At-sea distribution and population parameters of the black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2012/13.

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Abstract

This report is part of an ongoing long-term study of the black petrel, *Procellaria parkinsoni,* on Great Barrier Island (Aotea Island) that was begun in the 1995/96 breeding season.

During the 2012/13 breeding season, 409 study burrows within the 35-ha study area near Mount Hobson were checked and intensively monitored. Of these, 273 were used by breeding pairs, 101 by non-breeding adults and the remaining 35 burrows were non-occupied. By 30 April 2013, 213 chicks were still present in the study burrows and 7 had already fledged, corresponding to a breeding success of 81%. Nine census grids were monitored within the study area and accounted for 156 of the inspected burrows and 151 study burrows, with 90 burrows being used for breeding. Adult survival was estimated at 95.2% (± 1.3%). Eighty-five chicks from earlier breeding seasons were recaptured within the Mount Hobson colony area this season (a total of 149 'returned chicks' have been caught since the 1999/2000 season).

Twenty-six random transects were surveyed in the study area and when compared with transects conducted in the 2004/05 and 2009/10 seasons showed an apparent 110% increase in the number of breeding birds since 2009/10, and 65% increase since 2004/05. Much of this difference is likely to be due to changes in breeding rate and success. Analysis of the census grid and transect data estimated the black petrel population from the 35-ha area around Mount Hobson to be in the range of 3974 to 4233 birds, or approximately 1500 breeding pairs.

Fifty five high-resolution GPS i-Got-U™ data-loggers and 36 Lotek™ LAT1900-8 time-depth recorders were deployed between December 2012 and February 2013 on breeding black

petrels to obtain at-sea distribution and foraging behaviour. The at-sea distribution of black petrels was derived from 16 full or partial GPS tracks. Birds foraged around the northern New Zealand, East Cape and into the Tasman Sea. Foraging behaviour showed black petrels dived to a maximum of -27 m, with over 80% of dives less than 5 m. The majority of dives (90%) were during the day.

Keywords: black petrel, *Procellaria parkinsoni*, monitoring, transect, population estimate, breeding success, GPS data-logger, time-depth recorder, foraging, dive, fishing effort, bycatch, Great Barrier Island (Aotea Island), New Zealand

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 and Robertson 1996). The main breeding area on Great Barrier Island (Aotea Island) is around the summit of Mount Hobson (Hirakimata) (hereafter Mount Hobson). Monitoring work carried out during the 2012/13 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, 2009; Bell et al. 2011a Bell et al. 2011b, Bell et al 2011c, Bell et al. 2013), adding to the baseline data on the Great Barrier Island black petrel population. Field work carried out in 2006/07, 2010/11 and 2011/12 seasons was privately funded and has not been reported through the DOC publication process. The annual report for that season can be obtained from the lead author (EAB). Mark-recapture, breeding and population data from the 2006/07, 2010/11 and 2011/12 seasons have been included in this (2012/13) report. This study will assist in identifying effects that at-sea and land-based threats may have on the population and build on the earlier population parameter and tracking data (Bell et al. 2009, Bell et al. 2011a, Bell et al. 2011b, Bell et al. 2011c). The population estimate and population trend data has been updated, ensuring that any population changes will be detected in time to implement the appropriate management strategies.

2. Objectives

The main objectives of this study were 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 adult mortality, breeding success and recruitment to describe the population trend, and to investigate detailed at-sea distribution of black petrels during the breeding season. 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.

In summary, the study objectives were to:

- Collect data that will allow estimation of the black petrel population size and describe the population trend by comparing the estimate to relevant existing data. Key tasks conducted under this objective were:
    - 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 2012 and January/February 2013 and band all remaining fledglings during April 2013.
    - 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 area for new burrows and band and recapture as many breeding and non-breeding birds present as possible.
    - Continue the mark/recapture programme, capturing and banding as many birds as possible during the breeding season 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. to monitor the study burrows at the beginning, middle and end of the breeding season), and where possible, identify the sex of the resident adult.

  - Undertake random transects throughout the 35-ha study area and compare with the transect data collected in the 2004/05 and 2009/10 to determine population trend.
  - Determine a population estimate by extrapolating from random transect lines and census grids to the main Mount Hobson breeding area.
- Use high-resolution GPS data-loggers to determine at-sea distribution of black petrels during their breeding season (incubation and chick rearing) suitable to inform fisheries risk assessment.
- Use time-depth recorders to determine diving ability and behaviour of black petrels during their breeding season.

3. Methods

3.1 Study burrows

The study area (35 ha at and around the summit of Mount Hobson; Fig. 1) was visited three times during the breeding season; 27 November-17 December 2012. During this visit the study burrows (*n* = 409, Figs. 1-4) were either randomly selected from those 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 1995/96 season (Bell & Sim 1998a, b, 2000a, b, c, 2002, 2003a, b, 2005, Bell et al. 2007, Bell et al. 2009, Bell et al. 2011a). 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 or wall into the chamber. This opening was covered by a piece of plywood, which was camouflaged 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 colony (24 January-12 February 2013) 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 (25-30 April 2013). All remaining fledgling chicks were banded. This information was used 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 that had a known historical presence of black petrels, different strata, vegetation types and topography and were near known petrel launch sites (Bell and Sim 1998a). These original grids were replicated in 1998 (KDG2, PTG2 and SFG2) and in 1999 (KDG3, PTG3 and SFG3) to compare burrow densities between areas and to increase the accuracy of the population estimate (Bell and Sim 2000a, b).

These nine census grids (each 40 x 40 m) set up around Mount Hobson were systematically searched (at 1 m intervals) during the December 2012 visit by authors (EAB and JS) using Maddi (a Department of Conservation qualified bird dog owned by JS) 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

The transect survey of 2004/05 and 2009/10 breeding seasons (Bell et al. 2007, Bell et al. 2011b) was repeated in 2012/13 breeding season. Twenty-six new random transects were completed during the 2012/13 breeding season to determine burrow density throughout the study site (Fig. 5). All transects were surveyed using the same methods as given in the 2004/05 breeding season report (Bell et al. 2007). 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.

Four grades of petrel habitat have previously been identified throughout the study site 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 and undergrowth species) and coverage (scrub, secondary growth, or primary forest) (Bell et al. 2009; Bell et al. 2011b).

Each transect was 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-, medium- and high-grade petrel habitat) within the study site was determined using Manifold™ (Bell et al. 2009; Bell et al. 2011b).

This season's transect data was analysed and compared to the previous transect results from the 2004/05 and 2009/10 breeding seasons (Bell et al. 2007, Bell et al. 2011b, Francis and Bell 2010) to determine population trends. The 2013 transect data were analysed using the methods described by Francis & Bell (2010).

3.4 Night banding

Night work was undertaken during the December 2012 and January/February 2013 visits to the study area. This involved searching the study area by walking the track system and capturing any adult petrel 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 the December 2013 visit, sex was determined (if possible) by cloacal inspection.

3.5 Deployment of Time-Depth Recorders and GPS data-logger devices

A total of 55 GPS data-logger and 31 Time-Depth Recorder (TDR) devices were deployed on breeding black petrels on Great Barrier Island between December 2012 and February 2013. Each bird was weighed (using Pesola™ scales in December and electronic scales in January/February 2013) before and after deployment to obtain information on body condition and impact of carrying the devices. Thirty control birds were also weighed in December 2012 and 55 control birds were weighed in January/February 2013 to compare with the deployment birds.

Animal ethics approval for the use of all TDR and GPS data-loggers was given by DOC Animal Ethics Committee (14/9/2012, AEC245).

3.5.1 I-GotU™ high-resolution GPS data-logger devices

Fifty-five I-GotU™ GT-120 GPS data-logger devices (Mobile Action Technology, Inc., Taiwan) were deployed on known breeding adult black petrels on Great Barrier Island between December 2012 and February 2013. The birds were chosen from study burrows within the 35-ha study area if they had been successful breeders for at least five seasons and had been in the same pair for over the same five seasons. These GPS devices were 16 g units that measured 44 mm x 28 mm x 10 mm (after the original commercial package was removed and the devices were repackaged in plastic shrink-wrap). The total instrument load (percentage of bird's weight) is 2.3% (for a 700 g breeding bird). These GPS devices were attached to feathers in the central dorsal area using Tesa™ tape. When the birds were recaptured, the unit was removed by snipping the tape with scissors. Application of each GPS device took no longer than 13 minutes (mean (± SEM) = 9.58 ± 0.27 minutes; range 3.55-12.87 minutes) and removal of each GPS devices took no longer than five minutes (mean (± SEM) = 2.19 ± 0.13 minutes; range 0-4.37 minutes). These devices give accurate position location (to within 1 m, depending on satellite reception). The loggers' recorded position data every minute).

Detailed plots of each flight were mapped onto New Zealand bathymetry maps. Positional data and kernel density plots (with density contours of 95%, 75% and 50% use) from the tracks were used to identify areas of high use by black petrels (for all birds as well as separate sexes) within the New Zealand EEZ.

3.5.2 Lotek™ LAT1900-8 Time-Depth Recorder devices

A total of 36 Lotek™ LAT1900-8 Time-Depth Recorders (TDR) devices (Lotek Wireless, Ontario, Canada) were deployed on known breeding adult black petrels on Great Barrier Island between December 2012 and February 2013. As for the GPS devices, the birds were chosen from study burrows within the 35-ha study area if they had been successful breeders for at least five seasons and had been in the same pair for over the same five

seasons. These TDR devices were light (2 g) and small (8 mm x 15 mm x 7 mm) and were attached by two cable ties to the metal band already on the bird's leg and were removed by cutting the cable ties with scissors. The total instrument load (percentage of bird's weight) is 0.29% (for a 700 g breeding bird). Application of each TDR device took no longer than 5 minutes (mean (± SEM) = 3.09 ± 0.11 minutes; range 1.75-4.5 minutes) and removal of each TDR device took no longer than 1 ½ minutes (mean (± SEM) = 0.27 ± 0.03 minutes; range 0.13-1.2 minutes). These TDR devices record temperature, pressure and wet/dry state information; data was collected every second when the device was wet. All, excluding one, TDR devices were set to record depth >0.5 m; one device (deployed on a female, H29682) was programmed to record depth > 1 m.

3.6 Population estimate

Bell et al. (2007) noted that previous population estimates determined by direct extrapolation from the nine census grids have overestimated the black petrel population size due to the original census grids being established in areas of known high petrel density, whereas the distribution of burrows over the whole 35-ha study area is not uniform.

The population estimate for the 35-ha study area was determined by extrapolating from the 2012/13 transects and census grids after stratification of the 35-ha study area (stratifying the area into the four habitat grades based on burrow density, ranking and splitting the length of the transects and areas of the census grids into those habitat types, and then extrapolating to the habitat areas which make up the 35 ha).

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 in 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).

3.7 Population parameters using program MARK

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, *P*= probability of recapture). Adult sex-linked survival was

calculated using the Cormack Jolly Seber model (Phi(sex) *P*(t) and Phi(t) *P*(sex*t) where Phi = apparent survival, t = time, sex = sex of bird, *P*= probability of recapture). Juvenile survival and corresponding Chat values were also calculated, using the Burnham Jolly Seber model.

4 Results

4.1 Study burrows

Within the 416 study burrows (those burrows that could be accessed to determine occupancy out of the 423 numbered burrows in the 2012/13 season), 276 contained breeding birds, 104 contained non-breeding birds and 37 were non-occupied (Appendix 1, Tables 1 and 2). There were 53 failures (e.g. loss of eggs, infertility, predation, etc., Table 2). This corresponds to a breeding success of 80.8% (Table 2, Fig. 6).

Table 1 shows the percentage of occupied and non-occupied burrows within the study burrows and the percentages of non-occupied, breeding and non-breeding burrows. Data from the past 15 breeding seasons shows the ratio of breeding to non-breeding burrows has averaged 3:1, but the ratio of occupied to non-occupied has ranged from 5:1 to 19:1 (Bell & Sim 2000a, b, c, 2002, 2003a, b, 2005; Bell et al 2007, 2009; Bell et al. 2011a; Bell et al. 2011b). However, the last two seasons have had similar numbers of occupied and non-occupied burrows compared to the 2010/11 season and increased since 2007/08 (Table 1). The number of burrows used for breeding this season was slightly lower than the mean for the entire study (66% compared to 66.7 $\pm$ 0.8%, Table 1). Table 2 shows the failures and overall breeding success rate within the study burrows since 1995/96.

Figure 6 shows the trend in the numbers of non-occupied, breeding and non-breeding burrows since the 1998/99 breeding season. It appears that breeding success has been relatively stable (with regular fluctuations between years) despite the number of burrows being used for breeding reducing slightly over the same time (Fig. 6). The mean annual breeding success (1998/99 to 2012/13) within the study burrows is 74.5% ($\pm$ 1.5, Table 1).

4.2 Number of burrows in the census grids

A total of 156 burrows were found in the nine census grids (Appendix 1, Figs 2-4, Table 3) in the 2012/13 breeding season. Of these, 90 burrows were used by breeding pairs, 49 were used by non-breeding adults and 17 burrows were non-occupied (Table 3).

Figure 7 shows the trend in the number of non-occupied, breeding and non-breeding burrows in the census grids since the 1995/96. It appears that the number of burrows used for breeding in the census grids has decreased over the length of the study, despite a slight increase in burrows used for breeding this season (compared to last season). There is also an apparent decline in breeding success since the beginning of the study. Despite lower numbers of both non-occupied and non-breeding burrows this season, the overall trend for both non-occupied and non-breeding burrows shows an increase since 1995 (Fig 7).

There were also several 'potential' burrows within the grids, which were not included in any burrow estimate, but are annually monitored for activity. 'Potential' burrows are those which had been investigated and/or preliminarily dug out, but were not yet being used by breeding or non-breeding petrels.

4.3 Banding data

During the 2012/13 season, 761 adults were identified. Of these, 517 were already banded and 244 were banded this season (Appendix 1, Table 4). There were 223 chicks still present in the study burrows during the April visit and 219 chicks (that were within reach) were banded (Appendix 1, Table 4). Eight chicks had already fledged.

There have been 2568 chicks banded within the study area between 1995 and 2013 (Table 4 and 5) and these birds have begun to return to the colony as pre-breeders, non-breeders and breeders (*n* (2012/13 season) = 85; *n* (total) = 149, Table 5, Appendix 2). The proportion of 'returned chicks' from each season varies from 0 to 12.5% (mean ± SEM = 6.6 ± 1.1); the greatest number of chicks that have been recaptured is from the 2004/05 breeding season (*n* = 18), but the highest proportion of chicks recaptured were banded in the 1998/99 season (12.5%, Table 5). Figure 8 shows the number of chicks banded each season and the proportion of those chicks that have been recaptured in the 35-ha study area. Table 6

shows the number of returned chicks that have been recaptured each season; since the first chicks were banded in 1995/96, the number of recaptures of 'returned chicks' has increased to 85 (between 1999/00 and 2012/13).

There were 85 'returned chicks' recaptured at the colony this season (Table 6); of these, 58 attempted to breed, with 47 successfully raising chicks of their own. The remaining 27 did not breed, although several males were recaptured while calling to attract a mate. Figure 9 shows the total number of 'returned chicks' and number that was caught breeding and non-breeding each season between 1995 and 2013.

Since the first returned chick (banded on Great Barrier Island in the 1995/96 season) was recaptured as a pre-breeder in the 1999/00 season, 149 'chicks' have been recaptured as pre-breeders, non-breeders or breeding adults (Table 5); 148 from chicks banded on Great Barrier Island and one from Little Barrier Island (Appendix 2). The number of times 'chicks' have been recaptured ranges from 1 to 13 (mean ± SEM = 2.6 $\pm$ 0.2, Appendix 2). The frequency of first recapture of each age class is given in Figure 10. Although the youngest age at first return (to the colony) is 3 years, the mean age ± SEM at first return is 5.8 $\pm$ 0.2 (range 3 to 16 years, Appendix 2). Two birds have been caught and released alive at sea in South America at age 2, but have not been recaptured at the colony to date (Figure 10, Appendix 2).

Since returning to the Great Barrier Island (Aotea Island) colony, 93 of these 'returned chicks' have attempted to breed (Bell & Sim 2002, 2003a, b, 2005; Bell et al 2007, Bell et al 2009, Bell et al 2011a, Bell et al 2011b), with 76 breeding successfully over this period (Appendix 2). This means the age at first breeding attempt ranges from 4 to 16 years (mean ± SEM = 7.3 $\pm$ 0.2) and the age at first successful breeding also ranges from 4 to 14 years (mean ± SEM = 7.4 $\pm$ 0.2, Appendix 2).

4.4 I-GotU™ high-resolution GPS data-logger devices

There were 55 deployments of I-GotU™ high-resolution GPS data-logger devices between December 2012 and February 2013 (Table 7). Of these 55 deployments, three devices were still on the birds in April 2013 (Table 7); these will fall off the birds during the moult and

migration to South America. Four birds that had devices deployed were recaptured, but had lost their devices at sea (Table 7).

Of the GPS devices deployed, 36 were placed on males and 19 were placed on females (Table 7). The birds came from 45 different burrows and overall breeding success was higher in these burrows (87%) than in the study burrows as a whole (81%, Table 7), with most successfully fledging chicks.

Devices were worn for between 0 and 80 days (Table 7) and the birds showed few, if any, adverse affects from carrying the devices. Of the six birds that carried GPS devices between December and January (c. 54 days), two showed moderate levels of rubbing abrasions on the back; but this did not appear to affect breeding success. The remaining birds had no damage or abrasions regardless of deployment length. Mean weight loss of the GPS device birds over the entire deployment period was -8.2 g (± 9.7) although this ranged from -159 to 204 g (Table 8). Over the entire deployment period, males carrying devices lost more weight than females carrying devices (Table 8). Control birds lost more weight than birds carrying GPS devices over both the entire deployment period and each deployment section (December and January/February, Table 8).

Of the 55 GPS devices deployed, 39 devices failed due to battery power, device malfunction or loss of the device at sea and the remaining 16 recorded partial or full tracks; a total of 681.9 hours (Table 7). Distribution patterns through the chick rearing phase of the breeding season ranged across northern New Zealand from the Tasman Sea to East Cape (Figure 11). Of the 11 birds whose tracks began or finished within the Hauraki Gulf Marine Park (HGMP) (Figure 12) a total of 27.2 hours (4% of the total deployment) were spent with the boundaries of the HGMP (mean (± SEM) = 2.5 ± 0.8 hours; range 0.7-9.9 hours). Both males and females foraged in similar areas, but females appeared to forage further from Great Barrier Island (Aotea Island) colony, with one heading north to the Fiji Basin and another east to -170° (Figure 12).

4.5 Lotek™ LAT1900-8 Time-Depth Recorder devices

There were 36 deployments of Lotek™ LAT1900-8 Time-Depth Recorder (TDR) devices between December 2012 and February 2013 (Table 9). Of these 36 deployments, two devices were still on the birds in April 2013 (Table 9); these will be retrieved in the 2013/14 breeding season.

Of the TDR devices deployed, 24 were placed on males and 12 were placed on females (Table 9). The birds came from 30 different burrows and overall breeding success was higher in these burrows (90%) than in the study burrows as a whole (81%, Table 9), with almost all successfully fledging chicks.

Devices were worn for between 0 and 88 days (Table 9) and the birds showed no adverse affects from carrying the devices. Mean weight loss of the TDR device birds over the entire deployment period was -10.5 g (± 11.1) although this ranged from -159 to 140 g (Table 10). Over the entire deployment period, males carrying devices lost more weight than females carrying devices; on many occasions females increased in weight (Table 10). Control birds lost more weight than birds carrying TDR devices over both the entire deployment period and each deployment section (December and January/February, Table 10).

Of the 36 GPS devices deployed, 24 devices did not obtain dive information as the birds either did not leave the burrows or are still at sea (Table 9). The remaining 13 devices showed a range of diving depths and behaviour; there were 23 different dive period events (Tables 11 and 12, Appendices 3 and 4). Most dives were during the day (93.2%) and over 80% of the dives were shallow (>5 m) and this pattern was similar for males and females (Tables 11 and 12, Appendix 3). The deepest dive (-27.4 m) was by a male (H33630) on 1 February 2013 (Appendix 3). The one device programmed to only record dive depths > 1 m was deployed on a female (H29682); this bird recorded 101 dives over 135 hours of deployment (Appendix 3).

Most of the deployment time was spent in the air (79.7%, 393.5 hours) and nearly 60% of this time was spent flying during the day (Table 12, Appendix 4). This pattern was similar for both males and females (Table 12, Appendix 4). When on the surface, most of this time was

in daytime hours (89.6%, 89.6 hours) and again the pattern was similar for males and females (Table 12, Appendix 4).

Figures 13a and 13b show a representative dive record from a male (H33630, Fig. 13a) and female (H31240, Fig. 13b) black petrel at sea between 1 February and 2 February; it appeared that most of the time at sea was spent sitting on the water or surface feeding (at depths between 0 and -0.9 m) with deeper dives occurring over a short period of time (≤1.5 hours). Figures 13c and 13d each show a single dive from a male (Fig. 13c) and female (Fig. 13d); both suggesting pursuit behaviour (i.e. bird chasing prey underwater) once the bird got to the bottom of the dive.

4.6 Survival estimates and recapture probabilities

A Cormack Jolly Seber (CJS) analysis (adult survival and probability of recapture varying over time) model was run; Phi(t) *P*(t) where Phi=apparent survival, t=time, *P*= probability of recapture) of all adults recaptured between 1964 and 2013. This generated an adult apparent survival of 95.2% ± 1.3% for the 2012/13 season (since 1964); there is a suggestion of an increased in apparent adult survival over the study period (Table 13, Figure 14). The mean probability of recapture from one year to the next was 84.8% (± 2.6%) and the mean probability of fidelity to the nest site (burrow) was 88.9% (± 1.2%).

A Burnham analysis of survival of chicks banded in the 35-ha study site between 1995 and 2013 was also completed. Only 149 of over 2500 chicks banded on Great Barrier Island (Aotea Island) have been recaptured. As earliest age of return was 3 years, it was not possible to calculate apparent survival before a chick's third year; however, a model incorporating chick recapture and survival parameters gave an apparent juvenile survival estimate of 59.4% (± 1.2%).

4.7 Transect data

Twenty-six random transects were surveyed within the study area ranging in length from 178 m to 400 m, with between 4 and 40 burrows located in each (Fig. 5, Table 14).

Using Manifold™, vegetation and terrain survey data and ranking transects, four burrow density grades with corresponding habitat types have been identified within the 35-ha study area (Fig. 5):

- High-grade petrel habitat on ridges or spurs, usually in established canopy, with high density burrows (≥ 100 burrows/ha), 4.669 ha;
- Medium-grade petrel habitat on steep slopes, usually in established canopy or tall secondary growth, with medium density burrows (50-99 burrows/ha), 15.3013 ha;
- Low-grade petrel habitat, on low slopes or flat ground, often boggy, with low burrow density (1-49 burrows/ha), 13.5607 ha;
- Non-petrel habitat, on stream beds, cliffs, slips and swampy areas with scrub or *Garnia*, with no burrows, 1.7509 ha.

The transects were stratified into habitat grades along the length of the transect and the burrows along the length were assigned to the relevant habitat grade (Table 14).

4.6 Population estimate from census grids and transect data

One population estimate for the 35-ha study area was determined by extrapolating from transects and census grid data after stratification of the 35-ha study area into four habitat grades. This population estimate for the 2012/13 burrow-occupying black petrel population was between 3974 and 4233 adults (4104 $\pm$ 129 birds, Table 15), consisting of 1150 $\pm$ 92 non-breeding adults and 2954 $\pm$ 167 breeding adults (i.e. approximately 1500 breeding pairs).

Although it is suspected that any population estimate determined by extrapolating from the nine census grids only may overestimate the population size (as these grids were originally established in known areas of high petrel density and that the study site does not have a uniform distribution of burrows), comparing annual populations estimates using this data may suggest the trend of the black petrel population on Great Barrier Island. Table 16 gives the annual population estimates since 1995. Figure 15 shows the apparent declining trend in the overall population estimate and number of breeding pairs and apparent increase in the number of non-breeding birds.

4.7 Analysis of population estimate and trend using comparison of random transect surveys (2004/05, 2009/10 and 2012/12 breeding seasons)

Random transect surveys were completed in 2004/05 and 2009/10, and repeated again this season to determine population size and trends of the black petrel breeding population around the 35-ha Mt Hobson study area. There were a total of 510 burrows found in transects in 2012/13 compared to 298 from 2009/10 and 191 from 2004/05 (Table 17, Bell et al 2009, Bell et al 2011a). There was large increase in the total number of burrows located in the low habitat between 2004/05 (n = 5), 2009/10 (n = 39) and the current season (n = 136) and approximately twice the number of burrows in both medium and high habitat between 2004/05 and 2012/13 (Table 17). Bell et al (2011a) noted that there was a striking increase between 2005 and 2010 in the density of empty burrows in all three petrel-habitat strata; that increase continued between 2010 and 2013 (Table 18). There was over 1000% increase in the total number of empty burrows located in 2004/05 (n = 9) and 2009/10 (n = 106) and 100% increase between 2009/10 and 2012/13 (n = 220, Tables 17 and 18).

The 2012/13 estimate of population size was more than double that for 2010 and 65% higher than that for 2005 (Table 18). Both differences are highly significant (e.g. comparing 2013 and 2005, $Z = (3248–1964)/(314^2 + 204^2)^{0.5} = 3.43$, $P < 0.001$, two-sided test). The percentage increase since 2010 occurred in all three petrel-habitat strata, but was much greater in the poor and medium strata (189% and 140%, respectively) than in the high stratum (35%).

5 Discussion

The black petrel population on Great Barrier Island has been monitored since the 1995/96 breeding season (Bell & Sim 1998a, b, 2000a, b,c, 2002, 2003a, b, 2005; Bell et al 2007, 2009; Bell et al 2011a; Bell et al 2011b).

5.1 Breeding success

In the 2012/13 breeding season, there were 223 breeding successes and 53 breeding failures, equating to an overall breeding success rate of 81% (Table 2). This breeding success

is higher than most previous breeding seasons, except 2006/07, and is higher than the mean (74.5 ± 1.5%) of the overall study (Tables 1 and 2). This rate of breeding success remains higher than reported in the earlier studies; 1977 (50%) and 1978 (60%, Imber 1987) and 1988/89 (62%, Scofield 1989). The level of abandoned eggs and dead embryos was higher this season than last year (Table 2). Two eggs containing dead embryos had been abandoned once the contents began to decompose and another two had chicks that failed hatching at pipping. Crushed eggs may be due to competition over burrows as adults continue to fight over very good burrows in some locations of the colony (EAB pers. obs.). There were five dead chicks; healthy chicks during one check in February 2013, but dead at the next check in February 2013 or when the final check was completed in April 2013; it was not possible to determine causes of mortality for these chicks; although it was suspected that one died after a parent did not return and it is not possible for one parent alone to successfully raise a chick (Warham 1996). There was one case of disease (avian pox) this season, but it was the dry form and the chick fledged successfully (EAB, pers. obs.). This occurrence of avian pox may reduce body condition and ultimately survival. It will be important to continue to monitor for this, and other chicks return to the colony.

The level of egg abandonment was high (*n* = 8) and this was higher than most previous seasons (Table 2). Although one of these incidents may be related to handler disturbance, the remainder may be related to the age of the birds as younger birds seem to be less experienced in successfully incubating eggs to hatching (EAB, pers. obs.) or body condition (lighter adults appeared to have less commitment to the egg, EAB, pers. obs.).

It should also be noted that 8 chicks were assumed to have fledged before the April banding visit (Table 2). Chicks were assumed to have fledged successfully if traces of down, quill sheaths, pin feathers and/or recent activity in the burrow could be identified. If all of these chicks had died or been predated earlier in the season, this would reduce the breeding success to 78% (Table 2). This breeding success rate is high compared to many other seabird species (such as Westland petrel (*Procellaria westlandica*) 39-50%, Freeman & Wilson 2002, Warham 1996), but the apparent juvenile survival estimate (0.59 ± 0.01) suggests that nearly 50% of these fledged chicks will not survive to return to the colony.

Only two eggs were predated by rats (0.7% of all breeding attempts) within the study burrows and 8 eggs (3% of all breeding attempts) disappeared (but may have been predated by rats or crushed by parents, Table 2). There were no feral cat predation events recorded within the study burrows this season; however one juvenile petrel inside the study area, but not in a study burrow, was predated by a feral cat. All juvenile petrels since 1995/96 breeding season that have been predated by feral cats were out of burrows (stretching wings, attempting to fledge at a launch site, etc.) since carcasses were found in the open and in some cases well away from burrows (EAB, pers. obs.). Juvenile petrels are particularly vulnerable to feral cat predation at fledging time (Warham 1996). There have been 15 chicks predated by feral cats between the 1995/96 and 2012/13 breeding seasons (Table 2). It is, therefore, important to continue cat trapping in the area before, during and after the black petrel breeding season.

The number of burrows used for breeding has increased from last season, but is still showing an overall decline since the beginning of the study (Tables 1 and 2, Fig. 6). Breeding success has remained high and appears to be increasing (Tables 1 and 2, Fig. 6); this may be related to the fact that site fidelity is high (89%), once a pair begins to breed they are more likely to remain as a breeding pair and attempt to breed rather than skip breeding (i.e. become non-breeders) and most successful breeders (85%) in one year return to breed the following year (Bell et al 2011a). Skipping breeding and subsequent improvement of breeding chances following a gap year 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 to breed.

The percentage of non-occupied and non-breeding burrows has fluctuated from year to year (Tables 1 and 2, Fig. 6) which means that the number of non-breeding or pre-breeding birds in the study area varies each season. It is also possible that as many as half the non-breeding and pre-breeding birds become breeding birds the following year (Bell et al 2011a) and that they replace previous breeders that may have died, divorced or skipped a year. These changes in proportions of non-breeding birds may relate to whether the non-breeding and pre-breeding birds were successful in creating and maintaining a pair bond that season (and then will attempt to breed the next season). It is also possible that as the

number of monitoring visits to the colony has been increased to three trips during the incubation and chick rearing stages there has been more accurate determination of whether a burrow is being used by breeding or non-breeding birds (rather than remaining non-occupied).

The increased number of non-occupied burrows this season could be related to the condition of some study burrows as another study burrow has deteriorated this season to become unsuitable for breeding (without additional excavation by the birds) and one of the resident birds from this burrows was recaptured on the surface at night. 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 these burrows and as a result affect breeding success and burrow activity.

Using data since 1998/99, the proportion of non-occupied study burrows has been increasing, although it has dropped in recent years (Table 1, Fig. 6). This may be directly related to handler disturbance, observation hatches being dug or adult mortality (mean apparent adult survival rate of 0.91 $\pm$ 0.01). Analysis of adult survival and site fidelity suggested that black petrels have a relatively low apparent adult survival (91%) compared to other seabird species such as Antipodean albatross (*Diomedea antipodensis*) at 96% (Walker & Elliott 2004), but relatively high (89%) site fidelity. Although birds do not appear to abandon the burrow 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 known 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 the their characteristics, as several burrows have flooded in particularly wet years and collapsed over time, making then unusable for a year or more. This may account for the declining occupancy of burrows, but as there has been an immigration event from Hauturu/Little Barrier Island, site fidelity and the possibility of emigration from Great Barrier Island 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 would require a thorough search for recovery data from banding records and

continued (and wider) recapture effort at the study. It should be noted that the fidelity model only used a small number of recoveries and that more work needs to be done to determine whether this is true and whether emigration or mortality have a larger effect.

It should also be noted that many of the study burrows have been monitored for ten seasons or more and many of the resident birds have continued to use these burrows for the entire study period. This suggests that handler disturbance does not have a large impact, although the response between individual birds may vary (as some birds are more vulnerable to disturbance).

5.2 Recruitment

A total of 980 banded birds were identified this season; 761 were adults and 219 were chicks (Table 4). There were 517 recaptures of previously banded birds, including 85 that were 'returned chicks' (Tables 4 and 6). Although the adult banded as a chick on Little Barrier Island was not recaptured on Great Barrier Island again this season, this bird still represents the first recorded immigration event for black petrels. It is likely that birds from Little Barrier Island are being attracted to Great Barrier Island due to the number of birds' resident there (and resulting noise early in the breeding season). Immigration has implications for population modelling work (as most models assume no immigration), and further surveys and mark-recapture work is needed to maximise the chances of recapturing known birds and returned fledglings. This also has implications for the recovery of the Little Barrier Island population as pre-breeders are more likely to be attracted to Great Barrier Island than Little Barrier Island, slowing the population growth there. It is possible that the Little Barrier Island population may not recover until Great Barrier Island reaches carrying capacity; however as the population on Little Barrier Island is not being monitored for adult survival and recruitment, this is difficult to assess. It is important that the black petrel population on Little Barrier Island is monitored to determine population dynamics, status and trends.

Of the 85 returned chicks, 5 were recaptured in their natal burrows, 45 in their natal area (less than 50 metres from their 'hatching' burrow) and the other 35 were caught more than 100 m away from their natal areas. There is a probable capture bias towards the returning

males due to their behaviour, i.e. calling outside burrows. Despite being attracted to calling males, 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 area. Much of the 35-ha study area is difficult to reach and cannot be searched. This will need to be taken into account for further survival and recruitment analyses.

Since the first chick was recaptured in the 1999/00 season, 149 'chicks' have been recaptured at the Great Barrier Island colony (Table 6). There have been 58 records of 'returned chicks' attempting to breed during this period, and the age of first recorded breeding and that of first successful breeding are both between 4 and 16 years (Table 5, Fig. 9, Appendix 2). It is important to check for more 'returned chicks' and maintain intensive burrow monitoring in areas where returned 'chicks' are present. Many of the returned 'chicks' were recaptured at night during the December visit, so it is important to maintain a high level of night searching at this time of year. Additional searches using a DOC trained seabird dog ('Maddi') also resulted in five 'returned' chicks out of seven birds found on the surface and 24 burrows (including 3 new burrows in the census grids). Further, these data allow for mark/recapture analyses, which could greatly assist in understanding black petrel demographics.

5.3 Survival estimates

The mean apparent adult survival estimate for black petrels in the study area in 2012/13 since 1964 (95%, Table 8) was low for a seabird of this size, but comparable to adult black petrel survival estimates of 88% by Hunter et al (2001) and 85% by Fletcher et al (2008). The increase in overall apparent adult survival 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 regularly during the December trips, Figure 14) rather than changes in survival over time. It is important to undertake thorough surveys within the 35-ha study area to get better recapture rates of banded adults, juveniles and immigrating adults (including recoveries of dead adults) to increase the accuracy of the survival, immigration and fidelity estimates.

Chick recapture data (for chicks banded on Great Barrier Island since 1995) determined that apparent juvenile survival (for the first three years) was 59% which is similar to other juvenile seabirds of this size (Hunter et al 2001, Barbraud et al 2008, Fletcher et al 2008). As the SEABIRD model indicates that the population is stable or increasing only if mean annual juvenile survival is over 0.85 (Francis & Bell 2010, Bell et al 2011b), this apparent juvenile survival estimate indicates a population decline over the length of the study of greater than 2.5% per year. Better estimates of juvenile survival may be obtained over time if more returned 'chicks' are recaptured.

The increased amount and improvement of recapture data enables a more accurate calculation of mean apparent adult and juvenile survival and it is important that future analysis and population modelling reflects this.

5.4 Population estimate and trend

The population estimate for the 35-ha study area was calculated using stratified transect and census grid data since surveys and local knowledge of Great Barrier Island showed that petrel burrow densities were not identical throughout the 35-ha study area (EAB, pers. obs.). From the both this season's and earlier transect data it was found that the highest densities of black petrel burrows were located on ridges or spurs with established canopy.

The breeding population was estimated at approximately 1477 breeding pairs (2954 breeding birds) using the census grids and 2012/13 random transects (Table 15). 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.

The breeding bird population estimate (n = 2954) extrapolated from the census grids and random transects together is slightly lower than the estimate calculated by SEABIRD using transects only (n = 3248); this suggests that the census grids are providing a relatively accurate estimate and trend in the overall population status of black petrels on Great

Barrier Island (Aotea Island). It could also be possible that the increased number of breeding birds is related to higher numbers of adults returning to the colony this season compared to the previous two transect surveys. It is important to note that in addition to higher number of breeding birds at the colony this season, the number of non-occupied burrows also increased markedly from both the 2004/5 and 2009/10 transect surveys. This is likely to be related to more accurate identification of black petrel burrows (when empty) and the location of the transects (i.e. more going through poor habitat where birds may abandon sub-optimum burrows following failed breeding attempts).

Repeats of the random transect surveys throughout the 35-ha study area would improve overall study area population estimates and determination of burrow status. It could be important to examine the difference between two- and three-dimensional estimates of density and population size in this steep and difficult terrain. To gain a better population estimate of the black petrel population on the whole of Great Barrier Island (Aotea Island), further surveys need to be undertaken in other areas on the island (i.e. on or near the Hog's Back, Mount Heale and Mount Matawhero). In addition to the summit area of Mount Hobson, black petrels are 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. It is interesting to note that black petrel breeding burrows 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.

Using the original stratified 2004/05 and 2009/10 transect data, Bell et al (2011a) calculated that the black petrel breeding population was 22% less than the previous estimates (approximately 4% decline per year; Francis and Bell 2010) and 5% less than the estimate (1598) by Scofield (1989). The 2012/13 breeding population estimate was more than double that of 2009/10 and 65% higher than 2004/05 and occurred over all three habitat strata (Table 18). The greatest increase was in the poor petrel habitat which may be due to pre-breeders returning to the colony to establish burrows in new areas as they cannot access current occupied burrows in medium or optimum habitat. It is possible that greater

numbers of adults returned to the colony this season compared to other years as more activity (birds flying into the colony at night and calling from the ground) was noted in both December and January this season (EAB, pers. obs.) or that a great proportion of adults bred this season compared to the previous two transect survey seasons (204/05 and 209/10).

Despite this increase in breeding birds in 2012/13, assessing the breeding population trend from the original SEABIRD model using mean apparent juvenile survival (0.59 from Program MARK calculations) equates to over a 2.5% annual population decline. However, although it is difficult to compare the trend found in the transects with those found in the census grids (which may or may not represent the entire breeding population), it is likely that the black petrel population on Great Barrier Island (Aotea Island) has a mean rate of change of up to approximately 2.5% per year and although the direction of change is uncertain and may alter from year to year, it is most likely to be in decline. It is important to continue to monitor the black petrels on Great Barrier Island (Aotea Island) through the census grids and regular (c. 3 to 5 yearly) random transect surveys to accurately assess the trend of this population.

The number of burrows within the nine census grids continued to increase this season (*n* = 156) with another three burrows being located (despite 2 burrows being destroyed). Previous analysis of this and earlier increases (Francis and Bell 2010) suggested an approximate 2-3% increase annually in the breeding population assuming that there was no long-term trend in the percentage of burrows used for breeding. However, despite this increase in burrow numbers, currently there is a downward trend in the percentage of study burrows used for breeding (Fig. 6) and as such population growth is likely to be declining. It continues to be important to assess population growth in relation to survival (adult, pre-breeder and juvenile) as this increase is due to the increased search effort rather than an actual increase in bird numbers, breeding population or creation of new burrows.

New burrows do not necessarily mean that more black petrels are present in the colony, as a number of birds (*n* = 301) have moved between numbered burrows within the 35-ha study area between 1995/96 and 2012/13 breeding seasons. Loss of a partner (particularly

for females), predation events and competition between adults and pre-breeders can all cause movement between burrows (EAB, pers. obs., Warham 1996). Pre-breeding males appear to be attracted back to their natal area and can excavate new burrows in those areas (Warham 1996); in the 35-ha study area more than 35 pre-breeding (or non-breeding) birds have returned to their natal area (and in 15 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 have started to excavate new burrows nearby, hence increasing burrow numbers in certain areas (including census grids, EAB, pers. obs.).

Black petrels also transition between breeding and non-breeding in subsequent years; previous data suggests up to 37% of breeders (either successful or non-successful) change skip the next breeding season each year (Bell et al 2011a). Although black petrels have a high site fidelity (89%), and over 70% of pairs survive annually, previous analysis suggested over 10% of pairs divorce (Bell et al. 2011a). It is difficult to determine the reason for divorce, and the reasons why birds chose to skip a year may relate to breeding outcome, partner selection, burrow condition, handler disturbance or a combination of these (or other) factors. The trend in behaviour and outcome prior to the divorce event needs to be investigated. For example, if one bird skips a year (i.e. remaining in South America), does the other bird attempt to breed with a new partner when it returns to the colony? Does the original pair return to breed at a later date? Bell et al (2011a) suggested that original pairings return in about 1% of cases of divorce, but increasing recapture effort to determine whether birds have really divorced or skipped is vital. Further analysis of the present breeding and recapture data may give a clearer pattern to the levels and causes of skipping and divorce.

5.5 Foraging and diving behaviour

Little was known about the foraging range and at-sea distribution of the black petrel beyond anecdotal records from band recoveries, bird watching expeditions, fishermen, fisheries observers and other vessels (Bell et al 2011a). Many records provide only general locations, and may be related to black petrels' habits of following boats to scavenge (rather than the routes they would follow in the absence of fishing boats).

Bell et al (2011c) using three years of geo-locator light logger data showed that black petrels demonstrated large variability in habitat use patterns and foraging ranges which appeared to allow individuals to locate habitats with increased resource availability as environmental conditions change within the breeding season. During the breeding season foraging was centred on the central Hauraki Gulf and northern New Zealand (Bell et al 2011c). Limited high-resolution GPS tracking in 2006 also showed a central Hauraki Gulf pattern of distribution with foraging to East Cape and towards Fiji (Freeman et al 2010). The high-resolution GPS tracking undertaken this season during the chick rearing phase (January/February 2013) showed similar foraging location patterns to the earlier studies. Both males and females foraged into the same areas; northern New Zealand, Tasman Sea and East Cape and used habitat ranging from < 1000 m to > 5000 m deep (Figs. 11 and 12). Only 27.2 hours of the total 681.9 hours of deployment time (4%) was spent within the Hauraki Gulf Marine Park boundaries, suggesting that black petrels foraging outside the Hauraki Gulf towards seamounts (and the accompanying upwelling of nutrients and prey species) and continental shelf edges (Figs. 11 and 12). Females headed north towards Fiji, further west into the Tasman Sea and further east past East Cape (Figure 12) suggesting a slightly wider foraging range than males, but this needs further investigation and additional deployment of GPS devices to confirm these patterns.

For the first time dive depth information has been collected from black petrels; 13 adults (4 males and 9 females) wore LOTEK LAT 1900-8 Time-Depth Recording (TDR) devices resulting in 23 dive trips and over 570 hours at sea during January and February 2013 (Tables 11 and 12). Interestingly despite Imber (1976) reporting that stomach contents indicated nocturnal feeding due to the level of bioluminescent cephalopods in their diet, the TDR devices recorded the majority of dives over 1 m (93%) were during the day and this pattern was similar for both males and females (Table 11). Although two-thirds of the total deployment time was during daylight hours, nearly 80% of this time was spent flying (Table 12). Most activity on the water also occurred during the day (90%) and this pattern was similar for both males and females (Table 12). It appears that black petrels forage more during the day than previously thought. This foraging activity suggests that there may be two feeding strategies for black petrels; the majority during the day as deeper dives (greater than 1 m)

when targeting fish or other prey species that the birds observe from the air or surface or scavenging scraps or dead prey on or just below the surface (or possibly following fishing vessels) and the other at night when feeding on squid on and just below the surface (0-1 m). It is likely that black petrels also forage on the surface during the day including during their association with dolphins and whales targeting surface scraps for these feeding events (Pitman and Balance 1992).

Although one male dived to 27 m and one female to 20 m, the mean dive depth was 3 m (± 0.1) and the majority (80%) of dives were shallow (< 5 m, Tables 11 and 12). This suggests that the black petrels are predominately surface or shallow water feeders and the risk from fishing gear is close to the surface (generally less than 10 m). Most dives were short (<9 sec, 69%), but one dive by a male lasted 72 seconds and showed pursuit behaviour (i.e. chasing prey underwater). The prevalence of short dives also suggests that black petrels are primarily shallow divers or surface feeders. Although vital new data, these results are limited and as such it is important to gather further dive depth, timing and behaviour information from black petrels to clarify the timing of foraging and diving behaviour. Additional TDR devices should be deployed on breeding black petrels during the incubation and chick rearing stages of the breeding season to determine if there are differences in dive patterns and timing.

Bell et al (2013) showed that black petrel distribution had the highest overlap with snapper bottom longline, big-eye tuna surface longline and inshore trawl. This overlap was throughout the breeding season (October to May) and consistent over the three year tracking study (2007-10, Bell et al 2013) and suggests this overlap is likely to have occurred during the 2012/13 chick rearing stage. Over the three year (2007-10) analysis period there were 64 black-petrel captures on observed fishing; 51 between January and April, 6 in May, and 9 captures between October and December (Thompson 2010b, Thompson 2010c, Bell 2012). There have been two captures of black petrels on observed fishing this season between Great Barrier and Cuvier Islands (April 2013: EAB, pers. obs.). All these observed captures were consistent with the highest fisheries overlap periods over the incubation and chick-rearing stages. It is important to note that observer coverage in these fisheries has been very low (generally less than 1%) and improving observer coverage in inshore trawl

fisheries and in bluenose bottom longline fisheries, within the region of overlap, would help to better define the extent of the impact of fishing on black petrel populations.

The black petrels recorded as caught and killed on commercial fishing vessels in the New Zealand fisheries between 1 October 1996 and 30 June 2013 have been caught on both trawl and long-line vessels between October and May, either east of North Cape, near the Kermadec Islands or around Great Barrier Island (Robertson et al. 2003, Robertson et al. 2004; Conservation Services Programme 2008; Rowe 2009, 2010, Thompson 2010a, Thompson 2010b, Thompson 2010c, Bell 2012). The timing of their capture suggests that most may have been breeding adults. This means that their deaths would have reduced overall productivity and recruitment (as one bird cannot incubate an egg or raise a chick) and pair stability. The level of bycatch for black petrels outside New Zealand waters is unknown, and may impact on the population dynamics of the species. If breeding adults continue to be caught by commercial fishing operations in New Zealand and overseas, this species could be adversely affected even by a small change in adult survival, especially as black petrels have delayed maturity, low reproduction rates and high adult survival (Murray et al 1993). Continued bycatch of breeding adults in New Zealand and overseas fisheries has the potential to seriously affect the species.

Black petrels are recognised as the seabird species that is at the greatest risk from commercial fishing activity within New Zealand fisheries waters (Richard & Abraham 2013). There is a high level of uncertainty around estimates of total bycatch in New Zealand fisheries, but recent estimation work suggests the number black petrel captures in New Zealand commercial trawl and long-line fisheries may be several hundred per annum (Yvan Richard pers. comm.), suggesting that bycatch is potentially far exceeding the biological limit and could have serious impacts on the black petrel population.

It is important to better describe the at-sea distribution and foraging behaviour Great Barrier Island (Aotea Island) black petrel population. Long-term population data can be used to develop an accurate population model to determine adult survivorship, recruitment, mortality and productivity. Combined with further use of high-resolution GPS and geo-locator data-loggers, using improved technology, will allow assessment of factors

affecting the black petrel population on land and at-sea, particularly changes in habitat, foraging zones and prey species and identifying risks (such as fisheries interaction, predators and climate change).

6 Recommendations

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 2024/25 breeding season. This will ensure that 25 years of comparative data are collected to determine the population dynamics of black petrels, allowing us to develop a multi-generational population model to determine survivorship, mortality and the effects of predation, fisheries interaction and other environmental factors.
- There are three visits to the Great Barrier Island colony; (i) November/December to allow 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 recapture will enable the continuation of the mark-recapture programme; (ii) January/February to continue with the mark/recapture programme and to confirm breeding status of the adults (and study burrows), and (iii) April/May to allow surviving chicks to be banded before they fledge.
- The study burrows should be checked for breeding status during every visit to the study area, to give a more accurate estimate of breeding success and determine sex of adults. This would also provide an opportunity to recapture returning birds banded as chicks.
- A sample of 50 black petrels should carry high-resolution GPS data-loggers over three consecutive breeding seasons to accurately investigate foraging behaviour including distances, locations and flight patterns throughout the breeding period (in particular the apparent high risk period of chick rearing; end January to May). This information should be assessed in relation to fisheries overlap.
- A sample of 50 black petrels should carry time-depth recorders over three consecutive breeding seasons to accurately investigate foraging behaviour including depth, number of dives and location (if deployed in conjunction with

GPS loggers) throughout the breeding season (in particular the apparent high risk period of chick rearing; end January to May). This information should be assessed in relation to fisheries risk (in particular fishery type and gear).

- A sample of 50 black petrels should carry light-geolocator data-loggers over two consecutive breeding seasons and the intervening non-breeding period (including migration to and from South America) to accurately investigate foraging distances and locations, water temperature and flight patterns throughout the breeding and non-breeding seasons. This information should be assessed in relation to fisheries overlap.
- Further random transects are undertaken every five years throughout the 35-ha study area around Mount Hobson to increase the likelihood of adult and juvenile recaptures (to improve survival and immigration estimates) and to compare with earlier transect surveys to determine population trends.
- The exact limits of the entire Mount Hobson (Hirakimata) colony should be established and the area 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).

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Appendices

Appendix 1. Results from the study of black petrel burrows (*n* = 423) near Mount Hobson, Great Barrier Island (Aotea Island) during the 2012/13 breeding year.

Study burrows within census grids have their location noted (in brackets) in the burrow column: Palmers Track grid one, two, three (= P1, 2, 3); South Fork Grid one, two, three (= S1, 2, 3); or Kauri Dam Grid one, two and three (= K1, 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 asterix represents a dead adult. Grey-shaded box represents a non-study burrow.

Appendix 2 Number of recaptures, age at first recapture, age at first breeding and age at first successful breeding for black petrels (*Procellaria parkinsoni*) banded as chicks and recaptured in the study site on Great Barrier Island (Aotea Island) between 1995/96 and 2009/10, with a note about an immigrant banded as a chick on Hauturu/Little Barrier Island.

Appendix 3 Number, length and depth of dives, deployment time of 13 time-depth recording (TDR) devices for black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2012/13.

Appendix 4 Total deployment time, total day and night deployment time and total deployment time (day and night) on water or in air of 12 time-depth recording (TDR) devices (where dive depth was set at > 0.5 m) for black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2012/13.

Figures

Figure 1 Location of the black petrel (*Procellaria parkinsoni*) study burrows and census grids within the study area 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.

Figure 2 Location of black petrel (*Procellaria parkinsoni*) burrows found on the Kauri Dam Grid (each grid is 40 x 40 m), Great Barrier Island (Aotea Island). Approximate North is shown (N).

Figure 3 Location of black petrel (*Procellaria parkinsoni*) burrows found on the Palmers Track Grid (each grid is 40 x 40 m) on Great Barrier Island (Aotea Island). Approximate North is shown (N).

Figure 4 Location of black petrel (*Procellaria parkinsoni*) burrows found on the South Fork Grid (each grid is 40 x 40 m) on Great Barrier Island (Aotea Island). Approximate North is shown (N).

Figure 5 Locations of random transects and 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 1.8 ha of non-petrel habitat, 13.6 ha of low-grade (< 50 burrows per ha) petrel habitat, 15.3 ha of medium grade (50-99 burrows per ha) petrel habitat and 4.7 ha of high-grade (≥ 100 burrows per ha) petrel habitat.

Figure 6 Occupancy and breeding success of study burrows (1998/99 to 2012/13 breeding seasons) by black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island). Solid black line = breeding success; dashed black line = burrows used by breeding birds; dotted line = burrows used by non-breeding birds; solid grey line = unoccupied burrows.

Tables

Table 1

	OCCUPIED (%)	NON-OCCUPIED (%)	RATIO (OCCUPIED TO NON-OCCUPIED)	NON-OCCUPIED (%)	BREEDING BURROWS (%)	NON-BREEDING BURROWS (%)	RATIO (BREEDING TO NON-BREEDING)	BREEDING SUCCESS (%)
1998/99	93	7	13:1	7	71	23	3.0:1	77
1999/00	94	6	16:1	6	72	22	3.3:1	74
2000/01	95	5	19:1	5	66	29	2.3:1	76
2001/02	92	8	12:1	8	68	24	2.8:1	70
2002/03	88	12	7:1	12	63	25	2.5:1	69
2003/04	82	18	5:1	18	64	18	3.6:1	76
2004/05	86	14	6:1	14	63	23	2.7:1	80
2005/06	82	18	5:1	18	70	12	5.8:1	67
2006/07	91	9	10:1	9	70	21	3.3:1	83
2007/08	85	15	6:1	15	68	17	4.0:1	77
2008/09	89	11	8:1	10	69	21	3.3:1	76
2009/10	87	13	7:1	13	62	25	2.5:1	74
2010/11	85	15	6:1	15	66	19	3.5:1	61
2011/12	92	8	12:1	8	63	29	2.2:1	77
2012/13	91	9	10:1	9	66	25	2.6:1	81
MEAN (± SEM)	88.8 (± 1.1)	11.2 (± 1.1)	9.4:1 (± 1.1)	11.2 (± 1.1)	66.7 (± 0.8)	22.2 (± 1.2)	3.2:1 (± 0.2)	74.5 (± 1.5)

Table 2

Year	Number of study burrows	Eggs									Chick							OVERALL BREEDING SUCCESS (%)
		Laid	Predation (rat)	Crushed[1]	Abandoned	Infertile	Dead embryo	Disappeared egg[2]	Unknown[3]	Hatched	Predation (rat)	Predation (cat)	Died (disease)	Died (starvation)	Died (unknown causes)	Disappeared chick[4]	Fledged[5]	
95/96	80	57	1	0	0	0	0	2	0	54	0	0	0	0	0	0	54	**94**[6]
96/97	118	92	6	5	2	6	0	0	0	73	0	0	1	0	0	0	72	**78**
97/98	137	95	1	0	1	4	8	0	0	81	0	0	0	1	0	0	80	**84**
98/99	197	142	2	1	5	12	6	0	0	116	2	2	0	0	3	0	109	**77**
99/00	248	178	9	10	1	6	13	0	0	139	0	2	0	0	6	0	131	**74**
00/01	255	168	6	6	3	8	9	0	0	136	0	1	0	0	7	0	128	**76**
01/02	283	192	5	5	9	3	14	11	0	145	0	2	0	0	8	0	135	**70**
02/03	318	199	1	14	7	2	19	3	5	148	0	3	0	0	8	0	137[7]	**69**
03/04	324	208	2	13	0	7	16	0	0	170	0	2	0	0	10	0	158[7]	**76**
04/05	362	226	3	7	3	4	12	5	0	192	0	0	0	0	7	5	181[7]	**80**
05/06	366	257	15	27	1	0	9	19	0	186	0	2	0	0	12	0	172[7]	**67**
06/07	370	257	0	7	2	1	6	19	0	222	0	0	0	0	10	0	212[7]	**83**
07/08	379	256	5	9	11	4	0	19	0	208	0	0	0	0	9	1	198[7]	**77**
08/09	388	266	5	11	6	3	18	7	0	216	0	0	0	0	15	0	201[7]	**76**
09/10	393	244	8	2	3	3	20	20	0	188	0	0	0	0	8	0	180[7]	**74**
10/11	396	262	8	15	13	3	15	33	0	175	0	1	0	0	13	2	159[7]	**61**
11/12	363[8]	214	6	12	1	0	4	23	0	168	0	0	0	0	0	4	164[7]	**77**
12/13	416	276	2	11	8	4	12	8	0	231	0	0	0	0	5	3	223[7]	**81**

[1] These eggs have been crushed and only shell fragments were recovered from the burrow. Some may have been predated by rats, infertile or contained an embryo which died.

[2] These eggs were present in December, but were gone when first checked in January. Many of the burrows had been cleaned out and the adults were not caught again.

[3] 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 been cautious and assumed that they failed.

[4] These chicks were present in February, but were gone in April. 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 removed from the burrow by their parents.

[5] All chicks still present at the end of the April or May trip. It is assumed all will fledge safely.

[6] This breeding success rate is biased as most of these 80 study burrows were located in late February when chicks were already present (and these chicks were likely to survive to fledging).

[7] Of these, some chicks had already fledged prior to the banding visit (78 in 2002/03; 50 in 2003/04; 6 in 2004/05; 8 in 2005/06 (plus 24 unbanded due to a lack of bands), 1 in 2006/07, 8 in 2007/08, 2 in 2008/09, 22 in 2009/10, 21 in 2010/11, 6 in 2011/12 and 8 in 2012/13). The remaining chicks were banded.

[8] There were 401 study burrows checked in December and January, but only 363 were monitored over the complete 2011/12 breeding season (December 2011, January 2012 and April 2012). There were 38 burrows that could not be located by the field team in April 2012.

Table 3

YEAR		KAURI DAM				PALMERS TRACK				SOUTH FORKS				**TOTAL**
		Non-occupied	Breeding	Non-breeding	TOTAL	Non-occupied	Breeding	Non-breeding	TOTAL	Non-occupied	Breeding	Non-breeding	TOTAL	
GRID ONE	1995/96	1	10	4	15	3	7	3	13	2	5	4	11	**39**
	1996/97	1	10	5	16	0	13	6	19	1	12	2	15	**50**
	1997/98	0	8	9	17	0	13	7	20	1	11	3	15	**52**
	1998/99	1	12	6	19	1	15	6	22	0	11	5	16	**57**
	1999/00	3	11	8	22	1	18	5	24	1	10	6	17	**63**
	2000/01	1	12	9	22	0	16	9	25	3	10	4	17	**64**
	2001/02	4	11	8	23	1	19	5	25	4	8	5	17	**65**
	2002/03	2	16	5	23	3	15	7	25	4	6	7	17	**65**
	2003/04	3	18	2	23	3	14	8	25	6	7	4	17	**65**
	2004/05	1	17	7	25	5	14	7	26	4	11	3	18	**69**
	2005/06	3	20	2	25	6	16	4	26	5	11	2	18	**69**
	2006/07	3	16	6	25	3	20	4	27	1	13	4	18	**70**
	2007/08	3	15	7	25	6	17	4	27	0	10	8	18	**70**
	2008/09	5	16	5	26	2	20	5	27	3	10	7	20	**73**
	2009/10	4	15	7	26	2	19	9	30	7	8	5	20	**76**
	2010/11	5	16	4	25	3	20	5	28	8	9	3	20	**73**
	2011/12	7	18	1	26	2	17	9	28	5	7	8	20	**74**
	2012/13	**4**	**13**	**8**	**25**	**3**	**21**	**7**	**31**	**3**	**11**	**7**	**21**	**77**
GRID TWO	1998/99	0	15	4	19	0	10	1	11	1	2	1	4	**34**
	1999/00	0	16	5	21	0	10	1	11	1	1	2	4	**36**
	2000/01	0	13	9	22	0	10	1	11	1	3	0	4	**37**
	2001/02	1	16	6	23	0	10	1	11	0	3	1	4	**38**
	2002/03	2	16	5	23	2	8	2	12	0	3	6	9	**44**
	2003/04	4	16	4	24	1	7	4	12	5	2	2	9	**45**
	2004/05	3	16	6	25	2	7	4	13	2	4	6	12	**50**
	2005/06	6	15	4	25	3	9	1	13	5	7	0	12	**50**
	2006/07	2	19	4	25	1	9	3	13	1	4	7	12	**50**
	2007/08	5	17	3	25	0	8	5	13	0	6	6	12	**50**
	2008/09	1	20	5	26	2	9	3	14	5	6	1	12	**52**

	2009/10	3	18	5	26	2	8	4	14	2	3	5	11	**51**
	2010/11	3	19	4	26	1	11	2	14	4	8	0	12	**52**
	2011/12	2	19	5	26	1	8	5	14	3	7	3	13	**53**
	2012/13	**0**	**18**	**7**	**25**	**1**	**7**	**6**	**14**	**0**	**7**	**6**	**13**	**52**
GRID THREE	1999/00	2	3	0	5	0	9	0	9	1	3	0	4	**18**
	2000/01	1	3	3	7	2	6	2	10	0	3	1	4	**21**
	2001/02	1	4	2	7	3	6	1	10	0	4	1	5	**22**
	2002/03	1	3	3	7	2	6	3	11	1	4	0	5	**23**
	2003/04	2	4	1	7	4	7	1	12	1	3	1	5	**24**
	2004/05	2	4	1	7	6	5	5	16	1	4	0	5	**28**
	2005/06	2	4	1	7	9	7	0	16	1	4	0	5	**28**
	2006/07	1	5	1	7	6	7	3	16	1	3	1	5	**28**
	2007/08	1	4	2	7	9	5	2	16	1	3	1	5	**28**
	2008/09	2	4	2	8	5	6	5	16	1	5	0	6	**30**
	2009/10	2	4	1	7	4	7	4	15	0	5	1	6	**28**
	2010/11	2	4	1	7	7	5	3	15	1	4	1	6	**28**
	2011/12	0	4	4	8	5	8	5	15	0	4	2	6	**29**
	2012/13	**2**	**3**	**2**	**7**	**4**	**7**	**4**	**15**	**0**	**4**	**1**	**5**	**27**

Table 4

	95/96	96/97	97/98	98/99	99/ 00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	11/12	**12/13**
Recaptures of birds banded prior to 1995	19	31	24	23	29	27	27	27	21	22	22	19	19	18	14	13	9	**13**
Recaptures of birds banded in 1995/96	-	14	14	14	16	14	11	12	12	8	12	10	7	8	11	9	5	**5**
Recaptures of birds banded in 1996/97	-	-	113	86	84	73	63	57	43	37	39[9]	31	28	30	29	22	12	**21**
Recaptures of birds banded in 1997/98	-	-	-	32	32	30	28	24	18	27	18	13	13	17	15	11	12	**10**
Recaptures of birds banded in 1998/99	-	-	-	-	95	82	71	64	49	36	39	33	32	37	39	24	17	**29**
Recaptures of birds banded in 1999/00	-	-	-	-	-	86	75	66	47	51	52	37	31	39	34	33	20	**22**
Recaptures of birds banded in 2000/01	-	-	-	-	-	-	51	52	41	22	36	28	29	40	30	21	12	**22**
Recaptures of birds banded in 2001/02	-	-	-	-	-	-	-	68	88	26	25	22	21	26	36	20	18	**24**
Recaptures of birds banded in 2002/03	-	-	-	-	-	-	-	-	61	55	57	54	39	56	52	38	26	**36**
Recaptures of birds banded in 2003/04	-	-	-	-	-	-	-	-	-	22	28	23	21	26	27	24	16	**23**
Recaptures of birds banded in 2004/05	-	-	-	-	-	-	-	-	-	-	48	31	33	48	59	42	28	**47**
Recaptures of birds banded in 2005/06	-	-	-	-	-	-	-	-	-	-	-	46	34	49	50	35	23	**35**
Recaptures of birds banded in 2006/07	-	-	-	-	-	-	-	-	-	-	-	-	27	46	42	35	22	**43**
Recaptures of birds banded in 2007/08	-	-	-	-	-	-	-	-	-	-	-	-	-	29	20	19	18	**32**
Recaptures of birds banded in 2008/09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	71	55	46	**66**
Recaptures of birds banded in 2009/10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	29	**39**
Recaptures of birds banded in 2010/11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	**39**
Recaptures of birds banded in 2011/12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**11**
TOTAL RECAPTURES	19	45	151	155	256	312	326	370	380	306	377	347	334	469	529	412	341	**517**
Number of new-banded adults	41	179	60	129	145	97	114	179	67	135	108	85	53	183	107	82	49	**244**
TOTAL ADULTS	60	224	211	284	401	409	440	549	447	441	485	432	387	652	636	494	390	**761**
Number of new-banded chicks	59	69	85	116	137	137	160	62	110	184	143[10]	215	191	203	171	144	163	**219**
TOTAL NUMBER OF BIRDS	119	293	296	400	538	546	600	611	557	625	627	647	578	855	807	638	553	**980**
Number of chicks recaptured alive (returned to colony)	0	0	0	0	1	1	9	18	14	20	25	20	28	41	42	43	42	**85**
BAND RECOVERIES FROM DEAD BIRDS	0	1	1	0	2	1	2	2	0	0	2	1	1	2	3	2	0	**3**

[9] This includes the returned "chick" from Little Barrier Island (a female H-30807, banded as a chick in 1996/97 breeding season) and recaptured for the first time on Great Barrier Island in the 2005/06 breeding season; this was the first recorded immigration event.

[10] This does not include the 21 chicks that could not be banded due to a lack of bands (there was a total of 164 chicks still present in the study burrows).

Table 5

	Total number of banded chicks	Total number of returned chicks	Proportion (%) of returned chicks
1995/96	59	3	5.1
1996/97	69	7	9.7
1997/98	85	10	11.0
1998/99	116	15	12.5
1999/00	137	16	11.7
2000/01	137	9	6.4
2001/02	160	17	10.6
2002/03	62	6	8.8
2003/04	110	8	7.1
2004/05	184	18	9.6
2005/06	143	15	10.1
2006/07	215	11	5.1
2007/08	191	9	4.6
2008/09	203	4	2.0
2009/10	171	1	0.6
2010/11	144	0	0
2011/12	163	0	0
2012/13	219	0	0
TOTAL	**2568**	**149**	**5.8**
MEAN (± SEM)	143 ± 12	8 ± 2	7 ± 1

Table 6

	95/96	96/97	97/98	98/99	99/ 00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	11/12	12/13
Recaptures of chicks banded in 1995/96	-	-	-	-	1	1	2	3	2	1	2	1	2	2	2	2	1	1
Recaptures of chicks banded in 1996/97	-	-	-	-	-	-	2	2	3	2	1	0	0	1	2	2	0	1
Recaptures of chicks banded in 1997/98	-	-	-	-	-	-	5	6	4	1	2	3	1	4	6	6	3	3
Recaptures of chicks banded in 1998/99	-	-	-	-	-	-	-	6	3	6	6	6	6	8	5	5	3	8
Recaptures of chicks banded in 1999/00	-	-	-	-	-	-	-	1	2	10	9	5	5	8	2	1	4	7
Recaptures of chicks banded in 2000/01	-	-	-	-	-	-	-	-	-	-	4	1	5	2	8	3	1	4
Recaptures of chicks banded in 2001/02	-	-	-	-	-	-	-	-	-	-	1	2	6	8	2	2	5	10
Recaptures of chicks banded in 2002/03	-	-	-	-	-	-	-	-	-	-	-	2	2	4	2	4	1	4
Recaptures of chicks banded in 2003/04	-	-	-	-	-	-	-	-	-	-	-	-	1	3	8	7	3	5
Recaptures of chicks banded in 2004/05	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4	8	9	14
Recaptures of chicks banded in 2005/06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	5	9
Recaptures of chicks banded in 2006/07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	7
Recaptures of chicks banded in 2007/08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	7
Recaptures of chicks banded in 2008/09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
Recaptures of chicks banded in 2009/10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Recaptures of chicks banded in 2010/11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Recaptures of chicks banded in 2011/12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Recaptures of chicks banded in 2012/13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL RECAPTURE OF RETURNED CHICKS	0	0	0	0	1	1	9	18	14	20	25	20	28	41	41	43	42	85

Table 7

DEPLOYED	RETRIEVED	NUMBER OF LOGGERS DEPLOYED			NUMBER OF LOGGERS RETRIEVED	NUMBER OF BURROWS	BREEDING SUCCESS (%) IN BURROWS		NO. OF DAYS LOGGERS WORN		NUMBER OF TRACKS FROM DEVICES	NUMBER OF BIRDS THAT LEFT BURROW	NUMBER OF DEVICES WITH NO TRACKS			
		♂	♀	TOTAL			LOGGER	STUDY	MEAN (± SEM)	RANGE			TOTAL	BATTERY POWER	FAILED	LOTS AT SEA
Dec. 2012	Dec. 2012	19	5	24	24	18	72.2		2.3 ± 0.2	0-4[11]	0	0	24	24	0	0
Dec. 2012	Jan. 2013	3	3	6	6[12]	6	66.7		53.7 ± 1.0	50-57	3	6	3	1	0	2
Jan. 2013	Feb. 2013	12	8	20	20	16	93.8	80.6	5.2 ± 0.6	2-12	13	19	7	5	2	0
Jan. 2013	Apr. 13	1	1	2	2[13]	2	100		80 ± 0	80	0	2	2	0	0	2
Jan. 2013	-	1	2	3	0[14]	3	100		-	-	0	3	3	0	0	3
TOTAL		**36**	**19**	**55**	**52 (94.5%)**	**45**	**86.5 (± 7.1)**	**80.6**	**12.3 ± 2.9**	**0-80**	**16 (29.1%)**	**30 (54.5%)**	**39**	**30**	**2**	**7**

[11] One bird wore a GPS device for two hours only as it was deployed on the wrong bird and was removed as soon as the error was identified.
[12] All 6 birds recaptured, but two birds had lost their logger devices (i.e. had fallen off at sea)
[13] Both birds recaptured, but both had lost their logger devices (i.e. had fallen off at sea).
[14] All three birds were not recaptured during the April visit despite burrow gates, but the chicks were still being fed and fledged successfully.

Table 8

DEPLOYED	RETRIEVED	MEAN WEIGHT LOSS (g) ± SEM (range)		
		MALE	FEMALE	**ALL**
December 2012	December 2012	-26.0 ± 3.8 (-55 – 8)	3 ± 0 (3)	-24.8 ± 3.8 (-55 – 8)
December 2012	January 2013	109.0 ± 68.0 (41 – 177)	144.3 ± 20.5 (114 – 204)	132.5 ± 23.0 (41 – 204)
January 2013	February 2013	-32.2 ± 20.7 (-159 – 140)	-34.8 ± 22.9 (-108 – 103)	-33.2 ± 15.0 (-159 – 140)
January 2013	April 13	14 ± 0 (14)	23 ± 0 (23)	18.5 ± 4.5 (14 – 24)
ALL GPS DEPLOYMENTS		**-19.8 ± 8.8 (-159 – 177)**	**23.2 ± 25.7 (-108 – 204)**	**-8.2 ± 9.7 (-159 – 204)**
Control birds (December)		-46.1 ±5.3 (-100 – 5)	-22.5 ± 4.8 (-35 – -15)	-42.3 ± 4.3 (-100 – 5)
Control birds (January/February)		-49.5 ± 13.3 (-166 – 106)	-41.0 ± 16.9 (-177 – 227)	-44.5 ± 10.5 (-177 – 227)
ALL CONTROL BIRDS		**-48.0 ± 7.7 (-166 – 106)**	**-38.2 ± 14.3 (-177 – 227)**	**-43.7 ± 6.8 (-177 – 227)**

Table 9

DEPLOYED	RETRIEVED	NUMBER OF DEVICES DEPLOYED			NUMBER OF DEVICES RETRIEVED	NUMBER OF BURROWS	BREEDING SUCCESS (%) IN BURROWS		NO. OF DAYS DEVICE WORN		NUMBER OF TDR DEVICES WITH DIVE RECORDS	NUMBER OF BIRDS THAT LEFT BURROW	NUMBER OF DEVICES WITH NO DIVES			
		♂	♀	TOTAL			DEVICE	STUDY	MEAN (± SEM)	RANGE			TOTAL	BIRD DID NOT LEAVE BURROW	FAILED	LOTS AT SEA
Dec. 2012	Dec. 2012	19	1	20	20	15	66.7		2.3 ± 0.2	0-4[15]	0	0	20	20	0	0
Dec. 2012	Jan. 2013	0	1	1	1	1	100		55	55	1	1	0	0	0	0
Jan. 2013	Feb. 2013	3	8	11	11	10	81.2	80.6	9.1 ± 1.0	4-14	9	10	2	1	1	0
Jan. 2013	Apr. 13	1	1	2	2	2	100		87.5 ± 0.5	87-88	2	2	0	0	0	0
Jan. 2013	-	1	1	2	0[16]	2	100		-	-	1[17]	2	2	0	0	2
TOTAL		**24**	**12**	**36**	**34 (94.4%)**	**30**	**89.6 (± 6.8)**	**80.6**	**11.0 ± 3.7**	**0-88**	**13 (36.1%)**	**15 (41.7%)**	**24**	**21**	**1**	**2**

[15] One bird wore a TDR device for two hours only as it was deployed on the wrong bird (i.e. inexperienced breeder) and the device was removed as soon as the error was identified.

[16] Both birds were not recaptured during the April visit despite burrow gates, but the chicks were still being fed and fledged successfully. Both devices will be retrieved in the 2013/14 season.

[17] This TDR was downloaded on 30/1/13 while still on the bird and one dive sequence was recorded. This bird was not recaptured in the April visit and this device will be retrieved in the 2013/14 season.

Table 10

DEPLOYED	RETRIEVED	MEAN WEIGHT LOSS (g) ± SEM (range)		
		MALE	FEMALE	**ALL**
December 2012	December 2012	-26.0 ± 4.6 (-55 – 8)	3 ± 0 (3)	-24.6 ± 4.6 (-55 – 8)
December 2012	January 2013	138.0 ± 0 (138)	-	138.0 ± 0 (138)
January 2013	February 2013	-38.0 ± 90.9 (-159 – 140)	-7.9 ± 28.8 (-85 – 116)	-4.6 ± 30.2 (-159 – 140)
January 2013	April 13	2 ± 0 (2)	44 ± 0 (44)	23.0 ± 21 (2 – 44)
ALL TDR DEPLOYMENTS		**-26.3 ± 10.7 (-159 – 140)**	**22.5 ± 23.8 (-85 – 138)**	**-10.5 ± 11.1 (-159 – 140)**
Control birds (December)		-46.1 ±5.3 (-100 – 5)	-22.5 ± 4.8 (-35 – -15)	-42.3 ± 4.3 (-100 – 5)
Control birds (January/February)		-49.5 ± 13.3 (-166 – 106)	-41.0 ± 16.9 (-177 – 227)	-44.5 ± 10.5 (-177 – 227)
ALL CONTROL BIRDS		**-48.0 ± 7.7 (-166 – 106)**	**-38.2 ± 14.3 (-177 – 227)**	**-43.7 ± 6.8 (-177 – 227)**

Table 11

	NUMBER	DEPLOYMENT (HOURS AT SEA)	NUMBER OF DIVES						LENGTH OF DIVE (seconds)		DEPTH OF DIVE (m)		
			TOTAL	DAY	NIGHT	SHALLOW (0.9 - 5 m)	MEDIUM (5.1 – 10 m)	DEEP (> 10 m)	MAX	MIN	MAX	MIN	MEAN (± SEM)
MALE	4	129.8	39	32 (82.1%)	7 (17.9%)	34 (87.2%)	4 (10.3%)	1 (2.6%)	72	3	-27.4	-0.9	-2.6 ± 0.7
FEMALE	9	499.1	533	488 (90.6%)	35 (6.6%)	429 (80.5%)	76 (14.3%)	28 (5.3%)	57	1	-20.1	-0.9	-3.1 ± 0.1
ALL	13	628.9	572	515 (93.2%)	42 (7.3%)	463 (80.9%)	80 (14.0%)	29 (5.1%)	72	1	-27.4	-0.9	-3.0 ± 0.1

Table 12

	NUMBER	NUMBER OF DIVE TRIPS	TOTAL DEPLOYMENT (HOURS)			TOTAL DEPLOYMENT IN AIR (HOURS)			TOTAL DEPLOYMENT ON WATER (HOURS)		
			TOTAL	DAY	NIGHT	TOTAL	DAY	NIGHT	TOTAL	DAY	NIGHT
MALE	4	7	129.5	77.4 (59.8%)	52.1 (40.2%)	93.8 (72.4%)	45.3 (48.3%)	48.5 (51.7%)	35.3 (27.3%)	31.9 (90.4%)	3.4 (9.6%)
FEMALE	8	16	364.0	238.9 (65.6%)	125.1 (34.4%)	299.7 (82.3%)	181.3 (60.5%)	118.4 (39.5%)	64.7 (17.8%)	57.7 (89.2%)	7.0 (10.8%)
ALL	12	23	493.5	316.3 (64.1%)	177.2 (35.9%)	393.5 (79.7%)	226.6 (57.6%)	166.9 (42.4%)	100 (20.3%)	89.6 (89.6%)	10.4 (10.4%)
MEAN (± SEM)			21.5 ± 3.2	13.8 ± 1.9	7.7 ± 1.4	17.1 ± 3.0	9.9 ± 1.7	7.3 ± 1.4	4.4 ± 0.6	3.9 ± 0.5	0.5 ± 0.1

Table 13

SEASON	SURVIVAL ESTIMATE	SE
1995/96	0.8939	0.08
1996/97	0.9671	0.03
1997/98	0.8832	0.04
1998/99	0.9481	0.02
1999/00	0.9203	0.02
2000/01	0.9264	0.02
2001/02	0.8967	0.02
2002/03	0.8057	0.03
2003/04	0.9644	0.03
2004/05	0.8266	0.03
2005/06	0.8275	0.04
2006/07	0.9117	0.04
2007/08	0.9259	0.04
2008/09	0.9489	0.04
2009/10	0.9525	0.02
2010/11	0.9523	0.02
2011/12	0.8649	0.04
2012/13	0.9516	0.01

Table 14

TRANSECT	LENGTH OF TRANSECT					NUMBER OF BURROWS ALONG TRANSECT									
	TOTAL	NON-PETREL	LOW	MEDIUM	HIGH	LOW			MEDIUM			HIGH			TOTAL
						BREEDING	NON-BREEDING	EMPTY	BREEDING	NON-BREEDING	EMPTY	BREEDING	NON-BREEDING	EMPTY	
LT1	400	9	179	174	38	2	2	7	0	0	2	4	0	1	18
LT2	400	0	188	111	101	8	1	3	4	0	5	6	0	6	33
LT3	290	22	217	22	29	2	2	2	0	0	2	0	0	1	9
LT7	400	27	332	41	0	1	2	2	0	0	0	0	0	0	5
LT15	270	0	270	0	0	0	1	3	0	0	0	0	0	0	4
LT17	400	0	0	152	248	0	0	0	6	0	5	7	6	16	40
LT20	400	15	13	303	69	0	1	0	7	2	3	1	1	0	15
LT21	400	19	83	221	77	3	1	3	7	5	11	3	0	2	35
LT27	400	40	0	292	68	0	0	0	3	2	7	0	1	3	16
LT32	260	17	83	160	0	1	0	1	3	3	3	0	0	0	11
LT34	400	22	172	93	113	0	1	1	1	0	2	5	1	2	13
LT40	400	0	205	46	149	4	2	6	0	0	2	5	3	2	24
LT41	400	34	242	68	56	2	1	5	1	0	3	2	0	3	17
LT42	400	20	247	133	0	6	1	4	3	2	4	0	0	0	20
LT55	400	0	30	261	109	0	2	1	8	5	5	0	5	3	29
LT56	400	0	97	243	60	0	0	1	3	1	6	1	0	1	13
LT57	400	0	103	236	61	2	0	1	3	2	5	3	1	0	17
LT79	400	18	299	83	0	1	1	2	1	0	1	0	0	0	6
LT83	330	0	0	64	266	0	0	0	1	2	1	9	7	6	26
LT84	400	45	98	71	186	6	1	5	3	0	1	4	2	5	27
LT86	400	0	188	109	103	5	1	3	3	0	6	3	1	1	23
LT88	178	0	52	126	0	1	1	1	4	3	2	0	0	0	12
LT91	400	23	103	211	63	1	2	2	7	5	8	1	2	0	28
LT92	400	3	170	154	73	4	5	6	2	2	5	5	2	6	37
LT111	250	0	0	195	55	0	0	0	3	2	5	0	2	2	14
LT112	400	0	155	169	76	0	0	0	3	2	4	5	1	3	18
TOTAL	**9578**	**314**	**3526**	**3738**	**2000**	**49**	**28**	**59**	**76**	**38**	**98**	**64**	**35**	**63**	**510**

Table 15

RANK	Transect or Census Grid	Area (ha)	DENSITY (Number/ha)		TOTAL AREA	POPULATION ESTIMATE (35 ha)	
			Breeding adults	Non-breeding adults		Breeding adults	Non-breeding adults
LOW (1-49 burrows per ha)	LT1	0.0716	56	35	13.5607	759	475
	LT112	0.062	0	0		0	0
	LT15	0.108	0	12		0	163
	LT2	0.0752	213	17		2888	231
	LT20	0.0052	0	240		0	3255
	LT21	0.0332	181	38		2454	515
	LT3	0.0868	46	29		624	393
	LT32	0.0332	60	0		814	0
	LT34	0.0688	0	18		0	244
	LT40	0.082	98	31		1329	420
	LT41	0.0968	41	13		556	176
	LT42	0.0988	122	13		1654	176
	LT55	0.012	0	208		0	2821
	LT56	0.0388	0	0		0	0
	LT57	0.0412	97	0		1315	0
	LT7	0.01328	15	19		203	258
	LT79	0.1196	17	11		231	149
	LT84	0.0392	306	32		4150	434
	LT86	0.0752	133	17		1804	231
	LT88	0.0208	96	60		1302	814
	LT91	0.0412	49	61		664	827
	LT92	0.068	118	92		1600	1248
	KDG2	0.008	0	0		0	0
	KDG3	0.008	0	0		0	0
MEAN (± SEM)			69 ± 16	39 ± 13		931 ± 221	535 ± 170
MEDIUM (50-99 burrows per ha)	LT1	0.0696	0	0	15.3013	0	0
	LT111	0.078	77	32		1178	490
	LT112	0.0676	89	37		1362	566
	LT17	0.0608	197	0		3014	0
	LT2	0.0444	180	0		2754	0
	LT20	0.1212	116	21		1775	321
	LT21	0.0884	158	71		2418	1086
	LT27	0.1168	51	21		780	321
	LT3	0.0088	0	0		0	0
	LT32	0.064	94	59		1438	903
	LT34	0.0372	54	0		826	0
	LT40	0.0184	0	0		0	0
	LT41	0.0272	74	0		1132	0
	LT42	0.0532	113	47		1729	719
	LT55	0.1044	153	60		2341	918
	LT56	0.0972	62	13		949	199
	LT57	0.0944	64	26		979	398
	LT7	0.0164	0	0		0	0
	LT79	0.0332	60	0		918	0
	LT83	0.0256	78	98		1194	1500
	LT84	0.0284	211	0		3229	0
	LT86	0.0436	138	0		2112	0
	LT88	0.0504	159	74		2433	1132
	LT91	0.0844	166	74		2540	1132
	LT92	0.0616	65	41		995	627
	KDG1	0.008	0	0		0	0
	KDG2	0.032	188	39		2877	597
	KDG3	0.106	19	12		291	184

	SFG1	0.032	63	39		964	597
	SFG3	0.11	18	23		275	352
	PTG2	0.04	0	31		0	474
	PTG3	0.06	33	21		505	321
	MEAN (± SEM)		84 ± 12	26 ± 5		1282 ± 178	401 ± 75
HIGH (≥100 burrows per ha)	LT1	0.0152	526	0	4.669	2456	0
	LT111	0.022	0	114		0	532
	LT112	0.0304	329	41		1536	191
	LT17	0.0992	141	76		658	355
	LT2	0.0404	297	0		1387	0
	LT20	0.0276	73	45		341	210
	LT21	0.0308	195	0		910	0
	LT27	0.0272	0	46		0	215
	LT3	0.0116	0	0		0	0
	LT34	0.0452	221	28		1032	131
	LT40	0.0596	168	63		784	294
	LT41	0.0224	179	0		836	0
	LT55	0.0436	0	143		0	668
	LT56	0.024	83	0		388	0
	LT57	0.0244	246	51		1149	238
	LT83	0.1064	169	82		789	383
	LT84	0.0744	108	34		504	159
	LT86	0.0412	146	30		682	140
	LT91	0.0252	79	99		369	462
	LT92	0.0292	343	86		1601	402
	KDG1	0.152	171	66		798	308
	KDG2	0.12	250	63		1167	294
	KDG3	0.046	87	27		406	126
	SFG1	0.128	141	29		658	135
	SFG2	0.16	88	47		411	219
	SFG3	0.05	80	0		374	0
	PTG1	0.16	263	55		1228	257
	PTG2	0.12	100	63		467	294
	PTG3	0.1	120	38		560	177
MEAN (± SEM)			159 ± 22	46 ± 7		741 ± 103	214 ± 32
TOTAL POPULATION ESTIMATE (± SE)						2954 ± 167	1150 ± 92
						4104 ± 129	
POPULATION ESTIMATE RANGE						**3974 to 4233 adults**	

Table 16

YEAR	Breeding pairs	Non-breeding birds	Total population estimate (number of individual birds)
1995/96	1313	500	3125
1996/97	2188	688	5188
1997/98	2063	1125	5250
1998/99	2031	719	4781
1999/00	1667	584	3918
2000/01	1583	791	3958
2001/02	1688	625	4000
2002/03	1625	771	4021
2003/04	1625	563	3813
2004/05	1676	935	4286
2005/06	1298	1009	3605
2006/07	1400	968	3768
2007/08	1358	1020	3736
2008/09	1030	641	2701
2009/10	1059	916	3034
2010/11	882	490	2254
2011/12	783	483	2049
2012/13	1477	1150	4104
MEAN (± SEM)	1486 (± 93)	777 (± 50)	3755 (± 207)

Table 17

YEAR	NUMBER OF BURROWS												
	LOW				MEDIUM				HIGH				TOTAL
	BREEDING	NON-BREEDING	NON-OCCUPIED	TOTAL	BREEDING	NON-BREEDING	NON-OCCUPIED	TOTAL	BREEDING	NON-BREEDING	NON-OCCUPIED	TOTAL	
2004/05	3	2	0	5	59	39	6	104	50	29	3	82	191
2009/10	14	10	15	39	30	44	56	130	51	43	35	129	298
2012/13	49	28	59	136	76	38	98	212	64	35	63	162	510

Table 18

STRATUM	AREA (ha)	BURROW DENSITY (Number/ha)			POPULATION ESTIMATE (Breeding birds only)		
		2004/05	2009/10	2012/13	2004/05	2009/10	2012/13
NON-PETREL	1.75	0	0	0	0	0	0
LOW (1-49 burrows/ha)	13.6	4.9 (± 2.2)	12.0 (± 4.6)	34.7 (± 7.7)	134 (± 61)	327 (± 124)	945 (± 211)
MEDIUM (50-99 burrows per ha)	15.3	37.6 (± 5.4)	21.2 (± 3.0)	50.8 (± 6.6)	1150 (± 166)	649 (± 93)	1555 (± 201)
HIGH (≥100 burrows per ha)	4.67	72.8 (± 11.0)	58.8 (± 7.6)	80.0 (± 12.5)	680 (± 103)	550 (± 71)	747 (± 117)
TOTAL	35.3	29.3 (± 3.0)	22.7 (± 2.5)	48.4 (± 4.7)	1964 (± 204)	1525 (± 170)	3248 (± 314)

Figure 1

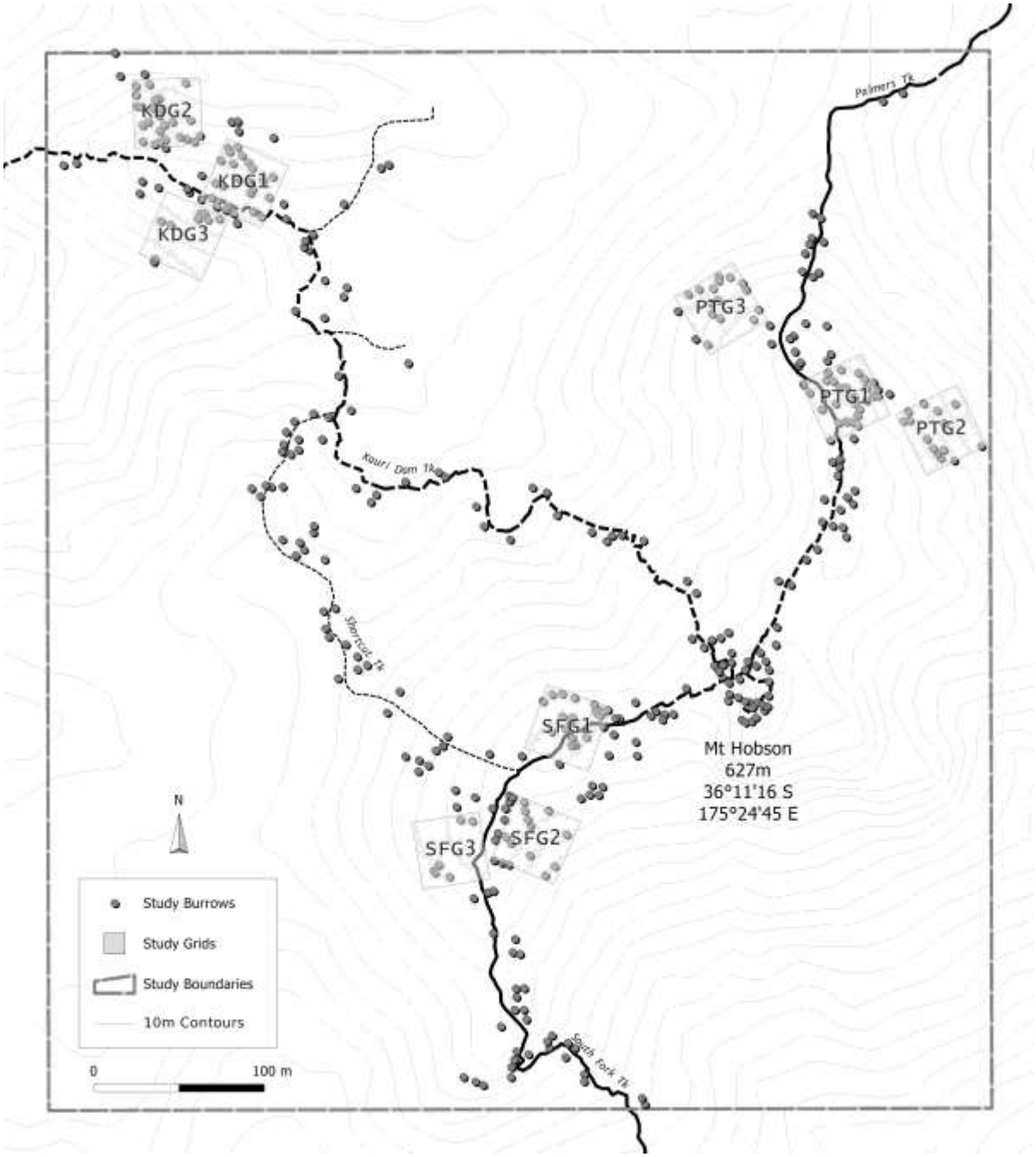

KDG2
KDG1
KDG3
PTG3
PTG1
PTG2
SFG1
SFG3
SFG2
Palmers Tk
Kouri Dam Tk
Shortcut Tk
South Fork Tk
Mt Hobson
627m
36°11'16 S
175°24'45 E
N
Study Burrows
Study Grids
Study Boundaries
10m Contours
0
100 m

Figure 2

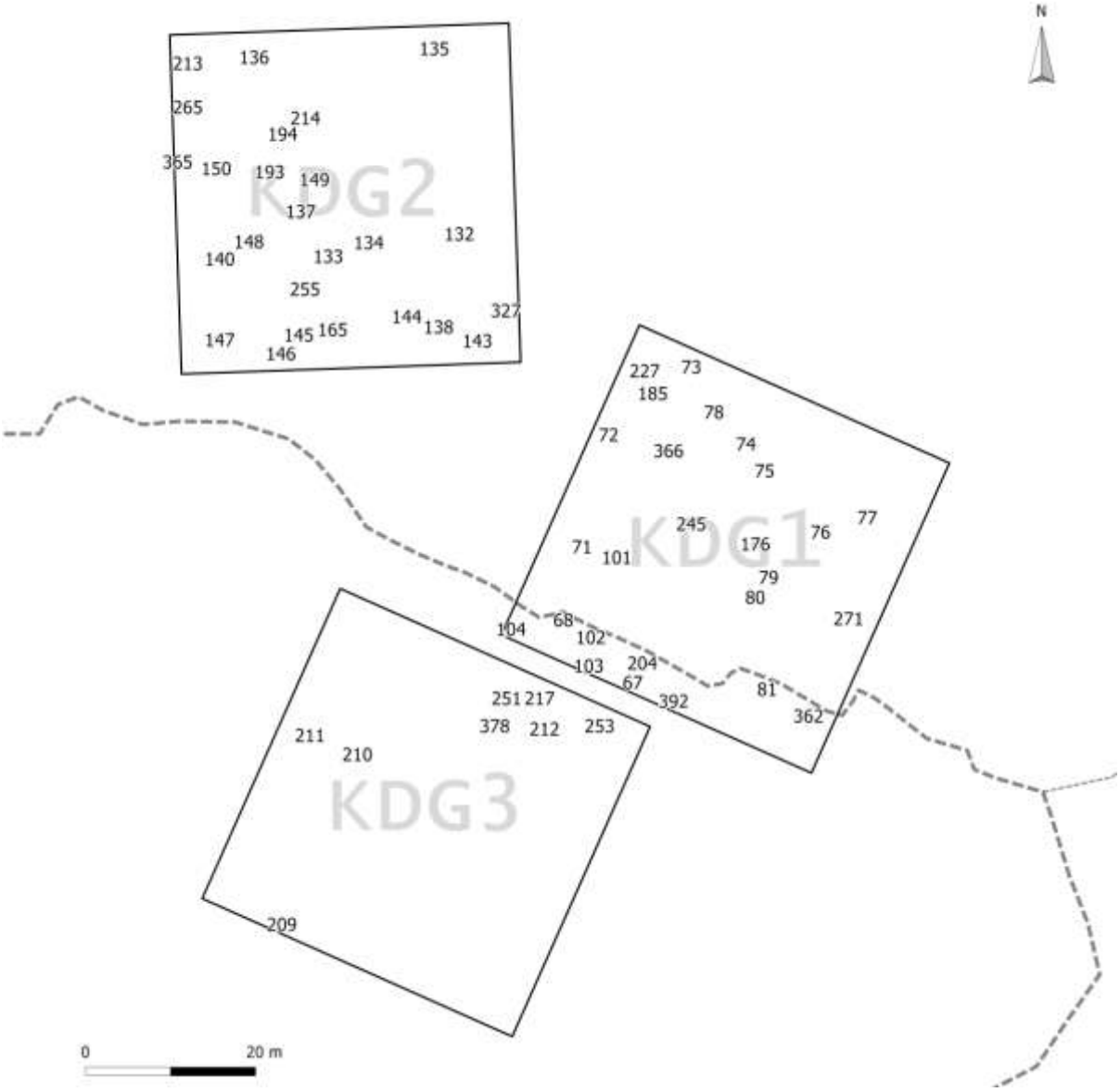

N
KDG2
KDG1
KDG3
213
136
135
265
214
194
365
150
193
149
137
148
140
133
134
132
255
144
138
327
147
145
165
146
143
227
73
185
78
72
366
74
75
77
245
76
71
101
176
79
80
271
68
104
102
103
204
67
392
81
362
251
217
378
212
253
211
210
209
0
20 m

Figure 3

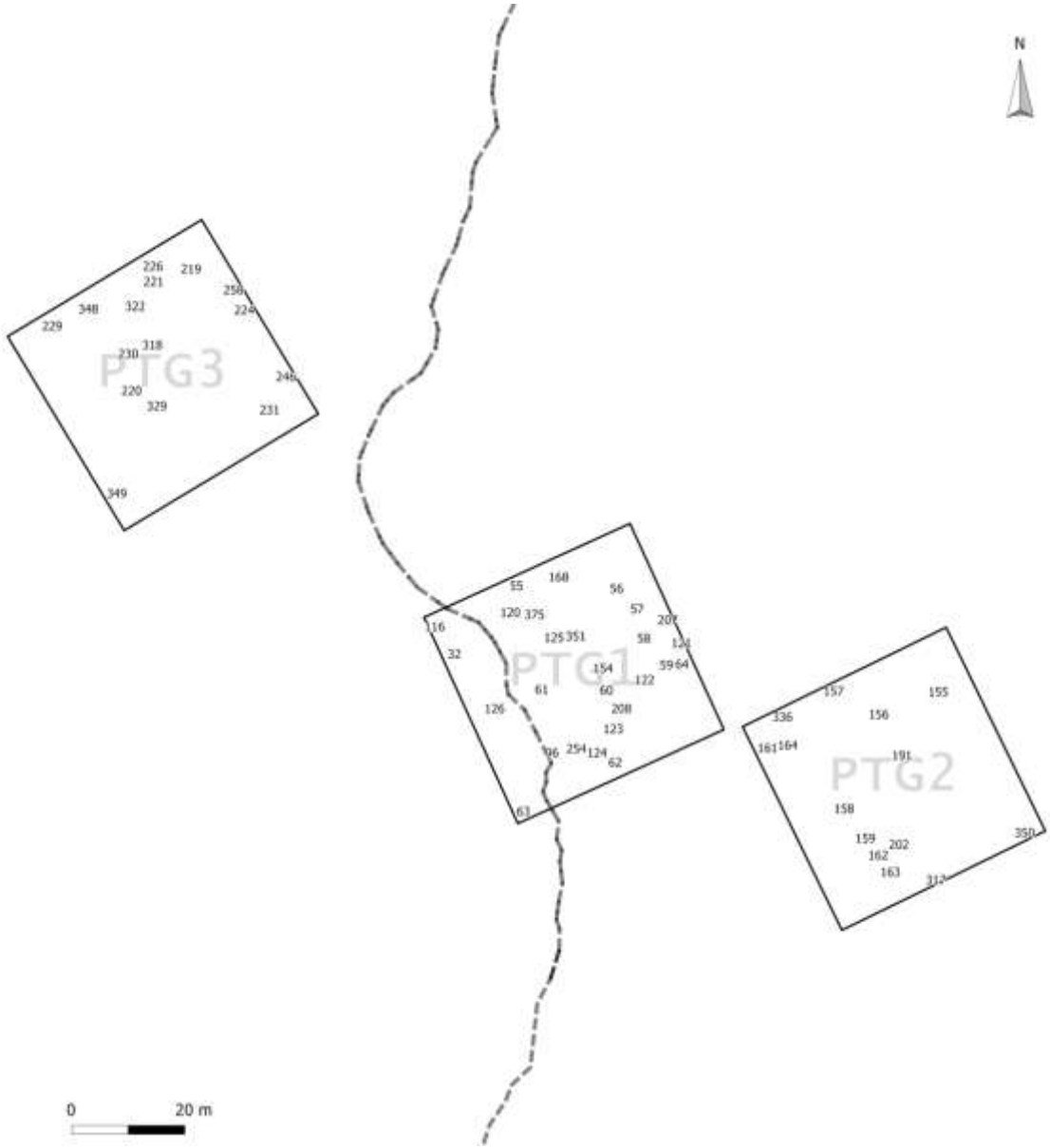


Figure 4

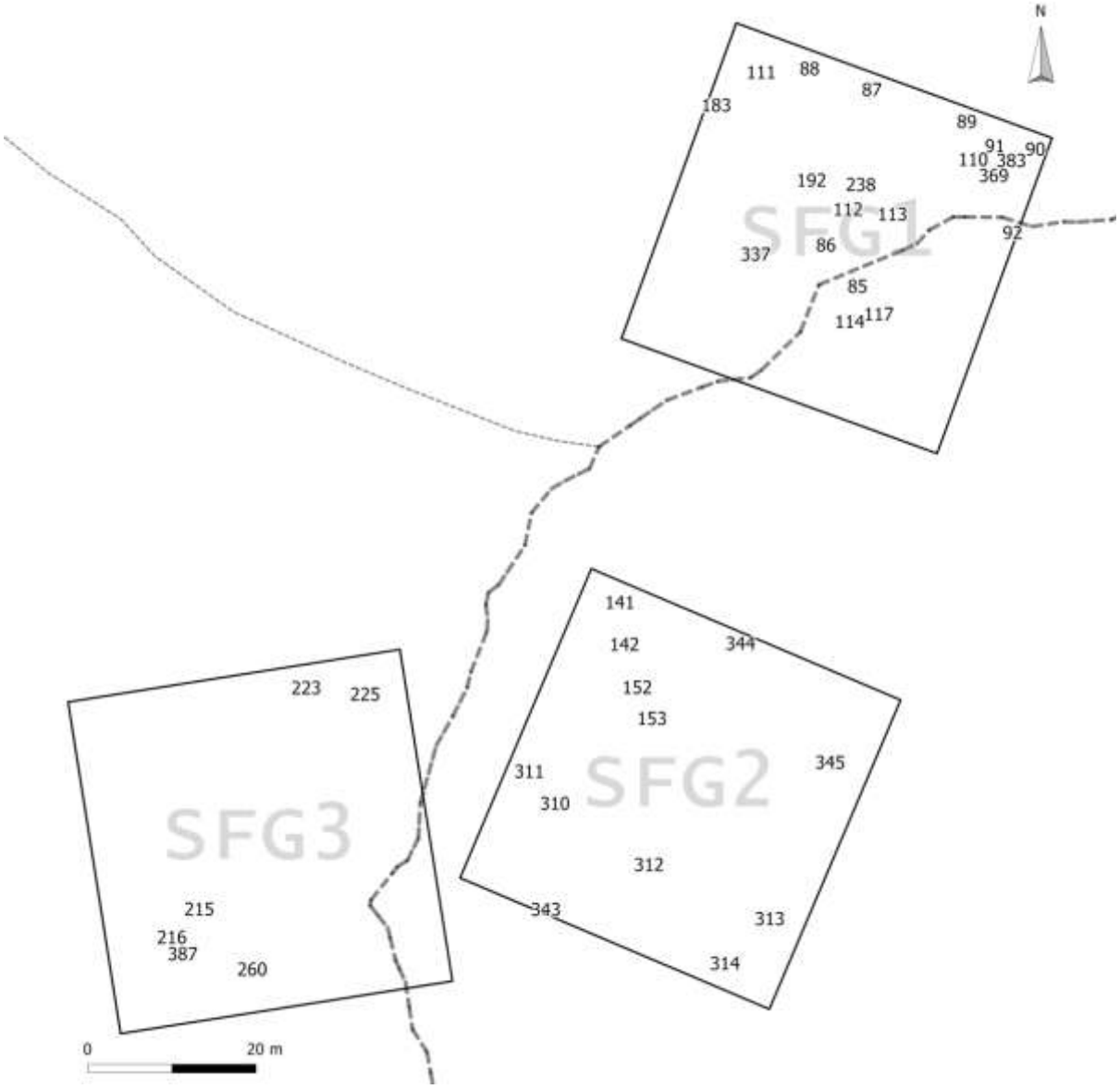

N
111
88
87
183
89
91
90
110
383
369
192
238
112
113
92
SFG1
337
86
85
114
117
141
142
344
152
153
311
345
SFG2
310
312
343
313
314
223
225
SFG3
215
216
387
260
0
20 m

Figure 5

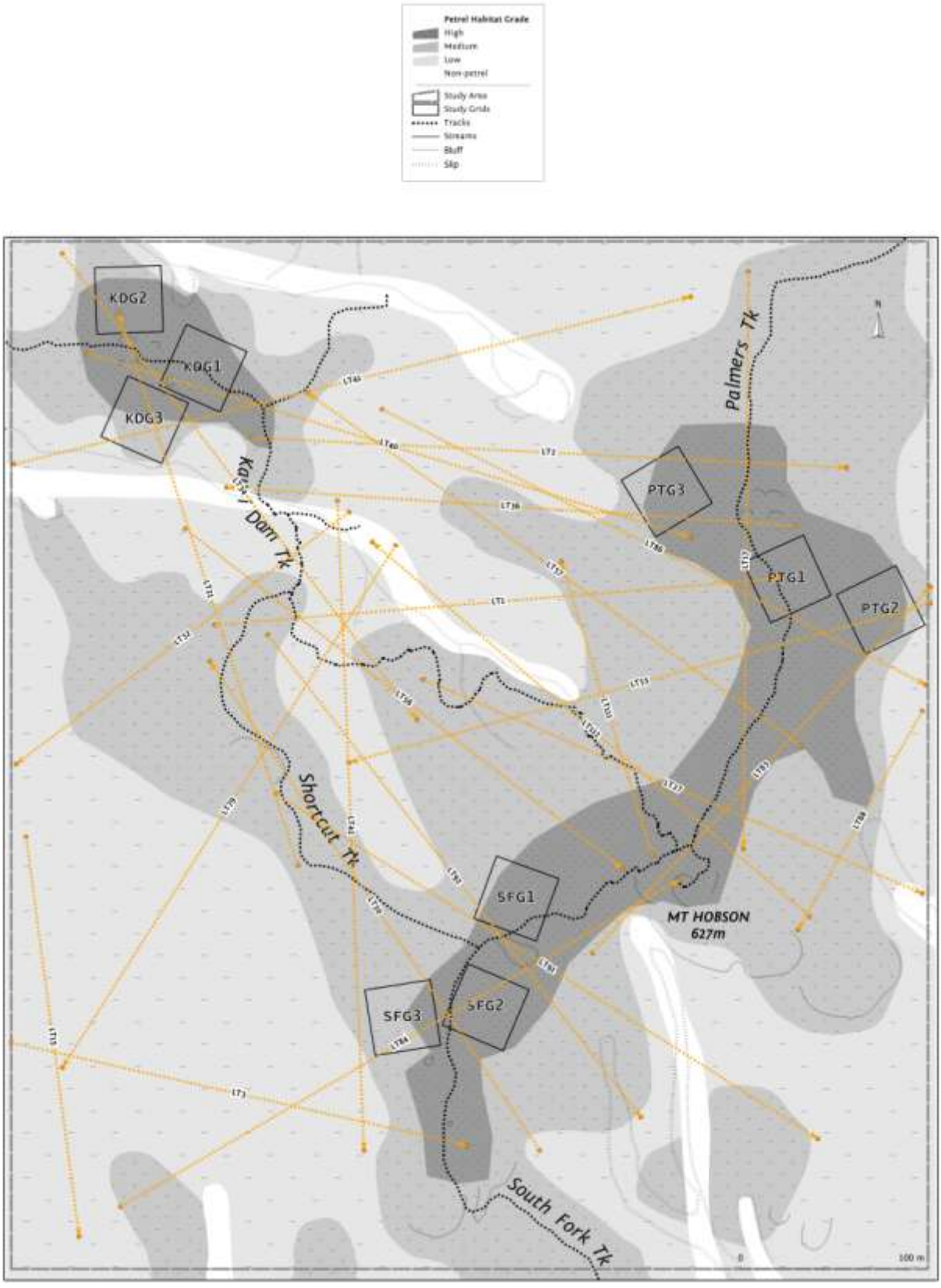

Petrel Habitat Grade
High
Medium
Low
Non-petrel
Study Area
Study Grids
Tracks
Streams
Bluff
Slip
KDG2
KDG1
KDG3
PTG3
PTG1
PTG2
SFG1
SFG3
SFG2
Palmers Tk
Kaipo Dam Tk
Shortcut Tk
South Fork Tk
MT HOBSON
627m
N
100 m

Figure 6

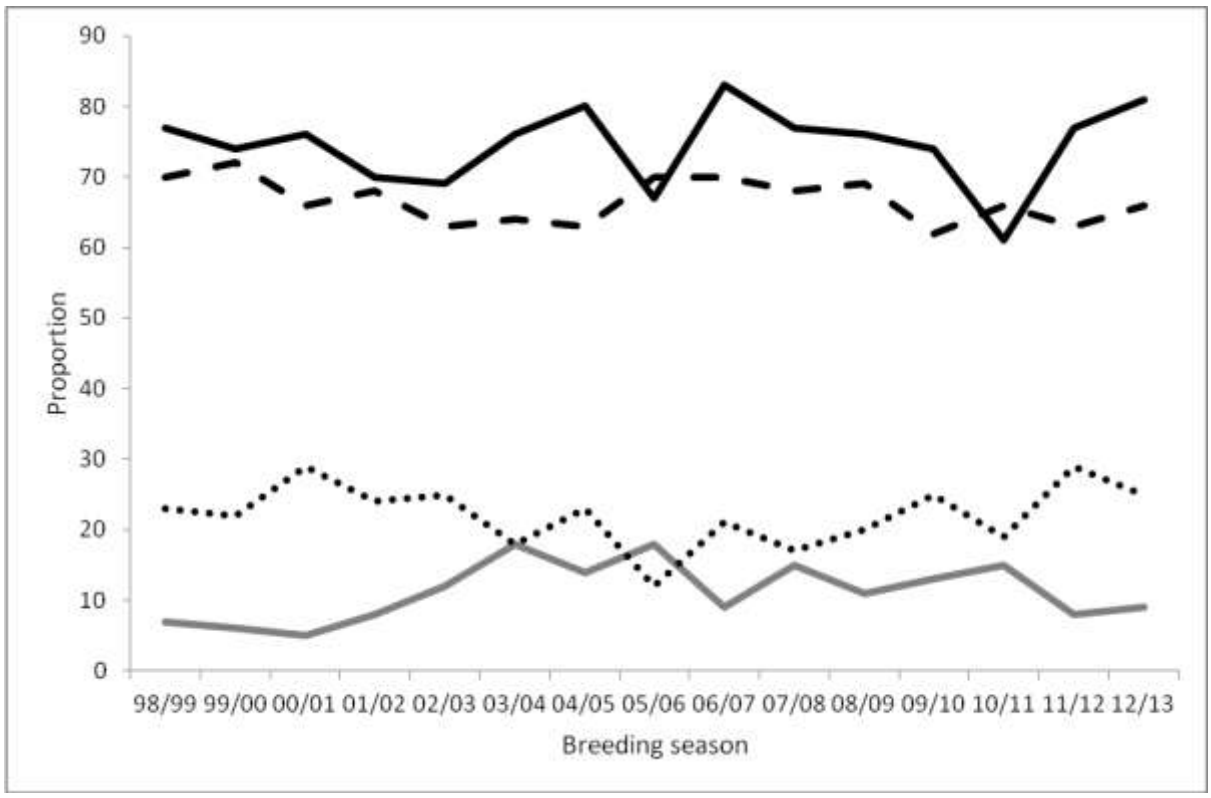

90
80
70
60
50
40
30
20
10
0
Proportion
98/99 99/00 00/01 01/02 02/03 03/04 04/05 05/06 06/07 07/08 08/09 09/10 10/11 11/12 12/13
Breeding season

Figure 7

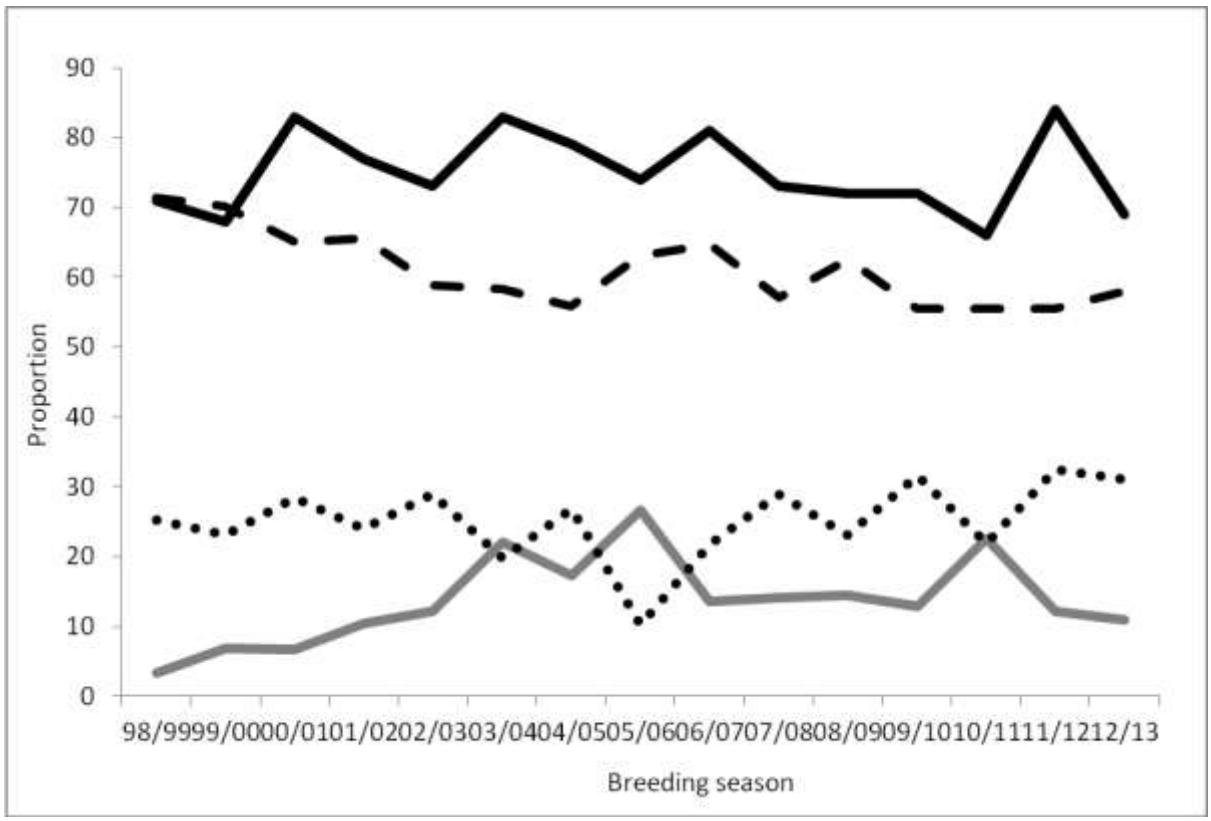

90
80
70
60
50
40
30
20
10
0
Proportion
98/9999/0000/0101/0202/0303/0404/0505/0606/0707/0808/0909/1010/1111/1212/13
Breeding season

Figure 8

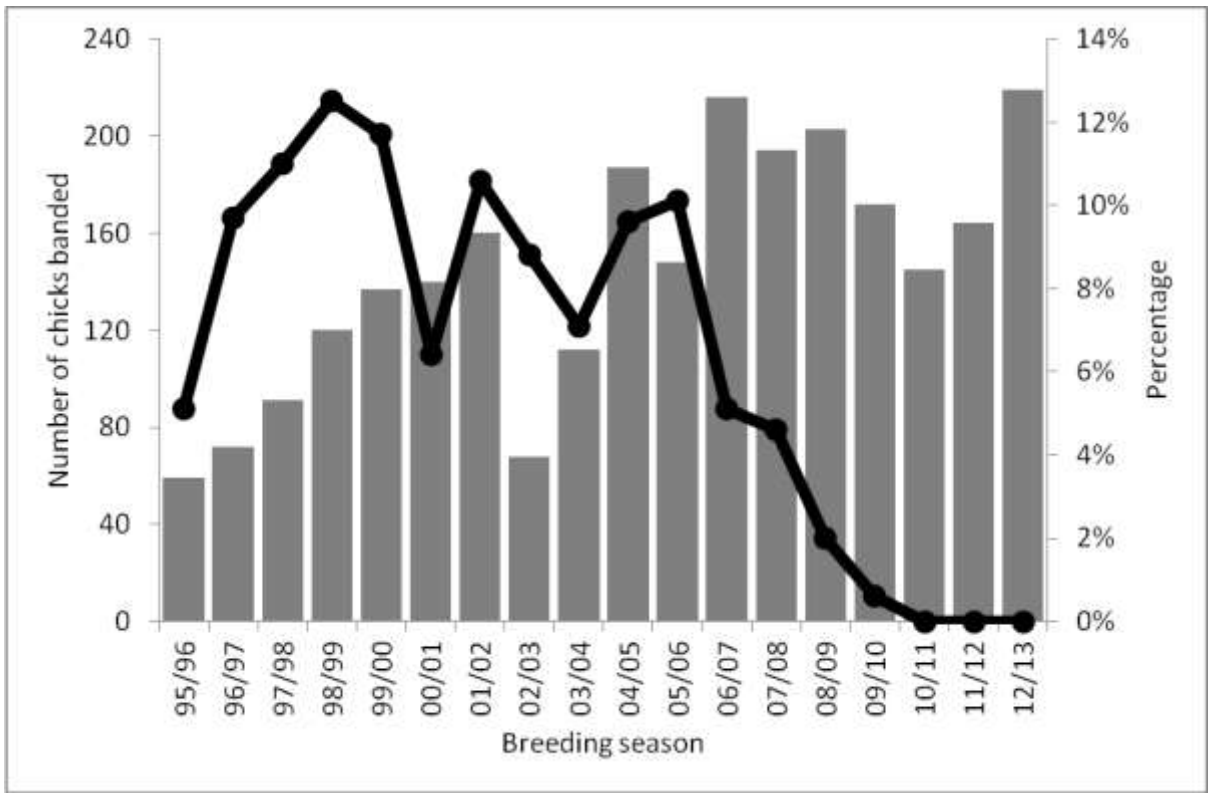

240
200
160
120
80
40
0
Number of chicks banded
14%
12%
10%
8%
6%
4%
2%
0%
Percentage
95/96
96/97
97/98
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06
06/07
07/08
08/09
09/10
10/11
11/12
12/13
Breeding season

Figure 9

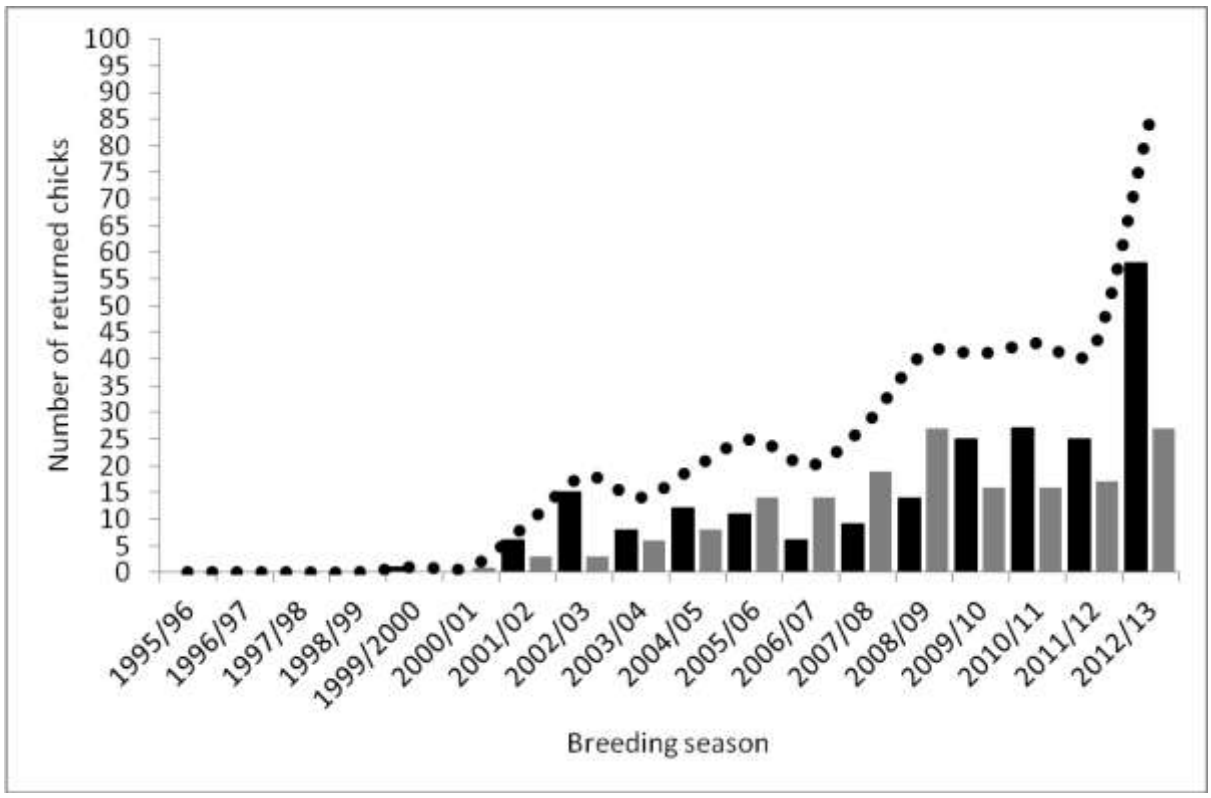

Number of returned chicks
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1995/96
1996/97
1997/98
1998/99
1999/2000
2000/01
2001/02
2002/03
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
2010/11
2011/12
2012/13
Breeding season

Figure 10

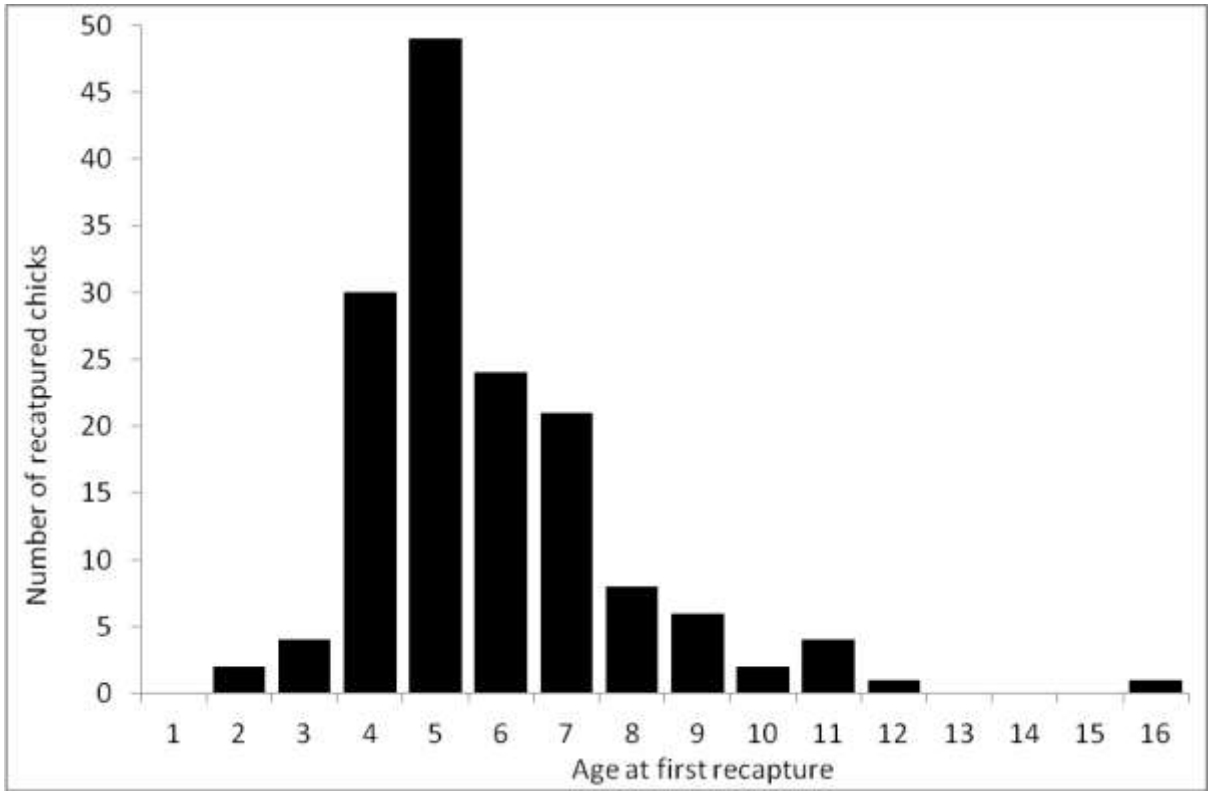

Number of recatpured chicks
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Age at first recapture

Figure 11

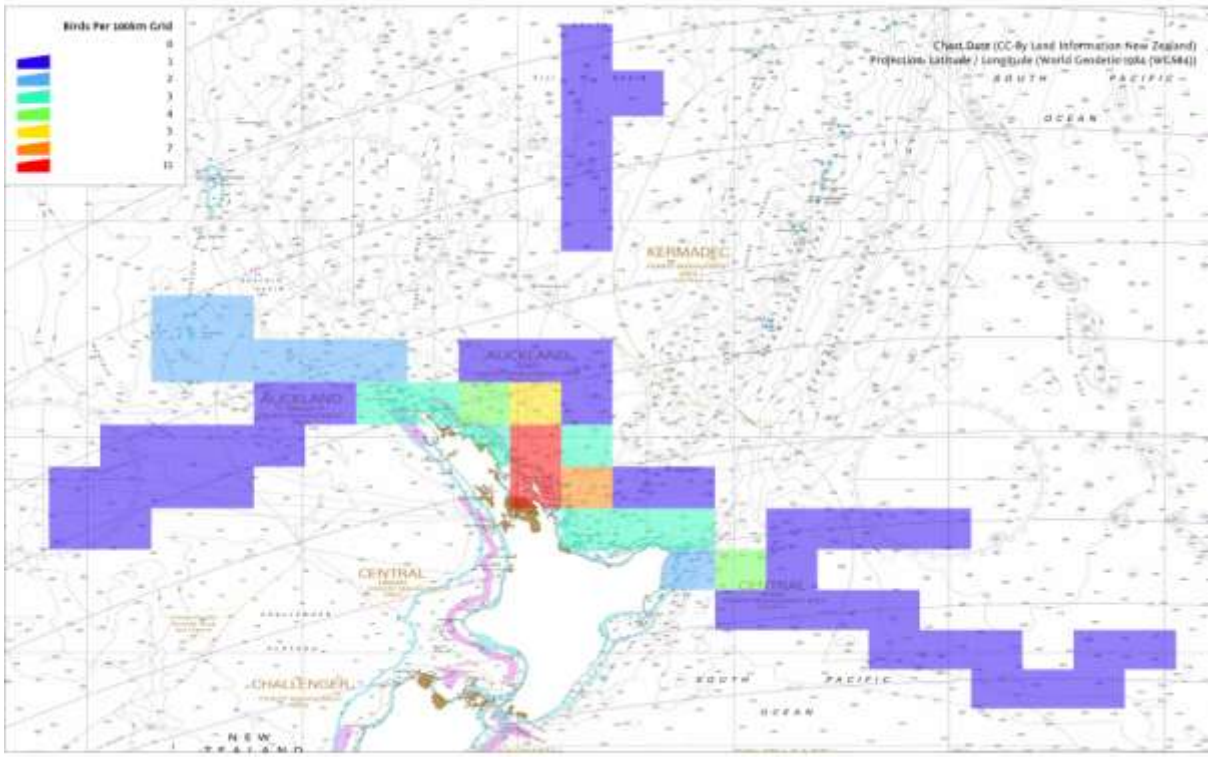

Birds Per 100km Grid
0
1
2
3
4
5
7
11
Chart Data (CC-By Land Information New Zealand)
Projection: Latitude / Longitude (World Geodetic 1984 (WGS84))
SOUTH PACIFIC OCEAN
KERMADEC
AUCKLAND
AUCKLAND
CENTRAL
CHALLENGER
SOUTH PACIFIC OCEAN
NEW ZEALAND

Figure 12

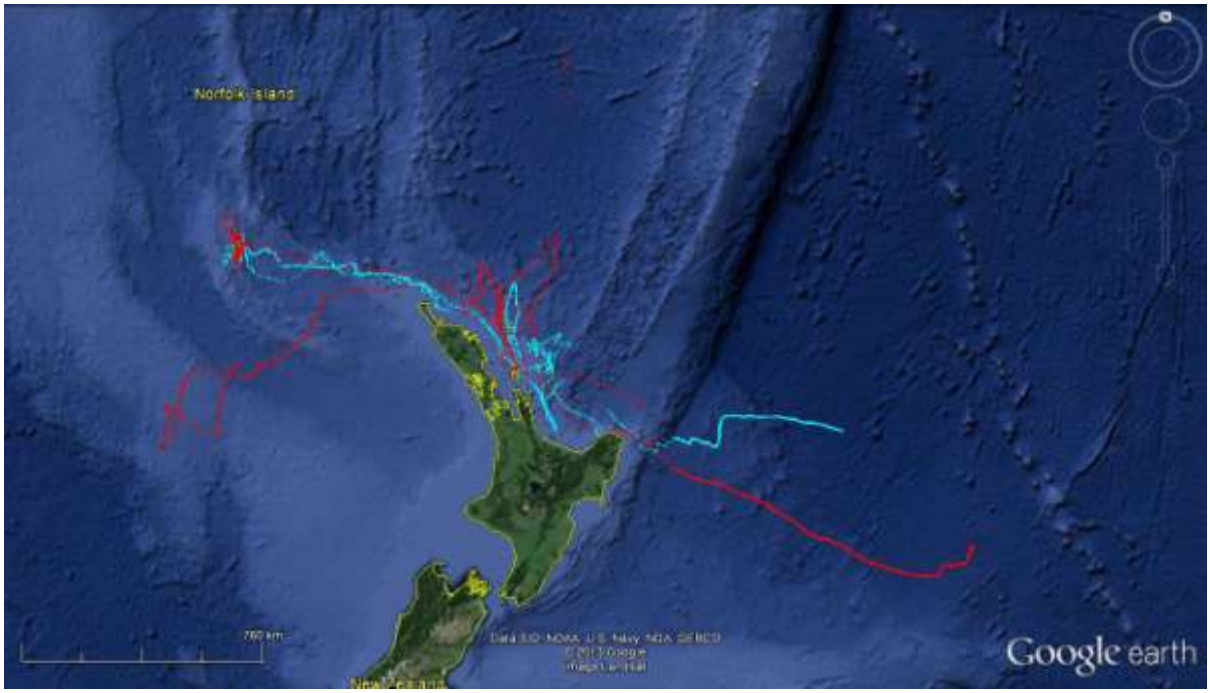


Figure 13a

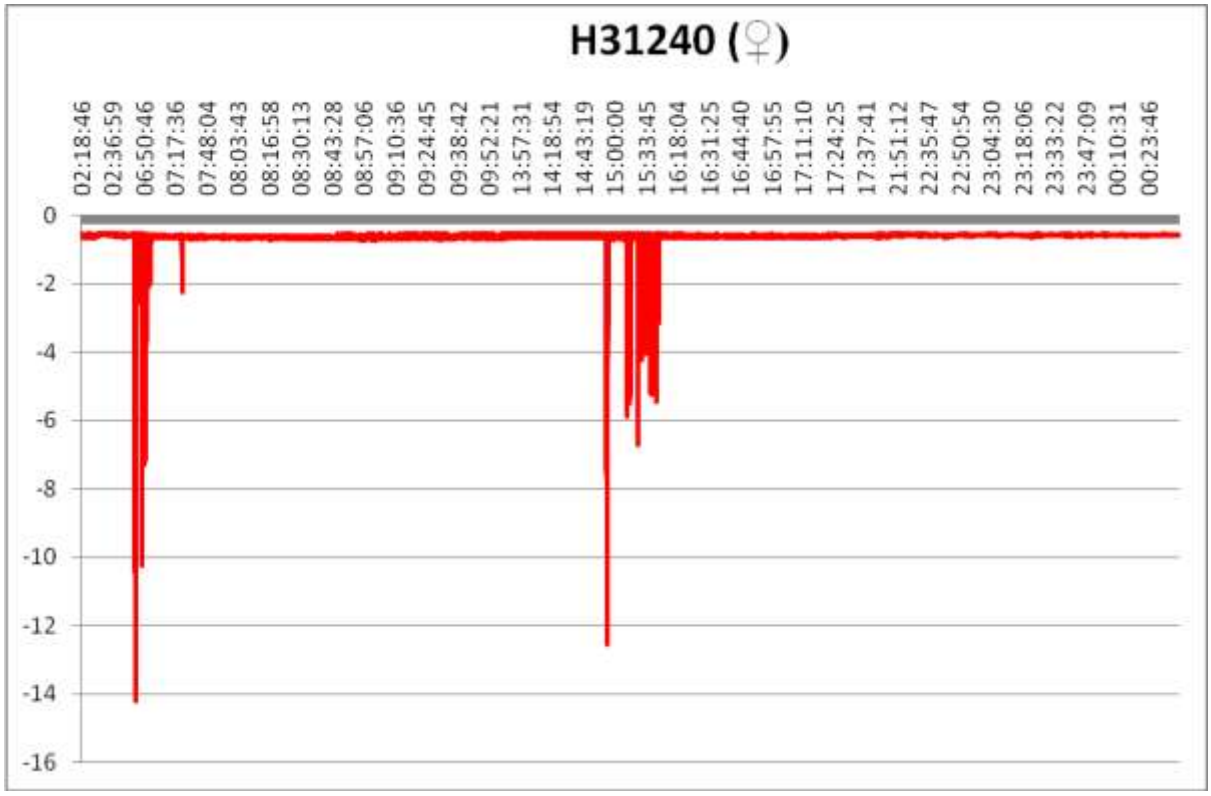

H31240 (♀)
02:18:46
02:36:59
06:50:46
07:17:36
07:48:04
08:03:43
08:16:58
08:30:13
08:43:28
08:57:06
09:10:36
09:24:45
09:38:42
09:52:21
13:57:31
14:18:54
14:43:19
15:00:00
15:33:45
16:18:04
16:31:25
16:44:40
16:57:55
17:11:10
17:24:25
17:37:41
21:51:12
22:35:47
22:50:54
23:04:30
23:18:06
23:33:22
23:47:09
00:10:31
00:23:46
0
-2
-4
-6
-8
-10
-12
-14
-16

Figure 13b

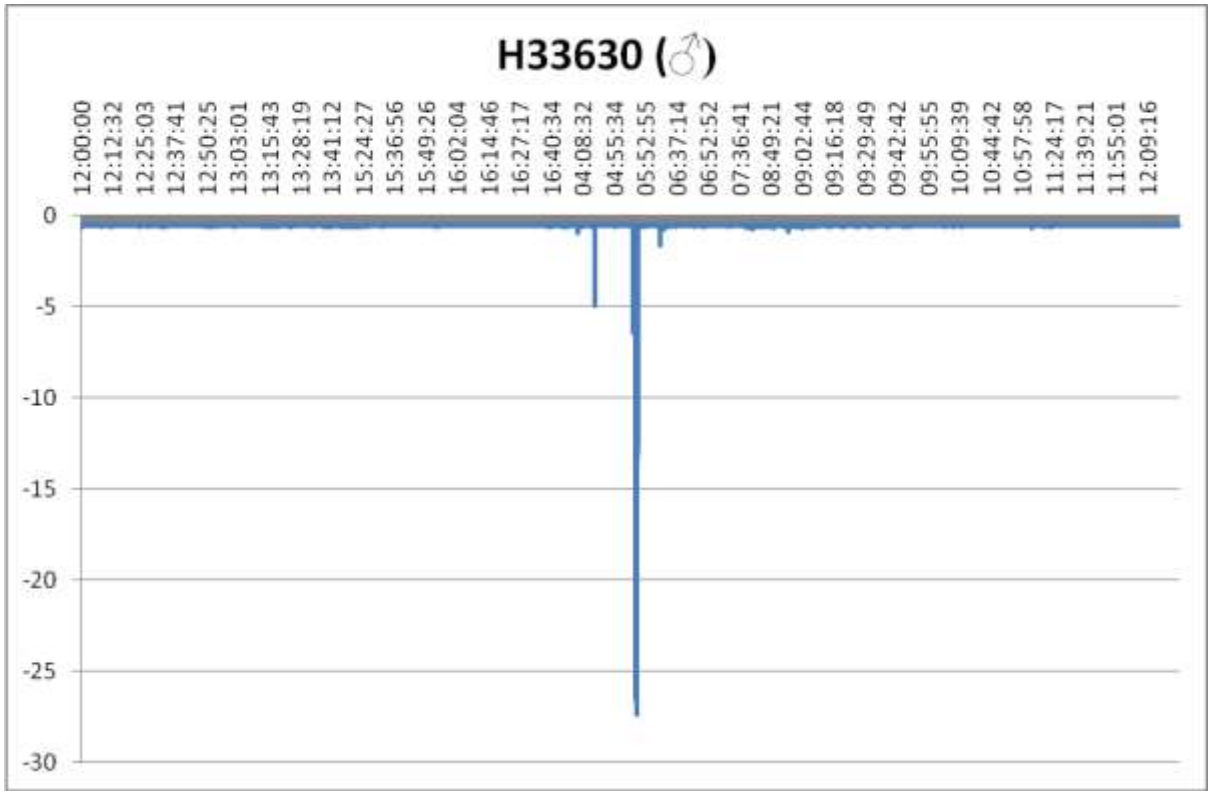

H33630 (♂)
12:00:00
12:12:32
12:25:03
12:37:41
12:50:25
13:03:01
13:15:43
13:28:19
13:41:12
15:24:27
15:36:56
15:49:26
16:02:04
16:14:46
16:27:17
16:40:34
04:08:32
04:55:34
05:52:55
06:37:14
06:52:52
07:36:41
08:49:21
09:02:44
09:16:18
09:29:49
09:42:42
09:55:55
10:09:39
10:44:42
10:57:58
11:24:17
11:39:21
11:55:01
12:09:16
0
-5
-10
-15
-20
-25
-30

Figure 13c

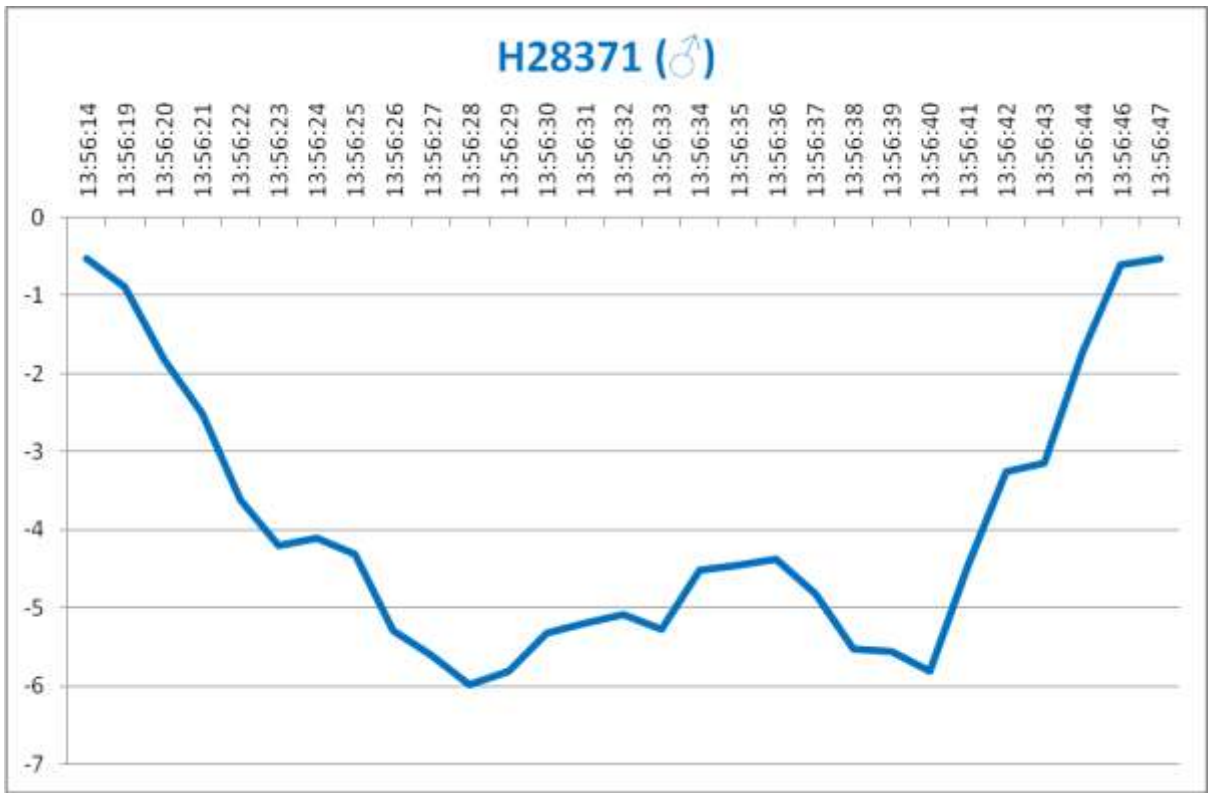

H28371 (♂)
13:56:14
13:56:19
13:56:20
13:56:21
13:56:22
13:56:23
13:56:24
13:56:25
13:56:26
13:56:27
13:56:28
13:56:29
13:56:30
13:56:31
13:56:32
13:56:33
13:56:34
13:56:35
13:56:36
13:56:37
13:56:38
13:56:39
13:56:40
13:56:41
13:56:42
13:56:43
13:56:44
13:56:46
13:56:47
0
-1
-2
-3
-4
-5
-6
-7

Figure 13d

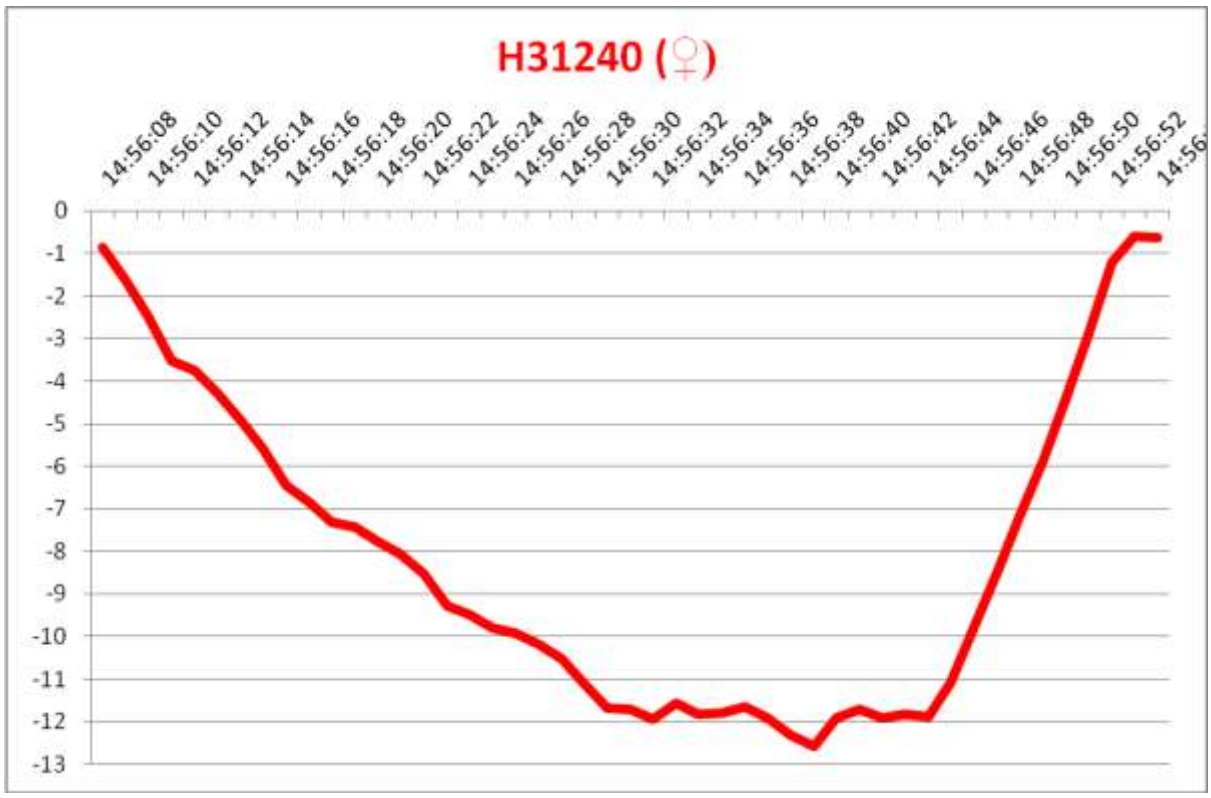

H31240 (♀)
14:56:08
14:56:10
14:56:12
14:56:14
14:56:16
14:56:18
14:56:20
14:56:22
14:56:24
14:56:26
14:56:28
14:56:30
14:56:32
14:56:34
14:56:36
14:56:38
14:56:40
14:56:42
14:56:44
14:56:46
14:56:48
14:56:50
14:56:52
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13

Figure 14

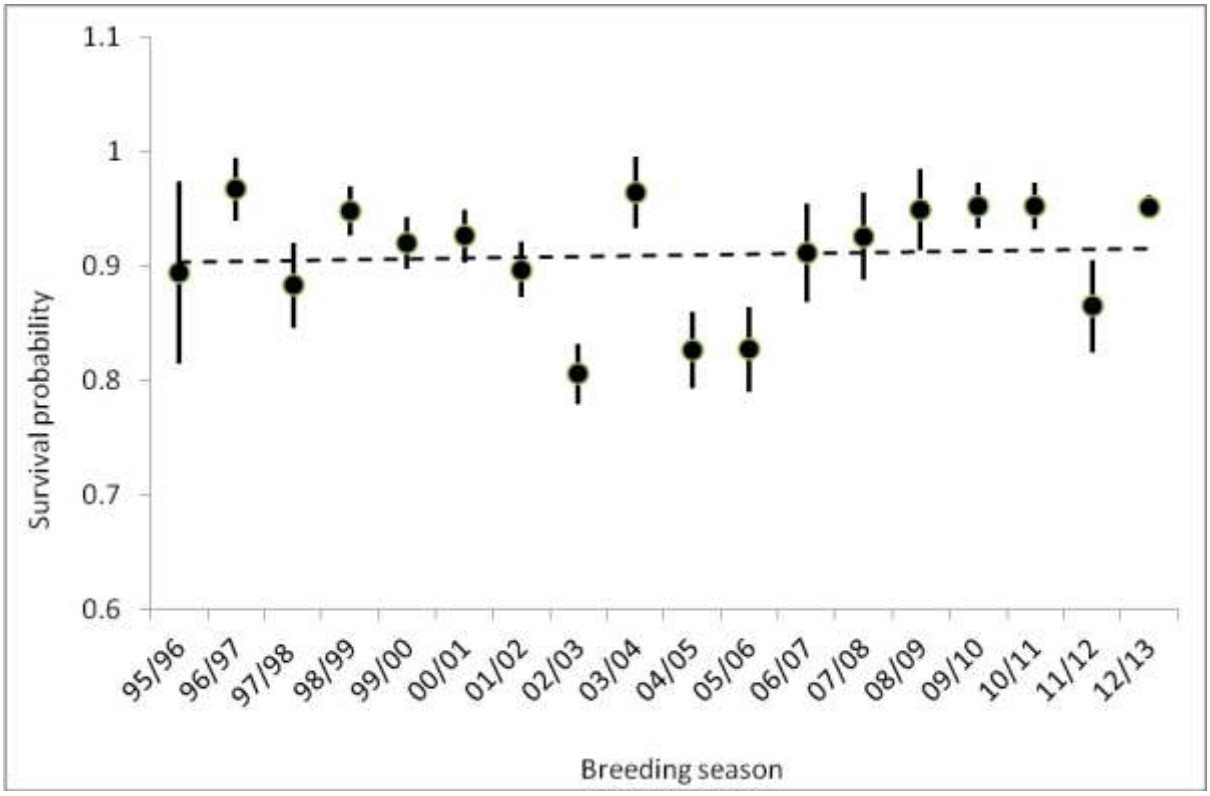
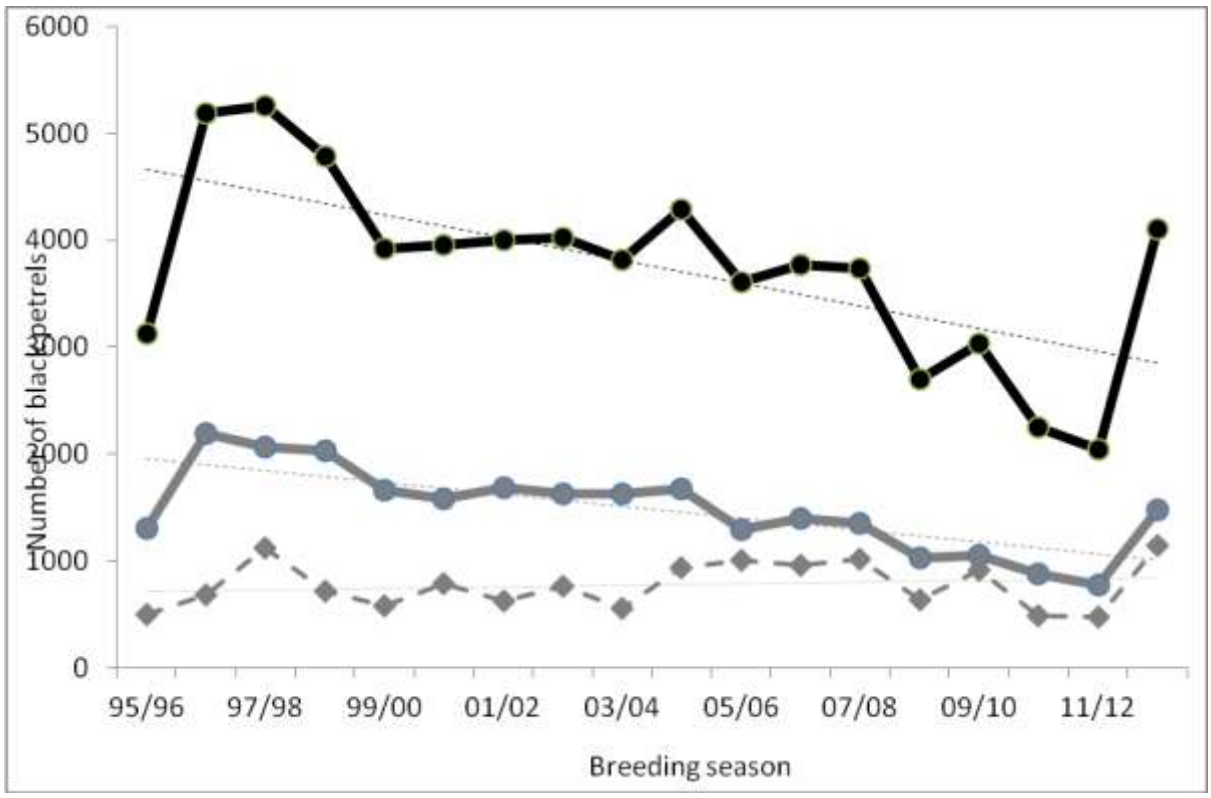

1.1
1
0.9
0.8
0.7
0.6
Survival probability
95/96
96/97
97/98
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06
06/07
07/08
08/09
09/10
10/11
11/12
12/13
Breeding season

Figure 15


6000
5000
4000
3000
2000
1000
0
Number of black petrels
95/96
97/98
99/00
01/02
03/04
05/06
07/08
09/10
11/12
Breeding season

Appendix 1.

Burrow	Band	Band	Band	Band	Band	Outcome
1	31370 (?M)	?				Non-breeding
2	?	?				Non-breeding
3	35298 (?M)	29927 (?F)				Chick
4	?	?				Non-breeding
5	27967 (M)	31971 (F)				Chick
6	33540 (M)	34394 (F)				Chick
7	30854	?				Abandoned egg
8	28351 (?M)	27702	38589			Non-breeding
9						Empty
10	36396	?				Chick
11						Empty
12	36361 (?M)	37562 (?M)	37595 (?F)			Chick
13	37550 (M)	37511 (F)				Dead embryo
14	34449 (M)	34421 (F)				Chick
15	37509 (?M)	?				Chick
16	36372 (?M)	35302 (?F)				Chick
17	31108 (M)	35258 (F)				Crushed egg
18	29815 (?M)	35209 (?F)				Chick
19	28376	33324				Chick
20	34264 (M)	33683 (F)				Dead embryo
21	33466 (M)	34956 (F)				Chick
22	36393 (?M)	?				Chick
23	38817	?				Non-breeding
24	34338 (?M)	36319 (?F)				Chick
25	31217 (M)	?				Chick
26	23014 (M)	28357 (F)				Chick
27	35198 (M)	35549 (F)				Chick
28						Empty
29						Empty
30	37565 (?M)	33071 (?F)	36151	27976		Chick
31	33052 (M)	33003 (F)	37502 (?M)			Chick
32 (P1)	31537	?				Non-breeding
33	28076 (?M)	31244 (?F)				Chick
34	31121 (M)	31248 (F)	32025 (?M)			Crushed egg
35	?	36320 (F)				Chick
36	33460 (M)	34359 (F)				Chick
37	31107 (M)	38801	36204			Non-breeding
38						Empty
39	25426 (M)	35251 (F)				Chick
40	36166	34384				Chick
41	31112 (?M)	31029 (?F)				Chick
42	27981	36360				Disappeared chick
43	25546 (?M)	31586 (?F)				Chick
44	31494 (M)	36364 (F)				Dead chick
45	29845	29087				Chick
46	34360 (M)	28813 (F)				Chick
47	31018 (M)	33786 (F)				Chick
48	36190 (M)	35267 (F)	37504 (?M)			Dead embryo
49	?	34380	37504 (?M)			Disappeared egg
50	31282 (M)	33747 (F)				Disappeared chick
51	36383 (?M)	37588 (?F)	38741			Infertile egg

52	31289 (?M)	34965 (?F)				Chick
53	31257 (M)	34764 (?F)	37587			Crushed egg
54	38724 (?M)	?				Non-breeding
55 (P1)	23635 (?M)	33638 (?F)				Chick
56 (P1)	29684	36327				Chick
57 (P1)	31153 (M)	33725 (F)				Chick
58 (P1)	28029 (?M)	31205 (?F)				Chick
59 (P1)	37527 (?M)	34392 (?M)				Non-breeding
60 (P1)	35455 (?M)	38819 (?F)				Egg (abandoned)
61 (P1)	29818 (?M)	?				Disappeared chick
62 (P1)	?	?				Empty
63 (P1)	35256	?				Non-breeding
64 (P1)	31366 (M)	33323 (F)				Chick
65	?	?				Non-breeding
66	30874 (M)	34853 (F)				Dead embryo
67 (K1)	36118 (?M)	31270 (F)				Non-breeding
68 (K1)	31172 (M)	32005 (F)				Chick
69	27604 (M)	31240 (F)				Chick
70	29824 (M)	31992 (F)				Chick
71 (K1)	34351 (?M)	34352 (?F)				Chick
72 (K1)	34901 (?M)	27977 (?F)				Chick
73 (K1)	28572 (M)	37524 (?F)	38567			Non-breeding
74 (K1)	31974 (M)	29693 (F)				Chick
75 (K1)	33589	28572	38599			Non-breeding
76 (K1)	33758 (M)	31089				Dead chick
77 (K1)	36354 (?M)	28390 (?F)				Chick
78 (K1)	30867	37572	38568			Non-breeding
79 (K1)	38563	38599				Non-breeding
80 (K1)	34843 (?M)	36344 (?F)				Dead chick
81 (K1)	28046 (M)	28370 (F)				Chick
82	35448 (M)	36345 (F)				Chick
83	34781 (?M)	34353 (?F)				Chick
84	35405 (?M)	35228 (?F)				Dead embryo
85 (S1)	?	36196 (F)				Abandoned egg
86 (S1)	25661 (M)	34365 (F)				Chick
87 (S1)	?	?				Non-breeding
88 (S1)						Empty
89 (S1)	31495 (M)	?				Chick
90 (S1)	33097 (M)	?				Chick
91 (S1)	?	?				Chick
92 (S1)	32928 (M)	36334 (F)				Chick
93						Empty
94	35200 (?M)	34886 (?F)				Chick
95	33089 (?M)	?				Chick
96 (P1)	29820 (?M)	35235 (?F)				Chick
97	34385 (?M)	36194 (?F)				Chick
98	?	?				Empty
99	33461 (?M)	31262 (?F)				Chick
100	38741	38560				Non-breeding
101 (K1)	38565	28572	35186			Non-breeding
102 (K1)	33389 (?M)	35239 (?F)				Dead embryo
103 (K1)	29690	25673				Chick
104 (K1)						Empty
105	35231 (?M)	37566 (?F)				Non-breeding
106	31038 (?M)	25458 (?F)				Dead embryo

107	33764 (M)	33799 (F)				Chick
108	27952	38802				Non-breeding
109	37528	37593	34734			Non-breeding
110 (S1)	33654 (?M)	37535 (?F)				Chick
111 (S1)	?	?				Empty
112 (S1)	28037 (M)	34796 (F)				Chick
113 (S1)	?	?				Non-breeding
114 (S1)	28360 (?M)	34953 (?F)				Chick
115	29065 (?M)	29077 (?F)				Chick
116 (P1)	25435 (?M)	25411 (?F)				Chick
117	25664 (M)	37600 (F)				Chick
118	27998 (M)	38551	38600			Crushed egg
119	34389 (?M)	33530 (?F)				Chick
120 (P1)	30167	?				Non-breeding
121 (P1)	33035 (M)	29817 (F)				Chick
122 (P1)	27961	36328				Chick
123 (P1)	?	?				Non-breeding
124 (P1)	25442 (M)	35255 (F)				Crushed egg
125 (P1)	?	?				Non-breeding
126 (P1)	37586	33477				Chick
127	33301 (?M)	35538 (?F)				Chick
128	31054 (M)	25495 (?F)				Dead embryo
129	?	?				Collapsed
130	36173 (?M)	?				Chick
131	35406	38583				Non-breeding
132 (K2)	36290	38585				Non-breeding
133 (K2)	25525 (M)	35241 (F)				Chick
134 (K2)	37503 (?M)	37574 (?F)				Chick
135 (K2)	25447 (M)	34377 (F)				Dead chick
136 (K2)	29699 (M)	38558 (?F)	38586 (?F)			Non-breeding
137 (K2)	25494 (M)	31572 (F)				Chick
138 (K2)	37573 (?M)	?				Non-breeding
139	33248 (M)	37557 (?F)	38743 (?F)	38554 (?F)	38943 (?F)	Non-breeding
140	29809 (M)	36179 (F)				Chick
141 (S2)	?	?				Non-breeding
142 (S2)	36390 (M)	37518 (F)				Chick
143 (K2)	?	?				Non-breeding
144 (K2)	36175	34417	37536 (M) (interloper)			Chick
145 (K2)	33575 (?M)	36370 (?F)				Infertile egg
146 (K2)	25460 (M)	25473 (F)				Chick
147 (K2)	34903 (M)	36368 (F)				Chick
148 (K2)	36355 (?M)	34376 (?F)				Non-breeding
149 (K2)	31569	25401				Chick
150 (K2)	25493 (M)	36353 (F)				Dead embryo
151	29837	33667				Infertile egg
152 (S2)	?	?				Non-breeding
153 (S2)	29978 (M)	33471 (F)				Chick
154 (P1)	34320 (M)	36382 (F)				Chick
155 (P2)	33473 (M)	?				Non-breeding
156 (P2)	?	?				Non-breeding
157 (P2)	?	?				Non-breeding
158 (P2)	?	?				Non-breeding
159 (P2)	37584	25441				Chick
160	36384 (?M)	38553 (?F)				Chick

161 (P2)	31542 (M)	?				Chick
162 (P2)	35544 (?M)	36329 (?F)				Chick
163 (P2)	33658 (?M)	?				Non-breeding
164 (P2)	33737 (?M)	37585 (?F)				Chick
165 (K2)	29700 (M)	37575 (F)				Chick
166	25437 (M)	?				Chick
167	36326	35543				Chick
168 (P1)						Empty
169	?	?				Empty
170	36380 (?M)	36378 (?F)				Chick
171	35529 (M)	36346 (F)				Chick
172	31048 (M)	36379 (F)				Chick
173	36389 (?M)	28018 (?F)				Chick
174	33719 (M)	28071 (F)				Chick
175	25503 (M)	28001 (F)				Chick
176 (K1)	?	?				Empty
177	37530 (?M)	37596 (?F)				Chick
178	36186 (M)	36312 (F)				Chick
179	37516 (?M)	33481 (?F)				Chick
180	25694 (?M)	29832 (?F)				Chick
181	29074 (M)	35204 (F)				Chick
182	29085 (?M)	34864 (?F)				Chick
183 (S1)	37534	?				Non-breeding
184	36140	?				Non-breeding
185 (K1)						Empty
186	37506 (?M)	37526 (?F)				Chick
187	31047 (?M)	31452 (?F)				Chick
188	38716	38708				Non-breeding
189	34349 (?M)	?				Non-breeding
190	34738 (M)	28016 (F)				Chick
191 (P2)	34800 (M)	34762 (F)				Chick
192 (S1)						Non-breeding
193 (K2)	29825 (?M)	27974 (?F)				Abandoned egg
194 (K2)	34720 (?M)	36181 (?F)	25483 (?M)	36355 (?M)		Chick
195	33327 (?M)	33311 (?F)				Chick
196						Empty
197	36311	?				Non-breeding
198	?	?				Empty
199	34730	?				Non-breeding
200	28073 (?M)	34265 (?F)				Chick
201	36373	38705				Chick
202 (P2)	33375	27996				Chick
203	30930 (M)	35233 (F)				Chick
204 (K1)	35000 (M)	32957 (F)				Chick
205	25697 (?M)	29664 (?F)				Chick
206	34936	34382				Chick
207 (P1)	?	?				Empty
208 (P1)	29912 (?M)	28354 (?F)				Chick
209 (K3)	34374	34416				Chick
210 (K3)	?	?				Non-breeding
211 (K3)	35197	37568				Non-breeding
212 (K3)	27956 (M)	31023 (F)				Chick
213 (K2)	36369 (?M)	36343 (?F)				Crushed egg
214 (K2)	?	?				Non-breeding
215 (S3)	?	?				Cook's petrel burrow

216 (S3)	36387	35541				Chick
217 (K3)	31991	38571				Chick
218	34387	?				Non-breeding
219 (P3)						Empty
220 (P3)	?	?				Non-breeding
221 (P3)	29695 (?M)	?				Chick
222	28049 (M)	34395 (F)				Chick
223 (S3)	33673 (M)	37531 (F)				Chick
224 (P3)	27958 (?M)	27992 (?F)				Chick
225 (S3)	13634 (?M)	34404 (?F)				Chick
226 (P3)	35252	28385				Chick
227 (K1)	25509 (M)	25407 (F)				Chick
228	33633 (M)	33308 (F)				Chick
229 (P3)	35531 (?M)	?				Rat predation
230 (P3)	?	?				Non-breeding
231 (P3)	37579	?				Non-breeding
232	?	?				Empty
233	29698 (?M)	34820 (?F)				Non-breeding
234	29835 (?M)	35245 (?F)				Chick
235	28044 (M)	?				Crushed egg
236	37542	37564				Chick
237	29098	34349				Non-breeding
238 (S1)						Empty
239	32013 (M)	33452 (F)				Chick
240	34276 (M)	37510 (F)				Chick
241	?	?				Non-breeding
242	28099 (?M)	28366 (?F)				Chick
243	33264 (?M)	36367 (?F)				Abandoned egg
244	37567	29841				Non-breeding
245 (K1)	34753 (M)	33315 (F)				Chick
246 (P3)	37507 (?M)	25586 (?F)				Dead embryo
247	34808	38821				Non-breeding
248	35297	35278				Chick
249	37515 (?M)	37563 (?F)				Chick
250	?	?				Empty
251 (K3)	?	?				Cook's petrel burrow
252	34794 (M)	34852 (F)				Chick
253 (K3)	38557	34698				Non-breeding
254 (P1)	?	?				Non-breeding
255 (K2)	34431 (?M)	29089 (?F)				Chick
256	36147	?				Non-breeding
257	34758	38915				Chick
258 (P3)	?	?				Empty
259	33508 (?M)	37592 (?F)				Chick
260 (S3)	25651 (?M)	14009 (?F)				Chick
261	32021 (?M)	37517 (?F)	37598 (?F)			Abandoned egg
262	34739 (M)	32902 (F)				Chick
263	29073	36339				Chick
264	?	?				Non-breeding
265 (K2)	35300 (M)	29682 (F)				Chick
266	31975 (M)	25444 (F)				Dead embryo
267	29823 (M)	28371 (F)				Chick
268						Empty
269	38733	38555				Non-breeding
270	33669 (M)	33791 (F)				Chick

271 (K1)	37571	38559				Non-breeding
272	?	?				Chick
273	?	?				Non-breeding
274	37521 (?M)	36335 (?F)				Chick
275	35229 (?M)	36316 (?F)				Chick
276	?	?				Non-breeding
277	33620 (?M)	33619 (?F)				Chick
278	34751 (?M)	25695 (?F)				Chick
279	?	?				Non-breeding
280	?	?				Non-breeding
281	32995 (?M)	34733 (?F)				Disappeared egg
282	33652 (?M)	33643 (?F)				Chick
283	38815	?				Non-breeding
284	32099 (?M)	37581 (?F)				Abandoned egg
285	35218	38560				Chick
286	36374 (?M)	36304 (?F)	37505 (?F)			Non-breeding
287	37532	36204	36187			Non-breeding
288	33671 (M)	33705 (F)				Chick
289	35536 (?M)	36192 (?F)	37523 (?M)			Chick
290	35212	35534				Chick
291	37505	?				Non-breeding
292	34734 (?M)	37559 (?F)				Disappeared egg
293	37560	37559	37594			Non-breeding
294	36185 (M)	27984 (F)				Chick
295	33630 (M)	29812 (F)				Chick
296	32980 (?M)	37589 (?F)				Chick
297	33755 (?M)	?				Chick
298	33646 (?M)	34429 (?F)				Chick
299	34937 (M)	?				Chick
300	35232 (?M)	?				Chick
301	33762 (M)	34397 (F)				Chick
302	?	?				Non-breeding
303	33797 (?M)	37514 (?F)				Chick
304	34370 (M)	36162 (F)	29837			Crushed egg
305	35244 (?M)	?				Chick
306	?	?				Empty
307	33796	34876				Chick
308						Empty
309	33476 (M)	?				Crushed egg
310 (S2)	36392 (?M)	33276 (?F)				Chick
311 (S2)	?	?				Cook's petrel burrow
312 (S2)	?	?				Disappeared egg
313 (S2)	34865 (?M)	36331 (?F)				Chick
314 (S2)	?	?				Non-breeding
315	33714 (?M)	33318 (?F)				Chick
316	33715 (?M)	38746 (?F)				Chick
317 (P2)						Empty
318	37578	?				Non-breeding
319	?	?				Chick
320	34941 (M)	33475 (F)				Non-breeding
321	38747 (?M)	37591 (?F)				Chick
322 (P3)	25555 (M)	38818 (?F)				Crushed egg
323	27526	29838				Chick
324	34299 (?M)	34403 (?F)				Chick
325	?	?				Chick

326	33546 (?M)	37590 (?F)				Disappeared egg
327 (K2)	34898 (?M)	34257 (?F)				Chick
328	33093 (?M)	33491 (?F)				Chick
329 (P3)	29665 (?M)	33528 (?F)				Chick
330	33090 (M)	33099 (F)				Chick
331	36174 (?M)	32924 (?F)				Disappeared egg
332	?	?				Rat predation
333	32927 (?M)	29082 (?F)	34624 (?M) (interloper)			Chick
334	37533	?				Disappeared egg
335	28358 (?M)	34379 (?F)				Chick
336 (P2)	?	?				Non-breeding
337 (S1)						Empty
338	34376 (?M)	37570 (?F)	36356 (?M)			Non-breeding
339	34722 (M)	33493 (F)				Crushed egg
340	34357	35540				Chick
341	?	?				Collapsed
342 (S2)	38816	?				Non-breeding
343(S2)	?	?				Non-breeding
344 (S2)	?	?				Non-breeding
345	34861 (?M)	34362 (?F)				Chick
346	37558 (?M)	?				Non-breeding
347	37529 (M)	37513 (F)				Chick
348 (P3)						Empty
349 (P3)	?	?				Empty
350 (P2)	?	?				Non-breeding
351 (P1)	34266 (M)	34390 (F)				Chick
352	37527	?				Non-breeding
353	35234	35545				Non-breeding
354	33480 (?M)	36337 (?F)				Chick
355	33467 (M)	36191 (F)				Dead chick
356	34580 (?M)	36375 (?F)				Chick
357	?	?				Empty
358	33474 (?M)	33494 (?F)				Chick
359	32985 (?M)	38556 (?F)				Chick
360	35237	33482				Chick
361	14018 (M)	?				Dead embryo
362 (K1)	?	?				Non-breeding
363	37569 (?M)	36336 (?F)				Non-breeding
364	34854 (?M)	38749 (?F)	38598 (?F)			Non-breeding
365 (K2)	?	?				Non-breeding
366 (K1)	?	?				Empty
367	35265	33550				Chick
368	37561	33451	38564	38820		Non-breeding
369 (S1)						Empty
370	34355	?				Non-breeding
371	34717 (M)	?				Chick
372	?	?				Non-breeding
373	36153	36199				Chick
374	34420 (?M)	36193 (?F)				Chick
375 (P1)	36169 (?M)	35542 (?F)				Chick
376	36363 (?M)	37520 (?F)				Chick
377	?	?				Non-breeding
378 (K3)						Empty
379 (K2)						Joined to burrow 209

380	29960 (M)	27979 (F)				Chick
381	?	?				Non-breeding
382	28362 (?M)	?				Chick
383 (S1)						Empty
384	25586	38944				Non-breeding
385	36112 (M)	?				Non-breeding
386	28352	35530	37544			Chick
387 (S3)	28363	37599				Non-breeding
388	31324 (?M)	33762 (?F)				Chick
389	29066 (?M)	28045 (?F)	37522 (?F)			Chick
390	?	?				Non-breeding
391	33244	28377	37554			Chick
392 (K1)	?	?				Cook's petrel burrow
393	28812 (?M)	35196 (?F)				Abandoned egg
394	34878 (M)	36305 (F)				Chick
395	35242	38812	38814			Non-breeding
396	35213 (M)	35243 (F)				Chick
397	38745	?				Non-breeding
398	35257	35299	37555			Chick
399	?	?				Non-breeding
400	28365	28399				Chick
401	34304 (?M)	36347 (?F)				Chick
402	31981 (?M)	36365 (?F)				Chick
403	37508 (?M)	36400 (?F)				Chick
404	36357 (?M)	29651 (?F)				Chick
405	34273	38809				Chick
406	37519 (?M)	?				Disappeared egg
407	33607 (?M)	35284 (?F)				Chick
408	35285 (?M)	33376 (?F)				Infertile egg
409	36377 (?M)	?				Chick
410	37537 (?M)	37576 (?F)				Chick
411	37539 (?M)	?				Chick
412	28056	37580				Chick
413	34505	37582				Chick
414	34317	37583				Chick
415	36163	33246				Chick
416	36308	38552				Chick
417	25536	36321				Chick
418	37577	37551				Chick
419	37548	38561				Chick
420	37507	31204				Non-breeding
421	26955	?				Chick
422	33369	?				Chick
423	38942	38950	38803			Non-breeding

Appendix 2

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)
25525	Male	1998/99	2012/13	6	7	8	10
25536	Male	1998/99	2012/13	4	6	14	14
25546	Male	1998/99	2012/13	8	5	7	7
25630	Male	1999/00	2005/06	2	5		
25631	? Male	1999/00	2003/04	1	4		
25635	Male	1999/00	2008/09	5	5	6	6
25637	Male	1999/00	2004/05	1	5		
25648	Male	1999/00	2008/09	4	5	8	
25651	Male	1999/00	2012/13	8	5	6	6
25658	Male	1999/00	2004/05	1	5	5	5
25659	Female	1999/00	2012/13	2	6	6	6
25661		1999/00	2012/13	5	9	9	10
25663	Male	1999/00	2008/09	6	4	7	8
25664	? Female	1999/00	2012/13	8	3	6	10
25669	Male	1999/00	2005/06	2	5	5	5
25673	Male	1999/00	2012/13	8	5	7	7
25677		1999/00	2006/07	1	7	7	7
28085	Male	1998/99	2005/06	1	5		
29098		1008/09	2012/13	1	4		
29912	? Male	2000/01	2012/13	5	5	5	6
29927		2000/01	2012/13	9	9	12	12
29960	Male	1999/00	2012/13	4	9	9	9
29978	Male	1999/00	2012/13	2	9	14	14
30161[18]		2007/08	2009/10	1	2		
30167		2007/08	2012/13	1	5		
30177		2007/08	2011/12	1	3		
30908	? Male	1995/96	2002/03	1	7		
30924	Male	1995/96	2010/11	9	6	6	6
30930	Male	1995/96	2012/13	13	4	5	5
31076		1997/98	2002/03	1	5		
31080		1997/98	2001/02	1	4		
31081	? Male	1997/98	2002/03	2	4		
31082	Male	1997/98	2001/02	1	4		
31089	Female	1997/98	2012/13	8	5	6	9
31194	Male	1996/97	2001/02	1	5	5	
31322[19]		2005/06	2009/10	1	3		
31324		2005/06	2012/13	1	7	7	7
31345	? Male	2005/06	2011/12	1	6		
31366	Male	1997/98	2012/13	11	5	6	6
31370	? Male	1997/98	2012/13	5	5	8	
31377	? Male	1997/98	2001/02	1	4		
31382	Female	1997/98	2008/09	5	4	5	5
31383	Male	1997/98	2003/04	1	6		
31405		1996/97	2004/05	2	6	7	7
31406	? Female	1996/97	2001/02	1	5		

[18] This bird was caught at sea off San Jose, Peru (entangled in a drift net) and released alive. It has not been recaptured at the colony to date.

[19] The bird was recovered dead on Te Rere Beach (near Goat Island Marine Reserve) on 14 January 2010 and had not been recaptured at the colony.

31413	Female	1996/97	2004/05	1	8	8	8
31415	? Male	1996/97	2003/04	1	7		
31422		1996/97	2012/13	1	16	16	
31424	? Male	1996/97	2008/09	5	6	8	8
31474	? Male	1998/99	2002/03	1	4		
31476	Male	1998/99	2004/05	2	4	6	
31478	Male	1998/99	2012/13	2	10	10	10
31490	? Male	1998/99	2002/03	1	4		
31491	Male	1998/99	2005/06	1	7		
31494	Male	1998/99	2012/13	6	6	9	10
31495	Male	1998/99	2012/13	9	4	5	5
31498	? Female	1998/99	2008/09	4	6	6	8
31527	? Male	1998/99	2002/03	1	4		
31537	? Male	1998/99	2012/13	5	8	8	8
31542	Male	1998/99	2012/13	11	4	6	7
31546	Male	1998/99	2007/08	1	9		
31956	Male	2000/01	2008/09	2	7		
32063		2000/01	2005/06	1	5		
32073[20]		2000/01	2007/08	1	7		
32091		2000/01	2007/08	1	7		
32099	? Male	2000/01	2012/13	6	5	8	8
32100		2000/01	2012/13	1	12	12	
32915		2001/02	2009/10	3	6	6	6
32921		2001/02	2012/13	1	11	11	11
32927	? Male	2001/02	2012/13	5	6	6	6
32957	Female	2001/02	2012/13	7	5	6	7
32979		2001/02	2006/07	1	5		
32980	Male	2001/02	2012/13	2	4	11	11
32985	? Male	2001/02	2012/13	1	11	11	11
32995		2001/02	2012/13	1	11	11	
33003		2001/02	2012/13	2	7	7	7
33015	Male	2001/02	2009/10	3	6		
33035	Male	2001/02	2012/13	5	6	7	7
33052	Male	2001/02	2012/13	6	6	6	6
33055		2001/02	2009/10	1	8	8	8
33067		2001/02	2009/10	1	8		
33068		2001/02	2009/10	2	7	8	
33071	Male	2001/02	2012/13	1	11		
33088[21]		2001/02	2004/05	1	2		
33208[22]	Male	2002/03	2010/11	4	5	7	
33218	? Female	2002/03	2008/09	2	5	6	
33225		2002/03	2006/07	1	4		
33244	Male	2002/03	2012/13	2	6	10	10
33246		2002/03	2012/13	1	10	10	10
33248	Male	2002/03	2012/13	6	6	8	8
33276		2003/04	2012/13	2	7	7	7
33335	Male	2003/04	2010/11	2	5	7	
33369		2003/04	2012/13	1	9	9	9
33375		2003/04	2012/13	4	5	5	5
33376		2003/04	2012/13	2	8	8	
33380		2003/04	2007/08	1	4		

[20] This bird was caught at sea in Ecuador and released alive. It has not been recaptured at the colony to date.
[21] This bird was caught at sea in Ecuador and released alive. It has not been recaptured at the colony to date.
[22] This bird was recovered dead on 29/1/11 in KDG2.

33389		2003/04	2012/13	4	6	6	7
33397	Male	2003/04	2008/09	1	5	5	5
33453		2005/06	2010/11	1	5		
33508	? Male	2005/06	2012/13	1	7	7	7
33518		2005/06	2009/10	1	4		
33528		2005/06	2012/13	1	7	7	7
33530		2005/06	2012/13	3	5	6	6
33540	Male	2005/06	2012/13	2	4	7	7
33546	Male	2005/06	2012/13	1	7	7	
33550		2005/06	2012/13	3	4	5	5
33575	Male	2005/06	2012/13	3	5	5	5
33581		2005/06	2011/12	2	5		
33589		2005/06	2012/13	3	5	5	5
33591		2005/06	2010/11	1	5		
33596		2005/06	2010/11	1	5	6	
33737	? Male	2002/03	2012/13	3	7	7	7
34273		2004/05	2012/13	2	7	7	7
34276	Male	2004/05	2012/13	3	5	8	8
34299		2004/05	2012/13	2	7	7	7
34304	? Male	2004/05	2012/13	1	8	8	8
34317		2004/05	2012/13	1	8	8	8
34320		2004/05	2012/13	3	5	8	8
34338		2004/05	2012/13	2	5	6	6
34349	Male	2004/05	2012/13	2	7		
34505		2006/07	2012/13	1	6	6	6
34520	Male	2006/07	2011/12	1	5		
34527		2006/07	2012/13	1	6	6	
34574		2006/07	2010/11	1	4		
34580		2006/07	2012/13	2	5	6	6
34599		2006/07	2012/13	1	6		
34600	Male	2006/07	2012/13	2	5		
34621		2006/07	2010/11	1	4		
34624		2006/07	2012/13	1	6		
34660		2006/07	2011/12	2	4	5	5
34698		2006/07	2012/13	1	6		
34804		2004/05	2009/10	2	4	5	5
34808	Male	2004/05	2012/13	1	8		
34820		2004/05	2012/13	2	6	6	
34828		2004/05	2009/10	1	5		
34836		2004/05	2011/12	2	6	7	
34843		2004/05	2012/13	3	5	6	6
34867		2004/05	2011/12	1	7	7	7
34886		2004/05	2012/13	2	7	7	8
34901	? Male	2004/05	2012/13	4	5	7	7
34903	? Male	2004/05	2012/13	3	5	7	7
35186		2008/09	2012/13	1	4		
35189	Male	2008/09	2012/13	1	4		
35397		2008/09	2012/13	1	4	4	4
35571		2009/10	2012/13	1	3		
36112	Male	2007/08	2012/13	1	5		
36118		2007/08	2012/13	2	4		
36140		2007/08	2012/13	1	5		
36147		2007/08	2012/13	1	5		
36216		2007/08	2011/12	1	4		
36241		2007/08	2012/13	1	5		

36290		2007/08	2012/13	1	5		
MEAN (± SEM)				2.6 ± 0.2	5.8 ± 0.2	7.3 ± 0.2	7.4 ± 0.2
30807[23]	Female	1996/97	2009/10	5	9	9	9

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

Appendix 3

Band	Sex	Burrow	TDR	Deployment (hours at sea)	Total number of dives						Length of dive (sec)		Depth of dive (m)		
					Total	Day	Night	Shallow (≤ 5 m)	Medium (5.1-10 m)	Deep (>10 m)	Max	Min	Max	Min	Mean (± SEM)
25503	Male	175	2827	36.4	5	5	0	3	2	0	32	3	-7.7826	-1.3056	-4.4125 (± 1.1278)
28001	Female	175	2838	8.9	4	3	1	2	2	0	18	7	-8.8536	-1.9686	-5.3907 (± 1.4802)
				29.6	7	7	0	5	2	0	37	2	-8.1396	-1.0710	-3.4155 (± 0.9787)
				56.6	21	21	0	14	7	0	39	2	-9.8226	-1.0200	-3.6501 (± 0.6194)
28371	Female	267	2833	6.2	0	0	0	0	0	0					
				44.9	16	1	0	10	5	1	33	4	-10.8528	-0.9078	-3.9748 (± 0.7020)
29682	Female	265	2856	135.1	101	92	9	61	26	14	40	1	-20.1348	-1.0098	-5.3662 (± 0.4445)
31023	Female	212	2832	33.2	25	12	13	24	1	0	18	1	-6.3240	-0.9486	-1.7148 (± 0.2605)
				21.9	15	7	8	13	2	0	36	3	-9.8736	-0.9690	-2.7472 (± 0.6813)
31240	Female	69	2835	22.3	23	23	0	13	7	3	45	3	-14.1984	-1.1424	-4.8308 (± 0.7480)
31572	Female	137	2845	12.6	1	1	0	1	0	0	5	5	-0.9384	-0.9384	-0.9384 (± 0)
				17.1	1	0	1	1	0	0	3	3	-1.1424	-1.1424	-1.1424 (± 0)
				6.0	0	0	0	0	0	0					
33315	Female	245	2839	7.3	2	2	0	2	0	0	9	5	-1.0608	-0.9792	-1.0200 (± 0.0408)
33630	Male	295	2834	11.4	1	0	1	1	0	0	4	4	-0.9894	-0.9894	-0.9894 (± 0)
				24.8	6	0	6	4	1	1	72	6	-27.4074	-0.9588	-7.5429 (± 4.0599)
33715	Male	316	2821	11.8	10	10	0	10	0	0	11	4	-1.8054	-0.9078	-1.1353 (± 0.0831)
				18.5	2	2	0	1	1	0	14	12	-5.0388	-2.5398	-3.7893 (± 1.2495)
33768	Male	301	2835	21.7	3	3	0	3	0	0	9	6	-2.0706	-0.9486	-1.5198 (± 0.3241)
				5.23	12	12	0	12	0	0	14	4	-2.1522	-0.9486	-1.1435 (± 0.0942)
34352	Female	71	2840	8.2	0	0	0	0	0	0					
				4.78	0	0	0	0	0	0					
				54.0	285	282	3	265	13	7	57	2	-16.9932	-0.9078	-1.9395 (± 0.1273)
36179	Female	140	2856	30.4	32	32	0	18	11	3	32	4	-10.7304	-1.1934	-4.78667 (± 0.5106)
TOTAL				628.9	572	515	42	463	80	29	72	1	-27.4074	-0.9078	-3.0286 (± 0.1377)
MEAN (± SEM)				26.2 (± 5.6)	23.8 (± 12.1)	21.5 (± 12.0)	1.8 (± 0.7)	19.3 (± 11.0)	3.3 (± 1.2)	1.2 (± 0.6)	26.4 (± 4.2)	4.1 (± 0.6)	-8.3156 (± 1.6042)	-1.1399 (± 0.0908)	

Appendix 4

Band	Sex	Burrow	TDR	Total deployment (hours)			Total deployment in air (hours)			Total deployment on water (hours)		
				Total	Day	Night	Total	Day	Night	Total	Day	Night
25503	Male	175	2827	36.4	22.6 (62.1%)	13.8 (37.9%)	28.6 (78.7%)	15.4 (53.9%)	13.2 (46.1%)	7.8 (21.3%)	7.2 (92.7%)	0.6 (7.2%)
28001	Female	175	2838	8.9	6.6 (73.8%)	2.3 (26.2%)	7.9 (88.8%)	5.6 (70.6%)	2.3 (29.4%)	1.0 (11.2%)	1.0 (98.9%)	0.01 (1.1%)
				29.6	19.5 (65.7%)	10.2 (34.3%)	26.6 (90.0%)	16.5 (61.9%)	10.2 (38.1%)	3.0 (10.0%)	3.0 (100%)	0 (0%)
				56.6	36.0 (63.7%)	20.6 (36.3%)	53.6 (94.8%)	33.1 (61.7%)	20.6 (38.3%)	2.9 (5.2%)	2.9 (99.8%)	0.01 (0.2%)
28371	Female	267	2833	6.2	6.2 (100%)	0 (0%)	3.3 (53.0%)	3.3 (100%)	0 (0%)	2.9 (47%)	2.9 (100%)	0 (0%)
				44.9	24.6 (54.8%)	20.3 (45.2%)	42.1 (93.7%)	21.9 (52.0%)	20.2 (48.0%)	2.8 (6.3%)	2.7 (97.1%)	0.1 (2.9%)
31023	Female	212	2832	33.2	21.6 (65.0%)	11.6 (35.0%)	25.4 (76.6%)	14.8 (58.1%)	10.7 (41.9%)	7.8 (23.4%)	6.8 (87.4%)	1.0 (12.6%)
				21.9	11.8 (53.8%)	10.1 (46.2%)	13.7 (62.5%)	4.6 (33.8%)	9.0 (66.2%)	8.2 (37.5%)	7.1 (87.0%)	1.1 (13.0%)
31240	Female	69	2835	22.3	13.9 (62.5%)	8.4 (37.5%)	14.6 (65.4%)	8.6 (58.9%)	6.0 (41.1%)	7.7 (34.6%)	5.4 (69.3%)	2.4 (30.7%)
31572	Female	137	2845	12.6	7.2 (57.2%)	5.4 (42.8%)	11.3 (89.9%)	6.4 (56.3%)	5.0 (43.7%)	1.3 (10.1%)	0.8 (65.4%)	0.4 (34.6%)
				17.1	13.9 (81.3%)	3.2 (18.7%)	9.0 (52.5%)	6.0 (66.2%)	3.0 (33.8%)	8.2 (47.5%)	8.0 (98.0%)	0.2 (2.0%)
				6.0	5.2 (87.3%)	0.8 (12.7%)	5.9 (98.3%)	5.2 (88.2%)	0.7 (11.8%)	0.1 (1.7%)	0.04 (40.3%)	0.06 (59.7%)
33315	Female	245	2839	7.3	7.3 (100%)	0 (0%)	3.8 (51.1%)	3.8 (100%)	0 (0%)	3.6 (48.9%)	3.6 (100%)	0 (0%)
33630	Male	295	2834	11.4	7.6 (66.2%)	3.9 (33.8%)	8.6 (75.2%)	4.9 (57.4%)	3.7 (42.6%)	2.8 (24.8%)	2.6 (92.8%)	0.2 (7.2%)
				24.4	14.3 (58.7%)	10.1 (41.3%)	17.1 (70.2%)	7.8 (45.7%)	9.3 (54.3%)	7.3 (29.8%)	6.5 (89.2%)	0.8 (10.8%)
33715	Male	316	2821	11.8	7.0 (59.6%)	4.8 (40.4%)	8.3 (70.1%)	4.9 (59.5%)	3.3 (40.5%)	3.5 (29.9%)	2.1 (59.6%)	1.4 (40.4%)
				18.5	8.4 (45.2%)	10.2 (54.8%)	11.8 (63.7%)	2.1 (18.0%)	9.7 (82.0%)	6.7 (36.3%)	6.3 (93.0%)	0.5 (7.0%)
33768	Male	301	2835	21.7	12.3 (56.5%)	9.5 (43.5%)	15.7 (72.2%)	6.3 (40.0%)	9.4 (60.0%)	6.0 (27.8%)	6.0 (99.1%)	0.05 (0.9%)
				5.2	5.2 (100%)	0 (0%)	4.2 (80.1%)	4.2 (100%)	0 (0%)	1.0 (19.9%)	1.0 (100%)	0 (0%)
34352	Female	71	2840	8.2	6.9 (84.5%)	1.3 (15.5%)	6.2 (76.2%)	5.0 (79.7%)	1.3 (20.3%)	1.9 (23.8%)	1.9 (100%)	0 (0%)
				4.8	4.8 (100%)	0 (0%)	4.8 (99.9%)	4.8 (100%)	0 (0%)	0.003 (0.1%)	0.003 (100%)	0 (0%)
				54.0	33.4 (61.9%)	20.6 (38.1%)	48.7 (90.2%)	28.6 (58.7%)	20.1 (41.3%)	5.3 (9.8%)	4.8 (91.3%)	0.5 (8.7%)
36179	Female	140	2856	30.4	19.9 (65.4%)	10.5 (34.6%)	22.3 (73.5%)	13.1 (58.5%)	9.3 (41.5%)	8.0 (26.5%)	6.8 (84.8%)	1.2 (15.2%)
TOTAL				**493.5**	**316.3**	**177.2**	**393.5**	**226.6**	**166.9**	**100.0**	**89.6**	**10.4**
MEAN (± SEM)				**21.5 (± 3.2)**	**13.8 ± 1.9 (64.2%)**	**7.7 ± 1.4 (35.8%)**	**17.1 ± 3.0 (79.5%)**	**9.9 ± 1.7 (64.3%)**	**7.3 ± 1.4 (35.7%)**	**4.4 ± 0.6 (20.5%)**	**3.9 ± 0.5 (88.6%)**	**0.5 ± 0.1 (11.4%)**