PYCROFT'S PETREL IN THE BREEDING SEASON AT HEN AND CHICKENS ISLANDS

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ABSTRACT

We studied Pycroft's Petrel, *Pterodroma pycrofti*, at a breeding colony in the Hen and Chickens Islands, New Zealand, during the prebreeding and breeding seasons of 1982/83. Breeding birds attended their burrows singly and in pairs, often for several days at a time, from at least 38 days before laying, and up to 19 days before laying. No parents were in their burrows during the fortnight before laying, except a day or so before laying.

In October/November the weights of breeders arriving at their burrows averaged about 150 g, but females arriving to lay weighed on average about 188 g, and males arriving to begin their first incubation stint averaged about 190 g — about 25% more than in October/November. The egg averaged 32 g. Daily weight loss over consecutive days in the burrow averaged 3.5-5 g/day, 2-3% of body weight.

Laying took place from the second week in November to the end of the first week in December. Egg dimensions are given. Incubation lasted about 45 days and the fledging period was 77-84 days. Weights of fledglings ranged 156-188 g. From small samples, hatching success was 72% and fledging success 50%. Losses were caused by infertility, desertion and breakage resulting from fighting, probably with tuataras.

One male failed breeder was at its burrow six weeks after its egg was broken.

Non-breeders are defined as adults not known to breed in the current breeding season but may include some failed breeders. Some occurred in burrows in each observation period, and one was recorded throughout the study period, but more were at the colony in January than earlier. Non-breeders and breeders did not differ significantly in weight in October/November, but non-breeders did not usually achieve the higher weights of breeders arriving to lay or incubate. Weight loss of non-breeders in burrows was similar to that of breeders.

The state of the brood patch, egg formation and the history of previously ringed birds are briefly discussed.

INTRODUCTION

Little has been published on the breeding biology of the small species of the genus *Pterodroma*. Hindwood & Serventy (1941) described the history, breeding and behaviour of *Pterodroma leucoptera leucoptera* at Cabbage Tree Island off the New South Wales coast near Newscastle, and Falla (1934) gave brief accounts of *P. cookii* and *P. pycrofti*. Fleming (1941) examined the relationships of four species of *Pterodroma* in the New Zealand area — *cookii, pycrofti, nigripennis* and *axillaris*. Although mainly concerned with the

taxonomic relationships of these species, Fleming included some field observations on the biology of Pycroft's Petrel. Some observations on Cook's Petrel in the field were reported by Reischek (1885) and Stead (1936). Bartle (1968) gave data on the laying and incubation of Pycrofts Petrel and the composition of the population on Aorangi Island in the Poor Knights Group in November/December 1964. Jenkins & Cheshire (1982) described the distribution and breeding biology of the Black-winged Petrel (*nigripennis*), which is rapidly increasing in the South-west Pacific. Grant *et al.* (1983) described the breeding of the Bonin Petrel (*P. hypoleuca*) from December to March 1979/80 and from December to May 1980/81 — the most complete of the studies on breeding behaviour and ecology of any of the small *Pterodroma* species.

The present study, on Lady Alice Island in the Hen and Chickens group, New Zealand, was designed to investigate the breeding biology of Pycroft's Petrel from the prelaying phase through to hatching. A colleague made a later visit to determine fledging success in the study burrows. My main objectives were to study attendance of breeding and non-breeding birds at nesting burrows from the prelaying period onwards, to record the spread of laying, to study the incubation behaviour and weight characteristics of the species, and to measure hatching and fledging success.

STUDY AREA AND METHODS

The study area was on Lady Alice Island in the Hen and Chickens group (35.5°S 174.4°E). Its 138 ha, rising to 150 metres a.s.l., are covered in open woodland dominated by kanuka (*Leptospermum ericoides*). It was briefly described by Percy (1956) under the name of Marotiri Island and by Skegg (1964) under the name Big Chicken. Maoris had occupied it for many years up to 1821. By the end of last century the vegetation was regenerating into a mixture of coastal scrub and woodland communities with the drier ridges largely covered with kanuka. Now the island has populations of tuatara (*Sphenodon punctatus*) and the introduced Polynesian rat or kiore (*Rattus exulans*) and for some years the New Zealand Wildlife Service had been studying the interaction between these two species. During these investigations the burrows of nesting seabirds were regularly inspected because the tuataras spend much of the day in them. As a result breeding colonies of Flesh-footed Shearwater (*Puffinus carneipes*) and Pycroft's Petrel, which are summer breeders, and of the Grey-faced Petrel (*Pterodroma macroptera*) and Little Shearwater (*Puffinus assimilis*), which are winter breeders, were known and some had been mapped.

In 1980, 1981 and 1982, D. G. Newman and M. J. Imber had banded some breeding adults and fledglings of Pycroft's Petrel. Pycroft's Petrel was thus known to breed in a scattered 'colony' on the low slopes surrounding Grave Bay at the western end of the island, mainly in coastal scrub including flax (*Phormium tenax*), kanuka and kawakawa (*Macropiper excelsum*), and also in a scattered 'colony' on the main ridge of the island at about 150 metres a.s.l. in dry kanuka scrub. I studied both colonies.

My wife and I made four visits to the island totalling 35 days of field observations, the first on 23-29 September 1982, the second from 25 October

to 5 November, the third from 23 November to 3 December and the fourth on 11-15 January 1983. In later visits made on 21-29 March and 11-15 April, Ian MacFadden of the NZ Wildlife Service recorded nestling weights and fledging success in the study burrows.

We inspected 48 burrows regularly, 32 of which were used by Pycroft's Petrels during this study. The remaining 16 were always empty by day. An egg was laid in at least 28. We banded 74 adults, most of which were caught in burrows, and handled them on 224 occasions.

The main set of observations is derived from daily visits to each of the study burrows. During September, when Pycroft's Petrels were still not spending time on land during the day, we marked previously known and newly found burrows with numbered labels and put lids over most of the nest chambers. Additional burrows were found on later visits.

On each daytime visit we inspected the burrows and noted the contents. Any bird present we weighed, examined for bare or downy brood patch and for tail or wing moult, and measured. Bill length was taken from the feather line on the forehead to the tip of the bill, and bill depth vertically at the gonys.

The bird was returned to its burrow, and we erected a fence of twigs across the entrance. Apart from occasional checks, we examined the burrows again only if the fence had been disturbed.

We hoped that bill, wing and other measurements might enable us to sex the birds, but this proved not to be so. However, at and just after laying, the cloaca of females was conspicuously enlarged and discoloured, whereas males had no such enlargement. Therefore, immediately before and for rather longer after laying, we could tell the sex of each bird without doubt (cf. Serventy 1956). With some females we palpated the egg in the abdomen.

In the October-November visit during the prelaying stage we found six pairs of birds together in burrows. We administered gelatin capsules of Sudan Black Dye to all 12 birds (which we could not sex at the time) in the hope that a dark ring in the yolk would show when yolk was laid down (Grau 1976). Later, we collected their eggs when laid (replacing them with dummies which the birds incubated until January) and processed them in the laboratory by the method described by Grau (1976).

We also visited the study area every night but did not open the burrows then. These visits were rather unproductive owing to the scattered pattern of burrows and the fact that Pycroft's Petrels seem to spend very little time on the surface. However, some birds which were active in the burrows at night were not there on the following or previous day. This was especially true in the prelaying stage and the birds may have been non-breeders: cf. Grey-faced Petrels (Imber 1976) and Sooty Shearwaters (*Puffinus griseus*) (Richdale 1963).

BREEDERS

Attendance at burrows

Figure 1 shows the pattern of attendance of the adults at the 21 burrows in which we knew that an egg was laid and could estimate the date of laying.

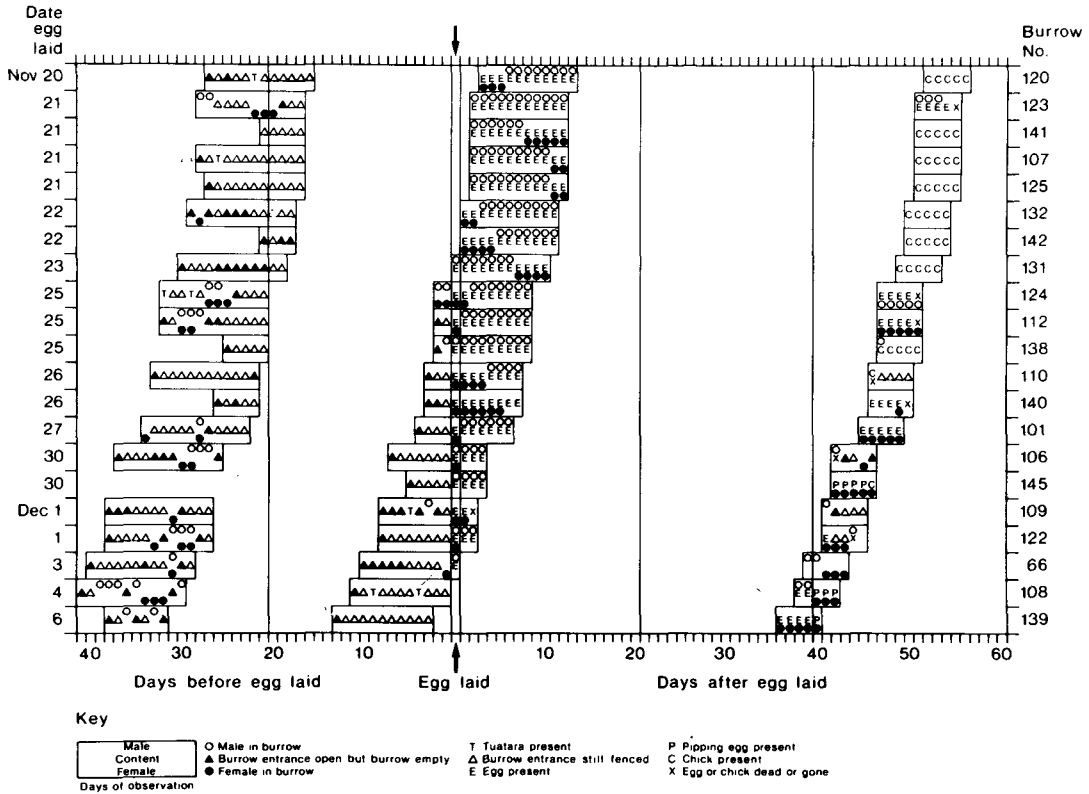

FIGURE 1 — Pattern of attendance of Pycroft's Petrels at each of 21 burrows in which an egg was laid

We had most of these burrows under observation off and on over several weeks before the egg was laid. In addition, we have quite good records of attendance at two other burrows, and we found five more late in the study when the eggs had already hatched. Only the adults from these 28 nests are considered as positive breeders. We sexed them by the state of the cloaca, by palpating the egg in the abdomen, or by incubating behaviour at the time of laying.

On our first visit in September we found no Pycroft's Petrels in burrows by day and saw or heard none at night. On the second visit in October-November, between 15 and 40 days before laying, birds were in burrows by day. Our third coincided with laying in most of the study burrows, but some eggs had been laid before we arrived and some were laid after we left. On our last visit, 35-55 days after laying, several eggs had hatched, some were hatching and some were still to hatch.

From Fig. 1 it is clear that, during periods between 20 and 40 days before the egg is laid, breeding Pycroft's Petrels can be found in their burrows by day. During our daily inspections at that time, on 14 occasions the male was alone in the burrow, on 12 occasions the female was alone, on 9 the pair was present, and on 181 occasions the burrow was empty. Among the 181 records were 23 when the fence at the burrow entrance was down, but the burrows were also used by tuataras, which we found in the burrows three times during this period, and probably by rats. The data show that the petrels were present for 1-3 consecutive days and there is little evidence that the pairs come and go together.

The birds are absent from the burrow in the days immediately before laying. The data suggest that the female arrives back at the burrow on the night that she lays and that the male is with her at that time or arrives in the following day or two. Having laid, the female incubates for a short time before being replaced by the male. From Fig. 1 we can get the following times for the first incubation stint of 19 females: 4 less than 1 day; 4 = 1; 2 = 2; 4 < 3; 1 = 3; 1 < 4; 1 = 4; 1 < 5; 1 =6 days. At one site (140) the female laid on 26 November and stayed 5 days before abandoning the egg. The abandoned egg was still intact in the nest in January.

The first incubation stint of the male is much longer, but our visits were too short to get complete data. We know that one male had incubated for 11 consecutive days, one for 10 and three for 9 days, but all these males were still incubating when we left.

At hatching only one adult was present in the burrow and, in the four cases where we found pipping/hatching eggs, the female was incubating. However, in at least two of these the male had been incubating until the beginning of the hatching process. From a few days after hatching, the chick is left alone in the burrow during the day.

We can also estimate the first incubation stint of males by relating the beginning of the females' second incubation stint to the estimated time of laying: for one this was on the eighth day after laying, for two the eleventh day, and for one the seventh day

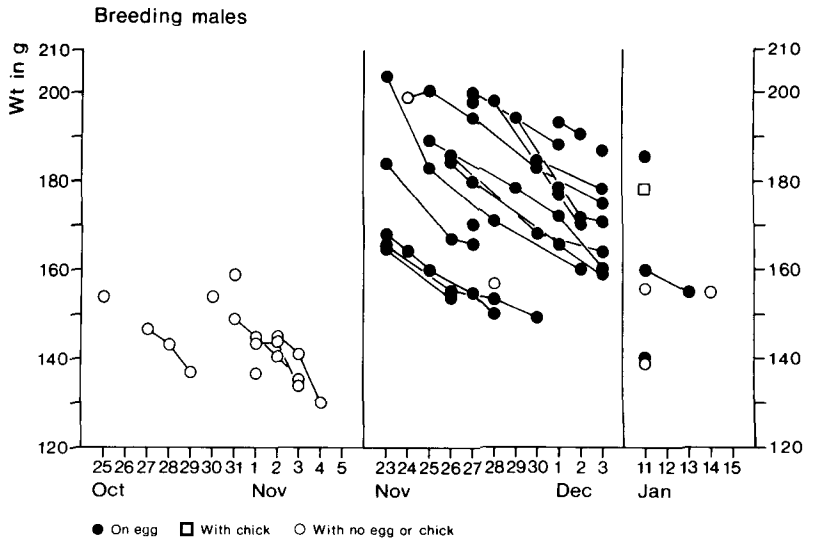

FIGURE 2 — Weights of breeding male Pycroft's Petrels caught in their burrows. Lines join weights on consecutive weighings, not necessarily on consecutive days for incubating birds

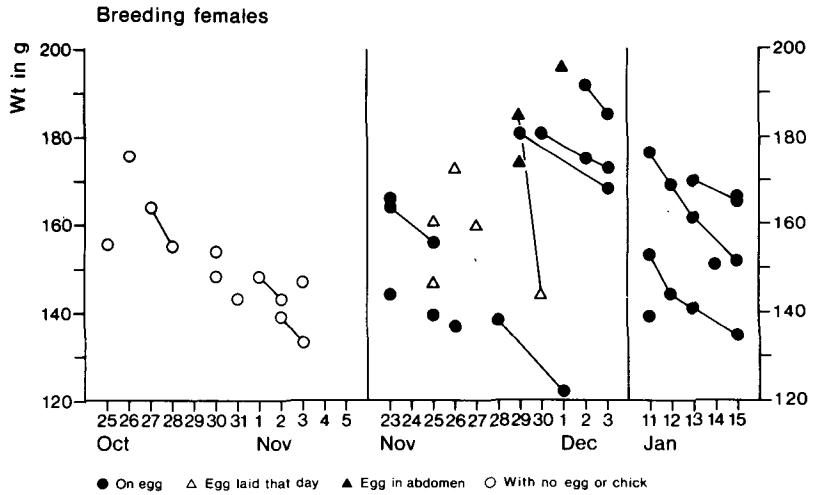

FIGURE 3 — Weights of breeding female Pycroft's Petrels caught in their burrows. Lines join weights on consecutive weighings, not necessarily on consecutive days for incubating birds

Weight

Weight is known to be highly variable in *Pterodroma* species (Bartle 1968, Imber 1976), mainly associated with periods of fasting when the birds come to land. The data can be considered under two headings: the weights of birds when first found in the burrow ("initial weights"); and the rate of weight loss while birds remain in their burrows.

Initial weights: Particularly in our November-December visit, the birds we weighed on the first day of our visit may have been in the burrows for several days before we arrived. As these measurements may be underestimates of the weights of returning birds we have excluded them from the analysis in Fig. 2 & 3.

In the October-November visit we recorded seven male and seven female breeders in the burrows. One bird of each sex was present on the day we arrived, and so they have been excluded. The mean weight of eight males is 150.33 g, SD 5.20 g, and of eight females 156.0 g, SD 11.80 g, and there is no significant difference between the sexes.

On arrival to begin incubation, nine breeding males averaged 192.3 g, SD 6.69 g. This was 41.97 g greater than the mean weight of adult males arriving during the prelaying period, an increase of about 28%.

The three females found in the burrows soon after dark with an egg in their abdomen weighed 196, 185 and 174 g. The one weighing 185 g was next day incubating an egg weighing 34.5 g and itself had a body weight of 144 g. The weights of five other females, their newly laid egg, and the total weight respectively were 161, 33.5 = 195 g; 160, 32.0 = 192 g; 147, 31.5 = 170 g; 173, 30.5 = 204 g; and 140, 32.5 = 173 g. Note that the bird weighing 185 g the day before laying weighed, together with her egg, only 178.5 g the following day. The average weight loss per day for incubating females is about 3.5 g (see below), and so some weight may be lost while the egg is laid.

Nevertheless, we can take the weights of female plus newly laid egg as the best indicator of weights of females at the time of their return to lay. For these eight birds the mean weight is 187.50 g, SD 11.50 g. This represents an increase of 20.2% (31.5 g) over the average weight of breeding females in the prelaying season (156 g). The initial weights of females plus egg and that of males returning to incubate are not statistically different.

We encountered no adults in March and April.

Weight loss: The weights of birds occupying burrows on successive days can be used as information on the rates of weight loss of birds on land. In the prelaying period, although the birds could go to sea and feed at night and still be in the burrows in consecutive days, we have only one record of a bird showing no weight loss on two consecutive days. All others lost weight.

Frequently we found birds in burrows on several consecutive days. To calculate the rate of a bird's weight loss, we took the weight of the bird when first found in the burrow and the last of the series of weights obtained when it was continuously in the burrow (based on no disturbance of the fence at the burrow entrance) and divided the weight loss by the number of days to produce an estimate of mean daily weight loss.

We have data for 10 birds during prebreeding attendance in October-November. Eight of these proved to be breeders. All showed similar weight losses ranging between 2 and 11 g per day, with a mean of 5.6 g (3.8% of the average initial weight, 148.0 g).

The daily weight loss in early incubation in November-December for 14 males (79 bird days) ranged from 2 to 7 g, with a mean of 3.58 g, being 1.91% of the initial weight (182.0 g) or 2.15% of the final weight (166.8 g). For seven females (17 bird days) the mean daily weight loss was 3.65 g, being 2.18% of the initial weight or 2.30% of the final weight. There are no statistically significant differences between the mean rate of weight loss for males and females in early incubation, or between all birds in early incubation and in the prebreeding period. Figure 2 shows that the slopes of weight loss do not show any regular pattern of change in rate in relation to initial weight.

The mean weights of males and females at the end of their incubation stints, allowing the mean daily weight losses for the days between last weighing and their departure, respectively were 151 g, SD 10.32, n = 8 and 142.25 g, SD 15.59, n = 4. These weights are 83% and 76% of the initial weights. The lowest weight recorded for an adult was for one female that weighed 122 g (approximately 65% of the mean initial weight) less than a day before she deserted her egg five days after laying.

Several adults were captured in attendance on egg or chick in January, and some of these were incubating on consecutive days. For both sexes together, the average weight loss of seven birds for 19 bird days was 4.89 g per day, which is c. 2.99% of initial weight and 3.17 % of final weight.

Laying dates

Figure 4 gives the laying dates known precisely or approximately for 22 burrows. Four more eggs were laid after 3 December. By their behaviour the adults at two other sites may have been failed breeders. At one of these, one member of the pair (? the female) arrived on 29 November weighing 201 g and remained in the burrow over 3 consecutive days. Its mate had been recorded on 24, 25 and 27 November weighing 166, 163 and 162 g, and both birds were in the burrow on 29 and 30 November. If this was a female returning to take over incubation the egg may have been laid not less that 12-15 days previously, i.e. 14-17 November. At the other site, two birds were recorded, one of them weighing 169 g on 26 November and 180 g on 1 December. If this bird also was the female returning to incubate, the egg may have been laid around 10-12 November. All these four birds had a bare brood patch, none had an enlarged cloaca, and none had an egg in the abdomen.

Laying is therefore more protracted than previous authors have indicated, extending perhaps from the second week in November to the end of the first week in December.

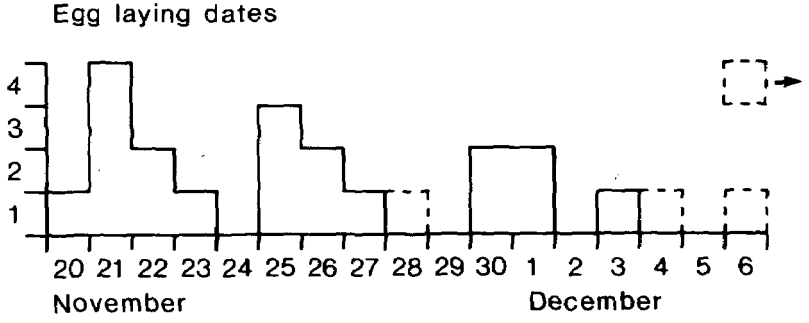

FIGURE 4 — Laying dates of Pycroft's Petrel. Broken lines indicate estimated dates

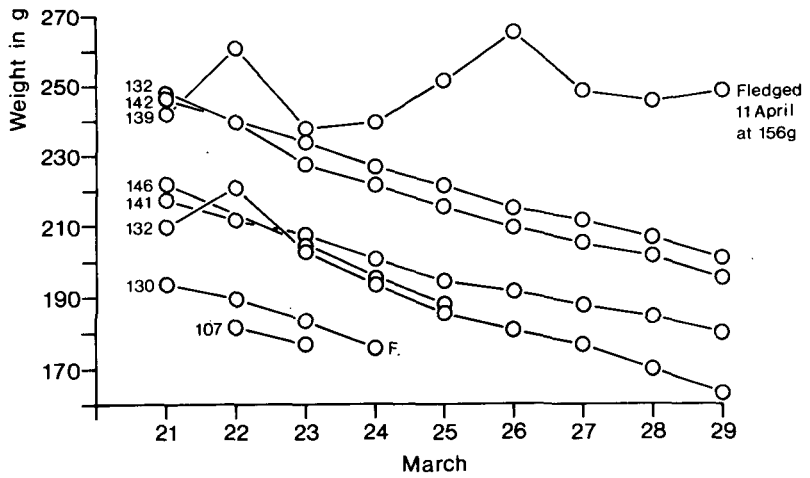

FIGURE 5 — Weights of eight nestling Pycroft's Petrels towards the end of their nestling period. The numbers refer to the burrow; F = fledged

Egg dimensions

We have the length and breadth of 22 eggs and the weights of 19 of them at or close to the date of laying. The dimensions (mm) are as follows:

Length: mean 48.90, SD 1.45, range 45.4-50.4
Breadth: mean 34.78, SD 1.67, range 32.0-36.3
Weight: mean 31.89 g, SD 2.46, range 25.5-35.5g

Three eggs, still intact on 11 January, were weighed and their reduced weights were compared with their weights at the time of laying. The data are as follows: (1) 31.5 g to 27.5 g, — 4.0 g; (2) 28.5 g to 23.0 g, — 5.5 g; (3) 32.0 g to 28.5 g, — 3.4 g. Overall this represents a 14.1% average loss of weight between laying and hatching.

Incubation

We have little information on the incubation period. From seven burrows the evidence is that incubation takes less than 48 days. At two others incubation was < 46 and < 45 days. Eggs may be pipped for at least four days before hatching. The only firm evidence is for one egg which hatched on the 46th day after laying, but an average incubation period might be 45 days.

Hatching success

From 18 sites with an egg, 13 eggs (72%) hatched successfully. Of the five failures, one was infertile, one was abandoned, two were broken and one contained a dead embryo.

Fledging

Ian MacFadden checked several Pycroft's Petrel burrows each day during visits in March and April for information on the weights of nestlings and the dates of fledging.

Weights: Figure 5 shows the weights of eight nestlings, four of which fledged during the observation period; their weights on the day before fledging being 156 g, 176 g, 177 g, and 188 g. Three of these birds fledged during the March visit, and based on their declining daily weights, two of them had not been fed for at least three and five nights before they fledged. The weights

of four other nestlings declined each day, with declines of 248 to 196, 218 to 180, and 247 to 201 g over eight days, and 221 to 163 g over seven days. It is clear that nestlings are not fed for at a week before they fledge, and so one factor that determines the time of fledging may be the body weight of the nestlings. From the known weights of fledging birds (156-188 g) it would seem that the last four birds above must have been on the point of fledging at the end of the period of observation.

The heaviest nestling we recorded was a bird that fledged on 11 April. On 22 March it weighed 261 g, on 26 March 266 g and on 29 March 249 g. The bird had certainly been fed on the night 28/29 March. In March 1981, M. J. Imber (pers. comm.) weighed seven chicks, of which one weighed 278 g and another 261 g.

Fledging period: We obtained sets of hatching and fledging dates, and hence accurate fledging periods, for only two nestlings. These were 77 and 82 days. However the four birds above, which must have been on the point of fledging when the observations ceased, were then 83, 82, 82 and 79 days old. Fledging thus normally occurs between 77 and 84 days of age, although at two other sites fledging may have occurred (the burrows being empty when first examined in March) at less than 76 and less than 73 days old. The observed fledging dates were 23, 25 and 26 March and 12 April. It is possible that two birds might have fledged before 21 March.

Fledging success: The records from many burrows are incomplete but of 12 burrows with complete records six (50%) successfully fledged a chick. Our activities during the study did not cause any known losses of eggs or chicks, apart from the three eggs collected experimentally.

NON-BREEDERS

During the study we caught, in burrows or on the surface, 32 Pycroft's Petrels which were not known to be breeding. None of these birds could be sexed. Some might have been failed breeders but this cannot be confirmed: for example, the pairs of birds at two burrows may have lost their egg very soon after it was laid because both burrows had no egg on 23 November. Of the 32 non-breeders, all but three were found in burrows by day.

Table 1. Records of non-breeding Pycroft's Petrels in the breeding colony: (a) number of individuals and captures in each observation period, and (b) the distribution of individuals according to the observation periods in which they were recorded.

(a)	Observation Periods	1 (Oct/Nov) 12 days	2 (Nov/Dec) 11 days	3 (Jan) 5 days
	No. of individuals caught	8	13	21
	No. of individuals first recorded	8	10	14
	No. of captures	13	33	27

(b)	Observation periods recorded	1	2	3	12	13	23	123
	No. of individuals	5	4	14	2	0	6	1

Attendance

Non-breeding birds were found on the island during each of the three main observation periods (Table 1): 8 were recorded in October-November, 13 in November-December and 21 in January. Even allowing for the number of days in each period, we found many more in January than in November-December, and more then than in October-November. Only one bird was recorded in all three observation periods, two in the first and second only, and six in the second and third only. The increase in January may be due to new arrivals or, conceivably, to failed breeders moving into different burrows.

In October-November, five birds were recorded a total of nine times singly in burrows. One "pair" was found on two consecutive days in a burrow but was not seen again. During the same period, six pairs of birds subsequently proved to breed were found together in burrows, but although pairs of proven breeders were together more often than "pairs" of non-breeders, the difference was not significant.

During October-November, all the non-breeding birds, except the one "pair", were in the burrow for only one day at a time. This is a lower frequency of presence in consecutive days than we found for the breeders, especially the breeding males, four of which were recorded on three consecutive days.

During November-December there was a stronger tendency for non-breeding birds to stay in the burrows over consecutive days (Fig. 6). Compared with October-November, when eight records were for one day only and only two for more than one day, the corresponding figures are five records for only one day and 11 for more than one day. Of the 11, four birds were present for three consecutive days. This difference in behaviour between October-November and November-December is significant ($X^2 = 4.06$, $p < .05$).

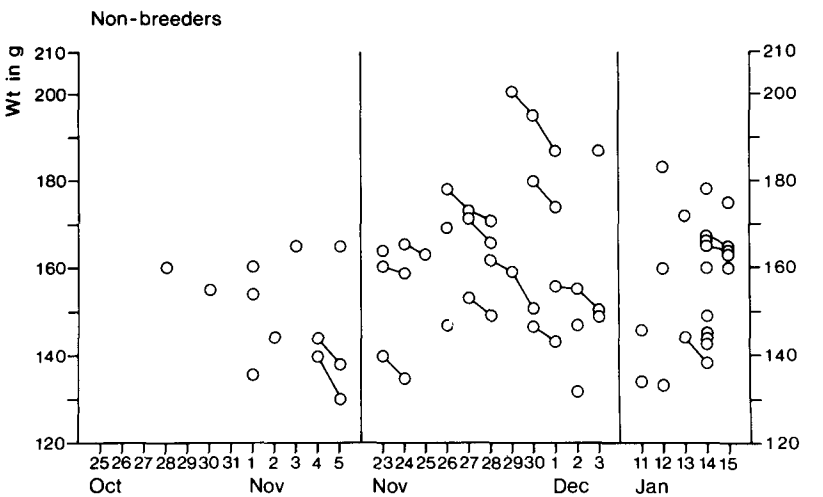

FIGURE 6 — Weights of non-breeding Pycroft's Petrels caught in burrows. Lines join weights on consecutive weighings.

The data for January are hard to interpret owing to the very short observation period and the difficulty of using data from the first and last days. However, 10 of the observations were of a single day only and only one was of two days only. Two records were for a minimum of two days and may have continued (Fig. 6). These data are too few to analyse but the visits of non-breeders in January do seem shorter. Table 1 shows that many non-breeders were recorded for the first time in January, and so more non-breeding birds may visit breeding colonies then.

Because breeders are committed to incubation and caring for the young, their behaviour contrasts markedly with that of non-breeders in November-December and January.

Constancy of burrows

Non-breeders were always recorded in the same burrows: none was found in more than one burrow throughout the study. In general the burrows occupied by non-breeding birds were not attended by other birds, but there were exceptions such as the following example.

In one burrow ♂95 and ♀96 were together from 30 October to 1 November, when ♂96 was present alone. When we arrived again on 23 November, birds 08 and 09 were together in the burrow, as they were on the following day. On 25 November, ♀96 was in the burrow with an egg. On 27 November, ♂95 was incubating the egg, and it continued until the end of our visit on 3 December. Birds 08 and 09, presumably a non-breeding "pair", were not recorded again in the study. Imber (1976) recorded similar cases for the Grey-faced Petrel.

In another burrow, bird 03 was present on the evening of 1 December and was alone there the following day. Its brood patch bare, it weighed 155 g. On 3 December it was still in the burrow, together with bird 79. No egg was recorded in November-December. In January the burrow was empty when we arrived but on 14 and 15 January a new unringed petrel, 45, was in the burrow. It had a bare brood patch with a little regrowth of down, and no sign of wing or tail moult.

By contrast one breeder, ♂75, which we found alone in one burrow on 31 October-2 November, was alone in another burrow on 3 November. This bird went on to breed with ♀80 in the latter burrow.

Non-breeders may turn up at colonies throughout the breeding season. For example, on 1 November bird 01 was alone in a burrow and on 26 November it was there again, alone. The burrow was empty on 29 November, but on 30 November and 1 December 01 and 23 were there together. In January the burrow was empty when we arrived, but on 14 January 01 and 23 were together in the burrow and on 15 January 01 was there alone. We do not know of an egg being laid in this burrow.

Weights

The mean weight of eight birds present on 10 occasions in October-November was 152.30 g, SD 10.57 g. This value is not significantly different from those of breeding males and females in October-November. Weight loss, which was measured over only two bird days, averaged 8.0 g per day, which was consistent with the rates of loss of breeders at this time.

In the November-December visit, excluding the weights on the first day of our visit, the mean initial weight for 15 non-breeders was 162.93 g, SD 18.28 g. The range of weights (132-201 g) accounts for the rather large standard deviation, but most were between 145 and 170 g. It is interesting to speculate whether those birds coming in with weights greater than 170 g could have been failed breeders. The mean weights of males and females returning to begin incubation in November-December were 192.3 and 187.5 g respectively. Only five of the non-breeding birds weighed more than 170 g on their return in November-December: the weights were 172, 178, 180, 201 and 187 g. On evidence derived from their attendance pattern, the first three of these birds may have been failed breeders, and the fourth may have lost its egg.

We can conclude that, although a few of the "non-breeding" birds may have been failed breeders, most seem to have been genuine non-breeders and to have maintained throughout November-December body weights very like those in October-November. The same was true in January*, when for 16 initial weights (excluding the first day of our visit), the mean was 158.69 g, SD 14.65 g. Again the range is very wide, 133-183 g, and four non-breeders caught in January weighed 172, 176, 178 and 183 g.

The rates of weight loss also are similar to those of breeding adults. For 15 bird days in November-December the average rate of loss was 4.53 g per day.

OTHER OBSERVATIONS

Brood patch

In petrels a conspicuous abdominal brood patch develops by losing its thick covering of down and becoming vascular. When 'bare' the brood patch of Pycroft's Petrel retains a narrow mesial band of down but is otherwise bare vascular skin. In our records we described brood patches as either 'bare' or 'downy'.

In October-November, we handled five breeders, of both sexes, and two non-breeders. All had brood patches completely covered with down.

In November-December, we examined the brood patches of 11 non-breeders, of which seven were bare and four were completely downy. In one burrow where two birds were present, possibly a pair, one bird's brood patch was downy and the other's was bare. In two other "pairs" of non-breeders, both had bare brood patches. We examined 13 male, 11 female and one unsexed breeders at this time. Of the five females found with their newly laid egg, or just before laying, three had downy and two had bare brood patches.

Two females were sitting alongside their egg, which was cold, and were not incubating. One of these, 02, was sitting beside a new egg, which was cold, on 30 November, and its brood patch was recorded as "rather downy; not vascular". It had been recorded in the burrow with ♂78 on 1 November,

*In these analyses we have regarded one bird, found on 13 January with the remains of an unhatched egg in its burrow, as a non-breeding bird because we have no evidence that this was indeed one of the parents of the egg.

and ♂78 was incubating the egg from the evening on 30 November to 3 December. When we returned in January the burrow had collapsed and contained broken egg shells. On the evening of 11 January, ♂78 was digging in the burrow (which we had repaired), and on 14 January ♀02 was caught digging in the burrow. Almost certainly, therefore, ♀02 had laid the egg. It is easier to understand why the female in another burrow was not incubating and the egg was cold when first recorded on 1 December: a medium-sized tuatara was in the burrow. Both petrel and tuatara were very active and the egg was badly soiled with mud. It seemed that this female had been fighting the reptile, possibly defending its egg. The female's brood patch was bare and vascular. We evicted the tuatara and ♀76 incubated until the night of 2-3 December. On the morning of 3 December the burrow was open, there were signs of upheaval and fighting: scrapings, dislodged soil and stones, a broken egg with the yolk intact on the ground, and no bird.

The males we found taking over their first incubation stint all had a bare brood patch, and one male already had a bare brood patch the day before the egg was laid.

In January birds which were still incubating had bare brood patches, although one, whose sex was not determined, had some new down even though it was still incubating: however, its egg had been laid very late in the season and was abandoned long before it would have been due to hatch. We examined 13 non-breeders in January. Of these, six had bare brood patches and seven had brood patches with extensive new growth of down. Of four "pairs" of non-breeders examined in January, both birds of one pair had bare brood patches whereas, in the other three pairs, one bird was bare while the other had regrowing down.

It is interesting to consider the brood patches of those birds which we thought might be failed breeders. Birds 01 and 23 occupied one burrow. On 26 November the brood patch of 01 was "completely downy", and on 27 November that of bird 23 was bare. These birds were together in the burrow on 14 January, when the brood patch of 01 was still bare and vascular, but that of bird 23 had down "regrowing extensively". At another burrow birds 16 and 27 were present during the laying period. At the end of November both had bare brood patches, and on 14 January the brood patch of bird 16 had considerable regrowth of down. Bird 73, having lost its egg on 3 December, broken during a fight in the burrow, was found in a different burrow on 11 January. Its brood patch was still bare and the remiges and rectrices were not in moult.

From these data it is difficult to tell whether pairs 01/23 and 16/27 had lost their egg. An interesting feature, however, is that bird 01 developed a bare brood patch between 26 November, when it was completely downy, and 14 January, when it was bare, whereas its presumed mate had a bare brood patch on 27 November and a downy one on 14 January. The positive data from bird 73 indicates that a bare brood patch can persist for almost 6 weeks after the loss of the egg.

Egg formation

Imber (1976) has drawn attention to the physiological adaptations which must be associated with the absence of breeding petrels from their breeding colonies, often for several weeks, before the egg is laid. Copulation is assumed to take place when the birds are attending the breeding colonies, and so either sperm is stored in the female for several weeks before fertilisaton (Hatch 1983) or development is delayed after fertilisation, or both. Grau (1976) has described the ring structure of avian egg yolk and has also developed staining methods to mark growth rings in the yolk and so identify the dates on which they were laid down. The dye used was Sudan Black and it was administered orally by capsule.

We administered dye capsules to three pairs of Pyrcroft's Petrels during their prelaying attendance in their burrows, about a month before laying, but could not administer a second capsule several days later because none of the birds remained in the burrows for long enough. The eggs were collected on the day they were laid and processed according to Grau's techniques (Imber, pers. comm.). On examination, none had any sign of a dark ring in the yolk, indicating that yolk was not being laid down at the time the dye was absorbed 26, 27 and 29 days before laying. The number of detectable concentric rings, however, was 12, 13 and 14, indicating that the birds took about two weeks to deposit the yolk.

We found breeding Pycroft's Petrels in their burrows by day from 40 days before laying to 20 days before laying. Indeed, they may well remain at or near their burrows until closer to laying, but our observation periods were too short. We did not see copulation but presumably it takes place at the breeding colony as with other petrels (Thoresen 1967, Serventy *et al.* 1971, Crockett 1975). Perhaps the female goes to sea, straight after copulation, with the fertilised egg, which then takes about 20 days to develop, or perhaps she goes to sea before the ovum has begun to develop and stores the sperm. After the ovum matures, fertilisation occurs and the egg takes a further 1-2 weeks to develop fully (cf. Imber 1976 for *P. macroptera*).

Failed breeders

Very little is known about failed breeders. Two sites with an egg in December had no egg or chick in January and no sign of the breeders, all of which were marked and known. At a third site, where the pair was known in November, broken egg shells were scattered near the entrance on our arrival on 11 January. That night the male was digging out the burrow, and on the night of 14 January the female was digging an extension to the burrow and was using a plastic tunnel with which we had sought to reconstruct the entrance. We did not note the state of the brood patch or of moult in these birds. At a fourth site, where the egg was broken on 3 December, the male was in the burrow on 11 January, six weeks later; its brood patch was still bare and it was not in wing or tail moult. The bird was gone the next day.

Known history of previously ringed birds

During the study we recaptured 12 ringed adults. All had been ringed as breeders, one in the breeding season of 1980/81 and the others in 1981/82. The following notes include their history in the 1982/83 breeding season.

One bird, of unknown sex, bred in the same burrow for the three consecutive years, with the same mate in the last two. A further six birds bred in the same burrow with the same mate in the last two years, and two males and one bird of unknown sex bred in the same burrows in the last two years.

There are two interesting situations. Bird 79, which had bred unsuccessfully in 1981/82, was caught in the same burrow on 30 October and 3 December 1982, weighing 155 and 149 g respectively. We classed it as a non-breeder in 1982/83, and it may not have attempted to breed in that year. Secondly, male 71 bred in burrow A in 1981/82 and in burrow B in 1982/83. It was recorded incubating in burrow B for 12 consecutive days in November-December (which confirmed that it was male) and was still incubating in January, when the intact egg was found to be dead. Male 75 was also caught in burrow A on 31 October, 1 November and 2 November, during which time its weight dropped from 149 to 141 g, and on the following day, 3 November, it was found in burrow C, weighing 135 g. It bred in burrow C where it was incubating on 3 December, female 80 having been found in the burrow with an egg in her abdomen on 1 December. Male 75 had bred with female 80 in burrow C in 1981/82 and again in 82/83: its presence in burrow B for three consecutive days in October-November was unusual.

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LITERATURE CITED

BARTLE, J.A. 1968. Observations on the breeding habits of Pycroft's Petrel. Notornis 15: 70-99.
CROCKETT, D.E. 1975. The Wedge-tailed Shearwater *Puffinus pacificus* in the northern Kermadecs. Notornis 22: 1-9.
FALLA, R.A. 1934. The distribution and breeding habits of petrels in northern New Zealand. Rec. Auck. Inst. Mus. 1:245-262.
FLEMING, C.A. 1941. Notes on neozelanic forms of the subgenus *Cookilaria*. Emu 41:69-80.
GRANT, G.S., WARHAM, J.; PETTIT, T.N.; WHITTOW, G.C. 1983. Reproductive behavior and vocalizations of the Bonin Petrel. Wilson Bull. 95:522-539.
GRAU, C.R. 1976. Ring structure of avian egg yolk. Poultry Science 55:1418-1422.
HATCH, S.A. 1983. Mechanism and ecological significance of sperm storage in the northern fulmars with reference to its occurrence in other birds. Auk 100:593-600.
HINDWOOD, K.A.; SERVENTY, D.L. 1941. The Gould Petrel of Cabbage Tree Island. Emu 41:1-20.
IMBER, M.J. 1976. Breeding biology of the Grey-faced Petrel *Pterodroma macroptera gouldi*. Ibis 118:51-64.
JENKINS, J.A.F.; CHESHIRE, N.G. 1982. The Black-winged Petrel (*Pterodroma nigripennis*) in the South-West Pacific and the Tasman Sea. Notornis 29:293-310.
PERCY, C.A. 1956. A primary survey of the vegetation of Marotiri Island. Tane 7:3-6.
REISCHEK, A. 1885. Notes on New Zealand ornithology. Trans. NZ Inst. 18:87-96.
RICHDALE, L.E. 1963. Biology of the Sooty Shearwater *Puffinus griseus*. Proc. Zool. Soc. Lond. 141:1-117.
SERVENTY, D.L. 1956. A method of sexing petrels in field observations. Emu 56:213-214.
SERVENTY, D.L.; SERVENTY, V.; WARHAM, J. 1971. The handbook of Australian sea-birds. 254 pp. Sydney: Reed.

SKEGG, P.D.G. 1964. Birds of the Hen and Chicken Islands. Notornis 11:159-176.
STEAD, E.F. 1936. A new nesting-site of Cook's Petrel *Pterodroma cooki*. Trans. Roy. Soc. NZ 66:315.
THORESEN, A.C. 1967. Ecological observations on Stanley and Green Islands, Mercury Group. Notornis 14:18-200.

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APPENDIX 1. **PYCROFT'S PETRELS** — Measurement of bill length, bill depth and wing length

BIRD	BILL		WING		BIRD	BILL		WING	
	L	D				L	D		
90	26.4	8.3	220	♀	09	25.9	8.2	227	
87	24.3	7.7	222	♀	15	25.8	8.2	219	♂
88	26.0	9.0	220		11	24.5	8.6	225	
71	25.4	8.2	216	♂	12	24.8	7.7	211	♂
72	23.0	7.9	220		13	24.3	7.8	210	♂
81	24.2	7.0	224		14	25.2	8.1	222	♀
91	24.3	8.1	216	♂	16	24.6	8.3	204	
89	24.4	8.0	216	♀	17	23.7	7.6	208	♂
92	24.7	7.7	214		18	25.9	8.0	219	♂
79	24.4	8.0	228		19	23.5	7.4	216	♂
95	24.2	8.0	219	♂	20	25.0	7.7	215	
96	23.6	7.3	221	♀	21	24.8	8.2	222	♀
98	23.5	7.5	216	♀	22	26.2	8.0	222	
99	24.5	8.2	225	♂	23	25.0	8.1	221	
73	26.0	8.2	224	♂	24	24.3	8.1	216	
72	23.9	7.8	224		25	25.3	7.8	221	♀
97	24.3	7.5	219		26	23.5	8.1	218	♀
00	25.3	8.6	221		27	24.9	8.0	226	
01	25.2	7.9	224		28	24.1	8.3	229	♂
75	26.3	8.3	223	♂	29	24.7	8.0	225	♀
02	25.3	7.9	213	♀	30	25.1	7.9	215	♂
03	23.6	7.8	222		77	25.1	8.2	224	♀
04	25.4	8.4	227		62	25.2	8.2	221	
76	23.4	7.8	228	♀	31	24.0	8.3	216	♀
05	24.4	8.1	220	♂	33	23.5	8.3	218	
78	23.7	8.0	223	♂	32	24.8	7.7	224	
80	24.2	8.2	225	♀	34	25.1	8.1	216	
06	24.8	8.0	217		35	25.0	8.2	228	
07	25.6	7.8	218		36	24.4	7.5	223	
74	26.6	8.2	219	♂	37	24.6	7.9	221	
10	26.5	8.6	221	♀	38	25.6	8.6	231	
08	23.5	7.9	219		39	24.0	8.0	218	
44	25.0	7.9	-		45	26.0	8.4	217	

Mean Bill length = 24.77, s.d. 0.87 mm;
Mean Bill depth = 8.02, s.d. 0.34 mm;
Mean Wing length = 220.18, s.d. 5.09 mm.

	TARSUS	MID TOE AND CLAW			TARSUS	MID TOE AND CLAW	
20	30.3	38.0		23	28.9	37.8	
44	30.2	35.4		11	28.8	38.1	
45	29.3	36.8		34	28.8	36.1	
05	29.0	38.5	♂	35	29.2	36.5	
62	31.0	37.6		87	28.8	36.5	♀
25	30.3	38.0	♀	96	30.4	38.3	♀
35	28.6	36.4		04	30.0	36.4	
16	30.1	37.7		80	29.6	38.3	
01	29.7	39.0		89	30.5	37.9	

Mean Tarsus length = 29.64, s.d. 0.73 mm;
Mean length Mid Toe and Claw = 37.41, s.d. 0.99 mm.