mamangi (*Coprosma arborea*), a species not initially monitored, were very abundant in 2009, especially where mamangi was a dominant understorey tree in kanuka stands. These carpets of seedlings were not seen in 2008, or earlier when rats were present.

In January 2009, a few small seedlings of karo were present on some shoreline sites, and mature karo trees nearby had an abundant crop of fruit, indicating that a much greater response was imminent. Because karo is severely affected by Pacific rats (Atkinson 1986), it was thought that the related kohuhu, uncommon on kānuka-dominated ridges, may also have been affected by them. No increase in seedling numbers was detected after rat eradication (Table 4).

3.4 HAVE PACIFIC RATS SLOWED THE SPREAD OF KAURI INTO KĀNUKA STANDS?

Data from Hauturu plots 3, 7, 8 and 14, situated on the lower edge of kauri distribution on the planezes, showed that numbers of kauri seedlings decreased slightly in those plots during the study (Table 4; Fig. 4) (although there was a slight but significant increase in seedlings in the 10-cm size class on plot 3 in 2008). Fewer kauri seedlings were also counted on Great Barrier Island in 2008, with the decrease being slightly larger on Great Barrier compared to Hauturu (Table 4; Fig. 2). This would indicate that although rats eat kauri seed, they appear to have had negligible effect on its rate of spread into forest contiguous with kauri stands.

3.5 HAVE PACIFIC RATS AFFECTED THE SPREAD OF BIRD-DISPERSED SPECIES INTO KĀNUKA STANDS?

Data from the 15 plots located in kānuka stands (Table 5) show that three species (taraire, karaka and tanekaha) were twice as numerous in the kānuka stands after rat eradication compared with before, kohekohe was five times more common, and supplejack was 41 times more common, indicating that while Pacific rats were present on Hauturu, bird-dispersed trees and vines had difficulty establishing in kānuka stands. There were no differences in the remaining six species during the study (Table 5). Most plots in forest on moister sites had nīkau and supplejack seedlings in 2008, and white maire was found on most plots (see section 3.1). Pacific rats had had major effects on the spread of some species into forest dominated by kānuka.

TABLE 5. INCREASE OF BIRD-DISPERSED SPECIES IN KĀNUKA STANDS ON HAUTURU AFTER RAT ERADICATION.

SPECIES	COMMON NAME	PLOTS SAMPLED	NUMBERS OF SEEDLINGS COUNTED (<5 + 10-cm SIZE CLASSES COMBINED)		INCREASE
			PRE-ERADICATION	POST-ERADICATION	
Beilschmiedia tarairi	Taraire	9, 10, 12, 15	16	25	×2
Beilschmiedia tawa	Tawa	12, 18	12	5	
Corynocarpus laevigatus	Karaka	12, 15	29	41	×2
Dysoxylum spectabile	Kohekohe	5, 10, 12, 15	37	187	×5
Elaeocarpus dentatus	Hīnau	18	–	–	
Hedycarya arborea	Pigeonwood	9, 13, 18	55	212	×4
Myrsine salicina	Toro	16	–	–	
Phyllocladus trichomanoides	Tānekaha	1, 3, 7, 8, 14	169	298	×2
Prumnopitys ferruginea	Miro	13	2	2	
Ripogonum scandens	Supplejack	15, 17	7	293	×41
Toronia toru	Toru	14	–	–	
Vitex lucens	Pūriri	11, 15	2	2	

4. Discussion

4.1 SEEDLING RESPONSES ON HAUTURU COMPARED WITH THE CONTROL ISLANDS

Nineteen species had sufficient seedlings on Hauturu and the control islands for the magnitude of rat effects on their seedling numbers to be examined (Table 4). Five of the 19 species (kauri, miro, pūriri, taraire and tawa) had fewer seedlings after rat eradication, suggesting that rats had not affected seedling establishment. Numbers of kauri seedlings did not show any increase (Figs 2 & 3), although Pacific rats eat seed, and kauri seedlings had been found to be more common in rat-proof exclosures on Hauturu (Campbell & Atkinson 2002). However, low germination rates in these exclosure trials meant that the differences were not statistically significant. It appears from this study that kauri seedling establishment is not affected by Pacific rats. Miro seeds under mature female trees are nearly all rat eaten (pers. obs.), so a response to rat eradication is anticipated even though it was not detected in 2008. The lack of response in pūriri to rat eradication contrasts with exclosure trials on Hauturu where a slight but significant increase in seedlings was found when rats were excluded (Campbell & Atkinson 2002). Although Pacific rats eat pūriri berries and frequently eat the kernels, data from Cuvier (Repanga) Island showed that up to 40% of the kernels were not destroyed when rats chewed the hard endocarp (Campbell & Atkinson 1999). In addition, as pūriri often establishes in disturbed sites such as small light gaps or windfalls, rat effects on pūriri seedling establishment are harder to quantify. This study's findings for taraire and tawa were consistent with those of other studies, which have shown these species to be unaffected by Pacific rats (Campbell & Atkinson 2002).

Several species, especially coastal karamū, nīkau, parapara, rewarewa, supplejack, tānekaha and white maire, experienced a dramatic increase in seedling numbers on Hauturu after rat eradication compared with the control islands. Although the increases in seedlings of remaining species (i.e. haekaro, kahikatea, karaka, kawakawa, kohekohe, pigeonwood and tāwari) after rat eradication were not as great, most had significantly more seedlings. Two-leaf-stage nīkau seedlings are palatable to rats, with both the leaves and basal root being eaten (Campbell 1978; Campbell & Atkinson 2002). At least two species (parapara and rewarewa) have their natural seed dispersal mechanisms (sticky seed and wind dispersal, respectively) curtailed by Pacific rats climbing fruiting trees to eat seed before it is dispersed (Campbell & Atkinson 2002). Kawakawa seedling numbers increased significantly on Hauturu compared with Taranga Island. Kawakawa fruit are highly palatable to rats, which readily eat them, but, as the seeds are small, rats can disperse them as well as destroy them (Williams et al. 2000). The overall effect on kawakawa, therefore, is likely to be less pronounced than for species whose seed is always destroyed by Pacific rats.

Seedling response depends on many factors, including those that influence the size of the seed crop, such as the rarity of seed trees, and the abundance of animals that exploit the seed crop. Many of the species that Pacific rats affect most (e.g. parapara and tāwapou) are rare on the northern islands, and rarity of mature trees has been documented as affecting reproductive processes and reducing the available seed crop (Wilcock & Neiland 2002). For these reasons, more species are likely to show a post-eradication response than just those recorded in this study, particularly those species that rats have made less abundant because of reduced juvenile recruitment. For example, the response of tanekaha to rat eradication (Figs 2 & 7) suggests that toatoa may also be affected by rats. Adult toatoa were very rare compared with tānekaha, and although no post-eradication seedling increase was detected in toatoa, this may merely reflect the rarity of seeding trees. Moreover, some species may require a longer time interval before significant responses can be detected. For example, hinau shows considerable annual variation in fruit production (Cowan & Waddington 1990), and several years elapsed before a marked, post-rat eradication response was observed on Kapiti Island (pers. obs. 2008). The initial lack of response of hīnau on Kapiti Island may have been a consequence of kākā (*Nestor meridionalis*) eating the kernels of hīnau fruit and destroying the seeds (Campbell & Atkinson 1999). Moorehouse (1997) found on Kapiti Island that kākā during their breeding season fed intensively in hīnau trees as the fruit ripened.

Clearly, among the monitored species, there was a gradient of Pacific rat effects from no effect through to severe reduction in seedling numbers (Figs 2 & 3)—which is consistent with exclosure studies and other inter-island comparisons (Campbell & Atkinson 2002). This study has quantified the relative impact of Pacific rats on rewarewa, tānekaha and white maire as dramatic and significant, and it has confirmed that kohekohe and karaka seedling numbers increase significantly following rat eradication. A few of the species that showed the greatest increase in seedling numbers after rat eradication, e.g. coastal karamū, nīkau and parapara, had very crowded seedling populations: in particular, nīkau and parapara seedlings were often found in dense concentrations beneath the parent trees. This pattern of seedling establishment contrasts with other species where seedlings were scattered and widespread, such as the wind-dispersed rewarewa, and bird-dispersed white maire and tānekaha. These crowded populations will suffer high mortality as they undergo self thinning; the number of seedlings that survive thinning from high-density, crowded seedling populations may not differ substantially from the numbers that survive from low-density seedling populations.

The log ratios (Fig. 2), and the predicted seedling count versus actual count (Fig. 3), show the marked differences in seedling response to the eradication of Pacific rats between the species that were monitored. Those with the biggest differences between the control islands and Hauturu are the species that have seeds or seedlings that rats actively seek out because of their palatability or nutritional value (Grant-Hoffman & Barboza 2009).

4.2 SEEDLING RESPONSES OF SPECIES MONITORED ONLY ON HAUTURU

For species that were monitored only on Hauturu, it was not possible to allow for climatic influences on seedling establishment, and thus determine the size of a seedling response that could be attributable to rats alone. By 2008, seven of the nine species monitored only on Hauturu had too few seedlings for statistical comparisons, and these seven did not show a general increase in seedlings elsewhere on the island.

A year after the last plot data were collected on Hauturu (January 2009), fruit was more conspicuous on several species than in earlier visits. Fruit of kiekie (*Freycinetia banksii* ssp. *baueriana*) was seen for the first time, ripe fruit was seen on maire (*Mida salicifolia*) and toru fruit was more obvious. A much heavier than usual crop of fruit was seen on coastal karamū shrubs compared with years when rats were present. However, it is not known whether this apparent abundance was a consequence of rat removal, or because less fruit had been eaten by birds.

4.3 HAVE RATS SLOWED THE SPREAD OF KAURI INTO KĀNUKA STANDS?

Pacific rats eat kauri seed (Campbell & Atkinson 2002), and rats (probably ship rats) on Great Barrier Island were reported as having eaten kauri seedlings up to 10 cm tall from propagating trays unless the seedlings were covered (A. Phelps, nurseryman, pers. comm. 2008). This would suggest that kauri seedling populations could have been affected by Pacific rats. However, because kauri seedlings were less common on both Hauturu and Great Barrier Islands after rat eradication, this study found no evidence that rats influenced the rate of spread of kauri into kānuka forest contiguous with kauri stands.

4.4 HAVE RATS SLOWED THE SPREAD OF BIRD-DISPERSED SPECIES?

Although a detailed distribution of seed trees relative to plot sites would need to be established to rigorously address this question, some measure of the effect of rats on uncommon, bird-dispersed forest trees can be gauged by the post-eradication influx of their seedlings into kānuka forests. If many more seedlings of these uncommon species establish, it would suggest that rats had been affecting their establishment.

The tree species present in the regenerating kānuka forest on Hauturu in 2002 had established in the presence of Pacific rats (and in many places, cattle as well), and their abundance in the forest reflected the dispersal ability of each species and, amongst other factors, the effects of rats on seedling establishment. Bird-dispersed seed stays on the ground until it germinates and, to a seed predator, is no different from seed that has fallen to the ground from a nearby tree. The greatest foraging pressure from Pacific rats coincides with the time of seed fall of many trees because rat numbers build from spring during the annual rat breeding cycle to reach maximum density in autumn (Towns & Atkinson 2005). Maximum rat densities are usually followed by a population crash in late autumn.

A comparison of seedling numbers before and after rat eradication on several plots in kānuka forest (Table 5) shows that 6 of the 12 bird-dispersed species monitored, especially pigeonwood, kohekohe and supplejack, had already become more common 4 years after rat eradication. Similarly in 2008, most plots in moister sites had nīkau and supplejack seedlings, and those of white maire were widespread on nearly all Hauturu plots. This recent influx of bird-dispersed seedlings into kānuka stands cannot be attributed to a natural process of forest succession that is unrelated to the removal of rats, especially as many of the species are known to have their seed eaten by rats (Campbell & Atkinson 2002).

4.5 POSSIBLE FUTURE CHANGES IN FOREST COMPOSITION ON HAUTURU

Although a species may initially have more seedlings after rat eradication, because of juvenile mortality it does not follow that a change of the same magnitude will persist into the mature vegetation. However, a post-eradication seedling increase does suggest that the abundance of rat-affected species will change, and that this will alter forest composition and ultimately forest structure. Forest species currently present in the maturing kānuka forest on Hauturu had established in the presence of Pacific rats. Most understorey species were those that rats had had little effect on, or ones that, despite being affected, managed to establish at lower densities. Most of these species appear near the line of unit slope in Fig. 3. Species that fall further from that line (except parapara) mainly are those that, while relatively common in the forest, are much more affected by rats. The elimination of rats from Hauturu will initiate marked changes in the populations of most species shown on upper side of the line of unit slope, and as a generalisation those farthest from the line are likely to increase most.

Although most species that have had their seedling numbers suppressed by rats are likely to become more common, species that are most suited to exploit new opportunities are those that were relatively abundant in the vegetation at the time of rat eradication. Generally, the ones that are most likely to increase in abundance are those that have been inhibited by rats, have the highest reproductive rates, mature in the shortest time and are widely dispersed by birds or by wind. The species that best fits those criteria is coastal karamū, but others that take only decades to mature are kohekohe, nīkau, pigeonwood, rewarewa, supplejack, tānekaha and white maire. Tāwari, and later hīnau, should increase at higher altitudes.

Thirty species are known to be adversely affected by Pacific rats, including four new ones added from this study (haekaro, kahikatea, tānekaha and tāwari) (Table 6). Three others appear to be unaffected by them. Four species listed in Table 6 are not found on Hauturu, but two of those (coastal maire and milk tree), which have a widespread distribution on northern islands (Appendix 2), are severely affected by Pacific rats.

At least 16 species identified in Table 6 are found in the vegetation on those northern islands that have always been rat free (e.g. Islands of the Poor Knights group, Green and Korapuki Islands in the Mercury Islands (Iles d'Haussez), and islands of the Alderman Island group). Although ngaio has not been confirmed as affected by rats, its abundance on rat-free islands contrasts with that on rat-inhabited ones and strongly indicates that rats depress seedling numbers (pers. obs.). All these 17 species should become more common in the lowland and coastal vegetation of Hauturu, but Coomes et al. (2003) have identified other factors that can influence vegetation recovery after the removal of herbivores. The direction of the development of the post-rat eradication vegetation will depend, in part, on how dense the shrub layer becomes after the first flush of seedlings have grown, and the seedling environment that then prevails.

In time, the following changes in forest composition are likely. Rats have suppressed the numbers of at least 16 species that contribute to shoreline scrub and coastal forest and, following rat eradication, coastal vegetation will probably

TABLE 6. SPECIES WITH SEEDLING POPULATIONS AFFECTED BY PACIFIC RATS.
Note: bold indicates species that are adversely affected by Pacific rats.

SPECIES	COMMON NAME	REFERENCE
Beilschmiedia tarairi	Taraire	Campbell & Atkinson 2002; this study
Beilschmiedia tawa	Tawa	Campbell & Atkinson 2002; this study
Coprosma arborea	Māmāngi	This study
Coprosma areolata***	Aruhe	Campbell 2002
Coprosma macrocarpa†	Coastal karamū	Campbell & Atkinson 2002; this study
Coprosma repens†	Taupata	Campbell & Atkinson 2002
Corynocarpus laevigatus†	Karaka	Campbell & Atkinson 1999; this study
Dacrycarpus dacrydioides	Kahikatea	This study
Dactylanthus taylori	Wood rose	Eckroyd 1996
Dysoxylum spectabile†	Kohekohe	Campbell & Atkinson 2002; this study
Elaeocarpus dentatus	Hīnau	Campbell 2002
Hedycarya arborea†	Pigeonwood	Campbell 1978; this study
Ixerba brexoides	Tāwari	This study
Knightia excelsa†	Rewarewa	Campbell 2002; this study
Macropiper excelsum†	Kawakawa	Campbell 1978; this study
Melicytus novae-zelandiae†	Coastal māhoe	Campbell & Atkinson 2002
Myrsine australis	Māpou	Campbell & Atkinson 2002
Nestegis apetala*†*	Broad-leafed maire	Campbell & Atkinson 2002
Nestegis lanceolata	White maire	Campbell 2002; Campbell & Atkinson 2002; this study
Passiflora tetrandra	Passion vine	Campbell 2002
Pennantia corymbosa***	Kaikōmako	Campbell 2002
Phyllocladus trichomanoides	Tānekaha	This study
Pisonia brunoniana†	Parapara	Campbell & Atkinson 2002; this study
Pittosporum crassifolium†	Karo	Atkinson 1972; Campbell & Atkinson 2002
Pittosporum umbellatum	Haekaro	This study
Pouteria costata†	Tawāpou	Campbell & Atkinson 2002
Prumnopitys taxifolia	Mataī	Campbell 2002
Pseudopanax arboreus†	Fivefinger	Campbell & Atkinson 2002
Pseudopanax lessonii†	Houpara	Campbell & Atkinson 2002
Rhopalostylis sapida†	Nīkau	Campbell & Atkinson 2002
Ripogonum scandens	Supplejack	Campbell 2002; this study
Streblus banksii*†*	Milk tree	Atkinson 1986; Campbell & Atkinson 2002
Vitex lucens	Pūriri	Campbell & Atkinson 2002

* Not found on Hauturu.

† Commonly found on rat-free islands.

contain more coastal karamū, coastal māhoe, houpara, karo, kawakawa and taupata. Taller coastal forest will contain more karaka, kohekohe, māhoe, ngaio, nīkau, parapara, pigeonwood, pūriri, tawāpou and white maire, with supplejack and passion vine contributing to the canopy. Lowland forest of the valley sides and river terraces is predicted to contain more karaka, kohekohe, nīkau, rewarewa, supplejack and white maire and, in the understorey, more coastal karamū and kawakawa. Forest of the mid-slope, planeze ridges will mostly likely consist of much more rewarewa, tānekaha and white maire, and more haekaro. Forest on the lower slopes of the central cone above the planezes will probably have more hīnau, kahikatea, kohekohe, supplejack, nīkau, pigeonwood and rewarewa, whereas at higher altitudes, tāwari is predicted to become much more common. Miro may also become more common at higher altitudes, but miro did not respond after rats were eradicated from Kapiti Island (Campbell 2002), even after a further decade (pers. obs. October 2008), suggesting that fruiting may be sporadic and that seedling establishment may be more related to fruit consumption by kākā than by Pacific rats.

Milk tree has never been found on Hauturu and coastal maire has not been reliably reported for Hauturu, which is an anomalous distribution since both trees have distributions that extend from north of the Bay of Islands to islands off the Coromandel Peninsula, with milk tree's distribution extending south to the Marlborough Sounds (see Appendix 2 for a detailed summary of their distributions). Distributions of both milk tree and coastal maire include most islands where stands of forest escaped burning during extensive clearing by Māori, and usually both species are absent from islands that had been extensively modified. Hauturu appears to be the notable exception within this distribution pattern; it has the least-modified vegetation of all the islands, yet neither species has been found there. One or both species are present on nearby islands (albeit at a distance of over 18 km away). Both species are medium-sized coastal trees with seed that is greatly sought after by Pacific rats and, as juvenile recruitment is severely depressed in the presence of rats, populations of these species on rat-inhabited islands consist of very old trees and few juveniles (Campbell & Atkinson 2002). Given the distribution records of, and the documented effects of rats on, milk tree and coastal maire, it appears they could have been made extinct on Hauturu by Pacific rats. A strong case could be made for the reintroduction of these tree species from Taranga or Great Barrier Islands.

5. Future work

This study aimed to discover further species that were affected by Pacific rats and determine the relative magnitude of rat effects on several species found on Hauturu, as part of a long-term objective of understanding the role of Pacific rats in altering the composition and structure of mainland forests after their arrival in New Zealand. Future investigations to determine the effect of Pacific rats on seedling establishment of additional forest species, and thus on the relative abundance of trees and forest composition, are becoming more difficult as opportunities for testing rat effects on other species have almost passed. For example, exclosure studies will become much more difficult to undertake, as planning is in progress to eradicate Pacific rats from Taranga Island[4], the last northern island of moderate size and vegetation complexity. Most future studies will have to depend on examining post-eradication size classes of species that may have been affected by Pacific rats. Analysis of population size classes of seedlings and saplings of species on Hauturu should be used to search for increases in the smaller size classes of species that have not yet responded to rat eradication.

Three of the eight conifers in the Hauturu flora, kahikatea, matai and tānekaha, have been shown to have their seedling abundance severely affected by Pacific rats. The fruit characteristics of the other podocarps, indicate that rats would be attracted to rimu (*Dacrydium cupressinum*), toatoa, thin-barked tōtara and tōtara (*Podocarpus totara*). Further investigations should be made into the role of Pacific rats in reducing seedling numbers of these species, to determine whether Pacific rats could have affected podocarp abundance in mainland forests. Populations of seedlings and saplings near mature female trees on Hauturu should be sampled for evidence of any post-rat eradication recovery in these conifer species, and kauri populations as well should be further investigated for evidence of a post-eradication seedling recovery.

Previous work has examined the role of Pacific rats in reducing seedling numbers by eating seed and, except for a few species such as nīkau and coastal karamū, it is not known whether rats also eat seedlings. Species for which seedlings have been reported as being eaten by Pacific rats include houpara, kawakawa, māhoe and supplejack. Other plants known to be eaten by other rat species may be palatable to Pacific rats as well. Norway rats have been reported as eating seedlings of kauri, rimu and tōtara, while ship rats have been reported as eating fivefinger and tawa (Campbell 1978). If Pacific rats reduce the seedling abundance of some species by regularly eating seedlings (as suggested by the post-eradication abundance of māmāngi) or seedlings of species that do not have fleshy or aggregated fruit, they may affect a wider range of forest species than currently assumed.

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4 Note added in press: brodificoum poison was distributed on 19 May 2011 to eliminate *R. exulans* from Taranga Island.

6. Acknowledgements

This study was partly funded by the Foundation for Research Science and Technology Contract ERAX 0201, and was completed with funding from DOC Contract NHE-03-07-01-01 (Investigation No. 3493) and from the Hauturu Supporters Trust.

Many thanks go to DOC for granting access to Hauturu/Little Barrier Island, Taranga Island and Great Barrier Island (Aotea Island), transport on the *Hauturu* and accommodation. Many people in DOC have assisted this study in various ways; I especially would like to thank Shane McInnes, Will Scarlett and Pete Barrow who provided assistance on Hauturu; and Richard Garrett, Richard Griffiths, Rory Renwick and the staff of the Warkworth Office; Keith Hawkins and Richard Parrish of the Whangarei Office; and Dave Agnew, Halema Jamieson and Hillary McGregor of the Great Barrier Office.

I am indebted to Ian Atkinson for assistance and field discussions during the pre-eradication surveys, and staff of DOC who provided field assistance with data collection during the post-eradication resurvey, including Ange Hogan, Sue Cameron, Bryce Lummis, Hillary McGregor and Halema Jamieson. I am grateful for the assistance and hospitality provided by Halema Jamieson and Alan Phelps. My wife Angela assisted with collection of vegetation data. I am grateful to Sue Hallas and two anonymous reviewers for constructive comments on the manuscript.

Finally, I thank Rory Renwick, DOC, and Judy Hanbury of the Hauturu Supporters Trust for their interest in the study and arranging funding for completion of the work. Tim Ball contributed greatly to the work by providing statistical analysis of the data and its graphical presentation. I thank Claudia Reidel for drafting the figures for publication.

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Appendix 1

COMMON AND SCIENTIFIC NAMES OF PLANT SPECIES MENTIONED IN THE TEXT

COMMON NAME	SCIENTIFIC NAME
Bush lawyer	*Rubus cissoides*
Coastal karamū	*Coprosma macrocarpa*
Coastal māhoe	*Melicytus novae-zelandiae*
Coastal maire	*Nestegis apetala*
Fivefinger	*Pseudopanax arboreus*
Haekaro	*Pittosporum umbellatum*
Hangehange	*Geniostoma rupestre* var. *ligustrifolium*
Hard beech	*Nothofagus truncata*
Hīnau	*Elaeocarpus dentatus*
Houpara	*Pseudopanax lessonii*
Kahikatea	*Dacrycarpus dacrydioides*
Kaikōmako	*Pennantia corymbosa*
Kānuka	*Kunzea ericoides*
Karaka	*Corynocarpus laevigatus*
Karamū	*Coprosma lucida*
Karo	*Pittosporum crassifolium*
Kauri	*Agathis australis*
Kawakawa	*Macropiper excelsum*
Kiekie	*Freycinetia banksii* ssp. *baueriana*
Kirk's daisy	*Brachyglottis kirkii*
Kohekohe	*Dysoxylum spectabile*
Kōhūhū	*Pittosporum tenuifolium*
Korokio	*Corokia buddleoides*
Kōwhai	*Sophora chathamica*
Lancewood	*Pseudopanax crassifolius*
Māhoe	*Melicytus ramiflorus*
Maire	*Mida salicifolia*
Māmāngi	*Coprosma arborea*
Māpou	*Myrsine australis*
Matai	*Prumnopitys taxifolia*
Milk tree	*Streblus banksii*
Miro	*Prumnopitys ferruginea*
Mountain fivefinger	*Pseudopanax colensoi*
Neinei	*Dracophyllum latifolium*
Ngaio	*Myoporum laetum*
Nīkau	*Rhopalostylis sapida*
Northern rātā	*Metrosideros robusta*
Parapara	*Pisonia brunoniana*
Passion vine	*Passiflora tetrapathaea*
Patē	*Schefflera digitata*
Pigeonwood	*Hedycarya arborea*
Pōhutukawa	*Metrosideros excelsa*
Puawananga	*Clematis paniculata*
Pūriri	*Vitex lucens*
Rewarewa	*Knightia excelsa*
Rimu	*Dacrydium cupressinum*

COMMON NAME	SCIENTIFIC NAME
Southern rātā	*Metrosideros umbellata*
Supplejack	*Ripogonum scandens*
Tainoka	*Carmichaelia cunninghamii*
Tānekaha	*Phyllocladus trichomanoides*
Taraire	*Beilschmiedia tarairi*
Taupata	*Coprosma repens*
Tawa	*Beilschmiedia tawa*
Tawāpou	*Pouteria costata*
Tāwari	*Ixerba brexoides*
Tāwheowheo	*Quintinnia serrata*
Tawhero	*Weinmannia silvicola*
Thin-barked tōtara	*Podocarpus hallii*
Tītoki	*Alectryon excelsus*
Toatoa	*Phyllocladus toatoa*
Toro	*Myrsine salicina*
Toropapa	*Alseuosmia macrophylla*
Toru	*Toronia toro*
Tōtara	*Podocarpus totara*
Wharangi	*Melicope ternata*
White maire	*Nestegis lanceolata*
Wood rose	*Dactylanthus taylori*

Appendix 2

DETAILED DISTRIBUTION RECORDS OF MILK TREE (*Streblus banksii*) AND COASTAL MAIRE (*Nestegis apetala*)

Milk tree

Milk tree has a patchy distribution in coastal forest on islands (Atkinson 1986), southwards from latitude 35° (near Mangonui, coastal Northland). Milk tree foliage and bark are very palatable to browsing mammals and, because rats eat the seed, the species has been almost eliminated from mainland coastal forest. Trees have thin bark and are vulnerable to fire, so often the species is uncommon on islands that have been extensively burnt.

The following is a summary of its distribution over the northern part of its range, from north to south. Its current northern limit is the Cavalli Islands, including modified Motukawanui Island and a stack close to Stephenson Island (Mahinepua Island) (Wright 1979; Conning & Miller 1999). Milk tree is on the inner islands of the Bay of Islands (Conning & Miller 1999), and the large islands of the eastern Bay of Islands (Beever et al. 1984).

Further south along the Northland coast, it is found on Piercy Island (Cameron & Taylor 1991), Rimariki Island (Cameron 1986), the Poor Knights Islands (Atkinson 1986; de Lange & Cameron 1999) and on the mainland near Whangarei at Bream Head (Pierce et al. 2002). Milk tree has not been recorded from the highly modified Mokohinau Islands (Esler 1978b), but there are records for it on nearby Fanal Island (Motukino) (Wright 1980). It is on the Marotere Islands (formerly Chicken Islands) (Atkinson 1971, 1986), Taranga Island (Wright 1978) and Sail Rock (Atkinson 1972).

Buchanan (1876) did not record milk tree from Kawau Island in the Hauraki Gulf, but even at that early date many species of introduced mammals had been released on Kawau Island. The species was not recorded from the extensively modified islands of the Hauraki Gulf: Tiritiri (Esler 1978b), Motutapu (Esler 1980) and Ponui (Brown 1979). It is absent from the main island of Great Barrier Island (Aotea Island) and the very modified islands of the west coast of Great Barrier Island, but is found on the east coast on Rakitu Island (Arid Island) (Cameron & Wright 1982).

An old mature milk tree was found on Cuvier (Repanga) Island in 2000 and the species was present on the islands west of the Coromandel Peninsula (Esler 1978a). It has been found in forest remnants on Great Mercury Island (Ahuahu) (Wright 1976), has been recorded on Kawhitu or Stanley Island, Atiu Island (Middle Island) and Green Island, and on Old Man Rock of the Mercury Islands (Iles d'Haussez) (Atkinson 1962, 1964; Taylor & Lovegrove 1997).

Milk tree has been documented as being present all on the larger islands of the Aldermen Island group (Court et al. 1973), and on Karewa Island (Sladden 1924), but it is absent from the more-modified islands of the Slipper Island (Whakahau) group (Court 1974). It is not found on the greatly modified islands of Motunau Island (Taylor 1991) or Moutohora Island (Parris 1971).

Coastal maire

Coastal maire has a geographical distribution similar to that of milk tree except that it has not been found further south than the Mercury Islands (Iles d'Haussez) (latitude 36°38′). In contrast to milk tree, it is absent from the Cavalli Islands (Wright 1979), but is present the inner islands of the Bay of Islands (Conning & Miller 1999). It was noted as an important component of the vegetation of Piercy Island (Cameron & Taylor 1991) and was found on an unnamed nearby island near Cape Brett (Cameron 1982). It is not found on the Rimariki Islands (Cameron 1986).

Coastal maire is present in forest on the Poor Knights Islands (de Lange & Cameron 1999), and on Bream Head on the northland mainland (Pierce et al. 2002). It is documented as being on Fanal Island (Motukino) (Wright 1980), but not on the Mokohinau group where the islands are more modified (Esler 1978b). It is on the Marotere Islands (Atkinson 1971; Cameron 1984) and Taranga Island (Wright 1978), but absent from Sail Rock (Atkinson 1972).

Buchanan (1876) did not record coastal maire on Kawau Island in the Hauraki Gulf, nor has it been recorded from the modified islands of the Hauraki Gulf: Tiritiri (Esler 1978b), Ponui (Brown 1979) and Motutapu (Esler 1980). It is present on Kaikoura and Nelson Islands off Port Fitzroy, Great Barrier Island (Anon. 2008; Campbell 2008) and was recorded for Rakitu Island (Arid Island) off the east coast of Great Barrier Island (Cameron & Wright 1982).

Coastal maire is on Cuvier Island (Repanga Island) (Beever et al. 1969), on Kawhitu or Stanley Island and Old Man Rock in the Mercury Islands (Iles d'Haussez) (Atkinson 1962; Taylor & Lovegrove 1997), but it has not been recorded from the other Mercury Islands (Lynch et al. 1972; Atkinson 1962, 1964), or from Great Mercury Island (Ahuahu) (Wright 1976) or islands west of Coromandel (Esler 1978a).

Coastal maire has not been reported from islands south of the Mercury group such as the Aldermen Islands (Court et al. 1973), Karewa Island (Sladden 1924), the Slipper (Whakahau) group (Court 1974), Motunau Island (Taylor 1991) or Moutohora Island (Parris 1971).

Appendix 3

DETAILS OF SEEDLING PLOTS ON EACH STUDY ISLAND

Table A3.1—Seedling plots, Hauturu.

Table A3.2—Seedling plots, Taranga Island.

Table A3.3—Seedling plots, Great Barrier Island.

TABLE A3.1. SEEDLING PLOTS HAUTURU: LOCATION, LENGTH, AREA, ALTITUDE, SPECIES SAMPLED AND REASON FOR PLOT ESTABLISHMENT.

PLOT	GPS* E269 # N655 #	LENGTH (m)	AREA (m^2)	ALTITUDE (m a.s.l.)	TOPOGRAPHIC SITE CATEGORY	SPECIES SAMPLED	COMMON NAME	REASON FOR PLOT ESTABLISHMENT
1	E # 5089 N # 3428	110	440	145	Planeze slope	*Nestegis lanceolata* *Phyllocladus trichomanoides*	White maire Tānekaha	White maire and tānekaha seedling populations
2	E # 5264 N # 2663	85	340	150	Planeze	*Brachyglottis kirkii* *Knightia excelsa* *Nestegis lanceolata* *Nothofagus truncata* *Toronia toru*	Kirk's daisy Rewarewa White maire Hard beech Toru	Rewarewa, hard beech and toru seedling populations
3	E # 5766 N # 2587	250	1000	225	Ridge formed from planeze	*Agathis australis* *Corokia buddleoides* *Knightia excelsa* *Phyllocladus trichomanoides* *Phyllocladus toatoa* *Pittosporum umbellatum* *Toronia toru*	Kauri Korokio Rewarewa Tānekaha Toatoa Haekaro Toru	Lower edge of kauri distribution; tānekaha seedling population
4	E # 5168 N # 2157	240	960	240	Ridge formed from planeze	*Knightia excelsa* *Toronia toru*	Rewarewa Toru	Toru and rewarewa populations
5	E # 7106 N # 1884	50	200	250	Ridge formed from planeze	*Dacrycarpus dacrydioides* *Dysoxylum spectabile* *Knightia excelsa*	Kahikatea Kohekohe Rewarewa	Kahikatea seedling population; bird-dispersed kohekohe
6	E # 6555 N # 0693	60	240	6	Talus overlaid on boulder beach	*Beilschmiedia tawa* *Coprosma macrocarpa* *Corynocarpus laevigatus* *Macropiper excelsum* *Melicytus ramiflorus* *Pisonia brunoniana* *Rhopalostylis sapida* *Vitex lucens*	Tawa Coastal karamū Karaka Kawakawa Māhoe Parapara Nīkau Pūriri	Karaka, coastal karamū and parapara seedling populations

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Table A3.1 continued

PLOT	GPS* E269 # N655 #	LENGTH (m)	AREA (m^2)	ALTITUDE (m a.s.l.)	TOPOGRAPHIC SITE CATEGORY	SPECIES SAMPLED	COMMON NAME	REASON FOR PLOT ESTABLISHMENT
7	E # 6007 N # 1428	250	1000	90	Ridge formed from planeze	*Agathis australis* *Corokia buddleiodes* *Knightia excelsa* *Nestegis lanceolata* *Nothofagus truncata* *Phyllocladus trichomanoides* *Pittosporum umbellatum*	Kauri Korokio Rewarewa White maire Hard beech Tānekaha Haekaro	Lower edge of kauri distribution; haekaro seedling population; bird-dispersed tānekaha
8	E # 5667 N # 1683	200	800	120	Ridge formed from planeze	*Agathis australis* *Beilschmiedia tawa* *Knightia excelsa* *Nestegis lanceolata* *Phyllocladus trichomanoides* *Pittosporum umbellatum* *Pseudopanax crassifolius*	Kauri Tawa Rewarewa White maire Tānekaha Haekaro Lancewood	Lower edge of kauri distribution; haekaro seedling population; bird-dispersed tānekaha
9	E # 5124 N # 1957	78	312	30	Stream terrace	*Beilschmiedia tarairi* *Beilschmiedia tawa* *Corynocarpus laevigatus* *Dysoxylum spectabile* *Hedycarya arborea* *Macropiper excelsum* *Rhopalostylis sapida* *Ripogonum scandens* *Vitex lucens*	Taraire Tawa Karaka Kohekohe Pigeonwood Kawakawa Nīkau Supplejack Pūriri	Kohekohe, nīkau and karaka seedlings beneath mature trees; bird-dispersed taraire and pigeonwood
10	E # 6446 N # 0819	220	880	20	Stream terrace	*Beilschmiedia tarairi* *Beilschmiedia tawa* *Corynocarpus laevigatus* *Dysoxylum spectabile* *Hedycarya arborea* *Phyllocladus trichomanoides* *Rhopalostylis sapida* *Ripogonum scandens* *Vitex lucens*	Taraire Tawa Karaka Kohekohe Pigeonwood Tānekaha Nīkau Supplejack Pūriri	Bird-dispersed kohekohe, nīkau and taraire under kānuka

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Table A3.1 continued

PLOT	GPS* E269 # N655 #	LENGTH (m)	AREA (m^2)	ALTITUDE (m a.s.l.)	TOPOGRAPHIC SITE CATEGORY	SPECIES SAMPLED	COMMON NAME	REASON FOR PLOT ESTABLISHMENT
11	E # 6725 N # 1486	28	112	85	Stream terrace	*Beilschmiedia tarairi*	Taraire	Kohekohe, taraire, tawa and nīkau seedlings under mature trees; bird-dispersed pūriri
						Beilschmiedia tawa	Tawa	
						Corynocarpus laevigatus	Karaka	
						Dysoxylum spectabile	Kohekohe	
						Hedycarya arborea	Pigeonwood	
						Knightia excelsa	Rewarewa	
						Nestegis lanceolata	White maire	
						Rhopalostylis sapida	Nīkau	
						Ripogonum scandens	Supplejack	
						Vitex lucens	Pūriri	
12	E # 5634 N # 1466	150	600	25	Stream terrace	*Beilschmiedia tarairi*	Taraire	Bird-dispersed kohekohe, nīkau, karaka, taraire, tawa and pūriri
						Beilschmiedia tawa	Tawa	
						Corynocarpus laevigatus	Karaka	
						Dysoxylum spectabile	Kohekohe	
						Hedycarya arborea	Pigeonwood	
						Macropiper excelsum	Kawakawa	
						Rhopalostylis sapida	Nīkau	
						Ripogonum scandens	Supplejack	
						Vitex lucens	Pūriri	
13	E # 7514 N # 1598	300	600	240	Mid-slope ridge	*Brachyglottis kirkii*	Kirk's daisy	Bird-dispersed miro and pigeonwood
						Hedycarya arborea	Pigeonwood	
						Knightia excelsa	Rewarewa	
						Nestegis lanceolata	White maire	
						Prumnopytis ferruginea	Miro	
						Ripogonum scandens	Supplejack	
14	E # 6853 N # 0827	200	800	130	Ridge formed from planeze	*Agathis australis*	Kauri	Lower edge of kauri distribution; bird-dispersed toru and tānekaha
						Brachyglottis kirkii	Kirk's daisy	
						Knightia excelsa	Rewarewa	
						Nestegis lanceolata	White maire	
						Phyllocladus trichomanoides	Tānekaha	
						Toronia toru	Toru	

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Table A3.1 continued

PLOT	GPS* E269 # N655 #	LENGTH (m)	AREA (m^2)	ALTITUDE (m a.s.l.)	TOPOGRAPHIC SITE CATEGORY	SPECIES SAMPLED	COMMON NAME	REASON FOR PLOT ESTABLISHMENT
15	Near bunk-house	200	800	15	Alluvial fan	*Beilschmiedia tarairi*	taraire	Coastal karamū seedling population; bird-dispersed kohekohe, taraire, pūriri, supplejack and karaka
						Beilschmiedia tawa	tawa	
						Coprosma macrocarpa	coastal karamū	
						Coprosma repens	taupata	
						Corynocarpus laevigatus	karaka	
						Dysoxylum spectabile	kohekohe	
						Hedycarya arborea	pigeonwood	
						Knightia excelsa	rewarewa	
						Nestegis lanceolata	white maire	
						Rhopalostylis sapida	nīkau	
						Ripogonum scandens	supplejack	
						Vitex lucens	pūriri	
16	E # 6845 N # 3320	150	600	560	Mid-slope ridge	*Ixerba brexoides*	tāwari	Miro and thin-barked tōtara seedling populations; bird-dispersed toro
						Nestegis lanceolata	white maire	
						Prumnopytis ferruginea	miro	
						Myrsine salicina	toro	
						Podocarpus hallii	thin-barked tōtara	
17	E # 6531 N # 3120	200	400	480	Mid-slope ridge	*Beilschmiedia tawa*	tawa	Hīnau seedling populations; bird-dispersed tawa, supplejack and nīkau
						Elaeocarpus dentatus	hīnau	
						Hedycarya arborea	pigeonwood	
						Knightia excelsa	rewarewa	
						Nestegis lanceolata	white maire	
						Prumnopytis ferruginea	miro	
						Rhopalostylis sapida	nīkau	
						Ripogonum scandens	supplejack	
18	E # 6554 N # 2920	100	400	400	Mid-slope ridge	*Elaeocarpus dentatus*	hinau	Bird-dispersed hīnau and pigeonwood; rewarewa seedling population
						Hedycarya arborea	pigeonwood	
						Knightia excelsa	rewarewa	
						Nestegis lanceolata	white maire	
						Rhopalostylis sapida	nīkau	
						Ripogonum scandens	supplejack	

* GPS coordinates all have E269 and N655 in common. Coordinates for plot 1 should read as follows: E269 5089, N655 3428. These coordinates are usually for the starting end of the seedling plot.

TABLE A3.2. SEEDLING PLOTS TARANGA ISLAND: LOCATION, LENGTH, AREA, ALTITUDE AND SPECIES SAMPLED.

PLOT	GPS* E266 # N658 #	LENGTH (m)	AREA (m^2)	ALTITUDE (m a.s.l.)	TOPOGRAPHIC SITE CATEGORY	SPECIES SAMPLED	COMMON NAME
1	E # 4208 N # 0328	60	120	25	Rocky talus fan	*Beilschmiedia tarairi*	Taraire
						Corynocarpus laevigatus	Karaka
						Dysoxylum spectabile	Kohekohe
						Hedycarya arborea	Pigeonwood
						Melicytus ramiflorus	Māhoe
						Pouteria costata	Tawāpou
2	E # 4150 N # 0123	44	176	15	Rocky talus fan	*Pisonia brunoniana*	Parapara
3	E # 4053 N # 0243	21	82	25	Coastal headland	*Beilschmiedia tawa*	Tawa
						Clematis paniculata	Puawhananga
						Coprosma macrocarpa	Coastal karamū
						Corynocarpus laevigatus	Karaka
						Dysoxylum spectabile	Kohekohe
						Macropiper excelsum	Kawakawa
						Melicytus ramiflorus	Māhoe
4	E # 4258 N # 0245	40	160	20	Rocky talus fan	*Corynocarpus laevigatus*	Karaka
						Dysoxylum spectabile	Kohekohe
						Pisonia brunoniana	Parapara
5	E # 3799 N # 0783	200	400	2	Shoreline talus slopes	*Coprosma macrocarpa*	Coastal karamū
						Coprosma repens	Taupata
6	E # 4241 N # 0213	100	200	260	Upper hill slopes	*Hedycarya arborea*	Pigeonwood
						Melicytus ramiflorus	Māhoe
						Rhopalostylis sapida	Nīkau
						Ripogonum scandens	Supplejack
7	E # 3745 N # 5036	100	200	260		*Beilschmiedia tarairi*	Taraire
						Beilschmiedia tawa	Tawa
						Corynocarpus laevigatus	Karaka
						Dysoxylum spectabile	Kohekohe
						Hedycarya arborea	Pigeonwood
						Melicytus ramiflorus	Māhoe
8	E # 4105 N # 0166	30	200	2	Old boulder beach	*Beilschmiedia tawa*	Tawa
						Clematis paniculata	Puawhananga
						Coprosma macrocarpa	Coastal karamū
						Coprosma repens	Taupata
						Corynocarpus laevigatus	Karaka
						Dysoxylum spectabile	Kohekohe
						Macropiper excelsum	Kawakawa
						Melicytus ramiflorus	Māhoe
						Rhopalostylis sapida	Nīkau
						Vitex lucens	Pūriri

* GPS coordinates all have E266 and N658 in common. Coordinates for plot 1 should read as follows: E266 4208, N658 0328. These coordinates are usually for the starting end of the seedling plot.

TABLE A3.3. SEEDLING PLOTS GREAT BARRIER ISLAND: LOCATION, LENGTH, AREA, ALTITUDE AND SPECIES SAMPLED.

PLOT	GPS* E272 # N655 #	LENGTH (m)	AREA (m^2)	ALTITUDE (m a.s.l.)	TOPOGRAPHIC SITE CATEGORY	SPECIES SAMPLED	COMMON NAME
1	E # 4677 N # 5171	90	360	60	Stream terrace	*Dysoxylum spectabile*	Kohekohe
						Knightia excelsa	Rewarewa
						Nestegis lanceolata	White maire
						Phyllocladus trichomanoides	Tānekaha
						Prumnopytis ferruginea	Miro
						Rhopalostylis sapida	Nīkau
2	E # 4706 N # 4846	140	560	59	Stream terrace	*Agathis australis*	Kauri
						Dacrycarpus dacrydioides	Kahikatea
						Dysoxylum spectabile	Kohekohe
						Hedycarya arborea	Pigeonwood
						Knightia excelsa	Rewarewa
						Nestegis lanceolata	White maire
						Phyllocladus trichomanoides	Tānekaha
						Podocarpus totara	Tōtara
						Prumnopytis ferruginea	Miro
						Rhopalostylis sapida	Nīkau
						Ripogonum scandens	Supplejack
						Vitex lucens	Pūriri
3	E # 4974 N # 4119	112	224	77	Stream terrace	*Agathis australis*	Kauri
						Beilschmiedia tawa	Tawa
						Dysoxylum spectabile	Kohekohe
						Hedycarya arborea	Pigeonwood
						Knightia excelsa	Rewarewa
						Nestegis lanceolata	White maire
						Phyllocladus trichomanoides	Tānekaha
						Rhopalostylis sapida	Nīkau
						Ripogonum scandens	Supplejack
4	E # 2682 N # 2057	46	184	74	Stream terrace	*Dysoxylum spectabile*	Kohekohe
						Hedycarya arborea	Pigeonwood
						Rhopalostylis sapida	Nīkau
5	E # 2177 N # 0189	108	380	200	Mid-slope hillside	*Toronia toru*	Toru
6	E # 3234 N # 4238	25	100	160	Mid-slope hillside	*Coprosma macrocarpa*	Coastal karamū
						Dysoxylum spectabile	Kohekohe
						Hedycarya arborea	Pigeonwood
						Ripogonum scandens	Supplejack
7	E # 7897 N # 4804	42	168	450	Ridge	*Phyllocladus trichomanoides*	Tānekaha
						Podocarpus totara	Tōtara
						Prumnopytis ferruginea	Miro
8	E # 4359 N # 1597	8	236	258	Stream terrace	*Agathis australis*	Kauri
						Beilschmiedia tarairi	Taraire
						Beilschmiedia tawa	Tawa
						Corynocarpus laevigatus	Karaka
						Dysoxylum spectabile	Kohekohe
						Elaeocarpus dentatus	Hīnau
						Hedycarya arborea	Pigeonwood

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Table A3.3 continued

PLOT	GPS* E272 # N655 #	LENGTH (m)	AREA (m^2)	ALTITUDE (m a.s.l.)	TOPOGRAPHIC SITE CATEGORY	SPECIES SAMPLED	COMMON NAME
						Knightia excelsa	Rewarewa
						Nestegis lanceolata	White maire
						Prumnopytis ferruginea	Miro
						Rhopalostylis sapida	Nīkau
						Ripogonum scandens	Supplejack
						Vitex lucens	Pūriri
9	E # 3349	204	408	122	Mid-slope hillside	*Coprosma macrocarpa*	Coastal karamū
	N # 7237					*Corynocarpus laevigatus*	Karaka
						Dysoxylum spectabile	Kohekohe
						Hedycarya arborea	Pigeonwood
						Knightia excelsa	Rewarewa
						Macropiper excelsum	Kawakawa
						Phyllocladus trichomanoides	Tānekaha
						Ripogonum scandens	Supplejack
11	E # 5095	134	536	90	Mid-slope hillside	*Beilschmiedia tarairi*	Taraire
	N # 5052					*Beilschmiedia tawa*	Tawa
						Corynocarpus laevigatus	Karaka
						Dysoxylum spectabile	Kohekohe
						Hedycarya arborea	Pigeonwood
						Knightia excelsa	Rewarewa
						Nestegis lanceolata	White maire
						Rhopalostylis sapida	Nīkau
						Ripogonum scandens	Supplejack
						Vitex lucens	Pūriri
12	E # 4423	69	138	127	Mid-slope hillside	*Beilschmiedia tarairi*	Taraire
	N # 7458					*Beilschmiedia tawa*	Tawa
						Dysoxylum spectabile	Kohekohe
						Hedycarya arborea	Pigeonwood
						Knightia excelsa	Rewarewa
						Rhopalostylis sapida	Nīkau
						Ripogonum scandens	Supplejack
						Vitex lucens	Pūriri
13	E # 4144	77	308	150	Mid-slope ridge	*Corynocarpus laevigatus*	Karaka
	N # 7469s					*Hedycarya arborea*	Pigeonwood
						Vitex lucens	Pūriri
14	E # 4456	56	224	5	Alluvium	*Coprosma macrocarpa*	Coastal karamū
	N # 1644					*Coprosma repens*	Taupata

* GPS coordinates all have E272 and N655 in common. Coordinates for plot 1 should read as follows: E272 4677, N655 5171. These coordinates are usually for the starting end of the seedling plot.

Appendix 4

MAPS SHOWING LOCATIONS OF SEEDLING PLOTS ON EACH STUDY ISLAND

Figure A4.1—Locations of seedling plots, Hauturu.

Figure A4.2—Locations of seedling plots, Taranga Island.

Figure A4.3—Locations of seedling plots, Great Barrier Island.

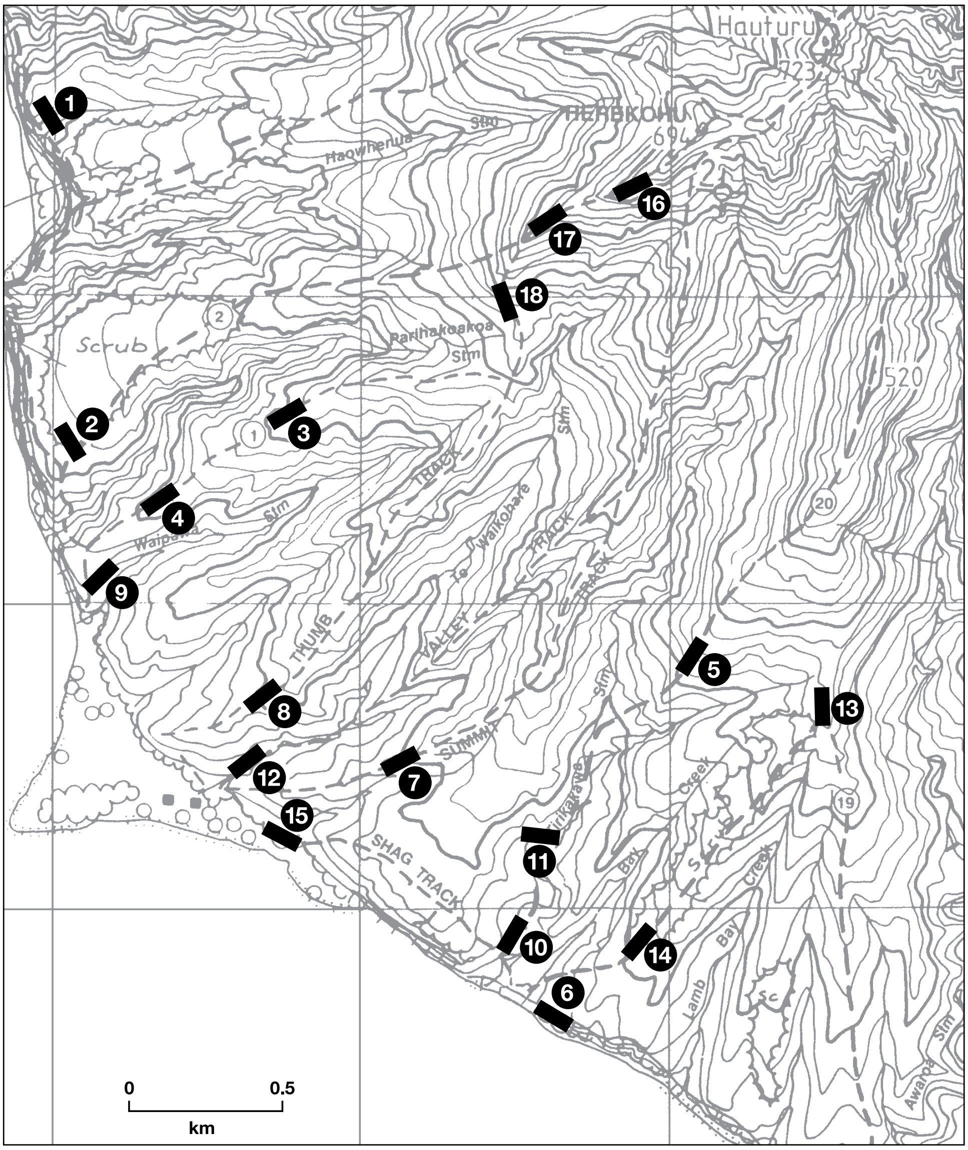

Figure A4.1. Locations of seedling plots, Hauturu.

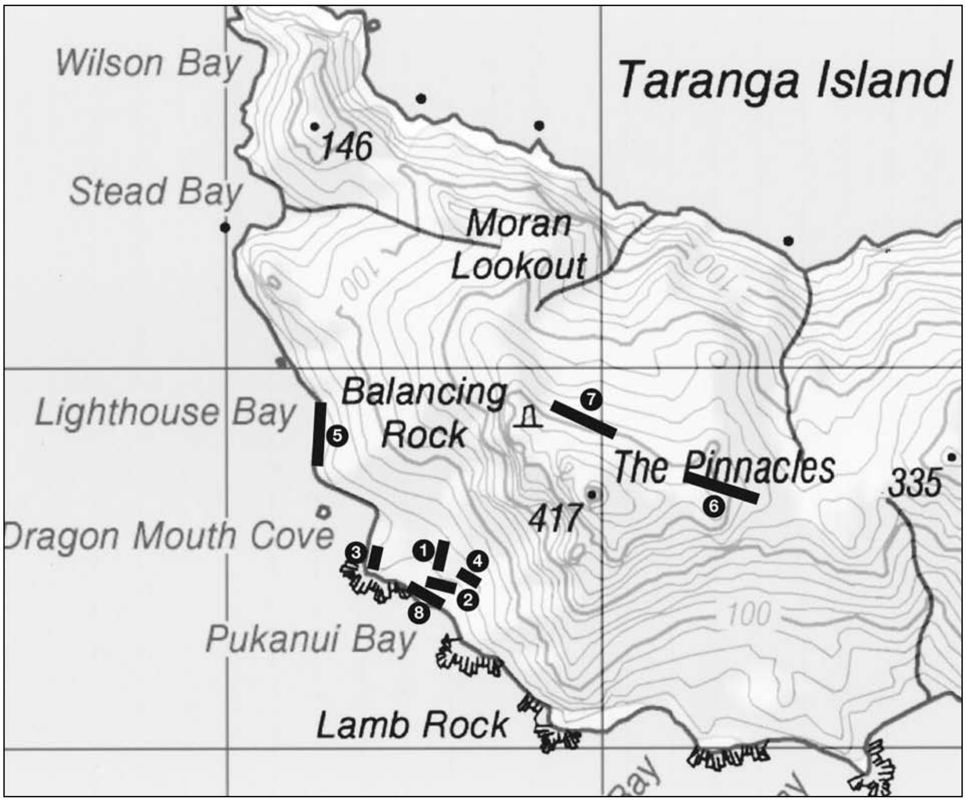

Figure A4.2. Locations of seedling plots, Taranga Island.

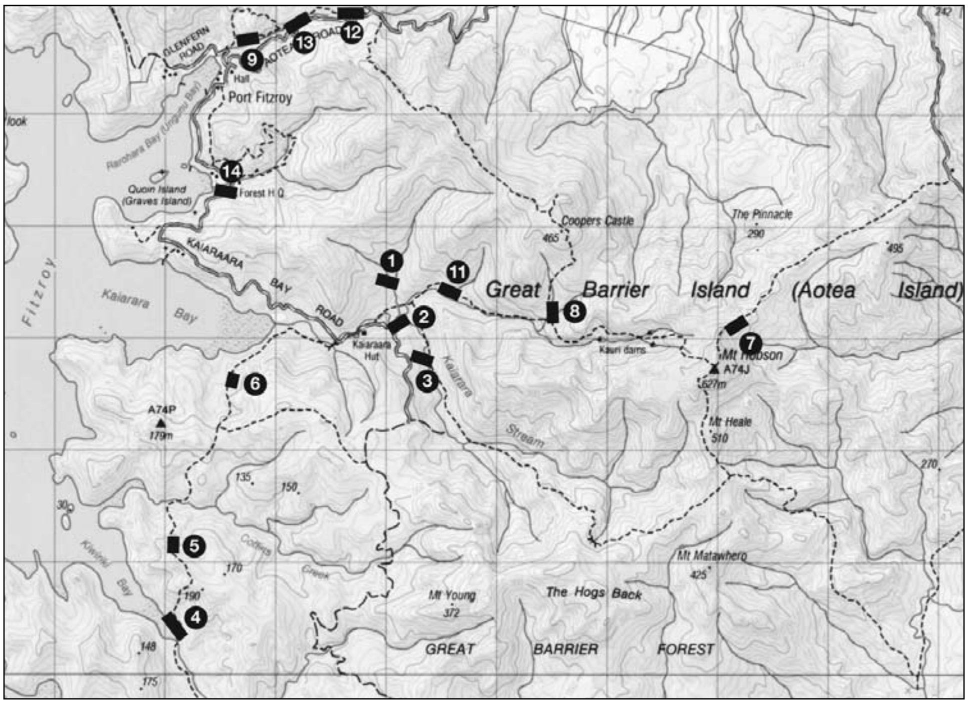

Figure A4.3. Locations of seedling plots, Great Barrier Island.