At-sea distribution and population parameters of the black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013/14.

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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 2013/14 breeding season, 410 study burrows within the 35-ha study area near Mount Hobson were checked and intensively monitored. Of these, 266 were used by breeding pairs, 101 by non-breeding adults and the remaining 43 burrows were non-occupied. By 1 May 2014, 185 chicks were still present in the study burrows and 2 had already fledged, corresponding to a breeding success of 70.3%. Nine census grids were monitored within the study area and accounted for 157 of the inspected burrows and 152 study burrows, with 95 burrows being used for breeding. Ninety-two chicks from earlier breeding seasons were recaptured within the Mount Hobson colony area this season (a total of 172 'returned chicks' have been caught since the 1999/2000 season). Analysis of the stratified census grid and mean transect data estimated that there were 2097 to 2465 birds present in the 35-ha area around Mount Hobson (Hirakimata). Modelling of the black petrel population on Great Barrier Island (Aotea Island) was updated and indicated the population trend may lie anywhere between -2.3% and +2.5% per annum, the uncertainty being driven primarily by uncertainty over juvenile survival. If juvenile survival is assumed not to exceed adult survival the model finds the population to be slowly declining. Thirty-three high-resolution GPS i-Got-U™ data-loggers and 17 Lotek™ LAT1900-8 time-depth recorders were deployed between January 2014 and February 2014 on breeding black petrels to obtain at-sea distribution and foraging behaviour. The at-sea distribution of black petrels was derived from 20 full or partial GPS tracks. Birds foraged around the northern New Zealand and towards East Cape. Foraging behaviour showed black petrels dived to a maximum of -34.3 m, with over 80% of dives less than 5 m. The majority of dives (67%) 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 2013/14 breeding season was a continuation of the survey and monitoring study begun in 1995/96 (Bell & Sim 1998a, Bell & Sim 1998b, Bell & Sim 2000a, Bell & Sim 2000b, Bell & Sim 2000c, Bell & Sim 2002, Bell & Sim 2003a, Bell & Sim 2003b, Bell & Sim 2005, Bell *et al.* 2007, Bell *et al.* 2009, Bell *et al.* 2011a, Bell *et al.* 2011b, Bell *et al* 2011c, Bell *et al.* 2013a, Bell *et al.* 2013b), 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 those seasons 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 (2013/14) 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, Bell *et al.* 2013b). 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 to band and resight adults and fledglings to establish adult mortality, fecundity, breeding success, recruitment and age-class survival to describe the population trend. In addition to this, at-sea distribution and behaviour of black petrels during the breeding season was also investigated. Since this study was a continuation of research from previous breeding seasons, we also aimed to provide more data to establish population trends and to determine causes and timing of mortality.

The specific 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 2013 and January/February 2014 and band all remaining fledglings during April 2014.
    - 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, fecundity, 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.
  - Determine a population estimate by extrapolating from stratified 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; Figure 1) was visited three times during the breeding season; 6-13 December 2013. During this visit the study burrows (n = 410, Figure 1) 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, Bell & Sim 1998b, Bell & Sim 2000a, Bell & Sim 2000b, Bell & Sim 2000c, Bell & Sim 2002, Bell & Sim 2003a, Bell & Sim 2003b, Bell & Sim 2005, Bell *et al.* 2007, Bell *et al.* 2009, Bell *et al.* 2011a, Bell *et al.* 2011b, Bell *et al.* 2011c, Bell *et al.* 2013a, Bell *et al.* 2013b). 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 (20 January-7 February 2014) 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 (24 April-1 May 2014). 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 & 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 & Sim 2000a, Bell & Sim 2000b).

These nine census grids (each 40 x 40 m) set up around Mount Hobson were systematically searched (at 1 m intervals) during the December 2013 visit by authors (EAB, CM and JS) using Rua (a Department of Conservation qualified bird dog owned by JS) to locate any new burrows and to determine occupancy rates (Figure 1). The same procedure as for study burrows (see section 3.1) was followed for all birds in the burrows in the grids.

3.3 Night banding

Night work was undertaken during the December 2013 and January/February 2014 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.

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

A total of 33 GPS data-logger and 17 Time-Depth Recorder (TDR) devices were deployed on breeding black petrels on Great Barrier Island between January 2014 and February 2014. Each bird was weighed (using Pesola™ scales) before and after deployment to obtain information on body condition and impact of carrying the devices. Thirty control birds were also weighed in January 2014 or February 2014 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 (5/12/2013, AEC267).

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

Thirty-three 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 January 2014 and February 2014. The birds were chosen from study burrows within the 35-ha study area if they had been successful breeders for at least one season and had been in the same pair for two 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 35 minutes (mean ± SEM = 17.32 ± 1.24 minutes; range 7.00-35.00 minutes) and removal of each GPS devices took no longer than 14 minutes (mean ± SEM = 10.74 ± 0.30 minutes; range 6.00-13.81 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 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.

3.4.2 Lotek™ LAT1900-8 Time-Depth Recorder devices

A total of 17 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 January 2014 and February 2014. 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 one season and had been in the same pair for two 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 ten minutes (mean ± SEM = 7.12 ± 0.38 minutes; range 5.17-10.00 minutes) and removal of each TDR device took no longer than two minutes (mean ± SEM = 1.19 ± 0.17 minutes; range 0.50-2.00 minutes). These TDR devices record temperature, pressure and wet/dry state information; data was collected every second when the device was wet. All TDR devices were set to record depth >0.5 m.

3.5 Transects

Three transect surveys have been completed; 2004/05 (Bell *et al.* 2007), 2009/10 (Bell *et al.* 2011b) and 2012/13 (Bell *et al.* 2013b). There were 26 random transects completed each time. 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. All three sets of transect data was compared using Program SEABIRD to determine population trends.

Four grades of petrel habitat were 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).

3.5 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 earlier 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).

3.6 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.

3.7 Population parameters using program SEABIRD

The long-term black petrel data was thoroughly analysed (Ministry of Fisheries project PRO2006-02) to model the effects of fishing on the population viability of selected seabirds using Program SEABIRD and methods for this can be found in Francis & Bell (2010); this includes a fit to both the banding data and to population estimates derived from the transects. These results were updated in 2010 with additional transect and study burrow data (Bell *et al.* 2011a). This analysis has been updated and reanalysed incorporating the past four years' (2010/11 to 2013/14) study burrow and census grid data to identify changes in burrow use and population trends. The BPET7 model (allowing an estimation of absolute population numbers in any year) was also updated using the most recent random transect surveys (2012/13; Bell *et al.* 2013b) to estimate population trajectory and degree of uncertainty. These updated results are compared with Program MARK and Bayesian multi-state mark-recapture modelling estimates.

3.8 Population parameters using Bayesian multi-state mark-recapture modelling

The annual survival rate of birds, as well as annual recruitment, probability of breeding and probability of attending the colony was estimated using re-sighting data of banded birds between 1995/96 and 2013/14 with a Bayesian multi-state mark-recapture model. The model predicts the state of each individual over time, with the three states being juvenile, adult or dead. Breeding state was not included in the model, making it simpler in its representation of the population than either the MARK or SEABIRD models. A single survival estimate was calculated for all juvenile age classes. The transition from juvenile to adult was estimated separately for age classes of 3 years or less, and for birds between 4 and 7 years old. All birds over seven years old were assumed to be adult. Any bird that were not banded as chicks were assumed to be adult from the time they were banded. Estimates of interest (such as the number of banded birds alive, the resight probabilities, and the juvenile and adult survival), were obtained for each time-step from these transition probabilities. A number of models were fitted to the mark-recapture data, with differing degrees of complexity. Annual variations in survival and resight probability were modelled as either constant, random effects (drawn from an underlying distribution), or as fixed effects (independently drawn for each year). The best model was chosen based on the Deviance Information Criterion (DIC) and the model deviance. These results were compared to

Program MARK and Program SEABIRD estimates, providing an independent assessment of the data.

4 Results

4.1 Study burrows

Within the 410 study burrows (those burrows that could be accessed to determine occupancy out of the 425 numbered burrows in the 2013/14 season), 266 contained breeding birds, 101 contained non-breeding birds and 43 were non-occupied (Appendix 1, Tables 1 and 2). There were 79 failures (e.g. loss of eggs, infertility, predation, etc., Table 2). This corresponds to a breeding success of 70.3% (Table 2, Figure 2). Table 2 shows the failures and overall breeding success rate within the study burrows since 1995/96.

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 16 breeding seasons shows the ratio of breeding to non-breeding burrows has averaged 3:1 (± 0.2) with a range of 2.2 to 5.8 over this period, and the number of the burrows used for breeding has decreased over the period (Table 1, Figure 2). Over this same 16-year period, the ratio of occupied to non-occupied burrows has ranged from 5:1 to 19:1; the number of non-occupied burrows has also increased over this time (Table 1, Figure 2). The last three seasons have had similar numbers of occupied and non-occupied burrows, but these numbers have decreased since 2010/11 (Table 1). The number of burrows used for breeding this season was lower than last season and the overall mean for the entire study (64.9% compared to 66.6 ± 0.8%, Table 1).

Figure 2 shows the trend in the proportion 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 over the same time (Figure 2). The annual breeding success this season was 70.3%, which is lower than the mean annual breeding success (74.3% ± 1.4) for the past 16 years of the study (Tables 1 and 2).

4.2 Number of burrows in the census grids

A total of 157 burrows were found in the nine census grids (Appendix 1, Figure 1, Table 3) in the 2013/14 breeding season. Of these, 95 burrows were used by breeding pairs, 37 were used by non-breeding adults and 35 burrows were non-occupied (Table 3).

Figure 3 shows the trend in the number of non-occupied, breeding and non-breeding burrows in the census grids since the 1998/99 season. 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 number of non-breeding burrows and slight increase in non-occupied burrows this season, the overall trend for both non-occupied and non-breeding burrows shows an increase since 1998 (Figure 3).

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 2013/14 season, 665 adults were identified. Of these, 531 were already banded and 134 were banded this season (Appendix 1, Table 4). There were 185 chicks still present in the study burrows during the April visit and all were banded (Appendix 1, Table 4). Two chicks had already fledged. An additional 12 chicks were banded in random burrows or on the surface within the study area.

There have been 2767 chicks banded within the study area between 1995 and 2014 (Table 4 and 5) and these birds have begun to return to the colony as pre-breeders, non-breeders and breeders (*n* (2013/14 season) = 92; *n* (total) = 172, Table 5, Appendix 2). The proportion of 'returned chicks' from each season varies from 0 to 12.9% (mean ± SEM = 6.9 ± 1.0); the greatest number of chicks that have been recaptured is from the 2004/05 breeding season (*n* = 20), but the highest proportion of chicks recaptured were banded in the 1998/99 season (12.9%, Table 5). Figure 4 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 92 (between 1999/00 and 2013/14).

There were 92 'returned chicks' recaptured at the colony this season (Table 6); of these, 61 attempted to breed, with 42 successfully raising chicks of their own. The remaining 24 did not breed, although several males were recaptured while calling to attract a mate. Figure 5 shows the total number of 'returned chicks' and number that was caught breeding and non-breeding each season between 1995 and 2014.

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, 172 'chicks' have been recaptured as pre-breeders, non-breeders or breeding adults (Table 5); 171 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 14 (mean ± SEM = 2.7 $\pm$ 0.2, Appendix 2). The frequency of first recapture of each age class is given in Figure 6. Although the youngest age at first recapture at the colony is 2 years, the mean age ± SEM at first return is 5.9 $\pm$ 0.2 (range 2 to 18 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 (Appendix 2).

Since returning to the Great Barrier Island (Aotea Island) colony, 98 of these 'returned chicks' have attempted to breed (Bell & Sim 2002, Bell & Sim 2003a, Bell & Sim 2003b, Bell & Sim 2005; Bell *et al*. 2007, Bell *et al*. 2009, Bell *et al.* 2011a, Bell *et al.* 2011b, Bell *et al.* 2013b), with 79 breeding successfully over this period (Appendix 2). This means the age at first breeding attempt ranges from 4 to 16 years (mean ± SEM = 7.2 $\pm$ 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 33 deployments of I-GotU™ high-resolution GPS data-logger devices between January 2014 and February 2014 (Table 7). Of these 33 deployments, five devices were still on the birds in May 2014 (Table 7); these will fall off the birds during the moult and migration to South America.

Of the GPS devices deployed, 15 were placed on males, 7 were placed on females and 11 on birds of unknown sex (Table 7). The birds came from 29 different burrows and overall breeding success was higher in these burrows (71.5%) than in the study burrows as a whole (70.3%, Table 7), with most successfully fledging chicks.

Devices were worn for between 3 and 10 days (Table 7) and the birds showed few, if any, adverse effects from carrying them. Mean weight loss of the GPS device birds over the entire deployment period was -60.0 g (± 10.0) although this ranged from -175 to 80 g (Table 8). Over the entire deployment period, males carrying devices lost more weight than females carrying devices and the control birds lost less weight than birds carrying GPS devices over the entire deployment period (December and January/February, Table 8).

Of the 33 GPS devices deployed, only one device failed due to water leakage, but another five were lost at sea and seven birds did not leave the burrows and the remaining 20 recorded partial or full tracks: a total of 861.21 hours (mean ± SEM = 47.85 ± 6.9 hours; range 7.47-117.55 hours). Distribution patterns through the early chick rearing phase of the breeding season ranged across northern New Zealand from the Kermadec Islands to East Cape (Figures 7 & 8). Of the 20 birds whose tracks began or finished within the Hauraki Gulf Marine Park (HGMP) a total of 122.99 hours (14.3% of the total deployment) were spent with the boundaries of the HGMP (mean ± SEM = 6.83 ± 2.1 hours; range 0-38.35 hours). Both males and females foraged in similar areas, but females appeared to forage further north from Great Barrier Island (Aotea Island) colony while males headed south towards East Cape (Figure 8).

4.5 Lotek™ LAT1900-8 Time-Depth Recorder devices

There were 17 deployments of Lotek™ LAT1900-8 Time-Depth Recorder (TDR) devices in January 2014 (Table 9). Of these 17 deployments, five devices were still on the birds in April 2014 (Table 9); these will be retrieved in the 2014/15 breeding season.

Of the TDR devices deployed, 10 were placed on males, 4 were placed on females and 3 on birds of unknown sex (Table 9). The birds came from 16 different burrows and overall breeding success was higher in these burrows (76.8%) than in the study burrows as a whole (70.3%, Table 9), with almost all successfully fledging chicks.

Devices were worn for between 3 and 97 days (Table 9) and the birds showed no adverse effects from carrying the devices. Mean weight loss of the TDR device birds over the entire deployment period was -27.9 g (± 24.2) although this ranged from -175 to 90 g (Table 8). Over the entire deployment period, females carrying devices lost more weight than males carrying devices (Table 8). Control birds lost more weight than birds carrying TDR devices over the entire deployment period (Table 8).

Of the 17 TDR devices deployed, only one device did not obtain dive information due to failure of the battery (although it has been returned to Lotek to attempt to retrieve the data) and five devices have yet to be retrieved as the birds are still at sea (Table 9). The remaining 11 devices showed a range of diving depths and behaviour; there were 19 different dive period events (Tables 10 and 11, Appendices 3 and 4). Most dives were during the day (67.1%) and over 80% of the dives were shallow (>5 m) and this pattern was similar for males and females (Tables 10 and 11, Appendices 3 and 4). The deepest dive (-34.3 m) was by a female (H28370) at 0911 hours on 29 January 2014 (Figure 9, Appendix 3).

Most of the deployment time was spent in the air (96.7%, 1110.5 hours) and over 60% of this time was spent flying during the day (Table 11, Appendix 4). This pattern was similar for both males and females (Table 11, Appendix 4). When on the water, most of this time was in daytime hours (78.9%, 30.7 hours) and again the pattern was similar for males and females (Table 11, Appendix 4).

4.6 Survival estimates and recapture probabilities using Program MARK

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 2014. This generated an adult apparent survival of 93.8% ± 2.4% for the 2013/14 season (since 1964); there has been no significant change in apparent adult survival over the study period (Table 12, Figure 10). The mean probability of fidelity to the nest site (burrow) was 98.3% (± 2.5%).

A Burnham analysis of survival of chicks banded in the 35-ha study site between 1995 and 2013 was also completed. Only 172 of over 2750 chicks banded on Great Barrier Island (Aotea Island) have been recaptured. As earliest age of return was 2 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 73.9% (± 2.0%).

4.7 Population estimate from census grids and earlier transect data

Random transects were surveyed within the study area in 2004/05, 2009/10 and 2012/13 breeding seasons (Bell *et al.* 2007, Bell *et al.* 2011b, Bell *et al.* 2013b). These transects ranging in length from 130 m to 400 m, with between 0 and 40 burrows located along each (Table 13). The following habitat grades were identified: high-grade petrel habitat (4.669 ha), medium-grade (15.3013 ha); low-grade (13.5607 ha) and non-petrel habitat (1.7509 ha) (Bell *et al.* 2013b) and each transect was stratified into these habitat grades along the transect length and the burrows along the length were assigned to the relevant habitat grade (Table 13). The mean number of burrows for each habitat grade was calculated from the three random transect surveys: between 13.3 (± 7.7) to 39.7 (± 1.2) non-breeding burrows, 21.7 (± 14.0) to 55.7 (± 12.8) breeding burrows and 24.7 (± 17.7) to 53.0 (± 26.6) empty burrows were identified (Table 13).

The population estimate for the 35-ha study area was determined by extrapolating from mean burrow data from the random transects and this season's census grid data after stratification of the 35-ha study area into four habitat grades. This population estimate for the 2013/14 burrow-occupying black petrel population was between 2097 and 2465 adults

(2281 ± 184 birds, Table 14), consisting of 439 ± 35 non-breeding adults and 1842 ± 149 breeding adults (i.e. approximately 900 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 15 gives the annual population estimates since 1995 and Figure 11 shows the trend in the overall population estimate and number of breeding pairs and non-breeding birds.

4.8 Population trends and modelling using Program SEABIRD

The population model in Francis & Bell (2010) and Bell *et al.* (2011b) was updated to include the most recent four years of mark/recapture data and the 2012/13 random transect surveys. The additional data changed the estimated probabilities of survival, re-sighting and transition parameters. The estimated mean age at first breeding increased from 6.7 to 6.9 years. Complete details of these analyses are given in Appendix 5.

Using the census grid data, Francis & Bell (2010) estimated that between 2000 and 2009 the total number of burrows increased at a rate of 2.2-3.1% per year and that the number of breeding birds over the earlier period increased at a similar rate. The additional data (2010-2014) showed a change occurring around 2005 with the number of breeding burrows increasing from 78 to 92, but the overall rate of increase in total number of burrows decreasing markedly; the trend of percentage of burrows used for breeding also suggests a decrease over the whole period (Appendix 5).

Using the outcome of active nests within the 35-ha study area between 1995 and 2014, the probability of transition between one breeding state to another was updated. Four states were identified: pre-breeder, non-breeding adult, successful breeding adult and failed breeding adult. Generally there was only minor changes to probability of transition in failed or successful breeding adults (Appendix 5). The probability of an adult skipping a year's breeding is higher if their previous year's breeding failed (23%) than if it was successful

(15%). Birds that skip breeding in one year are less likely to breed successfully the following year (44%) than a bird that did not skip (64% or 59%, depending on whether the previous year's breeding was successful or not) (Appendix 5). A major change was that the estimated time spent as a pre-breeder increased from 1.2 years to 3.0 years (Appendix 5).

Updating the model changed estimated probabilities of survival and resighting (recapture probabilities), but made little difference to estimates of age of first breeding. There was no change in mean survival for breeding adults (0.89), but estimates changed slightly for non-breeding adults (from 0.88 to 0.86) and all adults combined (from 089 to 0.88) (Appendix 5). The percentage of birds that breed each year increased from 72% to 77% while breeding attempts that were successful decreased from 77% to 76% (Appendix 5). Interestingly the percentage of birds breeding within the study area that were banded and survive to breed increased from 68% to 96% suggesting the majority of the birds are faithful to their chosen breeding site (Appendix 5).

As previously shown in Francis & Bell (2010) and Bell *et al.* (2011b) juvenile survival estimates continued to show the greatest uncertainty and when this was explored, reduced the previous 95% confidence interval for this parameter from 0.74-1.0 to 0.85-0.98 (Appendix 5). This continues to have a strong effect on the estimated population trajectory uncertainty with a mean rate for population growth over the modelling period ranging from -2.3%/year (if juvenile survival = 0.85) to +2.5%/year (if juvenile survival = 0.97) (Appendix 5). Given that juvenile survival is unlikely to exceed adult survival, then the trend is likely to be in slow decline.

4.9 Population parameters and population trends using Bayesian multi-state mark-recapture modelling

Using the annual banding and resighting data between 1964 and 2014, resighting probabilities and survival estimates were calculated for the black petrel population on Great Barrier Island (Aotea Island). This is an independent check on the MARK results, which were based on similar data. The best model (with the lowest DIC) had a fixed annual adult survival probability and an annually varying resighting probability. The model also included a random effect for the resighting probability of each bird. Some birds were seen nearly every year, whereas others were only seen intermittently, and the best model represented this variation. A model with annual variation in adult survival had a higher DIC; but explained more of the variation in the data (had the minimum deviance). All results are from the minimum DIC model.

A summary of the parameters form the Bayesian mark-recapture model is given in Table 16. Apparent annual survival had a mean of 69.8% (95% c.i.: 67.7% to 71.8%) for juveniles and 89.7% (95% c.i.: 89.0% to 90.4%) for adults. Other parameters include the probability of birds being at the colony, which has a mean of 91% for adults, 5.8% for juveniles aged 4 to 7 years and only 0.27% for birds three years or less. For the birds that were mostly likely to be resighted, the mean resight probability was estimate to vary from 26% in the first year (1995/96) to over 97% n 1999/2000, 2002/03, 2008/09 and 2012/13 (Figure 16). Variation in this resight probability reflects both annual variation in attendance of the birds at the colony and variation in the resight effort. The relative resight probability for bird that were banded outside the study area had a mean of 6.3%: birds tagged outside the study area are unlikely to be seen in any given year.

The model estimates the state of each bird for each year after it was banded (juvenile, adult, or dead) and so may be used to estimate the number of banded birds that are alive. This number steadily increased from 1995/96 through to 2009/10. Over the period 2009/10 to 2013/14 there was an average of around 1500 (mean 1480; 95 c.i. 1283 to 1612) banded birds alive, with around 1000 of those (mean 995; 95%c.i. 923 to 1092) estimated to be adult.

5 Discussion

The black petrel population on Great Barrier Island has been monitored since the 1995/96 breeding season (Bell & Sim 1998a, Bell & Sim 1998b, Bell & Sim 2000a, Bell & Sim 2000b, Bell & Sim 2000c, Bell & Sim 2002, Bell & Sim 2003a, Bell & Sim 2003b, Bell & Sim 2005; Bell *et al*. 2007, Bell *et al.* 2009; Bell *et al.* 2011a; Bell *et al.* 2011b, Bell *et al.* 2013).

5.1 Breeding success

In the 2013/14 breeding season, there were 187 breeding successes and 79 breeding failures, equating to an overall breeding success rate of 70% (Table 2). This breeding success is lower than most previous breeding seasons, except 2001/02, 2002/03, 2005/06 and 2010/11, and is lower 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 was the same as last season, but the number of rat predations, dead embryos and disappeared eggs (present in December, but missing in January/February) was higher this season than last year (Table 2). There were fewer crushed eggs; these 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 four dead chicks; generally healthy chicks during one check, but dead at the next check or when the final check was completed in April 2014; it was not possible to determine all the causes of mortality for these chicks; although it was suspected that two died from starvation. This may be due to the loss of a parent as it is not possible for one parent alone to successfully raise a chick (Warham 1996), but this will have to be confirmed next season if the burrow is inactive or only one partner returns.

The level of egg abandonment was high (n = 8) and this was the same as last season bringing the total number of abandoned eggs since 1995 to 84 (Table 2). Although the odd incident 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 two 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 69.5%. 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 (0.74 ± 0.02) suggests that over 25% of these fledged chicks will not survive to return to the colony.

Six eggs were predated by rats (2.3% of all breeding attempts) within the study burrows and 35 eggs (13.2% 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. 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 since 1995 (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 decreased from last season, and continues to show an overall decline since the beginning of the study (Tables 1 and 2, Figure 2). Breeding success has remained high and appears to be stable (Tables 1 and 2, Figure 2); this may be related to the fact that site fidelity is high (98%); once a pair begins to breed within the study area (particularly in a study burrow) they are more likely to remain in that burrow. A breeding pair are likely to 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. 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, Figure 2) 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 certain study burrows as another study burrow has deteriorated this season to become unsuitable for breeding (without additional excavation by the birds). 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 stabilised in recent years (Table 1, Figure 2). This may be directly related to handler disturbance, observation hatches being dug or adult mortality (apparent adult survival rate of 0.94 ± 0.02). Analysis of adult survival and site fidelity suggested that black petrels have a relatively low mean apparent adult survival (90%) compared to other seabird species such as Antipodean albatross (*Diomedea antipodensis*) at 96% (Walker & Elliott 2004), but high (98%) 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 if their partner dies or burrow deteriorates. 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 864 banded birds were identified this season; 665 were adults and 199 were chicks (Table 4). There were 531 recaptures of previously banded birds, including 92 that were 'returned chicks' (Tables 4 and 6). A total of 172 chicks have been recaptured in the study area (6.2%). Although the adult banded as a chick on Hauturu/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. Nearly 250 chicks were transferred from Great Barrier Island (Aotea Island) to Hauturu/Little Barrier Island between 1988 and 1990 and 6.2% have been recaptured (between 1990 and 2000) (Imber *et al.* 2003); of these 12 (4.8%) have returned to their natal area on Great Barrier Island. 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 92 returned chicks, 8 were recaptured in their natal burrows, 49 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, 172 ‘chicks’ have been recaptured at the Great Barrier Island colony (Table 5). There have been 61 records of ‘returned chicks’ attempting to breed during this period, and the age of first recorded breeding attempt is between 4 and 16 years and that of first successful breeding are between 4 and 14 years (Table 5, Figure 5, 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 also resulted in ‘returned’ chicks being found on the surface and new burrows (including one new burrow in a census grid). 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 the 2013/14 season from the MARK model was 94%, higher than the mean value over all years of 91.1%. The mean estimate of adult survival was 89.7% in the Bayesian model, and 88% in the SEABIRD model, with a range of around 3% between the estimates from the different models. These difference are due to the different assumptions used by the three methods. The apparent adult survival estimates compare with previous estimates of 88% by Hunter *et* *al*. (2001) and 85% by Fletcher *et al*. (2008). All the models suffer from being unable to distinguish mortality from emigration. 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 annual juvenile survival (for the first three years) was 74% which is similar to other juvenile seabirds of this size (Hunter *et al.* 2001, Barbraud *et al*. 2008, Fletcher *et al*. 2008). The annual juvenile survival form the Bayesian model was 69.7%, while the annual juvenile survival from the SEABIRD model was much higher, at 92%. SEABIRD appears to be using different assumptions in the calculation of juvenile survival. The updated SEABIRD model indicates that the population is stable or increasing only if mean annual juvenile survival is over 92% and as it is unlikely that juvenile survival is higher than adult survival, this suggests a population decline over the length of the study.

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. It is important to continue monitoring the black petrel population within the 35-ha study area to obtain a clearer picture of the trend of the Great Barrier Island (Aotea Island) black petrel population.

5.4 Population estimate and trend

The population estimate for the 35-ha study area was calculated using the three random transect surveys and this season's census grid data following stratification since surveys and local knowledge of Great Barrier Island (Aotea Island) showed that petrel burrow densities varied through 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 900 breeding pairs (1842 breeding birds) using the census grids and mean of all three random transect surveys (Table

14). 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.

This breeding population estimate is much lower than the estimates for last season from the 2012/13 transect survey and census grids (*n* = 2954) and that generated by Program SEABIRD using transects only (*n* = 3248). This suggests that less adults returned to the colony this season compared to previous seasons as shown by the high number of breeding birds detected in the 2012/13 transect survey (compared to the earlier two transect surveys). There was also a peak in the resight probability in 2012/13 in the Bayesian model, supporting a view that birds were more likely to be counted during 2012/13. It is important to note that in addition to lower number of breeding birds at the colony this season, the number of non-breeding birds also decreased. The number of non-occupied burrows increased as a result.

Although the census grid data alone suggests that the black petrel population in the 35-ha study area is stable (or slightly increasing), the SEABIRD model (using updated random transect and all mark-recapture data) suggests that the population is slightly decreasing, and that uncertainty in the rate of change is due primarily to uncertainty around the rate of juvenile survival. As it is unlikely that juveniles have a higher survival rate than adults (89%), the conclusion is that the black petrel population on Great Barrier Island (Aotea Island) within the 35-ha study area is slowly declining.

Repeats of the random transect surveys throughout the 35-ha study area would improve overall study area population estimates and overall trend of the black petrel population within the 35-ha study area. 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.

The number of burrows within the nine census grids continued to increase this season (n = 157) with another burrow being located. However, despite this increase in burrow numbers, currently there is a downward trend in the percentage of study burrows used for breeding. 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 over 300 birds have moved between numbered burrows within the 35-ha study area between 1995/96 and 2013/14 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 50 pre-breeding (or non-breeding) birds have returned to their natal area (and in 8 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 38% of breeders (either successful or non-successful) change skip the next breeding season each year. Although black petrels have a high site fidelity (98%), and over 76% 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).

Using geo-locator light loggers and high-resolution GPS devices 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 (Freeman *et al.* 2010, Bell *et al.* 2011c, Bell *et al.* 2013b). These earlier foraging studies showed that during the breeding season foraging was centred on the outer Hauraki Gulf, northern New Zealand, East Cape and towards Fiji (Freeman *et al.* 2010, Bell *et al.* 2011c, Bell *et al.* 2013b). 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 (Freeman *et al.* 2010, Bell *et al.* 2011c, Bell *et al.* 2013b). The tracking work this season shows similar patterns with birds foraging across northern New Zealand from the Kermadec Islands to East Cape (Figures 7 and 8). Nearly 123 hours of the total 861 hours of deployment time (13%) 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 rather than inshore areas. Overall, males and females foraged in similar areas, but females headed further north while males tended to forage towards East Cape. This suggests a slightly different foraging pattern and habitat between the sexes, but this needs further investigation and additional deployment of GPS devices to confirm these patterns.

Building on the dive depth information collected in 2012/13, 17 additional LOTEK LAT 1900-8 Time-Depth Recording (TDR) devices were deployed on breeding black petrels resulting in 19 dive trips and over 1190 hours at sea during January and April 2014 (Tables 9 and 10). Again like last season, the TDR devices recorded the majority of dives over 1 m were during the day (2013/14 = 94% and 2012/13 = 93%) and this pattern was similar for both males and females (Table 10). Although nearly two-thirds of the total deployment time was during daylight hours, over 95% of this time was spent flying (Table 11). Most activity on the water also occurred during the day (81%) and this pattern was similar for both males and females (Table 11). This foraging activity supports findings from the previous data collected in 2012/13 and 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). Despite Imber (1976) reporting that stomach contents indicated nocturnal feeding due to the level of bioluminescent cephalopods in their diet, it appears that black petrels forage more during the day than previously thought.

Although one male dived to 22 m and one female to 34 m, the mean dive depth was 3 m (± 0.3) and the majority (81%) of dives were shallow (< 5 m) (Table 10). This suggests that the black petrels are predominately surface or shallow water feeders and the risk from fishing gear is greatest close to the surface (generally less than 10 m). Most dives were short (<10 sec), but one dive by a female lasted 78 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 throughout the breeding season (October to May) with snapper bottom longline, big-eye tuna surface longline and inshore trawl which was consistent over the three-year tracking study (2007-2010). This suggests similar overlaps were likely to have occurred during the 2013/14 season. Over the same three-year analysis period there were 64 black-petrel captures on observed fishing vessels; 51 between January and April, 6 in May, and 9 captures between October and December (Abraham & Thompson 2012). 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 generally been very low 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 2014 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, Bell 2013a, Bell 2103b). 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.

Although 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 total bycatch estimates within New Zealand fisheries. Recent estimation work suggests the number black petrel captures in New Zealand commercial trawl and long-line fisheries may be several hundred per annum (Richard & Abraham 2013), suggesting that bycatch is potentially far exceeding the biological limit and could have serious impacts on the black petrel population. It is important that increased observer coverage is implemented in overlap zones used by black petrels and fishing vessels to determine risk and bycatch levels.

Further detailed information to better describe the at-sea distribution and foraging behaviour of the Great Barrier Island (Aotea Island) black petrel population is needed. Long-term population data can be used to develop an accurate population model to determine adult and juvenile survivorship, recruitment, site fidelity, 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 continue to 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).
- Future analysis of the resighting data should consider the association of birds and burrows, to allow estimate of movement of birds between burrows. This may increase the estimate of the apparent adult survival.

7 Acknowledgements

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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 2013/14 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 2013/14, 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 12 time-depth recording (TDR) devices for black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013/14.

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), 2013/14.

Appendix 5 Updated results from the analyses of Francis & Bell (2010) and Bell *et al.* (2011b) using mark/recapture, census grid and random transect data collected during the 2010/11 to 2013/14 black petrel (*Procellaria parkinsoni*) breeding seasons on Mount Hobson, Great Barrier Island (Aotea Island).

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 Occupancy and breeding success of study burrows (1998/99 to 2013/14 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.

Figure 3 Occupancy of census grid burrows (1995/96 to 2013/14 breeding seasons) by black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island). Dashed black line = burrows used by breeding birds; dotted line = burrows used by non-breeding birds; solid grey line = unoccupied burrows.

Figure 4 The number of black petrel (*Procellaria parkinsoni*) chicks banded each season (1995/96 to 2013/14) and the percentage of those chicks that have been recaptured in the study site on Great Barrier Island (Aotea Island). Grey column = the number of chicks banded per season and solid black line = percentage of those chicks that have been recaptured.

Figure 5 The number of breeding and non-breeding black petrel (*Procellaria parkinsoni*) 'returned chicks' recaptured each season between 1995/96 and 2013/14 in the study site on Great Barrier Island (Aotea Island). Dotted black line = total number of recaptured 'returned chicks', grey column = the number of non-breeding 'returned chicks' and black column = the number of breeding 'returned chicks'.

Figure 6 Observed frequency of age of first recapture of returned black petrel (*Procellaria parkinsoni*) 'chicks' to the 35-ha study area on Great Barrier Island (Aotea Island) between 1995/96 and 2013/14.

Figure 7 Kernel density plots of black petrel (*Procellaria parkinsoni*) GPS points during chick rearing in the 2013/14 breeding season on Great Barrier Island (Aotea Island). Darkest shade of colour represents the highest number of black petrels in that 100 km grid square.

Figure 8 GPS tracks of black petrel (*Procellaria parkinsoni*) during chick rearing in the 2013/15 breeding season on Great Barrier Island (Aotea Island) by female (red), male (blue) and unknown sexed birds (black).

Figure 9 Diving behaviour of a female black petrel (*Procellaria parkinsoni*) (H28370) during chick rearing (28-30 January 2014) in the 2013/14 breeding season on Great Barrier Island (Aotea Island).

Figure 10 Adult survival estimates for black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island) between 1995/96 and 2013/14. Estimates obtained by Cormack Jolly Seber model analysis (Phi (t) *P* (t)) using Program MARK.

Figure 11 Trends in annual population estimates from the nine census grids (after habitat stratification) for black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island) between 1996/97 and 2013/14. Solid black line = population estimate, solid grey line = breeding pairs and dashed grey line = non-breeding birds.

Figure 12 Annual variation in the variable resight probability, from the Bayesian mark-recapture model. This parameter is multiplied by a bird-specific resight probability that has no annual variation (with a mean of 95%), to derive the overall resight probability.

Tables

Table 1 Proportions of occupied, non-occupied, breeding and non-breeding burrows, ratio of occupied to non-occupied and breeding to non-breeding burrows, and breeding success, within the black petrel (*Procellaria parkinsoni*) study burrows on Great Barrier Island (Aotea Island) since the 1998/99 breeding season.

Table 2 Breeding success and causes of mortality in the black petrel (*Procellaria parkinsoni*) study burrows on Great Barrier Island (Aotea Island) between the 1995/96 and 2013/14 breeding seasons.

Table 3 Type and number of study burrows within the black petrel (*Procellaria parkinsoni*) census grids (Kauri Dam, Palmers Track and South Forks) in the study area on Great Barrier Island (Aotea Island) between the 1995/96 and 2013/14 breeding seasons.

Table 4 Banding, recapture and recovery data from all black petrels (*Procellaria parkinsoni*) caught within the study area on Great Barrier Island (Aotea Island) for the breeding seasons 1995/96 to 2013/14.

Table 5 Total number of black petrel (*Procellaria parkinsoni*) chicks banded each season since 1995 and the proportion of those chicks that have been recaptured within the study site on Great Barrier Island (Aotea Island) between 1995/96 to 2013/14.

Table 6 Number of black petrel (*Procellaria parkinsoni*) 'returned chicks' banded since 1995 that have been recaptured within the study site on Great Barrier Island (Aotea Island) between 1995/96 to 2013/14.

Table 7 Summary of I-GotU™ high-resolution GPS data-logger device deployments on black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013/14.

Table 8 Mean weight loss (± SEM) of black petrels (*Procellaria parkinsoni*) that carried I-GotU™ high-resolution GPS data-logger devices or LOTEK™ Time-Depth-Recording (TDR) devices and control birds on Great Barrier Island (Aotea Island), 2013/14.

Table 9 Summary of LOTEK™ Time-Depth-Recording (TDR) device deployments on black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013/14.

Table 10 Summary of the results from all the LOTEK™ Time-Depth-Recording (TDR) device deployments on black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013/14.

Table 11 Summary of total, night and day deployments (> 0.5 m depth) in the air or on the water from 12 LOTEK™ Time-Depth-Recording (TDR) devices on black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2013/14.

Table 12 Adult survival estimates for black petrels (*Procellaria Parkinsoni*) on Great Barrier Island (Aotea Island) between 1995/96 and 2013/14. Estimates obtained by Cormack Jolly Seber model [Phi(t) *P*(*t)] analysis (using Program MARK) with standard errors.

Table 13 Total length of all transects and number of black petrel (*Procellaria parkinsoni*) burrows in each habitat type after stratification in the 35-ha study site around Mount Hobson, Great Barrier Island (Aotea Island) combined for each survey year (2004/05, 2009/10 and 2012/13).

Table 14 2013/14 population estimate of black petrels (*Procellaria parkinsoni*) in the 35-ha study area around Mount Hobson, Great Barrier Island (Aotea Island) after stratifying and grading all transects and census grids. Area of each burrow density grade is 4.669 ha of high grade petrel habitat, 15.3013 ha of medium petrel habitat, 13.5607 ha of poor petrel habitat and 1.7509 ha of non-petrel habitat.

Table 15 Annual population estimates calculated by extrapolating from the nine census grids with habitat stratification and compared to estimates from the nine census grids without habitat stratification since 1995/96 season for black petrel (*Procellaria parkinsoni*) using the 35-ha study site on Mount Hobson, Great Barrier Island (Aotea Island).

Table 16 Parameters of the minimum DIC Bayesian mark-recapture model. The table gives the mean and 95% confidence interval from the posterior distribution, for the key model parameters. The model estimates an independent annual resight probability for adult birds, for each year (the year refers to the second year of the season, e.g. 2014 refers to the 2013/14 season). Other parameters are the annual survival (juvenile and adult); the resight probability for birds outside the study area (relative to inside); and the bird-specific resight probability (for birds 3 years or less, juveniles aged 4 to 7 and adults – estimated as a random effect).

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
2013/14	89.5	10.5	8.5:1	10.5	64.9	24.6	2.6:1	70.3
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	409	276	2	11	8	4	12	8	0	231	0	0	0	0	5	3	223[7]	**81**
13/14	410	266	6	3	8	8	3	35	0	203	0	0	0	4	0	12	187[7]	**70.3**

[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, 8 in 2012/13 and 2 in 2013/14). 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**
	2013/14	**3**	**16**	**6**	**25**	**4**	**21**	**7**	**32**	**5**	**9**	**7**	**21**	**78**
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**
	2013/14	**1**	**18**	**6**	**25**	**3**	**9**	**2**	**14**	**4**	**6**	**3**	**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**
	2013/14	**1**	**4**	**2**	**7**	**3**	**8**	**4**	**15**	**1**	**4**	**0**	**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	**13/14**
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	**11**
Recaptures of birds banded in 1995/96	-	14	14	14	16	14	11	12	12	8	12	10	7	8	11	9	5	5	**6**
Recaptures of birds banded in 1996/97	-	-	113	86	84	73	63	57	43	37	39[1]	31	28	30	29	22	12	21	**15**
Recaptures of birds banded in 1997/98	-	-	-	32	32	30	28	24	18	27	18	13	13	17	15	11	12	10	**9**
Recaptures of birds banded in 1998/99	-	-	-	-	95	82	71	64	49	36	39	33	32	37	39	24	17	29	**19**
Recaptures of birds banded in 1999/00	-	-	-	-	-	86	75	66	47	51	52	37	31	39	34	33	20	22	**17**
Recaptures of birds banded in 2000/01	-	-	-	-	-	-	51	52	41	22	36	28	29	40	30	21	12	22	**18**
Recaptures of birds banded in 2001/02	-	-	-	-	-	-	-	68	88	26	25	22	21	26	36	20	18	24	**22**
Recaptures of birds banded in 2002/03	-	-	-	-	-	-	-	-	61	55	57	54	39	56	52	38	26	36	**34**
Recaptures of birds banded in 2003/04	-	-	-	-	-	-	-	-	-	22	28	23	21	26	27	24	16	23	**19**
Recaptures of birds banded in 2004/05	-	-	-	-	-	-	-	-	-	-	48	31	33	48	59	42	28	47	**43**
Recaptures of birds banded in 2005/06	-	-	-	-	-	-	-	-	-	-	-	46	34	49	50	35	23	35	**28**
Recaptures of birds banded in 2006/07	-	-	-	-	-	-	-	-	-	-	-	-	27	46	42	35	22	43	**45**
Recaptures of birds banded in 2007/08	-	-	-	-	-	-	-	-	-	-	-	-	-	29	20	19	18	32	**23**
Recaptures of birds banded in 2008/09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	71	55	46	66	**54**
Recaptures of birds banded in 2009/10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	29	39	**40**
Recaptures of birds banded in 2010/11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	39	**32**
Recaptures of birds banded in 2011/12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	**26**
Recaptures of birds banded in 2012/13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**70**
TOTAL RECAPTURES	19	45	151	155	256	312	326	370	380	306	377	347	334	469	529	412	341	517	**531**
Number of new-banded adults	41	179	60	129	145	97	114	179	67	135	108	85	53	183	107	82	49	244	**134**
TOTAL ADULTS	60	224	211	284	401	409	440	549	447	441	485	432	387	652	636	494	390	761	**665**
Number of new-banded chicks	59	69	85	116	137	137	160	62	110	184	143[2]	215	191	203	171	144	163	219	**199**
TOTAL NUMBER OF BIRDS	119	293	296	400	538	546	600	611	557	625	627	647	578	855	807	638	553	980	**864**
Number of 'returned' chicks recaptured	0	0	0	0	1	1	9	18	14	20	25	20	28	41	42	43	42	85	**92**

[1] 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.

[2] 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).

BAND RECOVERIES FROM DEAD BIRDS	0	1	1	0	2	1	2	2	0	0	2	1	1	2	3	2	0	3	**0**

Table 5

	Total number of banded chicks	Total number of returned chicks	Proportion (%) of returned chicks
1995/96	59	4	6.8
1996/97	69	7	10.1
1997/98	85	10	11.8
1998/99	116	15	12.9
1999/00	137	16	11.7
2000/01	137	9	6.6
2001/02	160	17	10.6
2002/03	62	6	9.7
2003/04	110	8	7.3
2004/05	184	20	10.9
2005/06	143	15	10.5
2006/07	215	16	7.4
2007/08	191	13	6.8
2008/09	203	12	5.9
2009/10	171	4	2.3
2010/11	144	0	0
2011/12	163	0	0
2012/13	219	0	0
2013/14	199	0	0
TOTAL	**2767**	**172**	**6.2**
MEAN (± SEM)	145.6 ± 11.8	9.1 ± 1.5	6.9 ± 1.0

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	13/14
Recaptures of chicks banded in 1995/96	-	-	-	-	1	1	2	3	2	1	2	1	2	2	2	2	1	1	2
Recaptures of chicks banded in 1996/97	-	-	-	-	-	-	2	2	3	2	1	0	0	1	2	2	0	1	0
Recaptures of chicks banded in 1997/98	-	-	-	-	-	-	5	6	4	1	2	3	1	4	6	6	3	3	2
Recaptures of chicks banded in 1998/99	-	-	-	-	-	-	-	6	3	6	6	6	6	8	5	5	3	8	7
Recaptures of chicks banded in 1999/00	-	-	-	-	-	-	-	1	2	10	9	5	5	8	2	1	4	7	6
Recaptures of chicks banded in 2000/01	-	-	-	-	-	-	-	-	-	-	4	1	5	2	8	3	1	4	2
Recaptures of chicks banded in 2001/02	-	-	-	-	-	-	-	-	-	-	1	2	6	8	2	2	5	10	8
Recaptures of chicks banded in 2002/03	-	-	-	-	-	-	-	-	-	-	-	2	2	4	2	4	1	4	3
Recaptures of chicks banded in 2003/04	-	-	-	-	-	-	-	-	-	-	-	-	1	3	8	7	3	5	4
Recaptures of chicks banded in 2004/05	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4	8	9	14	14
Recaptures of chicks banded in 2005/06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	5	9	15
Recaptures of chicks banded in 2006/07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	7	11
Recaptures of chicks banded in 2007/08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	7	6
Recaptures of chicks banded in 2008/09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	9
Recaptures of chicks banded in 2009/10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	3
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	92

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			
		♂	♀	U	TOTAL			GPS	STUDY	MEAN (± SEM)	RANGE			TOTAL	DID NOT GO TO SEA	FAILED	LOTS AT SEA
Jan. 2014	Jan. 2014	0	0	1	1	1	1	100		3.0 ± 0.0	3	1	1	0	0	0	0
Jan. 2014	Feb. 2014	13	7	7	27	27	23	74.1	70.3	5.7 ± 0.4	3-10	20	19	8	7	1	0
Jan. 2014	-	2	0	3	5	0	5	40.4		-	-	0	5	5	0	0	5
TOTAL		**15**	**7**	**11**	**33**	**28 (84.8%)**	**29**	**71.5 (± 17.3)**	**70.3**	**5.6 ± 0.4**	**3-10**	**21 (63.6%)**	**25 (75.8%)**	**13**	**7**	**1**	**5**

Table 8

DEVICE	MEAN WEIGHT LOSS (g) ± SEM (range)			
	MALE	**FEMALE**	**UNKNOWN**	**ALL**
ALL GPS DEPLOYMENTS	-53.2 ± 17.5 (-145 – 50)	-37.1 ± 20.8 (-90 – 80)	-68.1 ± 6.5 (-40 – -90)	-60.0 ± 10.0 (-175 – 80)
ALL TDR DEPLOYMENTS	-25.7 ± 41.8 (-175 – 95)	-41.7 ± 21.9 (-15 – -85)	-15.0 ± 0.0 (-15)	-27.9 ± 24.2 (-175 – 95)
ALL CONTROL BIRDS	-43.0 ± 8.2 (-95 – -10)	-53.1 ± 15.9 (-155 – 65)	-75.1 ± 19.2 (-140 – 15)	-54.7 ± 9.2 (-155 – 65)

Table 9

DEPLOYED	RETRIEVED	NUMBER OF TDR DEVICES DEPLOYED				NUMBER OF TDR 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 TDR DEVICES WITH NO DIVES		
		♂	♀	U	TOTAL			DEVICE	STUDY	MEAN (± SEM)	RANGE			TOTAL	FAILED	STILL AT SEA
Jan. 2014	Jan. 2014	3	2	1	6	6	6	66.7	70.3	7.8 ± 0.7	6-10	6	6	0	0	0
Jan. 2014	Feb. 2014	3	1	1	5	5	5	100		9.2 ± 1.9	3-13	5	5	0	0	0
Jan. 2014	Apr. 2014	1	0	0	1	1	1	100		97	97	0	1	1	1	0
Jan. 2014	-	3	1	1	5	0	5	40		-	-	0	5	5	0	5
TOTAL		**10**	**4**	**3**	**17**	**12 (70.6%)**	**16**	**76.8 (± 14.5)**	**70.3**	**15.8 ± 7.4**	**3-97**	**11 (64.7%)**	**17**	**6**	**1**	**5**

Table 10

	NUMBER	DEPLOYMENT (HOURS AT SEA)	NUMBER OF DIVES						LENGTH OF DIVE (seconds)		DEPTH OF DIVE (m)		
			TOTAL	DAY	NIGHT	SHALLOW (< 5 m)	MEDIUM (5 – 10 m)	DEEP (> 10 m)	MAX	MIN	MAX	MIN	MEAN (± SEM)
MALE	5	454.5	251	232 (92.4%)	19 (7.6%)	200 (79.7%)	29 (11.6%)	22 (8.8%)	71	1	-22.2	-0.8	-3.2 ± 0.6
FEMALE	5	627.7	440	418 (95.0%)	22 (5.0%)	355 (86.6%)	49 (12.0%)	36 (8.8%)	78	1	-34.3	-0.9	-3.1 ± 0.4
UNKNOWN	2	66.2	22	21 (95.5%)	1 (4.5%)	20 (90.9%)	2 (9.1%)	0	20	2	-5.9	-1.0	-1.8 ± 0.7
ALL	**12**	**1148.4**	**713**	**671 (94.1%)**	**42 (5.9%)**	**575 (80.6%)**	**80 (11.2%)**	**58 (8.1%)**	**78**	**1**	**-34.3**	**-0.8**	**-3.0 ± 0.3**

Table 11

	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	5	7	454.5	274.8 (60.5%)	179.7 (39.5%)	447.4 (98.5%)	268.3 (60.0%)	179.4 (40.0%)	7.1 (1.5%)	6.3 (88.7%)	0.8 (11.3%)
FEMALE	5	10	627.7	387.4 (61.7%)	240.3 (38.3%)	612.3 (97.5%)	384.1 (62.7%)	228.2 (37.3%)	15.4 (2.5%)	12.4 (80.5%)	3.0 (19.5%)
UNKNOWN	2	2	66.2	42.1 (63.6%)	24.1 (36.4%)	50.8 (76.7%)	32.0 (63.0%)	18.8 (37.0%)	15.4 (23.3%)	12.0 (77.9%)	3.4 (22.1%)
ALL	**12**	**19**	**1148.4**	**704.3 (61.3%)**	**444.1 (38.7%)**	**1110.5 (96.7%)**	**684.4 (61.6%)**	**426.4 (38.4%)**	**37.9 (3.3%)**	**30.7 (81.0%)**	**7.2 (19.0%)**
MEAN (± SEM)			60.4 ± 13.7	37.1 ± 8.2	23.4 ± 5.6	58.4 ± 13.9	36.0 ± 8.3	22.4 ± 5.6	1.9 ± 0.6	1.5 ± 0.4	0.4 ± 0.2
				61.4%	38.7%	96.7%	61.6%	38.4%	3.1%	78.9%	21.1%

Table 12

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
2013/14	0.9380	0.02

Table 13

Season	Total Length of Transects	Total number of burrows	Number of burrows along transects								
			Low			Medium			High		
			Breeding	Non-breeding	Empty	Breeding	Non-breeding	Empty	Breeding	Non-breeding	Empty
2004/05	7468 m (2.99 ha)	191	3	2	0	59	39	6	50	29	3
2009/10	9133 m (3.65 ha)	297	13	10	15	32	42	55	51	44	44
2012/13	9578 m (3.83 ha)	510	49	28	59	76	38	98	64	35	63
Mean ± SEM			**21.7 (± 14.0)**	**13.3 (± 7.7)**	**24.7 (± 17.7)**	**55.7 (± 12.8)**	**39.7 (± 1.2)**	**53.0 (± 26.6)**	**55.0 (± 4.5)**	**36.0 (± 4.4)**	**36.7 (± 17.7**

Table 14

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	Transects	1.03	43	16	13.5607	579	214
	KDG2	0.008	0	0		0	0
	KDG3	0.008	0	0		0	0
MEAN (± SEM)			14 ± 14	5 ± 5		193 ± 193	71 ± 71
MEDIUM	Transects	1.52	74	33	15.3013	1128	503
	KDG1	0.008	0	0		0	0
	KDG2	0.032	188	0		2869	0
	KDG3	0.106	38	12		577	180
	SFG1	0.032	125	0		1913	0
	SFG3	0.11	36	0		556	0
	PTG2	0.04	0	31		0	478
	PTG3	0.06	33	21		510	319
	MEAN (± SEM)		59 ± 23	12 ± 5		944 ± 352	185 ± 78
HIGH	Transects	0.78	141	58	4.669	658	269
	KDG1	0.152	211	49		983	231
	KDG2	0.12	250	63		1167	292
	KDG3	0.046	87	27		406	127
	SFG1	0.128	109	68		511	319
	SFG2	0.16	75	23		350	109
	SFG3	0.05	80	0		374	0
	PTG1	0.16	250	55		1167	255
	PTG2	0.12	167	10		778	49
	PTG3	0.1	140	38		654	175
MEAN (± SEM)			151 ± 21	39 ± 7		705 ± 99	183 ± 34
TOTAL POPULATION ESTIMATE (± SE)						1842 ± 149	439 ± 35
						2281 ± 184	
POPULATION ESTIMATE RANGE						**2097 to 2465 adults**	

Table 15

YEAR	NON—STRATIFIED ESTIMATE			STRATIFIED ESTIMATE		
	Breeding pairs	Non-breeding birds	Total population estimate (number of individual birds)	Breeding pairs	Non-breeding birds	Total population estimate (number of individual birds)
1995/96	1677	1094	4448	242	201	684
1996/97	2552	948	6052	827	167	1821
1997/98	2479	1167	6125	816	205	1838
1998/99	2406	802	5615	940	153	2032
1999/00	1993	705	4691	616	285	1517
2000/01	1847	899	4594	642	366	1650
2001/02	1920	753	4594	684	222	1590
2002/03	1847	875	4569	658	268	1584
2003/04	1872	462	4205	355	113	1422
2004/05	2042	729	4813	698	448	1844
2005/06	2236	340	4813	727	146	1599
2006/07	2333	583	5250	851	174	1876
2007/08	2236	753	5226	724	293	1742
2008/09	2358	705	5420	804	454	2062
2009/10	2090	899	5080	631	452	1714
2010/11	2358	559	5274	809	212	1830
2011/12	2115	1142	5372	742	437	1921
2012/13	2163	1021	5347	708	485	1900
2013/14	2260	851	5372	878	301	2057
MEAN (± SEM)	2147 (± 56)	805 (± 51)	5098 (± 120)	718 (± 34)	283 (± 28)	1720 (± 71)

Table 16

Parameter	Mean	2.5 % quartile	97.5% quartile
Resight probability, 1995	26.43	14.72	40.69
Resight probability, 1996	47.06	32.95	61.89
Resight probability, 1997	74.25	60.8	86.55
Resight probability, 1998	86.55	79.94	92.43
Resight probability, 1999	89.2	82.31	95.35
Resight probability, 2000	98.17	95.15	99.92
Resight probability, 2001	94.78	90.74	98.36
Resight probability, 2002	94.88	90.66	98.33
Resight probability, 2003	99.33	97.7	99.98
Resight probability, 2004	82.77	77.86	87.45
Resight probability, 2005	68.99	63.91	74.18
Resight probability, 2006	81.42	76.76	85.76
Resight probability, 2007	75.77	70.99	80.38
Resight probability, 2008	72.57	67.87	77.22
Resight probability, 2009	97.33	94.3	99.65
Resight probability, 2010	91.81	88.05	95.25
Resight probability, 2011	84.97	80.54	89.29
Resight probability, 2012	65.78	61.08	70.5
Resight probability, 2013	98.85	96.63	99.95
Resight probability, 2014	86.18	81.19	91.15
Relative resight probability outside the study area	6.26	4.91	7.83
Annual juvenile survival	69.79	67.69	71.76
Annual probability of becoming adult (ages 4 to 7)	15.82	11.47	21.08
Annual adult survival	89.69	88.98	90.39
Bird-specific resight probability (3 years or less)	0.27	0.11	0.47
Bird-specific resight probability (juveniles aged 4 to 7)	5.79	2.5	9.38
Mean of bird-specific resight probability (adult)	91.08	87.08	94.56

Figure 1

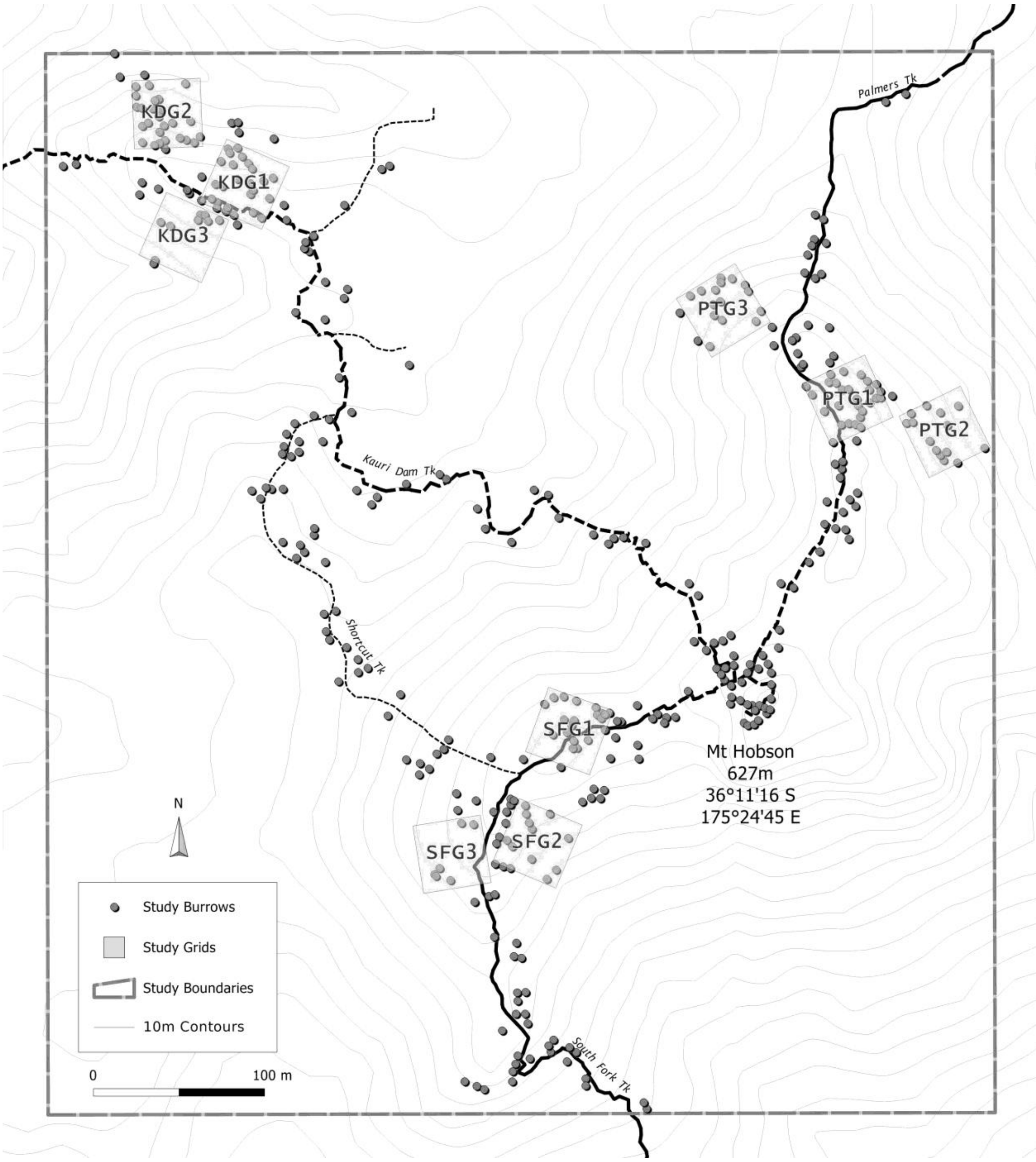

Palmers Tk
KDG2
KDG1
KDG3
PTG3
PTG1
PTG2
Kauri Dam Tk
Shortcut Tk
SFG1
Mt Hobson
627m
36°11'16 S
175°24'45 E
N
SFG3
SFG2
Study Burrows
Study Grids
Study Boundaries
10m Contours
0
100 m
South Fork Tk

Figure 2

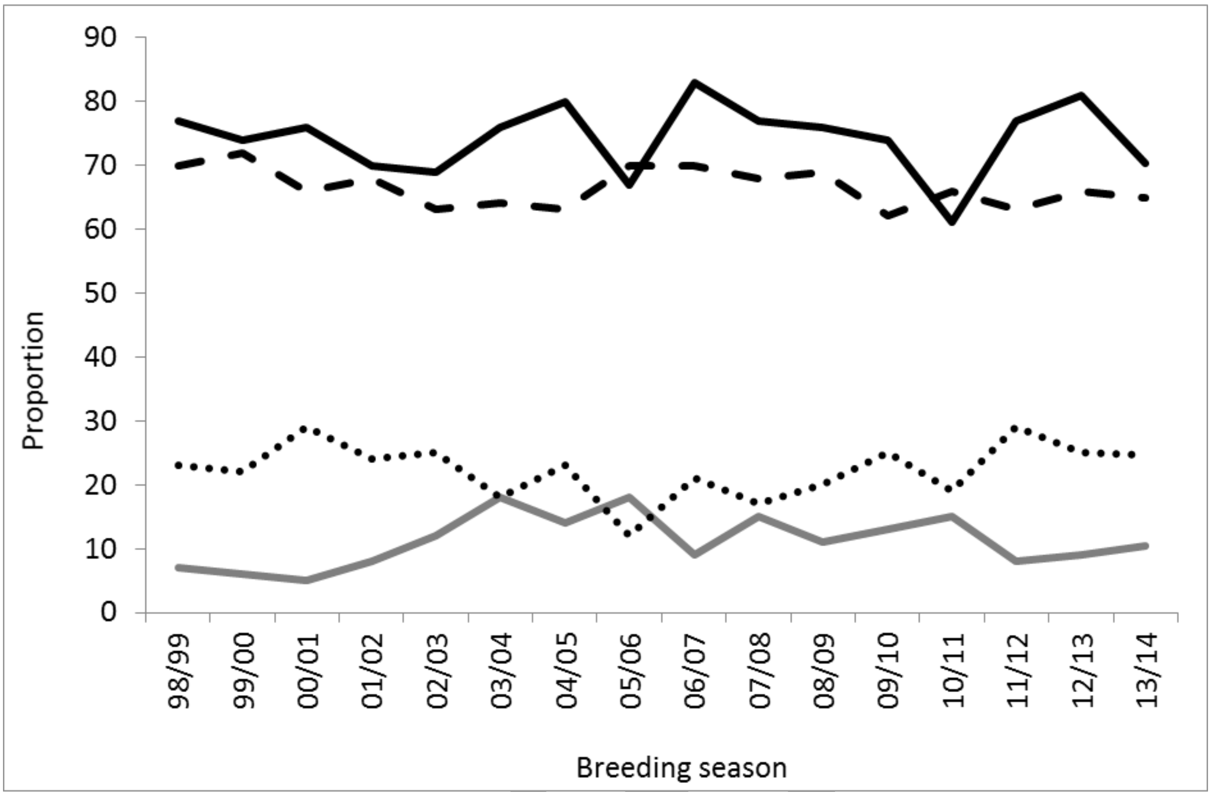

90
80
70
60
50
40
30
20
10
0
Proportion
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06
06/07
07/08
08/09
09/10
10/11
11/12
12/13
13/14
Breeding season

Figure 3

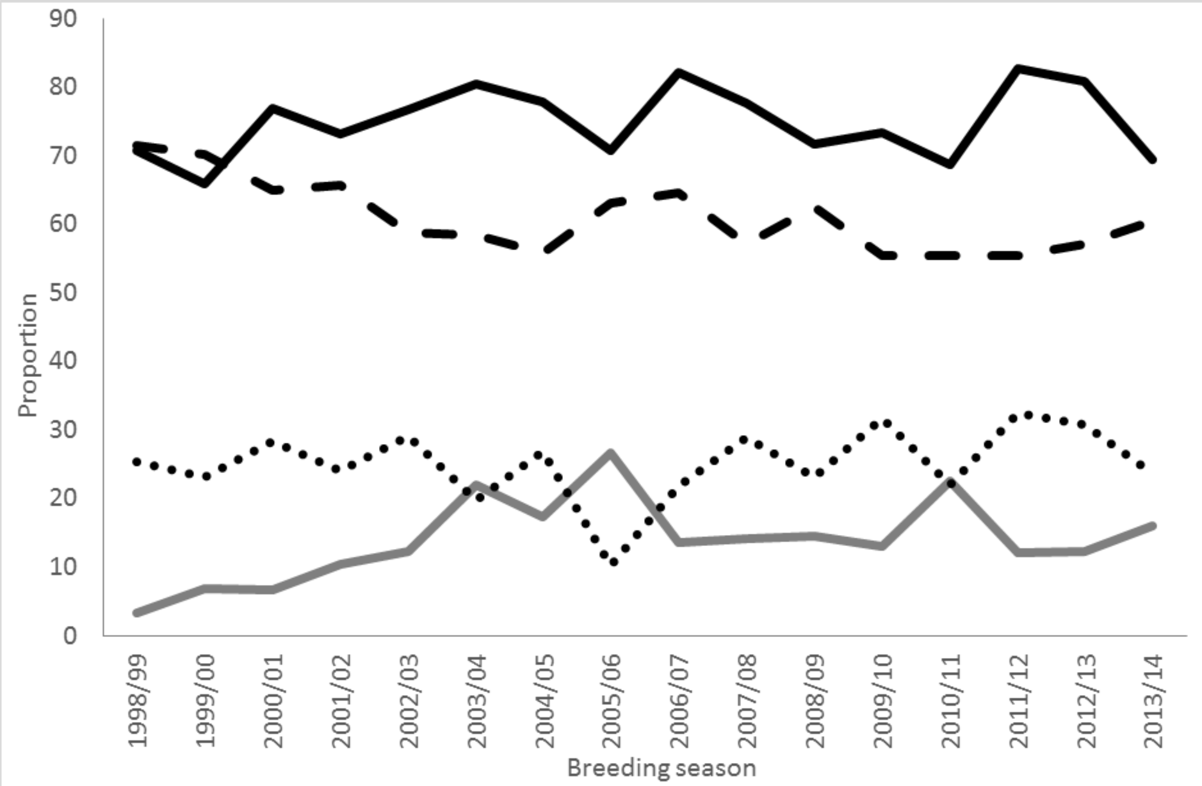
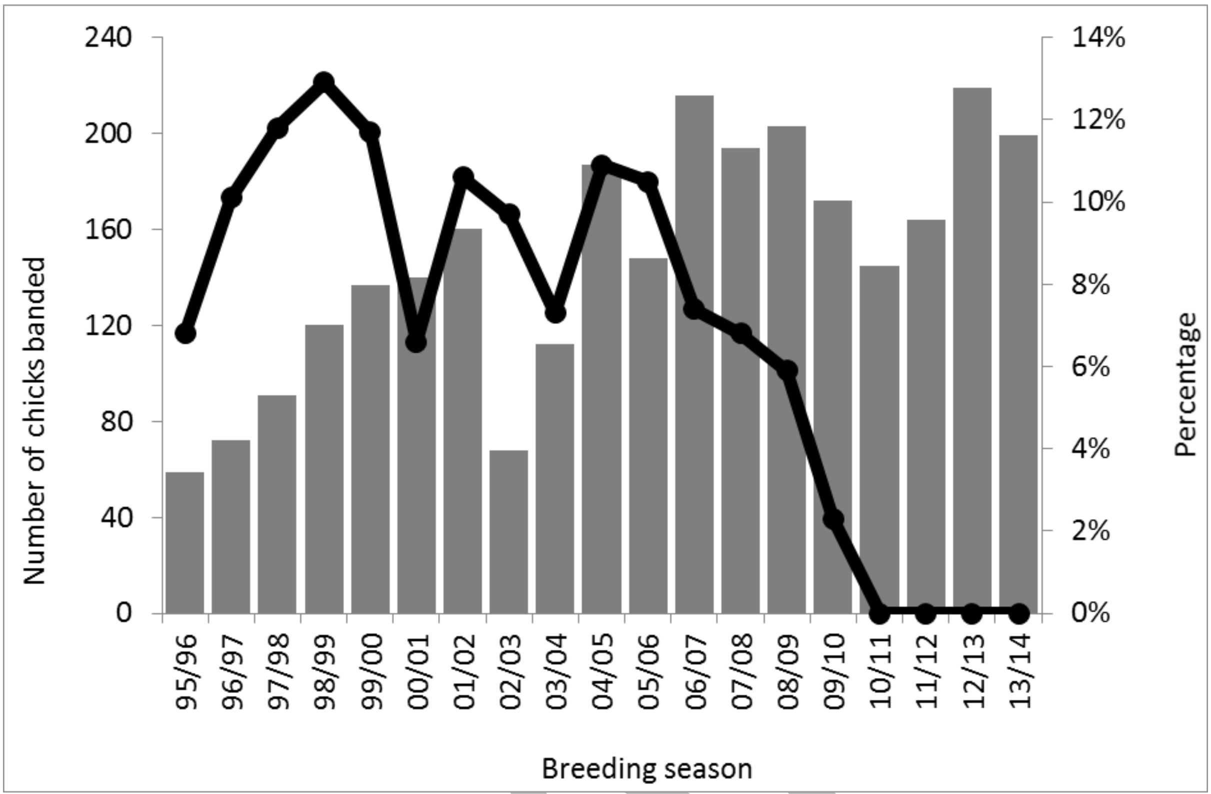

90
80
70
60
50
40
30
20
10
0
Proportion
1998/99
1999/00
2000/01
2001/02
2002/03
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
2010/11
2011/12
2012/13
2013/14
Breeding season

Figure 4



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
13/14
Breeding season

Figure 5

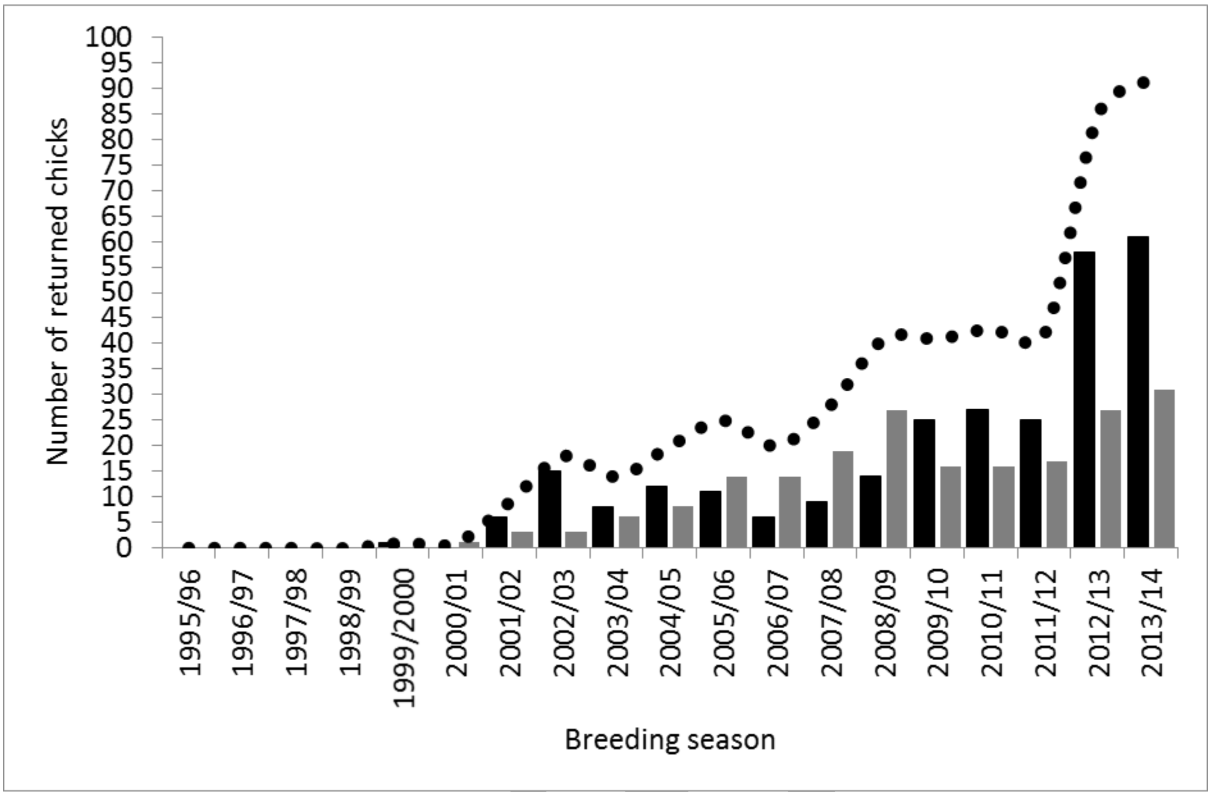

Number of returned chicks
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1995/96
1996/97
1997/98
1998/99
1999/2000
2000/01
2001/02
2002/03
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
2010/11
2011/12
2012/13
2013/14
Breeding season

Figure 6

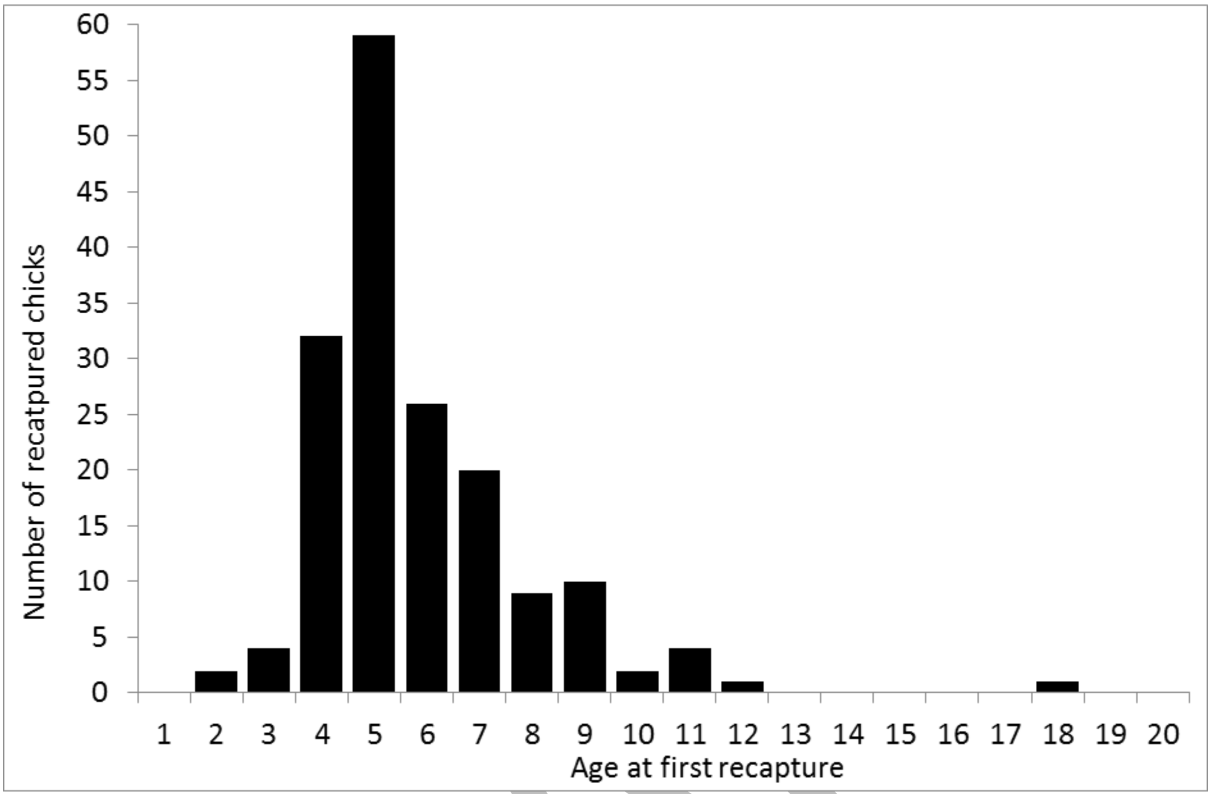
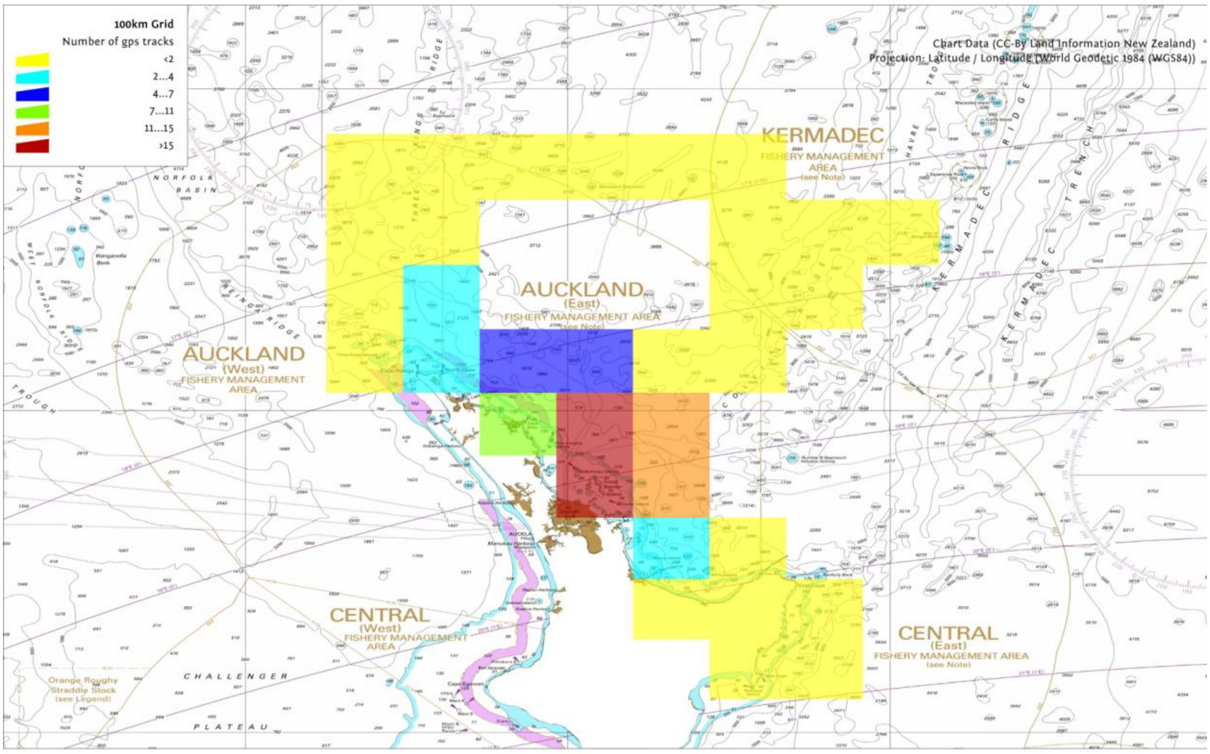

60
55
50
45
40
35
30
25
20
15
10
5
0
Number of recatpured chicks
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Age at first recapture

Figure 7



100km Grid
Number of gps tracks
<2
2...4
4...7
7...11
11...15
>15
Chart Data (CC-By Land Information New Zealand)
Projection: Latitude / Longitude (World Geodetic 1984 (WGS84))
KERMADEC
FISHERY MANAGEMENT AREA
AUCKLAND
(East)
FISHERY MANAGEMENT AREA
AUCKLAND
(West)
FISHERY MANAGEMENT AREA
CENTRAL
(West)
FISHERY MANAGEMENT AREA
CENTRAL
(East)
FISHERY MANAGEMENT AREA

Figure 8

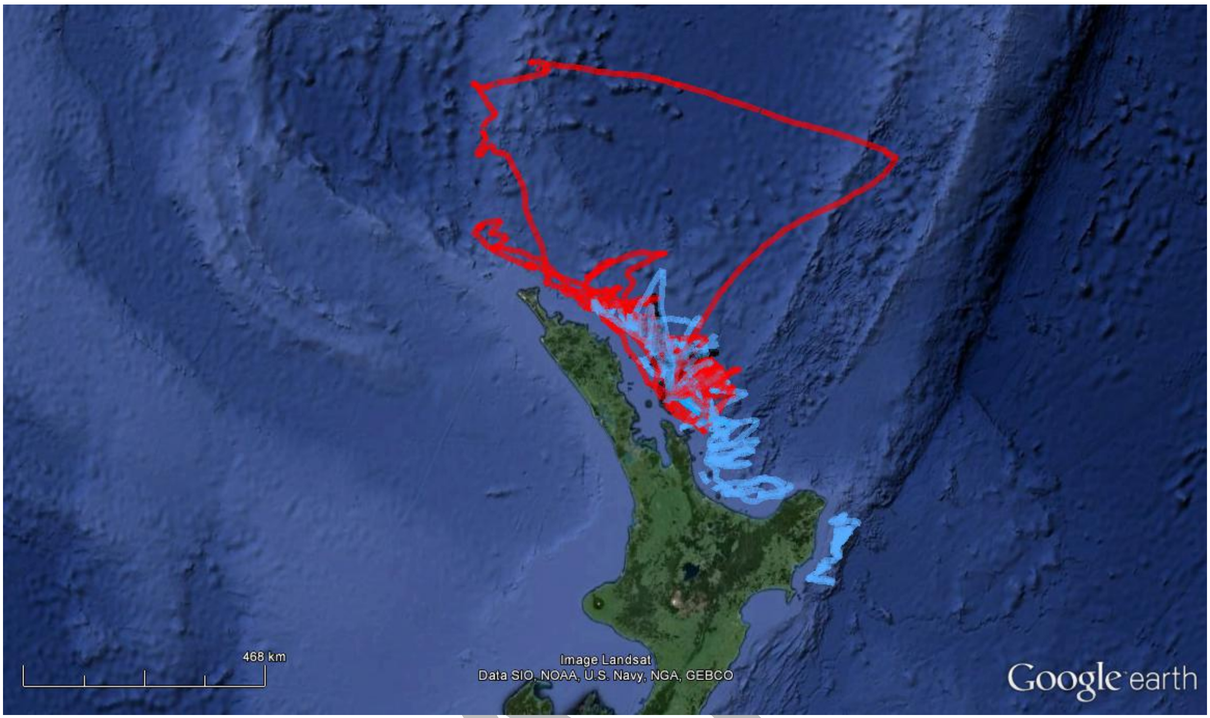

468 km
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth

Figure 9

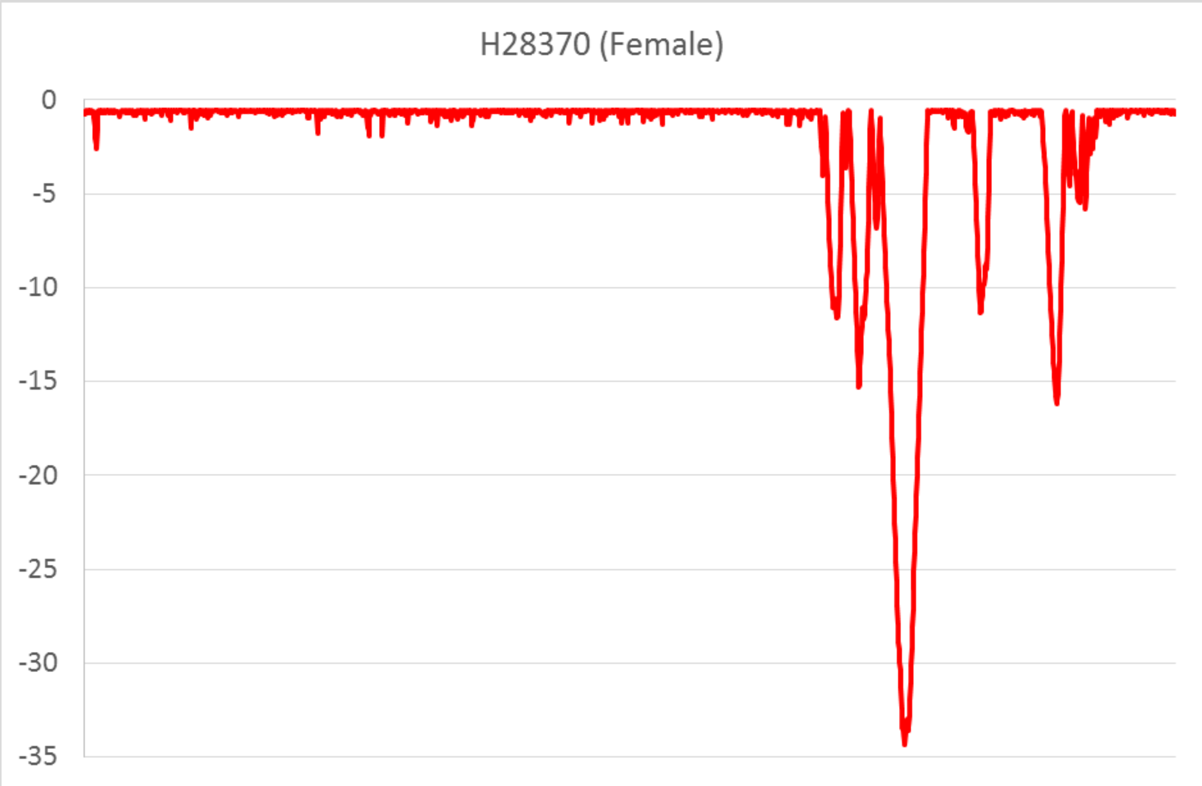


Figure 10

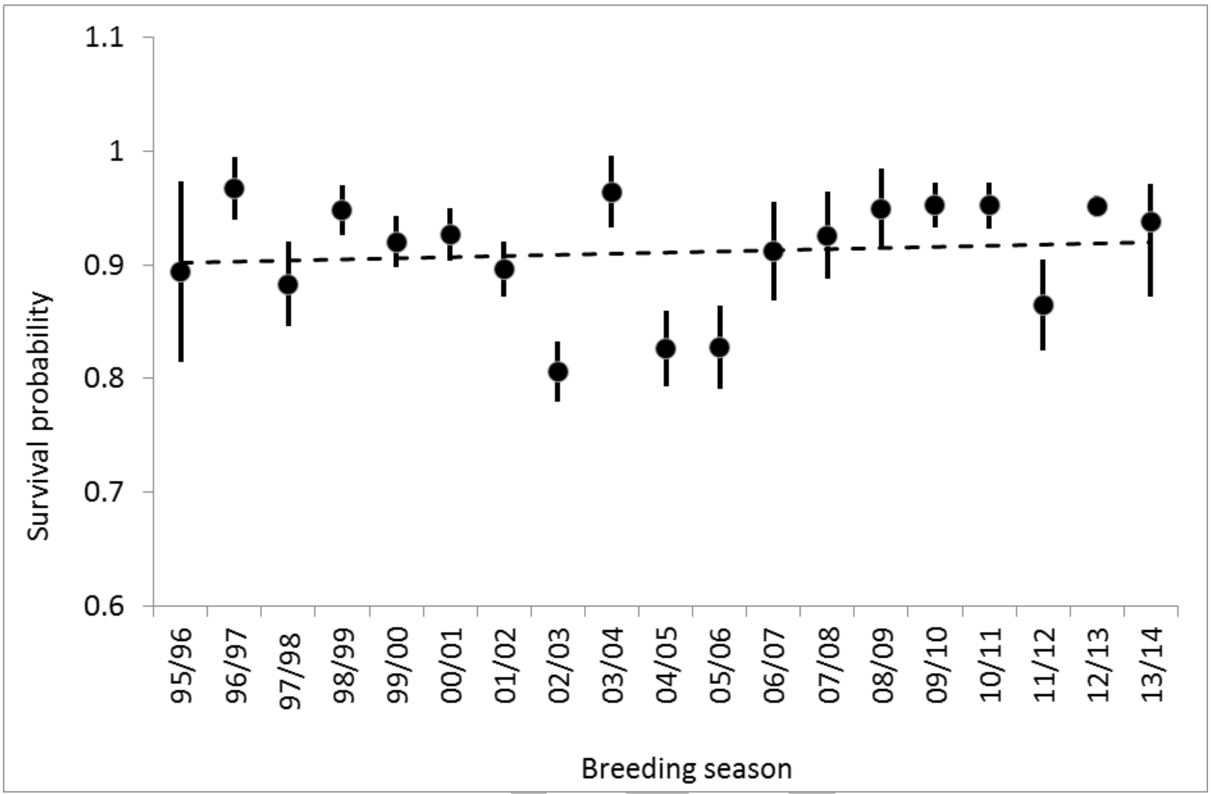

1.1
1
0.9
0.8
0.7
0.6
Survival probability
95/96
96/97
97/98
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06
06/07
07/08
08/09
09/10
10/11
11/12
12/13
13/14
Breeding season

Figure 11

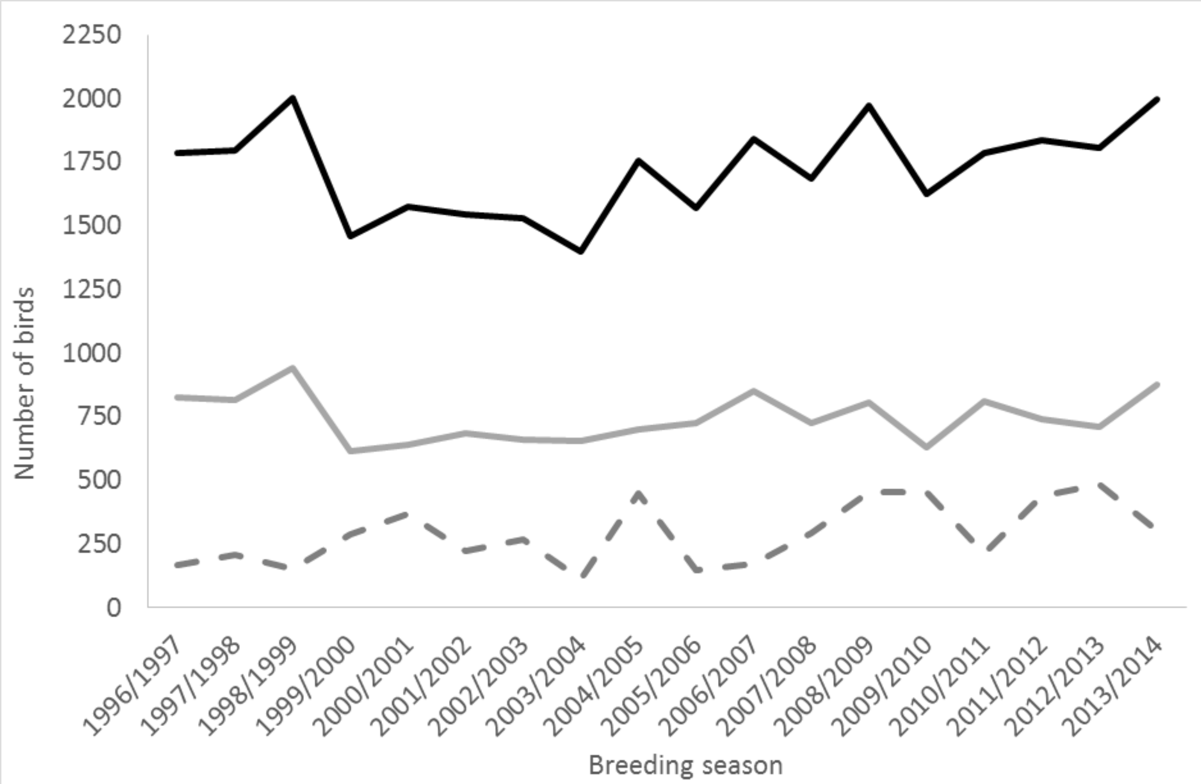
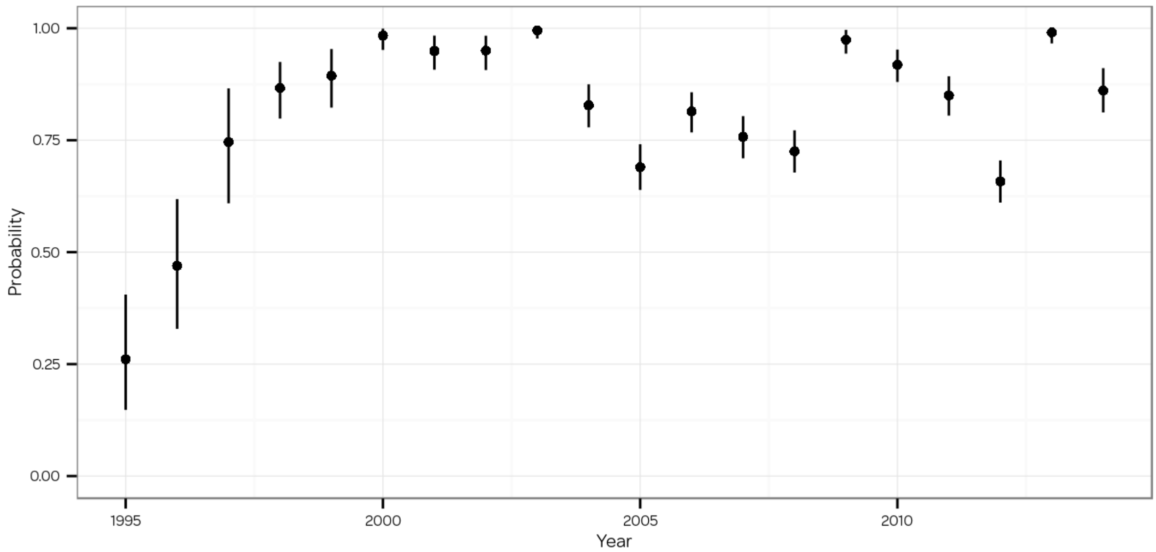

2250
2000
1750
1500
1250
1000
750
500
250
0
Number of birds
1996/1997
1997/1998
1998/1999
1999/2000
2000/2001
2001/2002
2002/2003
2003/2004
2004/2005
2005/2006
2006/2007
2007/2008
2008/2009
2009/2010
2010/2011
2011/2012
2012/2013
2013/2014
Breeding season

Figure 12



Appendix 1.

Burrow	Band					Outcome
1	?	?				Non-breeding
2	38630	34957				Chick
3	35298 (?M)	29927 (?F)	35219			Chick
4	28378 (?M)	39405 (?F)				Chick
5	27967 (M)	31971 (F)				Chick
6	33540 (M)	34394 (F)				Rat predation
7	39424	39425				Non-breeding
8	?	38648 (F)				Egg (disappeared)
9	?	?				Non-breeding
10	36396 (?M)	34401 (?F)				Chick
11	?	?				Empty
12	36361	37595				Chick
13	38856	?				Non-breeding
14	34449 (M)	34421 (F)				Chick
15	33329	35361				Non-breeding
16	39414	35302	36372			Egg (disappeared)
17	31108 (M)	38624 (F)				Non-breeding
18	35209 (M)	29815 (F)				Chick
19	28376	33324				Chick
20	34264 (M)	33683 (F)				Chick
21	34615 (M)	35265 (F)	33466	34956		Non-breeding
22	36393	38995				Chick
23	38855 (?M)	29847 (?F)				Egg (rat predation)
24	34338 (?M)	36319 (?F)				Chick
25	?	?				Non-breeding
26	23014 (M)	28357 (F)				Chick
27	35198 (M)	35549 (F)				Chick
28	?	?				Empty
29	?	?				Empty
30	36151 (?M)	37976 (?F)				Chick
31	33052 (M)	33003 (F)				Egg (disappeared)
32 (P1)	31537 (?M)	?				Dead chick
33	28076 (?M)	31244 (?F)				Chick
34	31121 (M)	31248 (F)				Chick
35	?	36320 (F)				Chick
36	33460 (M)	34359 (F)				Chick
37	36294 (M)	31107 (F)				Egg (crushed)
38	?	?				Empty
39	25426 (M)	35251 (F)				Chick
40	36166 (?M)	34384 (?F)				Chick
41	31112 (M)	31029 (F)				Disappeared chick
42	27981 (M)	36360 (F)				Chick
43	25546	?				Chick
44	31494 (M)	36364 (F)				Egg (crushed)
45	38861	39440	39441			Non-breeding
46	34360 (M)	28813 (F)				Chick
47	31018 (M)	33786 (F)				Chick
48	36190 (M)	35267 (F)				Egg (disappeared)
49	36322	34380				Egg (disappeared)
50	31282 (M)	33747 (F)				Chick
51	36383 (?M)	?				Infertile egg

52	38863	38872				Non-breeding
53	37487	?				Chick
54	39413	?				Non-breeding
55 (P1)	23635 (M)	33638 (F)				Chick
56 (P1)	36327 (M)	29684 (F)				Chick
57 (P1)	31153 (M)	33725 (F)				Chick
58 (P1)	28029 (?M)	31205 (?F)				Egg (disappeared)
59 (P1)	31125 (M)	34392 (F)				Chick
60 (P1)	?	?				Non-breeding
61 (P1)	28354	?				Non-breeding
62 (P1)	?	?				Empty
63 (P1)	35256	38637				Chick
64 (P1)	31366 (M)	?				Chick
65	39446	?				Non-breeding
66	30874 (M)	34853 (F)				Chick
67 (K1)	36118 (?M)	38645 (?F)				Non-breeding
68 (K1)	31172 (M)	32005 (F)				Chick
69	27604 (M)	31240 (F)				Egg (abandoned)
70	33589 (M)	31992 (F)				Non-breeding
71 (K1)	34351 (M)	34352 (F)				Chick
72 (K1)	34901 (?M)	?				Egg (rat predation)
73 (K1)	?	?				Non-breeding
74 (K1)	29693	31974				Chick
75 (K1)	28572 (M)	38599 (F)				Chick
76 (K1)	33758 (M)	31089 (F)				Dead chick
77 (K1)	28390	?				Egg (disappeared)
78 (K1)	30867 (M)	37572 (F)				Egg (disappeared)
79 (K1)	38563	38649				Non-breeding
80 (K1)	34843 (?M)	?				Chick
81 (K1)	28046 (M)	28370 (F)				Chick
82	35448	36345				Dead embryo
83	34781 (M)	34353 (F)				Dead chick
84	35405 (?M)	35228 (?F)				Disappeared chick
85 (S1)	38640	39407				Non-breeding
86 (S1)	25661 (M)	34365 (F)				Infertile egg
87 (S1)	38894	?				Non-breeding
88 (S1)	?	?				Empty
89 (S1)	31495 (M)	30910 (F)				Infertile egg
90 (S1)	33097 (M)	?				Chick
91 (S1)	?	?				Non-breeding
92 (S1)	32928 (M)	36334 (F)				Chick
93	?	?				Empty
94	35200 (?M)	34886 (?F)				Chick
95	33089 (?M)	?				Non-breeding
96 (P1)	29820	35235				Chick
97	34385 (M)	36194 (F)				Chick
98	?	?				Empty
99	39427	?				Non-breeding
100	38741	38560				Chick
101 (K1)	35186 (M)	38646 (F)				Non-breeding
102 (K1)	33389 (?M)	35239 (?F)				Chick
103 (K1)	25673 (M)	29690 (F)				Chick
104 (K1)	?	?				Non-breeding
105	37566 (M)	35231 (F)				Chick
106	38625	?				Egg (disappeared)

107	33764 (M)	33799 (F)				Chick
108	27952	39477				Chick
109	34734 (M)	37593 (F)				Chick
110 (S1)	33654 (?M)	37535 (?F)				Disappeared chick
111 (S1)	?	?				Empty
112 (S1)	28037 (M)	34796 (F)				Chick
113 (S1)	35193	?				Non-breeding
114 (S1)	?	?				Non-breeding
115	?	?				Non-breeding
116 (P1)	25435 (?M)	35435 (?F)				Egg (disappeared)
117	25664 (M)	37600 (F)				Chick
118	39442	?				Non-breeding
119	34389 (?M)	33530 (?F)				Egg (disappeared)
120 (P1)	?	?				Non-breeding
121 (P1)	29817	33035				Chick
122 (P1)	27961	36328				Chick
123 (P1)	29818	38858				Egg (disappeared)
124 (P1)		35255 (F)				Chick
125 (P1)	39434	?				Non-breeding
126 (P1)	33477 (?M)	37586 (?F)				Chick
127	33301 (M)	35538 (F)				Chick
128	31054 (M)	?				Non-breeding
129	?	?				Empty
130	39404	39444	38900			Non-breeding
131	35406	38583				Chick
132 (K2)	36290 (?M)	38585 (?F)				Egg (abandoned)
133 (K2)	25525 (M)	35241 (F)				Chick
134 (K2)	37503 (?M)	?				Chick
135 (K2)	25447 (M)	34377 (F)				Chick
136 (K2)	29699 (M)	38558 (F)	38586			Egg (abandoned)
137 (K2)	25494 (M)	31572 (F)				Chick
138 (K2)	34553	37573				Chick
139	38627 (?M)	38743 (?F)	38554			Non-breeding
140	29809 (M)	36179 (F)				Chick
141 (S2)	36233	?				Non-breeding
142 (S2)	?	?				Empty
143 (K2)	39450	?				Non-breeding
144 (K2)	36175	?				Chick
145 (K2)	34527	38701				Egg (rat predation)
146 (K2)	37536 (M)	39449 (F)				Non-breeding
147 (K2)	34903 (M)	36368 (F)				Chick
148 (K2)	36355 (?M)	34376 (?F)				Chick
149 (K2)	?	?				Non-breeding
150 (K2)	38621	33575				Non-breeding
151	33667 (M)	37518				Non-breeding
152 (S2)	28366	37519				Chick
153 (S2)	29978 (M)	33471 (F)				Chick
154 (P1)	34320	36382				Non-breeding
155 (P2)	?	?				Non-breeding
156 (P2)	38636	39433				Disappeared chick
157 (P2)	33473 (M)					Chick
158 (P2)	30175	?				Egg (disappeared)
159 (P2)	25441	37584				Chick
160	?	38553 (F)				Chick
161 (P2)	31051	31542				Egg (disappeared)

162 (P2)	35544 (?M)	36329 (?F)				Chick
163 (P2)	?	?				Empty
164 (P2)	35360	33737	37585			Egg (disappeared)
165 (K2)	29700	?				Chick
166	25437 (M)	34386 (F)				Chick
167	35543	36326				Chick
168 (P1)	?	?				Empty
169	?	?				Empty
170	36378	36380				Egg (disappeared)
171	35529 (M)	36346 (F)				Chick
172	31048	36379				Chick
173	28018	36389				Chick
174	28050 (M)	28071 (F)				Chick
175	25503 (M)	28001 (F)				Egg (disappeared)
176 (K1)	?	?				Empty
177	?	?				Non-breeding
178	36186					Chick
179	37516 (?M)	33481 (?F)				Chick
180	25694 (M)	?				Chick
181	29074 (M)	35204 (F)				Chick
182	29085 (?M)	?				Non-breeding
183 (S1)	37534	38893				Egg (disappeared)
184	?	?				Non-breeding
185 (K1)	?	?				Empty
186	37526	?				Egg (rat predation)
187	38632	31047	31452			Chick
188	34972	27965				Chick
189	36139	38851				Non-breeding
190	34738 (M)	28016 (F)				Chick
191 (P2)	34800 (M)	34800 (F)				Chick
192 (S1)	35187					Non-breeding
193 (K2)	29825	?				Non-breeding
194 (K2)	34720 (?M)	36181 (?F)				Chick
195	?	?				Non-breeding
196	?	?				Non-breeding
197	34660 (M)	36311 (F)				Egg (abandoned)
198	?	?				Non-breeding
199	34730 (?M)	34610 (?F)	38859 (?F)	39421 (?F)		Non-breeding
200	28073 (?M)	34265 (?F)				Chick
201	36373 (?M)	38705 (?F)				Egg (disappeared)
202 (P2)	33375	?				Chick
203	30930 (M)	35233 (F)				Chick
204 (K1)	35000 (M)	32957 (F)				Chick
205	28803 (?M)	38803 (?F)	25697 (?F)	29664 (?F)	39402 (?F)	Chick
206	34382	34936				Chick
207 (P1)	?	?				Empty
208 (P1)	38878	?				Non-breeding
209 (K3)	34374 (M)	34416 (F)				Dead chick
210 (K3)	37568	39447				Non-breeding
211 (K3)	35197	38883				Chick
212 (K3)	27956 (M)	?				Egg (disappeared)
213 (K2)	36369 (?M)	36343 (?F)				Chick
214 (K2)	?	?				Non-breeding
215 (S3)	?	?				Cooks
216 (S3)	35541 (M)	36387 (F)				Chick

217 (K3)	31991	?				Chick
218	38635	?				Non-breeding
219 (P3)	?	?				Non-breeding
220 (P3)	?	?				Non-breeding
221 (P3)	29695 (?M)	39067 (?F)				Chick
222	38866 (M)	34395 (F)				Non-breeding
223 (S3)	33673 (M)	37531 (F)				Chick
224 (P3)	27958 (M)	27992 (F)				Chick
225 (S3)	13634 (?M)	34404 (?F)				Chick
226 (P3)	28385	35252				Chick
227 (K1)	25509 (M)	25407 (F)				Chick
228	38642	33308	33633			Chick
229 (P3)	35531 (?M)	38868 (?F)				Egg (disappeared)
230 (P3)	39301	?				Non-breeding
231 (P3)	?	?				Empty
232	?	?				Empty
233	?	34820 (?F)				Disappeared chick
234	29835	?				Chick
235	?	34387				Non-breeding
236	29027	?				Non-breeding
237	34349 (M)	39415 (?F)				Non-breeding
238 (S1)	35518 (M)					Non-breeding
239	?	?				Non-breeding
240	34276					Chick
241	?	?				Non-breeding
242	?	?				Non-breeding
243	33264 (M)	36367 (F)				Chick
244	38643 (?M)	29841 (F)				Non-breeding
245 (K1)	34753 (M)	33315 (F)				Chick
246 (P3)	37507	37579				Egg (disappeared)
247	?	?				Empty
248	38639	35297				Egg (disappeared)
249	37515 (?M)	37563 (?F)				Chick
250	?	?				Non-breeding
251 (K3)	?	?				Cooks
252	34794 (M)	34852 (F)				Chick
253 (K3)	31023	?				Non-breeding
254 (P1)	?	?				Empty
255 (K2)	34431 (M)	29089 (F)	36822	35160 (?M)		Chick
256	32004	?				Non-breeding
257	39416	34758	38915			Chick
258 (P3)	?	?				Empty
259	33508	?				Chick
260 (S3)	25651 (?M)	14009 (?F)				Chick
261	32021 (?M)	?				Egg (disappeared)
262	34739 (M)	32902 (F)				Chick
263	29073	36339				Chick
264	?	?				Empty
265 (K2)	35300 (M)	29682 (F)				Egg (disappeared)
266	31975 (M)	25444 (F)				Chick
267	29823 (M)	28371 (F)				Infertile egg
268	38626					Non-breeding
269	38555	38862				Non-breeding
270	38864 (M)	33791 (F)				Non-breeding
271 (K1)	37571	38559				Egg (disappeared)

272	?	?				No response
273	?	?				Non-breeding
274	37521 (M)	?				Non-breeding
275	35229 (?M)	39418 (?F)				Non-breeding
276	?	?				Non-breeding
277	39417	33620	39417			Egg (disappeared)
278	34751 (M)	25695 (F)				Chick
279	?	?				Empty
280	?	36184 (F)				Egg (disappeared)
281	32995 (?M)	34733 (?F)				Chick
282	33652 (?M)	33643 (?F)				Chick
283	?	?				Non-breeding
284	32099 (M)	37581 (F)				Chick
285	35218	38566				Chick
286	?	?				Non-breeding
287	33699 (M)	36187 (F)				Chick
288	33671	33705				Chick
289	35536 (?M)	35583 (?F)	36192			Chick
290	35212 (M)	35534 (F)				Chick
291	?	?				Empty
292	?	?				Infertile egg
293	38638	38852				Chick
294	36185 (M)	27984 (F)				Chick
295	29812	33630				Chick
296	32980	37589				Chick
297	28034	33755				Egg (crushed)
298	33646 (?M)	34429 (?F)				Chick
299	34937 (M)	38857 (F)	38629			Chick
300	35232 (?M)	?				Non-breeding
301	33768 (M)	34397 (F)				Chick
302	?	?				Non-breeding
303	?	37514 (?F)				Non-breeding
304	?	?				Non-breeding
305	35244 (M)	33645 (F)				Chick
306	?	?				Empty
307	33796	34876				Chick
308	?	?				Empty
309	33476 (M)	30858 (F)				Disappeared chick
310 (S2)	33276	36392				Chick
311 (S2)	?	?				Cooks
312 (S2)	38867	?				Non-breeding
313 (S2)	34865 (M)	36331 (F)				Egg (disappeared)
314 (S2)	?	?				Empty
315	33714 (M)	33318 (F)				Chick
316	33715 (M)	38746 (F)				Egg (abandoned)
317 (P2)	?	?				Empty
318	25555 (M)	?				Disappeared chick
319	?	?				Empty
320	34941 (M)	39401 (F)				Egg (abandoned)
321	38747					Chick
322 (P3)	38634	?				Egg (disappeared)
323	27526 (M)	?				Non-breeding
324	?	34403 (?F)				Chick
325	38641	28000				Chick
326	?	?				Egg (abandoned)

327 (K2)	34898 (M)	25401 (F)	34257	38623 (M)		Chick
328	33093	33491				Egg (disappeared)
329 (P3)	29665 (M)	33528 (?F)				Chick
330	33090 (M)	33099 (F)				Chick
331	32025 (M)	32924 (F)				Chick
332	?	?				Non-breeding
333	32927 (M)	38631 (F)	29082			Egg (abandoned)
334	39436					Non-breeding
335	28358 (?M)	34379 (?F)				Chick
336 (P2)	?	?				No one home
337 (S1)	?	?				Empty
338	36356	37570				Chick
339	34722 (M)	33493 (F)				Chick
340	35540					Chick
341	?	?				Collapsed
342 (S2)	?	?				Non-breeding
343(S2)	?	?				Empty
344 (S2)	34687	39439				Chick
345	34362	34861				Chick
346	?	?				Non-breeding
347	37513	38877				Non-breeding
348 (P3)	39412	?				Non-breeding
349 (P3)	?	?				Empty
350 (P2)	?	?				Non-breeding
351 (P1)	34266 (M)	34390 (F)				Chick
352	?	?				Non-breeding
353	35545	35545				Chick
354	33480	?				Chick
355	33467 (M)	36191				Chick
356	34580 (?M)	36375 (?F)				Chick
357	38650	?				Non-breeding
358	33474 (?M)	33494 (?F)				Chick
359	32985 (?M)	38556 (?F)				Chick
360	33482 (M)	35237 (F)				Egg (disappeared)
361	14018 (M)	31264 (F)				Egg (crushed)
362 (K1)	34698	37525				Non-breeding
363	33581	36336				Chick
364	34854 (?M)	?				Disappeared chick
365 (K2)	?	?				Empty
366 (K1)	?	?				Empty
367	38628	?				Non-breeding
368	38564	34916	38853	38892		Egg (dead embryo)
369 (S1)	?	?				Empty
370	34355 (?M)	39350				Chick
371	34358	34717				Egg (disappeared)
372	?	?				Non-breeding
373	36153 (M)	36199 (F)				Chick
374	34420 (?M)	38644				Chick
375 (P1)	?	?				Non-breeding
376	36363 (?M)	37520 (?F)				Chick
377	?	?				Empty
378 (K3)	?	?				Empty
379 (K2)	?	?				Joined to 209
380	29960 (M)	27972 (F)				Chick
381	?	?				Empty

382	28362 (?M)	29834 (?F)				Chick
383 (S1)	?	?				Empty
384	?	?				Empty
385	?	?				Non-breeding
386	28352	?				Chick
387 (S3)	?	?				Empty
388	31324	33762				Chick
389	38647	28045	29066			Chick
390	?	?				Empty
391	33244	?				Chick
392 (K1)	?	?				Cooks
393	?	?				Non-breeding
394	34878 (M)	36305 (F)				Chick
395	35242 (M)	38814 (F)				Chick
396	35213 (M)	35243 (F)				Chick
397	?	?				Empty
398	39403	35299				Non-breeding
399 (P1)	35286	38873				Chick
400	28365	28399				Non-breeding
401	34304 (?M)	?				Chick
402	31981 (?M)	36365				Chick
403	37508	?				Chick
404	36357 (M)	29651 (F)				Chick
405	34273	?				Chick
406 (S2)	?	?				Empty
407	33607 (?M)	35284 (?F)				Disappeared chick
408	?	?				Non-breeding
409	36377 (?M)	36399 (?F)				Chick
410	37537	?				Infertile egg
411	?	?				Egg (disappeared)
412	28056	37580				Egg (disappeared)
413 (P1)	34505	37582				Chick
414 (P1)	34317	37583				Chick
415	33246	36163				Egg (disappeared)
416 (S1)	38552	36308				Chick
417	25536 (M)	36321 (F)				Chick
418	37551	38633				Disappeared chick
419	37548	38561				Dead embryo
420	31204 (?M)	39429 (?F)				Infertile egg
421	26955	39428				Disappeared chick
422 (P1)	33369	39431				Chick
423	?	?				Non-breeding
424 (P2)	28353	?				Rat predation

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	2013/14	7	7	8	10
25536	Male	1998/99	2013/14	5	6	14	14
25546	Male	1998/99	2013/14	9	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	2013/14	9	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	2013/14	6	9	9	10
25663	Male	1999/00	2008/09	6	4	7	8
25664	? Female	1999/00	2013/14	9	3	6	10
25669	Male	1999/00	2005/06	2	5	5	5
25673	Male	1999/00	2013/14	9	5	7	7
25677		1999/00	2006/07	1	7	7	7
28085	Male	1998/99	2005/06	1	5		
29027		2008/09	2013/14	1	5		
29098		2008/09	2012/13	1	4		
29912	? Male	2000/01	2012/13	5	5	5	6
29927		2000/01	2013/14	10	9	12	12
29960	Male	1999/00	2013/14	5	9	9	9
29978	Male	1999/00	2013/14	3	9	14	14
30161[1]		2007/08	2009/10	1	2		
30167		2007/08	2012/13	1	5		
30175		2007/08	2013/14	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	2013/14	14	4	5	5
30934		1995/96	2013/14	1	18		
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	2013/14	9	5	6	9
31194	Male	1996/97	2001/02	1	5	5	
31322[2]		2005/06	2009/10	1	3		
31324		2005/06	2013/14	2	7	7	7
31345	? Male	2005/06	2011/12	1	6		
31366	Male	1997/98	2013/14	12	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

[1] 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.

[2] 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.

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		
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	2013/14	7	6	9	10
31495	Male	1998/99	2013/14	10	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	2013/14	6	8	8	8
31542	Male	1998/99	2013/14	12	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[3]		2000/01	2007/08	1	7		
32091		2000/01	2007/08	1	7		
32099	? Male	2000/01	2013/14	7	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	2013/14	6	6	6	6
32957	Female	2001/02	2013/14	8	5	6	7
32979		2001/02	2006/07	1	5		
32980	Male	2001/02	2013/14	3	4	11	11
32985	? Male	2001/02	2013/14	2	11	11	11
32995		2001/02	2013/14	2	11	11	
33003		2001/02	2013/14	3	7	7	7
33015	Male	2001/02	2009/10	3	6		
33035	Male	2001/02	2013/14	6	6	7	7
33052	Male	2001/02	2013/14	7	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[4]		2001/02	2004/05	1	2		
33208[5]	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	2013/14	3	6	10	10
33246		2002/03	2013/14	2	10	10	10
33248	Male	2002/03	2012/13	6	6	8	8
33276		2003/04	2013/14	3	7	7	7
33335	Male	2003/04	2010/11	2	5	7	
33369		2003/04	2012/13	1	9	9	9

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

33375		2003/04	2013/14	5	5	5	5
33376		2003/04	2012/13	2	8	8	
33380		2003/04	2007/08	1	4		
33369		2003/04	2013/14	2	9	8	8
33389		2003/04	2013/14	5	6	6	7
33397	Male	2003/04	2008/09	1	5	5	5
33453		2005/06	2010/11	1	5		
33508	? Male	2005/06	2013/14	2	7	7	7
33518		2005/06	2009/10	1	4		
33528		2005/06	2013/14	2	7	7	7
33530		2005/06	2013/14	4	5	6	6
33540	Male	2005/06	2013/14	3	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	2013/14	4	5	5	5
33581		2005/06	2013/14	3	5		
33589		2005/06	2013/14	4	5	5	5
33591		2005/06	2010/11	1	5		
33596		2005/06	2010/11	1	5	6	
33737	? Male	2002/03	2013/14	4	7	7	7
34273		2004/05	2013/14	3	7	7	7
34276	Male	2004/05	2013/14	4	5	8	8
34299		2004/05	2012/13	2	7	7	7
34304	? Male	2004/05	2013/14	2	8	8	8
34317		2004/05	2013/14	2	8	8	8
34320		2004/05	2013/14	4	5	8	8
34338		2004/05	2013/14	3	5	6	6
34349	Male	2004/05	2013/14	3	7		
34435		2006/07	2013/14	7	7	7	7
34505		2006/07	2013/14	2	6	6	6
34520	Male	2006/07	2011/12	1	5		
34527		2006/07	2013/14	2	6	6	
34553		2006/07	2013/14	1	8		
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	2013/14	3	5		
34610		2006/07	2013/14	1	7		
34615		2006/07	2013/14	1	7		
34621		2006/07	2010/11	1	4		
34624		2006/07	2012/13	1	6		
34660		2006/07	2013/14	3	4	5	5
34687		2006/07	2013/14	1	7		
34698		2006/07	2013/14	2	7		
34804		2004/05	2009/10	2	4	5	5
34808	Male	2004/05	2012/13	1	8		
34820		2004/05	2013/14	3	6	6	
34828		2004/05	2009/10	1	5		
34836		2004/05	2011/12	2	6	7	
34837		2004/05	2013/14	1	9		
34843		2004/05	2013/14	4	5	6	6
34867		2004/05	2011/12	1	7	7	7
34886		2004/05	2013/14	3	7	7	8
34901	? Male	2004/05	2013/14	5	5	7	7
34903	? Male	2004/05	2013/14	4	5	7	7

34916		2004/05	2013/14	1	9		
35131		2008/09	2013/14	1	5		
35160		2008/09	2013/14	1	5		
35186		2008/09	2013/14	2	4		
35189	Male	2008/09	2012/13	1	4		
35187		2008/09	2013/14	1	5		
35193		2008/09	2013/14	1	5		
35360		2008/09	2013/14	1	5		
35361		2008/09	2013/14	1	5		
35380		208/09	2013/14	1	5		
35397		2008/09	2012/13	1	4	4	4
35518		2008/09	2013/14	1	4		
35571		2009/10	2012/13	1	3		
35583		2009/10	2013/14	1	4	4	4
36112	Male	2007/08	2012/13	1	5		
36118		2007/08	2013/14	3	5		
36139		2007/08	2013/14	1	6		
36140		2007/08	2012/13	1	5		
36147		2007/08	2012/13	1	5		
36216		2007/08	2011/12	1	4		
36233		2007/08	2013/14	1	6		
36241		2007/08	2012/13	1	5		
36290		2007/08	2013/14	2	5	6	
36294		2007/08	2013/14	1	6	6	
36474		2009/10	2013/14	1	4		
MEAN (± SEM)				2.7 ± 0.2	5.9 ± 0.2	7.2 ± 0.2	7.4 ± 0.2
30807[6]	Female	1996/97	2009/10	5	9	9	9

[6] 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 (5-10 m)	Deep (>10 m)	Max	Min	Max	Min	Mean (± SEM)
25473	F	146	2843	20.5	7	7	0	6	1	0	18	4	-5.8446	-0.9282	-2.7992 (± 0.7091)
28046	M	81	2085	138.3	75	68	7	55	11	9	40	1	-17.0238	-0.8058	-4.4034 (± 0.0443)
28370	F	81	2857	58.9	53	51	2	45	3	5	76	1	-34.3128	-1.0098	-3.3437 (± 0.7609)
30874	M	66	2835	62.5	48	47	1	45	3	0	40	3	-7.9152	-0.9996	-1.5421 (± 0.1999)
				19.8	26	26	0	26	0	0	6	2	-1.4382	-0.9996	-1.1569 (± 0.0275)
31172	M	68	2825	180.8	22	21	1	20	2	0	13	2	-5.9058	-1.2648	-2.8022 (± 0.2786)
31240	F	69	2838	95.7	44	43	1	23	14	7	50	1	-17.6356	-0.9996	-5.9707 (± 0.6854)
33052	M	31	2856	0.88	5	5	0	4	1	0	31	1	-7.4664	-1.1628	-2.8703 (± 1.2223)
				50.6	51	50	1	32	6	13	71	1	-22.2258	-0.9894	-5.7311 (± 0.8102)
33315	F	245	2839	34.3	5	4	1	5	0	0	5	1	-2.0502	-1.2648	-1.5994 (± 0.1547)
				157.1	164	154	10	133	15	16	78	1	-25.6122	-0.9792	-3.7186 (± 0.3227)
				181.8	119	111	8	105	7	7	38	1	-20.9918	-0.9792	-2.8233 (± 0.2895)
				18.8	21	21	0	15	5	1	20	1	-11.3628	-0.9588	-3.7215 (± 0.6907)
				14.7	10	10	0	8	2	0	16	1	-8.5578	-0.9588	-2.7101 (± 0.7930)
				6.2	8	8	0	8	0	0	1	1	-1.1832	-0.9078	-1.0315 (± 0.0398)
34852	F	252	2082	39.7	9	9	0	7	2	0	25	1	-9.9348	-1.1118	-3.7128 (± 0.9814)
35213	M	396	2083	46.4	24	15	9	18	6	0	33	3	-8.5578	-0.9078	-3.6512 (± 0.4891)
35406	U	131	2827	22.3	3	3	0	3	0	0	5	3	-1.1832	-0.9996	-1.1118 (± 0.0568)
36181	U	194	2845	43.9	19	18	1	17	2	0	20	2	-5.8548	-1.1118	-2.5564 (± 0.3526)
TOTAL				1193.2	713	671	42	575	80	58	78	1	-34.3128	-0.8058	-3.0135 (± 0.3230)
MEAN (± SEM)				119.3 (± 58.0)	71.3 (± 35.0)	67.1 (± 32.9)	4.2 (± 2.1)	57.7 (± 28.4)	8.0 (± 3.9)	5.8 (± 3.0)	58.6 (± 28.2)	3.1 (± 1.5)	-11.3188 (± 2.1218)	-1.0179 (± 0.0204)	

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
25473	F	146	2843	20.5	10.6	9.9	13.3	5.9	13.3	**7.2**	4.6	2.6
28046	M	81	2085	138.3	84.2	54.1	138.0	83.9	138.0	**0.3**	0.27	0.03
28370	F	81	2857	58.9	38.9	20.0	58.4	38.5	58.4	**0.5**	0.4	0.1
30874	M	66	2835	19.8	14.1	5.7	18.7	13.0	18.7	**1.1**	1.0	0.1
				17.7	9.3	8.4	12.6	4.7	12.6	**5.1**	4.6	0.5
31172	M	68	2825	180.8	107.6	73.2	180.6	107.5	180.6	**0.2**	0.15	0.05
31240	F	69	2838	95.7	46.4	49.3	91.8	51.9	91.8	**3.9**	3.8	0.1
33052	M	31	2856	50.6	30.7	19.9	50.3	30.4	50.3	**0.3**	0.2	0.1
				0.88	0.88	0.00	0.86	0.86	0.86	**0.02**	0.02	0.00
33315	F	245	2839	34.3	24.3	10.0	34.2	24.2	34.2	**0.1**	0.07	0.03
				181.8	111.7	70.1	181.0	110.9	181.0	**0.8**	0.77	0.03
				157.1	97.3	59.8	155.3	95.5	155.3	**1.8**	1.77	0.03
				6.2	6.2	0.0	6.1	6.1	6.1	**0.1**	0.1	0.0
				14.7	14.0	0.7	14.2	13.5	14.2	**0.5**	0.49	0.01
				18.8	10.0	8.8	18.7	9.9	18.7	**0.1**	0.08	0.02
34852	F	252	2082	39.7	28.0	11.7	39.3	27.7	39.3	**0.4**	0.3	0.1
35213	M	396	2083	46.4	28.0	18.4	46.3	27.9	46.3	**0.1**	0.05	0.05
35406	U	131	2827	22.3	14.0	8.3	14.9	8.9	14.9	**7.4**	7.0	0.4
36181	U	194	2845	43.9	28.1	15.8	35.9	23.1	35.9	**8.0**	5.0	3.0
TOTAL				**1148.4**	**704.3**	**444.1**	**1110.5**	**684.4**	**426.4**	**37.9**	**30.7**	**7.2**
MEAN (± SEM)				**60.4 (± 13.7)**	**37.1 ± 8.2**	**23.4 ± 5.6**	**58.4 ± 13.9**	**36.0 ± 8.3**	**22.4 ± 5.6**	**1.9 ± 0.6**	**1.5 ± 0.4**	**0.4 ± 0.2**
					61.4%	**38.7%**	**96.7%**	**61.6%**	**38.4%**	**3.1%**	**78.9%**	**21.1%**

Appendix 5

UPDATES OF BLACK PETREL ANALYSES: Chris Francis (9 June 2014)

Francis & Bell (2010) analysed data on the main population of black petrel (*Procellaria parkinsoni*), which breeds on Great Barrier Island. The following material updates some of the analyses of Sections 2.2.3 (concerning census grid counts) and 3 (population modelling) of that report, using additional data collected in the 2010-2014 breeding seasons (where the breeding season including the summer of 2009-2010 is here labelled 2010).

Census grid counts

These counts relate to nine 40 m x 40 m census grids within the 35 ha study area of Francis & Bell (2010) [see their Figure 1]. In each year, each known burrow in each grid was classified as breeding, non-breeding, or empty. Francis & Bell (2010) estimated that, between 2000 and 2009, the total number of burrows within the census grids increased at a rate of 2.2%–3.1% per year. Further, the number of breeders increased at a similar rate because the percentage of burrows used for breeding (which fluctuated between 57% and 69%) showed no significant trend.

With an additional 5 years' data, and some slight revisions of the earlier data, the picture is more complex. Two changes seemed to have occurred around 2005: the number of breeding burrows shifted up from a lower plateau (at about 78) to a higher plateau (at about 92) (Figure 1a) and the rate of increase in the total number of burrows fell markedly (Figure 1b).

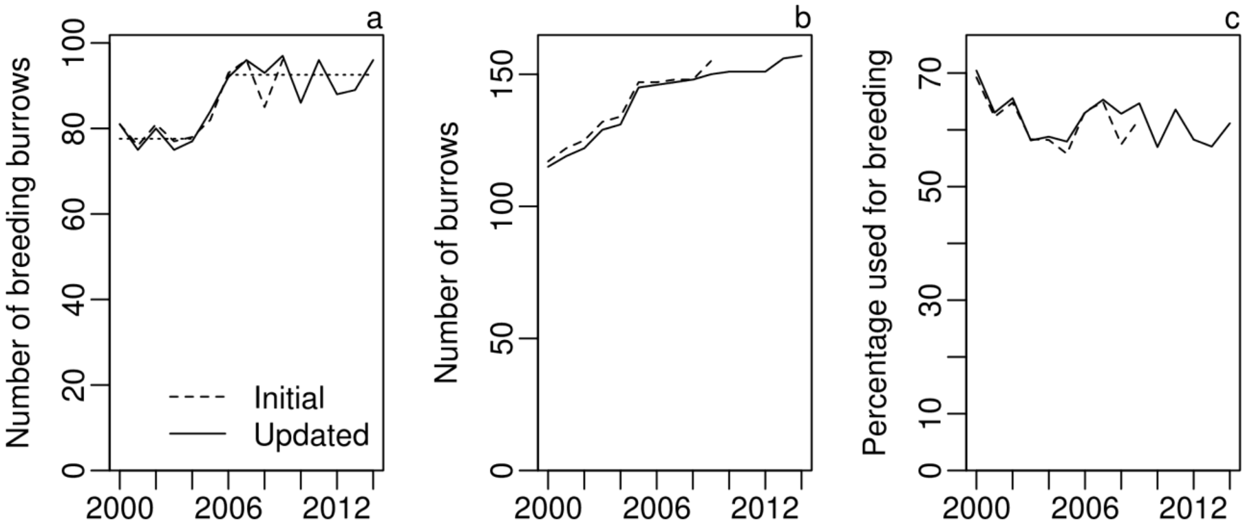


Figure 1: Trends in (a) the number of breeding burrows in the census grids (with the dotted lines showing the two plateaus mentioned in the text), (b) the total number of burrows, and (c) the percentage of burrows used for breeding, as shown in the initial analysis of Francis & Bell (2010) (dashed lines) and the present update (solid lines).

Population modelling

The quantity of black petrel data available for population modelling has increased substantially compared to that used by Francis & Bell (2010). The numbers of banded birds and resightings have both increased by over 60%, and there are now three abundance estimates instead of just one (Table 1).

Table 1: The two types of data used in the population modelling of Francis & Bell (2010) and the present report.

Data type	In original model	Additional in present report
Mark-recapture		
Years covered	1996-2009	2010-2014
Birds banded as chicks	1041	897
Birds banded as adults	1254	502
Number of resightings	3722	2298
Abundance estimates (and c.v.s)		
No. of breeders in 2005	1964 (0.10)	
No. of breeders in 2010		1525 (0.11)
No. of breeders in 2013		3248 (0.10)

The new modelling results presented here use the same model structure as BPET7, the main model of Francis & Bell (2010) [see their section 3.4], which partitioned the modelled population into 15 states (Table 2) and estimated 18 parameters, some of which were time-varying (Table 3).

Table 2: The 15 states in the partition of the population model (in each year every modelled bird is in exactly one of these states).

State *label(s)*	*number(s)*	*Description*
chick	1	Fledgling chicks in the season of their birth
age 1-age 9	2-10	Juveniles of ages 1-9 which have not returned to the breeding area
pbr	11	Pre-breeders: juveniles which have appeared in the study area but have not yet bred
nbr	12	Adults (birds that have previously bred) in the study area which did not breed in the current year
fbr	13	Adults that bred unsuccessfully in the study area in the current year
sbr	14	Adults that bred successfully in the study area in the current year
oth	15	Adults breeding outside the study area

Table 3: A: Parameters, and B: Transition matrix for the population model. Resighting probabilities were assumed to be zero for juveniles, and for adults in state oth. Most parameters were treated as time-invariant, but annual values were estimated for all resighting parameters as well as those for adult survival (nbrsurv, brsurv), except that survival rates for the last year (which are confounded with the resighting rates for the same year) were assumed equal to those for the previous year. Details of how each component of the transition matrix was calculated from the model parameters are given by Francis & Bell (2010).

A: Parameters

Parameter	Description
N0	Initial (1996) size of the adult population in the study area
P1stapp6	Probability a bird first appears as an adult in a breeding colony at age 6, given that it survives to that age
oddsmult	Slope of linear relation between logit(P1stappa) and age a
Pappstd	Probability, for a chick banded in the study area and surviving, that their first appearance in a breeding colony be within the study area
Pbr1st	Probability, for a chick that survives to breed, that it will breed in the first year it appears in a breeding colony as an adult (i.e. it is never a pre-breeder)
Pbrstd	Probability, for a pre-breeder in the study area that survives to breed, that breeding will happen in the study area
Tpbrbr/Tnbrbr/Tfbrbr/Tsbrbr	Probability that a pre-breeder/non-breeder/failed breeder/successful breeder in the study area in one year will breed the next year, given that it survives
Psuccess	Probability that a bird that breeds is successful (produces a fledgling)
juvsurv/nbrsurv/brsurv	Annual probability of survival for juveniles and pre-breeders/non-breeders/breeders
Prpbr/Prnbr/Prfbr/Prsbr	Probability of resighting a pre-breeder/non-breeder/failed breeder/successful breeder

B: Transition matrix

	chick	age1	age2	age3	age4	...	age9	pbr	nbr	fbr	sbr	oth
chick	0	1	0	0	0	...	0	0	0	0	0	0
age1	0	0	1	0	0	...	0	0	0	0	0	0
age2	0	0	0	1	0	...	0	0	0	0	0	0
age3	0	0	0	0	Pjv4	...	0	Pbr4	0	Pfbr4	Psbr4	Poth4
...	...	...	...	...	...	...	...	...	...	...	...	...
age8	0	0	0	0	0	...	Pjv9	Ppbr9	0	Pfbr9	Psbr9	Poth9
age9	0	0	0	0	0	...	0	0	0	Pfbr10	Psbr10	Poth10
pbr	0	0	0	0	0	...	0	Tprbpbr	0	Tpbrfbr	Tpbrsbr	Tpbroth
nbr	0	0	0	0	0	...	0	0	Tnbrnbr	Tnbrfbr	Tnbrsbr	0
fbr	0	0	0	0	0	...	0	0	Tfbrnbr	Tfbrfbr	Tfbrsbr	0
sbr	0	0	0	0	0	...	0	0	Tsbrnbr	Tsbrfbr	Tsbrsbr	0
oth	0	0	0	0	0	...	0	0	0	0	0	1

An important aspect of the model, and a major component of uncertainty in the modelling (see below), is that it attempts to cover all birds in the colony, although the available observations are for the study area only. Thus the last state in the partition contains adults that breed outside the study area. It is assumed that, at first breeding, each bird makes a choice of whether to breed inside or outside the study area, and they remain faithful to that decision for the rest of their lives.

With the additional data, there have been changes in the estimated probabilities of survival and resighting (Figure 2) and transition (Table 4). It is notable that changes in parameter estimates are least for breeders, somewhat greater for non-breeders, and greatest for pre-breeders. Changes in estimated ages at first breeding are relatively small (Figure 3).

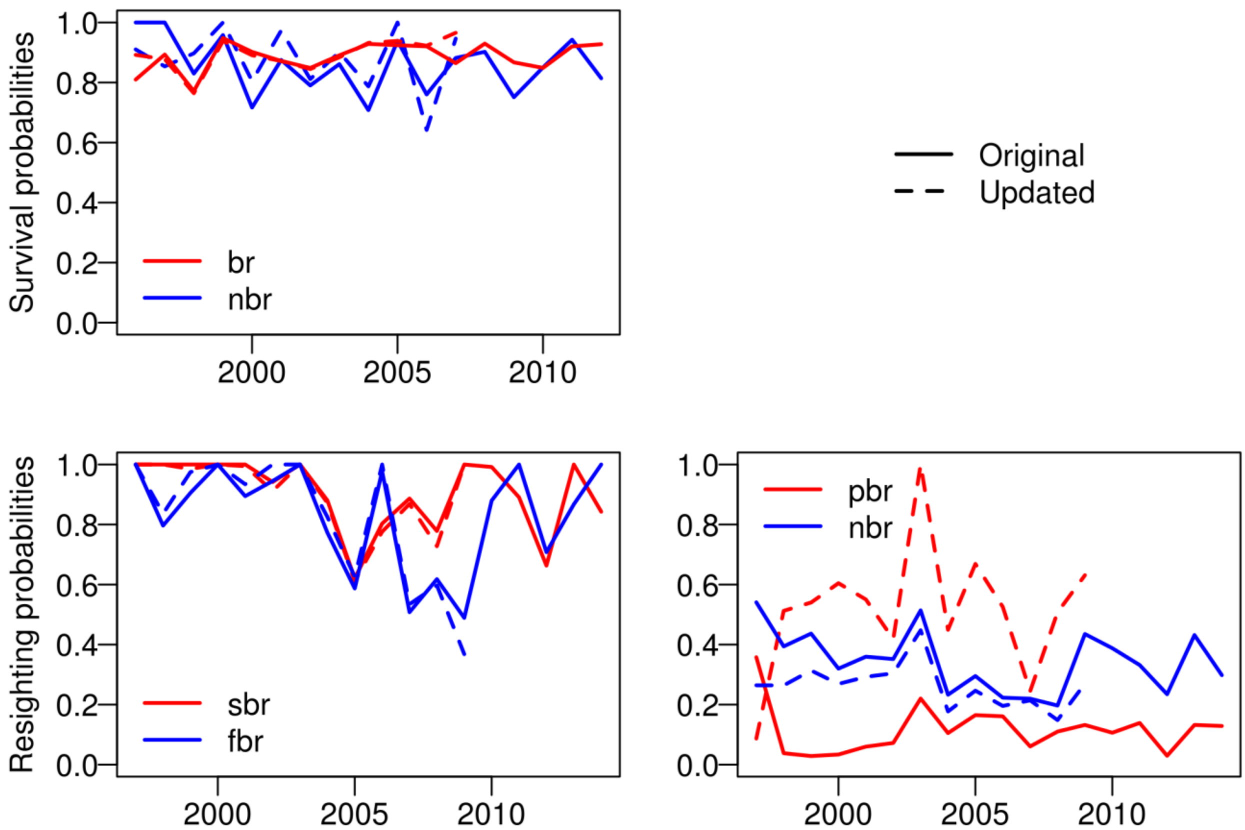


Figure 2: Estimated probabilities of survival (upper panel) and resighting (lower panels) from the original and updated population models. Survival rates labelled 2000 refer to the period between observations in 2000 (the 1999–2000 season) and 2001 (the 2000–01 season etc.).

Table 4: Original and updated estimates of the pre-breeder and adult parts of the transition matrix (note that the probabilities in each row sum to 1 and that components given as '0' are zero by definition).

	Original					Updated				
	pbr	nbr	fbr	sbr	oth	pbr	nbr	fbr	sbr	oth
pbr	0.24	0	0.12	0.40	0.25	0.80	0	0.05	0.15	0.01
nbr	0	0.57	0.10	0.33	0	0	0.42	0.14	0.44	0
fbr	0	0.21	0.18	0.60	0	0	0.23	0.19	0.59	0
sbr	0	0.15	0.20	0.65	0	0	0.15	0.21	0.64	0

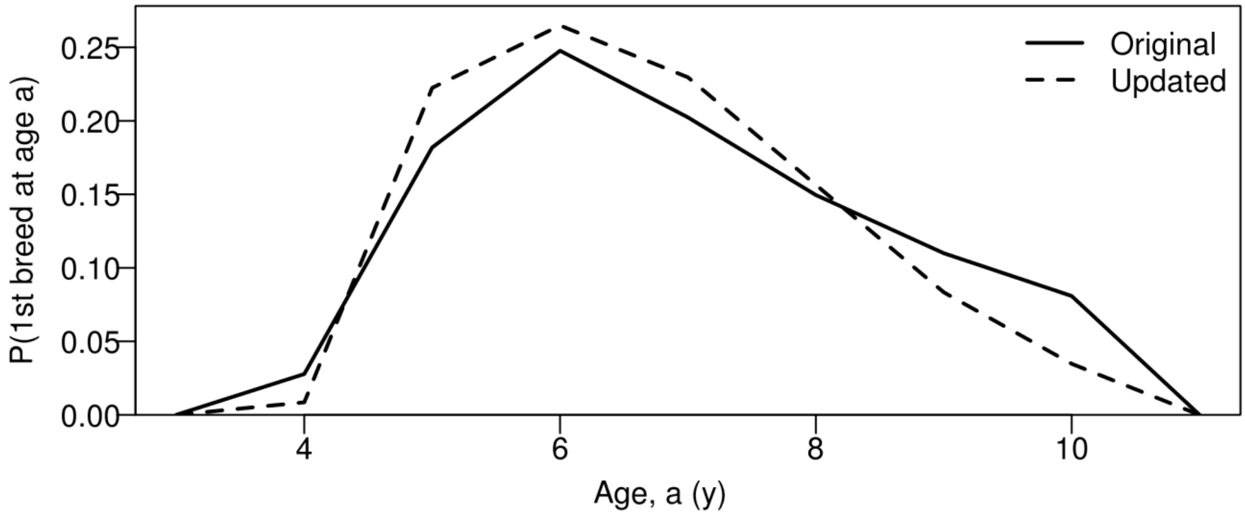


Figure 3: Original and updated estimates of the distribution of age at first breeding.

Looking at some key demographic parameters in Table 5, it again stands out that those that have changed most concern the juvenile and pre-breeding life stages. The changes for the pre-breeder stage are related to small samples sizes: the number of banded birds that had been resighted as a pre-breeder, and subsequently as a pre-breeder, was only 22 in the original data set, but is now 46.

The major uncertainty concerns the probability of juvenile survival. Only about 7% of birds banded as chicks are ever resighted and, as noted by Francis & Bell (2010), it is difficult for the population model to determine whether this is because of low juvenile survival, or because only a low proportion of surviving chicks breed in the study area. Thus it is not surprising that when the update reduced the estimated juvenile survival rate from 1.00 to 0.92, it increased the percentage of survivors breeding in the study area from 68% to 96%. Francis & Bell (2010) found that a profile on the juvenile survival parameter was a useful way to explore this uncertainty.

Table 5: Original (Francis & Bell, 2010) and updated (this report) estimates of selected black petrel demographic parameters (calculated from the model parameter estimates).

Parameter		*Original*	*Updated*
Mean age of first breeding		6.7 y	6.9 y
Mean time spent as a pre-breeder		1.2 y	3.0 y
Percentage of birds that skip the pre-breeder stage		2.9 %	3.1 %
Of birds that appear in the study area and survive to breed the percentage that breed in the study area		68 %	96 %
Average annual survival rates:	juveniles	1.00 y^{-1}	0.92 y^{-1}
	non-breeding adults	0.88 y^{-1}	0.86 y^{-1}
	breeding adults	0.89 y^{-1}	0.89 y^{-1}
	all adults	0.89 y^{-1}	0.88 y^{-1}
Percentage of adults breeding in any year		72 %	77 %
Percentage of breeding attempts that are successful		77 %	76 %

Profile on juvenile survival

An updated profile on the juvenile survival parameter showed that additional data considerably reduced the uncertainty about this parameter, with the 95% confidence interval changing from (0.74, 1.00) to (0.85, 0.98) (Figure 4A). As before, changing *juvsurv* within its confidence interval has little effect on some parameters, like the age at first breeding (Figure 4B) and adult survival rates (Figure 4C,D), but it still has a strong effect on the estimated population trajectory (Figure 5). The average rate of change in number of breeders between 1996 and 2014 for the three values of *juvsurv* are -2.3% y^{-1}, +0.6% y^{-1}, and +2.5% y^{-1} (for *juvsurv* = 0.85, 0.92, and 0.97 respectively).

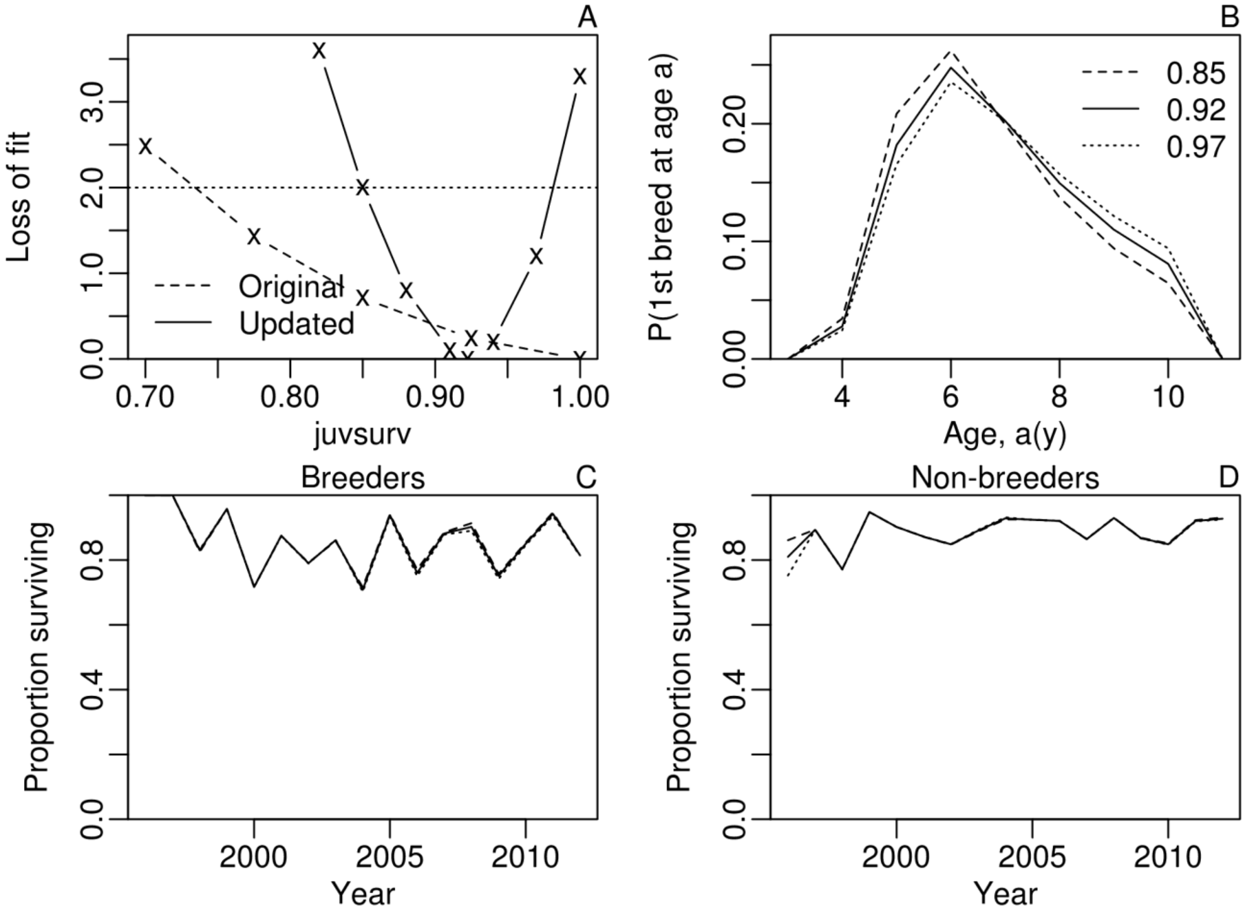


Figure 4: Profile on juvenile survival and its relationship to other parameters; A: profiles on *juvsurv* from original (broken lines) and updated (solid lines) models (the horizontal dotted line defines inferred 95% confidence intervals for *juvsurv*); B: estimated distribution of ages at first breeding for three values of *juvsurv* (0.85, 0.92, 0.97); C & D: estimated survival for breeders and non-breeders for same three values of *juvsurv*.

It is striking that the model is unable to fit the low 2010 abundance estimate for any value of *juvsurv*. Adding time variation to some transition parameters increased year-to-year variability in the trajectory (as it did in the original analysis - see figure 29 of Francis & Bell 2010), but it made little difference to the model's inability to fit the 2010 abundance estimate.

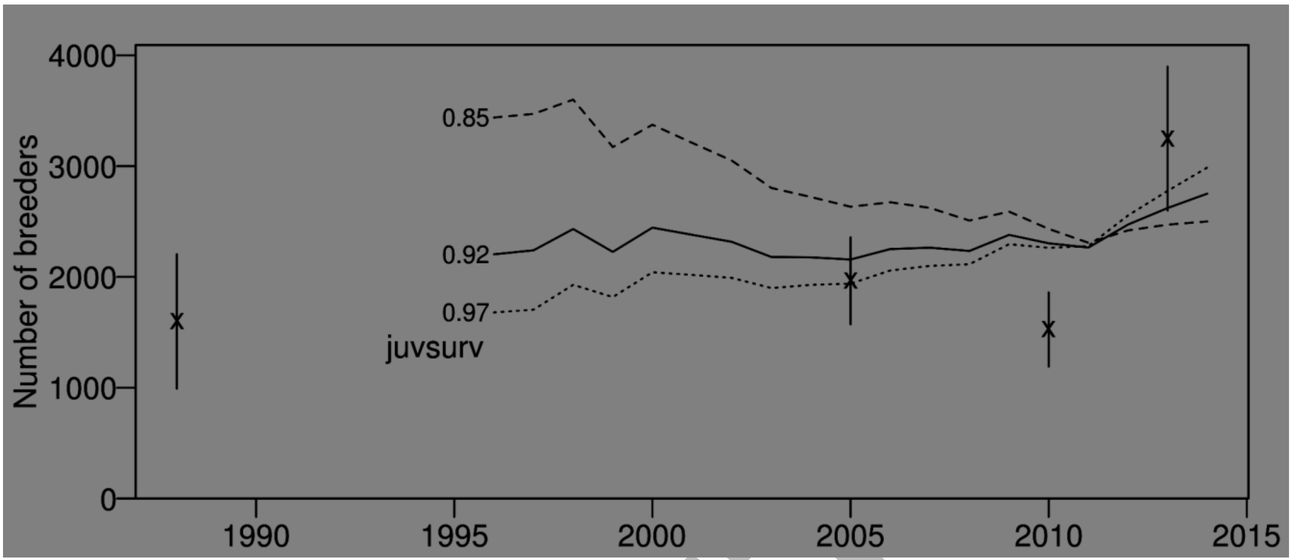


Figure 5: Estimated population trajectories (number of breeders in the study area) for three values of parameter *juvsurv* (0.85, 0.92, 0.97). Also shown are four abundance estimates ('x') and their 95% confidence intervals (vertical lines). The 1988 abundance estimate - calculated from the data of Scofield (1989) [it is the 'restricted' estimate in table 2 of Francis & Bell (2010)] - is included for reference only; it was not used in the population model because of uncertainty about its comparability with the later estimates.

Conclusions

The additional data has allowed us to update some key demographic parameters (Table 5). However, it has not provided a clear picture of population trend.

The two count data sets are contradictory: the census grid data suggest that the breeding population increased by about 18% around 2005, but has been stable since (Figure 1A), whereas the abundance estimates suggest a drop of 22% between 2005 and 2010, and then a huge rise of 113% in the 3 years between 2010 and 2013 (Table 1). Because of uncertainty in the juvenile survival rate the model estimates a rate of change between -2.3% y^{-1} (if *juvsurv* = 0.85) and 2.5% y^{-1} (if *juvsurv* = 0.97). If we assume that juvenile survival is unlikely to exceed the value of 0.88 estimated for all adults, then the upper bound on the rate of change reduces to -1.1% y^{-1}. Thus, with this assumption the conclusion from the model is that the breeding population is slowly declining.

References

Francis, R.I.C.C.; Bell, E.A. 2010. Fisheries risks to the population viability of black petrel (*Procellaria parkinsoni*). *New Zealand Aquatic Environment and Biodiversity Report No. 51*.

Scofield, R.P. 1989. Breeding biology and conservation of the black petrel (*Procellaria parkinsoni*) on Great Barrier Island. 69p. Unpublished MSc (Zoology) thesis, University of Auckland, Auckland, New Zealand.