

Feeding frequency, meal size and chick growth in Pycroft's petrel (*Pterodroma pycrofti*): preparing for chick translocations in *Pterodroma* species

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Abstract Many *Pterodroma* species are threatened, and translocations to predator-free islands are desirable for several species. As these birds are highly philopatric, only chicks that have not yet imprinted on their natal colony should be transferred but techniques to identify suitably aged *Pterodroma* nestlings are needed. We investigated feeding frequency, meal size and chick growth in Pycroft's petrel (*P. pycrofti*) on Red Mercury Island, New Zealand to provide this information. Mean daily probability of being fed decreased from 0.47 60-23 days before fledging to 0.004 in the last seven days before fledging. Mean meal size was 34 g and morphometric measurements at fledging were similar to mean adult measurements. The best indicator of chick age was wing length. Transferable Pycroft's petrel chicks should have wings measuring 149 - 184 mm and weigh 218 - 250 g.

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INTRODUCTION

Most gadfly petrels (*Pterodroma* spp.) breed on islands and are prone to extinction through catastrophic events or introduced mammalian predators (Priddel & Carlile 1997; Probst *et al.* 2000; Zino *et al.* 2001), and many species are now extinct in large parts of their former range (Taylor 2000). Conservation actions for the 21 threatened *Pterodroma* species (Stattersfield & Capper 2000) include eradication or control of introduced predators, in particular rats (*Rattus* spp), regulation of human activities in breeding areas, and habitat protection and restoration. However, establishment of new breeding colonies by translocation to predator-free islands or predator exclosures is the primary option for several species (Taylor 2000; Priddel & Carlile 2001). Translocation has been used successfully for the recovery of many land birds and in New Zealand more than 400 translocations of various taxa have been undertaken (Armstrong & McLean 1995).

Most seabirds, and petrels in particular, are highly philopatric (Warham 1990) and many

seabird translocations have failed due to the transfer of chicks that were already imprinted to their natal site (Priddel & Carlile 2001). Although the imprinting mechanism is not fully understood, it seems that in burrow-nesting petrels young birds develop natal site attachment in the days preceding fledging after they first emerge from their burrow to explore their surroundings (Warham 1990). It has been suggested that the orientation process may begin while chicks are still in their nests (Serventy *et al.* 1989).

Selecting nestlings for transfer requires knowledge of chick growth, feeding frequency and meal size in the target or a closely related species. However, few such studies have been conducted for *Pterodroma* species. The most complete such study was that of Priddel & Carlile (2001) who transferred nestling Goulds petrels (*P. leucoptera leucoptera*) from their natal nest sites to artificial nest boxes 150 m from their natal colony. They established the feeding frequency and meal size towards the end of chick development and determined a method to age chicks based on plumage development.

Pycroft's petrel (*P. pycrofti*) is endemic to New Zealand. Like most species in the genus it is a burrow breeder and nocturnal on land (Marchant

& Higgins 1990). The birds have a long breeding season, laying in late November, and fledging from mid-March to mid-April. Parents forage offshore, probably far from land, and chicks commonly experience fasting periods of several days.

In this study, we sought to measure changes in meal size and feeding frequency of Pycroft's petrel chicks as they developed towards fledging and to monitor their growth, thereby providing information that may be used when planning transfers of this and other *Pterodroma* petrels.

STUDY SITE AND METHODS

Study site

The study was conducted on Red Mercury Island (Whakau) (36°S, 175°E), the second largest (220 ha) and easternmost of the Mercury Islands, c. 6 km off Coromandel Peninsula, North Island, New Zealand. These islands are of volcanic origin and were joined to the mainland until 8,500 – 10,000 years ago (Towns *et al.* 1990). Red Mercury Island is 2.6 km at its widest part, and rises to 154 m above sea level. Like most of the larger islands in the group, it has been modified by human habitation, introduced Pacific rats (*Rattus exulans*), (now eradicated) and periodic burning. The last major fire occurred in the 1930s and the vegetation is now characterised by second-growth species. On the slopes and ridges, mapou (*Myrsine australis*), mahoe (*Melicytus ramiflorus*) and hangehange (*Geniostoma ligustrifolium*) are the dominant species, while in the valley and around the coast the canopy is dominated by pohutukawa (*Metrosideros excelsa*). Modification of the soils by Pycroft's and grey-faced (*Pterodroma macroptera gouldi*) petrels might be responsible for the poor development of the sub-canopy in some places (Lynch & Ferguson 1972). Pycroft's petrel burrows can be found almost everywhere on the island, but predominantly in two colonies, Roly-Poly Bay and Von Luckner Cove, the latter being the biggest.

Methods

Data were collected between 15 January and 26 March 2001. By 15 January all fertile eggs had recently hatched, and a majority of chicks had fledged by 26 March.

Study and control birds

Between 16 and 20 January we randomly selected 30 recently hatched chicks in the Von Luckner Cove colony. These birds were, thereafter, weighed daily. Between 20 and 26 January, another 50 chicks were found, 20 of which were weighed every second day and 30 chicks of which served as a control group to assess the potential effect of handling on survival and development of nestlings. The control chicks were weighed on 29 January, and again on

15 March when their wing length was also measured. Five of the chicks initially weighed every second day were randomly selected and reassigned to the daily weighing group after a flood drowned five of the main study chicks.

Monitoring of adult visits and emergence of nestlings

Toothpick palisades were erected just inside the entrances of all study burrows so that birds could not enter or leave without displacing them. From January until early March, before chicks first ventured out of their burrow, displaced toothpicks indicated that at least one adult bird had visited the burrow overnight. From the second week of March, displacement indicated either the visit of an adult, or that the chick had been outside the burrow. Each time a palisade was found displaced, it was re-erected.

Meal size and feeding frequency

Chicks were weighed between 0900 h and 1300 h from 18 January until they fledged, or until 26 March, to determine if they had been fed the previous night. All were weighed to the nearest 2 g or 5 g, using 300 g or 600 g Pesola scales respectively. An overnight weight increase indicated the chick had been fed, nestlings found to have the same weight as the previous day were assumed not to have been fed. On 1-2 February, 15-16 February and 3-4 March, 10 chicks known to have been fed that night were randomly selected from the study group and weighed at approximately 2300 h, then at 3 h intervals for the following 24 h, to determine the rate at which weight was lost during the 24 h following feeding. We then estimated the meal size by adding the mean weight loss in the 12 h following the meal to the overnight weight increase.

Morphological traits

Tail, bill and tarsus lengths of all 50 study chicks were measured at 6- to 8-day intervals in January and February and at 4- to 6-day intervals in March. Wing length was measured at 6- to 8-day intervals from mid-February to early March, then at 2- to 4-day intervals after the first week of March. Tarsus and bill lengths were measured to the nearest 0.1 mm with vernier callipers, wings and tail were measured with a ruler to the nearest millimetre. All measurements followed the protocols described by Marchant & Higgins (1990).

Fledging

Burrows were visited every day to check for the presence of chicks. Any fledgling no longer present in its burrow was considered to have fledged if it was previously fully feathered and in good health. The date of fledging was taken as the last day on

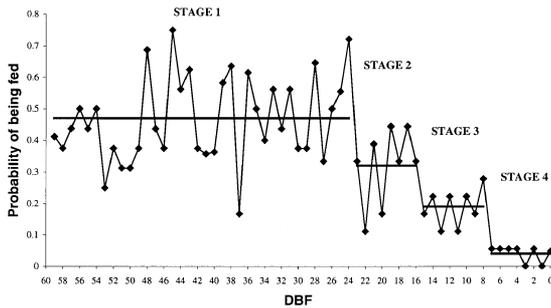


Figure 1 Probability of Pycroft's petrel chicks ($n = 18$) being fed as a function of their age expressed in days before fledging (DBF). Lines show the mean probability of being fed for each stage.

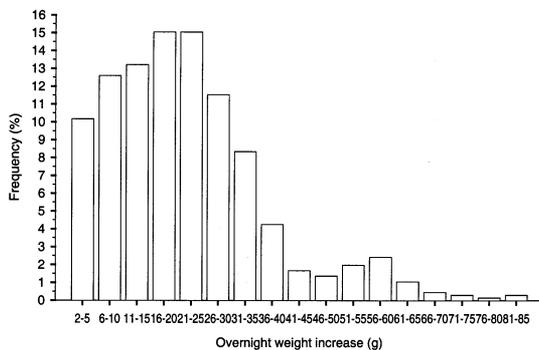


Figure 2 Overnight weight increase frequency for Pycroft's petrel chicks ($n = 34$ chicks, 338 meals) between 15 January and 26 April 2001, Red Mercury Island.

which the chick was found in the nest. Weight and wing length at fledging were those recorded on that day.

RESULTS

Feeding frequency and meal size

For those chicks that fledged before 26 March ($n = 26$), the probability of being fed on a given day during the 60 days prior to fledging declined in four different stages, 60-24, 23-16, 15-8, 7-0 days (Fig. 1). Few chicks received a meal during their last $7 \pm se 1.0$ days before fledging despite adults visiting their chicks during that period.

The overnight weight increase (OWI) of the study chicks varied widely, ranging from 1 to 86 g, mean $22 \pm se 1$ g (Fig. 2). It was not correlated with age (expressed in days before fledging (DBF)) of the chicks ($r^2 = 0.05$, $P < 0.001$, $n = 338$). More than 50% of the observed OWIs were < 20 g (Fig. 2).

During the three 24 h weighing sessions the mean weight increases recorded immediately after feeding were significantly different, contrary to

expectations the younger birds receiving the largest meals (Table 1) (ANOVA, $F = 10.8$, $df = 28$, $P = 0.0004$). However, the mean weight losses over the 24 hours following the meal (Table 1) did not differ significantly between the three groups (ANOVA, $F = 0.7$, $df = 28$, $P = 0.52$). Overall, the mean weight loss was $18.6 \pm se 1.4$ g during the 24 hours following a meal and $11.59 \pm se 0.57$ g in the first 12 hours following a meal. By adding this 12 g to the overnight weight increase we calculated the actual mean meal size received by nestlings between 15 January and 26 March 2001 to be $34 \pm se 1$ g (range = 13-98 g).

Weight change

Figure 3 shows the mean weight from 60 to 0 days before fledging for 26 study chicks fledging before 26 March. Maximum weight (mean = $286.5 \pm se 4.6$ g, range = 253-337 g) was attained at $26 \pm se 1$ DBF. On average, the maximum weight reached represented $175.8 \pm se 2.8\%$ of the mean adult weight (163 g, Warham 1990). The mean daily weight loss was $2.7 \pm se 1.8$ g between 24 and 15 DBF; $5.0 \pm se 1.4$ g between 14 and 10 DBF; and $5.4 \pm se 0.4$ g between 9 and 0 DBF. The rate at which chicks lost weight prior to fledging was not related to their probability of being fed.

During the last 30 days before fledging body weight was weakly correlated to age, equation (1): weight = $-0.159 \times DBF^2 + 7.867 \times DBF + 155.633$ ($r^2 = 0.63$, $P < 0.001$).

Wing length

On the day of first emergence from the burrows, the nestlings' wing length averaged $89.7 \pm se 0.7\%$ of adult wing length (range 81.6% - 95.3%; $n = 18$), and it was on average 98.1% of adult wing length at fledging. Wing length was strongly correlated with the age of the chicks (expressed in DBF); equation (2): wing length = $-3.474 \times DBF + 218.616$ ($r^2 = 0.95$, $P < 0.0001$) (Fig. 4).

Other measurements

Tail length of Pycroft's petrel chicks also increased steadily until fledging although it was less closely correlated with chick age ($r^2 = 0.86$, $P < 0.001$) than wing length. Mean tail length was 94.0% ($\pm se 2.4\%$) of mean adult length at fledging (Gangloff 2001). As expected from studies on other Procellariiformes, bill and tarsus length reached an asymptote approximately two weeks before chicks fledged and therefore were not good indicators of age ($r^2 = 0.17$, $P < 0.001$; and $r^2 = 0.16$, $P < 0.001$ for the bill and tarsus respectively) (Gangloff 2001).

Pre-fledging behaviour

Figure 5 illustrates the percentage of fences disturbed each day in relation to chick age (days

Table 1 Mean weights and weight changes ($\pm se$) (range) (g) of Pycroft's petrel chicks before feeding and during the 24h following feeding, on three different dates.

Dates	01-02 February (n = 10)	15-16 February (n = 9)	03-04 March (n = 10)
Morning before being fed	157.6 \pm 9.1 (98-185)	220.6 \pm 9.1 (168-250)	250.9 \pm 12.6 (187-304)
Increase just after feeding	44.5 \pm 3.7 (32-75)	18.0 \pm 3.1 (6-34)	24.9 \pm 5.2 (10-64)
12h after meal	194.3 \pm 9.8 (129-231)	225.1 \pm 8.7 (177-264)	266.8 \pm 10.2 (223-314)
24h after meal	188.2 \pm 9.7 (122-224)	219.1 \pm 8.2(174-254)	257.7 \pm 10.0 (215-308)
Decrease over 12h	11.2 \pm 1.2 (8-20)	13.4 \pm 1.8 (6-20)	10.3 \pm 2.0 (1-20)
Decrease over 24h	16.7 \pm 1.6 (11-27)	19.4 \pm 2.3 (12-30)	20.0 \pm 2.5 (7-32)

before fledging). Up until 8 DBF the percent of fences displaced each day was highly variable. Between 8 and 0 DBF, the proportion of disturbed fences was markedly higher, mean $96 \pm se$ 2% with little day to day variation

Observations were made each evening between 13 and 25 March. Chicks were first observed outside their burrows 1-15 (mean 7) days before fledging, corresponding with the increased percentage of disturbed fences observed in the last eight days before fledging (Fig. 5). Nestlings stayed at the entrance on the first one or two nights they emerged from their burrows. They then began to explore, first remaining within 2-3 m of the burrow and then, after three-four nights making longer exploratory forays, going up to 20-30 m from their burrow.

Fledging

Twenty-six of the 50 chicks that were weighed every day or every second day fledged before 26 March. The earliest chick to fledge was last seen in its burrow on 14 March. It is estimated that the last chicks would have fledged in mid-April. In 2000, the first chick also fledged on 14 March, and eight of 51 chicks fledged before 22 March (Wilson 2000). More fledging activity was observed on the island on nights with light to moderate wind, and a hazy or partially cloudy sky. During very windy nights, almost no fledging activity was observed.

Control group

Mean weights and wing lengths of control and study chicks on 29 January and 15 March are presented in Table 2. On 29 January, mean weights of these two groups were similar (Mann-Whitney U-test; $U = 960$; $P = 0.41$; $n = 62$). However, on 15 March, the control group was, on average, significantly heavier (Mann-Whitney $U = 630$; $P = 0.02$; $n = 51$), but wing lengths of the two groups were not significantly different (Mann-Whitney $U = 968$; $P = 0.37$; $n = 66$).

On 15 March, only 21 of the 30 control nestlings were found; remains of dead chicks were found in seven burrows but no sign of chicks or down was

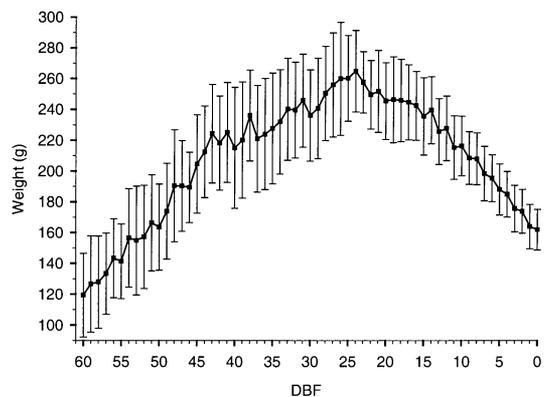


Figure 3 Mean weight of Pycroft's petrel chicks ($n = 26$) as a function of age expressed in days before fledging (DBF), Red Mercury Island. Error bars show standard deviations.

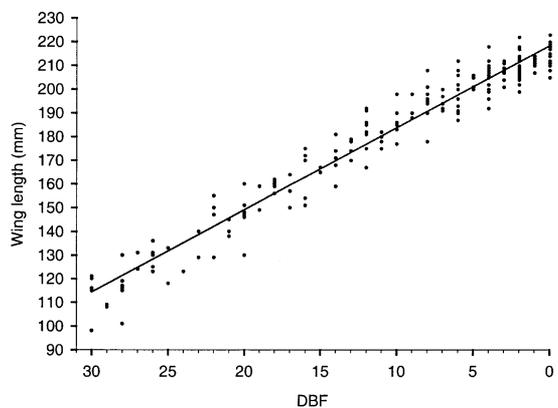
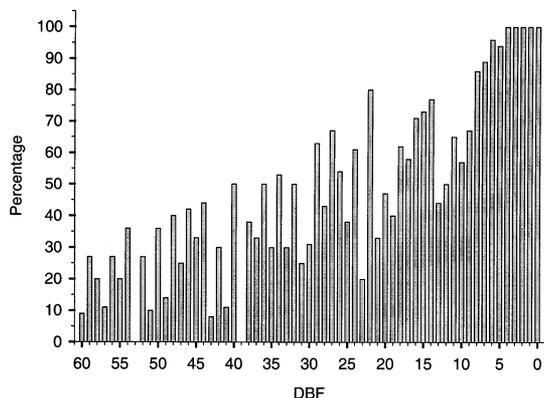


Figure 4 Wing length of Pycroft's petrel chicks ($n = 18$) as a function of age between 30 and 0 days before fledging (DBF), Red Mercury Island. Regression line (wing length = $-3.474 \times \text{DBF} + 218.616$; $r^2 = 0.95$, $P < 0.0001$) is shown.

Table 2 Mean weight and mean wing length ($\pm se$) of study and control groups of Pycroft's petrel chicks

	Mean weight (g)		Mean wing length (mm)
	29 Jan 2001	15 Mar 2001	15 Mar 2001
Study group	155 \pm 7 ($n = 30$)	215 \pm 5 ($n = 30$)	192 \pm 2 ($n = 30$)
Control group	161 \pm 6 ($n = 30$)	237 \pm 7 ($n = 21$)	185 \pm 5 ($n = 21$)

**Figure 5** Overnight disturbance of toothpick palisades placed at the entrance to Pycroft's petrel burrows as a function of days before fledging (DBF).

evident inside or outside the burrows of the other two. These nine chicks were all in burrows at the bottom of a valley and probably drowned during a heavy rainfall event. Between 10-17 February, five study nestlings also drowned. They were replaced by randomly chosen chicks from the 20 that were weighed every second day to maintain the sample size at 30.

DISCUSSION

Effect of handling on birds

Control chicks were significantly heavier than study ones on 15 March, while no difference was observed between the two groups in late January. Disturbance due to daily handling might have affected the study birds, but this weight difference could also have resulted from a difference in the chicks' average age. Older study chicks could have been closer to fledging, thus lighter, than their younger control counterparts on 15 March. Difference in wing length between the two groups, although not significant, suggests that study chicks were possibly older than the control chicks. As 26 of our study chicks had fledged when we left Red Mercury Island, and the remaining birds appeared healthy and almost ready to fledge handling did not appear to have impaired growth or survival.

Feeding pattern and meal size

Feeding frequencies observed for Pycroft's petrel

were similar to those described for temperate breeding Gould's petrel (Priddel & Carlile 2001) and Chatham petrel (Gardner 1999), but differed from the feeding pattern found by Gardner *et al.* (1985) and Imber *et al.* (1992) for tropical breeding Trindade petrel (*P. arminjoniana*) and Galápagos dark-rumped petrel (*P. phaeopygia*) respectively. The mean meal size received by Pycroft petrel nestlings was at the upper end of the range provided in different *Pterodroma* species when presented as a percentage of adult body weight (Table 3) although the difference between species was small (14-22%). This suggests that meal sizes of 15-20% of mean adult body weight should be a good guide for field workers when translocating *Pterodroma* chicks.

Weight and morphological parameters

Weight changes for both Pycroft's and Gould's petrel nestlings at comparable stages of their development were similar (Table 4). Gardner (1999) suggested that weight might be a good criterion for ageing Chatham petrel chicks. However, the correlation between these two factors was much stronger in her study than for Pycroft's petrels in this study, and we do not consider weight a reliable indicator of chick age of either species.

We found a very strong correlation between age and wing length in Pycroft's petrel (Fig.4). This together with the observation of a relatively constant wing growth up to fledging in several other *Pterodroma* species e.g. Trindade petrel (Gardner *et al.* 1985), soft-plumaged (*P. mollis*) and great-winged (*P. macroptera macroptera*) petrels (Jouventin *et al.* 1985), Galápagos dark-rumped petrel (Cruz & Cruz 1990) suggests that wing length is the best measurement for ageing *Pterodroma* nestlings.

Selection criteria and recommendations for the translocation of Pycroft's petrel nestlings

Translocating young seabirds from one island to another is labour intensive and risks chick mortality, mainly due to the need for chicks to be artificially fed. To maximise success, it is necessary to minimise the period during which translocated nestlings are dependant upon artificial feeding (Priddel & Carlile 2001).

Pycroft's petrel chicks reach their peak weight at about 26 DBF and should certainly not be transferred before that age. In order to reduce the

Table 3 Mean meal size received by chicks different *Pterodroma* species expressed as % of adult weight

Species	Meal size	Reference
Gould's petrel (<i>P. leucoptera</i>)	13.6	Priddel & Carlile 2001
Great-winged petrel (<i>P. m. macroptera</i>)	14	Schramm 1983
Galápagos dark-rumped petrel (<i>P. p. phaeopygia</i>)	16	Imber <i>et al.</i> 1992
Chatham petrel (<i>P. axillaris</i>)	17.2	Gardner 1999
Grey-faced petrel (<i>P. macroptera gouldi</i>)	18	Imber 1973
Providence petrel (<i>P. solandri</i>)	18.2	Bester <i>et al.</i> 2002
Phoenix petrel (<i>P. alba</i>)	18.2	Ricklefs 1984
Soft-plumaged petrel (<i>P. mollis</i>)	20	Schramm 1983
Pycroft's petrel (<i>P. pycrofti</i>)	21.9	This study

Table 4 Comparison of Pycroft's petrel nestlings on Red Mercury Island, New Zealand (2001) and Gould's petrel on Cabbage tree Island, Australia (1995). Data for Gould's petrel from Priddel & Carlile (2001).

	Pycroft's petrel	Gould's petrel
Feeding frequency	- 60 to 24 DBF: every 2 nd day - 23 to 16 DBF: every 3 rd day - 15 to 8 DBF: every 5 th day - no feeding afterwards	- 42 to 18 DBF: every 2 nd day - 17 to 11 DBF: every 3 rd day - no feeding afterwards
Overnight weight increase	22 ± se 1g	17.2 ± se 0.6g
Correlation between meal size and age	No correlation, $r^2 = 0.05$	No correlation, $r^2 = 0.048$
Weight:		
- age at peak weight	26 DBF;	29 DBF;
- daily weight loss	5.4g in the last 9 DBF	5.6g in the last 10 DBF
Age at first emergence	8 DBF	10 DBF

number of feeding events after the transfer, it is better to transfer chicks no earlier than 20 DBF. However, to ensure nestlings have not yet emerged from their burrow, it is best to transfer chicks no later than 10 DBF.

In this study, wing length proved to be the best criteria to age a chick. From equation (2), the wing length at 20 DBF and at 10 DBF is 149 mm (68.3% of adult wing length) and 184 mm (84.4% of adult wing length) respectively. Hence, the wing length of transferable chicks should be between 149 mm and 184 mm.

To reduce the number of feeds required, nestlings should not be underweight when transferred. From equation (1) the weight of a chick is about 250g at 20 DBF and about 218g at 10 DBF. It is therefore sensible to recommend that chicks selected weigh between 218g and 250g.

In terms of feeding, the objective must be to maintain chicks at or above adult weight but to avoid overfeeding. From this study, transferred birds should be given feeds of about 30 to 35 g every 3-4 days until they are 7 DBF (i.e. a wing length of 194 mm). In the last week before fledging they should not be fed unless they drop below mean adult weight.

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