Kiore (*Rattus exulans*) impact on breeding success of Pycroft's petrels and little shearwaters

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R.J. Pierce

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R.J. Pierce

Wildland Consultants Ltd, Northland Branch, P.O. Box 1305, Whangarei, New Zealand.

ABSTRACT

The Marotere or Chickens Islands support remnant populations of two small burrow-nesting seabirds, the summer-breeding Pycroft's petrel (*Pterodroma pycrofti*) and the winter-nesting little shearwater (*Puffinus assimilis haurakiensis*). The sequential eradication of kiore (*Rattus exulans*) from the three larger Chickens Islands during the 1990s provided an opportunity to measure the responses of these seabirds to kiore removal. Some of the seabird burrows are also inhabited by the endemic predatory reptile, the tuatara (*Sphenodon punctatus*). To assess whether breeding success of the two seabird species was limited by the presence of kiore or tuatara, and whether the two seabird species were in competition with each other, two study islands were used, Coppermine I. and Lady Alice I., from 1992 to 2000, and study burrows were checked early and late in the nesting period to determine breeding success. Success approximately doubled for both species when kiore were removed. Contemporaneous data for the two islands enabled other factors such as food supply and heavy rainfall to be eliminated as compounding variables. For example, the lowest breeding successes of little shearwater on Coppermine I. occurred in the same two years that productivity was high on kiore-free Lady Alice I. Similarly, for Pycroft's petrels, the years of lowest breeding success were in the presence of kiore, but in the same years there was significantly higher productivity in the kiore-free site. The presence of tuatara in burrows did not significantly influence the breeding success of these seabirds in the absence of kiore. However, in burrows used by both species of seabirds, late-fledging little shearwaters disrupted the nesting of Pycroft's petrels, causing some pairs to be displaced to other burrows or abandon nesting for the season; the effects of this competition on Pycroft's petrel are small, however, and more than compensated for by their increased productivity following kiore removal.

Keywords: Pycroft's petrel, *Pterodroma pycrofti*, little shearwater, *Puffinus assimilis haurakiensis*, kiore, *Rattus exulans*, tuatara, *Sphenodon punctatus*, breeding success, competition, pest removal.

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1. Introduction

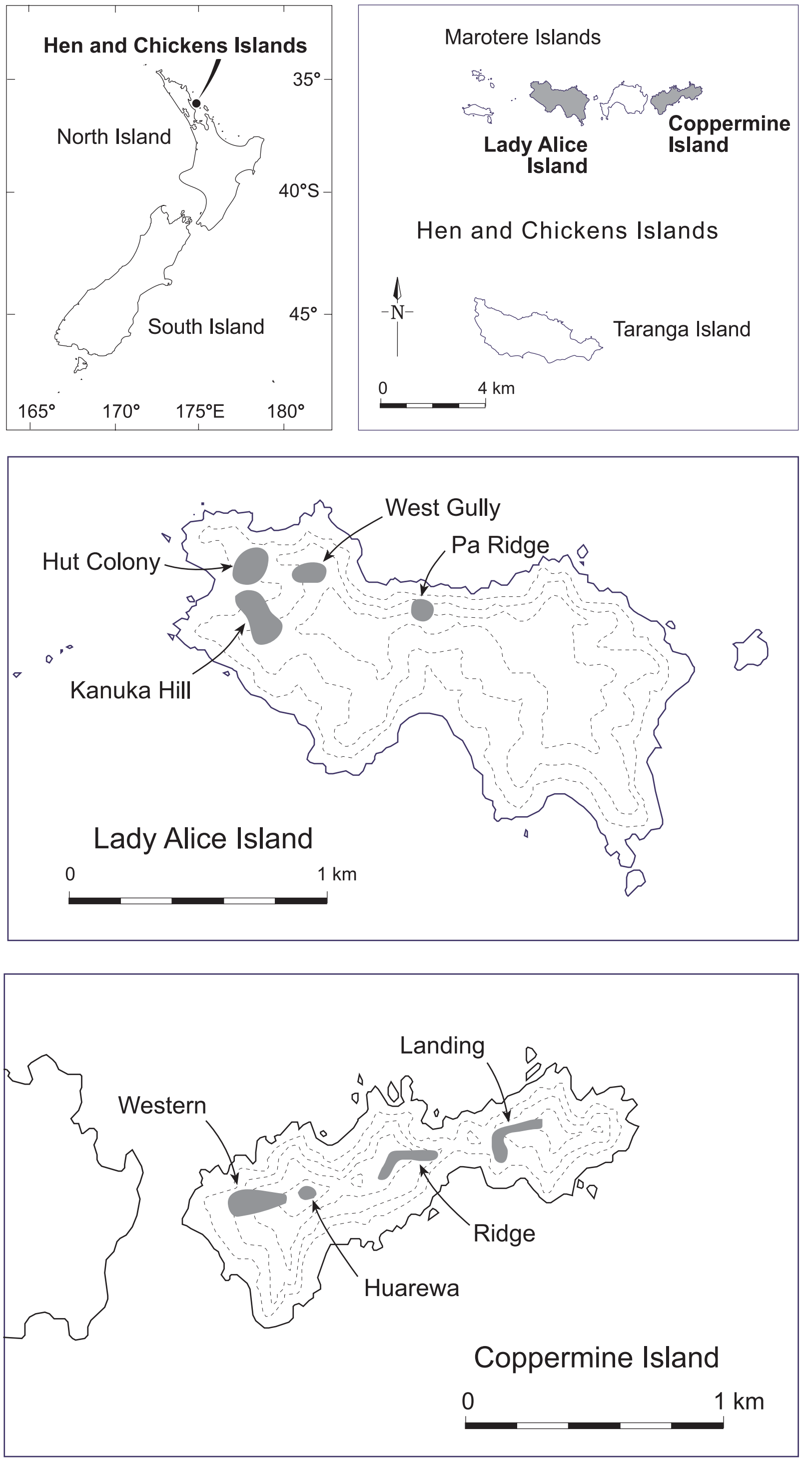
Kiore or Pacific rats (*Rattus exulans)* were very widespread on the New Zealand archipelago and, apart from some initial views to the contrary (Craig 1986), have been implicated in the loss of many small vertebrate and large flightless invertebrates, particularly from the mainland and larger islands (Atkinson & Moller 1990; Towns et al. 1997; Brook 1999). Evidence for kiore impact on the endemic predatory reptile, tuatara (*Sphenodon punctatus*) and other reptiles and invertebrates prompted their removal from a number of New Zealand islands in the 1980s and especially the 1990s (Towns et al. 1997). There is also growing evidence of kiore predation on many New Zealand birds, including seabirds (Thoresen 1967; Imber 1978, 1984; Booth et al. 1996), but there have been no prolonged studies or experimental controls to determine impact on breeding success. Many species of seabirds have in fact persisted to varying extents on some islands where kiore have been introduced. This includes some small burrowing seabirds, including diving petrels (*Pelecanoides urinatrix*), little shearwaters (*Puffinus assimilis haurakiensis*), and particularly Pycroft's petrels (*Pterodroma pycrofti*) and black-winged petrels (*Pterodroma nigripennis)* (Merton & Atkinson 1968; McCallum et al. 1984; Pierce & Parrish 1993).

The situation is complicated by the regular use of a number of seabird burrows, including some occupied by petrels on these islands, by tuatara (Newman & McFadden 1990; Tyrrell et al. 2000). As well as eating the abundant invertebrates that the droppings-enriched soils support, tuatara are known to eat bird chicks and eggs.

Trends in the populations of these and other seabird species coexisting with kiore have been generally unknown. There have been several problems in determining whether kiore have influenced seabird populations: firstly there has been a general lack of seabird monitoring on islands with and without kiore (Taylor 2000); secondly, information on the timing of kiore arrival on islands has generally been lacking (Brook 1999); thirdly, there have often been compounding variables, such as the presence of other pest species (Towns et al. 1997); and fourthly the role of food resources in population declines (important in many species—Warham 1990; Crawford 1998), has been difficult to assess.

During the 1990s, an opportunity to measure the impacts of kiore on the productivity of two small seabird species arose in the Marotere Group in the Hen and Chickens Islands (Fig. 1). A programme of sequential removal of kiore was planned that would enable good experimental controls to be maintained. Pycroft's petrel (a summer nester) and little shearwater (a winter nester) nested in small numbers on four members of the group: Coppermine I., Whatupuke, Lady Alice I., and Mauitaha (Merton & Atkinson 1968; Tennyson & Pierce 1995). Following a reconnaisance in 1992, two islands were selected for study—Lady Alice I. and Coppermine I. (Fig. 1)—because sufficient numbers of both species were present.

Figure 1. Location of the Hen and Chickens Islands, showing main breeding sites for Pycroft's petrels and little shearwaters on Lady Alice I. and Coppermine I.



This study set out to test the hypotheses that: breeding success of Pycroft's petrels and little shearwaters is not limited by the presence of kiore, nor tuatara, and that the two seabird species are not competing for burrows.

Pycroft's petrels and North Island little shearwaters are confined as breeding species to islands off the north-eastern North Island (Heather & Robertson 1996; Taylor 2000). In the past the numbers and range of Pycroft's petrels were much greater, with a stronghold for the species having been Norfolk Island, from which it was exterminated by predators (cats and rats) in the 1800s

(Marchant & Higgins 1990). Today the main colonies are confined to islands from the Aldermans north to the Hen and Chickens and Poor Knights (Taylor 2000). Little shearwaters are also probably greatly reduced in numbers. Early literature, e.g. Reischek (1885) noted 'considerable numbers' of little shearwaters in the early 1880s on Lady Alice I., where they were comparatively rare by the 1990s (this study).

The general biology of Pycroft's petrels was studied by Bartle (1968) and Dunnet (1985). Pycroft's petrels return to their island breeding grounds from early October to court and clean out burrows. Burrows are short by petrel standards, ranging in length from 45 cm to 1.6 m (this study), with a vegetation-lined chamber near the end. Normally they are burrowed into the soil, but this study located a few nests under tree roots and clumps of *Astelia* and flax (*Phormium tenax*) and inside hollow tree trunks. After burrow-cleaning, there follows a pre-laying exodus to sea, and birds return to lay in late November–December (Dunnet 1985). First laying occurs from about 20 November (Dunnet 1985). Incubation is shared between the sexes, with changeovers occurring at about 10–12 days (Dunnet 1985; this study). Eggs are rarely left unattended (this study). Hatching occurs at about 47 days and chicks are attended by a parent for the first few days, but therafter are visited for feeding only at night. The young fledge in mid-March to mid-April (Dunnet 1985; this study).

Booth et al. (2000) studied the breeding biology of little shearwaters on Lady Alice I. in 1994 which included study burrows set up in the first year of the current study. Little shearwaters are winter and spring nesters, with most eggs being laid in July–August. Burrows are 0.3–2.0 m long (Heather & Robertson 1996). Both sexes incubate but eggs are frequently left unattended for up to four days at a time (Booth et al. 2000). They hatch at about 55 days and chicks fledge in late October to early January (Booth et al. 2000; this sudy).

2. Study areas

The Marotere Islands are formed from alternating sandstone and mudstone of approximate Jurassic age intersected with andesitic dykes of early Miocene age, with some copper mineralisation occurring on the easternmost island, Coppermine I. (Moore 1984). Lady Alice I. (c.140 ha) and particularly Coppermine I. (c. 80 ha) are cliffed on much of their northern coastlines; there are well developed ridge systems, steepest on Coppermine I., which reaches 185 m elevation, whereas Lady Alice I. is more gently sloping, attaining 158 m elevation. The clay soils are for the most part thin on both islands, but there are scattered sites of thicker soil rich in humus, one of which (on Coppermine I.) has been terraced during Maori occupation.

The islands are forested, but much of both islands has been modified by burning, which occurred up to and including the late nineteenth or early twentieth centuries (Percy 1956; Bellingham 1984; Cameron 1984; Brook 1999). Much of the western end of Coppermine I. and the southern side of Lady

Alice I. appeared to escape the more recent fires and have the more advanced forest. Lady Alice I. was grazed by cattle until 1925 (Cameron 1984).

Study burrows were found throughout Coppermine I. and on the western half of Lady Alice I. They occurred from the summits down to about 5 m elevation on Lady Alice I. and 20 m elevation on Coppermine I. Both islands possessed several sites where many small petrel (mainly shearwater) burrows were abandoned and gradually collapsing. The largest of these colonies was at the summit of Coppermine I., where about 50 derelict burrows and a small number of active burrows were found in 1992. Others of up to 30 derelict and a few active burrows were found along the main ridge on both Coppermine I. and Lady Alice I. (Fig. 1).

Occupied burrows were found in a wide range of slopes and aspects on both islands. All were located beneath forest of which there were two main types:

- Kanuka (*Kunzea ericoides*) forest with an understorey of seedlings and shrubs dominated by hangehange (*Geniostoma rupestre*), kawakawa (*Macropiper excelsum*), mapou (*Myrsine australis*), *Coprosma* spp., mahoe (*Melicytus ramiflorus*), kohekohe (*Dysoxylum spectabile*), and flax and *Astelia.* Groundcover in some areas was dominated by the ferns *Phymatosorus diversifolius, Asplenium* spp. and *Doodia media*. In some areas, and increasingly during the 1990s, many kanuka emergents had collapsed, leaving a mixed broadleaf canopy 1.5 to 4 m tall. In one of the Coppermine I. sites (a terraced area above the Landing on the south side of the island) there was virtually no undergrowth under a dense kanuka canopy.
- Mixed broadleaf forest dominated by mature emergent pohutukawa (*Metrosideros excelsa*), karaka (*Corynocarpus laevigatus*), and tawapou (*Planchonella novaeseelandiae*); understorey was dominated by the same species that occurred beneath kanuka forest.

3. Methods

3.1 EXPERIMENTAL DESIGN

The study was based around the eradication of kiore from the Marotere group and hence their presence or absence from islands each year. Kiore were removed from Lady Alice I. in October 1994 and from Coppermine I. in July 1997 by aerial distribution of Talon® poison (Morgan et al. 1996; Ogilvie et al. 1997). Pycroft's petrels were monitored on both islands from the 1992/93 season until 1999/2000 (Table 1), and little shearwaters from 1993 on Lady Alice I. and 1995 on Coppermine I. (Table 2). This enabled not only 'before and after kiore' data to be collected on breeding success of both species, but also intra-year comparisons between the islands with different kiore status. These intra-year comparisons enabled annual variables such as differences in weather and food supply to be eliminated as compounding variables since they were the same for the two study populations in any given year.

TABLE 1. KIORE STATUS AND PYCROFT'S PETREL NEST MONITORING 1992–2000.

YEAR	LADY ALICE I.		COPPERMINE I.	
	KIORE STATUS	NESTS MONITORED	KIORE STATUS	NESTS MONITORED
1992/93	Present	32	Controlled	24
1993/94	Present	33	Present	24
1994/95	Absent	43	Present	30
1995/96	Absent	42	Present	27
1996/97	Absent	40	Present	32
1997/98	Absent	44	Absent	27
1998/99	Absent	51	Absent	21
1999/2000	Absent	52	Absent	24
2000/01	Absent	46	Absent	–

TABLE 2. KIORE STATUS AND LITTLE SHEARWATER NEST MONITORING 1993–2000.

YEAR	LADY ALICE I.		COPPERMINE I.	
	KIORE STATUS	NESTS MONITORED	KIORE STATUS	NESTS MONITORED
1993	Present	24	Controlled	–
1994	Present	29	Present	–
1995	Absent	21	Present	18
1996	Absent	25	Present	19
1997	Absent	22	Present/absent	21
1998	Absent	23	Absent	10
1999	Absent	23	Absent	24
2000	Absent	29	Absent	–

An earlier ground-based attempt to remove kiore from Coppermine I. occurred in the 1992/93 season, during which time the rats were depleted to very low densities (K. Hawkins pers. comm.), but they subsequently recovered across the island in 1993 to 1997. This provided a unique opportunity to examine how the productivity of one of the seabird species (Pycroft's petrel) responded to the reinvasion of the island by kiore, following a year of extremely low kiore densities.

3.2 KIORE STATUS

The presence and absence of kiore was the predator variable tested in this study. Attempts were also made to index kiore abundance to test for inter-year and inter-island differences. Records were kept of sightings of kiore over 15-minute periods in and around seabird burrows during night-time searches of seabird areas in December. Records were also kept of presence/absence of kiore sign (droppings) at burrow entrances during the final check of seabird breeding success.

3.3 PETREL BREEDING SUCCESS

To determine petrel breeding success, the islands were visited at least twice in the breeding season of each species. The first visit involved checking burrows to locate nests and nesting activity, followed by a visit late in the fledgling period to determine success to the late fledgling stage. For Pycroft's petrel, the first check was in December and the final one in mid-March; for little shearwater, the first check was in August and the final one in mid-October, with a follow-up in mid-December.

Initial searches were made during the day and night to look for sign of seabird activity, such as diggings and droppings. Many Pycroft's petrel burrows were located by eliciting responses to 'war-whooping' (Tennyson & Taylor 1990; Tennyson & Pierce 1995). Each burrow was permanently marked with a numbered metal tag nailed to a nearby tree, from which the compass direction and distance to the burrow were measured. Coloured flagging tape was also used closer to each burrow to enable it to be rapidly located.

During each visit, records were kept of burrow number, burrow contents, adult weights, and chick weights and wing measurements. Weights were recorded to the nearest gram with a 300 g Pesola balance, and measurements recorded to the nearest millimetre with Vernier calipers. All adults and large chicks were banded with size D bands (Pycroft's petrels) and X bands (little shearwaters). Records also were kept of all tuatara, other reptiles, kiore, and birds that were encountered in burrows. Failed nests were examined for possible cause of failure, e.g. flooding, and the stage at which failure had occurred was determined where possible. Kiore sign (droppings) in burrows and at burrow entrances was noted.

On Lady Alice I., additional checks of little shearwaters were made in mid-November from 1995 onwards to determine more precisely the time of fledging and the use of specific burrows by Pycroft's petrels at the start of their breeding season. The latter also involved night work including the use of 'war-whooping' to locate prospecting birds. In 1994, most little shearwater burrows on Lady Alice I. were checked more frequently as part of a separate breeding biology study, but some burrows were left as controls to determine observer impacts (Booth et al. 2000).

3.4 WEATHER

There are no weather stations in the Marotere Group. Rainfall records were examined from my private gauge at Mt Tiger at c. 250 m elevation, 35 km north-west of the island group. In particular, periods of heavy rainfall were noted by initially searching monthly rainfall data and, where totals exceeded 200 mm, I also examined daily records for instances of prolonged heavy rain. To check for consistency, I examined monthly summaries from Whangarei meteorological station, at 40 m altitude, and also 35 km north-west of the Marotere Group and 6 km from Mt Tiger.

3.5 ANALYSES

The χ^2 analysis was used to determine the effects of kiore on seabird breeding success, both between islands and between breeding seasons. Intra-island productivity between years was compared in the same way.

3.6 TUATARA

The role of tuatara in nest failures was tested in two ways. Firstly, the productivity of burrows was compared between burrows that regularly had tuatara present and those in which tuatara were not recorded during the study. Secondly, productivity of Lady Alice I. burrows was compared between areas that had highest densities of tuatara and areas where tuatara were seldom recorded during the study. These tests were conducted in post-kiore scenarios.

3.7 INTERSPECIFIC COMPETITION

The effects of burrow competition between the two seabird species was determined by comparing productivity of pairs among burrows of varying utilisation and timing by the other species. Thus, the effect of little shearwater occupancy on Pycrofts's petrels was determined by examining petrel responses to little shearwater occupancy of 'their' burrows and the time of completion of nesting by little shearwaters.

4. Results

4.1 KIORE STATUS

During December 1992, kiore were common on Lady Alice I., but they were not detected on Coppermine I. during the height of a poison baiting programme. In the following years, however, kiore had recovered in and around seabird colonies on Coppermine I. and were seen at approximately similar levels to those seen at Lady Alice I. colonies in 1993 and 1994 (Table 3).

4.2 BREEDING SUCCESS IN RELATION TO KIORE STATUS

Pycroft's petrel

The productivity of Pycroft's petrels to the late fledgling stage ranged from 19% to 62% on the two islands in the nine years of study. Both islands showed the same general pattern, with productivity being lowest in the presence of kiore

TABLE 3. KIORE NUMBERS AND SIGN DETECTED DURING SEABIRD CHECKS IN MID-DECEMBER AND MARCH.

Numbers of kiore given (with range) per 15-minute observation period, *n* is no. of observation periods; sign (mainly droppings) recorded as no. of active petrel nests with kiore sign.

YEAR	NO. OF KIORE /15 MIN Lady Alice I.	NO. OF KIORE /15 MIN Coppermine I.	NO. OF NESTS WITH SIGN Lady Alice I.	NO. OF NESTS WITH SIGN Coppermine I.
1992/93	Present	0 (n = 12)	10 (31%)	0
1993/94	2.2 (0–5, n = 14)	1.1 (0–3, n = 9)	4 (12%)	4 (17%)
1994/95	0	No data	0	9 (30%)
1995/96	0	2.0 (0–4, n = 11)	0	6 (22%)
1996/97	0	1.5 (0–4, n = 10)	0	9 (28%)
1997/98	0	0	0	0
1998/99	0	0	0	0
1999/00	0	0	0	0
2000/01	0	0	0	0

and highest in their absence (Fig. 2). Thus in 1992, productivity on Coppermine I., where kiore were controlled to extremely low levels, was three times that of Lady Alice I. in the same year (χ^2 = 8.02, 1 d.f., P < 0.01). In the following four years (1993–96 inclusive), during which time kiore had recovered on Coppermine I., petrel productivity was lower than it had been in 1992 (significant for the 1996 season). In three of these years (1994–96), kiore were present on Coppermine I., but absent from Lady Alice I., and during each of these years, breeding success was lower on Coppermine I. (significantly so in 1996, χ^2 = 5.11, 1 d.f., P < 0.05). Pooling these three years' data revealed a lower breeding success on 'kiore present' Coppermine I. (average 29%) than on 'kiore absent' Lady Alice I. (54%), which was a highly significant result (χ^2 = 7.86, 1 d.f., n = 213 nests, P < 0.01).

In the three post-kiore years (1997–99) on Coppermine I., productivity of the nest samples was consistently greater than that in each of the four preceding

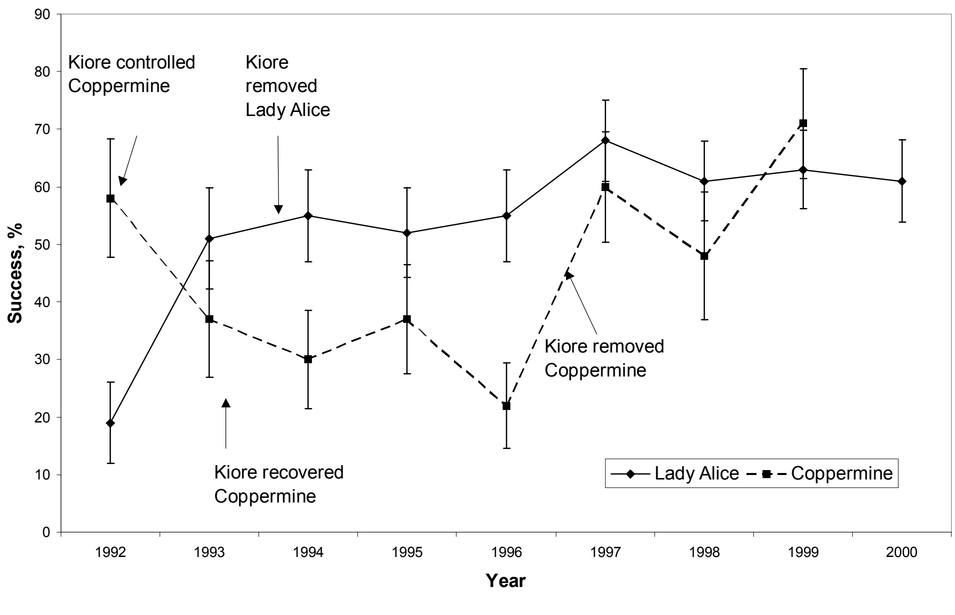


Figure 2. Mean breeding success ± SE for Pycroft's petrel on Lady Alice I. and Coppermine I., 1992–2000.

seasons 1993–96, and was closely similar to that in 1992, when rats were controlled to low levels. Pooling data from the 'kiore present' years on Coppermine I. and comparing with 'kiore absent' years on the same island indicated a significant difference (χ^2 = 5.38, 1 d.f., n = 185 nests, P < 0.05). Conversely, an inter-island comparison indicated that in1997–99, productivity was also closely similar between the two now 'rat-free' islands (χ^2 = 0.13, 1 d.f., n = 219 nests, P > 0.9).

Because of the low variability within samples of each of the 'kiore present' and 'kiore absent' scenarios, data from all Pycroft's petrel nests monitored in 1992–99 have been pooled in Table 4 for the two scenarios on each island. Petrels showed a statistically higher breeding success in the absence of rats on both islands (Lady Alice I., χ^2 = 5.73, 1 d.f., n = 380 nests, P < 0.05; and Coppermine I., χ^2 = 9.46, 1 d.f., n = 209 nests, P < 0.01). For all years combined, productivity was 69% higher in the absence of kiore on Lady Alice I., and 92% higher in the absence of kiore on Coppermine I.

Little shearwater

Productivity of little shearwaters ranged from 5% to 86% on the two islands. The general pattern was similar on both islands with productivity being highest in the absence of kiore (Fig. 3, Table 5). Thus on Lady Alice I., productivity averaged 43% (range 38–50%) in the presence of rats and 68% (range 52–86%) in their absence (χ^2 = 3.76, 1 d.f., n = 173 nests, P > 0.05). On Coppermine I., productivity averaged only about 5% in the two years when kiore were present and 56% in the three years after kiore were removed (χ^2 = 16.01, 1 d.f., n = 92 nests, P < 0.001). The extremely low productivity on Coppermine I. in 1995 and 1996 contrasted with high productivity in the same years on kiore-free Lady Alice I. (Fig. 3). In the three post-kiore years (1997, 1998 and 1999) on both islands, inter-island productivity was not significantly different (χ^2 = 0.28, 1 d.f., n = 129 nests, P > 0.1).

The lowest success recorded in the absence of rats (38% on Coppermine I. in 1997) is a conservative figure, because kiore were in fact still present in the early part of that breeding season. Six nests had sign of their eggs having been eaten by rats. Removal of these six nests from the calculation gives a breeding

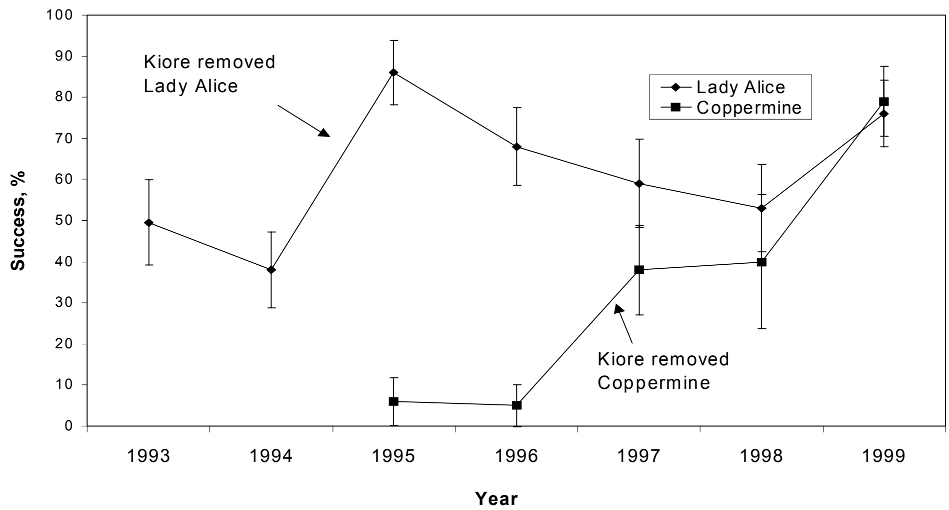


Figure 2. Mean breeding success ± SE for little shearwaters on Lady Alice I. and Coppermine I., 1993–2000.

TABLE 4. MEAN PRODUCTIVITY OF PYCROFT'S PETREL NESTS IN THE PRESENCE AND ABSENCE OF KIORE, POOLED DATA.

KIORE STATUS	LADY ALICE I.	COPPERMINE I.
Present	35.4% (19–51%, *n* = 65 nests)	31.0% (22–37%, *n* = 113)
Absent	59.7% (52–68%, *n* = 315)	59.4% (48–71%, *n* = 96)

TABLE 5. MEAN PRODUCTIVITY OF LITTLE SHEARWATERS IN THE PRESENCE AND ABSENCE OF KIORE, POOLED DATA.

KIORE STATUS	LADY ALICE I.	COPPERMINE I.
Present	43.4% (38–50%, *n* = 53 nests)	5.4% (5–6%, *n* = 37)
Absent/controlled	68.3% (52–86%, *n* = 120)	56.4% (38–79%, *n* = 55)

success of 53% (*n* = 15) in 1987 and the average 'kiore absent' success on Coppermine I. in Table 5 increases from 56.4% to 63.3%.

4.3 BREEDING SUCCESS IN RELATION TO TUATARA ABUNDANCE

Pycroft's petrel

To test for tuatara impacts, petrel productivity was compared in burrows with three levels of tuatara frequencies recorded during the post-kiore period of study: nil recorded, 64% (*n* = 142 nests); recorded on 1–2 occasions, 59% (*n* = 105); and recorded on 3–8 occasions, 58.5% (*n* = 53). There was no significant difference in breeding success between burrows with these three levels of tuatara occupancy.

A second test of tuatara impact on petrels is summarised in Table 6. Petrel productivity was compared between four different geographic areas on Lady Alice I. where tuatara occurred at different levels of abundance during this study. These data are also from non-kiore scenarios, and include all nest observations from 1994/95 to 2000/01 seasons. This analysis indicated no detectable difference in productivity between the Hut area, which had the

TABLE 6. PETREL BREEDING SUCCESS IN AREAS WITH DIFFERENT TUATARA ABUNDANCE, LADY ALICE I., 1994–2000.

No. of tuatara is the mean of the total tuatara recorded per burrow 1994–2000.

SITE	HUT	PA	GULLY	HILL
No. of tuatara	2.03	1.30	0.46	0.36
No. nests	133	21	68	73
Success	65.4%	9.5%	67.6%	64.4%

highest tuatara encounters, and West Gully and Kanuka Hill, which had the lowest encounter rates (Table 6). The site that had significantly lower productivity (Pa Ridge) than the others had tuatara encounters that were intermediate between the other sites, but the sample size for that site was small (21 nest attempts).

Little shearwater

Little shearwater productivity was not significantly different between burrows that sometimes contained tuatara and burrows in which tuatara were never recorded: nil recorded, 67.2% (n = 39 nests); recorded on 1–2 occasions,72.5% (n = 40); and recorded on 3–6 occasions, 64.3% (n = 14).

Sample sizes were too small statistically to present on a geographic basis for Lady Alice I., but are presented in Table 7. Nesting success appeared to be relatively even in the four different areas, with no evidence of lowered nesting success at the Hut and Pa Ridge, the two sites in which the highest densities of tuatara were recorded.

TABLE 7. BREEDING SUCCESS OF LITTLE SHEARWATERS IN AREAS WITH DIFFERENT TUATARA ABUNDANCE, LADY ALICE I., 1995–99.

No. of tuatara is the mean of the total tuatara recorded per burrow 1995–2000.

SITE	HUT	PA	GULLY	HILL
No. of tuatara	1.0	1.2	0.62	0.5
No. nests	26	15	34	40
Success	73%	80%	56%	77%

4.4 IMPACTS OF HEAVY RAIN ON BREEDING SUCCESS

Pycroft's petrels

Heavy and prolonged rain fell in only the 1996 and the 1998 seasons, the most severe falls occurring on:

1. 29–30 December 1996, when 190 mm fell at Mt Tiger, although the previous two months had recorded below average rainfall with only 100 mm recorded between 1 November and 28 December.
2. 27–28 November 1998, when 202 mm fell at Mt Tiger, followed a few days later by 67 mm on 3 December 1998; this period of rain followed on from the wettest winter recorded during the study.

The petrels were in a kiore-free scenario on Lady Alice I. in both years of heavy rain with all breeding birds well into incubation in late December 1996 and many having begun incubation in late November 1998. There was clear evidence of the physical impact of heavy rain on both occasions, and many burrows had accumulated pools of water. The only evidence of nests failing due to the flooding was in 1998, when one adult died in a collapsed burrow apparently caused by flooding, and two other live adults had rotting eggs attached by dried clay to their bellies. Despite these losses, breeding success in those years was still high and not significantly different from that of other years in the absence of kiore (Fig. 2).

On Coppermine I., the petrels were breeding in the presence of kiore during the 1996 deluge, but kiore were gone in the 1998 event. No evidence of burrow collapses or addled eggs was found. Breeding success was very low in the 1996 kiore-present scenario (compared with high the same year on kiore-free Lady Alice I.), and in 1998 results were not significantly different from those on Lady Alice I.

Little shearwater

There was only one period of heavy rain during the little shearwater breeding seasons of 1993–99. This occurred early in the 1998 season, when a total July rainfall of 399.5 mm was recorded at Mt Tiger, spread fairly evenly through the month, followed by 120 mm on 10–11 August. On both islands and particularly on Coppermine I., fewer nests were found than usual, with several pairs apparently abandoning their nesting attempts. Of those that did breed, their average success in that year was the lowest for all kiore-absent situations.

4.5 INTERSPECIFIC COMPETITION

Little shearwaters and Pycroft's petrels sometimes shared burrows for nesting on Lady Alice I. and Coppermine I., and this relationship was studied more closely on the former island from 1994 to 1999. During this time, 42 cases were found of Pycroft's petrels returning in spring to find that little shearwaters were nesting in 'their' burrows of the previous year or years. Of these cases, 23 (55%) resulted in Pycroft's petrels nesting in the same burrow after the shearwaters had failed or finished nesting, three (7%) moved to a different burrow, and 16 (38%) abandoned nesting for the season.

Reponses of Pycroft's petrels to little shearwater occupancy were examined in relation to little shearwater completion dates. These completion dates were mid-October (n = 18, 15 of which were failures), mid-November (n = 16, 13 involving fledged shearwater young), and after mid-November (n = 8, all involving fledged young).

Table 8 presents the outcome of these competitive cases. The three completion dates resulted in significantly different petrel responses. If little shearwaters had finished nesting by mid October, most petrels bred in the same burrow, but later completion dates resulted in increased displacement, and especially abandonment of nesting, by the petrels ($\chi^2 = 8.81$, 1 d.f., $P < 0.01$).

The 22 pairs that nested following the vacation of the burrow by shearwaters, had an average nesting success of 68%, which was not significantly different from petrels nesting in petrel-only burrows (60%, n = 315 nests) . All 17 pairs of petrel that did not breed (Table 8) were found in or outside their usual burrows (that the shearwaters had used) at various times in December.

TABLE 8. RESPONSES OF PYCROFT'S PETRELS TO DIFFERENT LITTLE SHEARWATER NEST COMPLETION DATES.

PETREL RESPONSE	SHEARWATERS FINISHED			TOTAL RESPONSES
	BY MID-OCT	LATE OCT TO MID-NOV	AFTER MID-NOV	
Nest in same burrow	16 (89%)	6 (38%)	0	22
Shift to new nest	0	3 (19%)	0	3
Abandon nesting	2 (11%)	7 (44%)	8 (100%)	17
Total responses	18	16	8	42

The 17 abandoned nesting attempts that were apparently due to shearwater occupancy, took place over six breeding seasons in which a total of 272 petrel nests was monitored. Assuming that 289 nests could have been initiated if little shearwaters were not a factor, these failed attempts represent a loss of up to 6% of potential breeding attempts. During this period, nesting petrels averaged a 60% breeding success, so potential lost productivity due to shearwaters during this time was up to about 3.6 %.

Of the six seasons, three (1996, 1998 and 1999) involved little shearwaters being significantly late, on average, in finishing nesting. There was a trend towards increased abandonment of nesting attempts by Pycroft's petrels in those years of late shearwater nesting, with 10 of the 16 cases occurring in those years, but this was not statistically significant.

The three petrel pairs that moved to new burrows moved a few metres to an unoccupied burrow (two pairs) and to dig a new burrow (one pair). Birds that had abandoned nesting apparently due to shearwater occupancy were found the following season in the same burrow they had been displaced from (one pair) or in a new burrow nearby (two pairs). Of 295 nesting attempts recorded between 1994 and 2000, there were only 12 involving birds shifting between burrows, of which at least three involved displacements by little shearwaters. At least two involved divorces, one a grey-faced petrel (*Pterodroma macroptera gouldi*) nesting pair, and the others 'unknown causes'. Mean distance shifted between burrows was 5 m (range 0.5–16 m). Three of these events involved one pair shifting amongst three burrows all within 6 m of each other, and initially involving displacement by little shearwaters.

5. Discussion

5.1 KIORE IMPACTS

Breeding success of Pycroft's petrels and especially little shearwaters varied widely between Lady Alice and Coppermine Islands over the study period, with several years of significant breeding failures. Many seabird species face major changes in the availability of their food resources (Crawford 1998), and this, together with bad weather, can contribute to significant breeding failures (Warham 1990). The temporal controls in this study, however, ruled out food failure and/or weather as significant contributing factors to all of the low productivity recorded, because high productivity was recorded during the same years on the kiore-free island. The three breeding failures (Pycroft's petrels on Lady Alice I. in 1992; little shearwaters on Coppermine I. in 1995 and 1996) and other years of moderate to low breeding success all corresponded to kiore presence on the islands. Following the removal of kiore, however, productivity of both species was consistently high, except for little shearwaters in 1998, when very wet weather was a factor in some failures. Apart from this heavy rain impact on little shearwaters, the wide range of La Niña and El Niño weather patterns and sea conditions experienced through the latter half of the 1990s (NIWA 2002) had no detectable influence on the productivity of either species on Lady Alice I., which was rat-free after October 1994.

These results demonstrate unequivocally the frequently high level of impact of kiore on the productivity of the two seabird species, and a subsequent increased productivity following the removal of kiore. The impact on little shearwaters was particularly severe, with almost complete breeding failures during two of the four years of kiore presence. This higher level of impact on little shearwaters is consistent with their behaviour of leaving eggs unattended for days at a time (Booth et al. 2000), compared with Pycroft's petrels, which seldom left eggs unattended (pers. obs.). Seasonal changes in kiore abundance and/or their food availability (Campbell et al. 1984; Newman & McFadden 1990; Roberts & Craig 1990), might also have contributed to this interspecific difference in susceptibility, as well as the higher impact on Coppermine I. little shearwaters in 1995 and 1996 than on Lady Alice I. little shearwaters in 1993 and 1994. Local patterns of kiore behaviour might also have contributed to these observed differences.

Precise levels of breeding success for the maintenance of populations are not known for Pycroft's petrels and little shearwaters. Based on studies of related species, M. Imber (pers. comm.) estimates at least 25% breeding success for the petrel and 30% for the shearwater as minimum maintenance levels. This level was not met by Pycroft's petrels in some kiore-present situations on the Marotere Group. Little shearwaters fell well short of that requirement on Coppermine I. in both years of study, but met the estimated threshold on Lady Alice I.

The high numbers of relict little shearwater burrows present on both islands during this study is consistent with a population that is not replacing itself. On islands lacking rats, however, such as the Poor Knights and Three Kings Islands, colonies of little shearwaters (and/or shearwaters generally) have a much higher occupancy rate, with little or no sign of relict burrows (pers. obs.).

In 1880 Reischek recorded little shearwaters to be present in 'considerable numbers' on Lady Alice I., although some of his observations might also have referred to fluttering shearwaters (*Puffinus gavia*) as he stated that the local Maori birded them at fledging time in February (Reisheck 1930), but little shearwaters would have long since departed by this time of year. By the 1960s, however, little shearwaters were listed as present in small numbers (Skegg

1961; Merton & Atkinson 1968). Later observers in the 1970s and 1980s (D.G. Newman unpubl. report 1980; McCallum et al. 1984) concurred with this and McCallum considered that the shearwaters had declined in the 100 years since Reischek's visit.

Some caution in this interpretation is needed, because little shearwaters can sometimes give a false impression of being present in 'considerable numbers'. This was certainly the case during a visit of mine to the Landing site on Coppermine I. during the night of 10 October 1996. Scores of shearwaters were calling from the air and from inside and outside burrows at the colony, with nearly continuous noise for two hours after dark and about two hours before dawn. This followed major (95%) breeding failure on the island that year, and it was interesting to note that on Lady Alice I. the following night (11 October 1996), where little shearwaters were breeding successfully (68% success), they were silent. However, the time of year of Reischek's visit to Lady Alice I. was December and not October. During 13 nights ashore in December in 1995–2000, no significant activity or vocalisation was found on Coppermine I. or Lady Alice I., irrespective of the breeding success at the time. From these data and the evidence of abandoned colonies, I conclude that there has definitely been a large decline in numbers of little shearwaters on the Chickens Islands since the 1880s, and probably a decline in fluttering shearwater numbers as well.

5.2 TUATARA IMPACTS

Tuatara are likely to recover greatly in numbers on these islands following kiore removal (Tyrrell et al. 2000). Although there were some instances of suspected tuatara predation of chicks, their presence in burrows did not significantly alter breeding success of the two seabird species. There was one possible exception to this, with the failure of Pycroft's petrels (but not little shearwaters) at the Pa Ridge site, where tuatara were recorded in moderately high numbers. Sample sizes at this site are small and it is not useful to speculate whether tuatara were indeed involved in the failures or whether other factors, e.g. inexperienced breeders, were involved more here than at the other sites. Monitoring of this and other petrel colonies on the island will determine whether this pattern continues and if it is significant at the population level.

5.3 COMPETITION

There was evidence of burrow competition in this study, with Pycroft's petrels potentially abandoning 6% of nesting attempts and losing 3.6 % of annual productivity because of prior occupancy of burrows by little shearwaters. This, however, was more than compensated for by the increased productivity of petrels following the removal of kiore. Over the next few decades there is likely to be a substantial increase in new Pycroft's petrel pairs attempting to breed on the Marotere Islands. During this time it seems unlikely that there will be significant competition from little shearwaters, because both species of seabird are currently uncommon and the availability of burrows (both old burrows and space for digging new burrows) is unlikely to significantly limit petrel breeding.

The age of first breeding is not known for either species, but the now very high productivity of little shearwaters on these islands will see their population increase greatly and possibly at a faster rate than that of the petrels. As little shearwaters increase there will almost certainly be an increase in the proportion of Pycroft's petrel pairs that are disrupted by shearwaters. It is not possible to predict the likely outcome of this for Pycroft's petrels, because there is a range of factors that will have an influence on breeding ecology. This includes the proportion of petrel burrows that are utilised by shearwaters, and the ability of Pycroft's petrels to excavate new burrows. Some evidence of potential effects of weather was seen in this study, with little shearwaters (but not Pycroft's petrels) delaying their breeding in particularly wet years. Some climatologists predict increases in heavy rain events in this part of New Zealand, which, if correct, would be a negative factor for petrels unless they too delayed breeding.

Possibly a greater threat to both species in the long term is the potential colonisation of the Marotere Group by other seabird species, particularly fluttering shearwaters and Buller's shearwaters (*Puffinus bulleri*). Fluttering shearwaters breed in small numbers on the large Chickens, but occur in larger numbers on the smaller kiore-free Muriwhenua and Pupuha Islands, 2 km from Lady Alice I. During this study and studies of flesh-footed shearwaters (*Puffinus carneipes*) in 1999 and 2000, two non-breeding Buller's shearwaters were found ashore on Lady Alice I. for the first time. These species are summer breeders, returning to clean out burrows in August (fluttering shearwater) or September (Buller's shearwater) and therefore could cause displacement of both Pycroft's petrels and little shearwaters.

Over the past 100 years, Buller's shearwaters have greatly increased on Aorangi in the Poor Knights. A study of a small colony of Pycroft's petrels in the 1960s took place in one part of Aorangi, into which Buller's shearwaters had not yet spread (Bartle 1968). However, I returned to this site on 2 January 1995 (when petrel pairs would have been incubating) and, despite intensive searching, found only one pair of Pycroft's petrels. Buller's shearwaters had colonised this part of Aorangi since the 1960s and had heavily burrowed the site.

5.4 STRATEGIES FOR SMALL SEABIRD CONSERVATION

Undoubtedly the best strategy for small seabird conservation is to provide as many pest-free islands as possible and to maintain them in a pest-free state. This will enable islands to recover with a wide diversity of species compositions. Locally, Taranga (Hen Island) has great potential for little shearwater and Pycroft's petrel recovery. These seabirds were found to be rare during surveys of Hen Island in the 1990s (pers. obs.; M. Thorsen pers. comm.) despite extensive searching. This island has sufficient habitat to support a very large and varied seabird fauna, but requires kiore to be eradicated to facilitate the restoration of biota generally, not only petrels and shearwaters.

Population monitoring of adult Pycroft's petrels and little shearwaters on Lady Alice I. is recommended to determine medium- and long-term responses of their populations to kiore removal. This monitoring should include quadrats in all four nesting clusters studied in the 1990s, for which baseline data are already available (put in place 2000).

It would also be useful to monitor recruitment of Pycroft's petrels and little shearwaters on Lady Alice I. to determine age at first breeding, and determine longevity and survival of adults based on banded samples. Large numbers of adults and fledglings of both species have been banded since 1992 on Lady Alice I., where in 2000/01 there were also several surviving petrels from banding undertaken in the early 1980s.

In the absence of kiore and other rats, abandoned seabird eggs remain comparatively intact in or near burrow entrances, but in the presence of kiore, most eggshells are smashed into tiny fragments, and there are also rat droppings at the site. These could be used as indicators of rat presence on islands to complement island quarantine procedures.

To enable seabirds elsewhere in the Hen and Chickens Group to survive, kiore would need to be removed from Hen and Mauitaha, and fully effective quarantine measures for the island group would need to be implemented.

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