BREEDING ECOLOGY AND CONSERVATION OF THE BLACK PETREL *(Procellaria parkinsoni)*

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ABSTRACT

The breeding of the Black Petrel on Little Barrier Island was studied during 1971-75 in 22 study burrows and then reviewed at about 2-yearly intervals. Predation by feral cats affected the population most, causing the number of breeding and non-breeding birds associated with study burrows to decline from 39 in 1971-72 to 14 in 1976-77. Cats were eliminated between 1977 and 1980. By 1982-83 further attrition due to poor recruitment had stopped.

The breeding season of the Black Petrel is from October to July. Eggs are laid from about 10 November to about 20 January but mainly in early December. Prelaying activities are brief, but other phases of the breeding cycle are not. Incubation shifts and the nestling period may be long because of limitations of the food supply.

The major breeding place is Great Barrier Island. Surveys there during chick-rearing in 1977 and 1978 revealed very little predation and relatively high breeding success. The cause of this is discussed.

INTRODUCTION

The Black Petrel *(Procellaria parkinsoni)*, or Parkinson's Petrel, which breeds only in New Zealand, is the smallest and most northerly breeding of its genus. It formerly bred on the North Island and northern South Island, in at least four widespread places reported in European times (Dieffenbach 1843, Reischek 1886, Buller 1905, Oliver 1955). It was a highly valued muttonbird of Maoris, some of whom called it Taiko. Their lore suggests other former breeding places, some far inland. The only authentic report of breeding on the main islands this century was in Taranaki (Medway 1960), some distance from where Dieffenbach first reported it, and where a few might still breed (D. G. Medway, pers. comm.).

At sea during the breeding season it ranges far to the north and east of the North Island (Murphy 1936, Imber 1976, T. G. Lovegrove pers. comm.) and also west into the Tasman Sea, reaching Australia (D. W. Eades, pers. comm.; Fig. 1). It migrates to the eastern tropical Pacific after the breeding season (Loomis 1918, Murphy 1936, Jehl 1974, Pitman & Unitt 1981, J. Farrand pers. comm.).

HISTORICAL NOTES

Dieffenbach (1843) made the first observations recorded of Black Petrels. In December 1839, guided by a local Maori, he was making a first attempt to climb Mount Taranaki (Egmont), North Island. "On the 8th we several times crossed the Mangorake. Its banks are steep, and from one of them Tangutu dug out a titi: this bird, a Procellaria, or mutton-bird as it is

commonly called, has many peculiarities. In the month of December it comes from the sea to the mountains inland, especially to the fore-hills of Mount Egmont. Here the female, which is at that time very fat, but afterwards becomes thin and emaciated, lays one egg, which is remarkably large for the size of the bird. Instead of building a nest, she deposits and covers over her egg in a deep channel under the roots of trees, or at the sides of a cliff, and never leaves the place until the egg is hatched. The natives believe that during this period the female takes no food, and have accordingly named it "the bird of one feeding" . . . ." This locality, then heavily forested, is upstream of the present Egmont Village, at about 300 m. It is now dairy-farming country.

FIGURE 1 — Black Petrel seen 35 km east of Sydney, Australia, on 26 November 1983. Many adults are on their prelaying exodus at this time of year and could travel far from their colony.

Photograph: D. W. Eades

Hutton (1870) discovered Black Petrels breeding above 460 m on Little Barrier Island (36°12′S, 175°05′E) in December 1867. Reischek (1886) observed some of their breeding habits there between 1882 and 1885, and he discovered them breeding west of Auckland in the Waitakere Ranges (37°S, 174°30′E) above 300 m in December 1884. Although he was wrong about the roles of the sexes in incubation, his observations are the most detailed previously recorded. Unlike Hutton, he discovered how they went to sea: "They are expert climbers; I saw them, by the aid of their sharp claws, their bill, and wings, climbing up trees out of the perpendicular, from whence they flew away". He found eggs from 28 November, but his finding a chick

"about the end of December" implies that earlier layings occur, and young chicks as late as April indicate a long laying period. Black Petrels were then abundant on Little Barrier, but ominous signs were the remains of many killed, Reischek thought by pigs and dogs, and the few young that remained by late April.

By Act of Parliament in 1894, Little Barrier (2817 ha, 722 m high) was purchased by the Crown to become New Zealand's first nature reserve. The first curator, arriving in 1897, killed one dog and several pigs during his first year (Mueller 1897) but feral cats persisted, though destruction of them had high priority. Drummond (1907) reported that cats were the only predator remaining. A notable effort was that of L. Hardgrave, who killed 360 cats and c.6000 Polynesian rats, or kiore *(Rattus exulans)*, during his 11 years' residence up to 1944 (Hamilton 1961).

From 1945 to 1954 there was an increase in studies of the fauna of Little Barrier. In December 1946 Sibson (1947) made observations on the calls and behaviour of Black Petrels. Both he and Parkin (*in* Turbott 1947) reported corpses, possibly cat-killed, on The Thumb. On 25 and 28 June 1947, J. W. St Paul found recent headless remains of eight fledglings cat-eaten on the Thumb-Summit track and on Tirikakawa Ridge (McKenzie 1948). From 30 December 1947 to 2 January 1948, a party observed incubating birds near the Summit and took a few measurements of eggs and wings (Sibson 1949). In November 1948, more remains were found on the high tracks (McKenzie 1950). During November-December 1949, five corpses were found, four on Thumb track (Dawson 1950). In May 1954, Edwards (1954) found four decomposed headless corpses, which he misidentified as Grey-faced Petrels *(Pterodroma macroptera gouldi)*, on Thumb and Summit tracks.

Between 1963 and 1971, Lois G. Bishop (later Wagener) and Sylvia M. Reed, accompanied by other Auckland members of OSNZ, made occasional studies of Black Petrels along the Thumb-Summit ridge and banded 12. However, their efforts were greatly handicapped by the growing scarceness of these petrels.

In 1968-69 the Wildlife Service tried to rid Little Barrier of cats. Feline enteritis virus was introduced and greatly reduced cat numbers (G. P. Adams, Internal Affairs Dept. files). Trapping killed another 130 cats, but the operation foundered for lack of staff and money.

My study began in 1971 as part of a Wildlife Service survey of potentially endangered birds in New Zealand. Studies of the status of the Black Petrel and Cook's Petrel *(Pterodroma cookii)* had high priority and could be done concurrently.

METHODS

The main study area extended from near the junction of Thumb and Summit tracks to beyond the Summit (Fig. 2 & 3), except for an isolated burrow by the Summit track at 490 m, which I checked only when passing from or back to the base hut at intervals of 2-5 days.

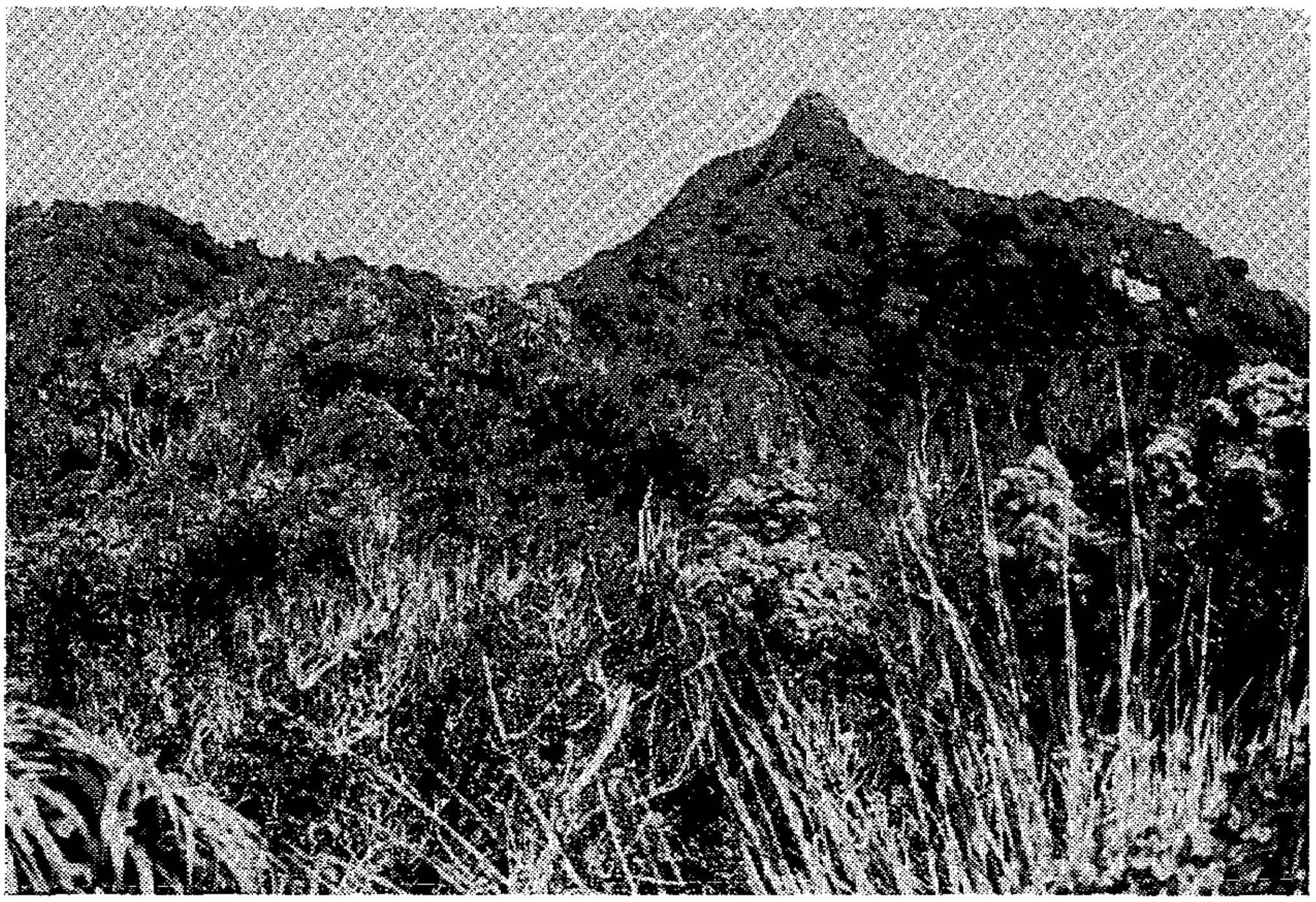

FIGURE 2 — Little Barrier Island: view from the summit towards The Thumb (W-SW). The study area extends from the foreground to the left distance. Camp was on the knoll at left.

FIGURE 3 — Plan of the study area on Little Barrier Island. Study burrows are numbered. Black circles: burrows disused throughout 1971-1983. Crossed circles: burrows in use in 1971 but becoming disused by 1983. Open circles: burrows in use throughout 1971-1983 (but two possibly disused briefly). Not all disused burrows are shown.

In the main study area I regularly examined 22 burrows through observation holes opening into the nest chambers and sealed with rock slabs. These 22 were about half of the Black Petrel burrows still recognisable in that area, but many of those not studied were disused. I assessed breeding success in the non-study burrows of the main area by external signs or by probing with a stick late in the breeding season.

Study periods were as follows. **1971-72:** 2-12 Nov, 22 Feb-9 Mar, 4-18 May. **1972-73:** 30 Nov-16 Dec, 16-25 Feb, 13-24 May. **1973-74:** 31 Oct-11 Nov, 15-22 Dec, 4-17 Feb, 11-21 May. **1974-75:** 18-27 Mar, 2 May. **1976-77:** 26-31 Mar. **1978-79:** 17-23 Mar. **1981-82:** 1-3 Apr. **1982-83:** 16 Jan. No visits were made in 1975-76, 1977-78, 1979-80 and 1980-81.

Beyond the main study area my assistants and I explored the main ridge westwards to and including The Thumb and eastwards to Kiriraukawa in May each year of 1972-74, and in March and partly in May 1975. During this survey we looked for corpses, banded and weighed fledglings, and noted whether burrows were used or disused. By means of this survey, we could compare events in the main study area to see that we were not disturbing the petrels unduly or affecting the intensity of cat predation.

I aged the corpses (adult or fledgling) by means of the skull and primary tips. Cats ate most fledgling skulls, discarding the bill, but they could not crush adult skulls. A skull could usually be aged by its bill plates: ivory tinged grey in fledglings and pale greenish-yellow in adults. The tips of the outer primaries were sharp-pointed and black in fledglings but more rounded, often slightly notched, and faded in adults.

During visits between October and March of 1971-74 we spent more time daily on 50 study burrows of Cook's Petrel, but on other visits we worked mainly on Black Petrels. We inspected study burrows in daytime. Occasional night work was done between the Summit and The Thumb to observe behaviour and band petrels. We banded all birds caught, and we colour-banded adults (green-male, black-female) in study burrows if one of a pair was sexed by cloacal inspection soon after laying. We routinely screened study burrow entrances with twigs or leaves.

Dimensions of eggs and all weights are given as range, mean and standard deviation.

The breeding population on Great Barrier Island was surveyed from 15 to 21 March 1977 and from 30 March to 14 April 1978. The same methods were used as in the extended survey on Little Barrier.

RESULTS

Calls

Although Reischek (1886) stated that Black Petrels make a call similar to that of Black Swans *(Cygnus atratus)* as they fly over their colonies, he seems to have been mistaken. Apparently he heard these calls in the Waitakere Ranges, where Black Swans often fly at night between Manukau and Kaipara Harbours (M. J. Williams, pers. comm.) and may have already been doing so in 1884. Sibson (1947, 1949) noted that these petrels are silent as they fly over Little Barrier, and I agree.

As noted by Sibson (1947), the main call is a staccato, rapid *clack, clack, clack* given from just inside the mouth of the burrow or from the ground outside. Although Sibson heard the call "from several directions" in one night in 1946, I heard it only four times in over 60 nights in the study area from November to March. On Great Barrier we heard this call every night in March, but in 1978 we did not hear it after the early morning of 3 April. This call seems to advertise that the calling bird owns a burrow or other nest site and wants a mate. Although males seem more successful than females in replacing lost mates (Table 1, but sample small and not statistically significant), I do not know whether only the males make the advertising call.

TABLE 1 — Remating success of sexed Black Petrels that lost mates on Little Barrier Island, 1972-1975

Sex	N widowed or divorced	N new mates attracted	N abandoning their burrow
Female	5	1	4
Male	6	3	3

A subdued variation of this call is sometimes duetted when the pair meets in the burrow, perhaps as part of a greeting ceremony. I have heard this call in the courtship period and during the changeover of a pair incubating an infertile egg beyond the normal period.

Chicks, when older than about 2-3 weeks, utter a honk or snort which has a startling effect, even when one expects it. Amplified in the nest chamber, it suggests a larger animal, thereby perhaps repelling an intruder.

Nest site

On Little Barrier all nests were in burrows 1-3 m long in the peaty soil of the ridge tops, or under tree bases, or in banks. Through generations of use they were often very spacious. I saw no new burrows dug. Although nests were as often below the level of the entrance as above it, all nest chambers remained dry, except for two after several days of torrential rain. Nests were not raised, but White-chinned Petrels *(Procellaria aequinoctialis)* do so only in wet places (Imber 1983).

On Great Barrier a greater range of nest sites was in use. As well as burrows, nests were in and under hollow logs and in cavities under banks and among tree roots. The most exposed nests had no live chicks, however.

It was evident on Great Barrier that the breeding population was closely linked to virgin forest. During 1920-1935, large areas of kauri *(Agathis australis)* forest were logged and the remaining brush was burned adjacent to the high central ridges where Black Petrels now breed. The fires destroyed the peat, old logs and bases of mature trees – all actual or potential nesting habitat for these petrels. However, rather than having a relict fire-induced distribution, the breeding population may actually have increased this century on Great Barrier and spread within unmodified forest, where I saw evidence of apparently new burrows being dug.

Other occupants of burrows

A Sooty Shearwater *(Puffinus griseus)* was found once in a disused study burrow. One burrow in the survey area was also used by Brown Kiwis *(Apteryx australis)* but apparently mainly when not in use by petrels. In the winter of 1973 a first-year cat died in a study burrow.

After several years of disuse, fallen leaves and root growth begin to fill the burrows. Then Cook's Petrels may take them over, sometimes extending them and filling the surplus space with their diggings. On The Thumb in 1945, P. C. Bull (pers. comm.) found only Black Petrel burrows. Now Cook's Petrel burrows, some obviously having belonged to the larger species, outnumber them there.

Return to the colonies

Turbott (1947, 1961) reported Black Petrels absent between 1 and 10 October 1945. During a faunal survey of Little Barrier beginning on 24 September 1975, the first sign was a fresh cat-kill on 10 October (D. Sutherland, pers. comm.). At my earliest inspection date, 1 November, many had already reoccupied their burows. Late breeders may not return until December, however.

Courtship and the prelaying exodus

Courtship activity was studied on 1-11 November 1971 and 1973. In burrows where an egg was subsequently laid, no bird was present on 59 of 68 burrow-days, the male was there on 6, and the pair on 3. Some birds also visited at night but did not stay till next day. Males spending a day or two alone at the nest were sometimes joined by their mate next day. One male, whose mate did not return, spent 31 October-4 November and 8-9 November in his burrow and, after 12 November-14 December when I was absent, was apparently visiting almost nightly between 15 and 22 December. His burrow was not used in following years.

Apparently it is mainly the males that effect the mating rendezvous by frequent visits to or attendance at the burrow. Females seem to make only occasional visits at night, rarely staying by day, until they meet their mate again, but then spend at least a day with him at the nest, when presumably they copulate.

The prelaying exodus of female and male follows immediately. During early December 1972, I observed 10 burrows over 123 burrow-days within 24 days to laying. When the pair had gone there were no visits, even at night, until the female arrived to lay or the male to incubate. Although no prelaying exodus was timed directly, I calculated some by using hatching dates and the incubation period to estimate laying dates. Thus, three females were absent for about 22, 23 and 23 days and another four were absent for at least 21, 22, 23 and 24 days. So the exodus may average 23 days for females but 24 days for males (see the section on incubation below).

Because laying extends over such a prolonged period, the exodus does not occur *en masse*, as in some shearwaters.

Laying

Females laid within 12 hours of their arrival. The distribution of laying dates for 15 females in 1972 and 8 in 1973 (Fig. 4) shows two peaks in 1972,

but the late peak seems to have been unusual, judging by observations of chick development on Little Barrier in early 1972 and on Great Barrier in 1977 and 1978. Although 20 November to 25 December seems the main laying period, the full period is much longer. For example, one chick which I found on Great Barrier on 2 April would probably have departed by 15 April; calculation backwards indicates that the egg would have been laid about 10 November. There are several records of fledglings departing in July (Bell 1976; T. A. Caithness, pers. comm.), and a fledgling in full plumage was still on Little Barrier on 21 July (T. G. Lovegrove, pers. comm.). This chick would have come from an egg laid in late January. These dates confirm Reischek's (1886) indication of an extended laying period.

Dimensions (mm) of nine eggs, seven measured in this study and two by Sibson (1949), were length 65.8-72.0, 69.3, 2.17 and width 46.8-54.2, 50.5, 2.10. The weights (g) of nine eggs the day after laying were 88.7-108.5, 98.8, 7.47. Five females within 12 hours after laying weighed 714-791 g, 747, 29.8. The ratio of their egg to body weight was 0.13. In White-chinned Petrels this ratio was 0.13 for three females (Imber 1983).

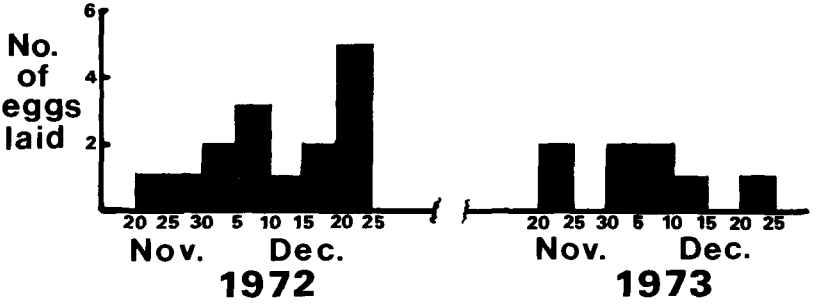

FIGURE 4 — Distribution of laying dates in study burrows on Little Barrier Island in 1972 and 1973

Incubation and hatching

The start of incubation was observed 10 times. Males took the first main shift. Four males returned first and awaited the female (for up to 3 days), both of one pair arrived on the same night, but five females had to start incubation (for 1,2,3,4 and 13 days). Thus, the prelaying exodus of males averaged one day longer than that of females, and the first incubation shift by females (including nil shifts) averaged 2.3 days. Two pairs were present during the day after laying, but I did not see this happen at any other time during incubation or chick-rearing.

Because few pairs were under observation and because the laying period and main incubation shifts were long, I did not time any complete shifts. I used weight changes during incubation (below) to calculate lengths of main shifts. The longer incomplete shifts noted were: first main shift (males) 17, 14, 11, 10 and 4 of 8 days; second main shift (females) 8 and 7 days; third main shift (males) 9 days. Females took the final incubation shift, including

hatching, in seven out of eight pairs. This shift lasted 3 days (one complete shift) and at least 2-4 days (six probably incomplete shifts). Eggs pipped 2-4 days before hatching.

The only incubation period I timed was 56.5 days. By comparison, those of two White-chinned Petrel eggs were 57 and 58 days (Mougin 1971).

I saw egg neglect only once. A male, weighing 55 g less than the lightest male beginning to incubate, arrived 3 days before the female laid but did not stay till she laid. She incubated for only 3 days, despite being the heaviest female weighed at laying. Her departure was probably caused by a brief visit by the male the fourth night. Five days later the male was again present but not incubating, and he left next night. Observations ceased next day. The male may have been too immature to incubate, although old enough to mate. The following year this pair hatched their egg.

The fertility rate of 66 eggs, by candling with sunlight, was 92.4%. Infertile eggs were incubated well beyond normal hatching time, at least an extra 15 and 17 days in the two cases measured. They were then usually expelled from the nest.

I found little evidence of eggs being eaten by kiore. Because incubation is normally attentive, these rats would have had few chances to take unprotected eggs. Further, the size and thickness of the shell of these eggs could have impeded kiore.

Weight changes during incubation

To incubate for long periods, birds put on considerable weight (Table 2). From the weight change through incubation and the rate of weight loss in males (Table 2), the length of shifts can be calculated. Males would have incubated for an average of 17-18 days in their first shift. Females would have incubated for about 16 days in their main shift, if their rate of weight loss was similar to that of the males, but I did not collect enough female weights for analysis.

The weight loss in five incubating males, as a percentage of initial weight, was 1.13% per day. One male was weighed during incubation in successive years. From 893 g on day 2 of his first shift in 1972 he lost 9.5 g/day over the following 13 days. From 972 g on day 2 of his first shift in 1973 he lost 12.0 g/day over 6 days. Perhaps weight loss is greater when the initial weight is heavier. Because of defecation, weight also declines more quickly at the start of a shift.

Chick-rearing

I observed eight chicks for a total of 56 chick-days during their first 10 days of life. Mothers were present 15 times, fathers 21 times, and the chick was alone 20 times. Thus, chicks were attended on 65% of these early days. There was no set pattern to parental attendance, but chicks were rarely alone during the first 2-3 days; usually mothers were present then and fathers afterwards. One mother, however, returned after only 4 days. Even those chicks which were alone by day during their first 10 days were being fed on 50% of nights. Thus there was much activity of breeders coming and going at that time (mainly February).

TABLE 2 — Weights (g) of female and male Black Petrels during courtship and at the beginning and end of their incubation shifts, and rate of weight loss during incubation in males

	Females				Males			
	N	Range	Mean ± SD		N	Range	Mean ± SD	
Courtship	8	587-791	682	57.4	9	620-855	723	77.1
Beginning of main incubation shift*	3	830-852	841	11.0	6	818-989	883	63.2
End of main incubation shift*	1	-	<690	-	5	631-756	709	48.0
Incubation weight loss								
Interval (days)	-	-	-	-	5	6-13	7.8	-
Weight loss (g/day)	-	-	-	-	5	8.7-12.0	9.9	-

*First shift of males

At about 1 month of age, chicks were being fed on 38% of nights (10 chicks studied over 82 chick-nights), which is about three feeds every eight nights. Parents still occasionally stayed with their chick by day. The mean weight of 12 feeds was 120.6 g (range 89-167 g, SD 22.34), making allowance for the weight loss of 28.8 g/day determined from four chicks not fed over 14 chick-days. Already chicks could take a great deal of food: one chick that was fed by its father one night, by both parents next night and by its mother on the third night increased from 385 g to 810 g.

Chicks attained maximum weights in April and May. Between 1 and 14 April 1978 on Great Barrier, 59% of 63 chicks weighed more than 1000 g. Between 4 and 17 May in 1972 and 1973 on Little Barrier, 26 chicks had an average weight of 947 g (range 725-1278 g).

Departure of chicks

Departures extended from mid-April to late July, but were rare in April and July. The mean fledgling period of six chicks was 107.3 days (range 96-122 d, SD 8.43). Departures tended to be at a peak around 20 May. Many chicks still weighed 900-1000 g when fully feathered but did not leave the island until their weight had declined. The estimated weight at departure of three chicks was 725, 752 and 794 g (average 757 g), which is above the average adult weight during courtship (704 g). No chick suspected as having flown still bore down when last seen.

Chicks received substantial meals to within 12 days of departure, and so I am not sure that there is a desertion period. One chick received 168 g of food 12 days before leaving; another, 96 g 8 days before leaving. It was difficult to detect parental visits in the last week because chicks may have taken little or no food, and their emergences made screening of burrows unhelpful. At this stage chicks were losing weight at 15.6-19.0 g/day. One chick was visited by a parent when I considered its departure overdue, but it had not been weighed.

Nocturnal observations and signs at the burrow mouth (down, defecations, regularly disturbed screens) showed that many chicks were emerging 10 nights before they would leave the island. On the surface they exercised their wings, searched for take-off points (a tree, bluff or high point providing a clear horizontal flight path), or merely sat and rested. I saw a chick climb a leaning, fern-clad tree until level with an opening in the canopy about 25 m away. It flapped vigorously, rising off the trunk, rested and looked about, then flapped again, repeating this for 15 minutes. Then it flew towards the opening but crashed into a branch. I searched the crash site but found nothing. Then I went to its burrow 30 m away and found that it had already returned there. It left later that night. Fledglings lacked adults' knowledge of good take-off points. For example, many breeders from one group of burrows used one stunted tree for take-off in certain winds, involving a walk of at least 50 m for some of them.

This long period spent preparing to leave made chicks very vulnerable to predation by cats. One fully feathered but heavy chick found outside its burrow on 4 May had not left on 12 May and was killed by a cat within the next three nights.

Breeding success

Predation by cats (Fig. 5) was the main cause of breeding failure (Tables 3, 4). The 1971/72 breeding season was initially very successful with 81% of eggs in the study burrows resulting in fledglings. Only 1% of adults and 6.7% of nestlings were killed by cats, but cats killed about 67% of fledglings once they began emerging. The reduction of cat numbers in 1968/69 probably did much for this relatively successful breeding season.

The 1972/73 breeding season was much less successful. The peak of laying in the study burrows was about two weeks later than in the previous year. Fewer eggs hatched (82.4% against 93.8%) and more chicks died (21.4% against 6.7%), but again cats were the main cause of failure. More chicks were killed on the nest (28.6% against 6.7%), and probably all of those emerging were killed. By 24 May 1973 no chicks had left the study area and only three were still alive: two had just begun emerging and the third was downy and seriously underfed. Cats were killing all emerging chicks at that time, and so these three probably did not survive. The number of adults killed by cats also increased (Table 4). That cats were numerous on Little Barrier at that time is shown not only by the damage done to the Black Petrels but also by the 72 cats killed by E. and B. Wisnesky in the preceding (1972) winter.

In the 1973/74 season, six breeders of the previous season did not return to their burrows. Most had probably divorced their mates because at least three had had their chick killed on the nest in the previous season. Predation of chicks both on the nest and on the surface continued at such high levels that less than 5% of pairs had their chick leave the island. Predation of adults, mainly late in the breeding season, was also still increasing.

In 1974/75 at least 28% of the study adults were killed by cats. Unlike previous seasons this predation occurred throughout the breeding season. In addition, cats killed all of the few chicks reared, mainly at emergence. The extended survey revealed the same everywhere (Table 4).

I did not visit Little Barrier during the 1975/76 breeding season. The cats had left so few breeding pairs intact that I had little to study, and the main purpose of the investigation (to report on conservation of Black Petrels) had already been achieved (Imber 1975). Observations by D. Smith, D. Sutherland and C. R. Veitch (pers. comm.) show that predation of adults and, later, chicks continued throughout the 1975/76 breeding season.

My survey of study burrows in March 1977 showed that only six pairs were present, compared with 18 pairs in 1971/72 and 1972/73. These remaining pairs may have reared up to four chicks that season, and one certainly fledged successfully because it later returned to breed. I found no sign of cat predation in the study area, but the extended survey showed that at least two chicks had been killed on the nest. From the very few petrel remains I saw then, it appeared that cat numbers had fallen greatly over the preceding two years. However, the restricted trapping and poisoning of cats in 1975 and 1976 probably was not the only cause of this. A second epidemic of feline enteritis may have occurred when cat numbers peaked in 1975.

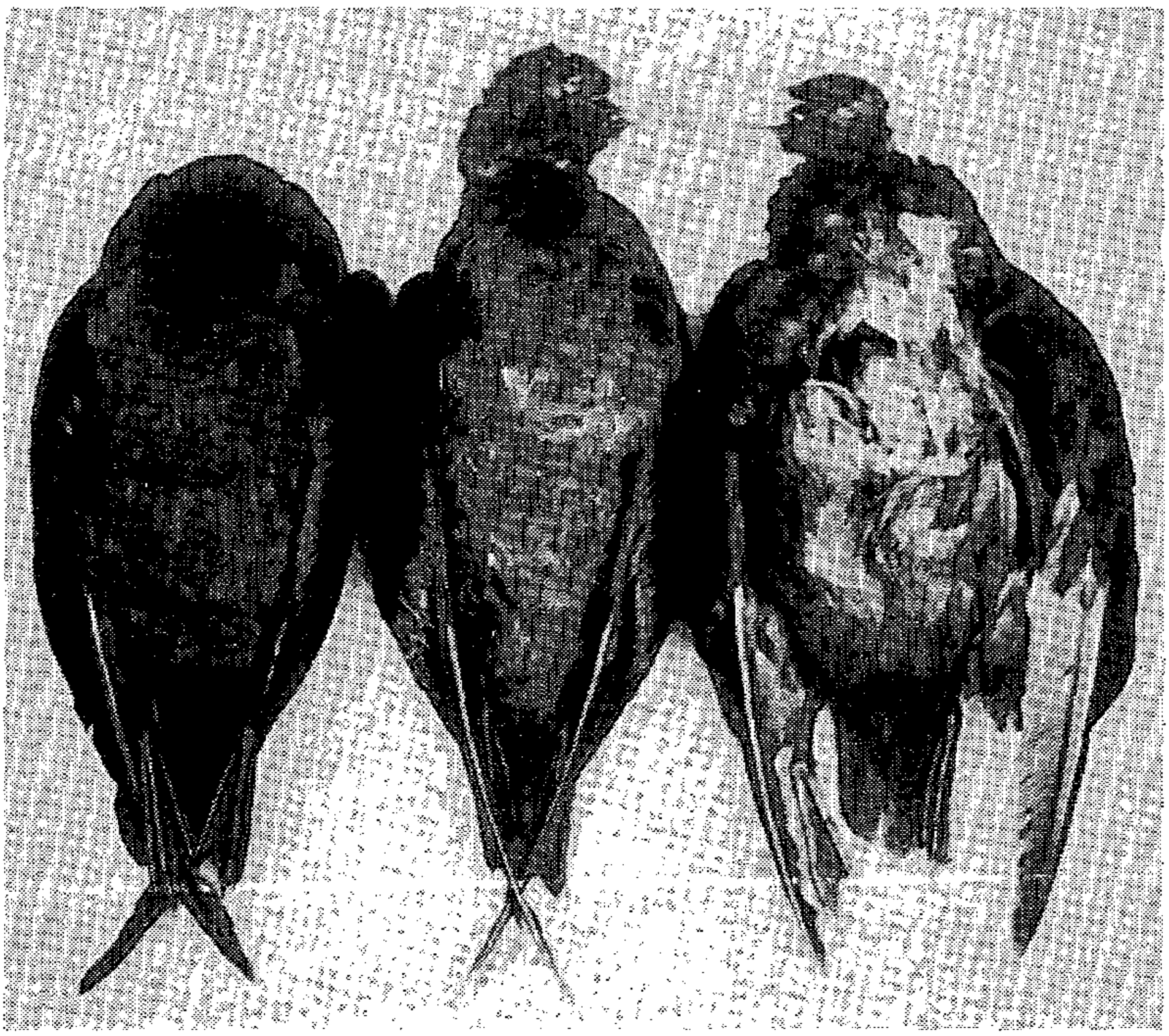

FIGURE 5 — Cat-killed Black Petrels, Little Barrier Island, May 1972. Left: fledgling beheaded by cat, only neck and skull eaten, as often occurred that year when the ratio of fledglings to cats was relatively high. Centre: Adult female (now a skin in the National Museum) showing russet belly because of worn plumage. She had been attacked by a cat and escaped but died just inside her burrow, her skull punctured by one of the cat's canine teeth. Right: fledgling partly eaten by cat, skull intact.

TABLE 3 — Breeding success and status of the 22 study burrows of Black Petrels on Little Barrier Island, 1971-1983

	1971/2	1972/3	1973/4	1974/5	1976/7	1978/9	1981/2	1982/3
Burrows in use	21	21	19	15	8	7	7	7
Birds using these burrows	39	39	33	25	14	13	12	12
Adult deaths at sea or divorces	1	6	1	1	?	?	?	?
Adults known killed by cats	0	1	2	7	0	0	0	0
Eggs laid	16	17	10	7	5	6	4	4-5
Eggs hatched	15	14	9	5	5	6	2	3?
Chicks killed on nest by cats	1	4(+)	3	1?	0	0	0	0
Chicks killed on surface by cats	7-8	5-7	4	3	0?	0	0	0
Chicks departing	5-6	0-2	1	0	4?	5	2	?
Minimum % of adults + chicks cat-killed	16.7	22.6	21.4	35.7	?	0	0	0

TABLE 4 — Results of surveys of Black Petrel burrows on Little Barrier Island from west of The Thumb to Kiriraukawa in May 1972-1974 and March and May 1975 (includes the study burrows)

	1972	1973	1974	1975
Burrows inspected	107	81	111	117
Burrows in use	98	*	85	<90
Chicks killed by cats	40-50	24+	34+	c.27
Adults killed by cats	2	6	10	37+
Chicks probably departed	c.22	0-5	1-2	0

*Not recorded

A full-scale campaign to eradicate the cats began in 1977 (Veitch 1980, 1983). In 1978/79 six pairs still occupied the study burrows. Their numbers, although low, were stable from 1977 to 1979 as the campaign against cats took effect, and also as a likely result of the eradication efforts in 1968/69. That campaign led to breeding successes in 1972 (Table 4) and probably also in 1970 and 1971. Allowing 6-7 years for the chicks to return to breed, some of those chicks should have entered the breeding population during the 1975/76 to 1978/79 seasons, thus checking the decline. In March 1979 I saw corpses of Cook's Petrels only, but a few Black Petrel fledglings were killed later by cats (Veitch, pers. comm.). At that time at least 40 cats were still on Little Barrier, but these were killed in 1979 and 1980 (Veitch 1983).

The study population reached its nadir in 1980/81 when only six burrows were used by 11 adults. The numbers breeding had declined because of the few chicks surviving the 1972/73 to 1975/76 breeding seasons. In 1981/82 and 1982/83 it seemed that the population was stable.

Breeding frequency

Established pairs laid an egg every year unless the pair bond was disrupted by death or divorce. Rearing a chick to fledging, however, seemed to hinder most pairs from doing the same in the following year, except for the earliest breeders. Presumably, the later a pair is involved in chick-feeding, which can be as late as mid-winter, the harder it is for them to return early enough or in satisfactory condition for the next season. For example, the pair in burrow 14 reared a fledgling in 1971/72 (egg laid 5 December) and in 1972/73 (egg laid 21 December), but in 1973/74 (egg laid 21 December) the chick was seriously underweight at 86 days old, when cats killed it and its mother. Of 10 pairs that reared fledglings in 1971/72 and bred again in 1972/73 without interference by cats, only five again reared fledglings. Among the five pairs that failed, one had an infertile egg, two failed before or near hatching, the chick of one pair died, and one pair reared a very light, late chick (691 g at 93 days and still very downy). Eggs of the five repeatedly successful pairs were laid between about 20 November and 5 December in 1971/72, except for one female that laid about 25 December in both years.

One female consistently laid earliest in the study burrows (usually by 25 November), and this pair reared a fledgling in every year studied except one (infertile egg) from 1971/72 to 1978/79.

Return of young birds and age at first breeding

The only chick recaptured on Little Barrier was reared in 1976/77 and was incubating a pipped egg on 16 January 1983 about 20 m from its natal burrow. A chick banded on Great Barrier on 14 March 1972 by R. M. Lockley was recaptured there on 17 March 1977 while it was 'clacking' near the entrance to a short burrow, quite late in the period of activity for non-breeders. In April 1978 its burrow had a fresh nest but no chick. Thus, some chicks return at 5 years and some breed at 6 years.

On Little Barrier the shortened life expectancy until recently of breeding adults and their pair-bonds, and the small prebreeding part of the population, may have caused a heavy demand for any returning young birds to mate with surviving breeders. Therefore, breeding may begin when birds are younger than they might be in a self-regulating, undepressed population.

Longevity and pair-bond stability

On 20 March 1975 I found an adult killed by a cat near the Summit. The bird had been banded near there in January 1963 when it was probably at least 5 years old, making it at least 17 years old at death. A male bred in a study burrow throughout the seasons 1971/72 to 1982/83 and so was still alive at over 17 years. In 1983 he was the only breeder definitely known to be still in my study burrows out of the 33 banded in 1971/72 and 1972/73; three others, including his mate, may also have survived.

Cats destroyed pair-bonds not only by killing the adults but also by killing nestlings, which apparently precipitated divorces. The female left in all three cases of probable divorce where I knew the sex of the remaining partner. Table 5 shows the subsequent effect of breeding success on pair-bonds. Failed breeders were significantly more likely to separate, even when I had allowed for a yearly average natural mortality of adults of 6% (but this was only 2.6% in 1971/72).

TABLE 5 — The effect of breeding success on stability of pair-bonds of Black Petrels on Little Barrier Island from 1972 to 1974

	Chick reared to fledging	No chick reared
Pair together next season	16	6
Pair* divorced next season	0	3

*Allowance made for probable death of some mates

$Chi^2 = 6.061$, $p < 0.05$

A number of breeders disappeared from the study burrows after losing mates by death or divorce. None of these bereaved birds was found in another study burrow or among the few adults caught in non-study burrows. Only

one was among the later corpses. The fate of these birds can only be guessed at, but perhaps some moved to Great Barrier, 30 km away.

Great Barrier Island survey

Breeding of Black Petrels on Great Barrier was not reported until 1964 (Bell & Brathwaite 1964). Until our 1977/78 surveys (Fig. 6), breeding was known only on and near Hirakimata, the summit of the island (Bartle 1967, Reed 1972, Bell 1976). Breeding colonies extend disjointedly from Cooper's Castle in the north (pers. obs.) to Te Ahumata in the south (C. R. Veitch, pers. comm.). Recently an adult, perhaps killed by a dog, has been found near Tryphena, 6 km further south (I. MacFadden, pers. comm.). I found the main breeding areas to be on Hirakimata (Mt Hobson) and the higher ridges radiating from it, around the western end of the ridge separating the north and south forks of the Kaiarara Stream, and on the shoulders of The Hog's Back (Fig. 6).

The surveys showed high breeding success on Great Barrier (Table 6). Black Petrels were using more varied nest sites and shorter burrows than on Little Barrier, where fewer than 50% of nestlings could be reached from the entrance compared with 60% on Great Barrier. This correlates with the very few deaths caused by cats (Table 6). Other evidence of cat predation was the scattered corpses of eight Cook's Petrels. Despite careful searches for burrows around all of these kills, I found only three in the north Kaiarara Valley. Elsewhere, corpses were apparently of prospecting birds landing at random, and so I concluded that very few Cook's Petrels breed on Great Barrier.

I trapped ship rats *(Rattus rattus)* and kiore from near sea level to the summit. Dogs had apparently dug open at least two burrows, although I found no evidence that petrels had been killed. Wild pigs' rooting was seen near one group of burrows. Mustelids are not known on Great Barrier. It is illegal to introduce them, but further liberations of noxious animals will always be a potential threat to petrels on this 300 km^2 island, with nearly 1000 inhabitants and many visitors.

The number of Black Petrels

The Black Petrel is known to breed only on Little Barrier and Great Barrier Islands. Little Barrier has 50-100 breeding pairs (Fig. 7). On Great Barrier we found about 175 burrows probably used by breeding pairs but, in such places as The Hog's Back, our survey was merely a transect of the breeding area. I estimate that Great Barrier has 500-1000 breeding pairs.

There are few non-breeders from Little Barrier, but from Great Barrier, with its high productivity and with young birds not breeding for at least 6 years, there may be nearly 2000 non-breeders. The total would then be 3000-4000 birds.

DISCUSSION

Comparison with breeding biology of White-chinned Petrels

Mougin (1970, 1971, 1975) studied White-chinned Petrels breeding on the Crozet Islands. In those aspects of Mougin's and my study that are comparable, I noted two major differences. Firstly, many more prospecting

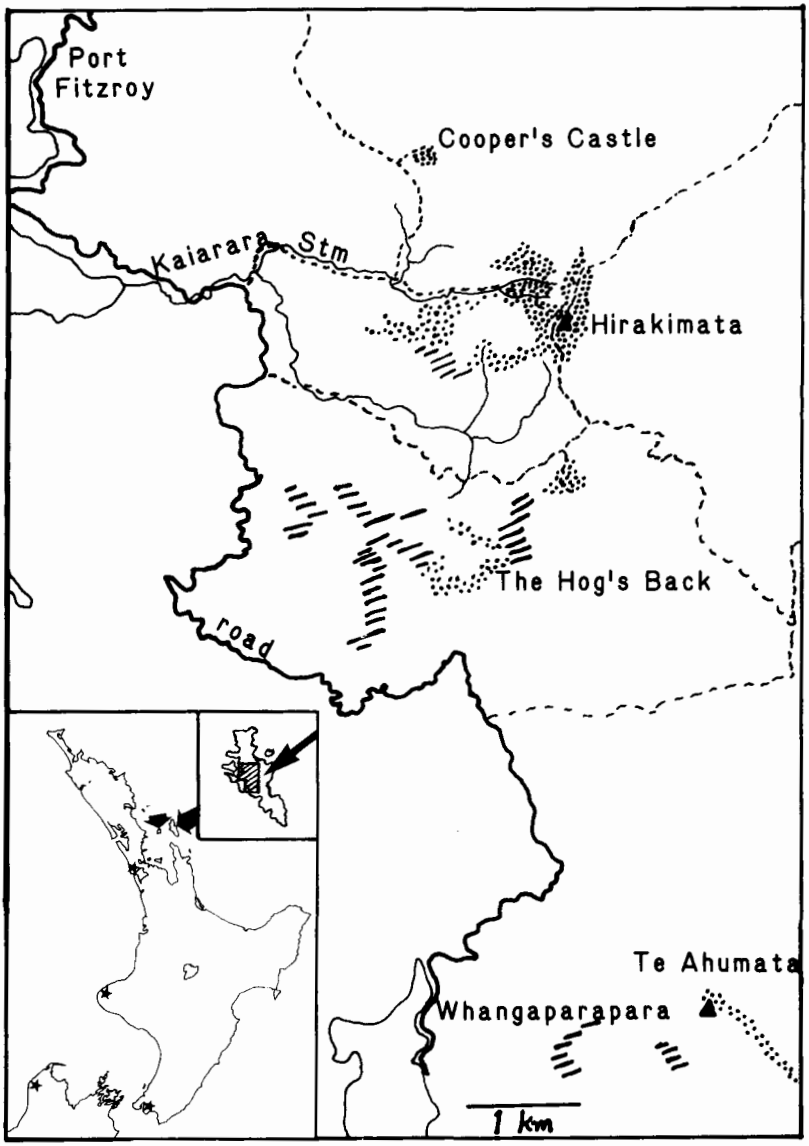

FIGURE 6 — Distribution of Black Petrels on Great Barrier Island in 1977-78. Solid line: unsealed road. Dashed line: walking tracks. Dotted areas: known or inferred distribution of breeding Black Petrels. Cross-hatching: additional, unexplored areas (virgin forest) that may hold burrows. Inset: northern New Zealand showing existing breeding places of Black Petrels (arrows) and former breeding sites (stars).

TABLE 6 — Breeding success two-thirds of the way through chick-rearing in Black Petrel burrows surveyed on Great Barrier Island in 1977 and 1978

	1977		1978*	
	N	%	N	%
Burrows inspected	83		188	
Chicks banded	22		64	
Chicks out of reach	18		40	
Empty, used burrows	39		69	
Burrows probably not suitable for breeding	4		15	
Breeding success at that stage+		50		60
Predated adults	1		0	
Predated chicks	0		1	
Eggs apparently eaten by rats	2		5	

*Includes most of the 1977 burrows studied

+Chicks per burrows probably having a breeding pair

birds visited Mougin's study burrows than visited mine. More than two birds visited 25% of his burrows in one breeding season and 45% in the next, whereas in my two seasons of most intensive observations (1972/73, 1973/74) more than two visited only one (3%) of my burrows. Even though Mougin made more burrow inspections (almost daily), the difference is likely to be significant. It reflects the healthy balance of breeders and non-breeders on the Crozets, contrasting with the few non-breeders on Little Barrrier.

Secondly, the breeding habits of Black Petrels show the effects of having to travel further for food and having to feed in less productive seas. Apart from some scavenging at ships (J. M. Moreland, pers. comm.), they feed at the edge of, or beyond, the continental shelf (Imber 1976). The shortest distance to the shelf edge from Little Barrier is 60 km north-eastwards, but in some other directions it is much greater because the North Island is in the way. At the Crozet Islands petrels can reach deep water within about 50 km in most directions, and those subantarctic waters are more productive than the subtropical seas well north of the subtropical convergence in which Black Petrels feed (Imber 1976). Notable differences in breeding habits are in the incubation routine and the duration of chick-rearing. Thus White-chinned Petrels incubated through seven shifts averaging 1.8, 11.0, 10.0, 10.3, 8.8, 7.8 and 7.7 days to complete their 57-58 day incubation period, whereas Black Petrels had only five consecutive shifts of 2.3, c.18, c.16, c.16 and c.4 days to hatching. White-chinned Petrels reared their 1000 g fledglings in 96 days (range 91-105 days) compared with Black Petrels' 757 g fledglings reared in 107 days (range 96-122 days).

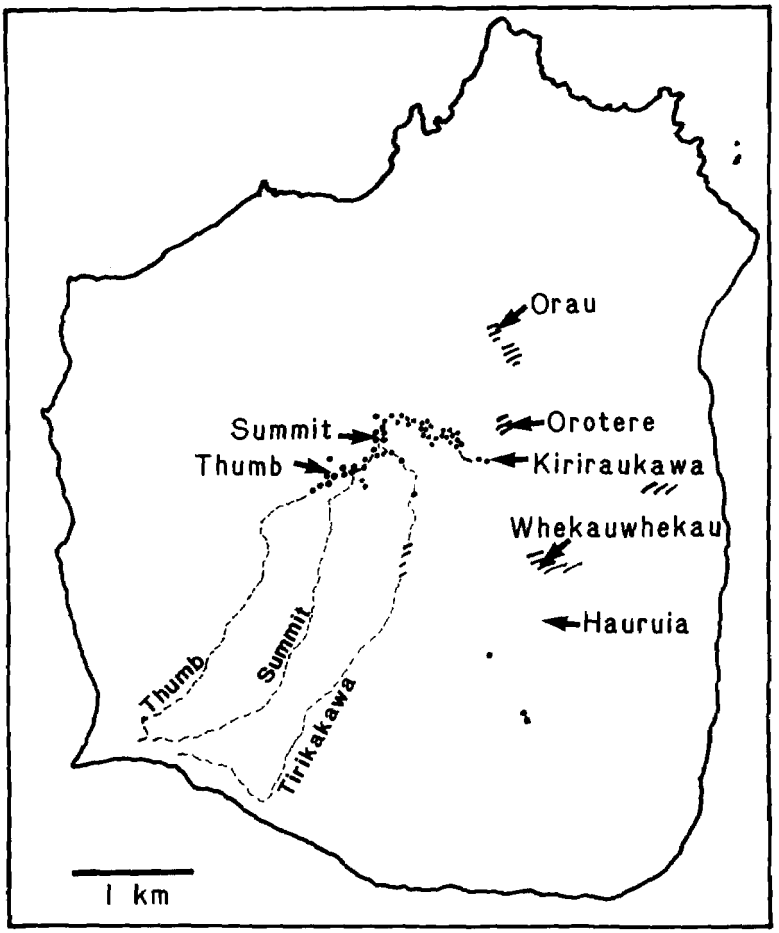

FIGURE 7 — Distribution of Black Petrels on Little Barrier Island around 1982. Dashed lines: walking tracks. Dots: active burrows in areas surveyed by the author. Cross-hatched areas: petrels present (known or reported to author) but actual number and distribution of active burrows not determined. Main peaks are arrowed.

Apparently Black Petrels economise on trips to and from the feeding grounds by feeding and incubating in longer shifts, presumably gaining relatively more weight before incubating than White-chinned Petrels do. Also, Black Petrels may visit chicks less often, bringing larger but more digested meals, possibly containing more stomach oil but less protein. The slower growth of chicks may be the result.

However, there may be an additional cause of the longer fledgling period. The limited data indicate that Black Petrel chicks depart in better condition than those of White-chinned Petrels (Mougin's chicks being lighter than the 1270 g adults). This difference may be related to the trans-Pacific migration of Black Petrels. Perhaps their chicks need adequate fat reserves to supplement poor feeding while they cross the central South Pacific, which is a region of low marine productivity (Shuntov 1972).

Feral cat predation

On Little Barrier cats preyed mainly on Cook's Petrels from October to March (Marshall 1961, Watson 1961), and predation increased in March when chicks leave (C. R. Veitch, pers. comm.; pers. obs.). At other seasons the cats ate kiore, land birds and insects (Marshall 1961, Watson 1961); at higher altitudes they attacked Black Petrels and, along the coastal cliff-tops, Grey-faced Petrels (Sibson 1947, McKenzie 1948).

The evidence shows that it is mainly the very large population of Cook's Petrels on Little Barrier that has been indirectly responsible for the plight of the other petrels. Without these easily caught small petrels (c.200 g), such a large number of cats could not have been sustained. By comparison, cats have a negligible effect on Black Petrels on Great Barrier, where Cook's Petrels are few. Cats fared well on Little Barrier on the very reliable summer supply of petrel food. The abundance of rats and Cook's Petrel fledglings through autumn would have continued to sustain them. But from late April to September, with Cook's Petrels unavailable, they became hungry and began regularly attacking the larger petrels. Coincidently Black Petrel fledglings began emerging. Grey-faced Petrels suffered most because they breed from March to December and are particularly active on land in winter: they may no longer breed on Little Barrier but they have many other colonies. The decline of Black Petrels was more protracted because, except during periods of highest numbers of cats, mainly fledglings were killed. However, the loss of this colony would have been unfortunate because the Great Barrier colony cannot be protected easily.

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