Aspects of the breeding biology of the Chatham petrel (*Pterodroma axillaris*)

Phillipa Gardner

'Thistledown', Coutts Island Road, RD, Christchurch, New Zealand

A B S T R A C T

The Chatham petrel (*Pterodroma axillaris)* is an endangered seabird endemic to the Chatham Islands, New Zealand. The breeding range is now restricted to Rangatira Island and the population is considered to be in decline. This report presents information on the breeding biology of the Chatham petrel.

Burrows were monitored throughout two breeding seasons (November 1995 to May 1996 and November 1996 to June 1997). Data were collected on the various stages of breeding: prospecting, pre-laying exodus, incubation and chick rearing. Eleven chicks were weighed daily to determine feeding frequency and meal size. Feathers were taken from Chatham petrels handled during the 1996/97 season to determine sex by DNA analysis.

Chatham petrels prospect from the middle of November and have a pre-laying exodus of about four weeks. Incubation length (c. 47 days) is comparable with similar-sized gadfly petrels. Data collected during this study indicated that Chatham petrel chicks fledge at a mean age of 84.7 days and are abandoned (period from last feeding to fledging) for approximately 11 days prior to fledging. From weights collected during the 1996/97 season it was possible to conservatively estimate mean meal size (37.8 g) and determine mean weight loss and gain over a 24-hour period. Feeding frequency remained relatively constant over the first two-thirds of the chick period, but was reduced in the final third. The information gathered will aid the development of a more effective management programme.

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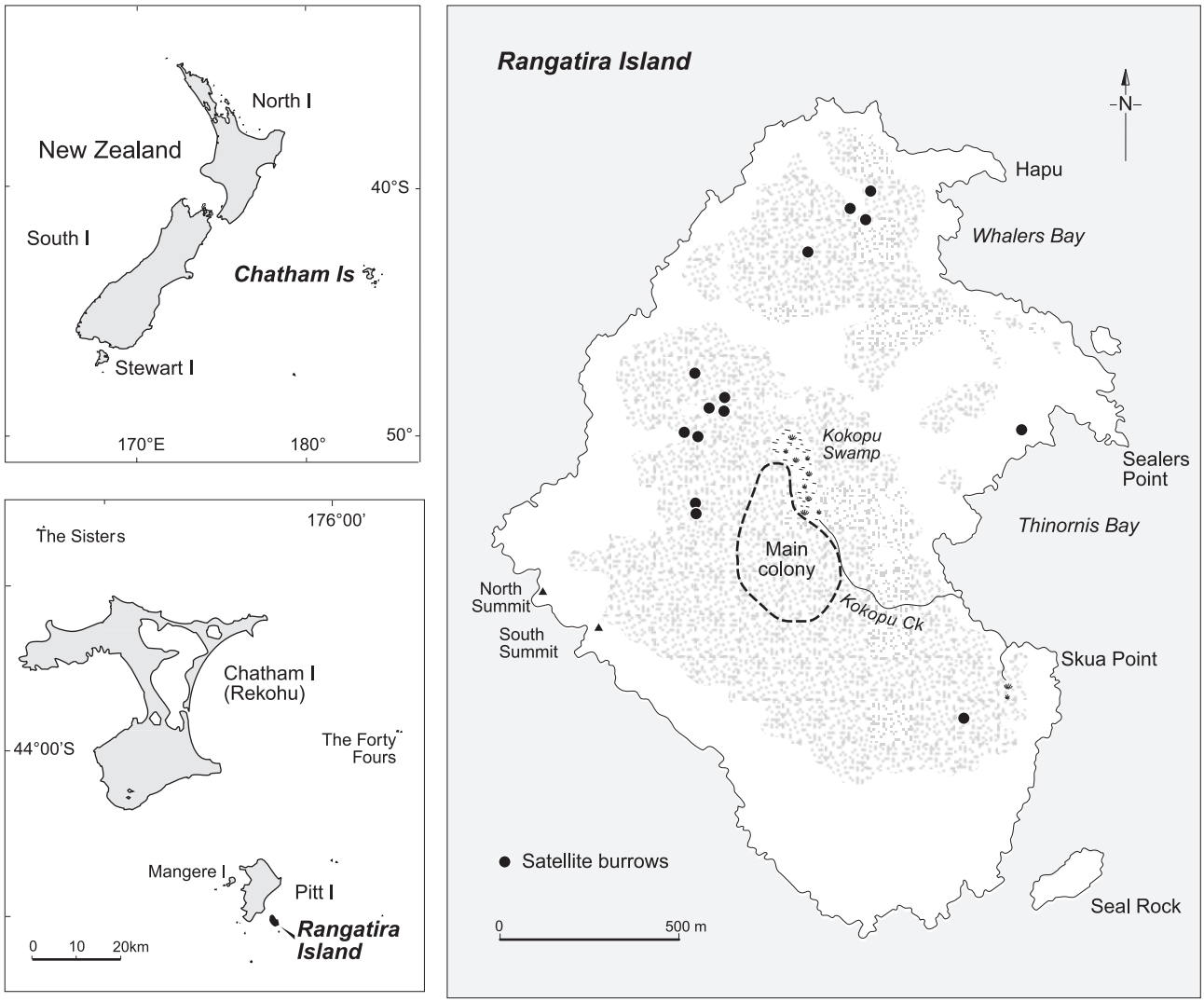

Figure 1. Map of Rangatira (South-East) Island, Chatham Islands, showing the main Chatham petrel breeding colony in the Kokopu catchment, and satellite burrows.

1. Introduction

The Chatham petrel (*Pterodroma axillaris*) is an endangered pelagic seabird endemic to the Chatham Islands, New Zealand. Although once found on the larger islands in the archipelago (Tennyson & Millener 1994; A.J.D Tennyson, pers. comm.), breeding is now restricted to Rangatira Island (formerly South-East Island) (see Fig. 1). The Chatham petrel has an estimated population of 500–1000 individuals (Kennedy 1994). Approximately 440 have been banded since 1977. The status (alive, breeding or non-breeding) of many of these banded individuals is not known. The pelagic distribution of the species is also unknown, but it has been suggested that, like the closely-related black-winged petrel (*Pterodroma nigripennis*) (Imber 1985; Warham 1990), it migrates to the north Pacific Ocean during winter (M.J. Imber, pers. comm.).

Information on the pre-history of the island is poor, but since European settlement on the Chathams, Rangatira Island has undergone major habitat changes. The forest was cleared for farming, which subsequently lasted some 100 years. In 1961, the last feral livestock (sheep and cattle) were removed, and in 1964 the island became a reserve under Crown ownership and the vegetation was allowed to regenerate (West 1994). By all anecdotal and pictorial accounts, the regeneration of Rangatira has been remarkable. The Kokopu Creek catchment is the only area on the island that may contain original forest. The greatest known concentration of Chatham petrel burrows is found in the Kokopu catchment. The forest on the island is dominated by ribbonwood (*Plagianthus regius chathamicus*) in various stages of maturity. Other tree species include tree daisies *(Olearia traversii, Olearia chathamica*), matipo (*Myrsine chathamica*), ngaio (*Myoporum laetum*), mahoe (*Melicytus chathamicus*), lancewood (*Pseudopanax chathamicus*) and karamu (*Coprosma chathamica*).

The soil on the island is acidic and very friable. Intense seabird burrowing activity destabilises the forest floor, which makes monitoring of Chatham petrels difficult, as the earth often crumbles as birds are removed from their burrows. Since 1994, artificial burrows have been placed over known Chatham petrel breeding burrows to reduce burrow damage.

Current knowledge about the species (sparse burrow distribution, low productivity and historical information) strongly indicates a population in decline (Taylor 1997). Broad-billed prions (*Pachyptila vittata*) negatively impact on Chatham petrel productivity, due to competition for burrows (Gardner & Wilson, this volume; Was & Wilson 1998). Burrow competition between the species may have intensified, possibly because of the loss of breeding habitats and habitat change throughout the archipelago.

Monitoring of Chatham petrels began in 1989 (West 1994), and information on breeding biology was collected by Department of Conservation staff and scientists (Taylor 1991; Kennedy 1994). However, this information was fragmented, because of the limited and often unpredictable time available for monitoring and research.

For this study the Chatham petrel (*Pterodroma axillaris*) was monitored for two consecutive breeding seasons—1995/96 and 1996/97. At the completion of data collection (June 1997) there were 104 labelled Chatham petrel burrows. These comprised current breeding burrows, those no longer in use and others that may never have been breeding burrows. There were 50 active burrows (45 breeding burrows and 5 visited by one or more Chatham petrels), and 44 identified breeding pairs.

Outcomes from this breeding biology study have implications for the future management of the species. Without reasonable baseline knowledge of breeding biology, it is difficult to implement management regimes. It is hoped that the following information will complement that which is already known.

2. Objectives

- To determine the length of the pre-laying exodus, incubation and chick rearing periods for Chatham petrels.
- To establish if an abandonment period exists before fledging.
- To establish the sex of individuals by DNA feather analysis.

3. Methods

3.1 GENERAL METHODS

Chatham petrels were studied on Rangatira Island over two breeding seasons—14 November 1995 to 13 May 1996 and 12 November 1996 to 7 June 1997. When I was not on the island, data were collected by Department of Conservation staff and volunteers.

3.1.1 Handling protocols

All Chatham Petrels caught were banded (D-size bands), which generally took between three and five minutes. Underwing inspections were made of any unbanded bird to confirm the individual as a Chatham petrel and not a black-winged petrel; the black wingpit (axillary feathers) of the Chatham petrel being diagnostic. Birds were only handled when necessary and every effort was made to minimise double handling by head-marking individuals with paint. Duco car touch-up paint was used in 1995/96 and white enamel paint in 1996/97. The Duco car paint (in pen form), while easier to apply, tended to stick the feathers together and, on some birds, eventually caused feather loss. Although not as hard-wearing, the enamel paint did not damage feathers and only in a few cases did birds need remarking later in the season. Birds in a breeding pair were given differing head-marks so that they could be easily recognised in the nest chamber. Birds of unknown breeding status found on the ground at night were also head-marked. White paint showed up best on the dark crown feathers and was easily seen at night.

Chatham petrels removed from a burrow were always returned to the burrow via the tunnel, not placed directly into the chamber.

3.1.2 Burrow monitoring

Study burrows were monitored from mid November to mid June. The frequency of monitoring fluctuated, depending on the phase of the breeding cycle. Between mid November and mid December (**prospecting**) burrows were inspected on alternate days. Between late December and early February (**incubation**) they were also checked on alternate days in 1995/96 but were not monitored during 1996/97 until three to four days prior to hatching. From the beginning of February to mid June (**chick rearing**) burrows were inspected up to five times

within a 24 hour period; once during the day, the rest at night. This followed Department of Conservation management policies for the species, which required that every effort be made to enable as many chicks to fledge as possible. This compromised the scientific study but reduced Chatham petrel chick loss.

A fence consisting of sticks, or sticks and leaves, was erected across the entrance of each burrow to determine if a bird had entered or left the burrow. Chambers were checked only if the fence had been disturbed. Fences (see Fig. 1, p. 37 in Gardner & Wilson, this volume) were re-erected after the burrow was checked.

As most of the study burrows were artificial (consisting of a box or dome chamber and nova pipe tunnel), burrow chambers could be monitored with minimal disturbance to the residing birds. Chamber lids were lifted only enough to see which bird was present in the burrow. The frequency and times of monitoring were not identical in the two consecutive seasons.

Prospecting

At the beginning of November, burrows known to have been used by Chatham petrels in the past were checked and tunnels cleared of any debris to allow returning Chatham petrels easy access to the burrow. Fences were erected and burrows monitored until the pre-laying exodus. When a fence was broken but no bird was present, the condition of the burrow was recorded to determine whether the activity could be attributed to Chatham petrels. Indications such as the manner in which the fence was knocked down, condition of the tunnel entrance (prospecting Chatham petrels clear all debris from in and around the burrow entrance), and whether sticks and / or leaves suggestive of nest building were present in the chamber were noted. When a Chatham petrel was present, it was removed and checked to determine whether it was banded. If banded, the band number was checked to establish if the bird was known from the burrow. During the 1995/96 season, Chatham petrels were weighed to determine whether there was a relationship between weight and sex.

The departure date (as close as possible) of each pair was recorded to determine the length of pre-laying exodus. During the 1995/96 season, burrows were not regularly monitored until two and a half weeks after the birds' departure. This period was chosen as Cook's petrel (*Pterodroma cookii*) has a pre-laying exodus of c. 4 weeks (Marchant & Higgins 1990). In the 1996/97 season, the time when burrows were not monitored was extended to three weeks. Burrows of birds that met late in the season (20 December to 31 January) were checked more regularly as these birds were less likely to follow the 'usual' pattern.

Incubation

During the 1995/96 season, the burrows were monitored at 2–3-day intervals. Department of Conservation staff candled eggs to establish fertility levels. In the 1996/97 season the burrows were not monitored during incubation to minimise disturbance to the birds. Monitoring resumed 3–4 days before the eggs were due to hatch. Observers did not feel under brooding birds unless the egg was past the expected hatch date. On two occasions, late-hatching eggs were candled to determine their status. In most nests, signs of hatching could in be seen, e.g. egg-shell remains, peeping or down seen beneath adults. Hatch dates (within 1–2 days of the chick hatching) were recorded so that incubation length could be determined.

Chick rearing

Once the guard period (1–4 days) was over, burrows were monitored daily during daylight hours and between 1–4 times during the night. The number of times a burrow was checked at night depended, to some degree, on the number of broad-billed prions ashore and the likely increase in burrow interference that could result from increasing numbers of broad-billed prions. Such intensive monitoring during this phase of the breeding cycle was necessary to protect Chatham petrel chicks, as they are vulnerable to broad-billed prion interference. To avoid deterring a Chatham petrel from feeding its chick, torchlight was removed from head-marked birds seen close to study burrows and these burrows were not checked until later that night. Once chicks started to leave their burrows at night and explore their surroundings, they were observed, wherever possible, with night vision (NV 100) monoculars to minimise any disturbance caused by the use of torchlight.

3.1.3 Failed burrows

Burrows that failed during the breeding cycle continued to be monitored, but at a reduced level (once a night). Chatham petrel activity at these burrows was recorded to ascertain when failed breeders departed the island.

3.2 TO ESTABLISH WHETHER A PERIOD OF ABANDONMENT OCCURS BEFORE CHICK FLEDGING

Six chicks were weighed daily during the 1996/97 season to determine meal size and feeding frequency. Two chicks from each of the early, middle, and late hatching periods were weighed. The chicks were randomly chosen, the only requirement being that they were residing in a box-type artificial burrow, as it was easier to remove the chick and reduced handling time. If one of the sample chicks died before fledging, it was replaced with an individual of similar age. Each chick had its own weigh bag to reduce the risk of cross contamination. Pesola scales (200 and 500 g) were used to weigh the chicks. Once the chick had been removed from the burrow and placed in the weigh bag, the lid of the chamber was replaced to reduce heat loss from the burrow. In most cases the chicks were handled for 1.5–2 minutes during weighing. Chicks were not weighed on days when it was raining (to avoid their down and the burrow chamber becoming wet), when an adult was present with the chick, or when the chick was out of the burrow.

All other chicks were weighed on alternate days to determine fledging weights. Weighing began approximately one week before fledging. Weighing commenced when the chick was of a suitable age, feather development close to completion and they were active on the ground surface outside their burrows at night. Observations on feather development were recorded every 4–5 days.

3.3 TO ESTABLISH THE SEX OF CHATHAM PETRELS

The accurate sexing of Chatham petrels is difficult, except by examining the cloaca shortly after laying (Taylor 1991). In an attempt to establish the sex of study individuals, feathers were removed during the 1996/97 breeding season for DNA analysis. A single feather approximately 20–25 mm long was removed from the lower neck or nape region of all birds handled. This included individuals from study burrows, and chicks and birds found at night during ground searches whose burrow was unknown. Surgical gloves were worn to avoid contamination of the samples. For removal, the feather shaft was grasped close to the skin and pulled quickly. The feathers were not difficult to remove and the discomfort to the bird appeared minimal. The feather was then placed in a phial containing 97–99% alcohol. The phials were labelled with the band number number of the sampled bird, the burrow they were from, if known or, if not known, the location where the bird was found, and the date.

4. Results

4.1 PROSPECTING, PRE-LAYING EXODUS, INCUBATION AND CHICK PERIODS

4.1.1 Prospecting

Chatham petrels began returning to the island in mid November in both the 1995/96 and 1996/97 breeding seasons. A few individuals may have returned earlier in November, as some burrow fences were knocked down in a manner similar to known Chatham petrel burrow visits, but no birds were observed. During prospecting, burrows were cleaned out, nests built and pair bonds re-affirmed or established.

Between 21 November 1995 and 15 December 1995 weights were taken from prospecting birds (n = 57), (Fig. 2). Initially weights were taken in an attempt to determine sex, but contrary to the findings of Imber (1976) with grey-faced petrels (*Pterodroma macroptera gouldi*), Chatham petrel weights were

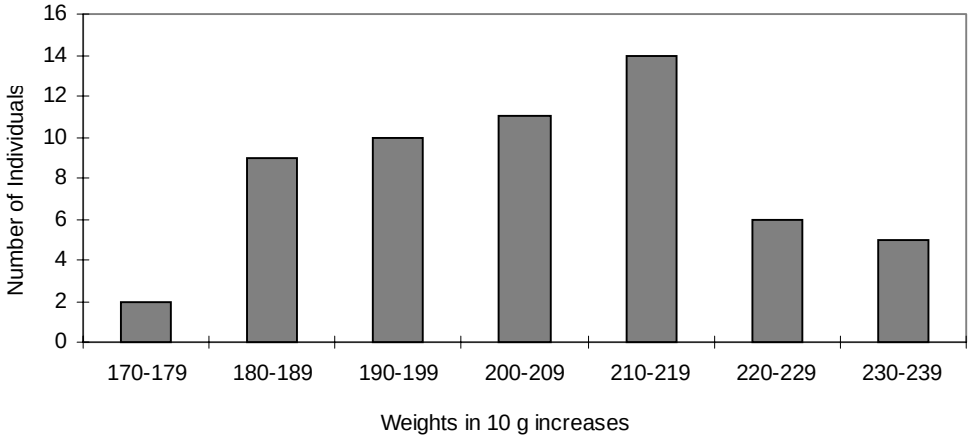

Figure 2. Weights of adult Chatham petrels taken during prospecting 1995.

inconclusive in determining sex. These weights did, however, provide information on the weight range of prospecting Chatham petrels. The mean weight was 206 g (range 176–236 g). Of these 57 individuals, 41 were known to have bred later in the season. The mean weight for these 41 birds was 205 g (range 176–236 g). The breeding status of the other 16 birds was unknown.

4.1.2 Pre-laying exodus

The ength of the pre-laying exodus was recorded as the time between departure date and lay date (Table 1). Only data from burrows where the pairs returned and laid have been included. I found no evidence to suggest that Chatham petrels visited their burrows during the exodus period. Most females appeared to lay immediately on their return.

TABLE 1. PRE-LAYING EXODUS LENGTH FOR CHATHAM PETRELS.

SEASON	*n*	MEAN	RANGE
1995/96	34	27 days	16–37 days
1996/97	32	28.6 days	14–46 days
1995/96 & 1996/97	66	27.8 days	14–46 days

Two pairs during the 1996/97 season left the island as if on a pre-laying exodus, but did not lay on their return. These two pairs each spent 29 and 34 days away from the island, a similar period to other breeding birds. One of these pairs had not previously bred, the other was a known pair. Figure 3 indicates that exodus length can vary. None of the experienced pairs (birds that had bred together for two or more seasons) were away less than 23 days or more than 34 days. It was new pairs (n = 12) that tended to be away on exodus for longer or shorter periods. Some departed late (as late as the middle of January) and returned after the usual exodus length. Others, however, departed late but returned to lay within the period when most breeding pairs lay. These pairs shortened their pre-laying exodus by up to half the mean length. A short exodus (less than 20 days) did not affect the breeding outcome. Of the five pairs in this category, two pairs raised chicks through to fledging, two pairs hatched chicks that died and one pair failed 2–3 days prior to the egg hatching. Those that failed did so due to broad-billed prion burrow interference.

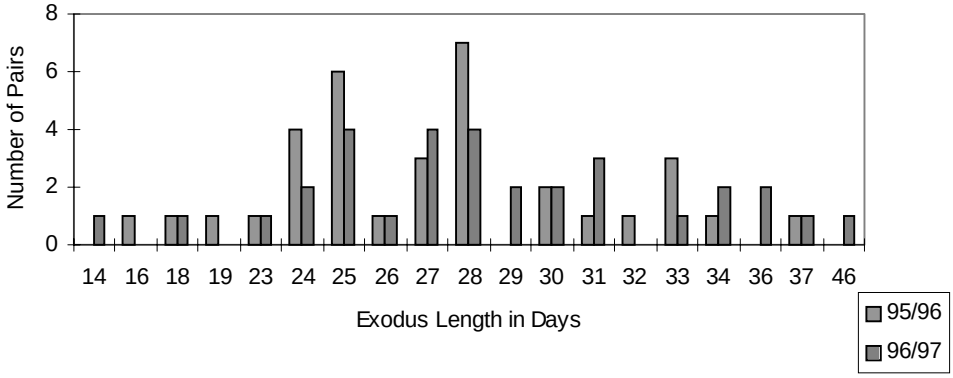

Figure 3. Length of pre-laying exodus during the 1995/96 and 1996/97 Chatham petrel breeding seasons.

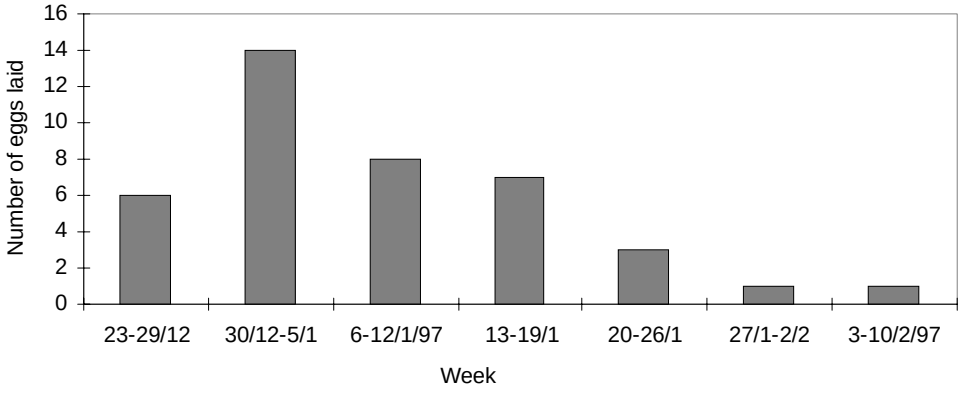

Figure 4. Lay dates for Chatham petrels and number of eggs laid each week during the 1996/97 breeding season.

4.1.3 Incubation

During the 1995/96 season, eggs were laid over a six-week period from 25 December 1995 to 5 February 1996. In the following season, the lay period was seven weeks, from 23 December 1996 to 10 February 1997 (Fig. 4). Of the nests where lay dates were known (n = 37), most eggs (1995/96 86.5%, 1996/97 73%), were laid over a three-week period (23 December–15 January). Late lay dates did not necessarily indicate breeding failure.

Mean incubation length was consistent over both seasons (Table 2). Most pairs (84.2%) incubated for between 44 and 49 days. Seven pairs incubated for a period greater than 49 days and two pairs for a period less than 44 days. Increases in incubation length can be attributed to periods when eggs were temporarily neglected. When neglect occurred naturally (not induced by broad-billed prion interference), it was usually during the first quarter of incubation. There were five abandonments during this period, four were the result of a partner not returning for the next incubation shift and one was due to burrow collapse. During this phase an egg was left unattended for between four and eight days and subsequently hatched. During the 1996/97 season, an egg was left unattended during the last quarter of incubation for four days and hatched.

TABLE 2. INCUBATION LENGTH FOR CHATHAM PETRELS.

SEASON	*n*	MEAN	RANGE
1995/96	30	46.7 days	42–52 days
1996/97	27	47.4 days	43–58 days
1995/96 & 1996/97	57	47 days	42–58 days

Eggs that were abandoned 1–3 days before hatching (n = 8) all failed to hatch. The majority of these abandonments were attributed to broad-billed prion interference (Gardner & Wilson, this volume).

4.1.4 Chick period

To develop a method for ageing chicks when their hatch date is unknown, I compared weight and age of eight chicks during the 1996/97 season. The quadratic equation, weight = $-0.121 \times \text{Age} + 13.275 \times \text{Age} - 25.53$ generated a curve from the data (Fig. 5). This curve fitted the data extremely well (corrected R-squared = 0.875). From this information it is possible to estimate the age of a

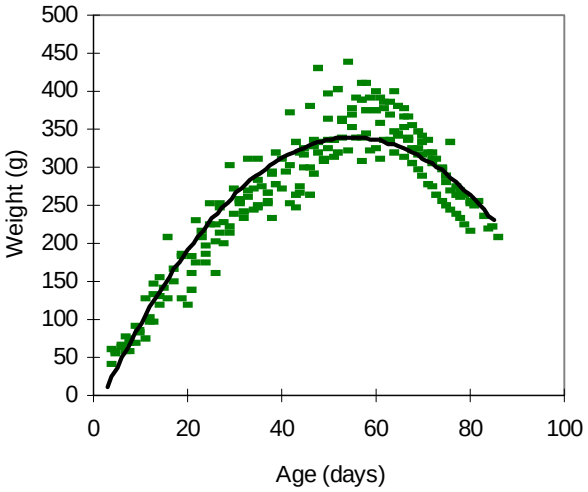

Figure 5. The relationship between weight and age of Chatham petrel chicks (1996/97).

healthy chick from its weight. Even though there are periods within the chick phase when an individual will weigh approximately the same weight, e.g. 35 days old and 65 days old, it is possible to establish the age by assessing other factors, such as feather development. This model suggests one can determine the age of a chick to within a week, from its weight.

Maximum chick weight was on average attained at 54.6 days. Chicks maintain their maximum weight for c. 10–12 days before losing weight prior to fledging. Although individual peak weights varied, the growth pattern was the same for all the chicks weighed. Of the four chicks weighed throughout development, all peaked at weights between 370–430 g.

4.1.5 Meal size and feeding frequency

Eleven chicks were weighed throughout the 1996/97 chick period to gather information on feeding frequency and meal size. Not all were weighed for the entire length of their development, as four chicks were killed by broad-billed prions. Each time one was killed I commenced weighing a chick of similar age.

To determine meal size, only weights that were recorded over sequential days and where feeding dates were known were used for analysis. By determining both the mean loss and gain, i.e. weight changes over a 24-hour period; 'loss' equating to the weight change in an unfed 24-hour period, and 'gain' to the change when the chick was known to be fed (Table 3), it was possible to conservatively estimate an average meal size of 37.8 grams.

A slightly different picture emerged when I divided the chick period into three distinct phases, 0–35, 36–65 and 66–89 days of age (Table 4). While mean weight loss remained relatively constant over the three phases, mean daily gain declined as the chick aged.

TABLE 3. MEAN WEIGHT LOSS AND GAIN (OVER A 24-HOUR PERIOD) OF CHATHAM PETREL CHICKS BETWEEN HATCHING AND FLEDGING.

MEAN (g)	s.d.	*n*
Loss = -13.703 Gain = 24.085	9.356 21.077	127 94

TABLE 4. MEAN WEIGHT LOSS AND MEAN WEIGHT GAIN OF CHATHAM PETREL CHICKS OVER THREE DISTINCT PHASES OF THE CHICK PERIOD.

AGE (IN DAYS)	MEAN (g)	RANGE OF LOSSES AND GAINS (g)	s.d.	*n*
0–35	Loss = –12.64 Gain = 33.67	–3 to –42 –6 to 86	7.63 21.38	28 34
36–65	Loss = –16.73 Gain = 22.88	–5 to –45 –18 to 81	10.37 22.33	34 40
66–89	Loss = –12.59 Gain = 15.14	–3 to –58 –9 to 44	8.56 14.48	61 16

I attempted to determine feeding frequency during each of the three phases of the chick period (Table 5). During the first two phases (0–65 days of age) chicks were fed on approximately 60% of days. However, during the final phase (66–89 days old) this reduced to approximately 20% of days.

TABLE 5. PERCENTAGE OF FEEDING DAYS OVER THREE AGE PERIODS.

AGE (IN DAYS)	% OF DAYS FED	*n*
0–35	59.35	123
36–65	58.11	148
66–89	21.55	16

4.1.6 Fledging

During the 1996/97 season chicks fledged over a five-week period (2 May 1997–7 June 1997). Most chicks (90%) fledged over a period of 22 days (2 May–23 May). The six chicks from the 1995/96 season (where fledge dates are known), also fledged during this period. Chicks fledged between 78 and 88 days of age (Fig. 6).

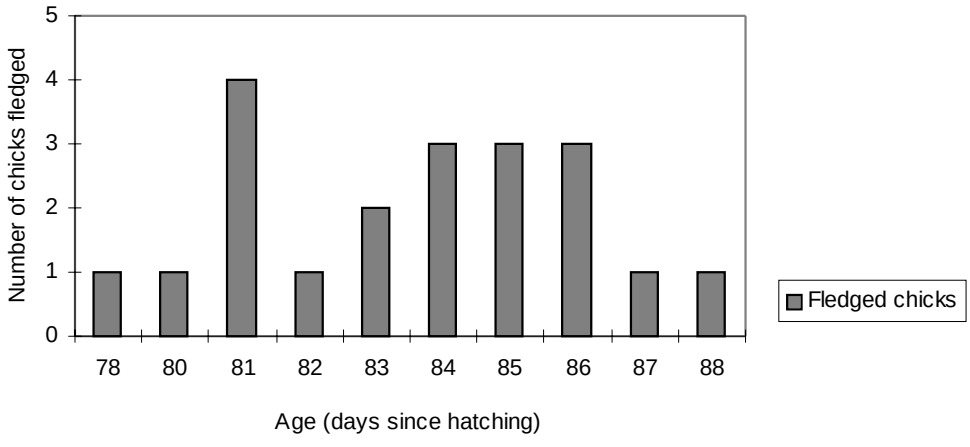

Figure 6. Age of Chatham petrel chicks at fledging (1996/97).

TABLE 6. LENGTH OF CHICK PERIOD (HATCHING TO FLEDGING).

SEASON	N	MEAN	RANGE
1995/96	6	84.7 days	81–90 days
1996/97	20	83.5 days	78–88 days
1995/96 & 1996/97	26	83.8 days	78–90 days

Fledging dates were considered to be the day on which the chick left the burrow and did not return. Ground searches were made 20–30 m around the burrow during the day and night once a chick had left its burrow, to ascertain if it was hiding on the surface. It is feasible that chicks may have hidden in burrows other than their own and not been found. Mean fledging age was similar over the two breeding seasons (Table 6). The small sample size during the 1995/96 season was due to an early end to the field season.

Fledging weights

Of the 20 chicks that fledged in the 1996/97 season, 18 were weighed. Three were last weighed three days before fledging, one two days before fledging, nine one day before fledging and five on the night they fledged. The mean fledging weight for the five weighed on the night they fledged was 209.4 g (range 196–231 g). From the weight data collected for all fledging chicks, it was possible to obtain the mean daily weight loss for each of the 3 days leading up to fledging. This was 20.6 g (n = 16) three days before fledging, 9.8 g (n = 7) two days before fledging and 5.7 g (n = 9) one day before fledging. The mean daily losses made it possible to estimate the likely mean fledging weight (209 g) for 12 of the 13 chicks that were not weighed on the day they fledged. The possible fledging weight for one of the 13 chicks was 252.2 g. This is 21.2 g heavier than the heaviest chick known to have fledged (231 g). In my opinion, it is unlikely the chick fledged at this weight, therefore it was not included in the analysis to determine likely mean fledging weight.

Feather development

General observations of chick feather development and down loss were made as chicks neared fledging (n = 18). Most chicks were fully feathered (no down showing) prior to fledging (mean = 3.1 days, range 0–7 days). Only one chick left its burrow and was presumed fledged with down around its neck (1% of its body surface).

4.1.7 Failed burrows

The length of time burrows were visited after a breeding attempt failed depended on the phase of the breeding cycle when failure occurred. The median length of time individuals visited burrows after failure was 24.0 days (n = 17). However, when separating failures into those that occurred during incubation and those that occurred during the chick period, a slightly different picture emerged. Of the 10 burrows that failed during incubation, the median length of time birds visited was 30.0 days (range 18–60). In contrast, the median length of time burrows were visited after failure during the chick period (n = 7) was 13.0 days (range 5–34, $p < 0.05$ Mann Whitney U-test). As this information was collected only during the 1996/97 season, further data are needed to verify this pattern.

4.2 ABANDONMENT BEFORE FLEDGING

During the 1996/97 season, it was possible to determine that a period of abandonment occurs before chick fledging. All of the 17 fledglings for which data were collected were abandoned before fledging. Abandonment periods were recorded as from the last visit by a parent to the time the chick no longer returned to its burrow and was presumed fledged. Mean abandonment was 11.1 days (range 7–20 days).

4.3 SEXING INDIVIDUALS BY FEATHER ANALYSIS

DNA analysis of the feathers by David Lambert at Massey University was unsuccessful in determining the sex of individuals. As none of the samples were from individuals where sex had been confirmed, it was necessary to complete a second test on each sample to validate the results. The process required more DNA material than could be extracted from the feathers collected. In the future, when sex markers for this species or group of birds have been better identified, and only one test is necessary, feathers may be used to determine sex.

5. Discussion

Knowledge of a species' breeding biology is imperative to any management programme. This study has provided information regarding length of pre-laying exodus, incubation, chick rearing and chick growth that will enable more effective management of Chatham petrels. However, while there is now some knowledge of these aspects, this study has also highlighted areas where more information is needed. The 'anomalies', those pairs and individuals that do not follow the 'normal' sequence of events add an unpredictable element to the management regime. As the success of each possible breeding pair is vital, being able to identify these pairs will enable managers and field staff to monitor them more accurately.

Experienced Chatham petrel pairs generally exhibited synchrony throughout the breeding period, similar to that displayed by other petrel species. They returned to the island during prospecting within a short period of each other (within a week), and frequently on the same night. These pairs spent 1–3 days together in the burrow before leaving on the pre-laying exodus. Individuals from inexperienced pairs sometimes made repeated visits to the island, interspersed with foraging trips, before they met. When a partner from a known pair did not return, the remaining bird spent longer on land, presumably trying to find a new mate (occasionally into the laying period). It is possibly more complicated and difficult for these individuals, and for those wishing to begin breeding, to find a mate now than in the past, due to fragmented burrow distribution and an assumed declining population. This hypothesis is supported by my observation of three birds that bred in the previous season (1995/96) but were seemingly unable to find a new partner. Birds using satellite burrows,

either on the periphery of the 'main colony' (Fig. 1) or hundreds of metres away, are probably even more affected by these factors. Many satellite burrows are no longer in use. Perhaps those occupants not able to find a mate were attracted to the activity over the Kokopu catchment. The delay in finding a mate during prospecting may affect the length of pre-laying exodus and therefore lay dates. However, this could not be determined in the present study.

While most Chatham petrels had a pre-laying exodus of about four weeks, others left for considerably longer or shorter periods (from 14 to 46 days). The length of the pre-laying exodus did not necessarily affect breeding success. Exodus lengths considerably longer than the mean may indicate birds needing extra time to build up condition. The exodus length of pairs that spent longer visiting the island during prospecting were not readily predictable. These pairs either returned after only two to three weeks, therefore laying within the most common lay period, or took the four-week exodus (in some cases longer) and returned to lay considerably later than most of the other pairs. For some pairs this did affect their breeding success as they were incubating well into the time when broad-billed prions had returned to the island after moulting. Therefore they had an increased risk of burrow interference which could subsequently cause desertion. Their chicks also hatched or were still young during the period of greatest broad-billed prion interference (late February to March), often resulting in chick death (Gardner & Wilson, this volume).

Although laying was spread over a six- to seven-week period, three quarters of the pairs laid over one three-week period during this time. While lay dates outside the three-week period did not necessarily imply breeding failure, it is possible that they may indicate pair instability. All experienced pairs laid within the three-week period. There were five pairs that laid late, where there was sufficient knowledge of their histories to attempt an explanation as to the cause. All five pairs had suffered a disruption, i.e. one of the pair did not return, a partner returned late or the known burrow occupant was courting two birds. All these new pairs departed the island on the pre-laying exodus later than any experienced pair. Four of these pairs returned to lay well outside the three-week period. For one of these four pairs, the breeding attempt failed. In this case, the experienced member of the partnership did not return to incubate.

Mean incubation length (approximately 47 days) was similar over both seasons. In cases where eggs were abandoned for a period, most occurred immediately after laying, before the male returned from the pre-laying exodus. This was not observed with experienced pairs.

During the chick period it was possible to determine the percentage of days chicks were fed during the three phases of the chick period, but not the number of meals they received. Chicks were, on occasions, fed by both adults on the same night. While mean weight loss remained constant over the three phases, mean daily gain declined. This could be a result of a decline in feeding frequency and/or meal size, or of older chicks using more energy to maintain themselves and therefore having less to store. The size of the reduction in feeding frequency in the latter third of the chick period is probably heavily influenced by the period of abandonment. Unfortunately, I did not have sufficient data to determine conclusively if meal size decreased over time. Warham (1990) suggested that while the point of decline in weight prior to fledging varies between individual chicks, it usually occurs once 60–80% of the chick period has past. Chatham petrel chick development fits this model.

It is obviously not necessary for chicks to reach a peak weight of at least 400 g to fledge. However, chicks that do perhaps have a safety net that lighter chicks do not. 'The ability of chicks to climb above adult weight and to store fat helps them to survive if the parents' food deliveries fall off and allows trans-equatorial migrants to depart early' (Warham 1990, p. 369). During this study, chicks that reached heavy peak weights (between 370–430 g) also fledged at, or above, mean fledging weight. Presumably it is an advantage for a chick to fledge heavier rather than lighter, as the extra grams 'act as an energy source to tide them over the first critical days and early attempts at foraging' (Warham 1990, p. 369).

All chicks from study burrows underwent a period of abandonment. Sixteen of the seventeen chicks were abandoned for 7 to 14 days. Only one chick was abandoned for longer (20 days). This chick was extremely heavy and may have taken longer to get down to an appropriate fledging weight. Knowing that a period of abandonment occurs is valuable if chick transfers are to take place. Chicks could be removed to the new site during this period and would not need much, if any, additional feeding. However, I believe it is necessary to gain information on when chicks begin emerging from their burrows (days before fledging). It is important to determine if removing chicks from their natal colony during the abandonment period is not rendered pointless by chicks having already ventured outside their burrows and, perhaps, having already identified the natal colony as their return site.

Most chicks fledged over a period of three weeks (2 May to 23 May). In the 1996/97 season two chicks fledged later (2 and 6 June 1997). Both were from new pairings. The mean fledging weight of 209.4 g is marginally heavier than the mean adult weight of 206 g recorded during prospecting. This pattern can also be seen with Cook's petrel, where chicks fledge at 108% of adult weight (Marchant & Higgins 1990; M.J. Imber, pers. comm.).

During the 1996/97 season, there was an age difference between fledging chicks of up to 10 days. The age of a chick at fledging probably depends on a number, or combination, of factors. These probably include weight, feather development, weather and suitable habitat (take-off trees). All but one chick were fully feathered (no down showing) prior to fledging. There were chicks that, although fully feathered, did not fledge for a further 1–7 days until their weight had presumably reached an adequate level. Weather probably also plays a role in determining the day that chicks choose to depart. On occasions, two or more chicks of different ages fledged on the same night.

Suitable take-off trees, or lack of them, could delay the departure of fledging chicks. Although similar-sized petrels are able to takeoff directly from the ground, this may, in part, be related to habitat. Chatham petrels may also be able to take off from the ground if the conditions are suitable, although this is likely to be difficult for chicks inexperienced in flying. One chick fledging in an open but sheltered area with no suitable take-off trees did not fledge when it appeared to be ready (good weight, fully feathered and good weather conditions). After night observations, I decided it was having difficulty finding a take-off tree. A large old *Olearia traversii* branch was leaned against a nearby flax bush and the chick attempted to fledge from the branch within 15 minutes of first locating it. Although I did not see the chick fledge, it did so the same night, after trying, unsuccessfully, to climb flax the previous five nights.

It is important to have an understanding of the behaviour of those pairs where breeding attempts failed. From a management perspective, if the length of time breeders continued to visit their burrows after failure could be determined, the burrows could be blockaded when Chatham petrel activity ceased; therefore preventing broad-billed prion occupancy. This would stop broad-billed prions forming any bond to these Chatham petrel burrows. Once a burrow had failed, pairs normally (but not always) returned to their burrows, re-affirmed their pair bonds and cleaned their burrows. There were three instances with experienced breeding pairs that failed during incubation, where the pairs spent a week or so in their burrows together and built an entirely new nest. They then departed and did not return again during the breeding season. In the 1996/97 season, pairs that failed during incubation were likely to return and visit their burrows for twice as long as pairs that failed during the chick phase. More information is required to determine burrow-use patterns of failed breeders.

This two-year study is just a beginning, and to verify the results presented here, the collection and analysis of additional data on breeding biology would be advantageous. More information on fledging weights, fledging behaviour and length of abandonment is essential before chick transfers are undertaken. From weights collected throughout the chick period, it was possible to develop a model to determine the approximate age of a chick by its weight. This will enable the age of chicks from new and / or natural burrows (which are difficult to monitor) with unknown hatch dates, to be estimated.

The information on breeding biology resulting from this study provides a time-line that roughly outlines the phases of the Chatham petrels' breeding season. This knowledge, along with information on productivity and inter-specific competition, will hopefully aid the continued development of the management strategy for the species.

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7. References

Imber, M.J. 1976: Breeding Biology of the Grey-faced Petrel (*Pterodroma macroptera gouldi*). *Ibis 118*: 51–64.

Imber, M.J. 1985: Origins, phylogeny and taxonomy of the gadfly petrels *Pterodroma* spp. *Ibis 127*: 197–229.

Kennedy, E. 1994: Chatham Petrel Recovery Plan, 1994–1998. Canterbury Conservancy, Department of Conservation (unpublished report).

Marchant, S.; Higgins, P.J. (eds) 1990: The Handbook of Australian, New Zealand and Antarctic Birds. Vol. 1 Oxford University Press, Melbourne.

Taylor, G.A. 1991: Report on the Chatham Island taiko and Chatham Island petrel recovery programmes (1990/91). *Threatened Species Occasional Publication 2*. Department of Conservation, Wellington.

Taylor, G. 1997: Chatham Petrel population demography. Threatened Species Unit, Department of Conservation (unpublished report).

Tennyson, A.J.D.; Millener, P.R. 1994: Bird extinctions and fossil bones from Mangere Island, Chatham Islands. *Notornis (Supplement)* 41: 165–178.

Warham, J. 1990: The Petrels, their ecology and breeding systems. Academic Press, London.

Was, N.; Wilson, K-J. 1998: Burrow occupancy of broad-billed prions *Pachyptila vittata* on South-East (Rangatira) Island, Chatham Islands, New Zealand. Lincoln University Wildlife Management Report to Wellington Conservancy, Department of Conservation (unpublished).

West, J.A. 1994: Chatham petrel (*Pterodroma axillaris*) - an overview. *Notornis (Supplement)* 41: 19–26.