Changes in numbers of woody plant seedlings on Kapiti Island after rat eradication

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ABSTRACT

Seedlings of woody plants were counted on Kapiti Island for two years before and two years after rat eradication in September 1996. A total of 840 sample plots (660 m^2) were located at 16 sites from shoreline to over 400 m altitude. Approximately 35 000 seedlings of 49 species were recognised and assigned to three height classes. Data from 21 species were analysed for seedlings 0–5 cm tall. Numbers of seedlings of *Elaeocarpus dentatus*, *Nestegis lanceolata*, *Passiflora tetrandra*, *Pittosporum crassifolium*, *Prumnopytis taxifolia*, *Pseudopanax crassifolius*, and *Ripogonum scandens* were predicted to increase after rat eradication; in fact, seedling numbers increased by 26 to 100% for all species except *Pseudopanax crassifolius* (53% fewer). During the four years, a spike of 5–10 times previous seedling numbers was recorded for several species. However, a spike in seedling numbers followed by few seedlings in the following year could not be attributed to rat eradication, especially when *Pseudopanax crassifolius* experienced a spike before eradication. Without the use of a control area containing rats, comparison of seedling numbers before and after rat eradication could not separate rat effects from natural variations in seedling numbers and ongoing recovery of vegetation after possum removal. However, an untreated contiguous area on Kapiti Island was not possible because of re-invasion risk, and no mainland area would have been suitable as a control.

Keywords: seedling numbers, woody seedlings, vegetation recovery, rat eradication, Kapiti Island, nature reserve.

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1. Introduction

Rats are present in most native forests on the New Zealand mainland, and have reached many offshore islands. They eat seed from a wide range of plants, thus reducing seedling numbers, and eat seedlings or flowers of some species (Campbell 1978). In mainland forests, rats usually coexist with other introduced mammals, and the effects that rats exert on native tree regeneration cannot easily be separated from those of larger herbivores. Lowered recruitment of trees, shrubs or vines caused by rats has rarely been demonstrated, even when rats are the only mammalian herbivore in relatively simple ecosystems found on small islands. Ongoing research on northern offshore islands has shown that the kiore or Pacific rat (*Rattus exulans*) depresses the recruitment of 11 species of coastal tree out of 17 studied (Campbell & Atkinson 1999; Campbell & Atkinson 2002).

This study on Kapiti Island was commissioned by the Department of Conservation, and aimed to measure differences in seedling numbers, before and after rat eradication, that might be attributable to rats eating seed or seedlings. The timing of the project meant that two years were available to count seedlings before eradication, and this was followed by a further two years' seedling counts after eradication. Seedlings were first counted in winter 1994 and rats were eradicated by two aerial applications of brodifacoum in September and October 1996 (Empson & Miskelly 1999).

1.1 THE STUDY AREA

Kapiti Island (41° 10´ S, 174° 55´ E) lies 5 km off the west coast of the lower North Island near Wellington. It is approximately 9 km long and 2 km wide and rises to 520 m on the main axial ridge. The western side of the island, which is very steep, is exposed to salt-laden north-westerly winds. In contrast, the eastern side consists of a series of steep interfluves between steep, east-flowing streams, and is largely covered in young forest and regenerating scrub. The east-facing side of the island is cool and moist.

Most of Kapiti Island was in tall forest in the distant past but the forest was burnt during the nineteenth century or earlier. Following the removal of the last goat (*Capra hircus*) in 1928 and widespread planting of forest species, the forest vegetation was left to regenerate and is now in various stages of succession (Esler 1967; Fuller 1987).

Through the latter half of the nineteenth century and into the early twentieth century the island was farmed. During farming and the period of onshore whaling that preceded it, many mammals were introduced, including cattle (*Bos taurus*), sheep (*Ovis aries*), goats, pigs (*Sus scrofa*), cats (*Felis catus*), axis deer (*Axis axis*), fallow deer (*Dama dama dama*), possums (*Trichosurus vulpecula*) and Norway rats (*Rattus norvegicus*). Kiore reached the island during the period of Maori settlement. Following the removal of cattle in 1916, larger mammals were progressively eliminated (Wilkinson & Wilkinson 1952), culminating in possums in 1986 after sustained intensive effort (Cowan 1992). Plans to eradicate rats and thus rid the island of the only remaining introduced mammals, were initiated soon after the successful eradication of possums. Eradication was to be accompanied by pre- and post-eradication monitoring programmes to record changes in numbers of birds, lizards, invertebrates, and seedlings (Empson & Miskelly 1999).

Three of the several regenerating natural vegetation types (biological names given in Appendix 1) on Kapiti Island recognised by Fuller (1987) were sampled:

- Tawa-hinau forest with toro, rewarewa and local matai, miro and northern rata (7 plots).
- Kanuka forest (5 plots).
- Coastal scrub dominated by fivefinger but containing high proportions of salt-tolerant species, especially akiraho, lancewood, and broadleaf (4 plots).

Predictions of possible rat effects on numbers of seedlings of many of the woody species found on Kapiti Island were made at the start of the study (Table 1). Data collected more recently from other localities (Campbell & Atkinson 2002) would alter the placement of some species.

Many of the woody plants likely to be affected by rats are widespread and common on Kapiti Island, and seedlings could be expected to be found in any plots located within a species' altitudinal range. Common species include *Beilschmiedia tawa* (tawa), *Hedycarya arborea* (pigeonwood), *Macropiper excelsum* (kawakawa), *Corynocarpus laevigatus* (karaka), *Dysoxylum spectabile* (kohekohe), *Pseudopanax arboreus* (fivefinger), *Coprosma grandifolia* (kanono), *C. lucida, C. robusta* (karamu), *Knightia excelsa* (rewarewa), *Melicytus ramiflorus* (mahoe), *Myrsine australis* (mapou), *Pseudopanax crassifolius* (lancewood), *Ripogonum scandens* (supplejack) and *Elaeocarpus dentatus* (hinau).

TABLE 1. POSSIBLE RAT EFFECTS ON NUMBERS OF WOODY PLANT SEEDLINGS ON KAPITI ISLAND.

SEED KNOWN TO BE EATEN BY RATS[1]: EFFECT EXPECTED	INSUFFICIENT DATA BUT EFFECT IS POSSIBLE	SEED APPEARS NOT TO BE EATEN BY RATS: NO EFFECT EXPECTED
Dysoxylum spectabile	*Beilschmiedia tawa*	*Alectryon excelsus*
Elaeocarpus dentatus	*Clematis paniculata*	*Carpodetus serratus*
Nestegis lanceolata	*Coprosma grandifolia*	*Coprosma areolata*
Passiflora tetrandra	*Coprosma lucida*	*Hedycarya arborea*
Pittosporum crassifolium	*Coprosma repens*	*Hoheria populnea*
Prumnopytis ferruginea	*Coprosma robusta*	*Myrsine australis*
Prumnopytis taxifolia	*Corynocarpus laevigatus*	*Raukaua anomalus*
Pseudopanax crassifolius	*Macropiper excelsum*	
Ripogonum scandens	*Melicope ternata*	
Rhopalostylis sapida	*Knightia excelsa*	
	Melicytus ramiflorus	
	Myoporum laetum	
	Parsonsia capsularis	
	Pennantia corymbosa	
	Pseudopanax arboreus	

[1]Based on data in Campbell (1978) but largely excluding species with small fruit that can be spread widely by birds.

2. Methods

2.1 EXPERIMENTAL DESIGN

The monitoring of seedling numbers on Kapiti Island in relation to rat eradication was governed by several limitations that influenced the choice of methods for data collection (Table 2).

TABLE 2. LIMITATIONS TO THE EXPERIMENTAL DESIGN AND THE CONSEQUENCES OF THE LIMITATIONS.

LIMITATIONS	CONSEQUENCES OF THE LIMITATIONS
Kapiti is a nature reserve	Seedlings could not be removed from the plots
Initial survey was timed to be two years before planned rat eradication	Seedlings could not be cleared from plots at outset (also see above) and still leave two years of comparable measurements Comparative data had to be restricted to seedlings that germinated in the current year
Possums had been eradicated c. 8 years previously	Seedling composition at the outset was at least in part a response to the absence of browsing of seedlings by possums or of their consumption of flowers or fruit Changes to the canopy cover of trees recovering from possum browsing would be ongoing Ongoing growth of ground layer plants that established after possum eradication would limit the time over which comparable data could be collected Size class data before and after rat eradication would not be comparable because of possum eradication
Rat extermination encompassed the entire island	No opportunities for a separate control area on the island, and a mainland control area would possess too many differences, especially with respect to herbivores, bird species, their numbers and fruit dispersal, and predator effects on depressing rat numbers

2.2 SAMPLE METHODS

Monitoring started only two years ahead of the planned rat eradication, and each plot was sampled for two years before eradication and for two years after. Because of these time constraints and the need to count many seedlings over a variety of sites, seedlings at each plot site were not marked to measure survival of individual seedlings. Plots were sited in places where seedlings would be expected to establish, usually in the stronger light of canopy gaps or under relatively open forest. So that the plots could be easily relocated, most were sited near marked tracks, and some were sited on or near rodent census lines, especially trap lines where T. Thurley (pers. comm.) had found a better-than-average catch rate. Plot locations are detailed in Campbell (unpublished reports 1995, 1996). Each plot was located within a single habitat type, so that all sample lines had similar slope, aspect and canopy cover. All plots were sited on relatively easy slopes in order to avoid trampling and damage to the sample plots as seedlings were being counted.

So that some of the less common tree species were sampled, plots were sited within 50 m of mature seed trees of miro, matai, white maire, hinau, nikau, karo, lancewood, tawa, cabbage tree, and ngaio. With dioecious species such as miro and matai, female trees were located before choosing a plot site.

Each seedling plot consisted of five 10 m long, permanently marked parallel sample lines, arranged 3 m apart in a 12 m × 10 m rectangle. Each sample line was approximately 3 m from the adjacent line to maximise the number of tree crowns that were sampled, to minimise the influence of each tree, to increase the range of micro sites, and to ensure that seedling plots were not trampled when the lines were sampled. When a plot was being marked out, a tree was sometimes encountered in the intended alignment of a sample line. In such instances, the sample line was shifted to whichever side of the tree produced less deviation of the line. For large trees directly in the path of the proposed sample line, the line was moved away from the previous line towards the next sample line to increase the distance between lines. On each sample line, a circular plot of 500 mm radius was scribed at each metre mark including zero. Thus each seedling plot of five lines had 55 sample plots, each with an area of 0.79 m^2, giving a total area for each seedling plot of 43.45 m^2.

A measuring device 500 mm long, shaped like an inverted U, with the upright sections 180 mm high to let it pass over most of the taller seedlings, was used to establish the boundary of each circular sample plot and determine whether a seedling was within the plot. All seedlings rooted within the perimeter of the circle were recorded, regardless of the orientation of the rest of the seedling. On uneven ground, the metre mark on the tape was projected vertically downwards and the centre of the sample circle was located on the ground at the intersection of the vertical line. The same techniques were used for an uneven substrate at the base of trees or when a sample line passed over a log.

Seedlings were divided into three height classes, 0–5 cm, 5–10 cm, and 10–15 cm (actual height categories $0 < 5$, $5 < 10$, $10 < 15$). Because the initial extension growth of seedlings differs between different species, these height categories did not represent comparable age classes among the species recorded.

Six plots were established in winter and were recorded thereafter in winter, and 10 plots were established in summer and re-sampled in summer. The timing of plot resurvey and seedling counts was thus standardised with respect to species that germinate at different times of the year. In order to have two years of comparable data before eradication, all seedlings on each sample plot were allocated to a size class, were counted and left in situ. For each subsequent survey seedlings were again allocated to species and size class, and counted.

2.3 DATA ANALYSIS

Seedlings of 49 species were recognised (see below, Table 6). Seedlings of some species such as karaka, kohekohe and tawa can have substantial extension growth and reach the 5–10 cm height class in the first year whereas other species can remain in the 0–5 cm height class for several years. The above species with fast-growing seedlings were excluded from data analysis. Data from only the 0–5 cm size class were analysed to minimise biases that could arise if mixed-age classes were counted; this especially applies to seedlings counted before rats were exterminated. During analysis, data from the 5–10 cm and 10–15 cm size classes were used to assess whether seedlings had survived from one year's count to the next and grown taller. Earlier summaries of seedling numbers (Campbell unpublished reports 1994, 1995, 1998, 1999) included all seedlings up to 15 cm in the counts.

To minimise the possibility of double counting seedlings before or after rat eradication and counteract various potential biases, the seedlings of each species in each size class, sample plot and line were compared on a year-by-year basis to determine survival and recruitment. If a flush of seedlings coincided with the first survey while rats were present, these seedlings could persist with declining numbers surviving, for the duration of the post-eradication period. Conversely, the same plots measured during the two years after eradication could have lost this flush of seedlings, and the seedling numbers be even lower than before eradication. Alternatively, if a flush of seedlings coincided with the first resurvey after eradication, these seedlings would persist into the following year, so that the post eradication numbers would be elevated for both of the post-eradication years, and thus artificially boost an apparent enhanced effect after rat eradication.

The following adjustments were made to the raw count data. If seedlings were present in the 0–5 cm size class in the second survey before eradication or the second survey after eradication, it was assumed that they had survived from the previous year and were not new ones. For example, if six seedlings had been recorded in the first year and two in the second year, it was assumed that the two individuals had survived from the previous year. Conversely, if 10 seedlings were counted in the second year, this was determined as four new seedlings in addition to the six recorded previously. This conservative method of analysis did not allow for occasions where some seedlings on a sample plot died and were replaced by others the following year. If no seedlings were present in the next highest size class (5–10 cm) in year one, and some were present in year two, it was assumed that these seedlings were previously in the smaller size class. The numbers of seedlings in both size classes were added together in both years to determine how many new seedlings had established.

Because seedlings were not marked individually, exact details of recruitment, survival and growth could not be followed using these methods. However, recruitment, growth, or death of seedlings between years could be tracked approximately by following seedling numbers in each size class on each sample plot in successive years. In any year the numbers of seedlings counted represented survivors from the previous year, less those previously counted that had died, with the addition of those that had established since the previous count. Seedlings may survive for several years without appreciable growth. Some seedlings of species that were encountered only infrequently could be relocated on particular sample plots for the entire duration of the survey.

3. Results

Over the four years of this study, approximately 35 000 seedlings were identified to species, assigned to one of three height classes, and counted on each of 840 sample plots. These sample plots were sited at 16 locations from near the shoreline to over 400 m altitude. Each sample plot was 0.79 m^2 in area, and in each year of the survey a total of 660 m^2 were sampled. The altitude, vegetation type, main tree species sampled, number of species of seedling and numbers of seedlings present in the first survey are summarised in Table 3.

TABLE 3. ALTITUDE, VEGETATION TYPE, MAIN SPECIES SAMPLED, NUMBER OF SPECIES, AND NUMBERS OF SEEDLINGS, FIRST SURVEY – 1994.

PLOT NO.	ALT. (m)	VEGETATION TYPE	MAIN TREE SPECIES SAMPLED	NO. OF SEEDLING SPECIES	TOTAL SEEDLINGS	SEEDLING DENSITY (seedlings/m)
W1	260	kanuka/fivefinger	lancewood	23	598	13.8
W2	60	coastal forest	titoki, kohekohe	15	833	19.3
W3	<20	coastal forest	karo	18	700[1]	16.2
W4	330	tawa-hinau	hinau, supplejack	15	95	2.2
W5	360	tawa-hinau	hinau	8	80	1.8
W6	<20	coastal forest	kaikomako, mapou	21	867	20.1
S1	240	kanuka/fivefinger	miro	23	643	14.9
S2	310	tawa-hinau	miro	17	268	6.2
S3	180	kanuka/fivefinger	matai	12	477	11.0
S4	350	tawa-hinau	tawa, pigeonwood	14	332	7.1
S5	240	tawa-hinau	white maire, supplejack	11	220	5.1
S6	90	kanuka/fivefinger	nikau, kohekohe	20	692	16.0
S7	405	tawa-kamahi	miro	13	175	4.0
S8	<20	coastal forest	ngaio, karaka	20	635	14.5
S9	360	kanuka/fivefinger	supplejack	14	119	2.7
S10	20	coastal forest	passion vine	15	284	6.6

[1] Estimated from a one-fifth size sample plot after one part of the plot became overgrown with regenerating kawakawa

The plots sites were chosen in order to sample seedlings near particular trees of interest and to sample the main vegetation types on the island. The distribution of seedling plots in relation to vegetation and altitude are shown in Table 4. Brief details of the vegetation and main woody species present at each plot are given in Table 5.

TABLE 4. GROUPING OF SEEDLING PLOTS ACCORDING TO VEGETATION TYPE.

VEGETATION TYPE	SEEDLING PLOT SERIES AND NUMBERS	ALTITUDINAL RANGE SAMPLED BY PLOTS (m)
Tawa-hinau forest, often with emergent northern rata (and kamahi at higher altitudes)	S2, S4, S5, S7, S9, W4, W5	270–405
Kanuka forest	S1, S3, S6, W1, W2	60–250
Mixed species coastal forest	S8, S10, W3, W6	5–20

TABLE 5. VEGETATION AT SEEDLING PLOT SITES, KAPITI ISLAND.

PLOT	VEGETATION
W1	Kanuka (15–16 m) over mixed tarata, mapou, toro, fivefinger, akiraho, kanono and lancewood (4 m). Several other species of trees and shrubs were present including *Coprosma lucida*, *C. robusta*, several young matai, miro, and white maire.
W2	Fivefinger (10 m), over pigeonwood, lancewood, mahoe, and kohekohe nearby (6 m). Understorey had pigeonwood, kaikomako, karaka, kohekohe and kawakawa (3–4 m). Kohekohe seedlings were abundant, with *Blechnum filiforme* and *Asplenium oblongifolium*.
W3	Northern rata (15 m) over hinau, kamahi (and raukawa, pigeonwood and mahoe) over tawa and mahoe (12 m). Four small-diameter mature hinau trees were nearby.
W4	Hinau and some tawa (10 m); most tawa was only (8 m). Occasional pigeonwood and kohekohe were in the sub-canopy. Shrub layer had horopito, mapou, kawakawa, and some supplejack. Rewarewa and some mamaku and *Cyathea cunninghamii* were nearby.
W5	Canopy was wind-shorn mahoe, karo, karaka, and mapou, but with some lancewood and houhere (5.5–6 m). Kawakawa, hangehange and rangiora understorey was sparse. Some dense patches of *Microsorum pustulatum* were on the ground.
W6	Kanuka (14–16 m) over tall fivefinger, lancewood (8–9 m) over mapou, heketara, kanono, akiraho, and *Coprosma lucida* and some ponga tree ferns. The understorey was moderately dense.
S1	Kanuka (14–16 m) over fivefinger, lancewood (8–9 m) over a mixture of mapou, heketara, kanono, akiraho, and *Coprosma lucida*. The understorey was moderately dense. Some ponga were present.
S2	Northern rata (17–20 m) over tawa and hinau (10–12 m) over an understorey of kanono, horopito, and heketara. The understorey was sparse and most of the ground was covered with litter. Several juvenile miro trees up to sapling size.
S3	Kanuka, (rewarewa), fivefinger (12–15m), over kohekohe, heketara, tawa (6 m), over ponga (5.5 m), over kohekohe (3.5 m). Some *Blechnum filiforme*. Kohekohe saplings were common. An adult female matai and a juvenile Hall's totara were upslope.
S4	Tawa (15 m) over a sparse understorey of pigeonwood, horopito, kanono and mahoe (1.5 m tall). *Microsorum pustulatum* was common.
S5	Northern rata with occasional rewarewa (16 m) over lancewood, fivefinger, tawa, toro, tarata (14 m), over pigeonwood, tawa, kanono, heketara, rewarewa, hangehange and ponga (4–5 m). Miro, white maire, and juvenile rewarewa were in a light gap.
S6	Kanuka (7 m) over kohekohe (5 m) over a mixture of heketara, akiraho, mahoe, and mapou (4 m). Four hinau were further up the ridge. Ground layer had abundant *Blechnum filiforme* with abundant kohekohe seedlings, most only as high as the fern.
S7	Tawa, rewarewa, and kamahi with minor amounts of pigeonwood, heketara, hinau, and toro (8 m), over Smith's tree fern, pigeonwood, kanono and horopito (4.5 m). A large miro was nearby. The ground layer had *Blechnum filiforme*.
S8	Kohekohe, karaka, ngaio, akiraho, kaikomako, pigeonwood, lancewood and karo (5 m) over mapou, titoki, kohekohe, and karo with a wind-shorn canopy (4 m).
S9	Kanuka (8.5 m) emergent above hinau, rewarewa, lancewood, putaputaweta, tawa, cabbage tree, fivefinger, hinau (7 m). Understorey had pigeonwood, tawa, mahoe, kanono and kawakawa.
S10	Kanuka (10 m) over fivefinger, hinau, lancewood, kohuhu, and mahoe (8 m) over pigeonwood, kohekohe, kanono, mapou, hangehange, and kawakawa. The canopy had some light gaps and passion vine entanglements.

Seedlings counted each year for each species for all plots are given in Table 6; Table 7 lists the percentage difference of woody plant species with commonly encountered seedlings before and after rat control. Table 8 ranks plant species from the greatest increase in seedling numbers after rat eradication to the largest decrease in numbers.

Asterisked species in Table 6 were excluded from further analysis for one of the following reasons:

- seedling growth in the first year could result in some seedlings being recorded in the second size class (5–10 cm), (*Alectryon excelsus*, *Beilschmiedia tawa*, *Corynocarpus laevigatus*, *Dysoxylum spectabile*, and *Rhopalostylis sapida*),

TABLE 6. SEEDLING TOTALS (0–5 CM) FOR ALL WINTER AND ALL SUMMER PLOTS FOR EACH YEAR.

SURVEY	W 1994	W 1995	W 1998	W 1999	S 1995	S 1996	S 1998	S 1999
*Alectryon excelsus**[1]	28	15	10	9	0	3	1	2
*Beilschmiedia tawa**	19	105	44	18	146	70	54	22
*Brachyglottis repanda**	3	2	0	0	0	0	0	0
*Carpodetus serratus**	0	0	0	0	14	8	3	5
Clematis paniculata	10	16	12	4	9	4	4	4
Coprosma areolata	1	1	3	2	25	18	47	37
*Coprosma foetidissima**	1	0	0	0	5	7	2	0
Coprosma grandifolia	343	392	239	104	202	442	506	404
Coprosma lucida	3	6	3	7	3	18	8	8
Coprosma propinqua	14	26	20	2	0	4	2	23
*Coprosma repens**	0	0	1	1	0	0	1	0
*Coprosma rhamnoides**	0	0	0	0	11	19	7	3
Coprosma robusta	4	34	34	10	5	3	3	1
*Corynocarpus laevigatus**	25	30	13	6	113	69	110	59
*Dysoxylum spectabile**	249	241	301	116	284	1195	965	812
Elaeocarpus dentatus	4	11	13	8	29	49	65	74
*Geniostoma rupestre**	3	5	18	3	1	152	3	23
*Griselinia lucida**	0	2	4	0	1	1	1	0
Hedycarya arborea	286	264	114	29	496	494	393	341
*Hoheria populnea**	1	2	5	1	0	0	0	0
Knightia excelsa	3	7	26	18	9	84	323	159
Macropiper excelsum	279	1061	195	199	104	66	541	353
Melicytus ramiflorus	38	41	7	6	4	48	49	39
*Melicope ternata**	0	0	1	0	0	0	0	0
*Myoporum laetum**	0	11	0	0	21	3	1	1
Myrsine australis	66	76	58	56	62	66	34	97
Myrsine salicina	0	17	8	10	24	22	27	20
Nestegis lanceolata	0	0	0	3	1	0	3	48
*Olearia paniculata**	2	1	3	4	1	21	7	2
*Parsonsia capsularis**	0	1	1	0	0	1	0	0
Passiflora tetrandra	0	1	13	12	2	65	276	119
Pennantia corymbosa	99	129	198	162	48	58	158	113
Pittosporum crassifolium	1	2	64	31	0	0	0	3
*Pittosporum eugenioides**	0	0	2	0	0	0	0	0
*Pittosporum tenuifolium**	0	0	0	0	9	2	1	1
*Prumnopytis ferruginea**	0	1	0	0	0	0	0	0
Prumnopytis taxifolia	0	0	0	0	0	0	0	18
Pseudopanax arboreus	44	85	60	23	180	143	210	113
Pseudopanax crassifolius	84	51	73	29	85	1384	237	153
*Pseudowintera axillaris**	2	2	2	2	4	5	5	7
*Raukaua anomalus**	26	3	0	0	3	0	2	29
*Raukaua edgerleyi**	0	1	1	0	0	0	0	0
*Rhopalostylis sapida**	9	13	9	25	246	320	172	310
Ripogonum scandens	60	43	248	144	224	283	955	688
*Rubus cissoides**	0	0	0	1	0	0	0	0
*Schefflera digitata**	0	0	0	0	0	1	6	4
*Weinmannia racemosa**	1	0	1	1	0	0	0	0
Total	1708	2697	1803	1046	2372	5128	5183	4096

[1] Plants with an asterisk have been excluded from analysis because of low numbers or rate of shoot extension during the first year's growth. Names in bold are graphed (Appendix 2).

TABLE 7. TOTAL SEEDLING NUMBERS OF WOODY PLANTS BEFORE AND AFTER RAT ERADICATION AND PERCENTAGE CNANGE.

	TOTAL BEFORE	TOTAL AFTER	CHANGE Nos	CHANGE %
Clematis paniculata	39	24	–15	–24
Coprosma areolata	45	89	44	33
Coprosma grandifolia	1379	1253	–126	–5
Coprosma lucida	30	26	–4	–7
Coprosma propinqua	44	47	3	3
Coprosma robusta	46	48	2	2
Elaeocarpus dentatus	93	160	67	26
Hedycarya arborea	1540	877	–663	–27
Knightia excelsa	103	526	423	67
Macropiper excelsum	1510	1288	–222	–8
Melicytus ramiflorus	131	101	–30	–13
Myrsine australis	270	245	–25	–5
Myrsine salicina	63	65	2	2
Nestegis lanceolata	1	54	53	96
Passiflora tetrandra	68	420	352	72
Pennantia corymbosa	334	631	297	31
Pittosporum crassifolium	3	98	95	94
Prumnopytis taxifolia	0	18	18	100
Pseudopanax arboreus	452	406	–46	–5
Pseudopanax crassifolius	1604	492	–1112	–53
Ripogonum scandens	610	2035	1425	54

TABLE 8. RANKING BY CHANGE IN SEEDLING NUMBERS AFTER RAT ERADICATION.

SPECIES	CHANGE %
Prumnopytis taxifolia	100
Nestegis lanceolata	96
Pittosporum crassifolium	94
Passiflora tetrandra	72
Knightia excelsa	67
Ripogonum scandens	54
Coprosma areolata	33
Pennantia corymbosa	31
Elaeocarpus dentatus	26
Coprosma propinqua	3
Myrsine salicina	2
Coprosma robusta	2
Pseudopanax arboreus	–5
Coprosma grandifolia	–5
Myrsine australis	–5
Coprosma lucida	–7
Macropiper excelsum	–8
Melicytus ramiflorus	–13
Clematis paniculata	–24
Hedycarya arborea	–27
Pseudopanax crassifolius	–53

- the plant had small, dry seeds and thus would be unlikely to be affected by rats (*Geniostoma rupestre*),
- conditions on the plot had become unfavourable for the species (*Myoporum laetum*),
- identification of very small seedlings could be confused with a similar species (*Raukaua anomalus* v. *Pseudopanax arboreus*),
- the remaining eighteen species were not found on many plots and fewer than ten individuals were present in most surveys (*Brachyglottis repanda*, *Carpodetus serratus*, *Coprosma foetidissima*, *Coprosma repens*, *Coprosma rhamnoides*, *Griselinia lucida*, *Hoheria populnea*, *Melicope ternata*, *Olearia paniculata*, *Parsonsia capsularis*, *Pittosporum eugenioides*, *Pittosporum tenuifolium*, *Prumnopytis ferruginea*, *Raukaua edgerleyi*, *Pseudowintera axillaris*, *Rubus cissoides*, *Schefflera digitata*, and *Weinmannia racemosa*).

Percentage changes in seedling numbers of the more common species are shown in relation to predicted rat effects (Table 9). Of the seven species in Group A predicted to increase after rats were exterminated, seedling numbers of six increased from 26% to 100%, whereas numbers of lancewood seedlings decreased by 53%. Two species of Group B (where an effect was predicted as possible) had a substantial increase in seedlings (rewarewa 67% and kaikomako 31%), two had a substantial decrease in seedling numbers (*Clematis paniculata* –24%, mahoe –13%), and six species showed little change. In Group C for which

TABLE 9. OBSERVED CHANGES IN SEEDLING NUMBERS AFTER RAT ERADICATION IN RELATION TO PREDICTED CHANGES.

GROUP A. EFFECT EXPECTED	CHANGE %	GROUP B. EFFECT POSSIBLE	CHANGE %	GROUP C. NO EFFECT EXPECTED	CHANGE %
Elaeocarpus dentatus	+26	*Clematis paniculata*	–24	*Coprosma areolata*	+33
Nestegis lanceolata	+96	*Coprosma grandifolia*	–5	*Hedycarya arborea*	–27
Passiflora tetrandra	+72	*Coprosma lucida*	–7	*Myrsine australis*	–5
Pittosporum crassifolium	+94	*Coprosma propinqua*[1]	+3	*Myrsine salicina*	+2
Prumnopytis taxifolia	+100	*Coprosma robusta*	+2		
Pseudopanax crassifolius	–53	*Knightia excelsa*	+67		
Ripogonum scandens	+54	*Macropiper excelsum*	–8		
		Melicytus ramiflorus	–13		
		Pennantia corymbosa	+31		
		Pseudopanax arboreus	–5		

[1] *Coprosma propinqua* was placed under possible effects and *Myrsine salicina* placed with *M. australis*, see footnote to Table 1.

predictive data were lacking or where no rat effect was expected, one species had substantially more seedlings after rats were eradicated (*Coprosma areolata* 33%), one had substantially fewer seedlings (pigeonwood –27%), and the two species of *Myrsine* showed no change.

Paired histograms (Appendix 2; Figs 1–42) compare seedling numbers before and after rat eradication for winter and summer plots separately. The *y* axis scale is standardised for each pair but varies according the numbers of seedlings in each species. Histograms of seedling numbers for summer and winter plots are plotted separately for the following reasons:

- the seedling totals from the winter plots are from 6 plots, whereas 10 plots were measured each summer;
- by keeping the data for the summer and winter plots separate throughout the study, year-to-year comparisons for species that germinate in different seasons (e.g. pigeonwood germinates in winter) were more comparable;
- some of the summer plots were sited near a species of special interest and approximately half were located in hinau-tawa forest above 270 m altitude (Table 4).

With the above precautions, trends can be compared between the two sets of plots.

On most histograms the second seedling count before and the second after rat eradication are lower because the first count of each pair includes all seedlings in the 0–5 cm size class. To avoid counting seedlings twice either before or after eradication, the second count excludes any seedlings that could have been counted in the preceding year (see Methods).

Clematis paniculata seedlings (Figs 1, 2) were not common. After rats were eradicated, fewer seedlings were present on both winter and summer plots. *Coprosma areolata* seedlings (Figs 3, 4) were more abundant in 1998, but by 1999 the numbers had dropped almost to pre-eradication levels; overall there was a 33% increase in numbers of seedlings after rat eradication. The other four species of coprosma, *C. grandifolia* (Figs 5, 6), *C. lucida* (Figs 7, 8), *C. propinqua* (Figs 9, 10) and *C. robusta*, (Figs 11, 12) showed no consistent pattern in seedling abundance between the summer and winter plots and no consistent trend before and after rat eradication. This was to be expected with species that have small fruit and seeds and are bird-dispersed.

After rats were eradicated, hinau (Figs 13, 14) showed a consistent increase in numbers of seedlings in the summer plots, which were mainly situated in forest containing hinau. The data from the summer plots could equally be interpreted as a continuing trend towards more hinau seedlings that had started before rats were eradicated, probably as a response to possum eradication almost a decade earlier. There were fewer pigeonwood seedlings on both the winter and summer plots after rat eradication (Figs 15, 16) and as it was consistent on both the winter and summer plots, the decline could have been a continuing trend that started before the seedling monitoring started. Rewarewa seedlings (Figs 17, 18) were almost four times more abundant in 1998 than in 1995-96; by 1999 about half the seedlings had died but numbers were still twice that recorded before rats were eradicated. Kawakawa (Figs 19, 20) showed an increase in seedling numbers on the summer plots, but no comparable increase in numbers on the winter plots. The winter and summer plots of mahoe (Figs 21, 22) showed contrasting patterns of seedling abundance. Seedlings were six times more common in the winter plots before rat eradication, whereas they were 1.5 times more common in the summer plots after eradication. Winter and summer plots of mapou (Figs 23, 24), had similar patterns of seedling numbers before rat eradication, but after rats were eradicated both numbers and pattern differed. Toro (Figs 25, 26) showed no particular pattern of seedling abundance.

White maire (Figs 27, 28) seedling numbers greatly increased in 1999 from pre-eradication numbers on a plot sited near an adult white maire tree. Numbers of passion vine seedlings (Figs 29, 30) increased by more than five times on one plot in 1998, and seedlings were encountered elsewhere. Most of these seedlings had disappeared by 1999, and most of those remaining appeared unthrifty. The patterns of seedling abundance of kaikomako (Figs 31, 32) were similar for summer and winter plots. On both the winter and summer plots seedlings were more abundant in 1998, but numbers had dropped about 20% by 1999.

Numbers of karo seedlings (Figs 33, 34) increased spectacularly in 1998. However, by 1999 half the seedlings from 1998 had died, there were few new seedlings and most of the flush of seedlings from the previous year appeared to be overcrowded and unthrifty. Matai seedlings (Figs 35, 36) were seen only in 1999, on a plot located near a mature female matai tree. Fivefinger (Figs 37, 38) seedling numbers before rat eradication showed a different pattern for the winter and summer plots, with more recorded in summer 1995. In summer 1998 half the fivefinger seedlings recorded were found on a single plot. Lancewood seedlings (Figs 39, 40) increased by sixteen times in 1996, before rats were eradicated. But although there were more seedlings in both 1998 and 1999 than the number recorded in 1995, it resulted in an overall decrease by 53% in seedling numbers after they were eradicated. On one plot numbers had dropped from over 1000 in 1996 to 88 in 1998. Conversely on another plot four seedlings were counted in 1996 and 79 were present in 1998. Between 1996 and 1998 supplejack seedling numbers (Figs 41, 42) increased by a factor of 3.5, especially on one plot at mid altitudes, but by the following year numbers had dropped back by 25%. Trends between winter and summer plots were similar.

4. Discussion

Initial predictions were that after rats were eradicated from Kapiti Island there may be more seedlings of at least seven species of woody plant. Of the seven species predicted to increase after rat eradication, six (hinau, white maire, passion vine, karo, matai, and supplejack) had more seedlings and the increases in numbers ranged from 26 to 100%. Lancewood, which had a spike in seedling numbers in 1996, had 53% fewer seedlings after rat eradication.

During the four years of this study, several species had one exceptional year for germination. A flush of several hundred seedlings was followed by a year when very few seedlings germinated. In such exceptional years, many seedlings were sometimes recorded on only a few plots. 1998 was an outstanding year for passion vine, karo, supplejack, rewarewa, and to a lesser extent kaikomako and *Coprosma areolata*. Matai seedlings were present in 1999 but none was recorded previously, and only a few white maire seedlings were recorded before 1999. Most of the remaining species except lancewood appeared not to have experienced an exceptional year during these four years.

As most of these increases in seedling numbers coincided with the first count after rats were eradicated, it is tempting to attribute increased numbers of seedlings to rat eradication. However, it would be foolish to suggest that a 'spike' in seedling numbers in the order of 5–10 times could be attributed to rat eradication, especially when lancewood experienced an exceptional year in 1996 before rats were eradicated. Because different species exhibit a spike in seedling numbers in different years, it suggests that the environmental cues that trigger heightened flower and fruit production differ between species. However, data for kawakawa, which shows that seedling numbers on the summer and winter plots peaked in different years, suggest that other factors may operate as well, for example, changes from season to season in whether certain birds roost above a plot.

Against this background variation of intermittent 10-fold fluctuations in seedling numbers from year to year in some species, two years' monitoring seedling of numbers ahead of rodent eradication is not sufficient to record the baseline variation in the phenology of the woody plants. Many trees flower and fruit more prolifically at intervals of two years or more. After germination, many seedlings can persist for several years, even if conditions are sub-optimal for their eventual survival. Furthermore, although some species germinate soon after dispersal (e.g. Burrows 1999) seed of others such as wharangi (*Melicope ternata*) can lie dormant for one or more years before seed germinates (unpublished data). Changes in seedling numbers of species that exhibit dormancy may not be directly related to rat eradication.

The limitations imposed on data collection (Table 2) dictated that comparisons of seedling numbers before and after rat eradication included small seedlings that had established over one or two years. These small seedlings reflect the size of seed crop that escapes the seed predators, and is not influenced by environmental conditions that determine whether a seedling establishes and survives at a site. However, a comparison of seedling numbers before and after rat eradication does not separate rat effects from natural fluctuations in seedling numbers unless a scientific control is used where rats are still present, a problem overlooked by Allen et al. (1994). The difference between the amount of seed that is potentially available to germinate and the amount that actually germinates must be determined by comparing seedling numbers on the treated area with a control area that still has rats. Moreover, at the start of this project, Kapiti Island vegetation was still recovering from the prolonged effects of possum browsing. Comparison of population size classes several years after rat eradication, as has been done on the northern islands (Campbell & Atkinson 1999; Campbell & Atkinson 2002), would show the combined effects of rats and possums, not that of rats alone. Many < 30 cm tall seedlings of trees such as kohekohe, titoki, and nikau were present in some sites because possums were no longer eating flowers, fruit or seedlings.

It was not feasible to set aside part of Kapiti Island as a scientific control area that still contained rats because when a pest animal is eradicated from a nature reserve, the entire reserve is treated at the same time to prevent re-invasion from any nearby untreated area. A scientific control area on the adjacent mainland was not suitable because too many factors (such as rat species, their predators, possums, bird and plant species) differed from Kapiti Island. Changes to the experimental design, such as recording natural variation in flowering and fruiting over a longer period of time, or the removal of all seedlings at each count so that only newly established seedlings were counted, would not have overcome the need for a separate control area.

It is not possible to resolve this dilemma of experimental design by recording the phenology of flowering and fruiting of the seeding species, or by the removal of all seedlings at each count so that only newly established seedlings are counted each year, and neither is it possible to compare size class distributions within plant populations before and after rat removal because of the changes induced by the removal of possums.

Strict limits have to be imposed on the time over which baseline information of seedling numbers can be collected without comparisons of seedling counts being invalidated by changes in the seedling environment. When plots have been located in relatively open vegetation where seedlings would be expected, the plots become overgrown after about five years with fast-growing shrubby species. On Kapiti Island these problems of vegetation change on seedling plots were exacerbated by changes induced by the removal of possums. Over time, the vegetation on plots located in such sites changes as the post-possum seedlings grow and alter the quality of light that reaches the forest floor.

For these reasons, more detailed analyses of the seedling data and statistical tests of significance were inappropriate, and simply would have given the data a false appearance of accuracy.

5. References

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Appendix 1. List of plant names

akiraho	*Olearia paniculata*
broadleaf	*Griselinia littoralis*
bush lawyer	*Rubus cissoides*
cabbage tree	*Cordyline australis*
fivefinger	*Pseudopanax arboreus*
Hall's totara	*Podocarpus cunninghamii*
hangehange	*Geniostoma rupestre*
heketara	*Olearia rani*
hinau	*Elaeocarpus dentatus*
horopito	*Pseudowintera axillaris*
houhere	*Hoheria populnea*
kaikomako	*Pennantia corymbosa*
kamahi	*Weinmannia racemosa*
kanono	*Coprosma grandifolia*
kanuka	*Kunzea ericoides*
karaka	*Corynocarpus laevigatus*
karamu	*Coprosma rubusta, C. lucida*
karo	*Pittosporum crassifolium*
kawakawa	*Macropiper excelsum*
kohekohe	*Dysoxylum spectabile*
kohuhu	*Pittosporum tenuifolium*
lancewood	*Pseudopanax crassifolius*
mahoe	*Melicytus ramiflorus*
mamaku	*Cyathea medullaris*
mapou	*Myrsine australis*
matai	*Prumnopytis taxifolia*
miro	*Prumnopytis ferruginea*
native jasmine	*Parsonsia capsularis*
ngaio	*Myoporum laetum*
nikau	*Rhopalostylis sapida*
northern rata	*Metrosideros robusta*
passion vine	*Passiflora tetrandra*
pate	*Schefflera digitata*

pigeonwood	*Hedycarya arborea*
ponga	*Cyathea dealbata*
puka	*Griselinia lucida*
putaputaweta	*Carpodetus serratus*
rangiora	*Brachyglottis repanda*
raukawa	*Raukaua edgerleyi*
rewarewa	*Knightia excelsa*
stinkwood	*Coprosma foetidissima*
supplejack	*Ripogonum scandens*
tarata	*Pittosporum eugenioides*
taupata	*Coprosma repens*
tawa	*Beilschmiedia tawa*
titoki	*Alectryon excelsus*
toro	*Myrsine salicina*
wharangi	*Melicope ternata*
white maire	*Nestegis lanceolata*

Appendix 2. Figures 1–42

Fig. 1

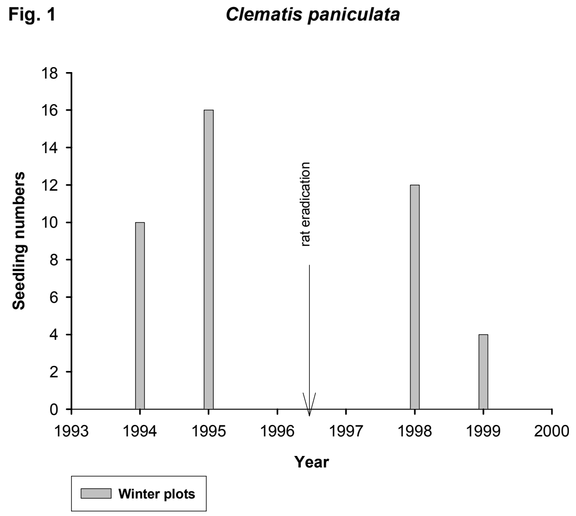


Fig. 2

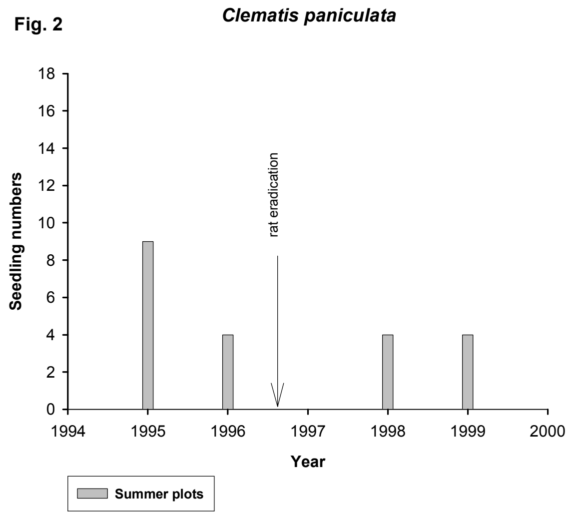


Fig. 3

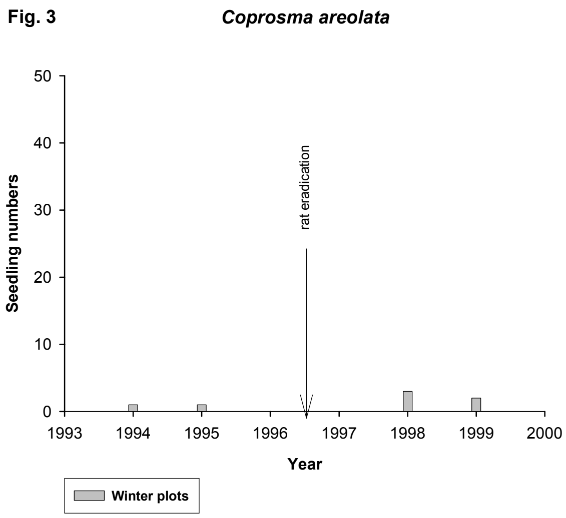
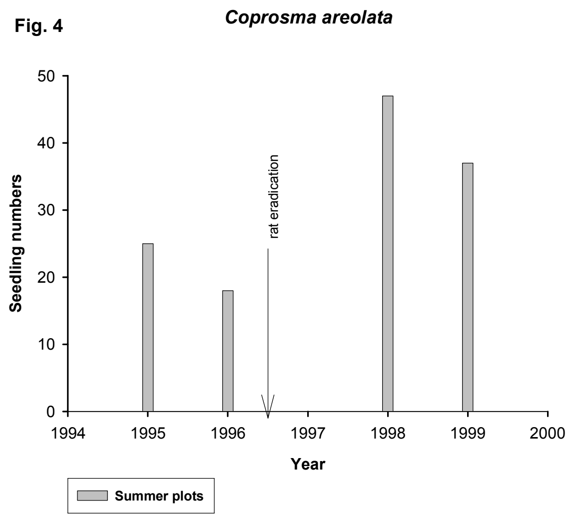


Fig. 4



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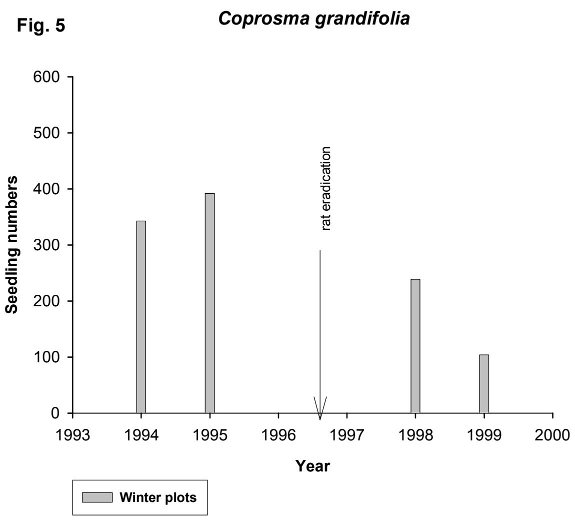


Fig. 6

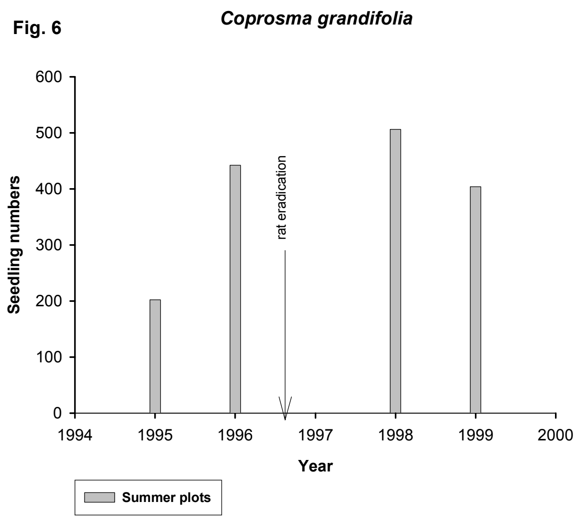


Fig. 7 *Coprosma lucida*

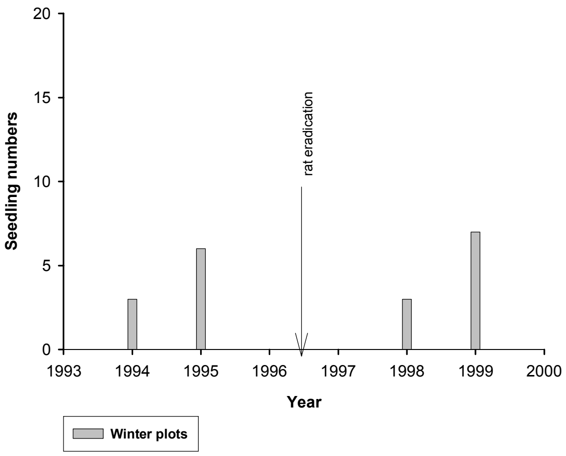


Fig. 8 *Coprosma lucida*

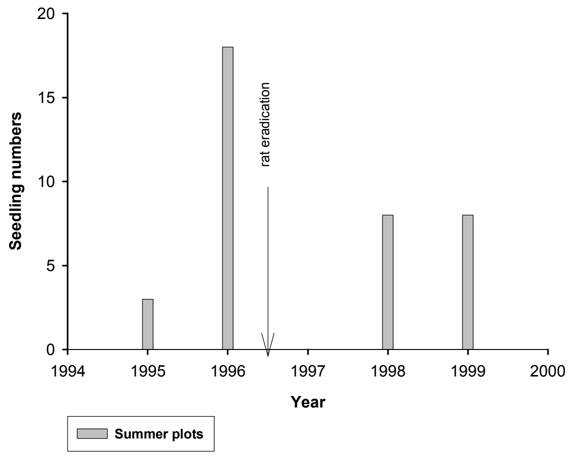


Fig. 9 *Coprosma propinqua*

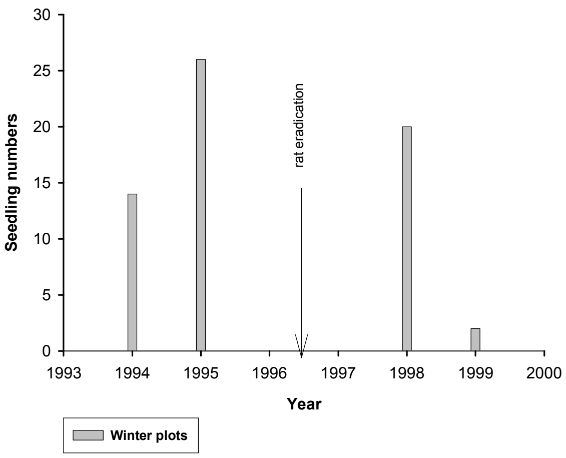


Fig. 10 *Coprosma propinqua*

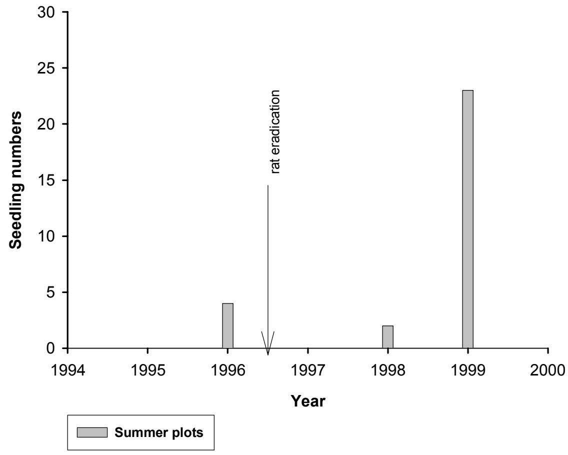


Fig. 11 *Coprosma robusta*

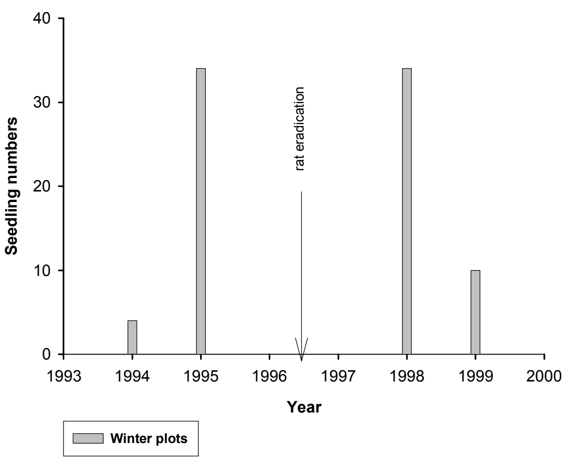


Fig. 12 *Coprosma robusta*

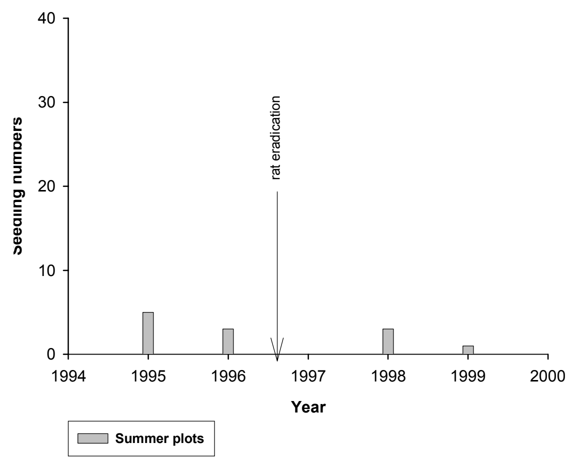


Fig. 13

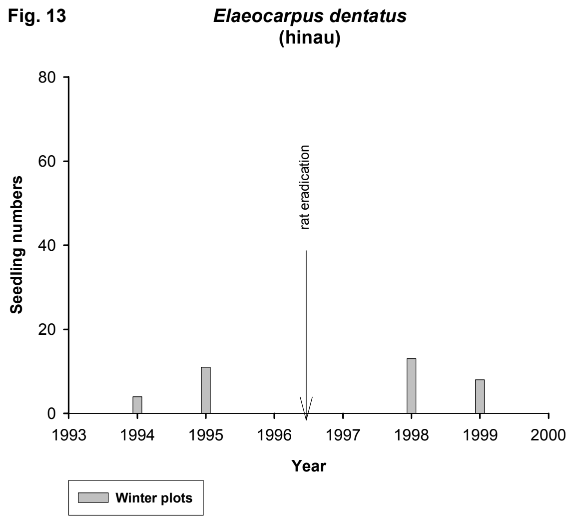


Fig. 14

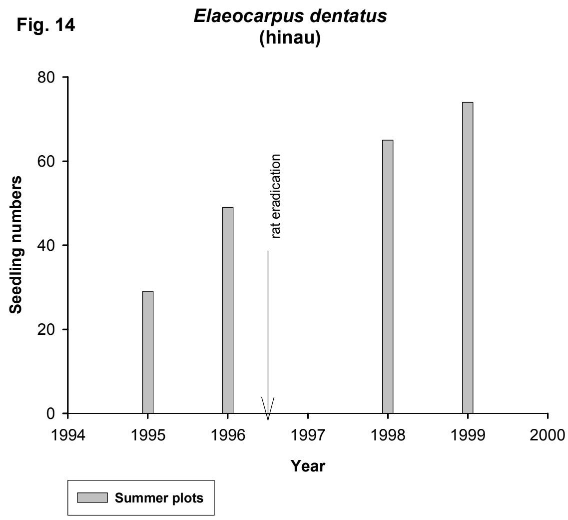


Fig. 15

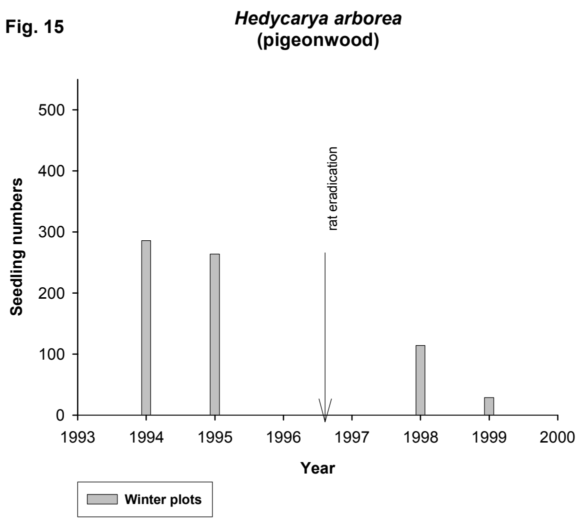
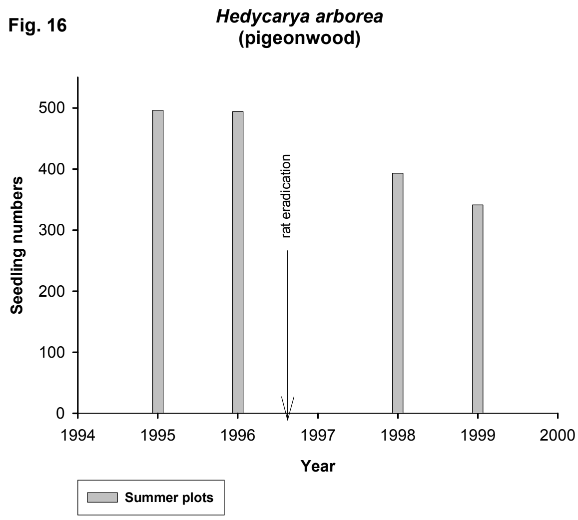


Fig. 16



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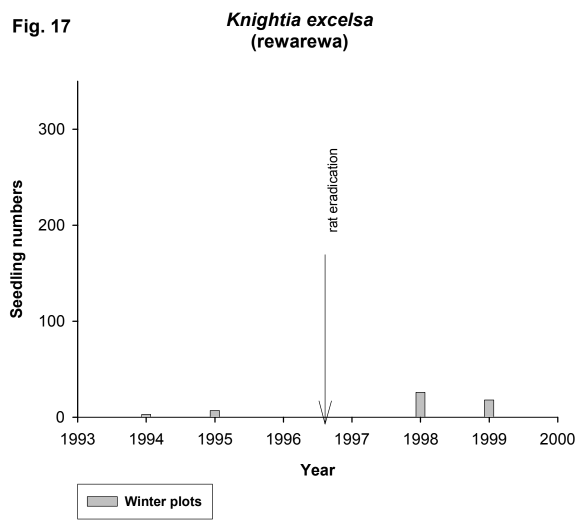

Fig. 18

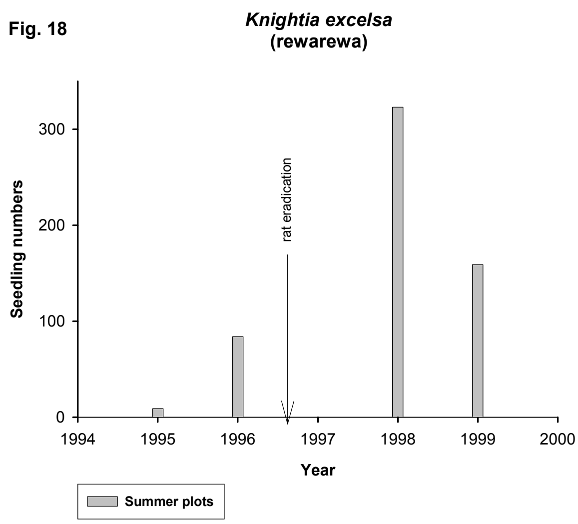

Fig. 19 *Macropiper excelsum* (kawakawa)

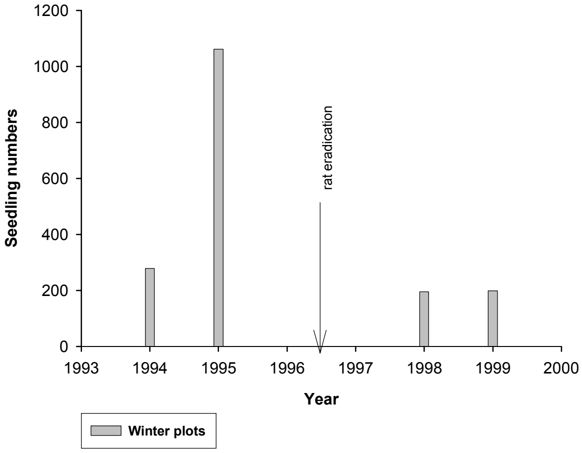

Fig. 20 *Macropiper excelsum* (kawakawa)

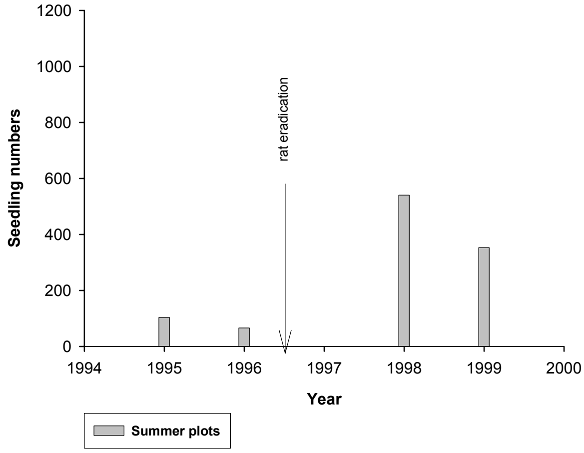

Fig. 21 *Melicytus ramiflorus* (mahoe)

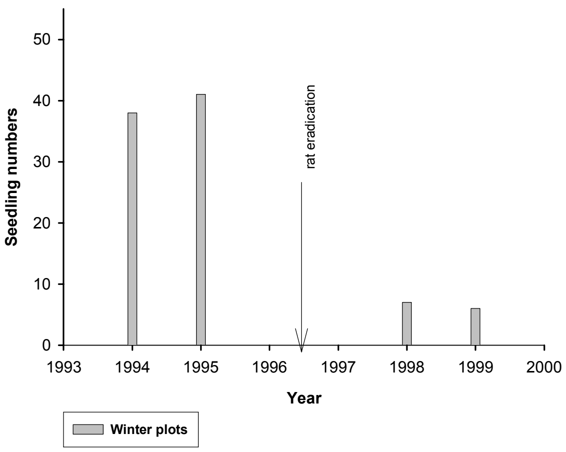

Fig. 22 *Melicytus ramiflorus* (mahoe)

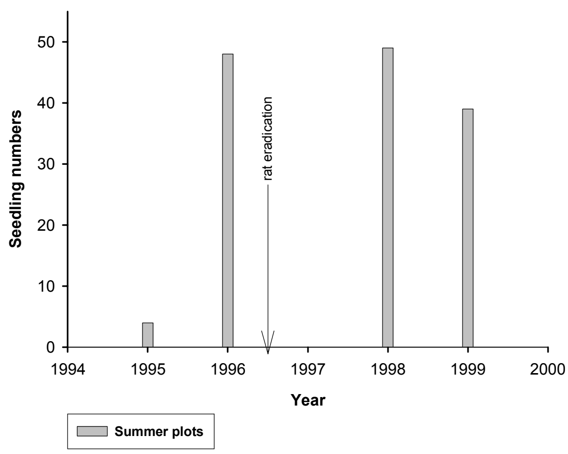

Fig. 23 *Myrsine australis* (mapou)

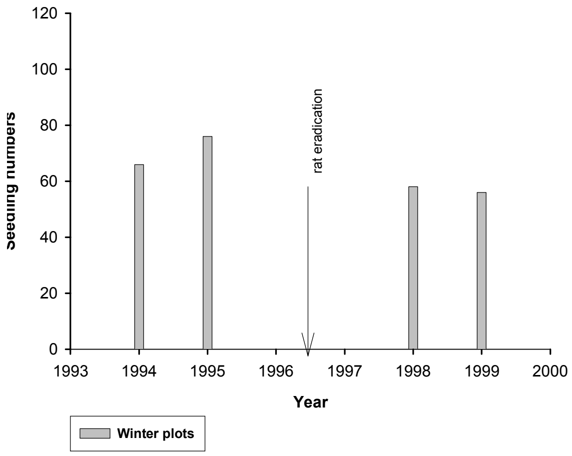

Fig. 24 *Myrsine australis* (mapou)

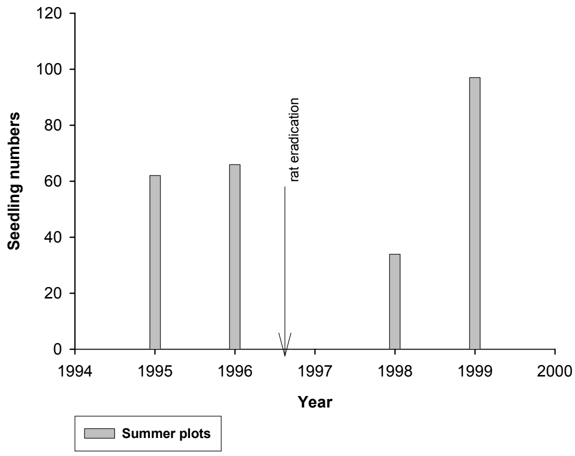

Fig. 25 ***Myrsine salicina* (toro)**

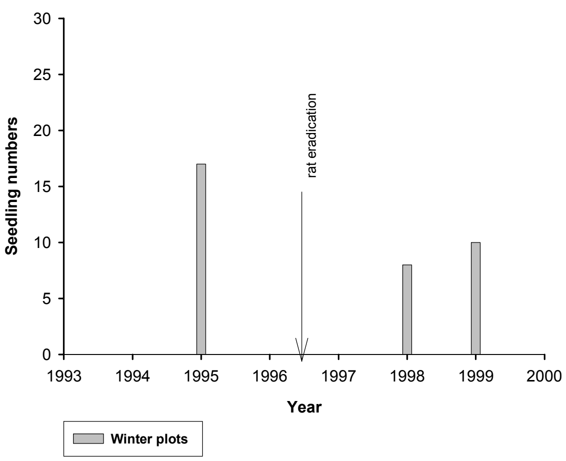

Fig. 26 ***Myrsine salicina* (toro)**

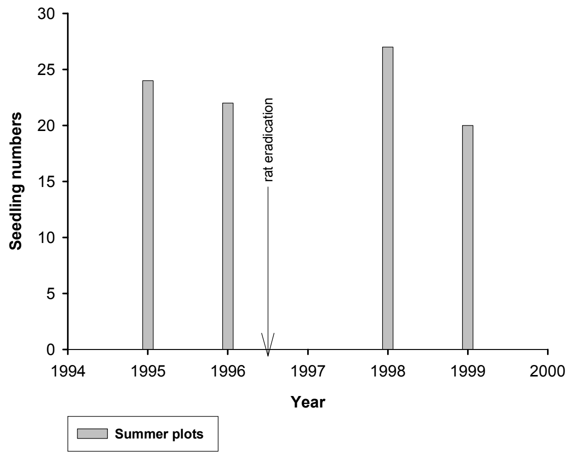

Fig. 27 ***Nestegis lanceolata* (white maire)**

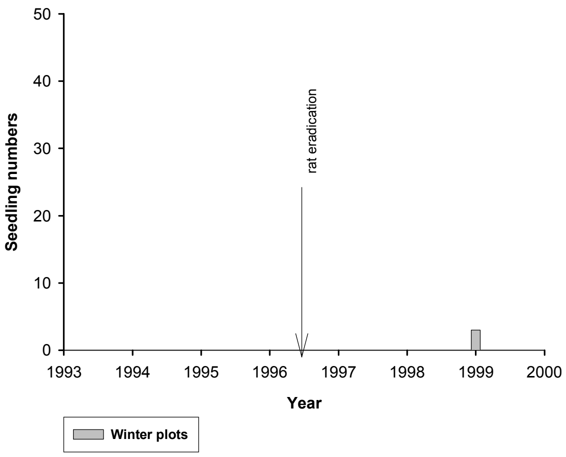

Fig. 28 ***Nestegis lanceolata* (white maire)**

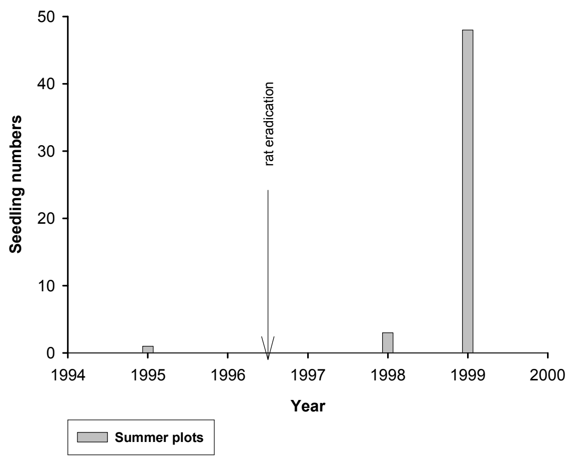

Fig. 29 ***Passiflora tetrandra* (passion vine)**

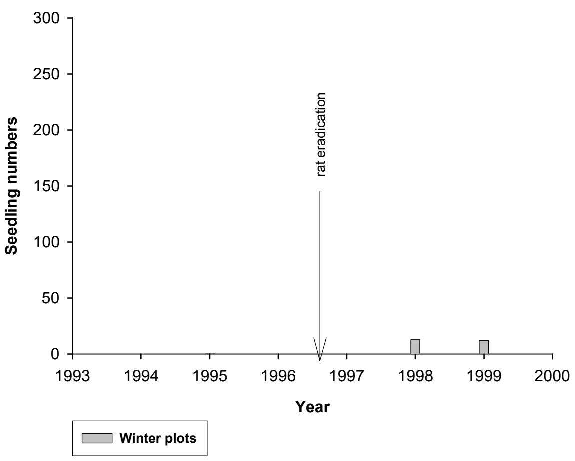

Fig. 30 ***Passiflora tetrandra* (passion vine)**

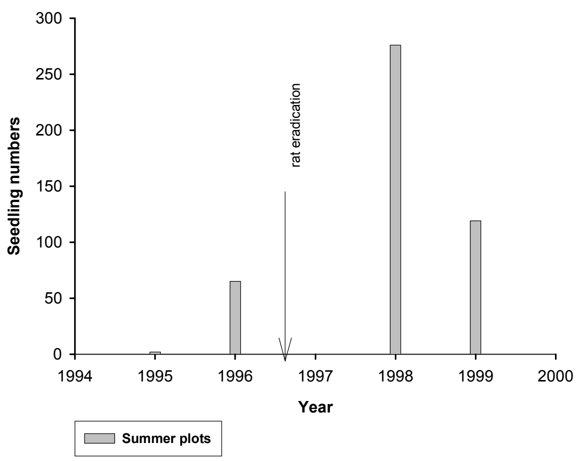

Fig. 31 ***Pennantia corymbosa*** **(kaikomako)**

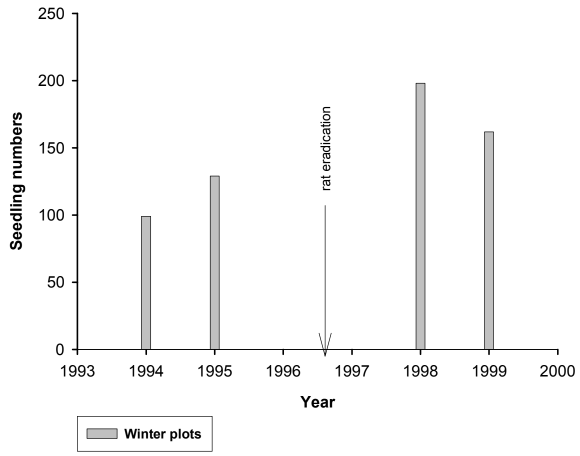

Fig. 32 ***Pennantia corymbosa*** **(kaikomako)**

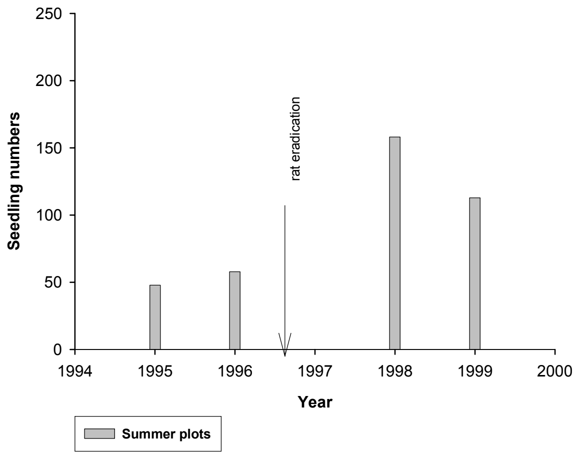

Fig. 33 ***Pittosporum crassifolium*** **(karo)**

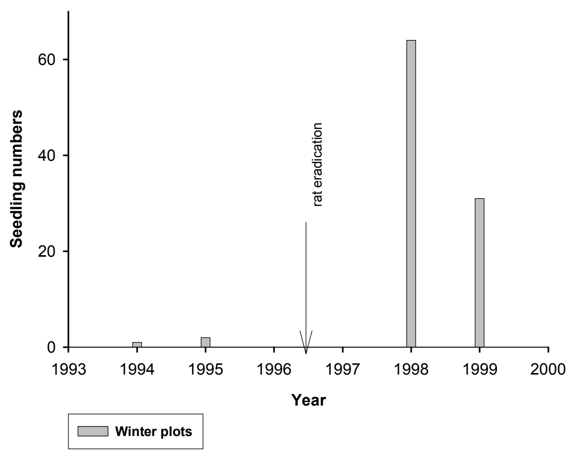

Fig. 34 ***Pittosporum crassifolium*** **(karo)**

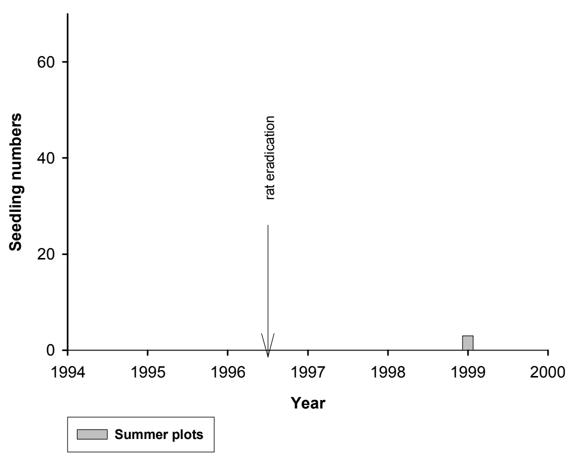

Fig. 35 ***Prumnopytis taxifolia*** **(matai)**

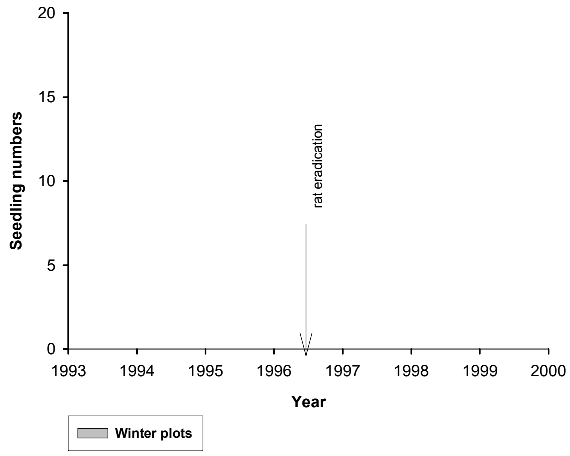

Fig. 36 ***Prumnopytis taxifolia*** **(matai)**

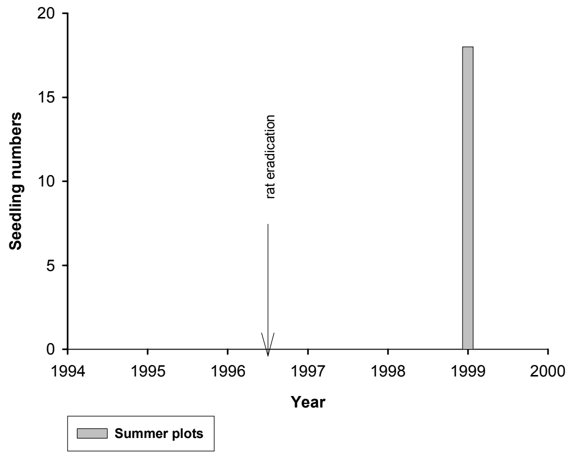

Fig. 37 ***Pseudopanax arboreus* (fivefinger)**

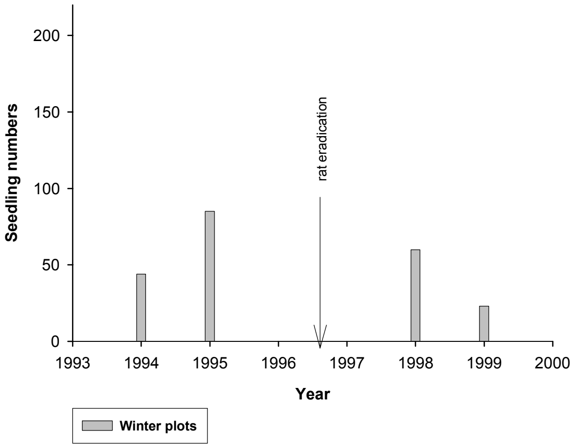

Fig. 38 ***Pseudopanax arboreus* (fivefinger)**

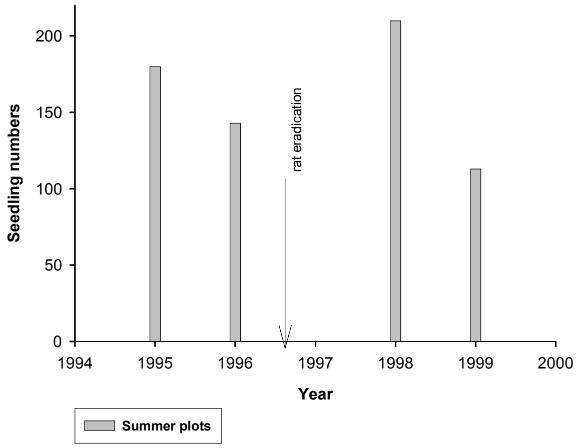

Fig. 39 ***Pseudopanax crassifolius* (lancewood)**

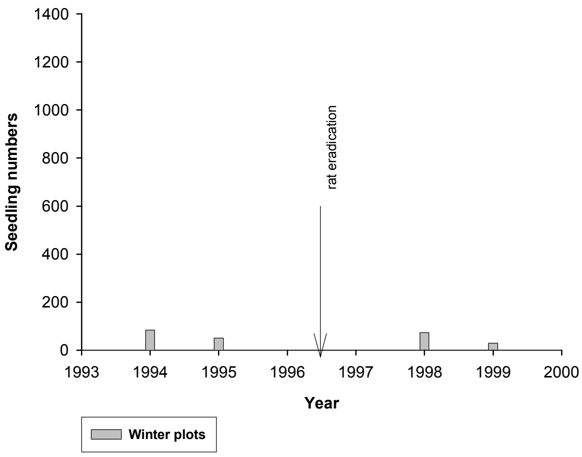

Fig. 40 ***Pseudopanax crassifolius* (lancewood)**

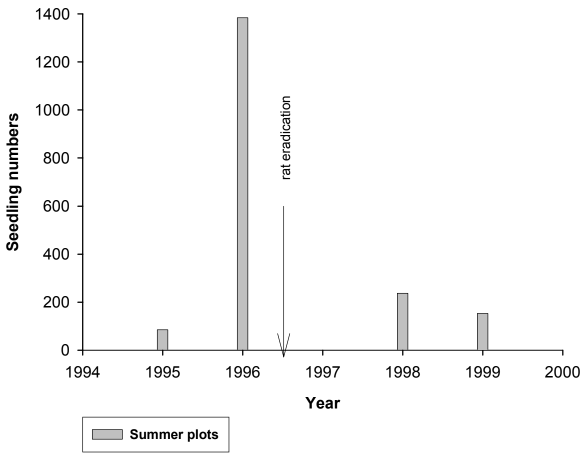

Fig. 41 ***Ripogonum scandens* (supplejack)**

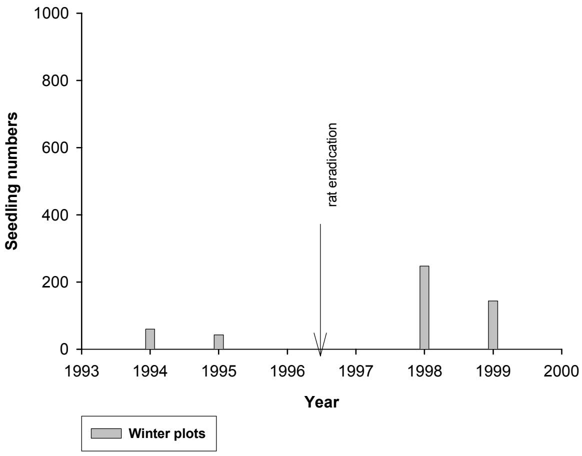

Fig. 42 ***Ripogonum scandens* (supplejack)**