Population parameters and distribution of the black petrel (*Procellaria parkinsoni*), 2005/06

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ABSTRACT

This report is part of a long-term study of the black petrel (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island). During the 2005/06 breeding season, 366 study burrows within the 35-ha study site near Mount Hobson were checked and intensively monitored. Breeding pairs used 257 burrows, non-breeding adults used 43 burrows, and the remaining 66 burrows were non-occupied. By 5 May 2006, 164 chicks were still present in the study burrows and 8 others were presumed to have already fledged, corresponding to a breeding success of 67%. Nine census grids were monitored within the study site and contained 148 of the inspected burrows, with 93 burrows being used for breeding. One new burrow (not recorded in previous years) was found. Twenty-four chicks from earlier breeding seasons were recaptured within the study site. Twenty-five percent of the random transects established within the study site in 2004/05 were re-surveyed. These results and previous data were analysed to clarify habitat grade characteristics and burrow density within the study site. This clearly identified zones of different burrow density (no burrows, low, medium and high burrow density areas). Based on these density ranges and incorporating habitat characteristics, the study area was stratified, and its black petrel population estimated to be in the range of 3164–4066 birds. Eleven geo-locator data-loggers were also deployed on breeding black petrels. These indicated that the foraging range for the black petrels was highly variable, with no apparent differences between the sexes. Seven birds foraged around the North Island of New Zealand, particularly along the continental shelf edges or seamounts. Four birds travelled near the Chatham Rise, two birds travelled further north towards Fiji, four birds travelled towards the eastern Australian coast and one bird travelled around the southern tip of the South Island of New Zealand. These preliminary results show how important accurate foraging and distribution information is for determining national and international fisheries risk for the black petrel. It is recommended that further tracking work is undertaken for this species.

Bell, E.A.; Sim, J.L.; Scofield, P. 2009: Population parameters and distribution of the black petrel (*Procellaria parkinsoni*), 2005/06. *DOC Research & Development Series 307*. Department of Conservation, Wellington. 47 p.

1. Introduction

The black petrel, *Procellaria parkinsoni*, is a medium-sized endemic seabird which is only known to breed on Hauturu/Little Barrier Island (36°199´S 175°082´E) and Great Barrier Island (Aotea Island) (36°187´S 175°4125´E), New Zealand (Heather & Robertson 1996). The main breeding area on Great Barrier Island lies around the summit of Mount Hobson. Monitoring work carried out in this area during the 2005/06 breeding season was a continuation of the survey and monitoring study begun in 1995/96 (Bell & Sim 1998a, b, 2000a, b, c, 2002, 2003a, b, 2005; Bell et al. 2007), adding to the baseline data on the Great Barrier Island black petrel population. This study will assist in identifying effects that long-line fishing, rat and cat predation and habitat disturbance may have on the population. The population estimate has been updated, ensuring that any population changes will be detected in time to implement the appropriate management strategies.

2. Objectives

The main objective of this study was to undertake an annual census of the black petrel population on Great Barrier Island via burrow monitoring and the banding of adults and fledglings to establish levels of adult mortality, breeding success and recruitment. Since this study was a continuation of research from previous breeding seasons, we also aimed to provide more data to establish population trends and to determine causes and timing of mortality.

The study objectives were to:

- Monitor a sample of black petrel burrows within the main breeding area on Great Barrier Island and band all adults present in the burrows during December 2005 and January/February 2006 and all remaining fledglings during April 2006
- Determine breeding success in the sample of long-term study burrows and record causes of breeding failure, such as predation or disappearance of parents
- Monitor and re-survey the census grids and study site for new burrows and band and recapture as many breeding and non-breeding birds present as possible
- Determine a population estimate by extrapolating from transect lines and census grids to the main Mount Hobson breeding area.
- Continue the mark/recapture programme and band as many birds as possible at the beginning of the breeding season (November/December) to determine juvenile (pre-breeder) survival, age of first return to the natal colony, age of first breeding attempt, age of first successful breeding attempt and adult (breeder) survival

- Confirm the breeding status of adults during each visit to the colony (i.e. monitor the study burrows at the beginning, middle and end of the breeding season) and, where possible, identify the sex of the resident adult
- Use light geo-locator data-loggers to determine the at-sea distribution of black petrels during the breeding season (incubation and chick rearing)

3. Methods

3.1 STUDY BURROWS

The study site (35 ha at and near the summit of Mount Hobson; Fig. 1) was visited from 1 to 11 December 2005. During this visit the study burrows ($n = 366$, Figs 1–4) were checked for the presence of adults and eggs. The study burrows were either randomly selected from burrows along the track system (i.e. within 10 m of either side), burrows that have returned chicks (pre-breeders) resident, or all burrows within the nine census grids. The study burrows have been selected regularly since the 1995/96 season (Bell & Sim 1998a, b, 2000a, b, c, 2002, 2003 a, b, 2005; Bell et al. 2007). To ensure accurate monitoring, the study burrows were accessible either through the main entrance or via an opening that had been excavated through the burrow roof into the chamber. This opening was covered by a piece of plywood, which was camoflaged with soil and debris. Any occupying adult was removed from the burrow, banded (or the band number recorded if a recapture), sexed by viewing the cloaca (if swollen, the bird is a female—the cloaca is particularly obvious immediately after egg laying), and returned to the burrow. The presence of any egg was noted.

On a second visit to the study area (planned for 14–29 January 2006), the intention was to monitor the study burrows intensively. Because of very bad weather conditions, this trip was cut short and a further visit to the colony was made from 20 to 27 February 2006, when the study burrows were intensively monitored again.

As in the December visit, any adults present were identified or banded, and returned to the burrow. The presence of eggs, eggshell fragments or chicks was noted and the absence of this sign was used to identify non-breeding birds. The study burrows were monitored again (1 to 5 May 2006) to determine breeding success.

The locations of study burrows were mapped by entering GPS co-ordinates into GIS-mapping software (Manifold™).

3.2 CENSUS GRIDS

The three original grids—KDG1, PTG1 and SFG1—were established in 1996 (Bell & Sim 1998a). These grids were located in areas with a known historical presence of black petrels, different strata, vegetation types and topography and were near known petrel-launch sites (Bell & Sim 1998a). These original girds

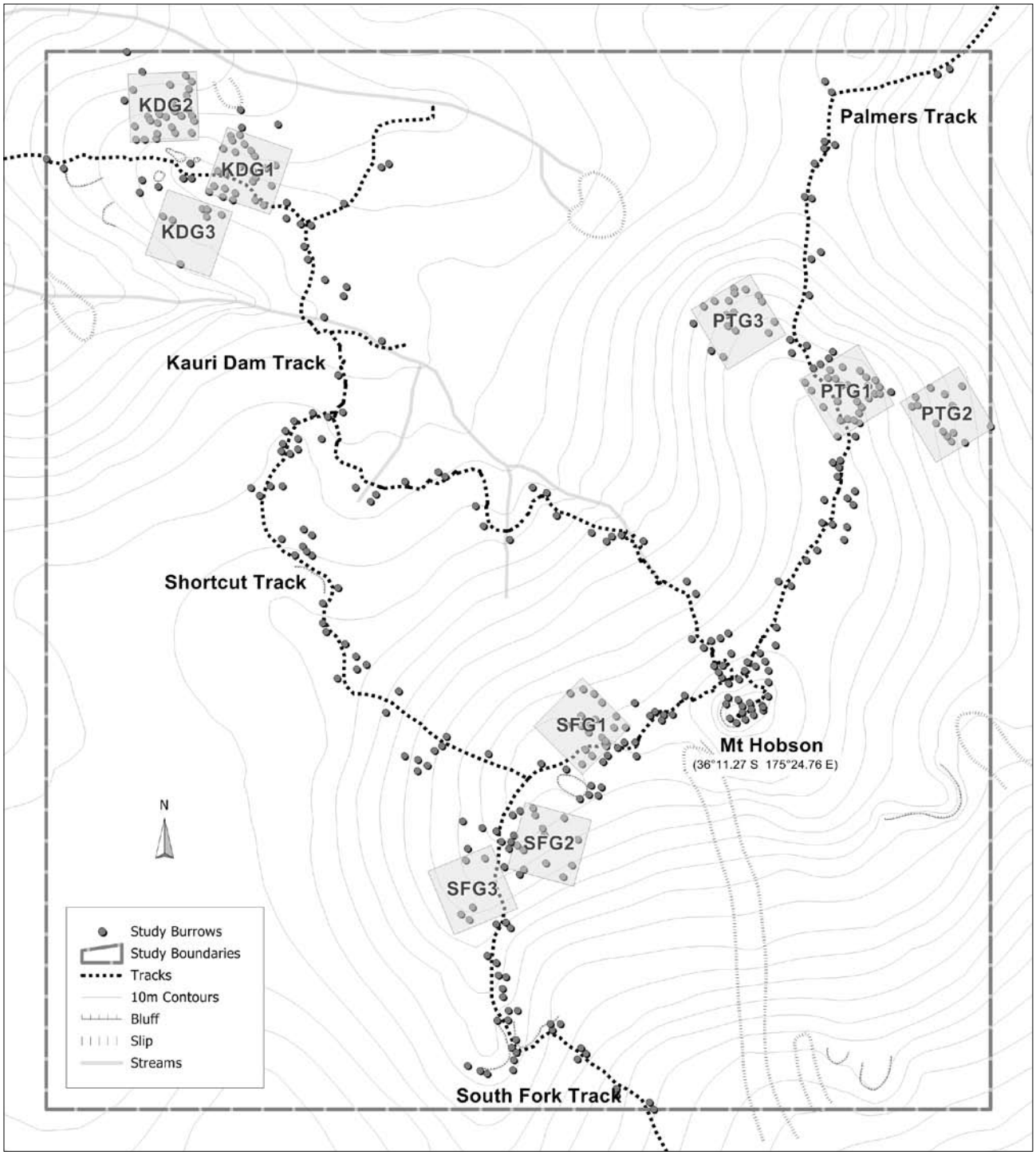
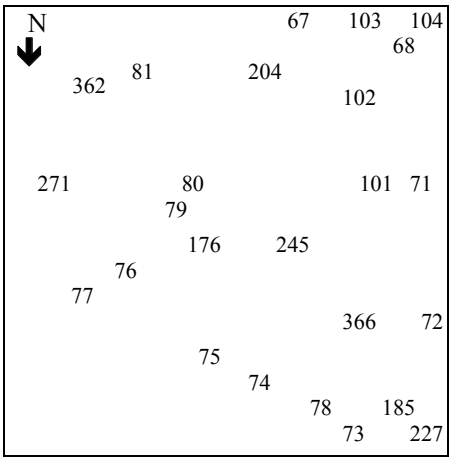
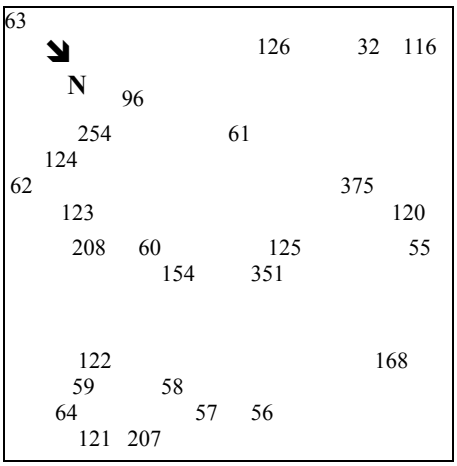


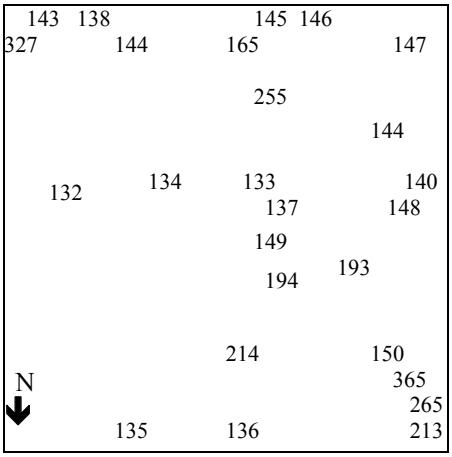
Figure 1. Location of the black petrel (*Procellaria parkinsoni*) study burrows and census grids within the study site on Great Barrier Island (Aotea Island). Altitude (621 m a.s.l.) is shown. Approximate North is shown (N). KDG = Kauri Dam Grid; SFG = South Forks Grid; PTG = Palmers Track Grid.



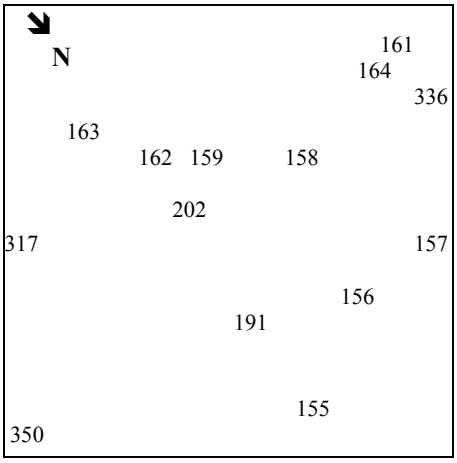
Kauri Dam grid one (KDG1)



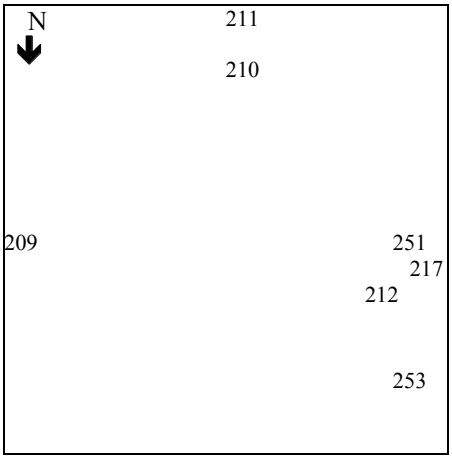
Palmer's Track grid one (PTG1)



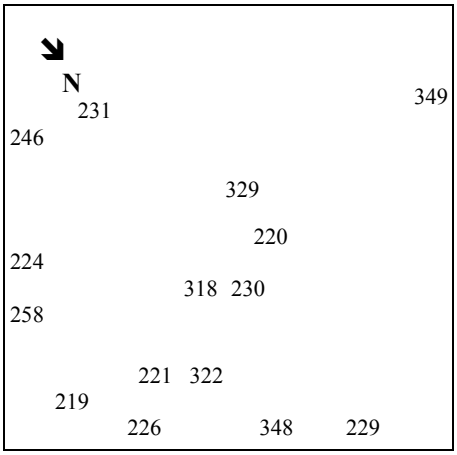
Kauri Dam grid two (KDG2)



Palmer's Track grid two (PTG2)



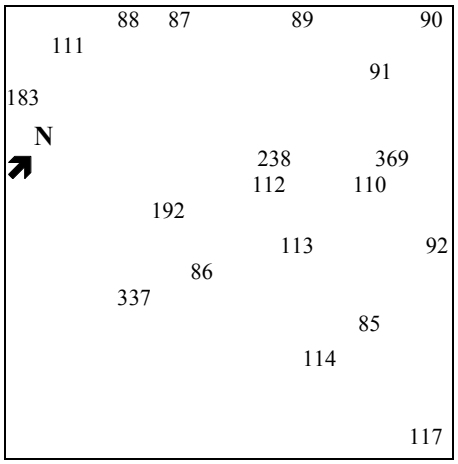
Kauri Dam grid three (KDG3)



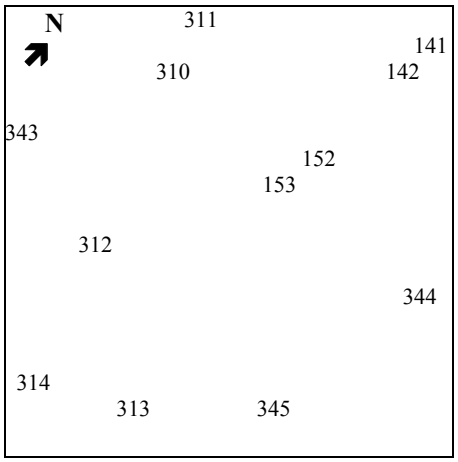
Palmer's Track grid three (PTG3)

Figure 2. Location of black petrel (*Procellaria parkinsoni*) burrows found in the Kauri Dam grid sites (each grid is 40 × 40 m), Great Barrier Island (Aotea Island).

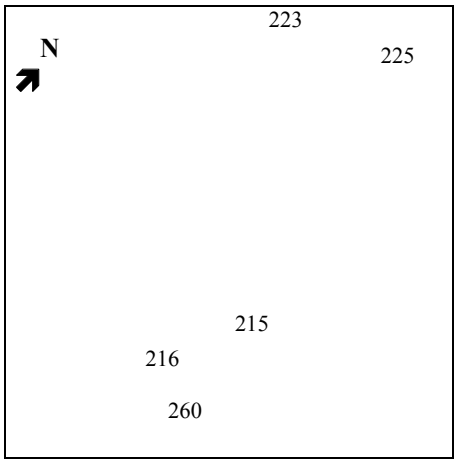
Figure 3. Location of black petrel (*Procellaria parkinsoni*) burrows found in the Palmers Track grid sites (each grid is 40 × 40 m) on Great Barrier Island (Aotea Island).



South Fork Track grid one (SFG1)



South Fork grid two (SFG2)



Kauri Dam grid three (SFG3)

Figure 4. Location of black petrel (*Procellaria parkinsoni*) burrows found in the South Fork grid sites (each grid is 40 × 40 m) on Great Barrier Island (Aotea Island).

were replicated in 1998 (KDG2, PTG2 and SFG2) and in 1999 (KDG3, PGT3 and SFG3) to compare burrow densities between areas and to increase the accuracy of the population estimate (Bell & Sim 2000a, b).

In the present study, these nine census grids (each 40 × 40 m) around Mount Hobson were systematically searched (at 1-m intervals) during the December visit to locate any new burrows and to determine occupancy rates (Figs 1–4). The same procedure as for study burrows (see Section 3.1) was followed for all birds in the burrows in the grids.

3.3 TRANSECTS

Twenty-six random transects were completed during the 2004/05 breeding season to determine burrow density throughout the study site (Bell et al. 2007). Seven of these transects were resurveyed in the same manner during December this season (LT1, 6, 12, 18, 19, 37 and 41). Any burrows located within the search area were treated in the same manner as given in the 2004/05 season report (Bell et al. 2007) and the same procedure as outlined in Section 3.1 was followed for any bird caught in the transect burrows.

In the present (2005/06) study, four grades of petrel habitat were identified, based on the density of petrel burrows and incorporating habitat characteristics such as terrain (slope and aspect), vegetation (emergent tree species, dense or moderate canopy species, scrub species and undergrowth species) and coverage (scrub cover, secondary growth or primary forest). Each transect of the original 19 transects and 7 resurveyed transects were then stratified using these four grades of habitat. The coverage area (two-dimensional only) of the four different grades of petrel habitat (non–petrel habitat, low grade, medium grade and high grade) within the study site was determined using Manifold™.

3.4 NIGHT BANDING

Night work was undertaken during the December 2005 visit to the study area. This involved searching the study area by walking the track system and capturing any adult on the surface. Several nights were also spent at known petrel launch sites, where birds were captured at take off or landing. All birds were banded or had their band numbers recorded. During this visit sex was determined if possible (by cloacal inspection).

3.5 POPULATION AND SURVIVAL ESTIMATES

Bell et al. (2007) noted that previous population estimates determined by direct extrapolation from the nine census grids on Great Barrier Island have overestimated the black petrel population size (Bell & Sim 1998a, b, 2000a, b, c, 2002, 2003a, b, 2005). This is due to the fact that these grids were established in areas of known high petrel density, whereas the study area does not have a uniform distribution of burrows. Extrapolation from transect data might give a fairer estimate, but it still fails to take into account the range of habitat types identified within the study site.

This can be shown by deriving three possible population estimates for the 35-ha study site:

- Extrapolating from the original census grids (multiplying their density values by 35)
- Extrapolating from transects only (multiplying their density values by 35)
- Extrapolating from the transects and census grids after stratification of the study site (by stratifying the 35-ha study site into the four habitat grades based on burrow density, ranking the transects and census grids into those habitat types, and then extrapolating from the ranked transects to the habitat areas which make up the 35-ha study site)

For all estimates, any breeding burrow was treated as having two resident birds present and any non-breeding burrows was treated as having 1.25 birds present (as for any non-breeding burrow there is a 25% chance of capturing more than one bird in the burrow when the resident male attracts a female to that burrow).

Adult survival and the corresponding dispersion coefficient (Chat) value were calculated using the Cormack Jolly Seber model for adult survival over time (Phi(t)

P(t)), where Phi = apparent survival, t = time and *P* = probability of recapture. Juvenile survival and the corresponding Chat value were also calculated, using the Burnham Jolly Seber model. Population trends were measured using multi-state models to determine the probability of changing states from chick to successful or non-successful breeder to non-breeder: S(.) *P*(.) psi(breeder to non-breeder*t), where S = survival rate, *P* = probability of recapture, psi = transition probability and t = time using five states (unknown status, successful breeder, unsuccessful breeder, chick, non-breeder). Adult survival was assumed to be constant and the probability of survival of chicks was set at 0.5 for the first 3 years and then 0.92 thereafter. These parameters were calculated by the Burnham Jolly Seber model, which relaxes the assumption of equal catchability, allows survival to be set for certain age classes, uses the information from both live captures and dead recoveries, and determines the rate of change between each transition state. All parameters were determined using Program MARK (http://welcome.warnercnr.colostate.edu/~gwhite/mark/mark.htm). The goodness of fit of the models (i.e. likelihood value) was measured using Aikakes Modified Information Criterion (AICc). Models with a lower AIC are better that those with higher AIC, i.e. it is more likely that the model fits the population and is likely to be an accurate explanation of, or value for, the parameter (such as survival).

3.6 DATA-LOGGERS

Eleven LOTEK™ LAT2500 geo-locator data-loggers (Lotek Wireless, Ontario, Canada) were attached to known breeding adult black petrels during the December 2005 visit. The birds were chosen from the Kauri Dam area (within the study site) if they had been successful breeders for at least five seasons and had been in the same pair for over eight seasons. These loggers were light (6 g) and small and fitted into a specially designed holder, which was then attached to the bird's leg by a small rubber strap. Six were placed on known males, three were placed on known females and two were placed on birds of unknown sex (one suspected male and one suspected female). All 11 geo-locator data-loggers were retrieved during the January 2006 visit. The data-loggers give data on position, flight time, time spent on the water, surface temperature and dive depth. The loggers record temperature and pressure data every 80 seconds. The data was downloaded in April 2006 and analysed using an algorithm program developed in the USA (Scott Schaffer, University of California Santa Cruz, pers. comm. 2006). A trip was distinguished by the departure from and return to the colony (i.e. Great Barrier Island) by the bird. Any bird could make one or more trips from the colony between deployment and retrieval of the loggers, depending on the stage of incubation and behaviour of the bird. Multiple trips for individual birds were identified separately (i.e. alphabetically). Detailed plots of each trip were then mapped onto New Zealand bathymetry maps (see Section 4.7). Ethical approval for the use of all geo-locator data loggers was given by DOC Ethics Committee (15 Dec 2005, AEC127).

4. Results

4.1 STUDY BURROWS

Of the 366 study burrows (those burrows that could be accessed to determine occupancy out of the 369 numbered burrows) in 2005/06, 257 contained breeding birds, 43 contained non-breeding birds and 66 were non-occupied (Appendix 1). There were 85 failures (e.g. loss of eggs, infertility, predation etc. before fledging, see Table 1, Appendix 1). This corresponds to a breeding success of 67% (Table 1, Appendix 1).

Data from the past nine breeding seasons (since 1997/98) show that the ratio of breeding to non-breeding burrows has averaged 3:1 (Bell & Sim 2000a, b, c, 2002, 2003a, b, 2005; Bell et al. 2007; Table 2). However, the ratio of breeding to non-breeding burrows for the 2005/06 breeding season (6:1) is much lower than the average and the percentage of non-occupied burrows was also higher than most of the previous seasons monirored (18%; Table 2, Fig. 5). The proportion of non-occupied burrows has steadily increased since the beginning of the study (Table 2, Fig. 5).

4.2 NUMBER OF BURROWS IN THE CENSUS GRIDS

A total of 148 burrows were found in the nine census grids, all save one known from previous years (Figs 2–4). The new burrow was a non-breeding burrow that was being dug out in South Fork Grid 1 (Fig. 4). Ninety-three of these burrows were used by breeding pairs, 15 were used by non-breeding adults and 40 burrows were non-occupied (Appendix 1). There were also several 'potential' burrows within the grids, which were not included in any burrow estimate. 'Potential' burrows were those which had been investigated and/or preliminarily dug out by petrels, but were not yet being used by breeding or non-breeding petrels. These potential burrows were monitored annually to check for black petrel activity.

4.3 TRANSECTS

During the 2004/05 breeding season, 26 transects had been measured and surveyed within the study area (Bell et al. 2007). Seven of these transects were resurveyed. No new burrows were located along any transect, but vegetation and terrain information was clarified. Six of the burrows located on these seven transects are now being monitored as part of the study burrow set.

In the 2005/06 breeding year, our resurveys and reanalysis of the original transect data identified four burrow density grades (with corresponding habitat types) within the study site:

TABLE 1. BREEDING SUCCESS AND CAUSES OF MORTALITY IN THE BLACK PETREL (*Procellaria parkinsoni*) STUDY BURROWS ON GREAT BARRIER ISLAND (AOTEA ISLAND) BETWEEN THE 1996/97 AND 2005/06 BREEDING SEASONS.

	YEAR								
	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06
Number of study burrows	137	197	248	255	283	318	324	362	366
Eggs									
laid	95	142	178	168	192	199	208	226	257
predated (rat)	1	2	9	6	5	1	2	3	15
crushed[a]	0	1	10	6	5	14	13	7	27
abandoned	1	5	1	3	9	7	0	3	1
infertile	4	12	6	8	3	2	7	4	0
dead embryo (at various stages)	8	6	13	9	14	19	16	12	9
disappeared[b]	0	0	0	0	11	3	0	5	19
unknown fate[c]	0	0	0	0	0	5	0	0	0
Chicks									
hatched	81	116	139	136	145	148	170	192	186
predated (rat)	0	2	0	0	0	0	0	0	0
predated (cat)	0	2	2	1	2	3	2	0	2
died (disease)	0	0	0	0	0	0	0	0	0
died (starvation)	1	0	0	0	0	0	0	0	0
died (unknown causes)	0	3	6	7	8	8	10	7	12
disappeared	0	0	0	0	0	0	0	4[d]	0
fledged[e]	80	109	131	128	135	137[f]	158[g]	181[h]	172[i]
Overall breeding success[j] (%)	84	77	74	76	70	69	76	80	67

[a] Apparently crushed accidentally by the parents or during fighting with interloping birds and only shell fragments were recovered from the burrow. However, some may have been predated by rats, infertile, contained an embryo which died or eggs may have been crushed when adults were handled.

[b] These eggs were present in November/December, but were gone when burrows were first checked in January. Many of the burrows had been cleaned out by birds and the adults were not seen again that season.

[c] There were five burrows not located in May 2003 and as a result it is not known if the eggs hatched successfully. To determine overall breeding success, we have conservatively assumed that they failed.

[d] These chicks were present in February 2004, but were gone in April 2004. The chicks were too young to have fledged. Some may have been predated by rats or cats, or died due to starvation or disease and been removed from the burrow by their parents.

[e] All chicks still present at the end of the April trip. It is assumed that all fledged safely.

[f] Of these, 78 chicks had already fledged prior to the banding visit, only 59 chicks were banded.

[g] Of these, 50 chicks had already fledged prior to the banding visit, only 108 chicks were banded.

[h] Of these, 6 chicks had already fledged prior to the banding visit, only 175 chicks were banded.

[i] Of these, 8 chicks had already fledged prior to the banding visit, 143 of the remaining 164 chicks were banded (due to a lack of bands).

[j] Percentage chicks fledged from number of eggs laid.

- High-grade petrel habitat on ridges or spurs, usually in established canopy, with high burrow density (≥ 100 burrows/ha)
- Medium-grade petrel habitat on steep slopes, usually in established canopy or tall secondary growth, with medium burrow density (50–99 burrows/ha)
- Low-grade petrel habitat, on low slopes or flat ground, often boggy, with low burrow density (1–49 burrows/ha)
- Non-petrel habitat, on stream beds, cliffs, slips and swampy areas with scrub or *Garnia*, with no burrows

TABLE 2. PROPORTIONS OF BREEDING, NON-BREEDING, OCCUPIED AND NON-OCCUPIED BLACK PETREL (*Procellaria parkinsoni*) BURROWS, AND RATIOS OF OCCUPIED TO NON-OCCUPIED BURROWS AND BREEDING TO NON-BREEDING BURROWS WITHIN THE STUDY BURROWS ON GREAT BARRIER ISLAND (AOTEA ISLAND) SINCE THE 1997/98 BREEDING SEASON.

	OCCUPIED (%)	NON-OCCUPIED (%)	RATIO OCCUPIED: NON-OCCUPIED	BREEDING BURROWS (%)	NON-BREEDING BURROWS (%)	RATIO BREEDING: NON-BREEDING
1997/98	98	2	49:1	68	30	2:1
1998/99	93	7	13:1	72	21	3:1
1999/00	94	6	16:1	72	22	3:1
2000/01	95	5	19:1	66	29	2:1
2001/02	92	8	12:1	68	24	3:1
2002/03	88	12	7:1	63	25	2.5:1
2003/04	82	18	5:1	64	18	3.5:1
2004/05	86	14	6:1	63	23	3:1
2005/06	82	18	5:1	70	12	6:1
Mean (± SEM)	**90 (± 2)**	**10 (± 2)**	**15:1 (± 4)**	**67 (± 1)**	**23 (± 2)**	**3:1 (± 0.4)**

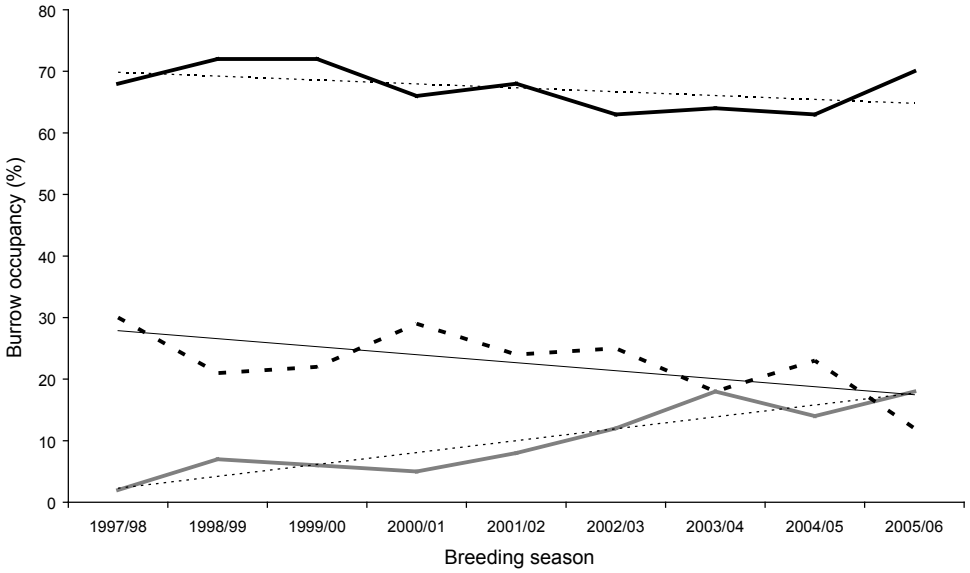


Figure 5. Occupancy of study burrows (1997/98 to 2005/06 breeding years) by black petrels (*Procellaria parkinsoni*) on Great Barrier island (Aotea Island). Solid black line = burrows used by breeding birds; solid grey line = unoccupied burrows and dashed line = burrows used by non-breeding birds; lighter dashed lines show linear trend.

Using Manifold™, vegetation and terrain survey data and ranking transects, the two-dimensional area for each of the habitat types in the 35-ha study area was found to be 7 ha of high-grade petrel habitat, 17 ha of medium-grade petrel habitat, 10 ha of low-grade petrel habitat and 1 ha of non-petrel habitat (Fig. 6).

4.4 BANDING DATA

There were 485 adults identified during the 2005/06 season, with 377 already banded and 108 banded this season (Table 3). There were 164 chicks still present in the study burrows, but because the number of bands available on the island was underestimated, only 143 chicks were banded (Table 3, Appendix 1). The chicks were in very good condition, with many ready to fledge. Eight chicks had already fledged.

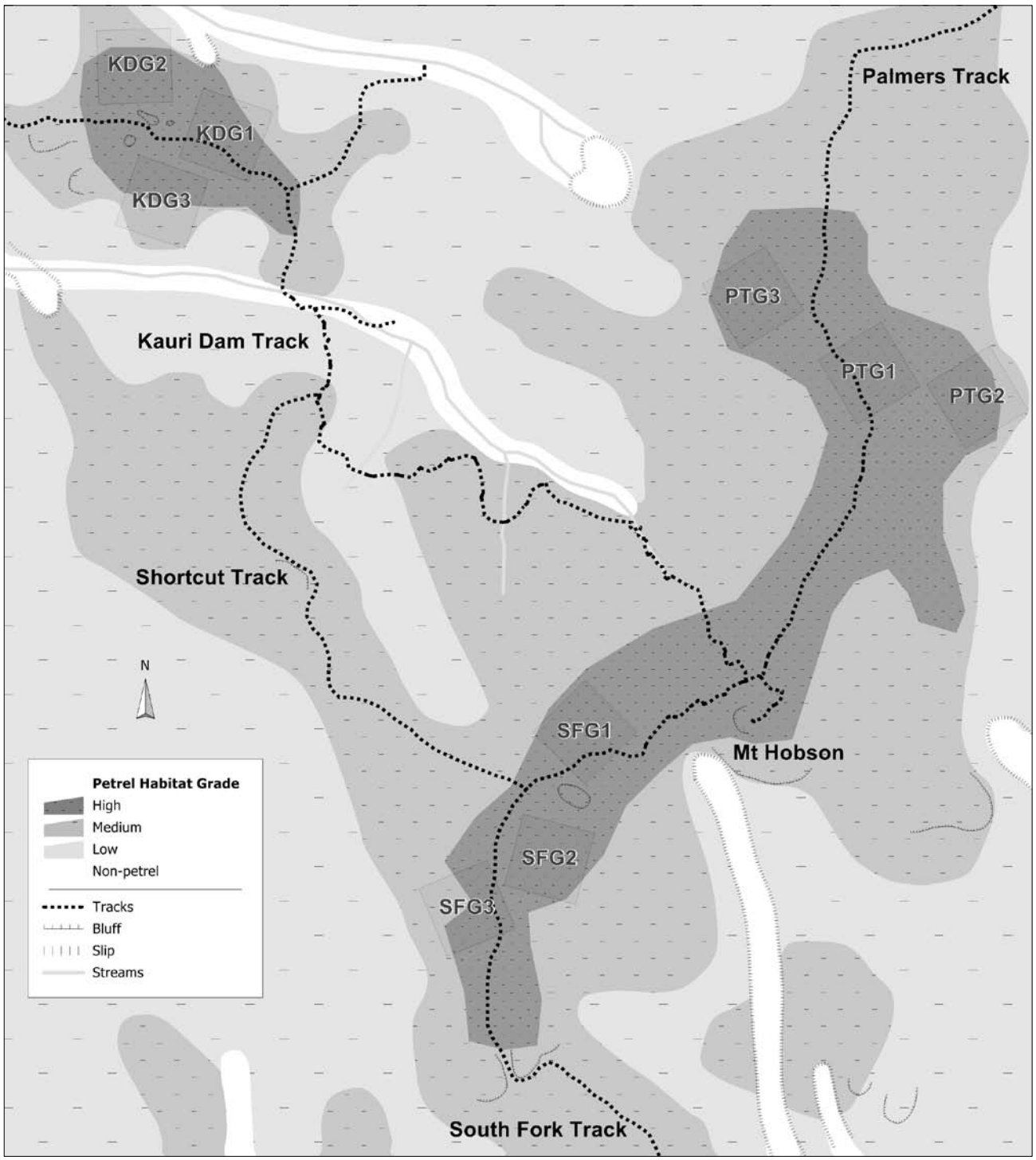


Figure 6. Habitat grades, based on black petrel (*Procellaria parkinsoni*) burrow density (incorporating habitat characteristics), within the 35-ha study site on Great Barrier Island (Aotea Island). There are 7 ha of high-grade petrel habitat, 17 ha of medium-grade petrel habitat, 10 ha of low-grade petrel habitat and 1 ha of non-petrel habitat.

There have been 1265 chicks banded within the study site between 1995 and 2006 (Table 3). These birds have begun to return to the colony as pre-breeders, non-breeder and breeders. The first returned chick (banded in the 1995/96 season) was recaptured as a pre-breeder in the 1999/00 season. Since the 1999/00 season, 50 returned chicks have been recaptured (some more than once) in subsequent years (Tables 3 & 4). While the youngest age at first recapture is 3 years, the mean (± SEM) age at first recapture is 5.0 ± 0.2 (Table 4). Twenty-four of these birds

TABLE 3. BANDING, RECAPTURE AND RECOVERY DATA FROM ALL BLACK PETRELS (*Procellaria parkinsoni*) CAUGHT WITHIN THE STUDY SITE ON GREAT BARRIER ISLAND (AOTEA ISLAND) FOR THE BREEDING SEASONS 1995/96 TO 2005/06.

	YEAR										
	95/96	96/97	97/98	98/99	99/ 00	00/01	01/02	02/03	03/04	04/05	05/06
Recaptures of birds banded prior to 1995	19	31	24	23	29	27	27	27	21	22	22
Recaptures of birds banded in 1995/96	–	14	14	14	16	14	11	12	12	8	12
Recaptures of birds banded in 1996/97	–	–	113	86	84	73	63	57	43	37	39
Recaptures of birds banded in 1997/98	–	–	–	32	32	30	28	24	18	27	18
Recaptures of birds banded in 1998/99	–	–	–	–	95	82	71	64	49	36	39
Recaptures of birds banded in 1999/00	–	–	–	–	–	86	75	66	47	51	52
Recaptures of birds banded in 2000/01	–	–	–	–	–	–	51	52	41	22	36
Recaptures of birds banded in 2001/02	–	–	–	–	–	–	–	68	88	26	25
Recaptures of birds banded in 2002/03	–	–	–	–	–	–	–	–	61	55	57
Recaptures of birds banded in 2003/04	–	–	–	–	–	–	–	–	–	22	28
Recaptures of birds banded in 2004/05	–	–	–	–	–	–	–	–	–	–	48
Total recaptures	**19**	**45**	**151**	**155**	**256**	**312**	**326**	**370**	**380**	**306**	**377**
Number of new adults (banded that season)	41	179	60	129	145	97	114	179	67	135	108
Total adults	**60**	**224**	**211**	**284**	**401**	**409**	**440**	**549**	**447**	**441**	**485**
Number of chicks (banded that season)	59	69	85	116	137	137	160	62	110	184	143
Total number of birds	**119**	**293**	**296**	**400**	**538**	**546**	**600**	**611**	**557**	**625**	**627**
Number of returned chicks from each cohort year that have been recaptured alive at the study site in the 2005/06 season	3	6	10	14	12	3	2	0	0	0	0
Band recoveries from dead birds	**–**	**1**	**1**	**–**	**2**	**1**	**2**	**2**	**–**	**–**	**2**

have attempted to breed over five seasons (2000/01 to 2005/06; Bell & Sim 2002, 2003a, b, 2005; Bell et al. 2007), with 15 breeding successfully over that period. Of the 27 birds that returned in the 2005/06 season, 15 attempted to breed, with 10 successfully raising chicks of their own. The age at first breeding ranges from 5 to 9 years (Mean ± SEM = 5.9 ± 0.2; Table 4) and the age at first successful breeding also ranges from 5 to 9 years (Mean ± SEM = 6.1 ± 0.3; Table 4). The remaining birds have not bred, although several males were recaptured while calling to attract a mate.

Of the 27 returned chicks, four were recaptured in their natal burrows, 16 in their natal area (< 50 m from their natal burrow) and other six chicks were caught > 100 m away from their natal areas.

An immigration event was recorded for the first time in 2005/06, as a chick (H30807) banded on Hauturu/Little Barrier Island in the 1996/97 breeding season (by Reg Cotter; Mike Imber, DOC, pers. comm. 2005) was recaptured as a breeding adult on Great Barrier Island (in burrow 243, successfully raising a chick, Appendix 1).

TABLE 4. NUMBER OF RECAPTURES, AGE AT FIRST RECAPTURE, AGE AT FIRST BREEDING AND AGE AT FIRST SUCCESSFUL BREEDING FOR n = 50 BLACK PETRELS (*Procellaria parkinsoni*) BANDED AS CHICKS AND RECAPTURED IN THE STUDY SITE ON GREAT BARRIER ISLAND (AOTEA ISLAND) WITH A NOTE ABOUT AN IMMIGRANT BANDED AS A CHICK ON HAUTURU/LITTLE BARRIER ISLAND.

BAND	SEX	SEASON BANDED	SEASON WHEN LAST RECAPTURED	NUMBER OF RECAPTURES	AGE AT FIRST RECAPTURE (YEARS)	AGE AT FIRST BREEDING (YEARS)	AGE AT FIRST SUCCESSFUL BREEDING (YEARS)
H25525	Male	1998/99	2005/06	1	7	–	–
H25536	Male	1998/99	2005/06	2	6	–	–
H25546	Male	1998/99	2005/06	3	5	5	7
H25630	Male	1999/00	2005/06	2	5	–	–
H25631		1999/00	2003/04	1	4	–	–
H25635	Male	1999/00	2005/06	2	5	6	–
H25637	Male	1999/00	2004/05	1	5	–	–
H25648	Male	1999/00	2005/06	2	5	–	–
H25651	Male	1999/00	2005/06	2	5	6	–
H25658	Male	1999/00	2004/05	1	5	–	–
H25659	Female	1999/00	2005/06	1	6	6	6
H25663	Male	1999/00	2005/06	3	4	–	–
H25664	? Female	1999/00	2005/06	3	3	6	–
H25669	Male	1999/00	2005/06	2	5	5	5
H25673	Male	1999/00	2005/06	2	5	5	–
H28085	Male	1998/99	2005/06	1	7	–	–
H29912	? Male	2000/01	2005/06	1	5	5	–
H30908	? Male	1995/96	2002/03	1	7	–	–
H30924	Male	1995/96	2005/06	5	6	6	6
H30930	Male	1995/96	2005/06	7	4	5	5
H31076		1997/98	2002/03	1	5	–	–
H31080		1997/98	2001/02	1	4	–	–
H31081	? Male	1997/98	2002/03	2	4	–	–
H31082	Male	1997/98	2001/02	1	4	–	–
H31089		1997/98	2003/04	2	5	6	–
H31194	Male	1996/97	2001/02	1	5	5	5
H31366	? Male	1997/98	2005/06	4	5	6	6
H31370	? Male	1997/98	2005/06	2	5	8	–
H31377	? Male	1997/98	2001/02	1	4	–	–
H31382	Female	1997/98	2003/04	3	4	5	5
H31383	Male	1997/98	2003/04	1	6	6	6
H31405		1996/97	2004/05	3	6	7	8
H31406	? Female	1996/97	2001/02	1	5	–	–
H31413	? Female	1996/97	2004/05	1	5	5	5
H31415		1996/97	2004/05	1	8	–	–
H31424	? Male	1996/97	2005/06	4	6	8	8
H31474	? Male	1998/99	2002/03	1	4	–	–
H31476	Male	1998/99	2004/05	2	4	6	–
H31490	? Male	1998/99	2002/03	1	4	–	–
H31491	Male	1998/99	2005/06	1	7	–	–
H31494	Male	1998/99	2004/05	1	6	–	–
H31495	? Male	1998/99	2005/06	4	4	6	6
H31498	? Female	1998/99	2004/05	1	6	6	–
H31527	? Male	1998/99	2002/03	1	4	–	–
H31536		1998/99	2003/04	1	5	–	–
H31542	Male	1998/99	2005/06	4	4	6	7
H32063		2000/01	2005/06	1	5	–	–
H32099	? Male	2000/01	2005/06	1	5	–	–
H32980	? Male	2001/02	2005/06	1	4	–	–
H33088		2001/02	2005/06	1	3	–	–
Mean (± SEM)				**1.9 ± 0.2**	**5.0 ± 0.2**	**5.9 ± 0.2**	**6.1 ± 0.3**
H30807[a]	Female	1996/97	2005/06	1	9	9	9

[a] Immigrant originally banded on Hauturu/Little Barrier Island, but now breeding successfully on Great Barrier Island (Aotea Island).

4.5 POPULATION ESTIMATES

Extrapolation from the census grid data to the 35-ha study site around the summit area of Mount Hobson, gives an estimate of the 2005/06 burrow-occupying black petrel population to be between 4008 and 5946 adults (Mean ± SEM = 4977 ± 969 birds; Table 5), consisting of 460 (± 151) non-breeding adults and 4517 (± 818) breeding adults (i.e. approximately 2250 breeding pairs).

Extrapolation from the transects to the 35-ha study site around the summit area of Mount Hobson gives an estimate of the 2005/06 burrow-occupying black petrel population of between 3876 and 4816 adults (4346 ± 470 birds; Table 6), consisting of 1003 (± 153) non-breeding adults and 2583 (± 317) breeding adults (i.e. approximately 1290 breeding pairs).

The third estimate involved extrapolation from the transects, with stratification of the 35-ha study area into the four habitat grades based on burrow density (see Section 4.3). This method produced an estimate for the 2005/06 burrow-occupying black petrel population of between 3154 and 4054 adults (3604 ± 450 birds, Table 7), consisting of 1009 (± 162) non-breeding adults and 2595 (± 288) breeding adults (i.e. approximately 1300 breeding pairs).

4.6 SURVIVAL ESTIMATES

We ran a Cormack Jolly Seber (CJS) analysis (adult survival and probability of recapture (varying over time) model: Phi(t) *P*(t) with AICc = 3430.3; Chat = 1.73) of all adults recaptured between 1995/96 and 2005/06. This generated a mean adult apparent survival of 0.7923 (± 0.03), but there is a suggestion of a slight increase in adult apparent survival over the study period (Table 8). The mean probability of recapture from one year to the next was 0.7836 ± 0.03 (Table 8).

TABLE 5. 2005/06 POPULATION ESTIMATE OF BLACK PETRELS (*Procellaria parkinsoni*) IN THE 35-ha STUDY SITE AROUND MOUNT HOBSON, GREAT BARRIER ISLAND (AOTEA ISLAND), EXTRAPOLATING FROM CENSUS GRIDS ONLY.

GRID	DENSITY (NUMBER/ha)		POPULATION ESTIMATE (35 ha)	
	BREEDING ADULTS	NON-BREEDING ADULTS	BREEDING ADULTS	NON-BREEDING ADULTS
Grid One (KDG1)	250	16	8750	560
Grid Two (KDG2)	187.5	31.25	6562.5	1094
Grid Three (KDG3)	50	8	1750	280
Grid Four (PTG1)	200	31.25	7000	1094
Grid Five (PTG2)	112.5	8	3937.5	280
Grid Six (PTG3)	87.5	0	3062.5	0
Grid Seven (SFG1)	136.5	23	4777.5	805
Grid Eight (SFG2)	87.5	0	3062.5	0
Grid Nine (SFG3)	50	0	1750	0
Mean (± SEM)	**129 ± 23**	**13 ± 4**	**4517 ± 818**	**460 ± 151**
Total population estimate			**4977 ± 969**	
Population estimate range			**4008 to 5946 adults**	

TABLE 6. 2005/06 POPULATION ESTIMATE OF BLACK PETRELS (*Procellaria parkinsoni*) IN THE 35-ha STUDY SITE AROUND MOUNT HOBSON, GREAT BARRIER ISLAND (AOTEA ISLAND), EXTRAPOLATING FROM TRANSECTS ONLY.

TRANSECT	DENSITY (NUMBER/ha)		POPULATION ESTIMATE (35 ha)	
	BREEDING ADULTS	NON-BREEDING ADULTS	BREEDING ADULTS	NON-BREEDING ADULTS
1	76	31	2660	1085
6	77	73	2695	2555
7	0	16	0	560
8	76	24	2660	840
9	63	49	2205	1715
10	176	48	6160	1680
11	38	8	1330	280
12	53	25	1855	875
13A	100	63	3500	2205
14	73	0	2555	0
15	84	26	2940	910
16	46	0	1610	0
17	100	24	3500	840
18	63	31	2205	1085
19	0	0	0	0
20	53	33	1855	1155
24	84	18	2940	630
25	113	70	3955	2450
26	138	33	4830	1155
31	30	0	1050	0
37	200	41	7000	1435
38	63	16	2205	560
40	46	58	1610	2030
41	88	48	3080	1680
93	47	0	1645	0
97	32	10	1120	350
Mean (± SEM)	**74 ± 9**	**29 ± 4**	**2583 ± 317**	**1003 ± 153**
Total population estimate (± SEM)			**4346 ± 470**	
Population estimate range			**3876 to 4816 adults**	

A CJS analysis of 421 birds of known sex suggested that there was no significant difference between male and female adult survival, as the best adult survival model was also Phi(t) *P*(t) compared with the model Phi(sex) *P*(t) (which is adult survival and probability of recapture (varying with sex and over time) where Phi = apparent survival, sex = sex of the bird, t = time, *P* = probability of recapture).

The multi-state model to determine the probability of transition from one state to another showed that there is a probability of approximately 0.08 (i.e. about an 8% chance) of either a successful breeder or an unsuccessful breeder changing to a non-breeder (i.e. skipping a year in breeding; Table 9). However, if a bird does skip a year, it is more likely to be a successful breeder in the following year (P = 0.4935 ± 0.02 compared with 0.313 ± 0.02). A model where the probability of transition (psi) from breeder to non-breeder varied with time was less parsimonious (the likelihood value (ΔAICc) = 2.1).

TABLE 7. 2005/06 POPULATION ESTIMATE OF BLACK PETRELS IN THE 35-ha STUDY AREA AROUND MOUNT HOBSON, GREAT BARRIER ISLAND AFTER STRATIFYING AND GRADING THE TRANSECTS. [AREA OF EACH BURROW DENSITY GRADE IS 7 ha OF HIGH GRADE PETREL HABITAT, 17 ha OF MEDIUM PETREL HABITAT, 10 ha OF POOR PETREL HABITAT AND 1 ha OF NON-PETREL HABITAT].

GRADE	TRANSECT	BURROW DENSITY (per ha)			AREA (ha)	BURROW DENSITY		POPULATION ESTIMATE	
		BREEDING BURROW	NON-BREEDING BURROW	NON-OCCUPIED BURROW		BREEDING BURROW	NON-BREEDING BURROW	BREEDING ADULTS (2 per burrow)	NON-BREEDING ADULTS (1.25 per burrow)
Low	7	0	13	13	10	0	130	0	163
(1–49 burrows/ha)	11	19	6	0		190	60	380	75
	12	26	20	0		260	200	520	250
	14	36	0	0		360	0	720	0
	16	23	0	23		230	0	460	0
	19	0	0	0		0	0	0	0
	31	14	0	0		140	0	280	0
	93	23	0	0		230	0	460	0
	97	16	8	0		160	80	320	100
	Mean (± SEM)	**17 (± 4)**	**5 (± 2)**	**4 (± 3)**		**174 (± 39)**	**52 (± 24)**	**349 (± 78)**	**65 (± 30)**
Medium	1	38	25	0	17	646	425	1292	531
(50–99 burrows/ha)	6	38	58	0		646	986	1292	1232
	8	38	19	6		646	323	1292	404
	9	31	39	0		527	663	1054	829
	15	42	21	0		714	357	1428	446
	17	50	19	0		850	323	1700	404
	18	31	25	0		527	425	1054	531
	20	26	26	0		442	442	884	553
	24	42	14	0		714	238	1428	298
	38	31	13	6		527	221	1054	276
	40	23	46	8		391	782	782	978
	41	44	38	0		748	476	1496	595
	Mean (± SEM)	**36 (± 2)**	**29 (± 4)**	**2 (± 1)**		**615 (± 39)**	**472 (± 66)**	**1230 (± 78)**	**590 (± 83)**
High	10	88	38	0	7	616	266	1232	333
(≥ 100 burrows/ha)	13A	50	50	17		350	350	700	438
	25	56	56	13		392	392	784	490
	26	69	25	6		483	175	966	219
	37	100	33	0		700	231	1400	289
	Mean (± SEM)	**73 (± 10)**	**40 (± 6)**	**7 (± 3)**		**508 (± 66)**	**283 (± 39)**	**1016 (± 132)**	**354 (± 49)**
Population estimate (± SEM)								**2595 (± 288)**	**1009 (± 162)**
Population estimate (± SEM)								**3604 (± 450)**	
								= 3154 to 4054 individuals	

TABLE 8. ADULT SURVIVAL ESTIMATES FROM CORMACK JOLLY SEBER ANALYSIS USING PROGRAM MARK (WITH STANDARD ERRORS AND 95% CONFIDENCE INTERVALS) AND PROBABILITY OF RECAPTURE FOR BLACK PETRELS (*Procellaria parkinsoni*) ON GREAT BARRIER ISLAND (AOTEA ISLAND).

PARAMETER	ESTIMATE	SE	95% CI (LOWER)	95% CI (UPPER)
Survival 1995/96–1996/97	0.6427	0.0960	0.4421	0.8031
Survival 1996/97–1997/98	0.8131	0.0445	0.7103	0.8854
Survival 1997/98–1998/99	0.7124	0.0435	0.6204	0.7896
Survival 1998/99–1999/00	0.8693	0.0284	0.8031	0.9156
Survival 1999/00–2000/01	0.8489	0.0265	0.7894	0.8938
Survival 2000/01–2001/02	0.8334	0.0277	0.7719	0.8808
Survival 2001/02–2002/03	0.7947	0.0273	0.7361	0.8430
Survival 2002/03–2003/04	0.7525	0.0293	0.6907	0.8054
Survival 2003/04–2004/05	0.9117	0.0433	0.7823	0.9674
Survival 2004/05–2005/06	0.7440	–	–	–
Mean	**0.7923**	**± 0.0254**		
Probability of recapture 1995/96–1996/97	0.6439	0.1141	0.4054	0.8274
Probability of recapture 1996/97–1997/98	0.7599	0.0481	0.6537	0.8415
Probability of recapture 1997/98–1998/99	0.8198	0.0403	0.7272	0.8859
Probability of recapture 1998/99–1999/00	0.9071	0.0253	0.8443	0.9462
Probability of recapture 1999/00–2000/01	0.8495	0.0274	0.7876	0.8958
Probability of recapture 2000/01–2001/02	0.8428	0.0276	0.7810	0.8896
Probability of recapture 2001/02–2002/03	0.9184	0.0214	0.8655	0.9516
Probability of recapture 2002/03–2003/04	0.7181	0.0322	0.6510	0.7768
Probability of recapture 2003/04–2004/05	0.6024	0.0383	0.5254	0.6745
Probability of recapture 2004/05–2005/06	0.7736	–	–	–
Mean	**0.7836**	**± 0.033**		

TABLE 9. ESTIMATES (AND STANDARD ERRORS) OF THE PROBABILITY OF EACH BLACK PETREL (*Procellaria parkinsoni*) CHANGING BREEDING STATE FROM ONE YEAR TO THE NEXT IN THE 35-ha STUDY SITE ON GREAT BARRIER ISLAND (AOTEA ISLAND).

PARAMETER	ESTIMATE	SE	95% CI	95% CI
Transition probability of going from **unknown** to **any other state** (except chick)	0.1200	0.0193	0.0871	0.1632
Transition probability of going from **any other state** (except chick) to **unknown**	0.0043	0.0013	0.0024	0.0078
Transition probability of going from a **breeder** to **failed breeder**	0.1714	0.0096	0.1534	0.1910
Transition probability of going from a **breeder** to **non-breeder**	0.0846	0.0071	0.0717	0.0997
Transition probability of going from a **failed breeder** to **breeder**	0.6104	0.0231	0.5642	0.6548
Transition probability of going from a **failed breeder** to **non-breeder**	0.0834	0.0134	0.0607	0.1137
Transition probability of going from a **chick** to **any other state**	0.0110	0.0016	0.0083	0.0146
Transition probability of going from a **non-breeder** to **breeder**	0.4935	0.0249	0.4449	0.5421
Transition probability of going from a **non-breeder** to **failed breeder**	0.3132	0.0233	0.2695	0.3605

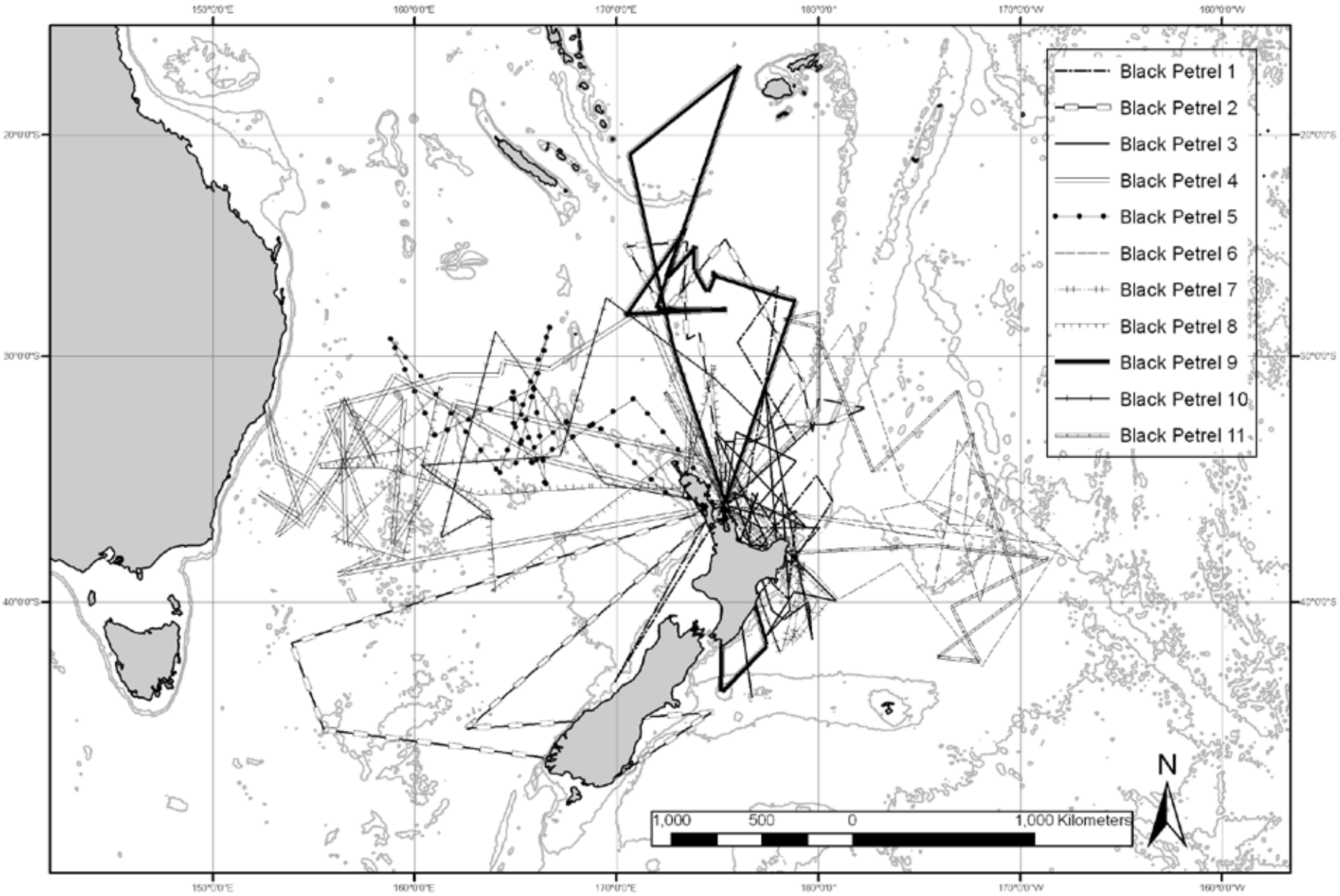


Figure 7. Complete or partial tracks of 17 trips from Great Barrier Island (Aotea Island) made by 11 black petrels (*Procellaria parkinsoni*) fitted with geo-locator data-loggers between December 2005 and January 2006 (lines connect daily position fixes).

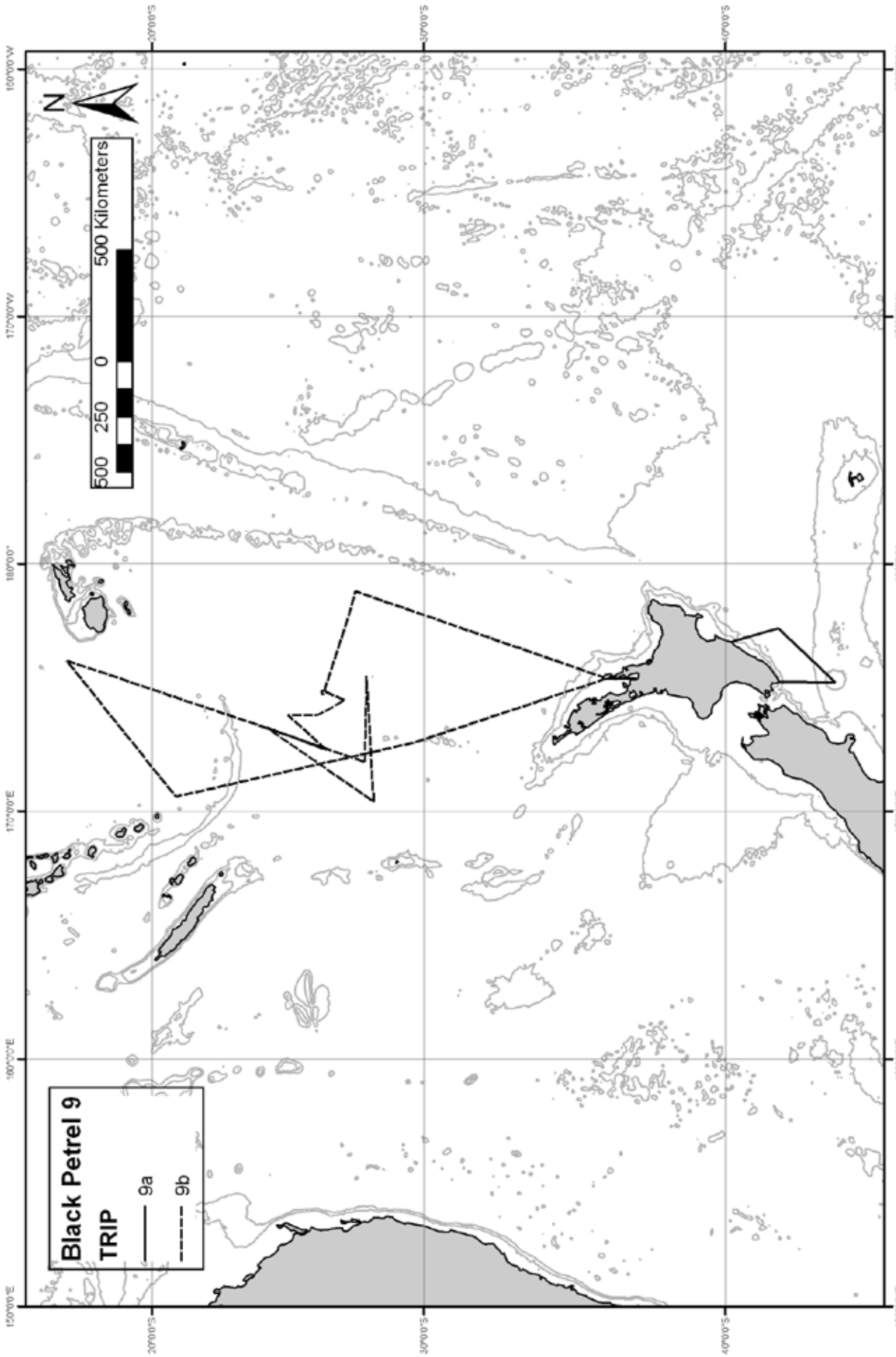


Figure 8. Geo-locator data-logger tracks from two trips made by black petrel (*Procellaria parkinsoni*) Bird 9 (H27534 (male)). Trip 9a (solid line) = 4 days, Trip 9b (dashed line) = 17 days.

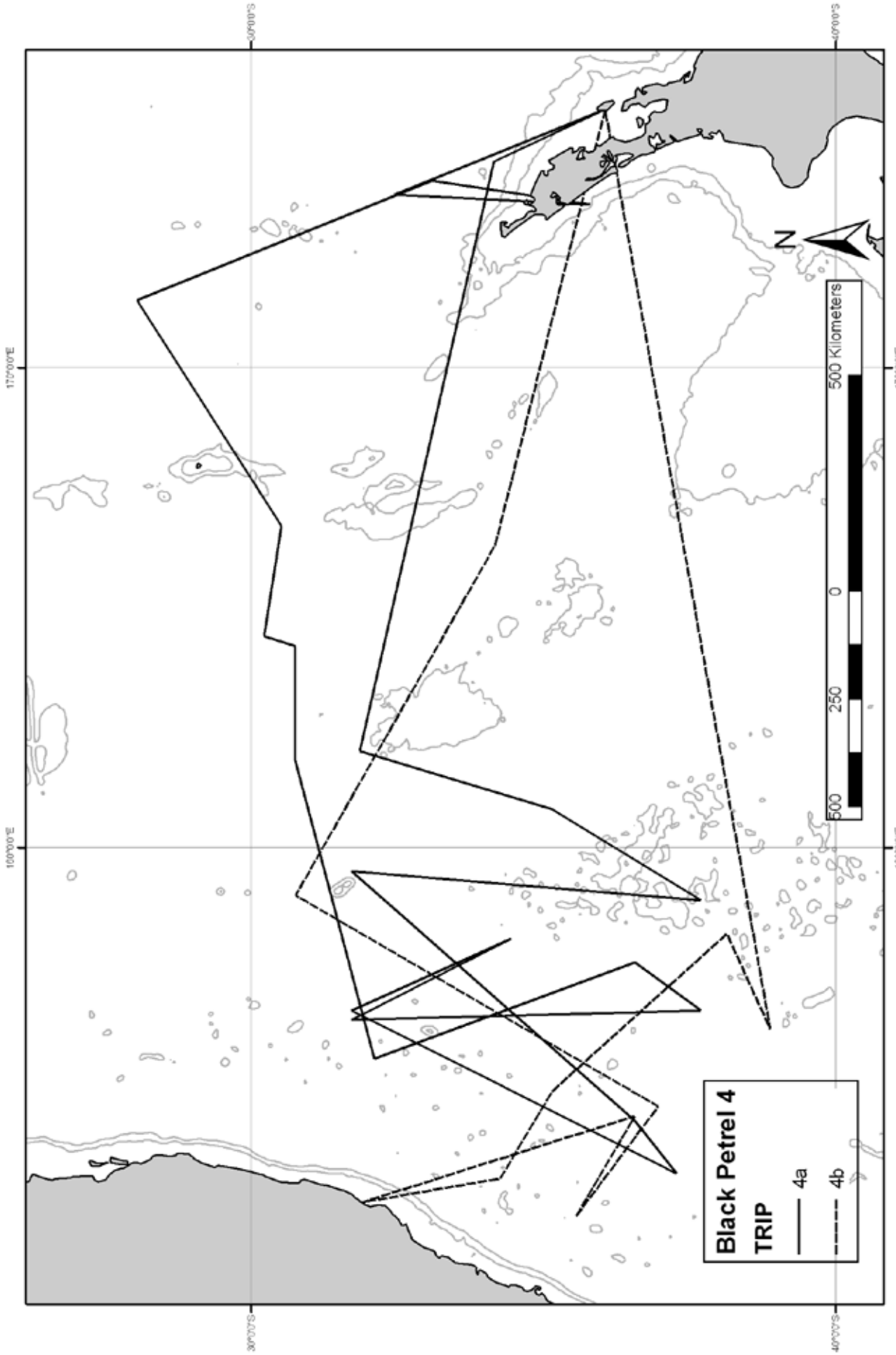


Figure 9. Geo-locator data-logger tracks from two trips made by black petrel (*Procellaria parkinsoni*) Bird 4 (H25511 (female)). Trip 4a (solid line) = 22 days, Trip 4b (dashed line) = 20 days.

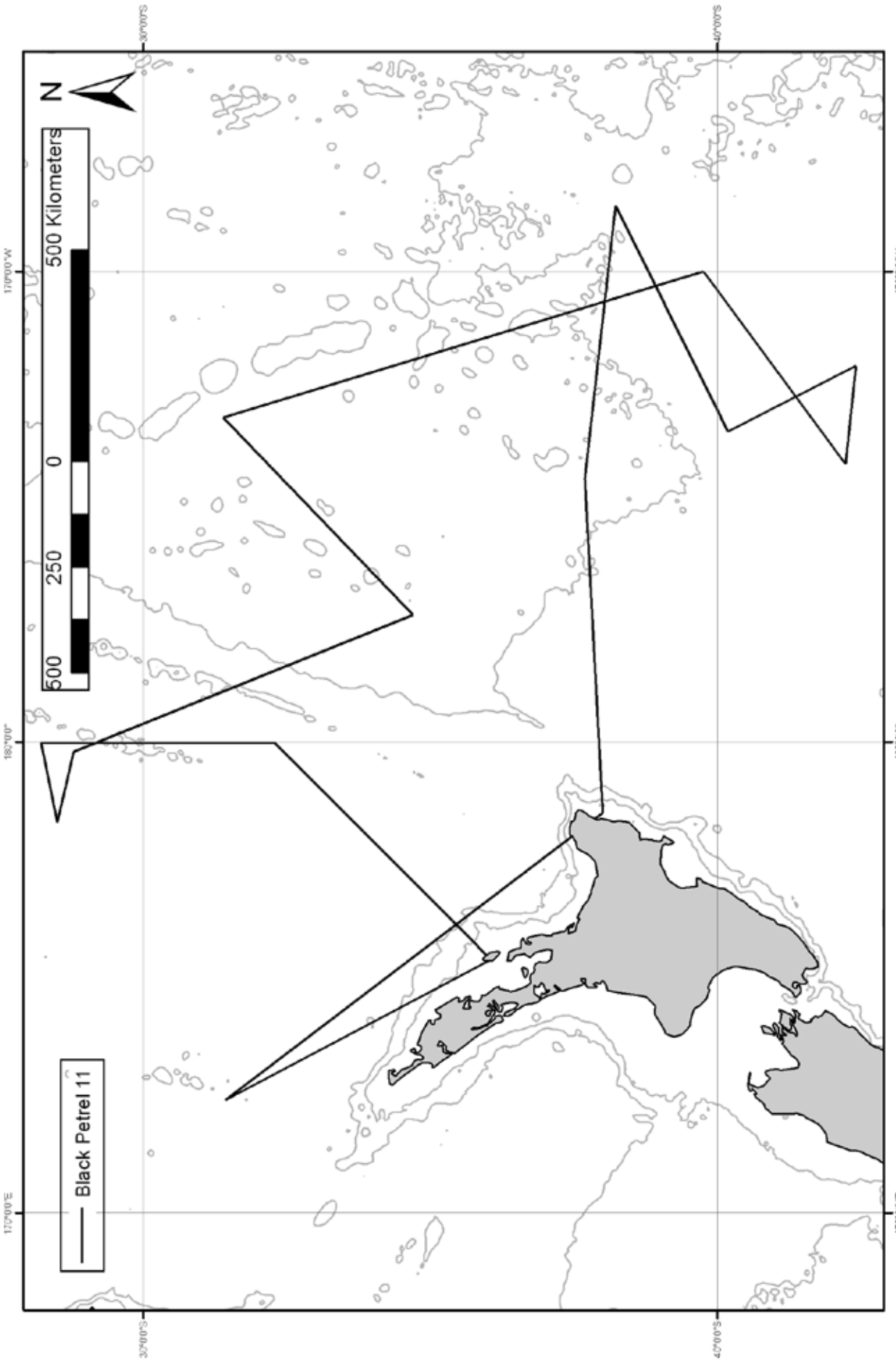


Figure 10. Geo-locator data-logger tracks from one trip made by black petrel (*Procellaria parkinsoni*) Bird 11 (H30869 (male)). Trip 11 (solid line) = 16 days.

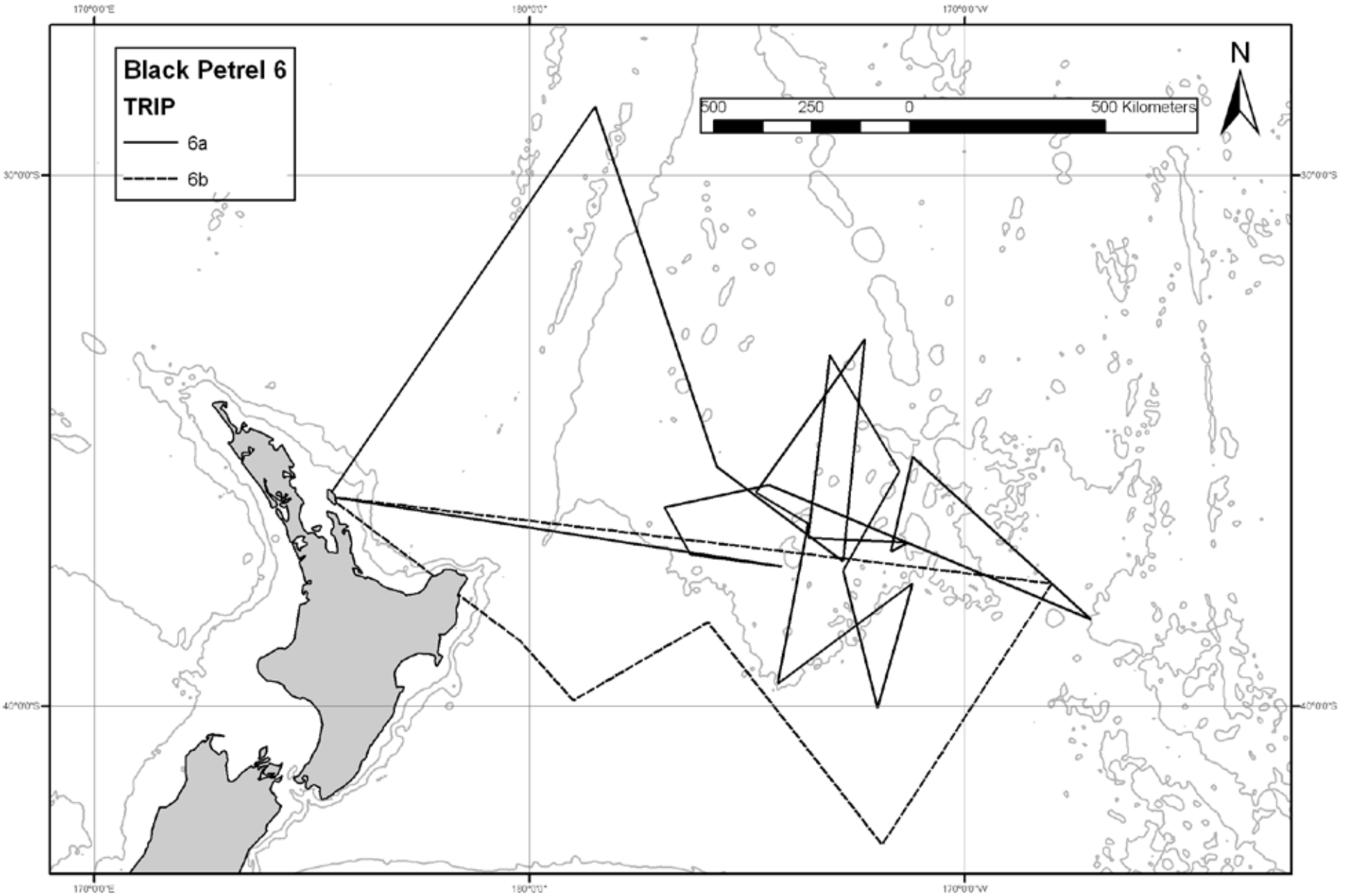


Figure 11. Geo-locator data-logger tracks from two trips made by black petrel (*Procellaria parkinsoni*) Bird 6 (H31023 (female)). Trip 6a (solid line) = 23 days, Trip 6b (dashed line) = 7 days.

A Burnham analysis of survival of chicks banded in the 35-ha study site between 1995 and 2005 was also completed. Only 50 of the more than 1100 chicks banded on Great Barrier Island have been recaptured. However, a model incorporating two chick survival parameters (one in which there was a single age-specific survival between 0–3 years and one for individuals > 3 years) gave an apparent survival estimate of 0.443 (± 0.02) during the first 3 years of life. This survival estimate increased to 0.979 (± 0.19) for birds > 3 years old.

4.7 GEO-LOCATOR DATA-LOGGERS

Of the 11 geo-locator data-loggers placed on known breeding birds during the incubation period, all were retrieved with reliable tracks from each logger. The loggers were worn for between 42 and 57 days, and the birds showed no apparent adverse affects (Appendix 2). The 11 birds came from nine burrows (both parents from burrow 71 and 102 had loggers attached (Appendix 2). Six chicks successfully fledged from these nine burrows and the remaining eggs failed due to the embryos dying inside the eggs (Appendices 1 and 2).

A total of 17 foraging trips were recorded (Appendix 2, Fig. 7). Six birds made two foraging trips and the remaining five birds made only one long foraging trip (Appendix 2; Figs 7–11). With the exception of one bird that made two very short trips, most trips (n = 11; 65%) of the trips were longer than 15 days and the maximum duration was 39 days (Appendix 2). Both males and females had variable foraging areas (Figs 7–11).

The birds mainly travelled to the west and east of northern New Zealand (Fig. 7), with the specific locations and lengths of foraging trips highly variable for both sexes. One bird (H27604, male) travelled much further south than the other birds (around Puyseger Point, Fiordland; Fig. 7) and another (H27534, male) travelled well north of New Zealand (to Fiji; Fig. 8). Four birds approached the Chatham Rise (Fig. 6) and four birds travelled towards Australia, with one bird (H25511, female) making two trips to similar areas on the Australian coast (Fig. 9). The presence of black petrels off the Australia coast had been previously confirmed through banding records—a pre-breeding adult (banded by the authors in the 2001/02 season) was captured off Australia in December 2004 and released alive (C.J.R. Robertson, Wild Press, pers. comm. 2005).

Although five birds foraged in the Bay of Plenty and East Cape area, two birds showed distantly different foraging patterns; one (H30866, male) made a trip through the Bay of Plenty to the East Cape area and towards the Chatham Rise (Fig. 10) and the other (H31023, female) made two trips to the same area of seamounts approximately 1100 km east of East Cape (Fig. 11).

5. Discussion

5.1 STUDY BURROWS

In the 2005/06 breeding season there were 172 breeding successes and 85 breeding failures, equating to an overall breeding success rate of 67%. This breeding success is the lowest since the study began (Table 1), but is still higher than rates reported in the earlier studies in 1977 (50%) and in 1978 (60%; Imber 1987) and in 1988/89 (62%; Scofield 1989). The level of rat predation was much higher in the 2005/06 season than previously recorded and this appears to have had an impact on overall breeding success. It was also assumed that 8 chicks fledged safely before the May 2006 banding visit (Table 1, note 9). Chicks were assumed to have fledged successfully if traces of down, quill sheaths, pin feathers and/or recent activity in the burrow could still be identified during the April 2006 visit. If any of these chicks had died or been predated earlier in the season, this would reduce the breeding success to 64%. The 67% breeding success rate is high compared with those for many other seabird species (such as Westland petrel (*Procellaria westlandica*) 39%–50%; Freeman & Wilson 2002; Warham 1996), but the apparent juvenile survival estimate (Section 4.6) suggests that as many as 50% of the chicks that fledge will not survive their first three years.

As previously mentioned, there was a much higher level of predation by both rats and cats in the 2005/06 season than in previous seasons (Table 1). Fifteen eggs were either predated or scavenged by rats (6% of all breeding attempts) within the study burrows and 19 eggs (7% of all breeding attempts) disappeared (but may have been predated by rats). Two juvenile petrels were predated by feral cats (1% of all breeding attempts), as were two adults from the study burrows. These were the first adults recorded as having been predated by feral cats in the study burrows. Three other juvenile petrels inside the study area, but not in study burrows, and two chicks outside the study area, were also predated by feral cats. All of the juvenile petrels appeared to have been predated after leaving their burrows to practise flying (stretching wings, attempting to fledge at a launch site, etc.), as their bodies were found in the open (EAB pers. obs.). Juvenile petrels are particularly vulnerable to feral cat predation just prior to fledging (Warham 1996). Adult petrels are also potentially vulnerable when they first return to the colony and sit on the ground outside burrow entrances calling to their mates. This appears to have been the case in both adult predation events, as the bodies were found very close to the burrow entrances in December 2005. Fourteen chicks are known to have been predated by cats between the 1997/98 and 2005/06 seasons (Table 1). It is important that cat trapping continues in the black petrel breeding area before, during and after the breeding season.

There were 172 chicks still present in the study burrows in May 2006 (Table 1). Compared with previous seasons, most chicks were in very good condition and many were about to fledge. The chick-banding trip was well-timed, as only eight chicks had already fledged and most chicks, although ready to fledge, were still present in their burrows. Chicks were noted trying to fledge on most nights, using trees and rocks in the area.

Although the number of burrows used for breeding has decreased since the 1999/00 season (Fig. 5), breeding success has remained relatively constant within a range of 67% to 84% (Table 1). Our analysis of all adult recaptures which found an 8% rate of birds skipping from successful breeding to non-breeding status, an 8% rate of skipping from unsuccessful breeding to non-breeding status (Table 9) and a reduction in the number of non-breeding birds (Fig. 5), could partially explain the decline in the number of burrows used for breeding. Reasons whether a burrow is used for breeding may relate to the characteristics of that burrow (exposure, depth, entrance, moisture) and any changes to those characteristics (flooding, collapse etc.; Warham 1996) may cause birds to move from or avoid the burrow and thus affect breeding success.

The decrease in the number of burrows used for breeding since 1999/00 and the increase in non-occupied burrows may be related to handler disturbance and observation hatches dug into burrows. Although birds do not appear to abandon the burrow at any time during the breeding season, they may choose to move to a new burrow the following year. Further surveys within the study area could determine whether birds have moved to nearby, but non-study, burrows to avoid disturbance. As stated earlier, the reduction in burrows used for breeding may also relate to changes in their characteristics, as several burrows have flooded in particularly wet years and collapsed over time, making then unusable for a year or more.

The percentage of burrows used by non-breeding birds has fluctuated since the 1997/98 season (but with a constant downward trend, Fig. 5). This means that the number of non-breeding or pre-breeding birds in the study area varies each season. This could be explained by transition rates, as 80% of non-breeding birds become breeding birds the following year (successful 49% or failed 31%, Table 9) and 20% remain non-breeding. This may relate to whether the birds were successful in creating and maintaining a pair bond that season (and then will attempt to breed the next season). It may also relate to migration, as it is not known if birds choose to remain in South America if they do not obtain adequate body condition to return to New Zealand.

Data from the past nine breeding seasons (1997/98 to 2005/06) shows that the number of non-occupied study burrows has been increasing and in 2005/06 the percentage of non-occupied burrows was also higher than in most of the previous seasons (18%; Fig. 5). It was suggested that this may be directly related to handler disturbance or adult mortality (M. Williams, Victoria University of Wellington, pers. comm. 2005). Our analysis of adult survival and site fidelity suggested that black petrels have low apparent adult survival (79%) compared with other seabird species (e.g. Antipodean albatross (*Diomedea antipodensis*) 96%; Walker & Elliott 2004; Warham 1996; Table 8). However, approximately 10% of birds may be permanently emigrating from the study area (Bell et al. 2007). This may account for the declining occupancy of burrows, but as there has been an immigration event from Little Barrier Island, site fidelity and the possibility of emigration needs further investigation. Work needs to be done separating the components of apparent survival to determine whether the low apparent survival is due to mortality or emigration. This work would require a thorough search for recovery data from banding records and continued (and wider) recapture effort at the study area. It should be noted that the fidelity model only used a small number of recoveries and that more work is needed to determine whether present survival estimates are true and to determine whether emigration or mortality have a larger effect.

5.2 CENSUS GRIDS

Nine grids were intensively monitored over three periods during the 2005/06 breeding season and only one new burrow was located in the grids (SFG1). This burrow was being dug out by a non-breeding bird (Appendix 1). As the black petrel study has progressed, the number of burrows found within the grids has increased from 118 in 1999/2000 to 148 in 2005/06. However, this increase this may be due to the increased search effort over the past two seasons (where complete searches of the census grids to find new burrows was undertaken).

New burrows do not necessarily mean that more birds are present in the colony, as 158 birds have moved between numbered burrows in the 35-ha study site and original burrows are no longer in use (due to collapse). Loss of a partner can result in a bird (particularly females) moving burrows (Warham 1996). Predation events and competition between adults and pre-breeders can also cause movement between burrows (Warham 1996). Males appear to be attracted back to their natal area and may excavate new burrows in those areas (Warham 1996). This has occurred on Great Barrier Island as several pre-breeding (or non-breeding) birds have returned to their natal area (and in ten cases to their natal burrows) and have been recorded either fighting with the resident pair (which can be their parents) for their natal burrow or starting to excavate new burrows nearby, hence increasing burrow numbers in certain areas (and census grids).

5.3 BANDING DATA

A female (H30807) banded on Hauturu/Little Barrier Island is now breeding on Great Barrier Island. This is the first immigration event recorded for black petrels. Immigration has implications for population modelling work (as many models assume no immigration), and further surveys and mark-recapture work is needed to maximise the chances of recapturing known birds and returned fledglings.

There is probably a capture bias towards the returning adult males because certain aspects of their behaviour—i.e. calling outside burrows—make them easier to detect. Despite being attracted to calling males, adult females are likely to be more difficult to detect as they will attend males in all parts of the colony, both inside and outside the study site. Much of the area within the study site is difficult to reach and cannot be searched. Aspects such as these will need to be taken into account in future survival and recruitment analyses.

Using the recapture data for chicks banded on Great Barrier Island, our Burnham analysis found that chick survival after the first 3 years increased to 97%, which is higher than the apparent adult survival (79%). This suggests that population decline in the monitored population is not associated with juvenile survival, as these survival figures are similar to those of other juvenile seabirds of this size (see literature review in Hunter et al. 2001). Again, these estimates may be biased by the low recapture rate of returned chicks. Further search effort throughout the year may increase the recapture rate; however, this effort may be limited by the difficulty in covering the entire study area imposed by the terrain. It is also possible that there is a bias towards the capture of male chicks, as their calling from outside the burrow makes them easier to detect. It is important that as many returned chicks as possible are captured so that more accurate survival estimates can be obtained.

5.4 POPULATION ESTIMATE

Three estimates for the population within the 35-ha study area were calculated by various means (Section 3.5, Tables 5–7). Surveys and local knowledge of Great Barrier Island showed that petrel burrow densities were not identical throughout the 35-ha summit study area, so there was concern that extrapolating from the census grids (i.e. known high burrow density areas) or from random transects to the entire 35-ha study area was likely to overestimate the black petrel population. These estimates are likely to incorrectly estimate the population by not adequately taking into account the range of habitat types and burrow densities identified with the study site. The estimates from the census grids (4977 ± 969 birds) and transects (4346 ± 470) birds) proved to be higher than the estimate produced by stratifying the 35-ha study site into four petrel burrow density grades (incorporating habitat characteristics) (3604 ± 450 birds). The stratification method probably gave the most accurate population estimate.

Further transects throughout the study area could improve this population estimate as well as allowing the four burrow density ranges within the area to be more accurately defined (and, possibly, more areas to be identified). It will also be important to examine the difference between two- and three-dimensional estimates of density and population size in this steep and difficult terrain.

The black petrel breeding population was estimated at approximately 1300 breeding pairs. This estimate only covers the 35-ha study area around the summit of Mount Hobson, although this is the main population location and contains the highest density of the population. We consider that delimiting the lower boundaries of the entire black petrel colony within the Mount Hobson Scenic Reserve is the highest priority for further work, so that a complete estimate of the black petrel population in this area can be achieved.

To gain a better population estimate of the whole black petrel population on Great Barrier Island, further surveys would need to be undertaken in other areas on the island. In addition to the summit area, black petrels are also known to nest on other high points around the summit area, in northern areas of the island, in small pockets of private land and towards the southern end of the island. Randomly selected census grids, transects or further intensive surveys in these areas would give a better idea of burrow density and range around the island. These surveys could be undertaken on or near Mount Heale, The Hogs Back, and Mount Matawhero in the Mt Hobson area. It is interesting to note that several pairs of black petrels have been found well below 300 m a.s.l. (EAB pers. obs.), which raises the possibility that other birds may also be breeding at lower elevations. This possibility should be investigated further.

5.5 ADULT SURVIVAL AND POPULATION TRENDS

The apparent adult survival estimates for black petrels in the study area (79%; Table 8) were unusually low for a seabird of its size, but comparable with other adult black petrel survival estimates made by Hunter et al. (85%; 2001). The data also suggested that adult survival has increased between 1995/96 and 2005/06 (Table 8). This may relate to the regular increase in the number of study burrows monitored over the study period and increased night capture effort (i.e. surveys carried out every night for seven nights during the December trip).

5.6 DATA-LOGGERS

Very little is known about the foraging range and at-sea distribution of black petrels beyond anecdotal records from bird-watching expeditions, fishermen, Ministry of Fisheries observers on fishing boats, and other vessels. However, these records only give general locations and may reflect the black petrel's habit of following boats to scavenge discarded fish waste.

The geo-locator data-loggers indicated that black petrels use a range of foraging areas (Figs 7–11). Although based on a small sample size (n = 11), the results of the trip recording indicate that black petrels prefer to forage on the continental shelf or seamounts, as most of the tracked birds seemed to make direct flights to specific water depths (as indicated by bathymetric contours) and/or underwater features such as seamounts, ridges or trenches (Figs 7–11). This pattern of behaviour occurred during both incubation and chick rearing, but the foraging trips during incubation were longer. In addition, the foraging locations of males and females appear to overlap.

The trips recorded by the geo-locator data-loggers during incubation (December to January) commonly alternated between a short trip (2–6 days) and a longer trip (15–22 days). The birds appeared to make more direct flights to feeding locations on shorter-duration trips (e.g. Fig. 10) compared with longer-duration trips, but further logger work is needed to confirm these preliminary results. Determining foraging behaviour throughout all stages of the breeding season (honeymoon, egg laying, incubation and chick rearing) may show increased variations in foraging locations and length of trips, as these may depend on the stage of breeding; for example, during incubation the adult only has to feed itself (and maintain condition for breeding and sitting for long periods on the egg) compared with chick rearing, when it also has to find extra food for the chick.

It is very important that further data-logger work be carried out to confirm and build on these preliminary results. To ensure a statistically viable data set, loggers should be deployed on at least 30 adult black petrels continuously for two breeding seasons (December 2007 (2007/08 season) to March 2009 (2008/09 season)). This would enable tracking during incubation, chick rearing, migration to South America, the non-breeding season in South America and migration back to the New Zealand breeding location; and further tracking during incubation and chick-rearing trips through the second breeding season.

5.7 CONSERVATION

A recent estimate indicates that about 6640 people visit Mount Hobson each year (Peter Cann, DOC, pers. comm.), but this use appears to have little or no impact on the breeding success of the black petrels in the area. Information about the black petrels at the track start/end points and on the summit has increased awareness of the birds and the unique environment they inhabit. However, littering and public fouling (defecation), which continues to be a problem in the summit area, is of concern because it may introduce disease or lead to an increase in rat numbers.

As stated in earlier reports (Bell & Sim 2000a, b, c, 2002, 2003a, b, 2005; Bell et al. 2007), the construction of raised walkways around the summit has decreased damage to the environment and, especially, to the black petrel burrows. As serious erosion continues to occur along the summit ends of the South Fork and Palmers Tracks (EAB, pers. obs.), the boardwalk system should be extended.

A total of 11 black petrels (including one banded by the authors) were recorded as bycatch on domestic longline vessels in the New Zealand fisheries between 01 October 1996 and 30 September 2005 (Robertson et al. 2004; Conservation Services Programme 2008). All of these birds were caught between November and April, either east of North Cape, near the Kermadec Islands or north of Great Barrier Island (Robertson et al. 2003, 2004; Conservation Services Programme 2008). The timing of their captures suggests that most may have been breeding adults. This means that their deaths would have reduced overall productivity and recruitment. The level of bycatch for black petrels and other seabirds outside New Zealand waters is unknown, and may impact on the population dynamics of the species. Data-loggers could also be used to identify areas of overlap with fisheries outside New Zealand waters.

Black petrels have delayed maturity, low reproduction rates and high adult survivorship. As a result, any change in adult survivorship, however small, will affect the population greatly (Murray et al. 1993). If breeding adults continue to be caught on long-lines in New Zealand and overseas waters, the species could be drastically affected. It is therefore important that monitoring of the Great Barrier Island black petrel population continues. An accurate population model is needed to determine adult survivorship, recruitment, mortality and productivity. Long-term population data, improved technology and further use of data-loggers can be used to develop this model, which could also be used to assess factors affecting the black petrel population, identify likely overlap areas with fisheries and estimate the effects of fisheries bycatch.

6. Recommendations

Based on the findings of this study (and previous years' reports), the authors recommend that:

- Monitoring of the black petrel population (using the study burrows) is continued at Great Barrier Island up to and including the 2008/09 breeding season. This will ensure that 10 years of comparative data are collected to determine the population dynamics of black petrels, allowing us to develop a population model to determine survivorship, mortality and the effects of predation, fisheries bycatch and other environmental factors (e.g. El Nino).
- The November/December visit to the study area should be continued. Visiting at this time allows a large number of birds to be banded or recaptured easily, as the birds are often outside the burrows during this period. A high rate of banding and recaptures will enable the continuation of the mark-recapture programme.

- The study burrows could be checked for breeding status during every visit to the study site, to give a more accurate estimate of breeding success and to determine the sex of adults occupying the burrows. This would also provide chance to recapture returning birds banded as chicks.
- The April/May visit should continue, as this allows time for chicks to be banded before they fledge.
- A sample of 30 black petrels should carry GPS data-loggers and/or geo-locator data-loggers for 16 months (December 2007 to March 2009) to provide data on foraging distances and locations, water temperature and flight patterns throughout the breeding and non-breeding seasons.
- The exact limits of the entire Mount Hobson black petrel colony should be established and the area of the colony calculated by a ground truth survey. Random transects should be established on other high points around the Mount Hobson area (e.g. Mount Heale, Mount Matawhero and The Hogs Back). These sites should be monitored as long as the study continues.
- Cat trapping should be implemented before and during the black petrel breeding season (November to June) especially during pre-laying (October/ November) and the fledging period (May to June).
- The walkway systems down Palmers (Windy Canyon) and South Fork Tracks should be extended. Construction should be completed between July and mid-October, when the chicks have fledged and before the adults return. This work will require full consultation with the appropriate experts to prevent the accidental destruction of known burrows and important plant species around the summit area.

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Appendix 1

Results from the study of black petrel burrows (n = 369) near Mount Hobson, Great Barrier Island during the 2005/06 breeding year

Study burrows within census grids have their location noted (in brackets) in the burrow column: Palmers Track grid one, two, three (= PTG1, 2, 3); South Fork Grid one, two, three (= SFG1, 2, 3); or Kauri Dam Grid one, two, three (= KDG1, 2, 3). Occupants of burrows are represented by band number or, if not caught, by a question mark (?). Where known, sex of bird is indicated in parentheses in the Band column: male (M); female (F). An asterisk represents a dead adult. Grey-shaded box represents a non-study burrow.

BURROW	BAND	OUTCOME
1	H31370 ?	Rat predation
2	H34770 (M) H34939 (F)	Disappeared egg
3	H31109 (M) ?	Chick H33547
4	H23017 (M) H28100 (F)	Disappeared egg
5	H31161 H33324	Non-breeder
6	H14014 (M) ?	Chick H33540
7	H31272 H30854	Chick H33588
8	H31103 (M) H31273 (F)	Chick H33589
9	?	Non-breeder
10	? ?	Crushed egg
11	H31458 H31585	Non-breeder
12	H33612 (M) H34870 (F)	Chick H31321
13	H34760 (F) H33089 (M)	Disappeared egg
14	H31284	Non-breeder
15	H25488 ?	Chick H31337
16	H34949 H34976	Disappeared egg
17	H31108 (M) ?	Chick H34994
18	H31204 H33326	Chick H33519
19		Empty
20	H34264 H25476 (M) H33457	Non-breeder
21	H33466 (M) H34956 (F)	Disappeared egg
22	H33320 (M) ?	Crushed egg
23	H33461 (F) ?	Disappeared egg
24	H25663 H33465 H34986	Non-breeder
25	? H31217 (M)	Chick H33538
26	H34963	Non-breeder
27	?	Non-breeder
28		Empty
29	H28004 (M)	Chick H33552
	?	
30	?	Non-breeder

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Appendix 1 continued

BURROW	BAND	OUTCOME
31	H34944 (F) H34874 (M)	Dead chick
32 (PTG1)	H34783 ?	Chick H33531
33	H31244 ?	Dead chick
34	H31248 (F) H31121 (M)	Chick H33543
35	H33654 ?	Chick H31333
36	H33460 ?	Crushed egg
37	H28036 (F) H31107 (M)	Crushed egg
38		Empty
39	H25426 (M) H31578 (F)	Chick H33515
40		Empty
41	H31112 H31029	Chick H33529
42	H33948 ?	Chick H31320
43	H25546 (M) H31586 (F)	Chick (unbanded)
44	H31130 H25424	Chick (fledged before banding)
45		Empty
46	? ?	Crushed egg
47	? H31018 (M)	Chick H31322
48	H31003 H31003	Dead chick
49	H31243 H31010	Chick H33503
50	H33747 (F) H31282 (M)	Chick H33504
51	? H22169 (M)	Chick H33535
52	H31289 H34965	Non-breeder
53	H34964 ?	Chick H33534
54		Empty
55 (PTG1)	? H33638	Chick H31334
56 (PTG1)		Empty
57 (PTG1)	H31153 (M) ?	Dead chick
58 (PTG1)	H28029 H31205	Dead embryo
59 (PTG1)	H31125 ?	Chick H31336
60 (PTG1)	H33659 (M)	Non-breeder
61 (PTG1)	H25505 (F) H30878 (M)	Chick H31346
62 (PTG1)	H31257 (M) ?	Cat predation
63 (PTG1)	H31424 H33267	Chick (H33533)
64 (PTG1)	H33713 H31366	Chick (fledged before banding
65	H31460 (F) ?	Dead embryo
66	H30874 H34853	Non-breeder
67 (KDG1)	H31270 (F) H31271 (M)	Chick H33563
68 (KDG1)	H32005 (F) H31172 (M)	Chick H33567
69	H27604 (M) H31240 (F)	Dead chick
70	H27665 (M) H31992 (F) H25536 (M)	Chick H33569
71 (KDG1)	H31023 (F) H31242 (M)	Chick H33568
72 (KDG1)		Empty
73 (KDG1)	H28572 (M) H30876 (F)	Chick H33590
74 (KDG1)	H31974 H29693	Chick H33591

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Appendix 1 continued

BURROW	BAND	OUTCOME
75 (KDG1)	H25421 H33314	Chick H33592
76 (KDG1)	H33758 ?	Chick H33593
77 (KDG1)	? H30870 (M)	Chick H33594
78 (KDG1)	H34875 H30867	Crushed egg
79 (KDG1)	? ?	Rat predation
80 (KDG1)	H29682 (F) H25404 (M)	Rat predation
81 (KDG1)	H31155 (F) ?	Chick H33561
82	H25635 (M) H33453 (F) H34736 (M)	Disappeared egg
83	H34781 (M)	Non-breeder
84	H 29677 (M) H33463 (F)	Disappeared egg
85 (SFG1)	? H31118 (M)	Chick H31326
86 (SFG1)		Empty
87 (SFG1)	H25664 H34954	Crushed egg
88 (SFG1)		Empty
89 (SFG1)	H30910 H31495	Chick H31327
90 (SFG1)	? H33097 (M)	Chick H31328
91 (SFG1)	? ?	Chick H31329
92 (SFG1)	H33660 (F) H32928 (M)	Chick H31331
93	H33655 (F) ?	Dead chick
94	H23018 H31028	Chick (unbanded)
95	H34262 H34938	Crushed egg
96 (PTG1)		Empty
97	H30872(M) ?	Chick H33517
98	?	Non-breeder
99	? H31201	Chick (fledged before banding
100	H29660 (M) H32924 (F)	Dead embryo
101 (KDG1)	? H25588	Chick H33596
102 (KDG1)	H22511 (F) H30866 (M)	Dead embryo
103 (KDG1)	H29690 H25673 H32905 H35000	Non-breeder
104 (KDG1)	?	Non-breeder
105	?	Non-breeder
106	H31038 H25458	Non-breeder
107	H33799 (F) H33764 (M)	Chick H33507
108	? H25452 (M)	Disappeared egg
109	H31052 ?	Chick H33596
110 (SFG1)	H31008 (M) H31007 (F)	Chick H31330
111 (SFG1)	? H31986	Crushed egg
112 (SFG1)	H28037 (M) H34796 (F)	Crushed egg
113 (SFG1)	H33322 (M) H25409 (F)	Disappeared egg
114 (SFG1)	H25453 H31142	Chick H31325
115	H31031 ?	Chick H33539
116 (PTG1)	H25411 ?	Disappeared egg
117 (SFG1)	H33693 H25664	Non-breeder
118	H31985 ?	Chick H31324

Continued on next page

Appendix 1 continued

BURROW	BAND	OUTCOME
119	? H31055	Chick H33530
120 (PTG1)	H32099	Non-breeder
121 (PTG1)	H25455 ?	Crushed egg
122 (PTG1)	H34988	Non-breeder
123 (PTG1)	H31053 ?	Chick H31345
124 (PTG1)	H28032 H33478	Non-breeder
125 (PTG1)	?	Breeder
126 (PTG1)	H33477 ?	Chick H33532
127	H34747 ?	Crushed egg
128	H31054 ?	Chick (unbanded)
129		Empty
130		Empty
131	H34948 H34970	Crushed egg
132 (KDG2)		Empty
133 (KDG2)	H25525 (M) H32027 (F)	Non-breeder
134 (KDG2)	H33313 (F) ?	Chick H33583
135 (KDG2)	? H25447	Rat predation
136 (KDG2)	H29691 H29699	Crushed egg
137 (KDG2)	H25494 (F) H31572 (M)	Chick H33582
138 (KDG2)	H33306 (M) H31565 (F)	Chick (fledged before banding)
139	H14012 (F) H23035 (M) H32980 (M)	Chick (fledged before banding)
140 (KDG2)	H25507 (F) H33484 (M)	Chick H33573
141 (SFG2)	?	Breeder
142 (SFG2)	H28026 H28027	Chick (unbanded)
143 (KDG2)		Empty
144 (KDG2)	H25459 H34969	Chick H33586
145 (KDG2)	H34947 H28074	Non-breeder
146 (KDG2)	H25460 ?	Chick H33564
147 (KDG2)	H34720 H34945	Non-breeder
148 (KDG2)	H27534 (M) H25483 (F)	Chick H33574
149 (KDG2)	H31569 (M) H25401 (F)	Chick H33581
150 (KDG2)	? H25493	Chick H33576
151	H25593 (M) H29674 (F)	Non-breeder
152 (SFG2)	H31983 (M) ?	Chick (unbanded)
153 (SFG2)	? ?	Chick (unbanded)
154 (PTG1)		Empty
155 (PTG2)	H33792 H33473 H34989	Non-breeder
156 (PTG2)	H33472 (F) H31559 (M)	Chick H31339
157 (PTG2)		Empty
158 (PTG2)	H25440 (F) H31451 (M)	Crushed egg
159 (PTG2)	H25441 (F) H31557 (M)	Chick H31342
160	H25690 (M) H29671 (F)	Chick (unbanded)
161 (PTG2)	H31542 (M) ?	Chick H31336
162 (PTG2)	H29658 (F) ?	Crushed egg
163 (PTG2)	H33658 H34961	Dead chick

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Appendix 1 continued

BURROW	BAND	OUTCOME
164 (PTG2)	H33606 (M) H34962 (F)	Chick H31343
165 (KDG2)	H29700 ?	Chick H33485
166	H25437 (M) ?	Chick H31335
167	H28012 (M) H33657 (F)	Rat predation
168 (PTG1)		Empty
169		Empty
170	H33770 (F) ?	Dead embryo
171	H28006 ?	Chick H33516
172	H31048 (M) H34727 (F)	Dead chick
173	H31143 H28018	Chick (unbanded)
174	H28071 (F) ?	Dead embryo
175	H25503 (M) H28001 (F)	Chick H34996
176 (KDG1)	H27702 ?	Crushed egg
177	H31462 H31459	Rat predation
178	H33302 (M) H34715 (F)	Rat predation
179	H25694 (M)	Non-breeder
180	H31560 ?	Chick (unbanded)
181	H31463 (M) H31561 (F)	Chick (fledged before banding)
182	H25514 H34864	Chick (unbanded)
183 (SFG1)	H32063 H34985	Non-breeder
184	H34781 (M)	Non-breeder
185 (KDG1)		Empty
186	H31577 ?	Chick H33513
187	H31047 H31452	Chick H33514
188	*H26956 (F) H34971 H34872	Non-breeder
189	H34758 (M) H34868 (F)	Rat predation
190	H34738 ?	Disappeared egg
191 (PTG2)	H34800 ?	Chick H31340
192 (SFG1)		Empty
193 (KDG2)		Empty
194 (KDG2)		Empty
195	H33311 H33327	Chick H33575
196	? ?	Chick (unbanded)
197	? H29685	Disappeared egg
198	H25699 (M) H31593 (F)	Disappeared egg
199	? ?	Rat predation
200	H34265 H28073	Chick H33518
201	H31581 (M) H28002 (F)	Chick H33502
202 (PTG2)	H33329 (F) H28031 (M)	Chick H31341
203	H29668 (F) H30930 (M)	Chick H33553
204 (KDG1)	H34726 H34999	Chick H33562
205	? H29664	Chick H33506
206		Empty
207 (PTG1)		Empty
208 (PTG1)	H29912 ?	Dead embryo
209 (KDG3)		Empty

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Appendix 1 continued

BURROW	BAND	OUTCOME
210 (KDG3)	H25691 (M) ?	Chick H33565
211 (KDG3)	H33310 (F) H25669 (M)	Chick H33566
212 (KDG3)	H28040 (F) H30869 (M)	Chick H33564
213 (KDG2)		Empty
214 (KDG2)	H25687	Non-breeder
215 (SFG3)		Empty
216 (SFG3)	H28051 (M) H29673 (F) H25651 H33470	Rat predation
217 (KDG3)	H31991 H32903	Dead embryo
218	H34731 H32010	Chick H33527
219 (PTG3)		Empty
220 (PTG3)		Empty
221 (PTG3)	H33704 ?	Chick H33523
222	H29657 (F) H28049 (M)	Chick H33541
223 (SFG3)	H33673 ?	Chick (unbanded)
224 (PTG3)	? H25564	Chick H33521
225 (SFG3)	H31600 H13634	Chick (fledged before banding)
226 (PTG3)	H27058 ?	Chick H33522
227 (KDG3)	? H33702	Chick H33587
228	? H33308 (F)	Chick H34990
229 (PTG3)	H28042 ?	Chick H33525
230 (PTG3)		Empty
231		Empty
232		Empty
233	H29698 H25558	Cat predation
234	H25571 (M) ?	Dead embryo
235	H25566 (F) H28044 (M)	Chick H33526
236	? ?	Crushed egg
237		Empty
238 (SFG1)		Empty
239	H25700 (F) H32013 (M)	Chick H33554
240	*H31973 (M) H33777 (F)	Chick H33545
241	H34769 H34975	Non-breeder
242	H28099 ?	Chick (unbanded)
243	H33264 (M) H30807 (F)	Chick H33556
244	H33757 (F) H33800 (M)	Chick H33557
245 (KDG1)	H34753 ?	Chick H33595
246 (PTG3)	H25586 (M) ?	Chick H33520
247	H33499 H34951	Non-breeder
248	H33307 (F) H28067 (M)	Chick (unbanded)
249	H33760 ?	Disappeared egg
250	H31168 (F) H30924 (M)	Rat predation
251	?	Non-breeder
252	H34852 (F) ?	Chick H31312
253		Empty
254		Empty
255		Empty

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Appendix 1 continued

BURROW	BAND	OUTCOME
256		Empty
257	H30877 H33759	Chick H33599
258 (PTG3)		Empty
259	H32025 (M) H33495 (F)	Chick H33506
260 (SFG3)	H33266 (M) H14009 (F)	Chick (unbanded)
261	H32021 H34983	Dead chick
262	H32902 (F) H34739 (M)	Crushed egg
263	H28085	Non-breeder
264		Empty
265 (KDG2)	H33312 H33492	Chick H33577
266	H31975 (M) H25444 (F)	Chick H33555
267		Empty
268		Empty
269	H34958 H34959	Non-breeder
270	H33669 (M) H33791 (F)	Chick H33510
271 (KDG1)	? H32920 (M)	Crushed egg
272	?	Breeder
273	H33708 (M)	Non-breeder
274	H23034 H33706	Chick (unbanded)
275	H34978	Non-breeder
276		Empty
277	? H33620	Chick H311311
278	H34751 (F) H34757 (M)	Chick H31316
279		Empty
280	? H33319 (F)	Crushed egg
281	H33602 ?	Chick H31317
282	H33652 H33643	Crushed egg
283		Empty
284		Empty
285		Empty
286		Empty
287	H33670 (F)	Chick
	H33699 (M)	(unbanded)
288	H33705 ?	Rat predation
289	H33621 (M) H34955 (F)	Chick (fledged before banding)
290	? H33617 (M)	Disappeared egg
291	H33618 (M) ?	Chick H33505
292	H31966 ?	Dead chick
293	? H33317	Chick H31310
294	H32931 (M) H34869 (F)	Chick H31319
295	? H33630 (M)	Rat predation
296	H28054 (F) H33682 (M)	Chick H33544
297	H33755 H28034	Chick H33511
298	H33646 H25579	Crushed egg
299	H34937 (M) H34980	Non-breeder
300	H33716 (M) H33497 (F)	Chick H31313
301	H33768 (M) H28060 (F)	Chick H33597
302	H33686 (M) H33787 (F)	Chick H31318

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Appendix 1 continued

BURROW	BAND	OUTCOME
303	H33797 (F) H34977 H32004 (M) H33464	Crushed egg
304		Empty
305	H33645 H33788	Chick (unbanded)
306		Empty
307	H33796 H34876	Chick H34991
308		Empty
309	H28020 H33476	Chick H33512
310 (SFG2)		Empty
311 (SFG2)		Empty
312 (SFG2)		Empty
313 (SFG2)	H34865 H34900	Chick (unbanded)
314 (SFG2)		Empty
315	H33714 H33318	Chick H31315
316	H33715 H33325	Chick H34992
317 (PTG2)		Empty
318 (PTG3)		Empty
319	H33722 ?	Dead chick
320	H34941 (M) H33475 (F)	Chick H34995
321	H34968 H33771 H33617 (M)	Chick H33549
322 (PTG3)	H25555 (M) H34300 (F)	Chick H33543
323	H27504 (F) H27526 (M)	Chick (unbanded)
324	H13638 H34952	Abandoned egg
325	? ?	Chick H31332
326	H34742 (F) H25688 (M)	Chick H33546
327 (KDG2)	H34257 (F) H33498 (M)	Rat predation
328	H33093 (F) H33491 (M)	Chick H33571
329 (PTG3)	H33637 (M) ?	Chick H33528
330	H33090 (M) ?	Chick H33542
331	H34967	Rat predation
332	H34730 ?	Chick H33550
334	? ?	Crushed egg
335		Empty
336 (PTG3)		Empty
337		Empty
338	H34766 H34946	Chick H33578
339	H34722 H33493	Chick H33579
340	H33458 ?	Dead chick
341	H34858 H33459	Chick (unbanded)
342	H25648 (M)	Non-breeder
343 (SFG2)		Empty
344 (SFG2)	H33471 (F) H34984 (M)	Chick (unbanded)
345 (SFG2)	H34861 ?	Chick (unbanded)
346	H34795 (M)	Non-breeder
347	H33496 ?	Chick (H33600)
348 (PTG3)		Empty
349 (PTG3)		Empty
350 (PTG3)		Empty
351 (PTG1)	H34266 ?	Chick (unbanded)

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Appendix 1 continued

BURROW	BAND	OUTCOME
352	H33481 H34966	Disappeared egg
353	H33479 ?	Chick H33536
354	H33480 ?	Chick H33537
355	H33467 (M) ?	Disappeared egg
356	H28804 ?	Chick H33509
357	H34982 ?	Crushed egg
358	H33494 N33474	Chick H34993
359	H34771 (M) H34940 (F)	Chick H33501
360	H33482 ?	Chick H33558
361	H33483 (F) ?	Chick H33559
362 (KDG1)	H33490 H34987	Chick H33560
363	H31238 (F) ?	Chick H33570
364	H34854 ?	Chick H33572
365 (KDG2)		Non-breeder
366 (KDG1)		Empty
367	H31175 H34957	Chick H33548
368	H33451 (M) H34942 (F)	Crushed egg
369 (SFG1)		Non-breeder

Appendix 2

DETAILS OF GEO-LOCATOR DATA-LOGGER DEPLOYMENT ON INDIVIDUAL BLACK PETRELS (*Procellaria parkinsoni*)

Where more than one trip was recorded, separate trips are denoted by different lettered suffixes

BAND	SEX	BURROW NO.	DEPLOYED	RETURNED	NO. OF DAYS LOGGER WORN	NO. OF TRIPS	TRIP LENGTHS(S) (DAYS)	BREEDING RESULT
27604	Male	69	3 Dec 2005	19 Jan 2006	48	2	Trip a = 26 days Trip b = 6 days	Chick
31460	Female	65	10 Dec 2005	14 Jan 2006	35	1	19 days	Dead embryo
25493	? Female	150	4 Dec 2005	15 Jan 2006	43	1	22 days	Chick
25511[a]	Female	102	3 Dec 2005	29 Jan 2006	58	2	Trip a = 22 days Trip b = 20 days	Dead embryo
30866	Male	102	4 Dec 2005	14 Jan 2006	42	2	Trip a = 6 days Trip b = 4 days	
31023[b]	Female	71	3 Dec 2005	29 Jan 2006	58	2	Trip a = 23 days Trip b = 7 days	Chick
31242	Male	71	4 Dec 2005	14 Jan 2006	42	1	21 days	
31271	Male	67	3 Dec 2005	14 Jan 2006	43	1	15 days	Chick
27534[c]	Male	148	3 Dec 2005	15 Jan 2006	44	2	Trip a = 4 days Trip b = 17 days	Chick
25460	? Male	146	4 Dec 2005	14 Jan 2006	42	2	Trip a = 29 days Trip b = 3 days	Chick
30869[d]	Male	212	4 Dec 2005	15 Jan 2006	43	1	39 days	Chick

[a] = Bird 4 in Fig. 9.
[b] = Bird 6 in Fig. 11.
[c] = Bird 9 in Fig. 8.
[d] = Bird 11 in Fig. 10.