Notornis, 2003, Vol. 50: 183-190
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Post-fledging migration, age of first return and recruitment, and results of inter-colony translocation of black petrels (*Procellaria parkinsoni*)

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Abstract Between 1986 and 1990, 249 black petrels (*Procellaria parkinsoni*) close to fledging were transferred from Aotea (Great Barrier Island) 32 km west to Hauturu (Little Barrier Island) in New Zealand's Hauraki Gulf. At the same time, 50 black petrels of similar age to those transferred were banded as controls on Hauturu and 229 on Aotea. Searches for these birds returning to breeding sites on both islands began in 1991 but three times more search effort was made on more-accessible Aotea. During their first 4.8 years of life at sea the only recovery came from off Ecuador (close to where two 6 year olds were also recovered). Since then to 2001, 32 birds have been recaptured or recovered in New Zealand. Most were first recaptured at 5-6 years old and first breeding at 6-7 years old. A maximum of 42% survived to 6 years old. Survival rates of transferred and control birds were similar. The 1990 cohort had significantly better survival than did the 1986-89 cohorts, and this cohort, just 21% of the experimental birds, contributed 43% of chicks known to have been reared by experimental birds to 2001. Neither body mass at departure nor the El Niño-Southern Oscillation was clearly related to this differential survival. Most transferees returned to Aotea; none of the 1986-89 cohorts was found on Hauturu but 2 of the 3 1990 transferees that were recaptured returned to Hauturu. Given that fledglings were always transferred at a similar stage of development, the earliest transfer of heavy fledglings was the most successful.

Imber, M.J.; McFadden, I.; Bell, E.A.; Scofield, R.P. 2003. Post-fledging migration, age of first return and recruitment, and results of inter-colony translocation of black petrels (*Procellaria parkinsoni*). *Notornis 50(4)*: 183-190.

Keywords black petrel; *Procellaria parkinsoni*; Aotea; Great Barrier Island; Hauturu; Little Barrier Island; migration; post-fledging survival; recruitment; translocation

INTRODUCTION

Many petrel colonies worldwide have declined or become extinct through predation, human exploitation and loss of breeding habitat. In New Zealand, black petrels (*Procellaria parkinsoni*) bred at 5 or more sites on North Island and western South Island before 1900 (Imber 1987; Medway 2002). However, the only 20th century record was in 1958 from Taranaki (Medway 1960), and this petrel is now extinct on New Zealand's main islands. On Hauturu (Little Barrier Island) in the North Island's Hauraki Gulf, black petrels were subjected to predation, mainly by feral cats (*Felis catus*), for over 100 years (Imber 1987) before these predators were exterminated in 1980 (Veitch 2001). The 50-100 breeding pairs then remaining were only 33% of the 1971 remnant of an original colony probably of many thousands of breeding pairs (Reischek 1886; Imber 1987).

The only other surviving colony, on Aotea (Great Barrier Island) 32 km to the east, was much larger and apparently stable (Imber 1987; Scofield 1989). However, this colony exists on a populated island with attendant risks of the introduction of new predators, such as Mustelidae; of attack by dogs, cats and feral pigs; and of fire damage. The New Zealand Wildlife Service and its successor, Department of Conservation, believed that re-establishing a larger, hence more viable, colony

Received 29 January 2002; accepted 20 July 2003

on Hauturu (a nature reserve) would aid in securing the species' future.

Translocation has often been a successful means of conserving land bird species in New Zealand (Armstrong & McLean 1995). The main problem with seabirds is that they are strongly philopatric and strong fliers, so transferred adults would simply return to their natal home. When this experiment began one translocation of fledgling petrels, of Leach's storm-petrels (*Oceanodroma leucorhoa*), had been reported (Kress 1980) but with subsequent breeding not confirmed. A translocation of short-tailed shearwaters (*Puffinus tenuirostris*) resulted in 2 of 157 fledglings returning to breed from a 1960-1971 trial, but none from 50 transferred in 1954 (Serventy *et al.* 1989). Since 1990/91, successful translocations, with birds subsequently returning to breed, have been achieved with fluttering shearwaters (*P. gavia*) (13% of 242 transferees that survived to fledge returning within 7-12 years: Bell 1995; EAB pers. obs.). In a within-island translocation of Gould's petrel (*Pterodroma leucoptera*) 3 (10%) returned to the translocation site at nearly 4 years old (Priddel & Carlile 2001). Common diving-petrels (*Pelecanoides urinatrix*) returned within 1-2 years after transfer to Mana Island in 1997-99 (C.M. Miskelly pers. comm.).

The status of the black petrel colonies in the 1980s provided an ideal situation for a fledgling translocation experiment. There were only two colonies, one depressed, one robust. The translocations could be made from the latter with non-transferred controls at either end to compare survival rates, and both colonies could be searched for returning experimental birds. There were vacant burrows on Hauturu, from the decline of the colony, some of which could be used to receive transferees. The islands were sufficiently close that the logistics of transfer were not too difficult, yet available banding data suggested that each colony was a discrete unit.

The objectives of this experiment were: 1. to transfer fledglings from one island to the other so as to establish and subsequently refine translocation techniques (e.g. selection of birds for transfer, handling, methods of transfer, supplementary feeding); 2. to determine what proportion of the transferees returned to breed in the receptor colony, compared to those returning back to the donor colony, and to the numbers of "controls" returning to each colony.

Breeding black petrels return to colonies in October and November. Most eggs are laid mid-November to late December with a peak in 1-10 December. After about 58 days of incubation most eggs hatch around 1 February. Chicks take about 107 days to be full-fledged and their departures to sea peak around 20 May (Imber 1987). Non-breeders and pre-breeders visit colonies from November to early April.

METHODS

Study sites

Hauturu (Little Barrier I., Fig. 1) is a 2817 ha nature reserve rising to 722 m, comprising relatively pristine subtropical rainforest and very rugged topography. Access to the petrel burrows, which are above 500 m, is practically limited to the vicinity of tracks along ridge-tops. Aotea (Great Barrier I., Fig. 1) is a 285 km^2 inhabited island (population 1130) rising to 621 m, but of easier topography. The petrel burrows, above 300 m, are accessible by well-formed public tracks and recent boardwalks through the main colony, and the adjacent terrain enables extensive searching off tracks. Burrows are in subtropical mature and regenerating rainforest.

Translocation of fledglings

We first tested whether translocated fledglings would stay in receptor burrows, so that they could be fed if necessary. To preclude experimental effects on the rare black petrel we used the abundant grey-faced petrel (*Pterodroma macroptera gouldi*) on Moutohora, Bay of Plenty. In December 1985, 6 grey-faced petrel fledglings about 15 days from departure were shifted 0.5 km. All stayed in their receptor burrows, so we presumed that fledgling black petrels would behave likewise.

Like many procellariiforms, black petrel fledglings take little food during their last 7-15 days in the burrow, and lose weight till departing at about 700-800 g (Imber 1987). They begin emerging at night from around 15 days before departure, when they may become imprinted on their surroundings and natal colony. Thus the intention in this translocation experiment was to transfer as many as possible at about 15 days from departure, so that they would have some opportunity to become imprinted on the transfer site, and need little or no feeding. Ideal birds for transfer were ≥1000 g and with little down remaining. Because the laying period is prolonged (Imber 1987), fledglings varied widely in age and, for our single annual transfer, it was necessary to include some older birds (down-free, lighter) which were close to departure.

Over several days before the planned transfer, 4-6 people in two or three teams searched burrows around Hirakimata on Aotea (Fig. 1), in the main concentration of burrows in this colony. Only fledglings that could be reached through the burrow entrance were caught, but a tendency for mature fledglings to vacate the nest and sit just inside the burrow entrance facilitated this. All fledglings caught were banded, weighed, had

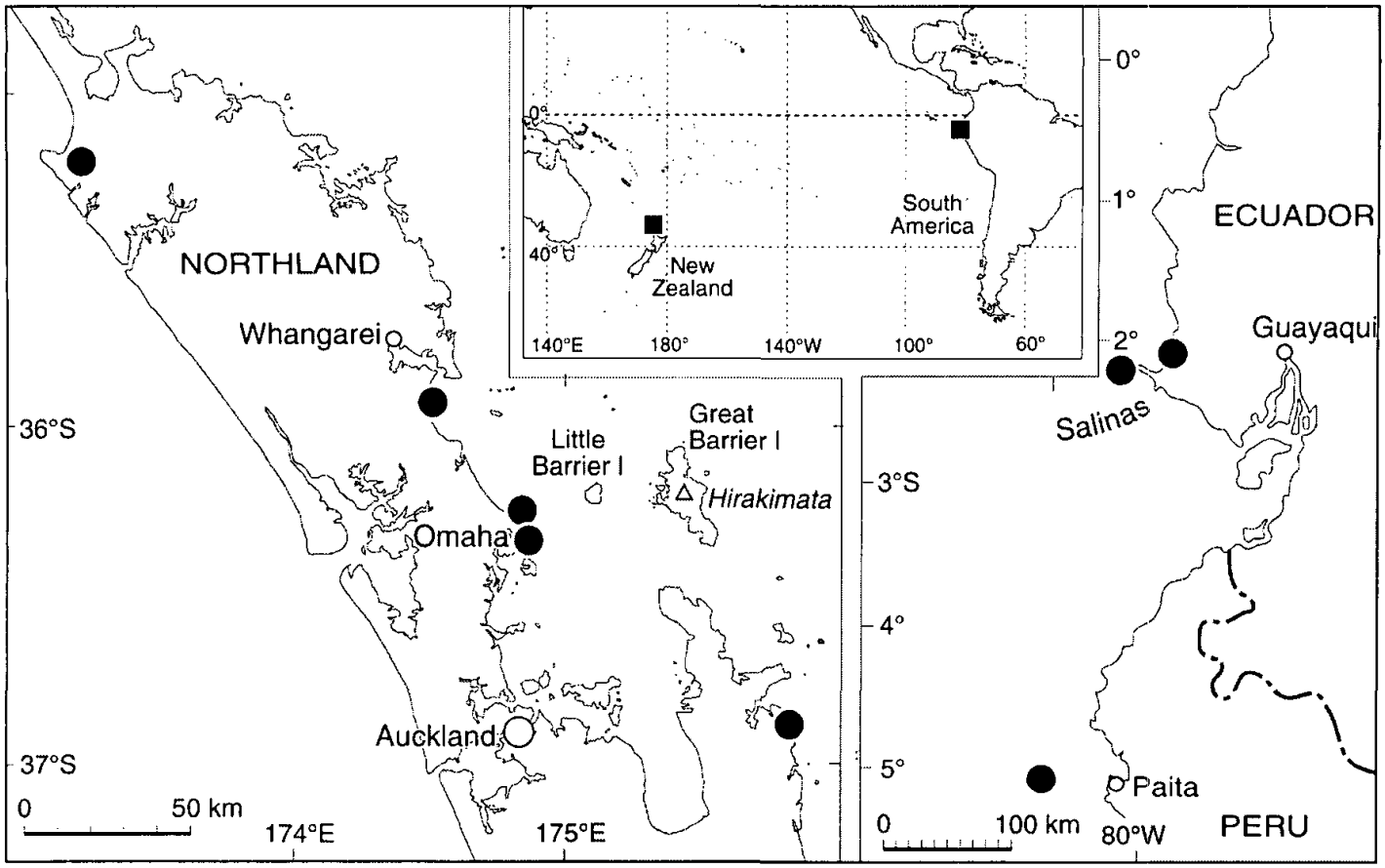

Fig. 1 Map of the South Pacific Ocean, northern New Zealand and the Gulf of Guayaquil area, South America, showing recoveries of black petrels involved as controls on, or transferees between, Aotea (Great Barrier Island) and Hauturu (Little Barrier Island) during 1986–90. Right: Recoveries from 0.5-7 years of age off South America (includes a 1984 recovery from earlier fledgling bandings). Left: Recoveries from 4.8 years of age onwards in New Zealand, except on the breeding colonies (shown).

plumage development noted, and were checked for abnormalities (e.g. some avian pox, and congenital and developmental deformities were occasionally found). Birds were returned to their burrows at this stage, but the burrows of those considered suitable for transfer were marked with coloured plastic tape. All intended transferees were recaptured the day before transfer, put in individual cardboard boxes, and carried down to the departure point where they were held overnight for early morning transfer.

Three transfers to Hauturu (1986-88) were by helicopter, and two (1989-90) by boat. On Hauturu the boxes containing the birds were ferried by helicopter to the summit ridge. In 1990, because of low cloud, the birds were carried up on foot.

The receptor burrows on Hauturu had been identified, prepared and numbered in advance. Most of these were burrows that had become disused during the previous 15 years; some were burrows where breeding had failed that season or the chick had already departed; a few were natural cavities. We cleaned out the unused sites, and improved natural cavities by making them more confined.

All transferred fledglings were weighed and put into the receptor burrows on the day of the transfer. Those requiring food (6-11 each transfer) were placed in more accessible sites. Food given was freshly defrosted squid (*Nototodarus* sp.) cut into strips, offered at about 3-day intervals, and most received 1-3 meals of about 30-100 g. When the bird persistently rejected the food, feeding ceased.

Apart from visits to feed fledglings, the transferees were left to fend for themselves. When feeding birds, checks were made around receptor burrows for any birds either needing assistance or already dead. The exact day of departure was not recorded.

Searching for returning birds

Studies on Hauturu had indicated that black petrels began returning to the colony from about 5 years of age (Imber 1987), though this was based on few data. Thus, searches in both colonies began in 1991 and, except on Hauturu, have been carried out annually since then with results to the 1999/2000 breeding season reported here (Table 1). The search effort was three times greater on Aotea than on Hauturu due to its accessibility, and to ongoing studies (Bell & Sim 1998a, b, 2000a, b, c). The more rugged topography and scattered distribution of burrows in the Hauturu colony made it less accessible.

Table 1 Dates and effort (person-days) spent searching for black petrels (*Procellaria parkinsoni*) involved in the 1986-1990 translocation experiment on Hauturu and Aotea. Methods: burrow checks during daytime (BD), capture of birds on surface at night (SN).

	Hauturu			Aotea		
Season	Effort	Method	Dates	Effort	Methods	Dates
1991-1992	4	BD	6-10 Nov	17	SN	10-18 Nov, 3-12 Mar
1992-1993	15	BD	14-28 Jan	3	SN	28-31 Jan
1993-1994	0	-		3	SN	3-6 Mar
1994-1995	0	-		8	SN	24-30 Nov, 15/16 Feb
1995-1996	13	BD	1-14 Feb	17	BD,SN	30 Jan- 16 Feb
1996-1997	13	BD	14-27 Jan	34	BD,SN	21 Jan- 24 Feb
1997-1998	0	-		35	BD,SN	21 Jan- 25 Feb
1998-1999	16	BD	26 Jan-11 Feb	34	BD,SN	25 Jan- 28 Feb
1999-2000	0	-		37	BD	17 Jan- 23 Feb
Total (days)	61			188		

Table 2 Dates of transfers, numbers of fledgling black petrels transferred from Aotea to Hauturu or banded as controls on each island during 1986-1990, and mean weights (g ± sd) at transfer.

		Transferred birds		Control birds		Total
Year	Date of transfer	No.	Mean weight	Hauturu	Aotea	birds
1986	10 May	46	941 ± 84	11	43	100
1987	4 May	60	918 ± 85	14	60	134
1988	15 May	40	998 ± 129	13	37	90
1989	3 May	49	1070 ± 126	7	38	94
1990	30 April	54	1077 ± 111	5	51	110
Total		249		50	229	528

Search work has involved capturing birds on the surface at night on Aotea, but predominantly it has been through monitoring study burrows with nests accessible from the entrance or through artificial, covered access holes. Birds thus caught were checked for bands, banded if necessary, and their breeding status was recorded. Birds were sexed by cloacal examination on Hauturu but not on Aotea because birds were studied too late in the breeding season for cloacal sexing.

Statistical analyses

We used Cormack-Jolly-Seber mark-recapture analyses to examine survival of transferred and control birds. Recapture histories were analyzed using the live recaptures Cormack-Jolly-Seber option of programme MARK (White & Burnham 1999). We also investigated the relationship between weight of transferred and control birds and their survival. Their weight at banding was assumed to be their weight at emergence. The best standard model was constrained using the weight covariates by incorporating the values into the design matrix (White & Burnham 1999). Putative values of survival at given weight were then calculated by back-transformation of the beta values and results were graphed.

RESULTS

The translocations and losses before fledging

The numbers and weights of transferred black petrel fledglings and the dates of the transfers are shown in Table 2. The losses or deaths recorded during the operations, until the fledglings' departures, included 4 lost from their carrying boxes in 1987. This reduced the number transferred that year from 64 to 60. No fledglings transferred to Hauturu were found dead there. One Hauturu control died soon after banding as its band only was found there next year; one Aotea control was killed by an Australasian harrier (*Circus approximans*), after getting a leg caught in shrubbery; and one transferee found to have bird pox on arrival at Hauturu was not released. These 7 birds have been excluded from the experimental data (Table 2). One departing fledgling was apparently drawn to city lights, being found in the Auckland suburb of Mangere 5 days after transfer: it was released in the Hauraki Gulf. No other recoveries or recaptures were made in New Zealand during the following 4.8 years of each cohort's life.

Post-fledging migration

Two transferred fledglings were recovered off

Table 3 First time recaptures or recoveries in the New Zealand region, and first recorded breeding age, of black petrel fledglings banded as controls and transferees on Aotea and Hauturu from 1986 to 1990, by years after banding = age. Recoveries within first month excluded.

	Age (Years)							
	<4.8	<5>	<6>	<7>	<8>	<9>	<10>	>10.5
No. recovered/ recaptured for first time	0	7	10	4	3	2	2	4
No. beached/ blown inland	0	3	1	1	0	0	0	0
No. breeding for first time	0	0	4	3	2	2	1	3

South America. A 1990 female was shot just off Salinas (2°S, 81°W), Ecuador on 4 May 1991 (J.A. Gerwin pers. comm.). Its mass was 650 g (female mean = 682 ± s.d. 57 g (Imber 1987)). It was "very fatty" and in moult: heavily in the body; the primaries nearly complete (10th emerging, 9th about $\frac{3}{4}$ grown, rest new); secondaries worn but for 1 and 2 new and $3\frac{3}{4}$-grown; no tail moult, but whether worn or new was not noted. The beak already showed yellowish colour of adults. It was shot, along with 8 unbanded, and deposited in the Philadelphia Academy of Sciences, U.S.A., where it is preserved as a skin and tissue samples. This bird had been fed twice after transfer.

A 1986 transferee was recovered as by-catch on an unknown type of fishing vessel off Paita, northern Peru (5°S, 81.5°W) in December 1991. From an earlier banding of fledglings, in 1978 on Aotea, a 6.5 year old was found dead on a beach at Palmar, near Guayaquil, Ecuador (2°S, 80.5°W) in September 1984. These 3 recoveries were spread throughout the year, and made within a radius of 160 km (Fig. 1).

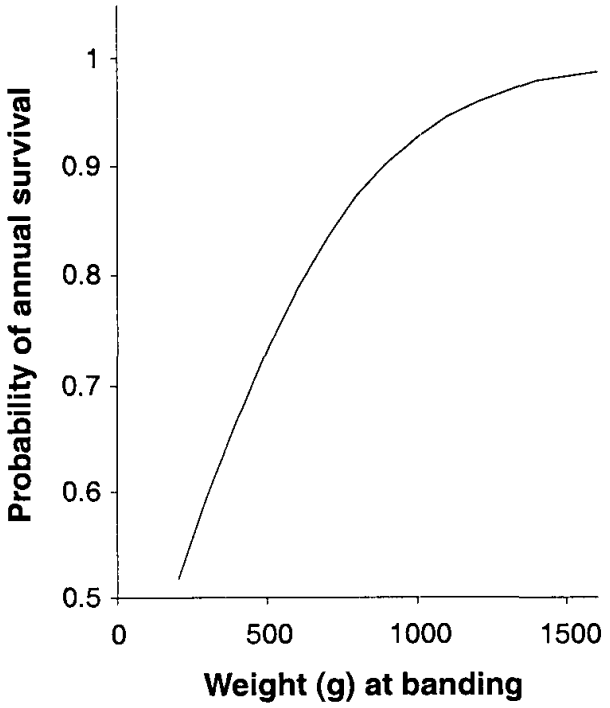

Fig. 2 Regression of weight (g) at banding of all fledglings involved as controls or transferees in the 1986-90 translocations from Aotea to Hauturu, against their probability of annual survival. The data were back-transformed using their beta values.

Age of first return to New Zealand and first breeding

The first recaptures or recoveries in the New Zealand region of these fledglings after they had departed were of birds nearing, or older than, 5 years of age (Table 3). The same pattern was found in those beached or blown inland in New Zealand (Table 3). However, a downy chick banded in March 1992 on Aotea (S. Rowe pers. comm.) was recaptured there in February 1996 (Bell & Sim 1998a), so a few return at 4 years of age.

Age at first breeding tended to be 1-2 years later than age at first return (Table 3). Data are few but it is notable that 3 of the 4 birds first breeding at 6 years were on Hauturu, perhaps indicating earlier breeding in this depressed colony. Aotea birds mostly bred first at 7 years of age.

Recovery and survival rates

Recoveries plus first-time recaptures by cohort (cohort year refers to the latter year of a breeding season) up to 2000 are shown in Table 4. Recoveries of the 1990 cohort were significantly greater than for other cohorts. Even allowing an 8% per year correction for annual mortality the difference was significant ($P<0.05$). The lightweight 1987 cohort had the lowest recovery rate but this was not significantly different from that of 1986, 1988 and 1989.

The rates of recoveries according to treatment are shown in Table 5. There was no difference between the first-time recapture plus recovery rates of all controls and all transferees. The corresponding rate for Hauturu controls was lower than that for Aotea controls because of the lesser search effort on the former (Table 1: 61 days cf. 188 days (32.5%)), the reasons for which are explained in Methods. The recapture rate (i.e. live birds at the

Table 4 First-time recaptures plus recoveries (%) up to 1999/2000 of black petrel fledglings involved as controls or transferees on Aotea and Hauturu during 1986-90.

Cohort	No. banded	Recoveries plus recaptures	
		No.	%
1986	100	5	5.0
1987	134	5	3.7
1988	90	5	5.6
1989	94	5	5.3
1990	110	14	12.7

χ^2 (1986-1989 vs 1990) = 7.69; 1 df; $P<0.01$

Table 5 Comparison of first-time recapture plus recovery rates to 1999/2000 of control and transferred black petrel fledglings banded on Aotea and Hauturu during 1986-90.

Cohort	No. banded	Recoveries plus recaptures	
		No.	%
Hauturu controls	50	2	4.00
Aotea controls	229	16	6.99
All controls	279	18	6.45
Transferees	249	16	6.43

χ^2 (all controls vs transferees) = 0.00, 1 df, ns

colony) of Aotea controls was 6.1% (14 of 229), which is 3 times that of the Hauturu controls (1 of 50 = 2%), though this is not statistically significant.

The annual survival rate of control birds was 86.7 ± se 1.07 % whilst the annual survival of transferred birds was 87.1 ± se 4.95 %. A model where survival varied only with time fitted the data significantly better than a model where survival varied by group (Delta AICc =130.54). This indicates that the difference in survival of the control and transfer groups was not as significant as the variation in survival with time. Furthermore, these data indicate that a maximum of 42% of these birds would have survived to 6 years of age.

Survival in relation to weight at emergence showed a positive trend (Fig. 2). The range of weights, 450-1430 g, equated to annual survival rates increasing from 70% to 98%.

Results of translocations

Recaptures on the breeding grounds to the 2000/01 breeding season are analysed in Table 6. The 1990 cohort, that had survived so well, was further notable for its disproportionate contribution to the numbers of experimental birds found breeding, and with a chick. This cohort, just 21% of the experimental birds, produced 43% of chicks known to have been reared by experimental birds to 2000/01. The 1990 cohort was the only one from which transferees (2) were found breeding on Hauturu. Only one bird from this cohort of transferees was found back on Aotea. The number of transferees found on Hauturu may be corrected for the lesser search effort there. Assuming similar survival rates for the transferred cohorts from each island, a recapture effort on Hauturu equivalent to that on Aotea (see previous section) may have yielded as many as 6 recaptures of the 1990 transferees on Hauturu.

None of the transferees from the 1986-89 cohorts was found on Hauturu (Table 6). It appears that those surviving to breeding age returned to Aotea, where they bred more successfully than controls of those years (18 chicks cf. 3 from controls, to 2000/01).

DISCUSSION

Post-fledging migration

Three recoveries of 1-6 year-old birds on or just off the coasts of Ecuador and northern Peru throughout the year, together with the absence of recoveries in New Zealand waters of birds less than 4 years old, indicate that black petrels probably spend these years of immaturity entirely in the eastern tropical Pacific Ocean. These seas have already been recognised as wintering grounds of this species (Pitman 1986; Pitman & Ballance 1992). Black petrels have been observed off the west coasts of the Americas from northern Peru (5°S) to southern Mexico (15°N) and off the Galapagos Islands (Jehl 1974; Pitman 1986; Pitman & Ballance 1992; R.L. Pitman pers. comm.). The concentration of all 3 recoveries within a 160 km radius may indicate that this area off the Gulf of Guayaquil is preferred by this species. Pitman (1986), though not differentiating between black petrels and white-chinned petrels (*Procellaria aequinoctialis*), showed the greatest concentration of these birds north of 5°S to be in this area. Probably most or all were black petrels.

Fledgling black petrels apparently leave New Zealand seas and migrate eastward immediately upon leaving the colonies. From 12 - 18 May 1994 MJI observed seabird by-catch aboard a tuna longliner vessel in the eastern Bay of Plenty, New Zealand. Black petrel fledgling departures peak around 20 May (Imber 1987). Although the longliner was fishing across the probable flight path of fledglings passing from the colonies to beyond East Cape, MJI saw none. Only a few adults in brownish worn plumage were feeding busily behind the vessel, probably foraging to feed late-fledging chicks.

The earliest returns to New Zealand were recorded at 4 years of age (1 bird), and around 5 years of age. The occurrence of 2 beach-wrecks and 1 blown inland at 5 years old, possibly during their first summer back in New Zealand seas, may indicate

Table 6 Recaptures on the breeding grounds and breeding success to 2000/01 of black petrels transferred from Aotea to Hauturu, or left as controls, during 1986-90.

Cohort	No.	No. recaptured	No. breeding	No. with chick
Hauturu controls, 1986–89	45	0	0	0
Hauturu controls, 1990	5	1	1	0
Transferees on Hauturu 1986-89	195	0	0	0
Transferees on Hauturu 1990	54	2	2	2
Transferees on Aotea 1986-89	195	8	6	5
Transferees on Aotea 1990	54	1	1	1
Aotea controls, 1986-89	178	7	2	2
Aotea controls, 1990	51	7	5	5
All 1990 (n =110) as % of total in the experiment	20.8	42.3	52.9	53.3

that the return migration or having to learn about new foraging areas imposes increased mortality at that time.

Survival by cohort

Mass at fledging in procellariiforms has been hypothesised as an important predictor of survival (Sagar & Horning 1998). In our study there was a positive relationship between weight of all birds (controls and transferees combined) and their survival rate. The 1990 cohort, the heaviest, had a significantly higher recovery rate than did the 4 earlier cohorts. However, the mean weight at transfer in each year only weakly correlated with recovery rate (r^2=0.35, P>0.1). The 1987 cohort was the lightest, and this could have been an important cause of its poor recovery rate and reproductive performance (no offspring recorded to 2001).

As fledgling black petrels migrate into the eastern tropical Pacific, we examined possible effects of the El Niño - Southern Oscillation (ENSO) on the birds. The El Niño phase produces a warm sea current flowing southwards off Colombia and Ecuador, and thus directly affects some seas where black petrels congregate. It causes decreases in marine productivity in otherwise rich areas, whereas effects of the cold La Nina phase are little known (Ribic *et al.* 1992). Studying the effects of ENSO on seabirds in the eastern tropical Pacific from 1984 to 1989, they found that both an El Niño event (1986-87) and a La Nina event (1988) were important factors, causing decreases of abundance and diversity of species. They did not record black petrels, probably because their study area was further west and more pelagic than the normal range of this species.

We examined the ENSO cycles during the period 1986-1995 (Wolter 2002) but found no clearly obvious features that could explain the different recovery rates of the 5 cohorts. Both the 1986-87 El Niño and the 1988 La Nina were associated with poorly surviving black petrel cohorts. The 1990 cohort experienced moderate El Niño conditions throughout its 5 adolescent years.

Results of the translocation experiment

Whereas the 1986-89 transfers were apparently unsuccessful (no birds recovered on Hauturu), results from the 1990 transfer are encouraging. Although only two 1990 transferees have been found on Hauturu, the low search effort there suggests more could be present. Also, the converse of the high survival of the 1990 cohort, but recapture of only one transferee back on Aotea, is that the majority of the surviving transferees may have in fact settled on Hauturu.

Why only 1990 transferees returned to their adopted site is not obvious. It was the earliest transfer but by only 3 days. The birds were one of the heaviest cohorts at transfer, and this could have caused them to spend most time on Hauturu before departing, hence helping to imprint them on the new site. Considering various factors, we suggest that the combination of early transfer, high mass, and higher survival of the 1990 cohort was the cause of the relative success of this transfer.

Conclusions

The survival rates of the transferred and control birds were not significantly different, indicating that the experiment did not have a detrimental effect on the populations of this vulnerable species. Therefore, the techniques used in this experiment would be appropriate for other petrel transfers. If extensive supplementary feeding is not undertaken, fledglings should be transferred as early as possible in the pre-fledging desertion period, and be selected for maximum weight. Results of this study suggest that for black petrels this means transfer by 30 April and mean weight above 1000 g. The translocation experiment had only limited success given that 9 of 11 recaptured

transferees returning to their natal island. Earlier transfer with supplementary feeding of all fledglings may be needed to make the technique more successful.

There was higher mortality in several cohorts of black petrel fledglings during their first 5 years of life in the eastern tropical Pacific, or on the associated migration. Presumably, oceanographic or meteorological factors were responsible for this. Invoking fisheries by-catch mortality, a possible cause, would make it difficult to explain the significantly higher survival in one of the five cohorts studied.

ACKNOWLEDGEMENTS

This experiment could not have been carried out without the valuable contributions and hard work of many volunteers, among whom special thanks are due to Stella Rowe and Alison Davis; and Trevor Bennet, Derek Bettesworh, Hugh Clifford, Reg Cotter, Athol Gardner, Brenda Green, Lyndsay Hatch, Peter Hodum, Tamara Jones, John and Tim Rowe, Paul Scofield, Terry Smith, Cliff Taylor, Graeme Taylor, Alan Tennyson, Gavin Woodward and anyone inadvertently omitted. Several staff of the New Zealand Wildlife Service (which initiated the project), and Department of Conservation, participated in the work, with Craig Hodsell being involved in most of the transfers; also Mike Aviss, Shaarina Boyd, Derek Brown, Terry Greene, Craig Syms and Phil Thompson. Stella Rowe organised and led a survey on Aotea in 1992.

Our warmest thanks to Alex and Mike Dobbins for their constant support and hospitality during the transfer operations at the Hauturu end; also later rangers on Hauturu: Chris Smuts-Kennedy and Irene Petrove. On Aotea, Don Woodcock and his staff, particularly Brownie Walker, of the New Zealand Forest Service/Department of Conservation, gave us their full support. They provided the boat for the transfers in 1989 and 1990, and inter-island boat transport in later years, for which we are very grateful.

Our thanks go to Neville Stephenson, helicopter pilot in the four years that we used his services; also to the crews of MV "Hauturu" for transport over the years. We are very grateful to Jean-Claude Stahl, Peter Gaze, Murray Williams and Jaap Jasperse for extensive comments on drafts of this paper, Chris Edkins for drawing the figures, and Mala Nesaratnam for word-processing.

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