Population parameters of the black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island), 2009/10.

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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 2009/10 breeding season, 393 study burrows within the 35-ha study area near Mount Hobson were checked and intensively monitored. Of these, 244 were used by breeding pairs, 99 by non-breeding adults and the remaining 50 burrows were non-occupied. By 9 May 2010, 158 chicks were still present in the study burrows and 22 had already fledged, corresponding to a breeding success of 74%. Nine census grids were monitored within the study area and accounted for 155 of the inspected burrows and 152 study burrows, with 88 burrows being used for breeding. Forty-one chicks from earlier breeding seasons were recaptured within the Mount Hobson colony area this season (a total of 94 'returned chicks' have been caught since the 1999/2000 season). Twenty-six random transects were surveyed in the study area and when compared with transects conducted in the 2004/05 season showed an apparent 22% decline over that period. Modelling of the black petrel population on Great Barrier Island (Aotea Island) was updated and indicated the population trend may lie anywhere between -2.4% and +1.6% per annum, the certainty driven primarily by uncertainty over juvenile survival. Analysis of the census grid and transect data estimated the black petrel population from the 35-ha area around Mount Hobson to be in the range of 2781 to 3287 birds.

Keywords: black petrel, *Procellaria parkinsoni*, monitoring, population estimate, breeding success, predation, 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 2009/10 breeding season was a continuation of the survey and monitoring study begun in 1995/96 (Bell & Sim 1998a, b, 2000a, b, c, 2002, 2003a, b, 2005; Bell et al. 2007, 2009; Bell et al. in press), adding to the baseline data on the Great Barrier Island black petrel population. Field work carried out in 2006/07 season was privately funded and has not been reported in the DOC publication format. The annual report for that season can be obtained from the lead author (EAB). Mark-recapture, breeding and population data from the 2006/07 season has been included in this (2009/10) report. This study will assist in identifying effects that long-line and other fishing types, rat and cat predation and habitat disturbance may have on the population and build on the earlier data (Bell et al 2009). The population estimate and population trend data has been updated, ensuring that any population changes will be detected in time to implement the appropriate management strategies.

2. Objectives

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

In summary, the study objectives were to:

- 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 2009, January/February 2010 and all remaining fledglings during May 2010.
- Collect data that will allow estimation of population size and trends.
- 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.

- Determine a population estimate by extrapolating from random transect lines and census grids to the main Mount Hobson breeding area.
- Compare random transect data collected in 2004/05 season with those surveyed in the 2009/10 season results to determine population trend.
- Continue the mark/recapture programme and band as many birds as possible during the breeding season to determine juvenile (pre-breeder) survival, age of first return to the natal colony, age of first breeding attempt, age of first successful breeding attempt and adult (breeder) survival.
- Update and build on Seabird Modelling results (using data between 1996 to 2009) using the population and mark/recapture data collected this 2009/10 breeding season to determine population trends
- 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.

3. Methods

3.1 Study burrows

The study area (35 ha at and around the summit of Mount Hobson; Fig. 1) was visited three times during the breeding season; 3-14 December 2009. During this visit the study burrows (n = 393, Figs. 1-4) were either randomly selected from those along the track system (i.e. within 10 m of either side), burrows that have 'returned chicks' (pre-breeders) resident, or all burrows within the nine census grids. The study burrows have been selected regularly since 1995/96 season (Bell & Sim 1998a, b, 2000a, b, c, 2002, 2003a, b, 2005; Bell et al. 2007; Bell et al. 2009; Bell et al. in press). 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 (22 January-15 February 2010) 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 (6-10 May 2010). All remaining fledgling chicks were banded. This information was used to determine breeding success.

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

3.2 Census grids

The three original grids (KDG1, PTG1 and SFG1) were established in 1996 (Bell & Sim 1998a). These grids were located in areas that had a known historical presence of black petrels, different strata, vegetation types and topography and were near known petrel launch sites (Bell and Sim 1998a). These original grids were replicated in 1998 (KDG2, PTG2 and SFG2) and in 1999 (KDG3, PTG3 and SFG3) to compare burrow densities between areas and to increase the accuracy of the population estimate (Bell and Sim 2000a, b).

These nine census grids (each 40 x 40 m) set up around Mount Hobson were systematically searched (at 1 m intervals) during the December 2009 visit and again in February 2010 by authors (EAB and JS) using Maddi (a Department of Conservation qualified bird dog owned by JS) to locate any new burrows and to determine occupancy rates (Figs. 1-4). The same procedure as for study burrows (see section 3.1) was followed for all birds in the burrows in the grids.

3.3 Transects

The transect survey of 2004/05 breeding season (Bell et al. 2007) was repeated in 2009/10 breeding season. Twenty-six random transects were completed during the 2009/10 breeding season to determine burrow density throughout the study site (Fig. 5). Sixteen of these transects (LT7, LT9, LT12, LT18, LT36, LT37, LT38, LT45, LT49, LT67, LT72, LT85, LT106, LT107, LT112 and LT115) were randomly selected as new this season and the other ten (LT6, LT8, LT10, LT11, LT17, LT18a, LT19, LT25, LT38a and LT41) were randomly selected from the 2004/05 breeding season transects. All transects were surveyed using the same methods as given in the 2004/05 breeding season report (Bell et al. 2007). Any burrows located within the search area were treated in the same manner as given in the 2004/05 season report (Bell et al. 2007) and the same procedure as outlined in Section 3.1 was followed for any bird caught in the transect burrows.

Four grades of petrel habitat 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. in press).

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. in press).

This season's transect data was compared to the previous transect results from the 2004/05 breeding season (Bell et al. 2007, Francis and Bell 2010) to determine population trends.

3.4 Night banding

Night work was undertaken during the December 2009 and January/February 2010 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 2009 visit, sex was determined (if possible) by cloacal inspection.

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 (Bell & Sim 1998a, b, 2000a, b, c, 2002, 2003a, b, 2005). This is because the original census grids were 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 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.

Population trends were measured using multi-state models to determine probability of changing states from successful or non-successful breeder to non-breeder: S(.) *P*(.) psi(breeder to non-breeder*t), where S = survival rate, *P* = probability of recapture, Psi = transition probability and t = time using five states (unknown status, successful breeder, unsuccessful breeder, chick, non-breeder). Adult survival was assumed to be constant and the probability of survival of chicks was set at 0.5 for the first 3 years and then 0.9 thereafter. These parameters were calculated by the Burnham Jolly Seber model. All parameters were determined using Program MARK (http://welcome.warnercnr.colostate.edu/~gwhite/mark/mark.htm). The goodness of fit of the models (i.e. likelihood value) was measured using Aikekes Modified Information Criterion (AICc). Models with lower AIC are better that those with higher AIC, i.e. it is more likely that the model fits the population and is likely to be an accurate explanation of, or value for, the parameter (such as survival)

3.7 SEABIRD model update

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). These results have been updated and reanalysed incorporating this season's study burrow population and transect data. These updated results are compared with Program MARK estimates.

4 Results

4.1 Study burrows

Within the 393 study burrows (those burrows that could be accessed to determine occupancy out of the 400 numbered burrows in the 2009/10 season), 244 contained breeding birds, 99 contained non-breeding birds and 50 were non-occupied (Appendix 1, Tables 1 and 2). There were 64 failures (e.g. loss of eggs, infertility, predation, etc., Table 2). This corresponds to a breeding success of 74% (Table 2, Fig. 6).

Table 1 shows the percentage of occupied and non-occupied burrows within the study burrows and the percentages of non-occupied, breeding and non-breeding burrows. Data from the past twelve breeding seasons shows the ratio of breeding to non-breeding burrows has averaged 3:1, but the number of occupied to non-occupied has varied greatly (Bell & Sim 2000a, b, c, 2002, 2003a, b, 2005; Bell et al 2007, 2009; Bell et al. in press; Bell et al. in prep). However, the last three seasons have all had similar numbers of occupied and non-occupied burrows (Table 1) and this season had the lowest proportion of burrows used for breeding since the study began (62%, Table 1). Table 2 shows the failures and overall breeding success rate within the study burrows since 1995/96.

Figure 6 shows the trend in the numbers of non-occupied, breeding and non-breeding burrows since the 1998/99 breeding season. It appears that breeding success has been slowly increasing despite the number of burrows being used for breeding reducing slightly over the same time (Fig. 6). The mean annual breeding success (1998/99 to 2009/10) within the study burrows is 75% (± 1, Table 1).

4.2 Number of burrows in the census grids

A total of 155 burrows were found in the nine census grids (Appendix 1, Table 3, Figs 2-4) in the 2009/10 breeding season. Of these, 88 burrows were used by breeding pairs, 41 were used by non-breeding adults and 26 burrows were non-occupied (Table 3). Figure 7 shows the trend in the number of non-occupied, breeding and non-breeding burrows in the census grids since the 1995/96.

The number of burrows in the census grids has increased over the length of the study (Fig. 8). Francis and Bell (2010) inferred that this increase in the number of burrows found in the grids between 1999/2000 and 2008/2009 corresponded to an increase in the breeding population of between 2.2 and 3.1% per annum. This calculation was reassessed using the entire data set of breeding burrows (1999/2000 to 2009/10) and resulted in a lower estimate of between 1 and 1.5% increase per annum (further details available in Appendix 2). Figure 9 shows the trend in the total number of burrows, total number of burrows used for breeding and annual breeding success in the census grids.

There were also several 'potential' burrows within the grids, which were not included in any burrow estimate. '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 2009/10 season, 636 adults were identified. Of these, 529 were already banded and 107 were banded this season (Appendix 1, Table 4). There were 158 chicks still present in the study burrows during the May visit and these were banded (Appendix 1, Table 4). Twenty-two chicks had already fledged. Thirteen additional chicks in non-study burrows were also banded (Table 4).

There have been 2042 chicks banded within the study area between 1995 and 2010 (Table 4 and 5) and these birds have begun to return to the colony as pre-breeders, non-breeders and breeders (n=94, Table 5, Appendix 3). The proportion of 'returned chicks' from each season varies from 0 to 13% (mean ± SEM = 6 ± 1); the highest proportion of chicks recaptured were banded in the 1998/99 season (Table 5). Figure 10 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 41 (between 1999/00 and 2009/10, Table 6).

There were 41 'returned chicks' recaptured at the colony this season (Table 6); of these, 25 attempted to breed, with 12 successfully raising chicks of their own. The remaining 16 did not breed, although several males were recaptured while calling to attract a mate. Figure 11 shows the total number of 'returned chicks' and number that were caught breeding and non-breeding each season.

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, 95 'chicks' have been recaptured as pre-breeders, non-breeders or breeding adults (Table 5); 94 from chicks banded on Great Barrier Island and one from Little Barrier Island (Appendix 3). The number of times 'chicks' have been recaptured ranges from 1 to 10 (mean ± SEM = 2.3 ± 0.2, Appendix 3). The frequency of first recapture of each age class is given in Figure 12. Although the youngest age at first return is 3 years, the mean age ± SEM at first return is 5.5 ± 0.2 (Appendix 3, range 3 to 10 years). Forty-seven of these 'returned chicks' have attempted to breed over eleven seasons (1999/2000 to 2009/10, Bell & Sim 2002, 2003a, b, 2005; Bell et al 2007, 2009, in press), with 38 breeding successfully over this period (Appendix 3). This means the age at first breeding attempt ranges from 5 to 10 years (mean ± SEM = 6.6 ± 0.2) and the age at first successful breeding also ranges from 5 to 10 years (mean ± SEM = 6.9 ± 0.2, Appendix 3).

4.4 Survival estimates and recapture probabilities

Bell et al. (in press) noted that there was a confounding influence in estimating adult survival using a sex-based model as there was a recapture probability difference between male and females. These tests were repeated this season using updated sex information (n=609 black petrels of known sex) and the results were very similar; Cormack Jolly Seber (CJS) survival models comparing two sexes; Phi(sex*t) *P*(t) (adult survival and recapture probability vary with sex and time) and Phi(t) *P*(sex*t) (recapture probability vary with time) where Phi=apparent survival, sex=sex of the bird, t=time, *P*= probability of recapture) only had AICc values that differed by less than 0.16.

Using data from 1995/96 to 2009/10 and the Cormack Jolly Seber adult survival model that takes into account the difference in recapture rates for sexed birds, Phi(t) *P*(sex*t), the mean adult survival was 0.9033 ± 0.03 (Table 8). Figure 13 shows a slight decline in adult survival over this study, but as noted in previous reports this may be due to poor survival over 2003/04, 2005/06 and 2006/07 seasons or low recapture rates during these seasons (Bell et al 2009; Bell et al. in press).

4.5 Transect data

Twenty-six random transects were surveyed within the study area (Fig. 5, Table 9). They ranged in length from 130 m to 400 m, and between 3 and 25 burrows were located in each (Table 9).

Using the transect data, four burrow density grades with corresponding habitat types were identified within the 35-ha study area:

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

Using Manifold™, vegetation and terrain survey data and ranking transects, the two-dimensional area for each of the habitat types in the 35-ha study area was found to be 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 (Fig. 5).

The transects were stratified into habitat grades along the length of the transect and the burrows along the length were assigned to the relevant habitat grade (Table 9).

4.6 Population estimate from census grids and 2009/10 transect data

As stated in previous reports (Bell et al 2007, 2009; Bell et al. in press), the original population estimates determined in earlier reports by extrapolating from the nine census grids only are suspected to overestimate the population size (Bell & Sim 1998a, b, 2000a, b, c, 2002, 2003a, b, 2005). This is due to the fact that 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.

As such, the population estimate for the 35-ha study area was determined by extrapolating from transects and census grid data after stratification of the 35-ha study area into four habitat grades. The population estimate for the 2009/10 burrow-occupying black petrel population was between 2781 and 3287 adults (3034 $\pm$ 253 birds, Tables 9 and 10), consisting of 916 $\pm$ 60 non-breeding adults and 2118 $\pm$ 193 breeding adults (i.e. approximately 1059 breeding pairs).

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

A random transect survey was completed in 2004/05 and repeated again in 2009/10 to determine population size and trends of the black petrel breeding population around the 35-ha Mt Hobson study area. There were a total of 298 burrows found in transects from 2009/10 compared to 191 from 2004/05 (Table 11, Bell et al 2009). There was nearly an 800% increase in the total number of burrows located in the low habitat between 2004/05 (n = 5) and 2009/10 (n = 39, Table 11) and over 1000% increase in the total number of empty burrows located (n = 9 in 2004/05 and n = 106 in 2009/10, Table 11).

The 2009/10 breeding population estimate calculated from the random transects was 22% lower than the 2004/05 estimate in Francis and Bell (2010, Table 12) which is a marginally significant change ($Z = (1964-1525)/(204^2+170^2)^{0.5} = 1.65$, $P = 0.098$, two-sided test). It was also 5% less that the 1988 estimate of 1598 based on data collected by Scofield (1989). However the number of breeding burrows per hectare located within the low-grade habitat increased by 244% (from n=4.9 to n = 12, Table 12). Breeding burrows in medium and high density areas decreased by 56% and 81% respectively (Table 12). Further details can be found in Appendix 2.

4.8 Population trends and modelling using Program SEABIRD

The population model in Francis & Bell (2010) was updated to include the 2009/10 mark/recapture data and the 2009/10 population estimate from random transects surveys. The additional data made little difference to the estimated probabilities of survival, re-sighting or transition parameters. The estimated mean age at first breeding dropped from 6.7 to 6.6 years. Complete details of these analyses are given in Appendix 2.

Using the outcome of active nests within the 35-ha study area, the probability of transition between one breeding state to another was calculated. Four states were identified: successful breeder, failed breeder, non-breeding bird and pre-breeder. The probability of either a successful breeder or an unsuccessful breeder changing to a non-breeder was 0.37 (37%, Table 13). If a bird does skip a year, it is more likely to be a successful breeder in the following year (36% compared to 10%, Table 13). Interestingly pre-breeders were more likely to attempt to breed (51%, with most being successful breeders, 40%) as become non-breeders (26%) or remain pre-breeders (23%, Table 13).

Updating the model made little difference to estimates of most parameters (such as adult survival and age at first breeding). Juvenile survival estimates showed the greatest uncertainty and when this was explored, gave a wide 95% confidence interval for this parameter of 0.67 to 0.91 (Appendix 2). This uncertainty lead to uncertainty in the estimation of population growth, with a mean rate for population growth over the modelling period ranging from -2.5% per year (if juvenile survival = 0.67) to +1.6% per year (if juvenile survival = 0.91, Appendix 2).

5 Discussion

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

5.1 Breeding success

In the 2009/10 breeding season, there were 180 breeding successes and 64 breeding failures, equating to an overall breeding success rate of 74% (Table 2). This breeding success is similar to the previous two breeding seasons (76% and 77%, Table 2) and it is equal to the mean (75 ± 1%) of the overall study. 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 dead embryos, crushed eggs and disappeared eggs was higher this season than previous years (Table 2). Six of the eggs containing dead embryos had been abandoned once the eggs began to decompose. Ten eggs also had chicks that were unable to complete hatching as these dead embryo incidences were pipping eggs. The level of crushed eggs may relate to the competition over burrows as adults continue to fight over very good burrows in some locations of the colony (EAB pers. obs.). There were a high number of dead chicks; six of these were healthy chicks in the last check in February 2010, but were dead when the final check was completed in May 2010. It was not possible to determine causes of mortality for most of these chicks; although one case were trauma from one adult standing on the chick and another was starvation as one adult was found dead earlier in the season and it is not possible for one parent alone to successfully raise a chick (Warham 1996). There were no cases of disease (avian pox) this season (EAB, pers. obs.).

The level of egg abandonment was low (n = 3). This was lower than the previous two seasons (Table 2) and is still thought that this may be related to handler disturbance or the age of the birds as younger birds seem to be less experienced in successfully incubating eggs to hatching (EAB, pers. obs.).

It should also be noted that 22 chicks were assumed to have fledged before the May 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 any of these chicks had died or been predated earlier in the season, this would reduce the breeding success to 65% (which would then make it the lowest breeding success rate of the study, Table 2). This breeding success rate is high compared to many other seabird species (such as Westland petrel (*Procellaria westlandica*) 39-50%, Freeman & Wilson 2002, Warham 1996), but the apparent juvenile survival estimate (0.46 $\pm$ 0.03 for the first three years) suggests that as many as 50% of these fledged chicks will not survive their first three years.

Eight eggs were predated by rats (3% of all breeding attempts) within the study burrows and 20 eggs (8% of all breeding attempts) disappeared (but may have been predated by rats or crushed by parents, Table 2). There were no feral cat predation events recorded within the study burrows this season; however one juvenile petrel inside the study area, but not in study burrows and four chicks outside the study area were predated by feral cats (including two much lower down below the study area). All of these juvenile petrels appeared to have been predated when outside the burrow (stretching wings, attempting to fledge at a launch site, etc.) as their bodies 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). Fourteen chicks are known to have been predated by cats between 1996/97 to 2007/08 seasons (Table 2). It is, therefore, important to continue cat trapping in the area before, during and after the black petrel breeding season.

Despite the drop this season, the number of burrows used for breeding has stabilised since the 1999/2000 season (Fig. 6), breeding success has remained high since 1998 – within a range of 67% to 83% - and appears to be increasing (Table 2, Fig. 6). Analysis of adult recaptures found a 15% rate of skipping from successful breeding to non-breeding status as well as a further 22% rate of skipping from unsuccessful breeding to non-breeding status; however if a bird does skip a year, it is likely to breed successfully (36%) rather than unsuccessfully (10%) the following year (Table 13). Interestingly, by adding the latest two years data to the dataset (1995/96 to 2009/10), over half the non-breeding birds of one year will remain non-breeding birds in year two (Table 13) compared to earlier analysis of the dataset (1995/96 to 2007/08) where only quarter of the birds remained non-breeders (Bell et al. in press). Skipping and subsequent improvement of breeding chances 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 number of burrows used by non-breeding birds or remaining non-occupied increased this season (Fig. 6), but this could be related to the condition of some study burrows. Three study burrows deteriorated this season to become unsuitable for breeding (without additional excavation by the birds). The resident birds from these burrows were either not recaptured or had moved to another burrow nearby. 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.

Despite the small drop this season, it appears that the percentage of burrows used for breeding has remained relatively constant over the past twelve breeding seasons (mean 67%, Tables 1 and 2) whereas the percentage of non-occupied and non-breeding burrows has fluctuated from year to year (Table 1). This may mean that once a pair begins to breed they are more likely to remain as a breeding pair and attempt to breed rather than skip breeding (i.e. become non-breeders) and that the number of non-breeding or pre-breeding birds in the study area varies each season. It is also possible that as 46% of non-breeding birds and 51% of pre-breeders become breeding birds the following year (Table 13), 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).

Using data from the past twelve breeding seasons (since 1997/98) the proportion of non-occupied study burrows has been slightly increasing, although it has fluctuated in more recent years (Table 1, Fig. 6). This may be directly related to handler disturbance, observation hatches being dug or adult mortality (mean apparent adult survival rate of 0.9033 ± 0.03). Analysis of adult survival and site fidelity suggested that black petrels have a relatively low apparent adult survival (90% compared to other seabird species such as Antipodean albatross (*Diomedea antipodensis*) 96%, Walker & Elliott 2004). However, nearly 10% of birds may be permanently emigrating (Bell et al 2007, Bell et al. in press). Although birds do not appear to abandon the burrow at any time during the breeding season, they may choose to move to a new burrow the following year. Further surveys within the study area could determine whether birds have moved to nearby, but non-study, burrows to avoid disturbance. As stated earlier the reduction in burrows used for breeding may also relate to changes in 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 (Bell et al. in press).

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 this may have to be related to individual birds (as some birds are more vulnerable to disturbance).

5.2 Survival estimates

The apparent adult survival estimates for black petrels in the study area (90%, Table 8) were unusually low for a seabird of this size, but comparable to adult black petrel survival estimates made by Hunter et al (88%, 2001) and Fletcher et al (85%, 2008). Program SEABIRD also suggested that total adult survival for breeders has increased between 1995/96 and 2008/09 (Appendix 2), despite sex-based survival estimates showing a decrease over the same period (Bell et al., in press). However, these sex-based trends are not significant and may be related to different recapture probabilities for males and females. The increase in overall apparent adult survival may relate to the regular increase in the number of study burrows monitored over the study period and increased night capture effort (i.e. surveys carried out every night for ten nights during the December trips).

Although the adult recapture data for the census grids between 1999/2000 to 2009/10 suggests the black petrel population is increasing between 1 to 1.5%, comparing the overall data with just that relating to the “foundation burrows” (i.e. those which have been monitored for ten years or more), indicates that the population has slightly decrease (Bell et al. 2007). However, as survival in this foundation group was lower than the entire dataset, the population trend may be related to occupancy of the census grid burrows and the possibility of handler disturbance rather than mortality. Again 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.

A total of 807 banded birds were identified this season; 636 were adults and 171 were fledglings (Table 5). There were 529 recaptures of previously banded birds, including 41 that were ‘returned chicks’ (Tables 5 and 6). One adult (banded as a chick on Little Barrier Island) and first caught on Great Barrier Island in 2005/06 was recaptured again this season. This bird represents the first recorded immigration event for black petrels. It is likely that birds from Little Barrier Island are being attracted to Great Barrier Island due to the number of birds’ resident there (and resulting noise early in the breeding season). Immigration has implications for population modelling work (as most models assume no immigration), and further surveys and mark-recapture work is needed to maximise the chances of recapturing known birds and returned fledglings.

Of the 41 returned chicks, 4 were recaptured in their natal burrows, 12 in their natal area (less than 50 metres from their 'hatching' burrow) and the other 25 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 analysis.

Since the first chick was recaptured in the 1999/00 season, 94 'chicks' have been recaptured (Table 5). There have been 79 records of 'returned chicks' attempting to breed during this period, and the age of first recorded breeding and that of first successful breeding are both between 4 and 10 years (Table 5, Fig. 11, Appendix 3). 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 2009 visit, so it is important to maintain a high level of night searching at this time of year. Further, these data allow for mark/recapture analyses, which could greatly assist in understanding black petrel demographics.

Bell et al (in press) analysed chick recapture data (for chicks banded on Great Barrier Island since 1996) using a CJS analysis (incorporating two chick-survival parameters, 0–3 years and > 3 years) and found that chick survival up to year 3 was 0.4600 (± 0.03) and after the first 3 years increased to 0.8992 (± 0.04), which is only slightly lower (and not significantly different) than the mean apparent adult survival (0.9033 ± 0.03). These survival figures are similar to other juveniles seabirds of this size (Hunter et al 2001, Barbraud et al 2008, Fletcher et al 2008). When the mean annual apparent juvenile survival of 0.7923 (± 0.05) is related to black petrel population growth estimates from the SEABIRD model, they indicate a population decline over the length of the study of 1.4% per year (Appendix 2). The model indicates that the population is stable or increasing only if mean annual juvenile survival is over 0.85 (Appendix 2). Better estimates of juvenile survival may be obtained over time if more returned 'chicks' are recaptured.

5.3 Population Estimate

The population estimate for the 35-ha study area was calculated using stratified transect and census grid data since surveys and local knowledge of Great Barrier Island showed that petrel burrow densities were not identical throughout the 35-ha study area (EAB, pers. obs.). Earlier black petrel population estimates (Bell & Sim 1998a, b, 2000a, b, c, 2002, 2003a, b, 2005) were likely to be overestimates as they did not take into account the range of habitat types and range of burrow density identified with the 35-ha study area. From the 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 1059 breeding pairs (2118 breeding birds) using the census grids and 2009/10 random transects (Table 10). This estimate only covers the 35-ha study area around the summit of Mount Hobson, although this is the main population location and contains the highest density of the population. We consider that delimiting the lower boundaries of the entire black petrel colony within the Mount Hobson Scenic Reserve is the highest priority for further work, so that a complete estimate of the black petrel population in this area can be achieved. The population estimate extrapolated from the census grids and random transects is higher than the estimate calculated by SEABIRD using only the transects; this may be due to the fact that breeding burrows have been under-estimated within the transect surveys. This may be due to eggs not being laid or failed already at the time of survey (and incorrectly assessed as empty or non-breeding). There may be a bias (and likely underestimate) in breeding burrows when undertaking random transects in December as the burrows are only assessed once. For example, a mean of 26% further eggs were laid in study burrows in January/February than were present in December (2006/07 to 2009/10 breeding seasons), so the random transect survey could be underestimating breeding burrows by at least 25%.

Francis and Bell (2010) used the original stratified 2004/05 transect data to estimate the population at 1964 breeding birds and compared it to the earlier estimates by Scofield (1989) suggesting a population increase of 1.2% per annum. This was recognised as a very uncertain estimate as the survey methods were different and covered different areas (Francis and Bell 2010). The random transect survey was repeated this season and these results were compared to the 2004/05 results; the 2009/10 breeding population estimate (1525) was 22% less than the 2004/05 estimate (approximately -4% decrease per year) and 5% less than the estimate (1598) by Scofield (1989). However, assessing the breeding population trend using the census grid data estimated an annual increase in the number of breeding birds between 1 and 1.5% per year and mean apparent juvenile survival (0.79 from Program MARK calculations) equates to an 1.4% annual population decline (Appendix 2). Two estimates cannot be introduced into the SEABIRD model (the Scofield survey and census gird estimates of population growth) and it is difficult to know how much these estimates will affect the population growth of the entire breeding population. It is difficult to compare the Scofield estimate as the methods are different and the trends in the census grids may not represent the whole population. However, it is likely that mean rate of change of the black petrel population on Great Barrier Island has not exceeded 2% per year, although the direction of change in uncertain (and may alter from year to year), but is most likely to be in decline.

It was noted that the number of non-occupied burrows along the transects had increased markedly between the two survey periods and from those within the census grids (Appendix 2). This may have been a result of the survey technique as only one team completed the 2009/10 random transects while two teams completed the 2004/05 random transects. Unlike 2004/05 where survey teams may have been less experienced and/or more cautious in identifying and assessing burrows, in 2009/10 EAB could confirm whether every burrow was suitable for black petrels and confirm the breeding status of each. It could be valuable to resurvey the original transects using one team to confirm the number and status of burrows and reassess the population estimates. Alternatively a further random transect survey could be repeated in five years and compared to the first two surveys.

Further transects throughout the study area would improve this population estimate as well as more accurately defining the range of the four burrow density habitat grades (or possibly identify more). It is also important to examine the difference between two- and three-dimensional estimates of density and population size in this steep and difficult terrain. It is important to undertake further transects within the 35-ha study area to improve this population estimate.

To gain a better population estimate to the whole black petrel population on Great Barrier Island, further surveys would need to be undertaken in other areas on the island. In addition to the summit area 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. These surveys could be undertaken on or near the Hog's Back, Mount Heale and Mount Matawhero. It is interesting to note that several pairs of black petrels have been found well below 300m a.s.l. (EAB pers. obs.), which raises the possibility that other birds may also be breeding at lower elevations. This possibility should be investigated further.

5.4 Population trends

Nine grids were intensively monitored over each visit during the 2009/10 breeding season. Three new burrows were found; the number of burrows within the grids has risen from 118 in 1999/2000, 148 in 2005/06, 152 in 2008/09 and to 155 in 2009/10. There has been a 32% increase in burrow numbers between 2000 and 2009 (Francis and Bell 2010). It is important to realise that although Francis and Bell (2010) suggested that this increase in burrow numbers in the census grids between 2000 and 2009 corresponded to an increase in the breeding population of between 2.2 and 3.1% per year, this was based on the assumption that there was no long-term trend in the percentage of burrows used for breeding. With the addition of another year's data, there was a marginally significant downward trend in the percentage of burrows used for breeding ($P = 0.045$, Fig. 9, Appendix 2). As such population growth was calculated by fitting regression lines to counts of breeding burrows using the additional years breeding burrow data and based on calculating all years counts (rather than the first and last year's only) and growth was reduced to between 1 and 1.5% (Appendix 2). However it is important to assess population growth in relation survival (adult, pre-breeder and juvenile) as this growth may be 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 birds are present in the colony, as several birds (n=263) have moved between numbered burrows within the 35-ha study area between 1995/96 and 2009/10 breeding seasons and certain original burrows are no longer active (due to collapse or flooding). Loss of a partner can result in a bird (particularly females) moving burrows (Warham 1996). Predation events and competition between adults and pre-breeders can also cause movement between burrows (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). This has occurred in the study area on Great Barrier Island when several pre-breeding (or non-breeding) birds have returned to their natal area (and in eleven 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 (and census grids, EAB, pers. obs.).

Transition data showed a 37% probability of either a successful breeder or an unsuccessful breeder changing to a non-breeder (i.e. skipping a year, Table 13). Also if that bird skips a year, it is more likely to skip another year than attempt to breed the following year (54% compared to 46%, Table 13). The option of skipping may relate to a number of factors including breeding outcome, partner selection, burrow condition, handler disturbance and divorce. Further analysis suggested a 13% divorce rate; however, over 70% of pairs survive annually and 64% of any pair (new or surviving) nest in any one year (Bell et al. in press). It is difficult to determine the reason for divorce, and the reasons why birds chose to skip a year may relate to breeding outcome, 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? The analysis suggests 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 Conservation

A recent estimate indicates that about 7000 people visit Mount Hobson each year (Peter Cann, DOC, pers. comm.), but this use appears to have little or no impact on the breeding success of the black petrel in this area. Information about the black petrels at the track start/end points and on the summit has increased awareness of the birds and the unique environment they inhabit. However, littering and public fouling (defecation), continues to occur in the summit area is of concern because it could introduce disease or lead to an increase in rat numbers.

The recent construction of raised walkways around the summit reduced damage to the overall environment and to the burrows in that area. Serious erosion had been occurring along certain sections of the South Fork and Palmers Tracks, and DOC (Great Barrier Area Office) extended the boardwalk system into the South Forks and Palmers Track areas between 2007 and 2009. The Kauri Dam section was completed in February 2011 (Ken Scott, DOC, pers. comm.). The contract construction team (Walkway Solutions) consulted with local DOC staff and the authors. A number of burrows were identified within the construction zone and these were avoided by the new boardwalk.

A total of 38 black petrels (including two banded by the authors) were recorded by government observers as bycatch on commercial fishing vessels in the New Zealand fisheries between 1 October 1996 and 30 June 2009 (Robertson et al. 2004; Conservation Services Programme 2008; Rowe 2009, 2010; Thompson 2010a, b, c). These birds have been caught on both trawl and long-line vessels between October and May, either east of North Cape, near the Kermadec Islands or north of Great Barrier Island (Robertson et al. 2003, 2004; Conservation Services Programme 2008; Rowe 2009, 2010, Thompson 2010a, b, c). 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. 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 especially as black petrels have delayed maturity, low reproduction rates and high adult survival (Murray et al 1993). Even a small change in adult survival could affect the population greatly (Murray *et al*. 1993). Continued bycatch of breeding adults in New Zealand and overseas fisheries has the potential to seriously affect the species.

Black petrels are recognised as one seabird species that is at the greatest risk from commercial fishing activity within New Zealand waters (Rowe 2009, Abraham et al 2010, Baird & Gilbert 2010). There is a high level of uncertainty around estimates of total bycatch in New Zealand fisheries, but recent estimation work suggests the number black petrel captures in New Zealand commercial trawl and long-line fisheries may be several hundred per annum (Yvan Richard pers. comm.). This suggests that bycatch is potentially far exceeding a biological limit and could have serious impacts on the black petrel population.

It is important to continue to monitor the Great Barrier Island black petrel population. Long-term population data combined with improved technology and further use of data-loggers can be used to develop an accurate population model to determine adult survivorship, recruitment, mortality and productivity as well as assess factors affecting the black petrel population, particularly likely overlap or risk areas with fisheries and the overall effects of fisheries bycatch by the commercial fishing industry.

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, commercial fishing and other environmental factors.
- The November/December visit to the study area should be continued. Visiting at this time allows a large number of birds to be banded or recaptured easily, as the birds are often outside the burrows during this period. A high rate of banding and recapture will enable the continuation of the mark-recapture programme.
- 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.
- The April/May visit should continue, as this allows time for chicks to be banded before they fledge.
- Further random transects are undertaken every five years throughout the 35-ha study area around Mount Hobson to increase the likelihood of adult and juvenile recaptures (to improve survival and immigration estimates) and to compare with earlier transect surveys to determine population trends.
- The exact limits of the entire Mount Hobson (Hirakimata) colony should be established and the area calculated by a ground truth survey. Random transects should be established on other high points around the Mount Hobson area (e.g. Mount Heale, Mount Matawhero and The Hogs Back). These sites should be monitored as long as the study continues.
- Cat trapping should be implemented before and during the black petrel breeding season, November to June, especially during pre-laying (October/November) and the fledging period (May to June).

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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 2009/10 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 2009/10 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 2009/10.

Table 5 Total number of black petrel (*Procellaria parkinsoni*) chicks banded each season and the proportion of those chicks that have been recaptured within the study site on Great Barrier Island (Aotea Island) for breeding seasons 1995/96 to 2009/10.

Table 6 Number of black petrel (*Procellaria parkinsoni*) ‘returned chicks’ that have been recaptured within the study site on Great Barrier Island (Aotea Island) for breeding seasons 1995/96 to 2009/10.

Table 7 Number of black petrel (*Procellaria parkinsoni*) ‘returned chicks’ that were recaptured each season and whether the ‘returned chick’ attempted to breed within the study site on Great Barrier Island (Aotea Island) for breeding seasons 1995/96 to 2009/10.

Table 8 Adult survival estimates for black petrels (*Procellaria Parkinsoni*) on Great Barrier Island (Aotea Island) between 1996/97 and 2008/09. Estimates obtained by Cormack Jolly Seber model [Phi(t) *P*(sex*t)] analysis (using Program MARK) with standard errors and 95% confidence intervals.

Table 9 Total length of each transect, section length of each transect in each habitat type after stratification and number of black petrel (*Procellaria parkinsoni*) burrows in each section of transect in the 35-ha study site around Mount Hobson, Great Barrier Island (Aotea Island).

Table 10 2009/10 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 the 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 11 Comparison of the number of black petrel (*Procellaria parkinsoni*) burrows by habitat grade from random transects surveys in 2004/05 breeding season and 2009/10 breeding season on Great Barrier Island (Aotea Island).

Table 12 Comparison of estimated densities of black petrel (*Procellaria parkinsoni*) breeding burrows and numbers of breeding birds (population estimate) by habitat grade from random transects surveys in 2004/05 breeding season and 2009/10 breeding season on Great Barrier Island (Aotea Island).

Table 13 Probability estimates for breeding state in one year changing to a different state in the following year for adult black petrel (*Procellaria parkinsoni*) in the 35-ha study area on 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 Location of black petrel (*Procellaria parkinsoni*) burrows found on the Kauri Dam Grid (each grid is 40 x 40 m), Great Barrier Island (Aotea Island). Approximate North is shown (N).

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

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

Figure 5 Locations of random transects and habitat grades, based on black petrel (*Procellaria parkinsoni*) burrow density (incorporating habitat characteristics) within the 35-ha study site on Great Barrier Island (Aotea Island). There are 1.8 ha of non-petrel habitat, 13.6 ha of low-grade (< 50 burrows per ha) petrel habitat, 15.3 ha of medium grade (50-99 burrows per ha) petrel habitat and 4.7 ha of high-grade (≥ 100 burrows per ha) petrel habitat.

Figure 6 Occupancy and breeding success of study burrows (1998/99 to 2009/10 breeding years) 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 7 Occupancy of census grid burrows (1995/96 to 2009/10 breeding years) 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 8 Number of burrows (1995/96 to 2009/10 breeding years) in each census grid on Great Barrier Island (Aotea Island). A = Kauri Dam; B = Palmers Track; C = South Forks; solid black line = Grid One; dashed line = Grid Two; dotted line = Grid Three.

Figure 9 Total numbers of burrows, percentage used by breeding black petrels (*Procellaria parkinsoni*) and breeding success (1995/96 to 2009/10) in the census grid on Great Barrier Island (Aotea Island). Solid black line = total number of burrows; dotted black line = burrows used by breeding birds; solid grey line = breeding success.

Figure 10 The number of black petrel (*Procellaria parkinsoni*) chicks banded each season (1995/96 to 2009/10) 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 11 The number of breeding and non-breeding black petrel (*Procellaria parkinsoni*) 'returned chicks' recaptured each season between 1995/96 and 2009/10 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 12 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).

Figure 13 Adult survival estimates for black petrels (*Procellaria parkinsoni*) on Great Barrier Island (Aotea Island) between 1996/97 and 2008/09. Estimates obtained by Cormack Jolly Seber model analysis (Phi (t) *P* (sex*t)) using Program MARK.

Appendices

Appendix 1 Results from the study of black petrel burrows (n = 393) near Mount Hobson, Great Barrier Island (Aotea Island) during the 2009/10 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 Updated results from the analyses of Francis & Bell (2010) using mark/recapture and transect data collected during the black petrel (*Procellaria parkinsoni*) 2009/10 breeding season on Mount Hobson, Great Barrier Island (Aotea Island).

Appendix 3 Number of recaptures, age at first recapture, age at first breeding and age at first successful breeding for black petrels (*Procellaria parkinsoni*) banded as chicks and recaptured in the study site on Great Barrier Island (Aotea Island) between 1995/96 and 2009/10 (n = 94), with a note about an immigrant banded as a chick on Hauturu/Little Barrier Island.

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	3:1	77
1999/00	94	6	16:1	6	72	22	3:1	74
2000/01	95	5	19:1	5	66	29	2:1	76
2001/02	92	8	12:1	8	68	24	3:1	70
2002/03	88	12	7:1	12	63	25	3:1	69
2003/04	82	18	5:1	18	64	18	4:1	76
2004/05	86	14	6:1	14	63	23	3:1	80
2005/06	82	18	5:1	18	70	12	6:1	67
2006/07	91	9	10:1	9	70	21	3:1	83
2007/08	85	15	6:1	15	68	17	4:1	77
2008/09	89	11	8:1	10	69	21	3:1	76
2009/10	87	13	7:1	13	62	25	2.5:1	74
MEAN ± SEM	89 ± 1	11 ± 1	9.5:1 (± 1)	11 ± 1	67 ± 1	22 ± 1	3:1 (± 0.3)	75 ± 1

Table 2

Year		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
Number of study burrows		80	118	137	197	248	255	283	318	324	362	366	370	379	388	393
Eggs	- laid	57	92	95	142	178	168	192	199	208	226	257	257	256	266	244
	- predation (rat)	1	6	1	2	9	6	5	1	2	3	15	0	5	5	8
	- crushed[1]	0	5	0	1	10	6	5	14	13	7	27	7	9	11	2
	- abandoned	0	2	1	5	1	3	9	7	0	3	1	2	11	6	3
	- infertile	0	6	4	12	6	8	3	2	7	4	0	1	4	3	3
	- dead embryo	0	0	8	6	13	9	14	19	16	12	9	6	0	18	20
	- disappeared egg[2]	2	0	0	0	0	0	11	3	0	5	19	19	19	7	20
	- unknown[3]	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0
Chicks	- hatched	54	73	81	116	139	136	145	148	170	192	186	222	208	216	188
	- predation (rat)	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	- predation (cat)	0	0	0	2	2	1	2	3	2	0	2	0	0	0	0
	- died (disease)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	- died (starvation)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	- died (unknown causes)	0	0	0	3	6	7	8	8	10	7	12	10	9	15	8
	- disappeared chick	0	0	0	0	0	0	0	0	0	4[4]	0	0	1	0	0
	- fledged[5]	54	72	80	109	131	128	135	137[6]	158[6]	181[6]	172[6]	212[6]	198[6]	201[6]	180[6]
OVERALL BREEDING SUCCESS (%)		94[7]	78	84	77	74	76	70	69	76	80	67	83	77	76	74

[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] 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 and 22 in 2009/10). The remaining chicks were banded.

[7] 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).

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
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
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

Table 4

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

[8] 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. This bird has been caught each year since this first capture.
[9] 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).
[10] This includes 211 chicks from the study burrows.
[11] This includes 201 chicks from the study burrows.
[12] This includes 158 chicks from the study burrows.

Table 5

	Total number of banded chicks	Total number of returned chicks	Proportion (%) of returned chicks
1995/96	59	3	5
1996/97	69	6	9
1997/98	85	10	12
1998/99	116	15	13
1999/00	137	16	12
2000/01	137	8	6
2001/02	160	12	8
2002/03	62	6	10
2003/04	110	5	5
2004/05	184	8	4
2005/06	143	5	4
2006/07	215	0	0
2007/08	191	0	0
2008/09	203	0	0
2009/10	171	0	0
TOTAL	2042	94	7.5
MEAN (± SEM)	136 ± 13	6 ± 1	6 ± 1

Table 6

	YEAR														
	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
Recaptures of chicks banded in 1995/96	-	-	-	-	1	1	2	3	2	1	2	1	2	2	2
Recaptures of chicks banded in 1996/97	-	-	-	-	-	-	2	2	3	2	1	0	0	1	2
Recaptures of chicks banded in 1997/98	-	-	-	-	-	-	5	6	4	1	2	3	1	4	6
Recaptures of chicks banded in 1998/99	-	-	-	-	-	-	-	6	3	6	6	6	6	8	5
Recaptures of chicks banded in 1999/00	-	-	-	-	-	-	-	1	2	10	9	5	5	8	2
Recaptures of chicks banded in 2000/01	-	-	-	-	-	-	-	-	-	-	4	1	5	2	8
Recaptures of chicks banded in 2001/02	-	-	-	-	-	-	-	-	-	-	1	2	6	8	2
Recaptures of chicks banded in 2002/03	-	-	-	-	-	-	-	-	-	-	-	2	2	4	2
Recaptures of chicks banded in 2003/04	-	-	-	-	-	-	-	-	-	-	-	-	1	3	8
Recaptures of chicks banded in 2004/05	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4
Recaptures of chicks banded in 2005/06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Recaptures of chicks banded in 2006/07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Recaptures of chicks banded in 2007/08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL RECAPTURE OF RETURNED CHICKS	0	0	0	0	1	1	9	18	14	20	25	20	28	41	41

Table 7

	BREEDING SEASON														
	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
TOTAL NUMBER OF CHICKS (banded that season)	59	69	85	116	137	137	160	62	110	184	143[13]	215[14]	191	203[15]	171[16]
TOTAL RECAPTURE OF 'RETURNED CHICKS'	0	0	0	0	1	1	9	18	14	20	25	20	28	41	41
'RETURNED CHICKS' THAT ATTEMPTED TO BREED THAT SEASON	0	0	0	0	1	0	6	15	8	12	11	6	9	14	25
'RETURNED CHICKS' THAT DID NOT BREED THAT SEASON	0	0	0	0	0	1	3	3	6	8	14	14	19	27	16

[13] 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).
[14] This includes 211 chicks from the study burrows.
[15] This includes 199 chicks from the study burrows.
[16] This includes 158 chicks from the study burrows.

Table 8

SEASON	SURVIVAL ESTIMATE	SE
1996/97	0.8939	0.0796
1997/98	0.9671	0.0273
1998/99	0.8832	0.0370
1999/00	0.9481	0.0218
2000/01	0.9203	0.0229
2001/02	0.9264	0.0232
2002/03	0.8967	0.0243
2003/04	0.8057	0.0264
2004/05	0.9644	0.0315
2005/06	0.8266	0.0333
2006/07	0.8275	0.0371
2007/08	0.9117	0.0433
2008/09	0.9259	0.0383
2009/10	0.9489	0.0357
MEAN	0.9033 ± 0.03	

Table 9

TRANSECT	LENGTH					NUMBER OF BURROWS									
						LOW			MEDIUM			HIGH			TOTAL
	TOTAL LENGTH	NON-PETREL	LOW	MEDIUM	HIGH	BREEDING	NON-BREEDING	NON-OCCUPIED	BREEDING	NON-BREEDING	NON-OCCUPIED	BREEDING	NON-BREEDING	NON-OCCUPIED	
LT6	130	0	0	47	83	0	0	0	0	1	1	2	2	0	6
LT7	180	19	161	0	0	3	1	1	0	0	0	0	0	0	5
LT8	400	53	44	303	0	1	0	0	1	3	4	0	0	0	9
LT9	320	39	102	109	0	1	0	0	1	2	1	0	0	0	5
LT10	400	0	0	116	284	0	0	0	1	2	1	8	9	4	25
LT11	400	6	265	129	0	0	1	0	1	1	1	0	0	0	4
LT12	400	40	144	105	111	0	0	0	1	2	1	3	1	0	8
LT17	400	0	26	361	13	0	0	0	5	4	2	0	1	0	12
LT18	400	37	275	88	0	2	3	4	0	2	1	0	0	0	12
LT18a	400	22	74	193	111	0	0	0	0	3	2	3	2	0	10
LT19	300	10	196	69	25	0	0	0	1	1	0	1	0	0	3
LT25	400	0	0	19	381	0	0	0	1	0	0	6	5	10	22
LT36	400	58	268	74	0	0	0	0	0	2	1	0	0	0	3
LT37	190	0	10	55	125	1	0	0	1	0	0	4	3	1	10
LT38	400	53	103	177	67	2	0	1	1	0	0	2	2	4	12
LT38a	400	0	76	178	146	0	0	0	2	3	2	4	4	0	15
LT41	400	0	0	288	112	0	0	0	1	5	5	3	1	0	15
LT45	400	0	0	288	112	0	0	1	3	1	5	1	2	3	16
LT49	400	11	137	168	84	0	2	0	1	3	1	1	3	1	12
LT67	336	0	214	97	25	2	0	3	2	0	3	0	1	0	11
LT72	270	28	120	122	0	1	1	0	1	2	3	0	0	0	8
LT85	260	8	79	173	0	0	2	3	0	2	7	0	0	0	14
LT106	400	0	91	242	67	0	0	0	1	0	7	2	1	3	14
LT107	400	0	186	151	63	0	0	1	2	0	3	4	0	0	10
LT112	360	36	133	91	100	1	0	1	1	2	4	4	2	1	16
LT115	387	0	0	129	258	0	0	0	2	3	1	3	4	8	21
TOTAL						14	10	15	30	44	56	51	43	35	298

Table 10

RANK	Line Transect or Census Grid	Area (ha) of each transect or grid in that rank	DENSITY (Number/ha)		TOTAL AREA	POPULATION ESTIMATE (35 ha)	
			Breeding adults	Non-breeding adults		Breeding adults	Non-breeding adults
LOW (1-49 burrows per ha)	LT7	0.0644	93	19	13.5607 ha	1263	263
	LT8	0.0176	0	0		0	0
	LT9	0.0408	49	0		665	0
	LT11	0.106	0	12		0	160
	LT12	0.0576	0	0		0	0
	LT17	0.0104	0	0		0	0
	LT18	0.11	36	34		493	462
	LT18a	0.0296	0	0		0	0
	LT19	0.0784	0	0		0	0
	LT36	0.1072	0	0		0	0
	LT37	0.004	500	0		6780	0
	LT38	0.0412	97	0		1317	0
	LT38a	0.0304	0	0		0	0
	LT49	0.0548	0	46		0	619
	LT67	0.0856	47	0		634	0
	LT72	0.048	42	26		565	542
	LT85	0.0316	0	79		0	1073
	LT106	0.0364	0	0		0	0
	LT107	0.0744	0	0		0	0
	LT112	0.0532	38	0		510	0
	KDG2	0.02	0	0		0	0
	KDG3	0.02	0	0		0	0
	MEAN (± SEM)		41 ± 23	10 ± 4		556 ± 309	142 ± 61
MEDIUM (50-99 burrows per ha)	LT6	0.0188	0	67	15.3013 ha	0	1017
	LT8	0.1212	50	31		758	473
	LT9	0.0436	46	57		702	877
	LT10	0.0464	43	0		660	0
	LT11	0.0516	39	24		593	371
	LT12	0.042	48	60		729	911
	LT17	0.1444	69	35		1060	530
	LT18	0.0352	0	71		0	1087
	LT18a	0.0772	0	49		0	743
	LT19	0.0276	73	45		1109	693
	LT25	0.0076	263	0		4027	0
	LT36	0.0296	0	85		0	1292
	LT37	0.022	91	0		1391	0
	LT38	0.0708	28	0		432	0
	LT38a	0.0712	56	53		860	806
	LT41	0.1152	17	54		266	830
	LT45	0.1152	52	11		797	166
	LT49	0.0672	30	56		455	854
	LT67	0.0388	103	0		1577	0
	LT72	0.0488	41	51		627	784
	LT85	0.0692	0	36		0	553
	LT106	0.0968	21	0		316	0
	LT107	0.0604	66	0		1013	0
	LT112	0.0364	55	69		841	1051
	LT115	0.0516	78	73		1186	1112
	KDG1	0.02	0	0		0	0
	KDG2	0.04	100	31		1530	474
	KDG3	0.06	67	21		1020	319
	SFG1	0.03	200	42		3060	638
	SFG3	0.11	91	11		1391	174
	PTG2	0.04	50	31		765	174
	PTG3	0.06	67	0		1020	0
	MEAN (± SEM)		58 ± 10	33 ± 5		881 ± 150	478 ± 74
HIGH (≥100 burrows per ha)	LT6	0.0332	121	75	4.669 ha	563	352
	LT10	0.1136	141	99		658	462
	LT12	0.0444	135	28		631	131
	LT17	0.0052	0	240		0	1122
	LT18a	0.0444	135	56		631	263
	LT19	0.01	200	0		934	0
	LT25	0.1524	79	41		368	192
	LT37	0.05	640	75		2988	350

	LT38	0.0268	149	93		697	436
	LT38a	0.0584	137	86		640	400
	LT41	0.0448	134	28		625	130
	LT45	0.0448	45	56		208	261
	LT49	0.0336	60	112		278	521
	LT67	0.01	0	125		0	584
	LT106	0.0268	149	47		697	218
	LT107	0.0252	317	0		1482	0
	LT112	0.04	200	63		934	292
	LT115	0.1032	58	48		271	226
	KDG1	0.14	214	71		1001	333
	KDG2	0.12	267	52		1245	243
	KDG3	0.08	50	0		233	0
	SFG1	0.13	62	67		287	314
	SFG2	0.16	38	39		175	182
	SFG3	0.05	0	0		0	0
	PTG1	0.16	250	63		1167	292
	PTG2	0.12	317	73		1479	340
	PTG3	0.1	40	75		187	350
MEAN (± SEM)			146 ± 26	63 ± 9		681 ± 121	296 ± 44
TOTAL POPULATION ESTIMATE (± SE)						2118 ± 193	916 ± 60
						3034 ± 253	
POPULATION ESTIMATE RANGE						**2781 to 3287 adults**	

Table 11

YEAR	NUMBER OF BURROWS									
	LOW			MEDIUM			HIGH			TOTAL
	BREEDING	NON-BREEDING	NON-OCCUPIED	BREEDING	NON-BREEDING	NON-OCCUPIED	BREEDING	NON-BREEDING	NON-OCCUPIED	
2004/05	3	2	0	59	39	6	50	29	3	191
2009/10	14	10	15	30	44	56	51	43	35	298

Table 12

STRATUM	AREA (ha)	BURROW DENSITY (Number/ha)		POPULATION ESTIMATE (Breeding birds only)	
		2004/05	2009/10	2004/05	2009/10
NON-PETREL	1.75	0	0	0	0
LOW (1-49 burrows/ha)	13.6	4.9 (± 2.2)	12.0 (± 4.6)	134 (± 61)	327 (± 124)
MEDIUM (50-99 burrows per ha)	15.3	37.6 (± 5.4)	21.2 (± 3.0)	1150 (± 166)	649 (± 93)
HIGH (≥100 burrows per ha)	4.67	72.8 (± 11.0)	58.8 (± 7.6)	680 (± 103)	550 (± 71)
TOTAL	35.3	29.3 (± 3.0)	22.7 (± 2.5)	1964 (± 204)	1525 (± 170)

Table 13

YEAR ONE STATE	YEAR TWO STATE			
	SUCCESSFUL BREEDER	FAILED BREEDER	NON-BREEDING	REMAIN PRE-BREEDER
PRE-BREEDER	0.40	0.11	0.26	0.23
SUCCESSFUL BREEDER	0.66	0.19	0.15	-
FAILED BREEDER	0.61	0.17	0.22	-
NON-BREEDING	0.36	0.10	0.54	-

Figure 1

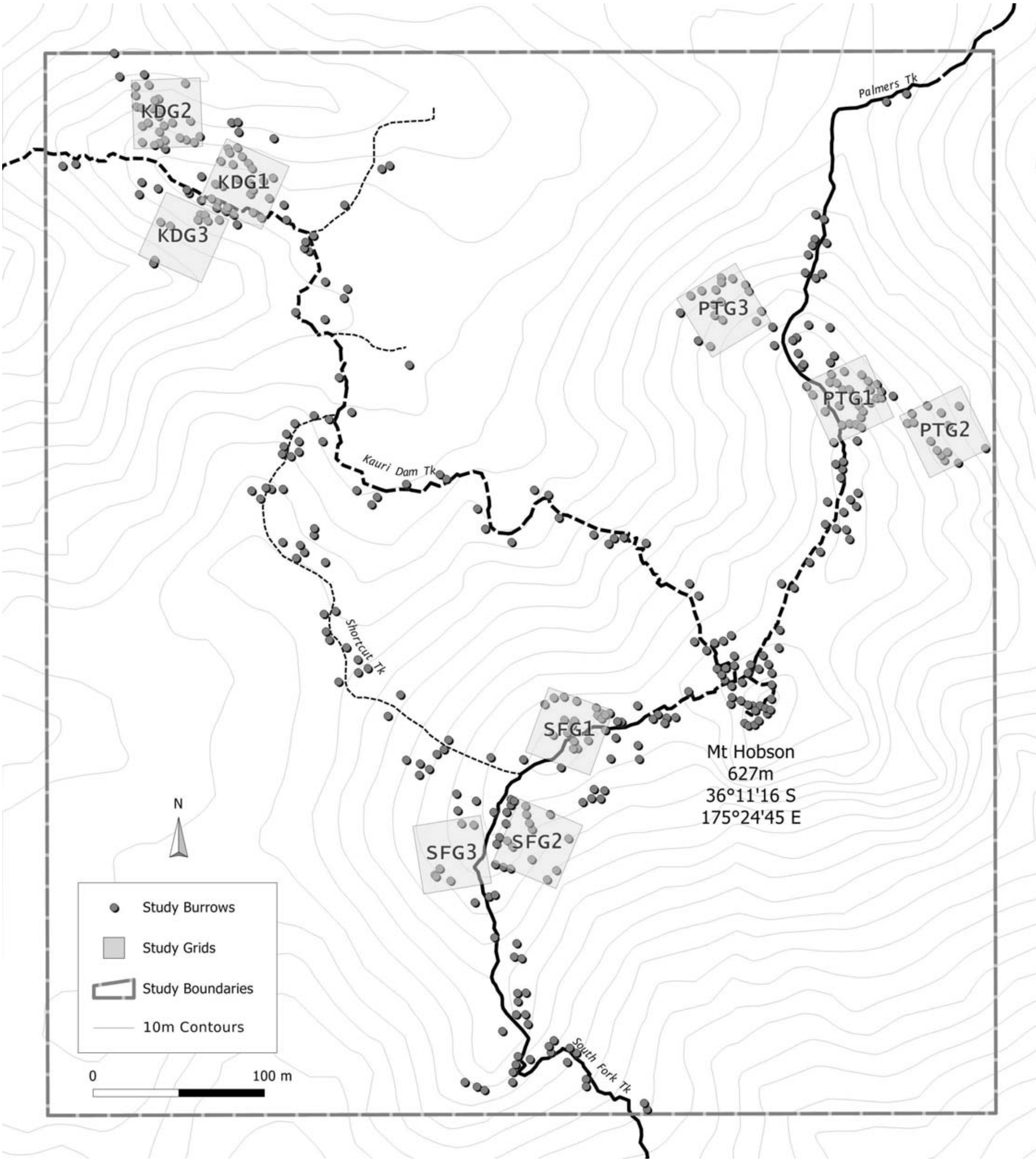

KDG2
KDG1
KDG3
Palmers Tk
PTG3
PTG1
PTG2
Kauri Dam Tk
Shortcut Tk
SFG1
SFG2
SFG3
South Fork Tk
Mt Hobson
627m
36°11'16 S
175°24'45 E
N
Study Burrows
Study Grids
Study Boundaries
10m Contours
0
100 m

Figure 2

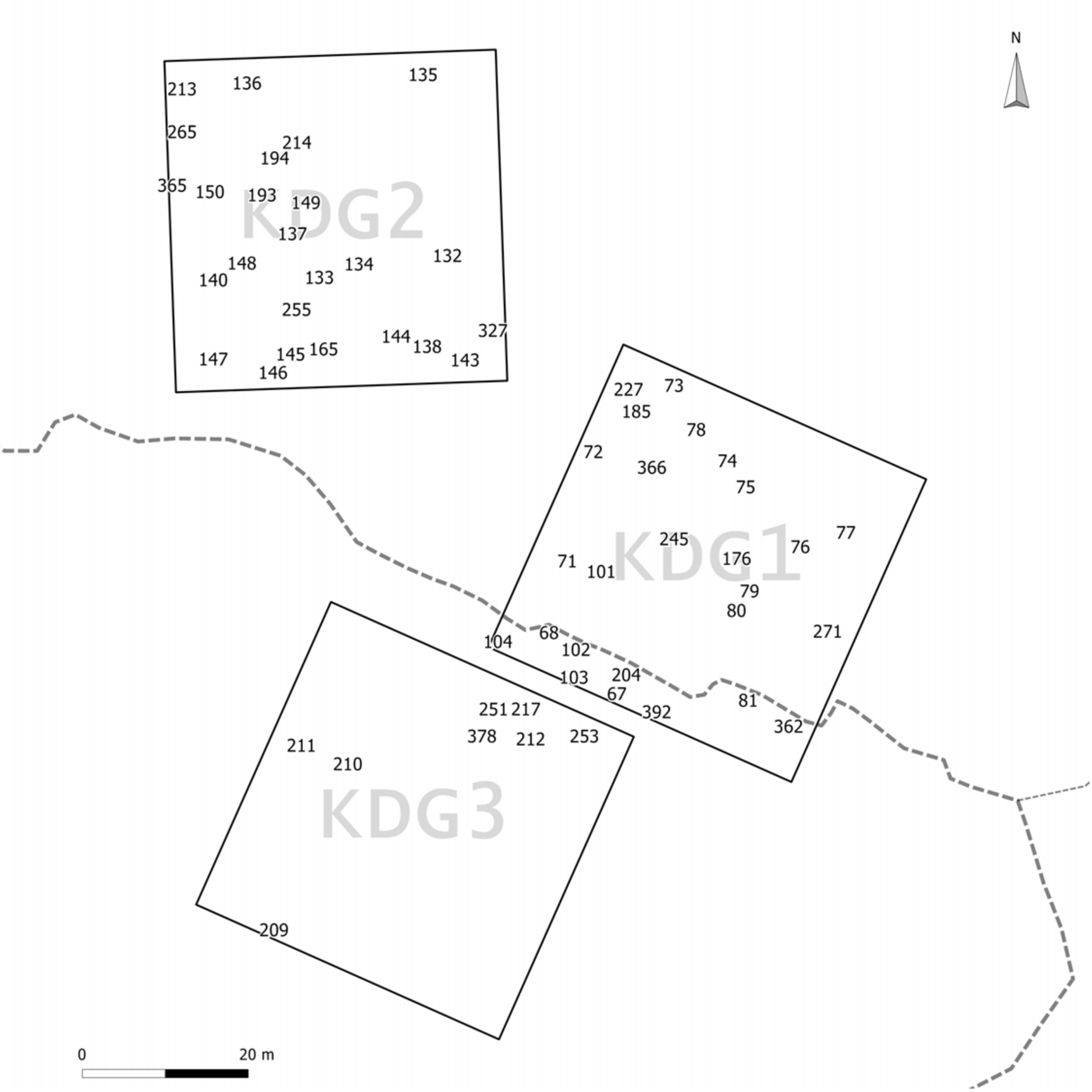

N
KDG2
213
136
135
265
214
194
365
150
193
149
137
148
134
132
140
133
255
327
144
138
147
145
165
143
146
KDG1
227
73
185
78
72
366
74
75
245
77
76
71
101
176
79
80
271
104
68
102
103
204
67
392
81
362
KDG3
251
217
378
212
253
211
210
209
0
20 m

Figure 3

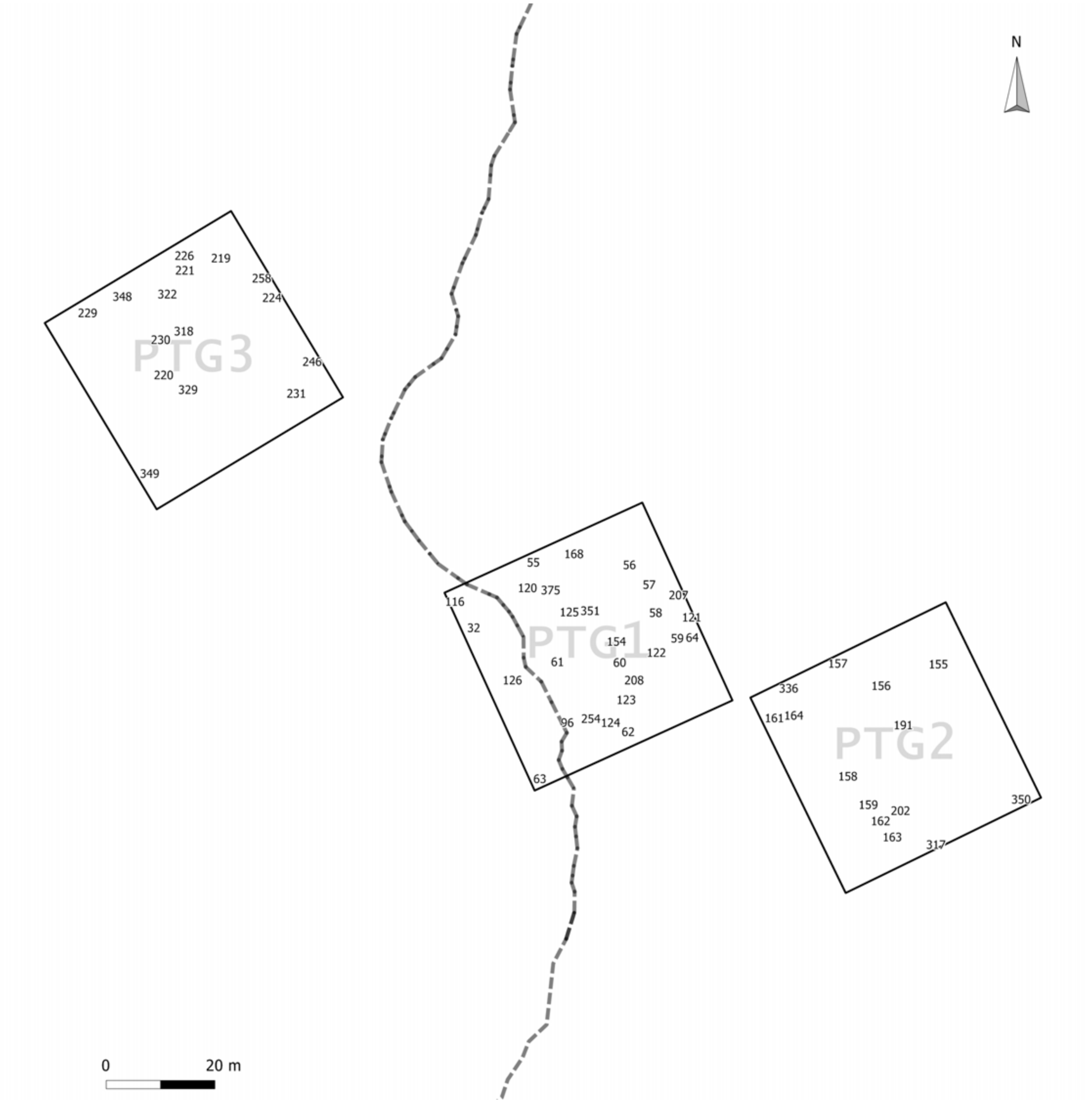

N
PTG3
226
219
221
258
348
322
224
229
318
230
246
220
329
231
349
PTG1
55
168
56
57
120
375
207
116
125
351
58
121
32
154
59
64
61
60
122
126
208
123
96
254
124
62
63
PTG2
157
155
336
156
161
164
191
158
159
202
350
162
163
317
0
20 m

Figure 4

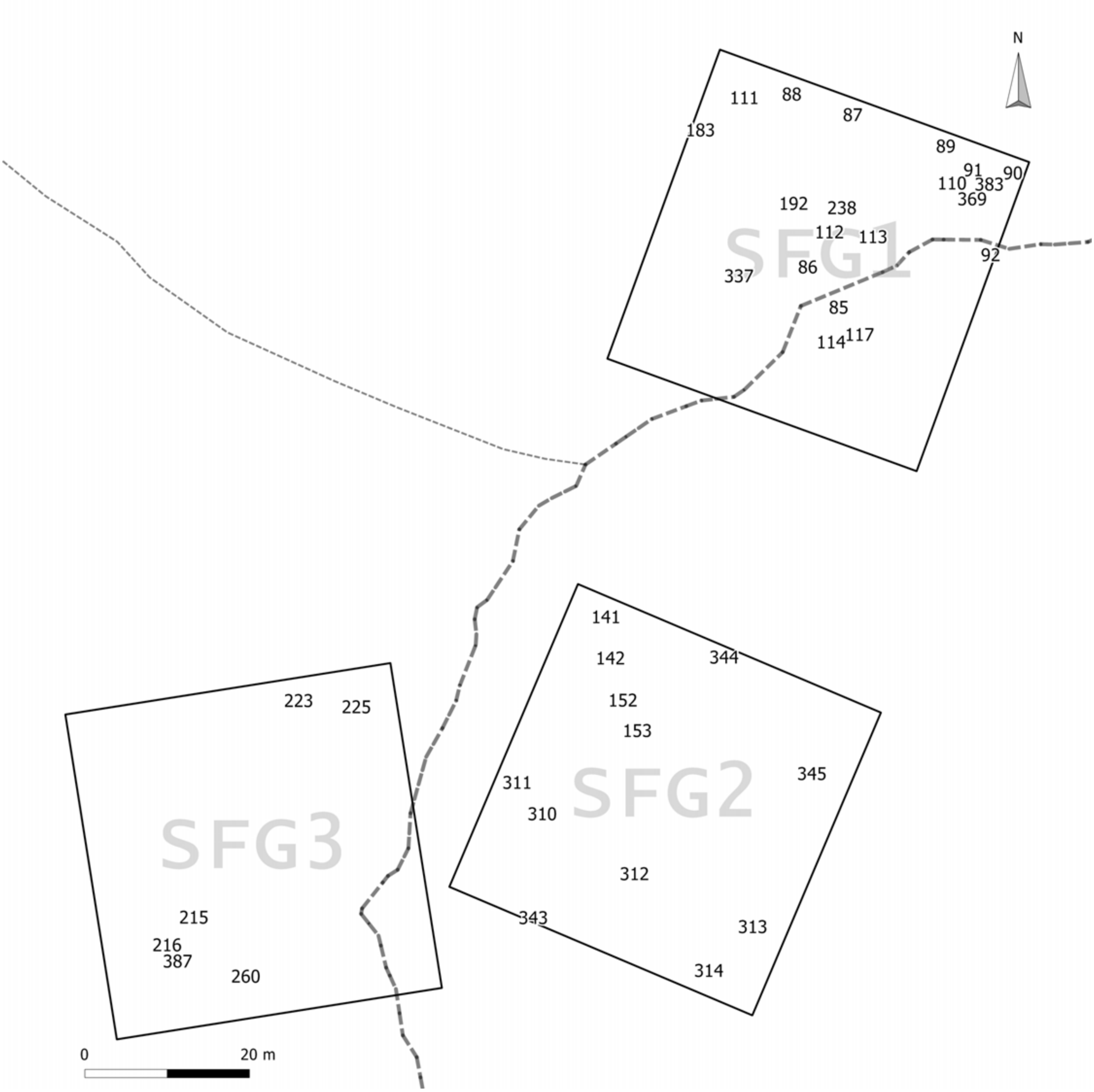

N
111
88
87
183
89
91
90
110
383
369
192
238
112
113
SFG1
92
337
86
85
114
117
141
142
344
152
153
345
311
SFG2
310
312
343
313
314
223
225
SFG3
215
216
387
260
0
20 m

Figure 5

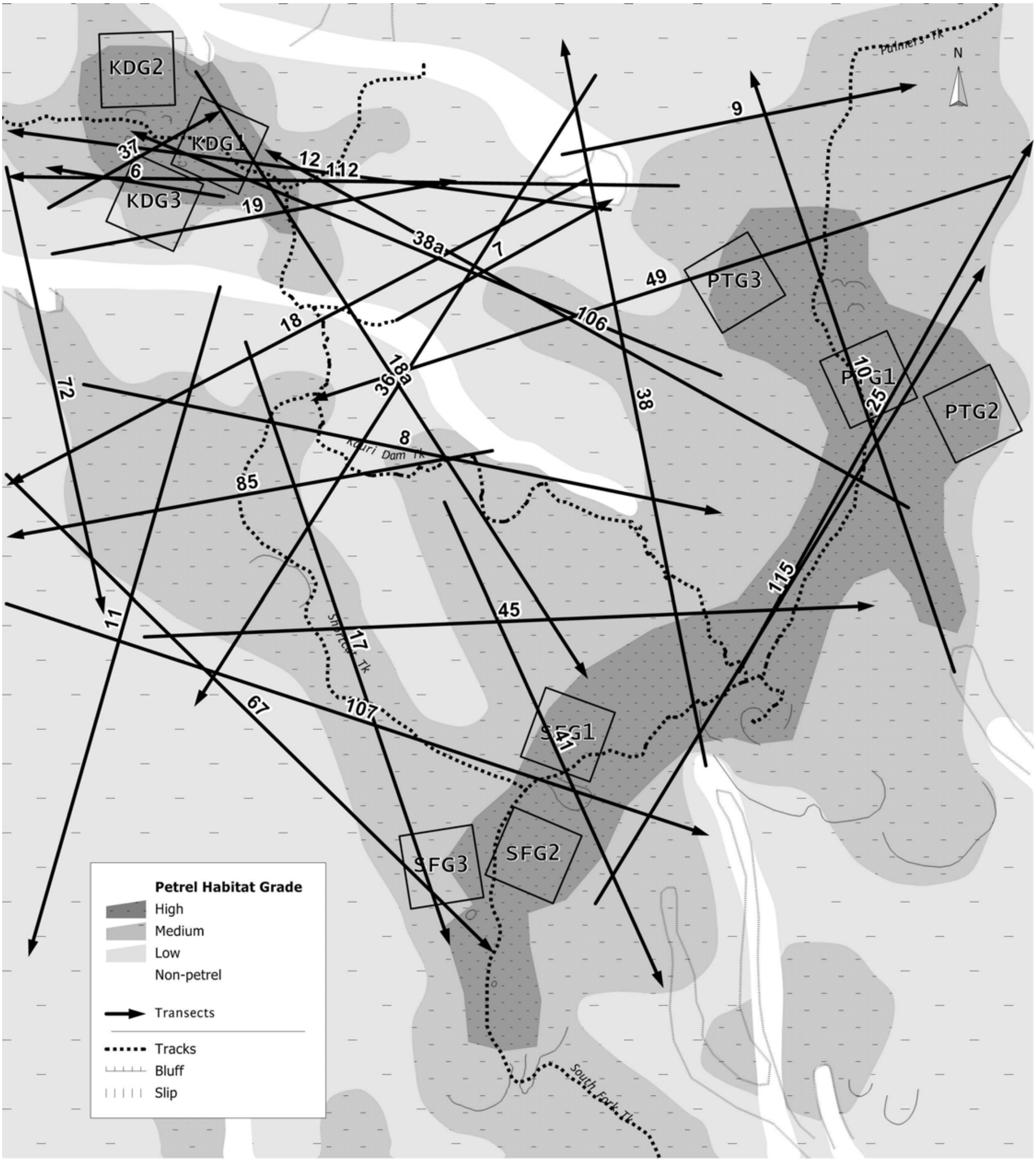

KDG2
KDG1
KDG3
PTG3
PTG1
PTG2
SFG1
SFG2
SFG3
N
Palmers Tk
Kauri Dam Tk
Sharps Tk
South Fork Tk
9
37
6
12
112
19
38a
7
49
18
106
18a
36
72
8
38
10
25
85
115
45
11
17
107
67
41
Petrel Habitat Grade
High
Medium
Low
Non-petrel
Transects
Tracks
Bluff
Slip

Figure 6

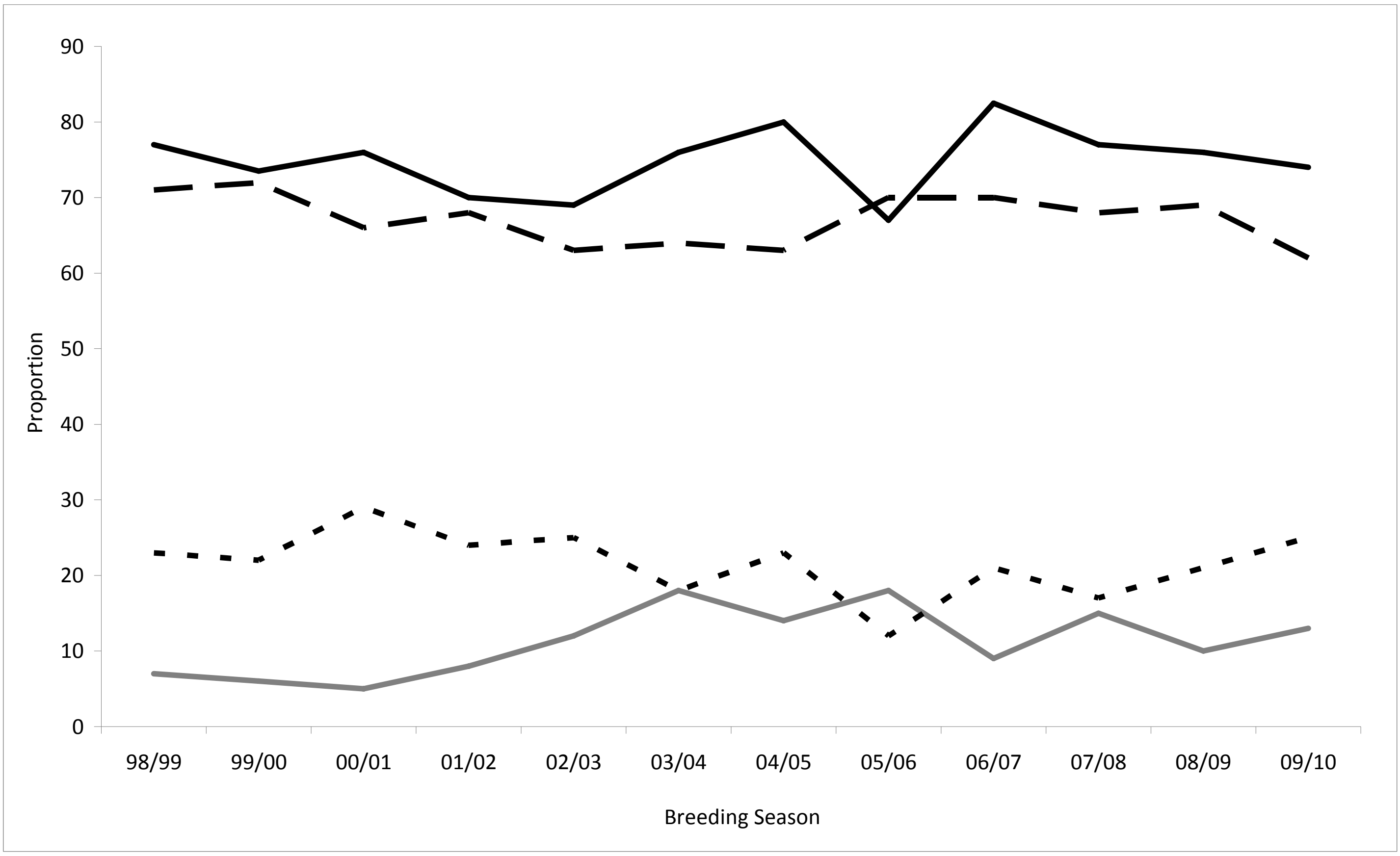

90
80
70
60
50
40
30
20
10
0
Proportion
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06
06/07
07/08
08/09
09/10
Breeding Season

Figure 7

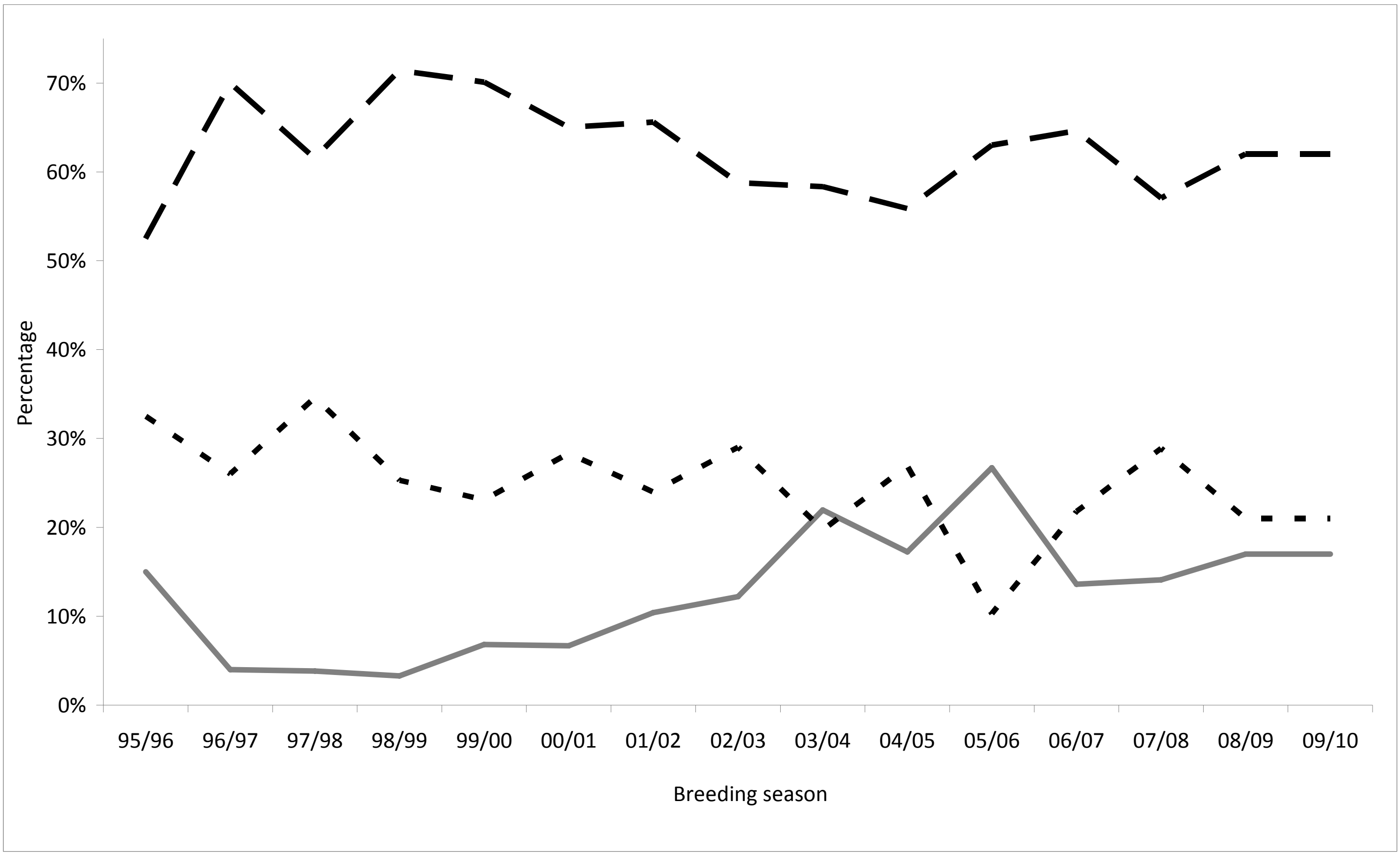

70%
60%
50%
40%
30%
20%
10%
0%
Percentage
95/96
96/97
97/98
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06
06/07
07/08
08/09
09/10
Breeding season

Figure 8 (A)

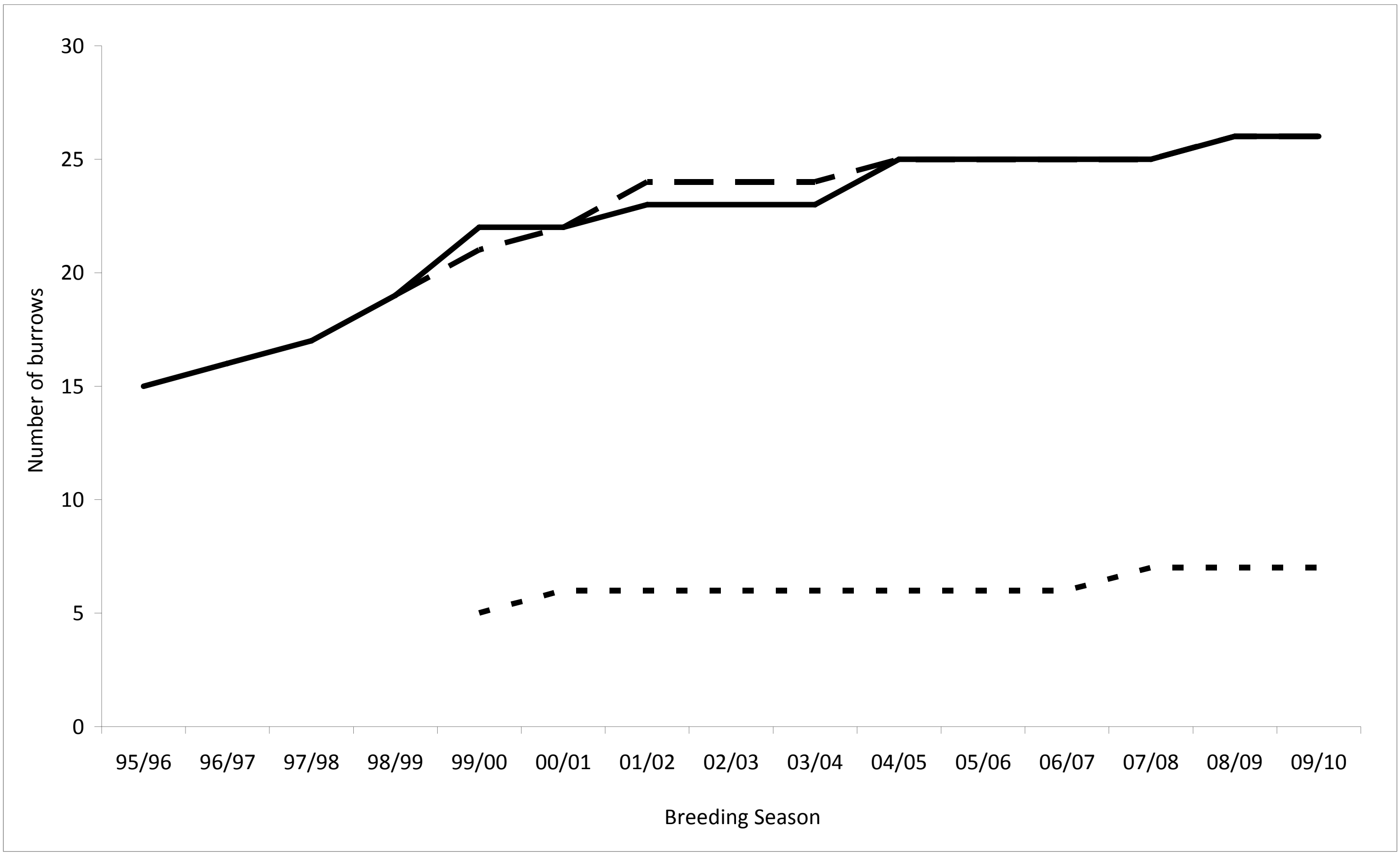

30
25
20
15
10
5
0
Number of burrows
95/96
96/97
97/98
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06
06/07
07/08
08/09
09/10
Breeding Season

Figure 8 (B)

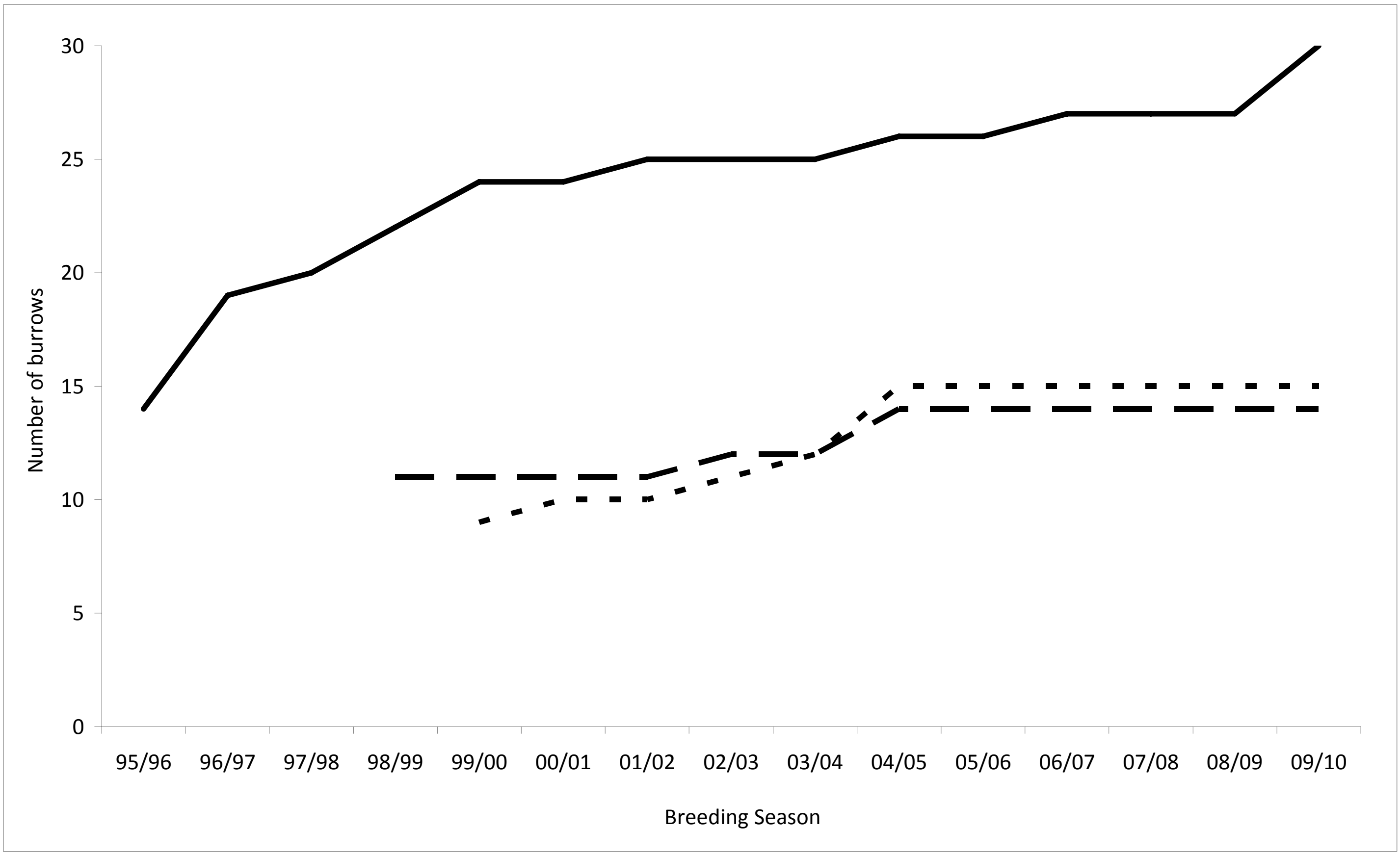

30
25
20
15
10
5
0
Number of burrows
95/96
96/97
97/98
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06
06/07
07/08
08/09
09/10
Breeding Season

Figure 8 (C)

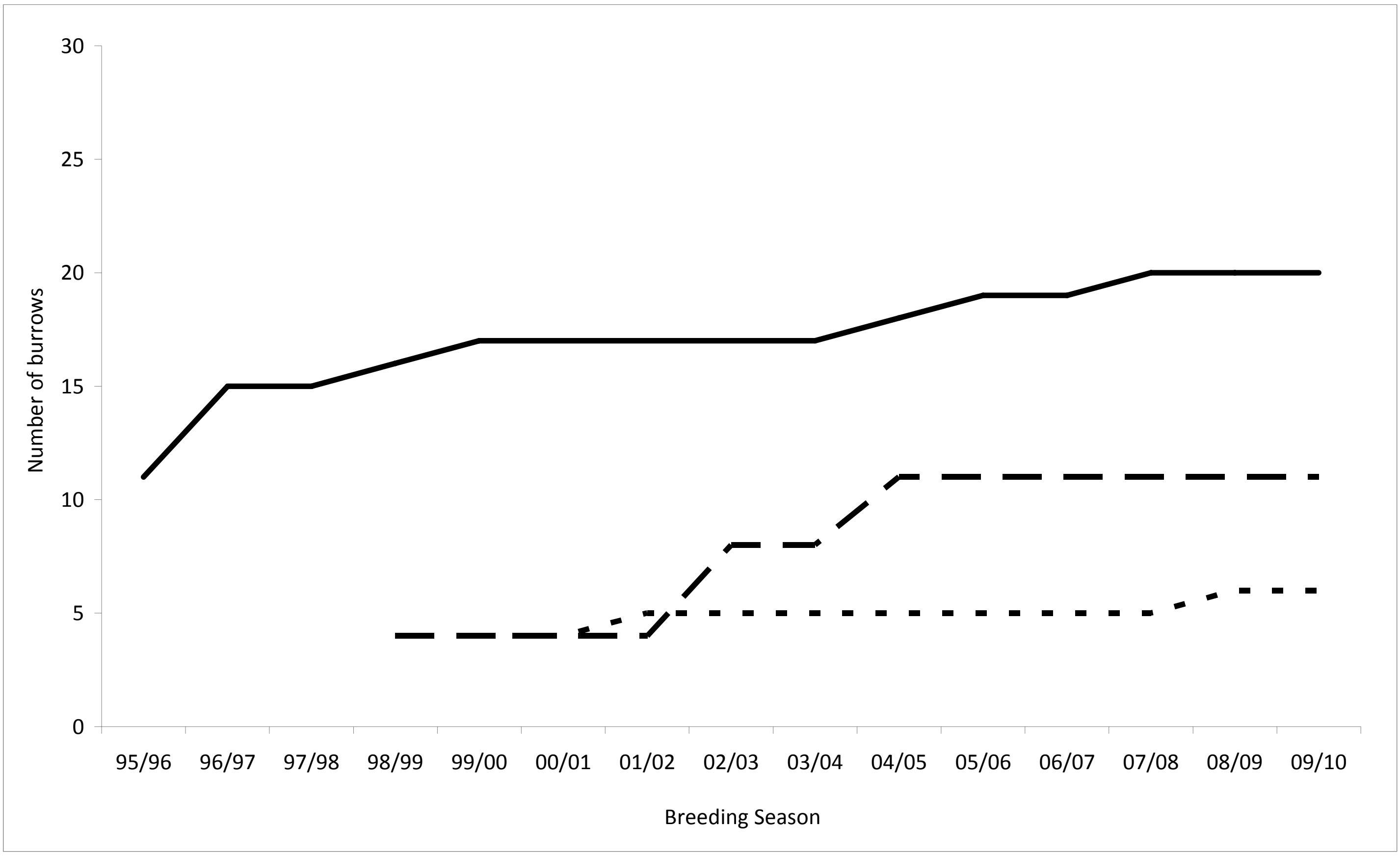

30
25
20
15
10
5
0
Number of burrows
95/96
96/97
97/98
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06
06/07
07/08
08/09
09/10
Breeding Season

Figure 9

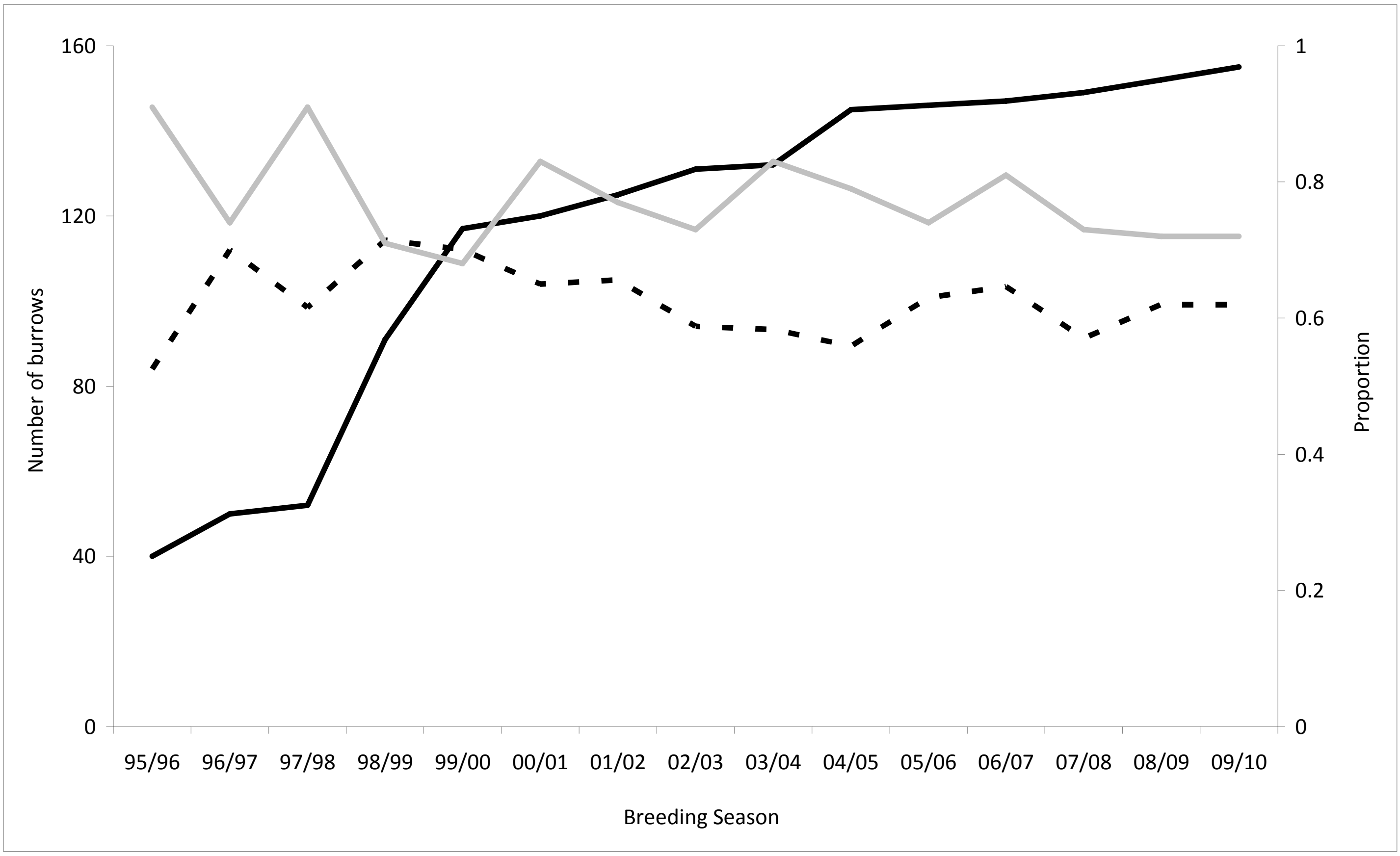
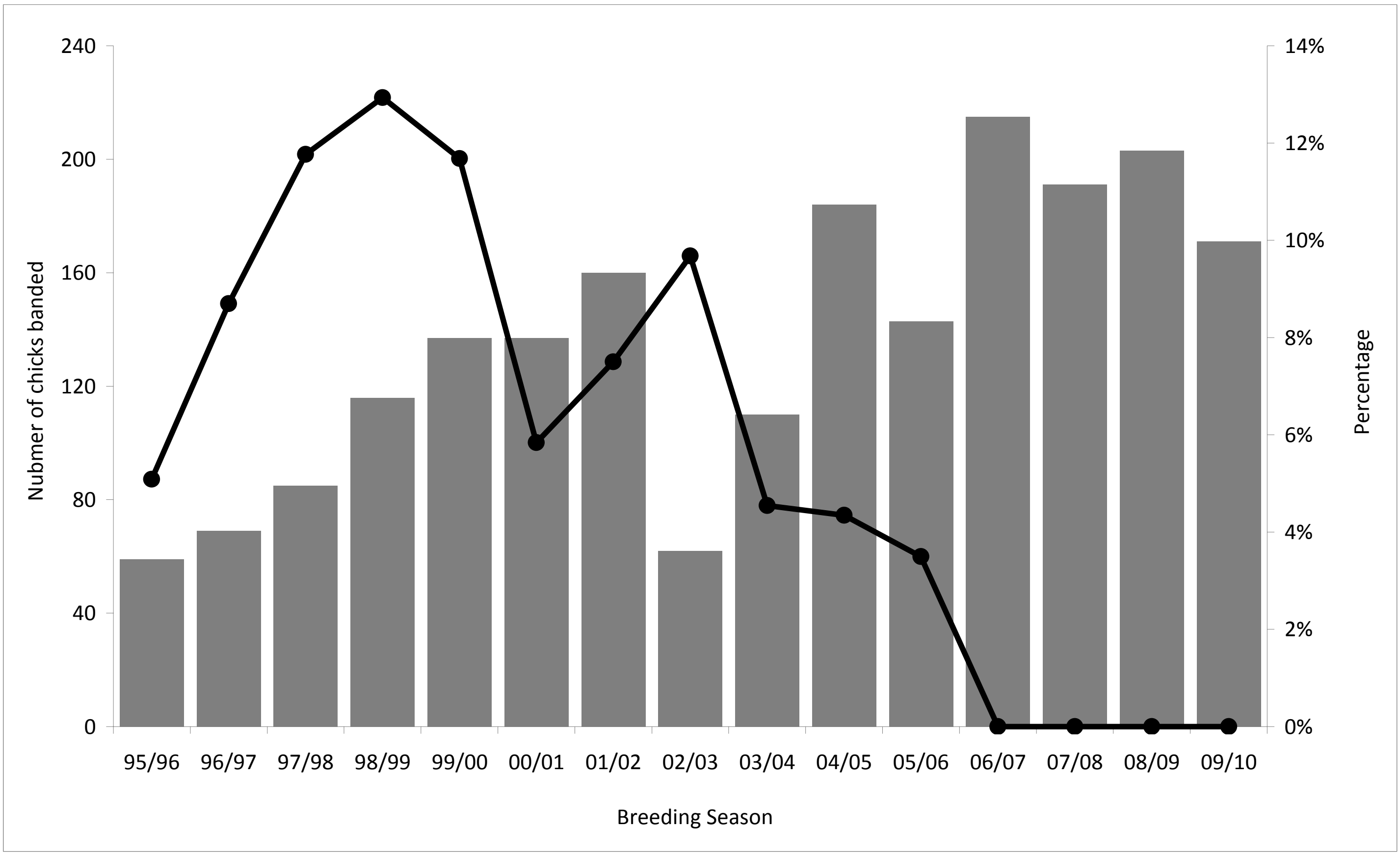

160
120
80
40
0
Number of burrows
1
0.8
0.6
0.4
0.2
0
Proportion
95/96
96/97
97/98
98/99
99/00
00/01
01/02
02/03
03/04
04/05
05/06
06/07
07/08
08/09
09/10
Breeding Season

Figure 10



Nubmer of chicks banded
0
40
80
120
160
200
240
Percentage
0%
2%
4%
6%
8%
10%
12%
14%
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
Breeding Season

Figure 11

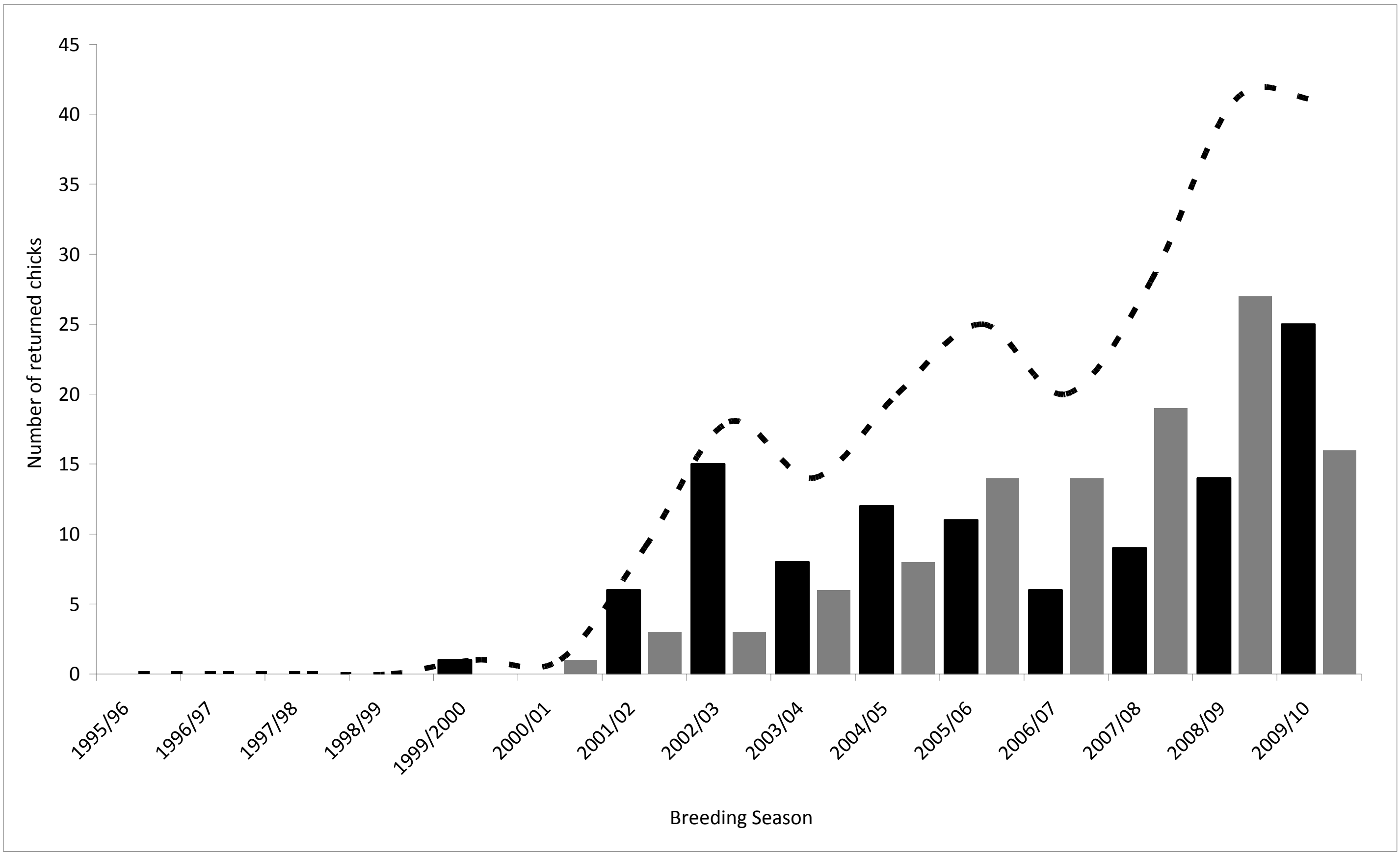

Number of returned chicks
45
40
35
30
25
20
15
10
5
0
1995/96
1996/97
1997/98
1998/99
1999/2000
2000/01
2001/02
2002/03
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
Breeding Season

Figure 12

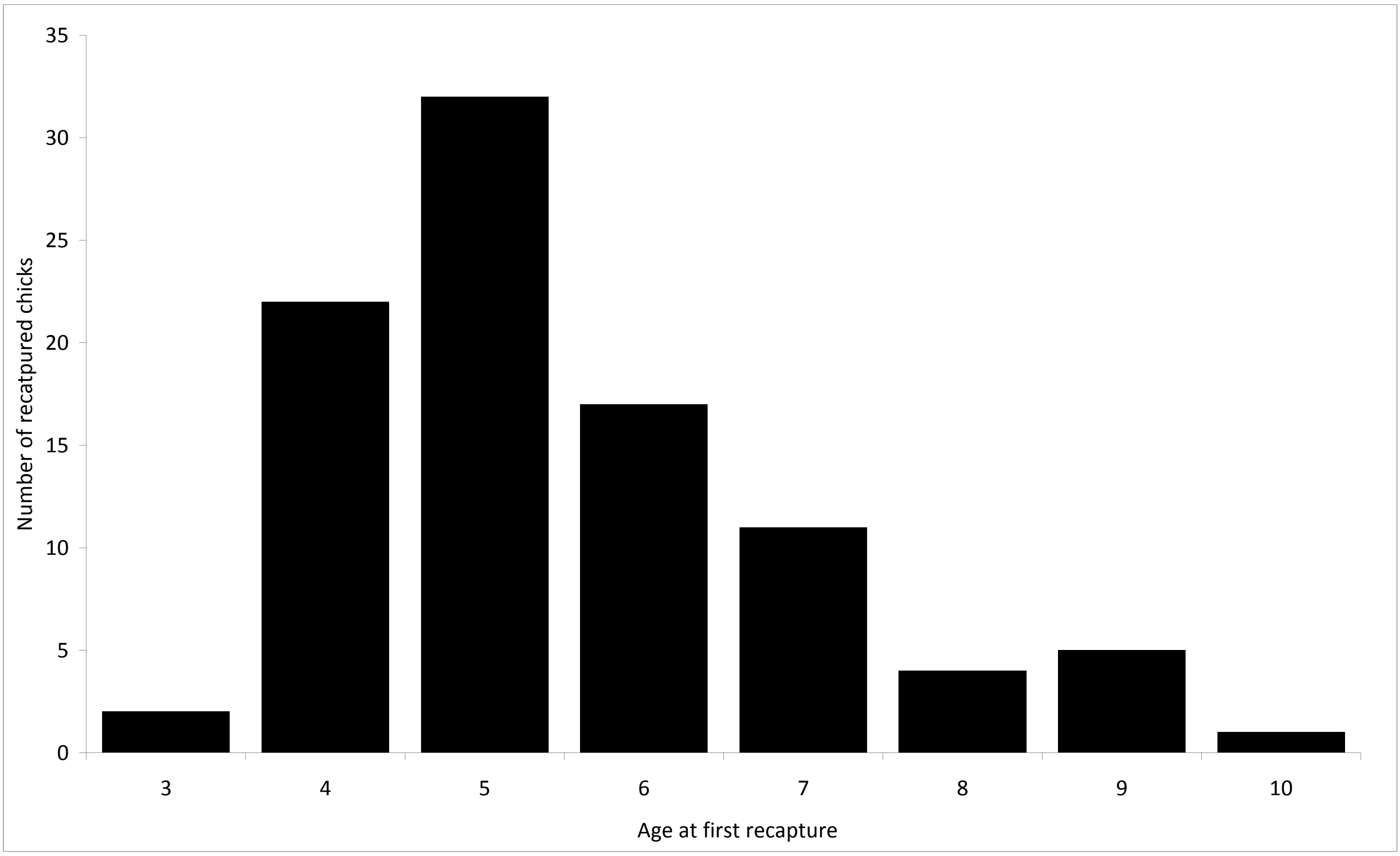
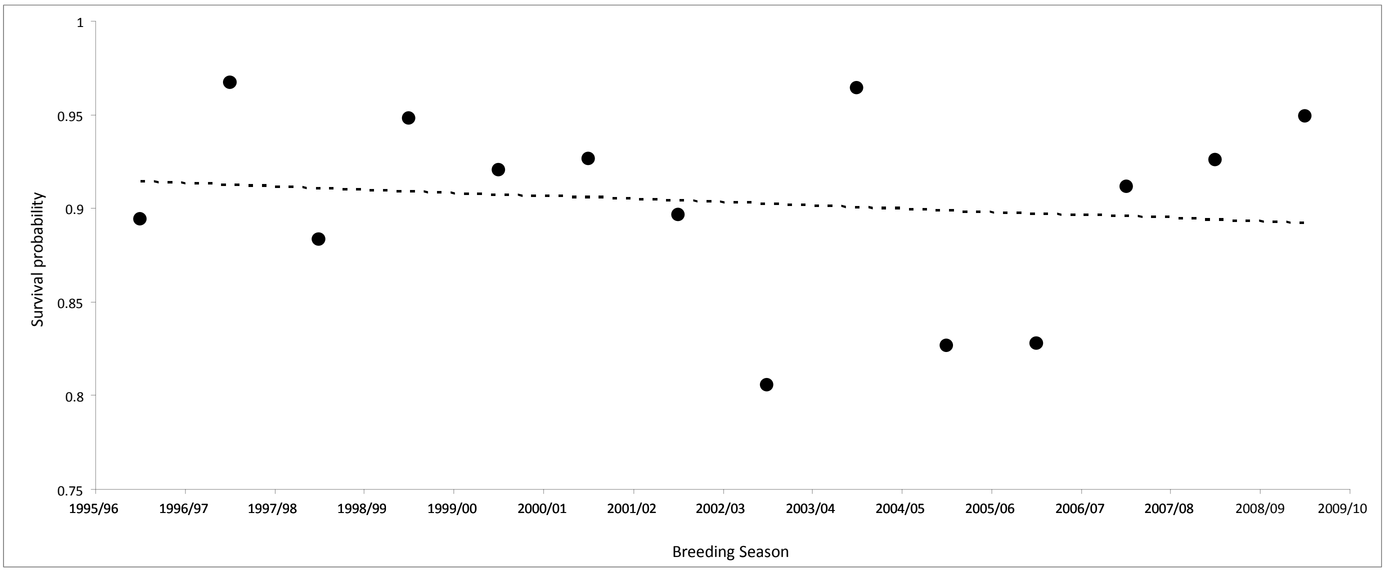

Number of recatpured chicks
0
5
10
15
20
25
30
35
3
4
5
6
7
8
9
10
Age at first recapture

Figure 13


1
0.95
0.9
0.85
0.8
0.75
Survival probability
1995/96
1996/97
1997/98
1998/99
1999/00
2000/01
2001/02
2002/03
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
Breeding Season

Appendix 1.

Burrow	Band	Band	Band	OUTCOME
1	?	?		Non-breeding
2	?	?		Non-breeding
3	31109 (M)	31382 (F)		Dead chick
4	28378 (M)	28100 (F)		Non-breeding
5	27967 (M)	31871 (F)		Chick (35384)
6	14014 (M)	34394 (F)		Chick (35386)
7	31272	30854		Chick (35181)
8	29810	29827	28351	Non-breeding
9	?	?		Non-breeding
10	32901 (M)	29680 (F)		Chick (29096)
11	29068	?		Non-breeding
12	33612 (M)	34427 (F)		Chick (29014)
13	33089 (M)	34760 (F)		Disappeared egg
14	34449	34421		Dead embryo
15	25488	34260		Chick (35361)
16	34949	34976		Chick (29091)
17	31108 (M)	29067 (F)		Dead chick
18	29815	?		Chick (35150)
19	28376 (M)	33324 (F)		Chick (35383)
20	34264 (M)	33683 (F)		Chick (35121)
21	?	34956 (F)		Chick (35189)
22	29847	?		Chick (29048)
23				Empty
24	25663	33465		Chick (35108)
25	31217 (M)	25487 (F)		Chick (35385)
26	23014 (M)	28357 (F)		Chick (35375)
27	?	?		Non-breeding
28				Empty
29	?	?		Non-breeding
30	36151	27976		Crushed egg
31	33052 (M)	33003 (F)		Chick (35158)
32 (P1)	31537	34783		Chick (35371)
33	28076	31244		Chick (35352)
34	31121 (M)	31248 (F)		Chick (35390)
35	33654	32040		Chick (35109)
36	33460 (M)	34259 (F)		Chick (29031)
37	?	28036 (F)		Chick (29043)
38				Empty
39	25426 (M)	?		Dead chick

40	36166	34384		Chick (35138)
41	31112	31029		Chick (35351)
42	31498	33948		Crushed egg
43	25546 (M)	31586 (F)		Non-breeding
44	31130	25424		Chick (29045)
45	34450	?		Non-breeding
46	34360 (M)	28813 (F)		Chick (29038)
47	31018 (M)	33786 (F)		Chick (29047)
48	27969	28400		Non-breeding
49	36190 (M)	31243 (F)		Chick (35123)
50	31282 (M)	33747 (F)		Chick (35124)
51	22169 (M)	29670 (F)		Chick (35378)
52	31289	34961		Chick (35377)
53	34964	34764		Chick (35376)
54				Empty
55 (P1)	23635	33638		Chick (35354)
56 (P1)	29616	27960		Dead chick
57 (P1)	31153	33725		Chick (35356)
58 (P1)	31205	?		Chick (35358)
59 (P1)	27962	31125		Chick (35359)
60 (P1)	31032	25455		Chick (35366)
61 (P1)	29818	28355		Dead chick
62 (P1)	31257	?		Chick (35373)
63 (P1)	31424	34391		Chick (35374)
64 (P1)	31366	33323		Chick (35360)
65	27548	?		Dead chick
66	30874	34853		Chick (35397)
67 (K1)	31270	31271		Chick (35400)
68 (K1)	31172	32005		Chick (35154)
69	27604	31240		Dead embryo
70	29824	31992		Chick (35156)
71 (K1)	34351	34352		Chick (35155)
72 (K1)	?	?		Non-breeding
73 (K1)	28572	36206		Chick (35179)
74 (K1)	31974	29693		Chick (35182)
75 (K1)	27977	33068		Abandoned
76 (K1)	31089	33758		Chick (35183)
77 (K1)	28390	27702		Non-breeding
78 (K1)	30867	27971		Dead chick
79 (K1)				Empty
80 (K1)	25404	29682		Chick (35184)

81 (K1)	28046	28370		Non-breeding
82	31478	34736	33453	Chick (29093)
83	34353	34781		Chick (29095)
84	29677	33463		Dead embryo
85 (S1)	29848	33762		Non-breeding
86 (S1)	28368	29099		Crushed egg
87 (S1)	29849	?		Disappeared egg
88 (S1)	?	?		Non-breeding
89 (S1)	31495	30910		Chick (35102)
90 (S1)	33097	32935		Chick (35104)
91 (S1)	?	?		Non-breeding
92 (S1)	32928	33660		Chick (35107)
93				Empty
94	34777	?		Chick (35114)
95	34938	34262		Dead embryo
96 (P1)	29819	29820		Non-breeding
97	34385	36194		ChicK (35141)
98	?	?		Non-breeding
99	31262	33461		Non-breeding
100	29660	32924		Chick (35382)
101 (K1)	25692	25588		Chick (35186)
102 (K1)	27970	?		Dead embryo
103 (K1)	25673	29690		Chick (35153)
104 (K1)				Empty
105	29823	?		Non-breeding
106	31038	25458		Chick (35120)
107	33764	33799		Chick (35126)
108	27952	28369		Chick (35112)
109	25635	31052		Chick (29097)
110 (S1)	31008	29058		Chick (35105)
111 (S1)	?	?		Crushed egg
112 (S1)	28037	?		Chick (35106)
113 (S1)	29837	33322		Non-breeding
114 (S1)	31142	34953		Chick (29050)
115	29065	29077		Non-breeding
116 (P1)	25435	25411		Chick (35370)
117	25664	?		Non-breeding
118	31985	36164		Chick (35101)
119	31055	?		Chick (35353)
120 (P1)	32099	29081		Infertile
121 (P1)	33035	29817		Chick (35357)
122 (P1)	27961	34423		Dead embryo

123 (P1)	31053	31246		Chick (35368)
124 (P1)	28356	28032		Chick (35372)
125 (P1)	?	?		Non-breeding
126 (P1)	33477	33723		Dead embryo
127	34747	?		Chick (29046)
128	31054	?		Disappeared egg
129				Empty
130	29821	36173		Infertile
131	36180	34948		Non-breeding
132 (K2)	29842	27973		Dead embryo
133 (K2)	25525	32027		Chick (35171)
134 (K2)	33313	34721		Chick (fledged before banding)
135 (K2)	25447	34377		Chick (35166)
136 (K2)	29699	33485		Chick (35164)
137 (K2)	25494	31572		Chick (35170)
138 (K2)	33306	31565		Chick (35177)
139	27968	33248		Non-breeding
140	29809	36179		Chick (35159)
141 (S2)	?	?		Crushed egg
142 (S2)	28026	28027		Chick (29039)
143 (K2)	36182	?		Non-breeding
144 (K2)	34417	36175		Chick (35176)
145 (K2)	29826	33397	25474	Chick (35173)
146 (K2)	25473	25460		Chick (35174)
147 (K2)	29808	34430	34935	Rat predation
148 (K2)	27534	25483		Chick (35160)
149 (K2)	31569	25401		Chick (35169)
150 (K2)	25471	25493		Chick (35161)
151	34361	25415		Crushed egg
152 (S2)				Empty
153 (S2)	?	?		Non-breeding
154 (P1)	27997	28353		Non-breeding
155 (P2)	33473	33792		Dead chick
156 (P2)	?	?		Non-breeding
157 (P2)	27963	27995		Chick (35362)
158 (P2)	25440	31451		Dead embryo
159 (P2)	31557	25441		Dead embryo
160	?	?		Non-breeding
161 (P2)	31542	31051		Dead embryo
162 (P2)	29658	25442		Chick (35365)
163 (P2)	33658	29064		Dead embryo
164 (P2)	?	?		Non-breeding
165 (K2)	29661	29700		Chick (35175)

166	31122	?		Chick (35355)
167	33657	28012		Abandoned
168 (P1)				Empty
169				Empty
170	31967	33770		Chick (35187)
171	29814	27957		Chick (35140)
172	34727	31048		Chick (35144)
173	28018	31143		Chick (29030)
174	28071	33772		Chick (35131)
175	25503	28001		Chick (35118)
176 (K1)	34378	?		Abandoned
177	36186	?		Chick (29017)
178	25648	?		Dead embryo
179				Empty
180	29832	?		Chick (29021)
181	31561	?		Chick (29025)
182	34864	29085		Disappeared egg
183 (S1)	25661	34365		Dead chick
184	29844	27986	34804	Non-breeding
185 (K1)				Empty
186	29665	31577		Crushed egg
187	31047	31452		Chick (35136)
188	27965	?		Chick (35191)
189	34758	34868		Chick (29002)
190	34738	?		Chick (29018)
191 (P2)	34800	34762		Chick (35363)
192 (S1)	?	?		Non-breeding
193 (K2)	29825	27974		Chick (35168)
194 (K2)	34720	36181		Chick (35167)
195	29840	33327	33311	Dead embryo
196	28361	29079		Crushed egg
197	28016	29084		Disappeared egg
198	31593	34403		Dead chick
199	?	?		Non-breeding
200	28073	34265		Chick (35142)
201	31581	28002		Chick (35122)
202 (P2)	33375	27996		Chick (35364)
203	30930	29668		Chick (35132)
204 (K1)	35000	32957		Chick (35399)
205	25697	29664		Chick (35125)
206	34936	34382		Chick (35128)
207 (P1)				Empty
208 (P1)	28354	?		Chick (35367)

209 (K3)	34416	34374		Chick (35152)
210 (K3)	33310	25691		Chick (fledged before banding)
211 (K3)	33218	27955		Crushed egg
212 (K3)	31023	?		Non-breeding
213 (K2)	?	?		Non-breeding
214 (K2)	29088	33208		Non-breeding
215 (S3)				Empty
216 (S3)	28051	29673		Chick (29035)
217 (K3)	32903	31991		Chick (35151)
218	34388	?		Chick (35133)
219 (P3)	?	?		Non-breeding
220 (P3)	?	?		Non-breeding
221 (P3)	29695	33704		Chick (35146)
222	28049	34395		Chick (35388)
223 (S3)	33673	?		Dead embryo
224 (P3)	27958	27992		Crushed egg
225 (S3)	13634	?		Abandoned
226 (P3)	27058	28041		Chick (35145)
227 (K1)	25509	25407		Chick (35178)
228	27954	33633	33308	Disappeared egg
229 (P3)	33756	27993		Chick (35148)
230 (P3)				Empty
231 (P3)	25586	27994	36195	Non-breeding
232				Empty
233	29698	?		Chick (29027)
234	29835	?		Chick (29029)
235	28044	25566		Dead chick
236	?	?		Non-breeding
237	34795	28359		Chick (29098)
238 (S1)				Empty
239	32013	25700		Chick (35149)
240	32915	34980		Chick (fledged before banding)
241	27982	27998		Non-breeding
242	28366	28099		Non-breeding
243	30807	33264		Chick (35393)
244	29841	33800		Disappeared egg
245 (K1)	29843	34753	33315	Chick (35185)
246 (P3)				Empty
247				Empty
248	29831	?		Dead embryo
249				Empty

250	30924	31168		Chick (29016)
251 (K3)				Non-breeding
252	34794	34852		Chick (29007)
253 (K3)				Empty
254 (P1)	?	?		Non-breeding
255 (K2)	34431	29089		Chick (35172)
256	?	?		Non-breeding
257	30877	?		Chick (29001)
258 (P3)				Empty
259	29813	32025	33495	Chick (35127)
260 (S3)	25651	14009		Chick (29033)
261	32021	?		Chick (29032)
262	32902	34739		Chick (29024)
263	29833	29073		Non-breeding
264				Empty
265 (K2)	33312	33492		Chick (35162)
266	31975	25444		Chick (35392)
267	31956	28371		Non-breeding
268				Empty
269	34958	34383		Chick (35129)
270	33669	33791		Chick (35137)
271 (K1)	32920	?		Non-breeding
272	?	?		Chick (35103)
273				Empty
274	23034	33706		Chick (35110)
275	28360	?		Non-breeding
276				Empty
277	33620	33619		Chick (29006)
278	25695	34751		Chick (29010)
279	?	?		Non-breeding
280	32929	36184		Dead chick
281	33602	34733		Chick (29011)
282	33652	33643		Chick (29022)
283	29836	?		Non-breeding
284	?	?		Non-breeding
285	?	?		Non-breeding
286	33614	?		Non-breeding
287	33699	36187		Chick (29036)
288	33705	33671		Chick (29037)
289	27953	36192		Chick (35113)
290	?	?		Non-breeding
291	36161	33618		Non-breeding
292	34734	?		Chick (29003)
293	33317	?		Chick (29004)
294	27984	36185		Non-breeding
295	33630	29812		Chick (35117)

296	33682	?		Non-breeding
297	28034	33755		Dead chick
298	34429	33646		Rat predation
299	27966	34937		Dead chick
300	33716	33497		Chick (29008)
301	33768	34397		Chick (29094)
302	33686	33787		Chick (29012)
303	33797	34977		Chick (29013)
304	34370	?		Chick (29015)
305	33645	33788		Chick (29023)
306				Empty
307	33796	34876		Crushed egg
308				Empty
309	30858	33476		Non-breeding
310 (S2)				Empty
311 (S2)				UNKNOWN (possibly Cook's petrel burrow)
312 (S2)	28364	29086		Chick (29041)
313 (S2)	28000	29845	34865	Abandoned
314 (S2)				Empty
315	33714	33318		Chick (29009)
316	33715	33325		Chick (29090)
317 (P2)				Empty
318	29062	?		Non-breeding
319	?	?		Chick (out of reach)
320	?	?		Non-breeding
321	33771	34968		Chick (35190)
322 (P3)	25555	34300		Chick (31547)
323	27526	27504		Chick (35111)
324	34952	13638		Chick (29049)
325	?	?		Abandoned
326	25688	34742		Chick (35188)
327 (K2)	34898	?		Non-breeding
328	33093	33491		Dead embryo
329 (P3)	29063	31970		Non-breeding
330	33090	33099		Chick (35387)
331	34967	36174		Chick (35389)
332	34730	?		Chick (35192)
333	32927	29082		Chick (35193)
334	36152	34950	29078	Non-breeding
335	28358	34379		Chick (29092)
336 (P2)				Empty
337 (S1)	?	?		Non-breeding
338	34766	34376		Chick (35163)
339	33493	34722		Chick (35165)
340	33458	34357		Chick (29020)
341	?	?		Non-breeding
342 (S2)	33266	?		Chick (29042)

343(S2)				Empty
344 (S2)	34984	33471		Dead embryo
345	34861	34362		Chick (29040)
346				Empty
347	33496	34401		Chick (29005)
348 (P3)				Empty
349 (P3)	34387	?		Infertile
350 (P2)	?	?		Non-breeding
351 (P1)	34266	34390		Chick (35369)
352	34966	33481		Chick (35381)
353	36172	?		Chick (35379)
354	33480	34393		Chick (35380)
355	33467	36191		Chick (35130)
356	27978	33719		Non-breeding
357	29061	34982		Non-breeding
358	33494	33474		Chick (35115)
359	34940	34771		Chick (35119)
360	33482	25510		Dead chick
361	14018	31264		Chick (35396)
362 (K1)	33490	?		Non-breeding
363	34267	34415		Non-breeding
364	34854	34414		Chick (35157)
365 (K2)				Empty
366 (K1)				Empty
367				Empty
368	33451	?		Rat predation
369 (S1)				Empty
370	34355	28015		Rat predation
371	34358	34717		Chick (29019)
372	34407	?		Chick (35116)
373	36153	36199		Chick (29026)
374	34420	?		Chick (35139)
375 (P1)	27959	36169		Non-breeding
376	27999	29846	36205	Chick (29044)
377				Empty
378 (K3)	?	?		Non-breeding
379 (K2)	?	?		Non-breeding
380	27972	29960		Chick (35180)
381	29822	36201		Non-breeding
382	29834	28362		Chick (29028)
383 (S1)				Empty
384	27964	34386		Chick (35143)
385	27975	29807		Non-breeding
386	27991	28352		Non-breeding
387 (S3)	28363	29100		Chick (29034)
388	31494	?		Rat predation
389	28045	29066		Crushed egg
390	28375	34263		Non-breeding

391	28377	33244		Non-breeding
392 (K1)				UNKNOWN (possibly Cook's petrel burrow?)
393	28812	29083		Chick (35134)

APPENDIX 2

UPDATE OF SEABIRD MODELLING REPORTED IN FRANCIS AND BELL (2010)

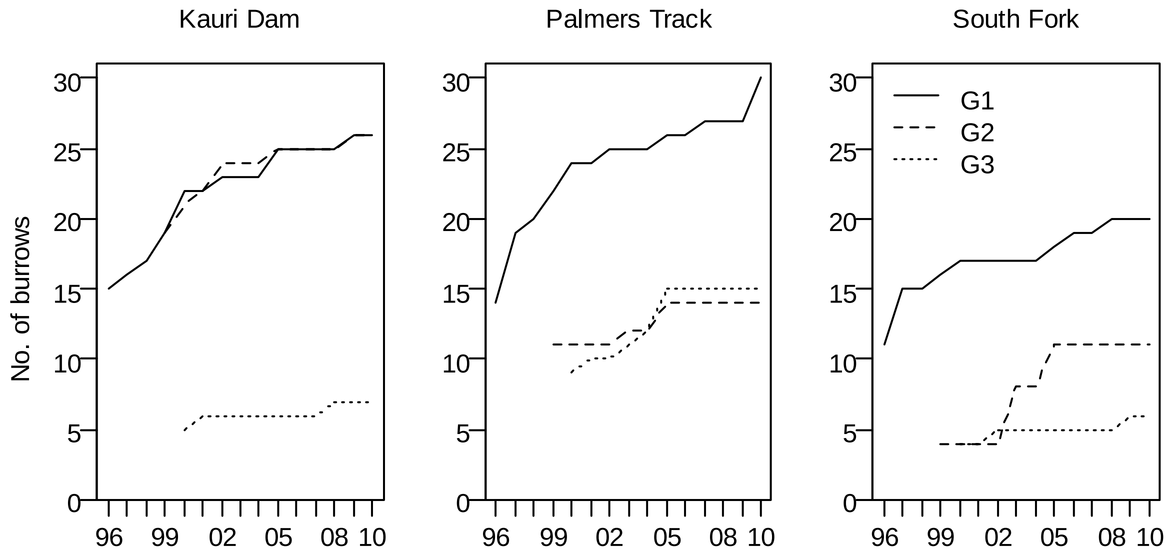
CENSUS GRID COUNTS

A check of the original census grid counts revealed several slight errors. The revised data, including the 2010 counts, show trends broadly similar to those found by Francis & Bell (2010, Table 1, Figure 1).

Table 1 Original (as in Table 4 in Francis & Bell 2010) and revised estimates of total numbers of burrows in all census grids from 2000 to 2010, and the percentage that were used for breeding.

		Year										
	Version	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
No. burrows	Original	117	122	125	132	134	147	147	148	148	155	–
	Revised	117	120	125	131	132	145	146	147	149	152	155
% breeding	Original	69.2	62.3	64.8	58.3	58.2	55.8	63.3	64.9	57.4	61.9	–
	Revised	70.1	65.0	65.6	58.8	58.3	55.9	63.0	64.6	57.0	62.5	54.2

Figure 1 Counts of burrows between 1996 and 2010 in nine census grids, with three grids (G1, G2, G3) in each of three locations: Kauri Dam, Palmers Track and South Fork (as a revision and update of Figure 3 in Francis & Bell 2010).



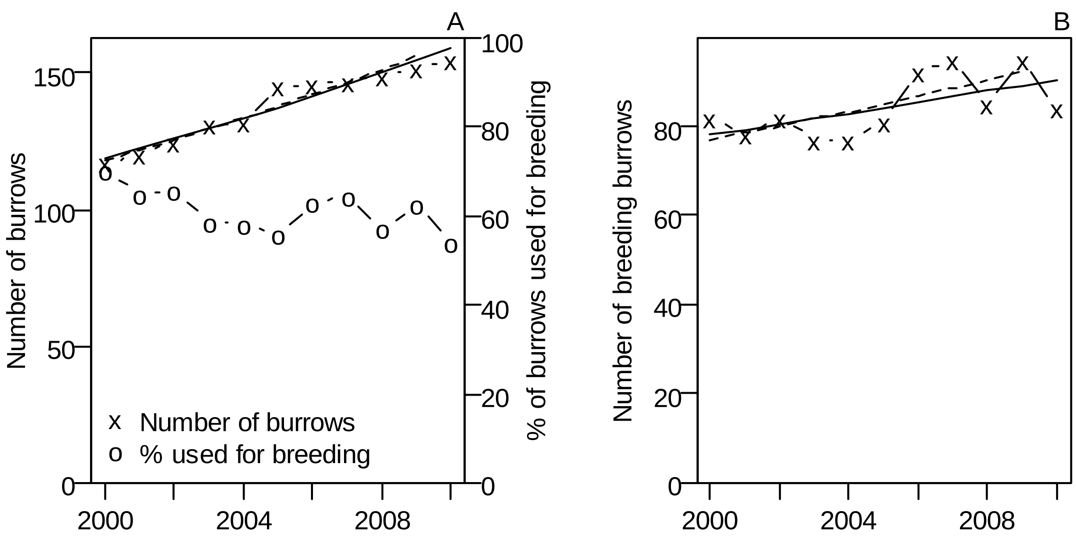
From the census grid data, Francis & Bell (2010) inferred an average annual increase in the number of breeders of 2.2%–3.1% per year. We present updates of these estimates using the original method of calculation and two alternative methods (Table 2). In all cases the lower limit of the range of estimates is 0.7 times the upper limit to allow for the fact that between 0 and 30% of burrows not previously detected could be overlooked in any year. Francis & Bell (2010) calculated their upper limit using just the 2000 and 2009 burrow counts [$(155/117)^{1/9}$ = 1.032]. The same method, applied to the updated data produced slightly lower estimates (compare lines 1 and 2, Table 2). In retrospect, it seems that it would have been more robust to base the calculation on the counts for all years (by regressing log counts on years), and not just the first and last years. This was the second method, illustrated in Figure 2A; its estimates were slightly higher than those from the original method (compare lines 2 and 3, Table 2). Both these methods use the assumption that there has been no long-term trend in the percentage of burrows that was used for breeding in each year. However, with an additional year's data, there is now a statistically significant downward trend in this percentage (P =

0.045, see Figure 2A). Though the significance of this trend is marginal (it is not significant if we omit either the first (P = 0.19) or last year (P = 0.15)), it suggests that we should calculate the population growth rate by fitting similar regression lines to counts of breeding burrows (as illustrated in Figure 2B). This produced lower estimates of growth (last line, Table 2).

Table 2 Estimates of the annual rate of increase in the number of breeders from census grid data using three methods of calculation over the periods 2000–2009 and 2000–2010.

		Annual rate of increase (% per year)	
Method	Data	2000–2009	2000–2010
Francis & Bell (2010)	Original	2.2–3.1	
Same method	Updated	2.1–3.0	2.0–2.9
Regression on all burrow counts	Updated	2.2–3.1	2.1–3.0
Regression on breeding burrows	Updated	1.4–2.0	1.0–1.5

Figure 2 Trends in the number of burrows in census grids ('x') with regression lines (fitted to all years (solid lines) or to 2000–2009 (broken lines)): A, for all burrows; and B, for breeding burrows. Also plotted in panel A is the annual percentage of burrows used for breeding ('o'). (Regression lines are exponential curves calculated by regressing log(y) on x.)



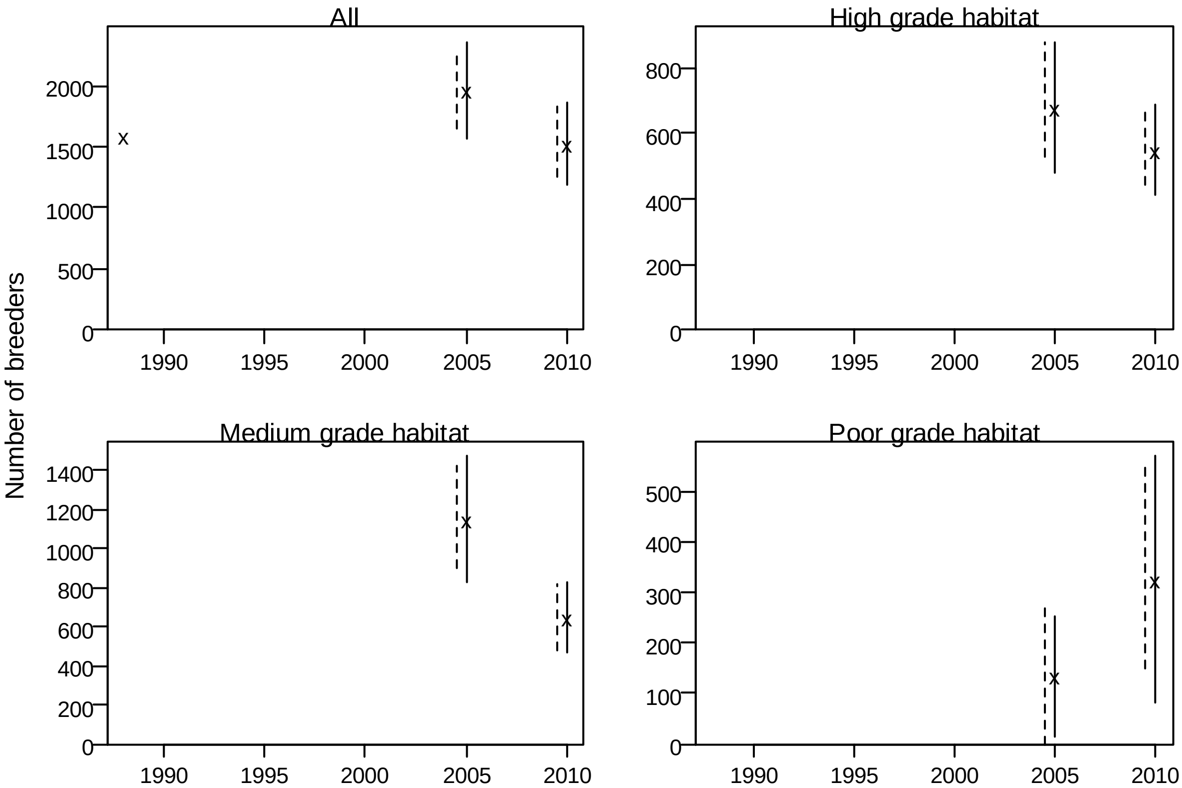
TRANSECT COUNTS

The transect survey of 2005 (Francis & Bell 2010) was repeated in 2010 with the same design, and same number of transects, except that 16 of the transects surveyed were new, and 10 were repeats of 2005 transects (these were 2005 transects 6, 8, 10, 11, 17, 18, 19, 25, 38, and 41, which were chosen at random). The 2010 estimate of population size was 22% less than that in 2005, which is a marginally significant change ($Z = (1964-1525)/(204^2 + 170^2)^{0.5} = 1.65$, $P = 0.098$, two-sided test), and 5% less than the 1988 estimate of 1598 (which was based on the data of Scofield 1989, Table 3, Figure 3A). The drop since 2005 was largest in the stratum for medium grade petrel habitat, which contained more than half the estimated population in 2005, but was also seen in the high grade stratum (Figure 3B, Figure 3C).

Table 3 Estimated densities of breeding burrows and numbers of breeding birds, by stratum (with s.e.s in parentheses) from transect counts in 2005 and 2010.

Stratum	Area (ha)	Burrow density (no./ha) 2005	Burrow density (no./ha) 2010	Population number (breeders) 2005	Population number (breeders) 2010
Non-petrel habitat	1.75	0	0	0	0
Poor grade	13.6	4.9 (2.2)	12.0 (4.6)	134 (61)	327 (124)
Medium grade	15.3	37.6 (5.4)	21.2 (3.0)	1150 (166)	649 (93)
High grade	4.67	72.8 (11.0)	58.8 (7.6)	680 (103)	550 (71)
All	35.3	29.3 (3.0)	22.7 (2.5)	1964 (204)	1525 (170)

Figure 3 Comparison of all transect-based estimates of population size (numbers of breeders) for the whole study area, and for each habitat stratum. Vertical lines are 95% confidence intervals estimated from s.e.s (solid lines) or bootstrap resampling (broken lines).

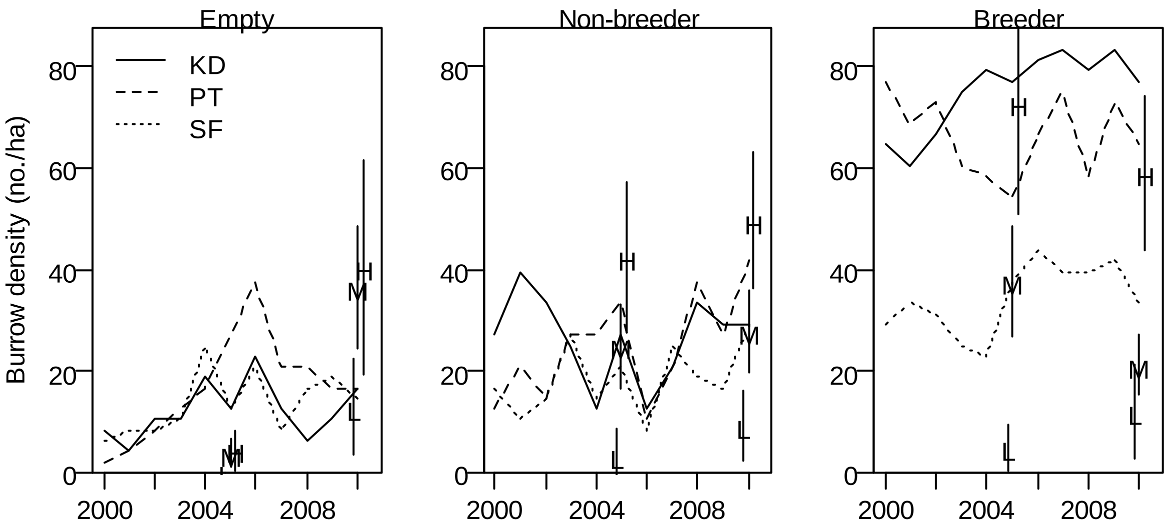


There are two striking, but unexplained, patterns in the incidence of empty burrows. The first, in the 10 transects that were repeated, there was a huge increase in the numbers of empty burrows seen (Table 4). Also, densities of empty burrows from the two transect surveys are markedly different from those from the census grids (Figure 4). Note that the census grids are mostly in the high grade habitat stratum, with some overlap with the medium grade stratum (see Figure 4 in Francis & Bell 2010).

Table 4 Comparison of burrow counts in 2005 and 2010 for the 10 transects that were repeated. Counts are broken down by burrow type (empty, non-breeder, and breeder) and habitat type (poor, medium, and high grade).

	Empty burrows				Non-breeder burrows				Breeder burrows			
Year	Poor	Med.	High	All	Poor	Med.	High	All	Poor	Med.	High	All
2005	0	1	3	4	0	19	19	38	2	24	32	58
2010	0	17	14	31	1	21	24	46	0	15	27	42

Figure 4 Comparison of estimated burrow densities, by type (empty, non-breeder, and breeder), from the three groups of census grids (lines) and from the three habitat strata ('L' = low grade; 'M' = medium grade; 'H' = high grade) in the 2005 and 2010 transect surveys. Vertical lines through transect-survey estimates are 95% confidence intervals.



POPULATION MODELLING

The final population model of Francis & Bell (2010), BPET7, was updated to include the additional year's mark-recapture data and the 2010 population estimate from transect counts. The two population estimates were assumed to be normally distributed with c.v.s (calculated from the s.e.s of Table 3) of 0.10 and 0.11, respectively. The additional data made little difference to estimated probabilities of survival and resighting (Figure 5), age at first breeding (Figure 6, the estimated mean age at first breeding dropped from 6.7 y to 6.6 y), or adult transition parameters (Table 5).

Table 5 Comparison of original and updated estimates of transition parameters for pre-breeders and adults (pbr = pre-breeder; nbr, non-breeder; sbr = successful breeder; fbr = failed breeder; oth = breeding outside study area). Values written as '–' are zero by definition.

	Original					Updated				
	pbr	nbr	fbr	sbr	oth	pbr	nbr	fbr	sbr	oth
pbr	0.24	–	0.12	0.40	0.25	0.23	–	0.11	0.40	0.26
nbr	–	0.57	0.10	0.33	–	–	0.54	0.10	0.36	–
fbr	–	0.21	0.18	0.60	–	–	0.22	0.17	0.61	–
sbr	–	0.15	0.20	0.65	–	–	0.15	0.19	0.66	–

Figure 5 Comparison of original and updated estimates of survival and resighting probabilities (br = breeder; sbr = successful breeder; fbr = failed breeder; nbr, non-breeder).

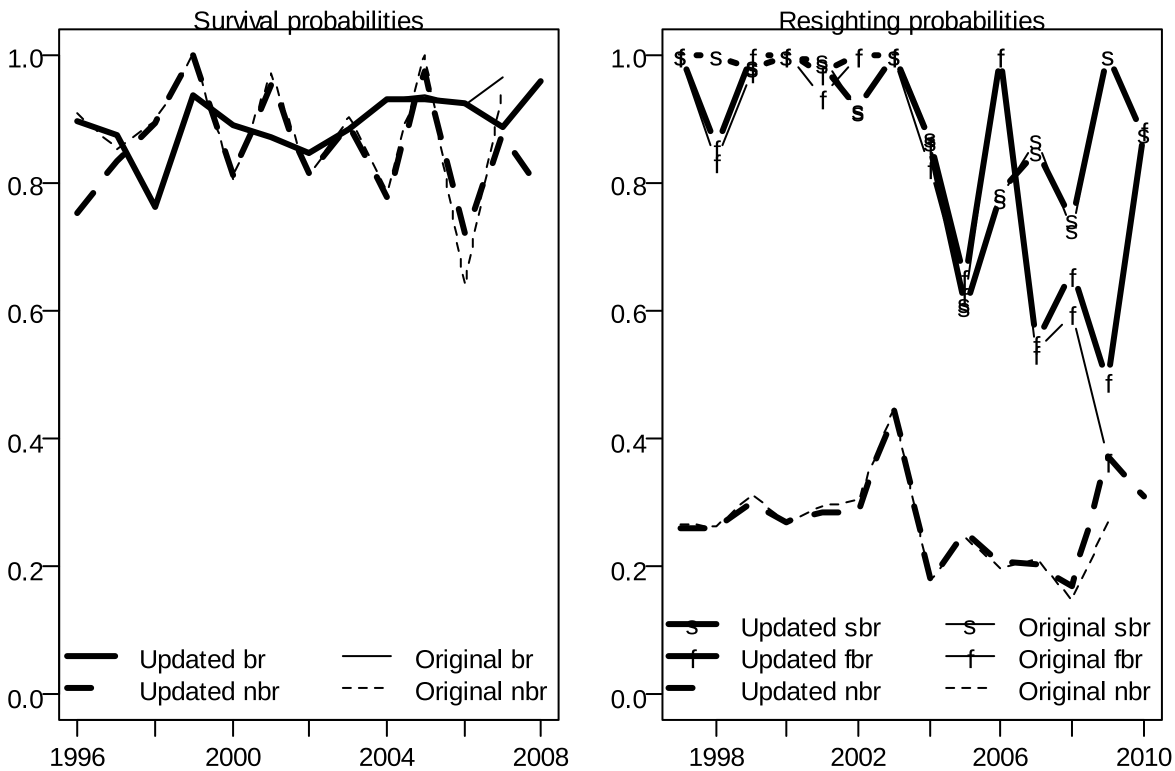
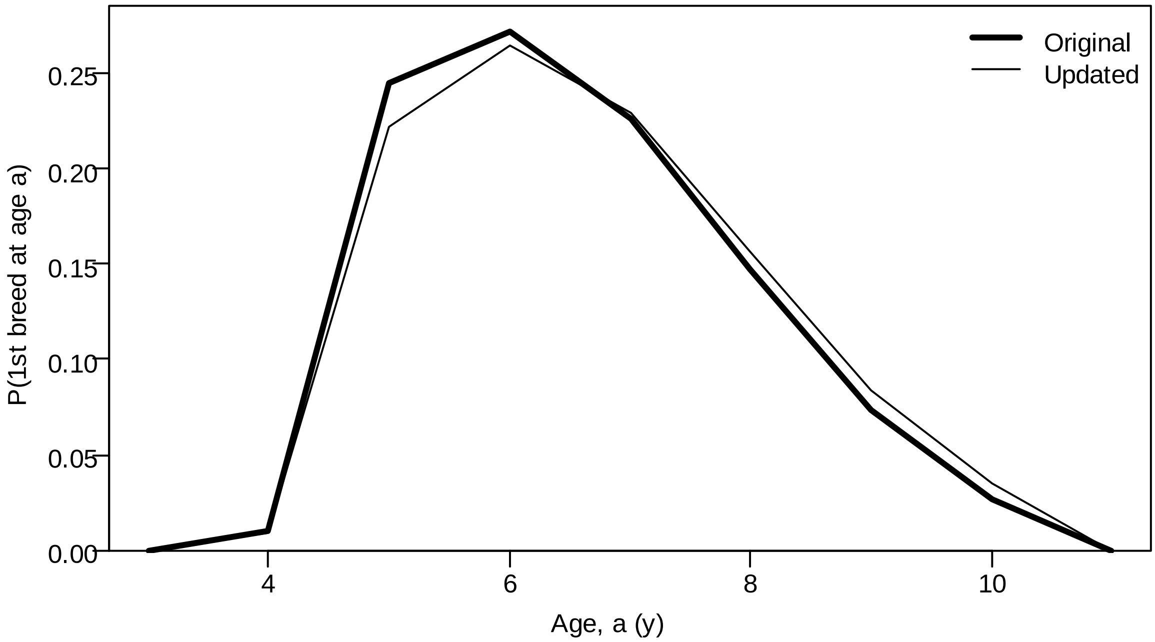


Figure 6 Comparison of original and updated estimates of the distribution of ages at first breeding.



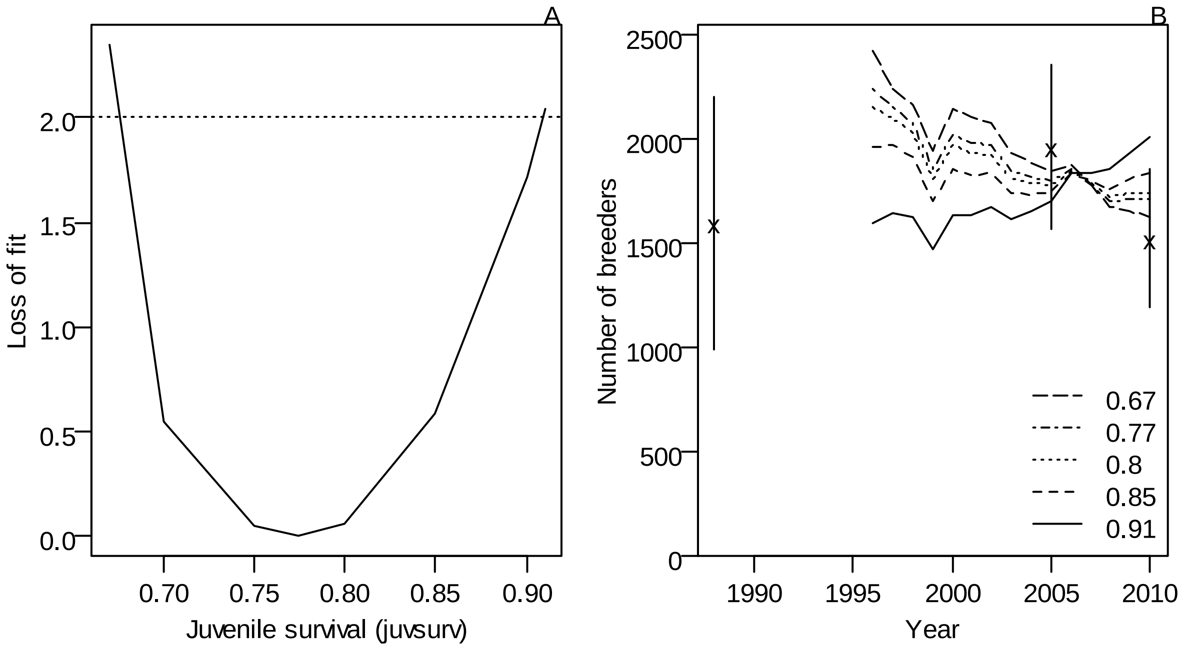
The greatest uncertainty in the model estimates relates to the parameter juvsurv (the annual survival probability for juveniles). The mark-recapture data contain very little information about this parameter, whose value is driven mostly by the two population estimates. This uncertainty was explored by means of a likelihood profile on juvsurv, which showed that the 95% confidence interval for this parameter is rather wide (0.67–0.91) (Figure 7A). This leads to a wide confidence interval for the mean rate of population growth over the modelling period: from –2.5% per year to +1.6% per year (Figure 7B; Table 6). This uncertainty does not affect estimates of the other important demographic parameters (adult survival and transition parameters, and age at first breeding) whose values are virtually unchanged across this profile.

Table 6 Relationship between the annual probability of juvenile survival and the estimated rate of population increase (as calculated from the trajectories in Figure 7B using a regression approach like that for Table 2).

Juvenile survival (proportion/yr)	0.67	0.7	0.75	0.77	0.8	0.85	0.9	0.91
Rate of population increase (%/yr)	–2.5	–2.6	–2.1	–1.8	–1.4	–0.5	1.1	1.6

There are two pieces of information that are relevant to population growth rates, but which could not be provided to the population model: the 1988 population estimate of 1598 breeders (s.e. 304, see Table 2 in Francis & Bell 2010); and the estimates of population growth rate from the census grid data (Table 2). It is difficult to know how much weight to give to this additional information. There is clearly doubt as to the comparability of the 1988 population estimate with the more recent estimates (see Discussion in Francis & Bell 2010), and trends in the census grids may not be representative of those in the whole population. However, it seems most likely that the mean rate of change of this population over the study period has not exceeded 2% per year, though the direction of change is uncertain.

Figure 7 Results of a likelihood profile on juvsurv (annual probability of juvenile survival), showing (as functions of juvsurv) A, the loss of fit (the horizontal dotted line indicates a 95% confidence interval for juvsurv); and B, population trajectories [also shown in this panel are the three population estimates from transect counts (‘x’), and their 95% confidence intervals (vertical lines); note that the 1988 population estimate was not used in the model].



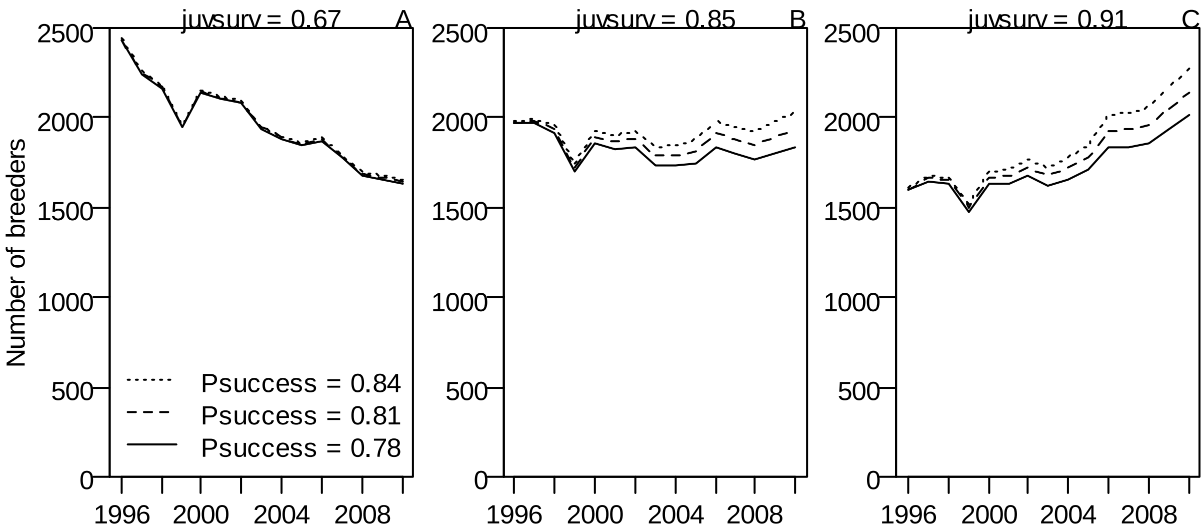
THE EFFECT OF PREDATION: The estimated probability of breeding success was 0.78 (this is model parameter Psuccess, which is defined as the number of live fledglings in any year divided by the number of pairs that produced an egg). Nine causes of breeding failure were identified, two of which were associated with predation (by rats or cats). From the relative probabilities of these causes (Table 7) we can calculate that the removal of predators might be expected to increase the probability of breeding success to 0.81 [= 0.78 + (0.11+0.02)(1–0.78)]. This figure may be conservative, because it is possible that predation was involved in some cases where either the egg or chick disappeared. If all such cases involved predation then the removal of predators would increase Psuccess to 0.84.

Table 7 Causes of breeding failure, and their relative probabilities (averaged over all years). The causes fall in two groups, depended on whether they prevented the egg from hatching or the chick from fledging.

Egg didn't hatch		Chick didn't fledge	
Cause	Probability	Cause	Probability
Dead embryo	0.22	Chick died	0.15
Egg crushed	0.17	Cat predation	0.02
Egg disappeared	0.15	Chick disappeared	0.01
Rat predation	0.11		0.18
Egg infertile	0.10		
Egg abandoned	0.06		
	0.82		

The potential effect of eliminating predation depends strongly on the level of juvenile survival (juvsurv). This was shown by rerunning the population model at three points on the above likelihood profile with Psuccess increased first to 0.81, and then to 0.84. When juvsurv was 0.67 (the lower bound of its 95% confidence interval), the increase in Psuccess made virtually no difference (Figure 8A), whereas for juvsurv = 0.91 (the upper bound) there was a clear change in population trend (Figure 8C), with the mean annual growth rate increasing from 1.6% to 2.1% and 2.5% per year as Psuccess increased. For juvsurv = 0.85, at which the trajectory was close to flat, the effect was slightly less (Figure 8B) (the corresponding growth rates were –0.5%, –0.1%, and 0.2%).

Figure 8 Effect on population trajectories of increasing the probability of breeding success (Psuccess) by removing predators. Each panel shows trajectories associated with one point on the likelihood profile of Figure 7; the solid line is the trajectory from the profile (plotted in Fig. 7B), for which Psuccess = 0.78; the other two lines show how the trajectory changed when Psuccess was increased to 0.81 and 0.84.



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Appendix 3

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	2008/09	3	7	8	10
25536	Male	1998/99	2009/10	3	6		
25546	Male	1998/99	2009/10	7	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	2009/10	5	5	6	6
25658	Male	1999/00	2004/05	1	5	5	5
25659	Female	1999/00	2005/06	1	6	6	6
25661		1999/00	2009/10	2	9	9	10
25663	Male	1999/00	2008/09	6	4	7	8
25664	? Female	1999/00	2009/10	5	3	6	10
25669	Male	1999/00	2005/06	2	5	5	5
25673	Male	1999/00	2009/10	6	5	7	7
25677		1999/00	2006/07	1	7	7	7
28085	Male	1998/99	2005/06	1	5		
29912	? Male	2000/01	2009/10	4	5	5	6
29927		2000/01	2009/10	1	9		
29960		1999/00	2009/10	2	9	9	9
29978		1999/00	2007/08	1	9		
30908	? Male	1995/96	2002/03	1	7		
30924	Male	1995/96	2009/10	8	6	6	6
30930	Male	1995/96	2009/10	10	4	5	5
31076		1997/98	2002/03	1	5		
31080		1997/98	2001/02	1	4		
31081	? Male	1997/98	2002/03	2	4		
31082	Male	1997/98	2001/02	1	4		
31089		1997/98	2009/10	5	5	6	9
31194	Male	1996/97	2001/02	1	5	5	
31322[17]		2005/06	2009/10	1	3		
31366	? Male	1997/98	2009/10	8	5	6	6
31370	? Male	1997/98	2005/06	3	5	8	
31377	? Male	1997/98	2001/02	1	4		
31382	Female	1997/98	2008/09	5	4	5	5
31383	Male	1997/98	2003/04	1	6		
31405		1996/97	2004/05	2	6	7	7
31406	? Female	1996/97	2001/02	1	5		
31413	Female	1996/97	2004/05	1	8	8	8
31415	? Male	1996/97	2003/04	1	7		
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		1998/99	2008/09	1	10	10	10
31490	? Male	1998/99	2002/03	1	4		
31491	Male	1998/99	2005/06	1	7		

[17] The bird was recovered dead on Te Rere Beach (near Goat Island Marine Reserve) on 14 January 2010

31494	Male	1998/99	2009/10	4	6	9	10
31495	Male	1998/99	2009/10	7	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	2009/10	3	8	8	8
31542	Male	1998/99	2009/10	8	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 [18]		2000/01	2007/08	1	7		
32091		2000/01	2007/08	1	7		
32099	? Male	2000/01	2008/09	3	5	8	8
32915		2001/02	2009/10	3	6	6	6
32927	? Male	2001/02	2009/10	3	6	6	6
32957	Female	2001/02	2009/10	4	5	6	7
32979		2001/02	2006/07	1	5		
32980	? Male	2001/02	2005/06	1	4		
33003		2001/02	2008/09	1	7	7	7
33015	Male	2001/02	2009/10	3	6		
33035		2001/02	2008/09	2	6	7	7
33052	Male	2001/02	2009/10	3	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	
33208	? Female	2002/03	2009/10	2	6	7	
33218	? Female	2002/03	2008/09	2	5	6	
33225		2002/03	2006/07	1	4		
33244		2002/03	2008/09	1	6		
33248		2002/03	2008/09	3	6		
33335	Male	2003/04	2008/09	1	5		
33375		2003/04	2009/10	2	5	5	5
33380		2003/04	2007/08	1	4		
33389		2003/04	2009/10	1	6	6	
33397	Male	2003/04	2008/09	1	5	5	5
33518		2005/06	2009/10	1	4		
33540		2005/06	2009/10	1	4		
33550		2005/06	2009/10	1	4		
33556		2005/06	2009/10	1	4		
33737		2002/03	2009/10	1	7	7	7
34276		2004/05	2009/10	1	5		
34320		2004/05	2009/10	1	5		
34338		2004/05	2009/10	1	5		
34804		2004/05	2009/10	2	4	5	5
34828		2004/05	2009/10	1	5		
34843		2004/05	2009/10	1	5		
34901		2004/05	2009/10	1	5		
34903		2004/05	2009/10	1	5		
MEAN (± SEM)				2.3 ± 0.2	5.5 ± 0.2	6.6 ± 0.2	6.9 ± 0.2
30807 [19]	Female	1996/97	2009/10	5	9	9	9

[18] The bird was caught at sea in Ecuador and released alive. It has not been recaptured at the colony to date.

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