

Black petrel (*Procellaria parkinsoni*) population study on Hauturu-o-Toi/Little Barrier Island, 2015/16



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Frontispiece: Niki MacArthur (WMIL, banding a black petrel chick with Adam Clow and Ashe Pollock (Whitianga fishers) assisting, May 2016.

ABSTRACT

This report covers the population monitoring of black petrels, *Procellaria parkinsoni*, on Hauturu-o-Toi/Little Barrier Island in the 2015/16 breeding season. On Hauturu-o-Toi/Little Barrier Island, 149 study burrows were monitored, of which 92 were original study burrows established in 1997 by Mike Imber. Only 56% were being used by breeding pairs, but those pairs had 85.2% breeding success with 69 chicks fledging this season. Twenty automated acoustic devices were placed out across Hauturu-o-Toi/Little Barrier Island in December 2015 and were retrieved in March 2016. Black petrel calls were recorded at five locations: Thumb Ladder (LC7), Summit (LC11), Track 7 junction (LC15), Track 8 highpoint (LC16) and Track 8 halfway to Mt Kiriraukawa (LC17). Thirty-six transects were completed with a total of 49 breeding, 18 non-breeding and 50 unoccupied burrows found ($n = 117$ burrows). Surveys with a seabird-detector dog covered 52.5 km (approximately 73 ha) finding 121 breeding burrows. Analysis of the acoustic recorder units and surveys estimated that there were approximately 620 breeding pairs of black petrels present on Hauturu-o-Toi/Little Barrier Island.

Keywords: black petrel, *Procellaria parkinsoni*, monitoring, transect, population estimate, breeding success, acoustic device, Hauturu-o-Toi/Little Barrier Island, New Zealand

1. INTRODUCTION

The black petrel, *Procellaria parkinsoni*, is a medium-sized endemic seabird which is only known to breed on Hauturu-o-Toi/Little Barrier Island (36°199'S 175°082'E) (hereafter LBI) and Great Barrier Island/Aotea (36°187'S 175°4125'E) (hereafter GBI), New Zealand (Heather and Robertson 2015).

The National Plan of Action for Seabirds called for an accurate estimate of the total population size of black petrels (MPI 2013). In order to complete this, the uncertainty around the population size on LBI must be corrected. On-going research occurs at the known black petrel breeding colonies on GBI (Bell *et al.* 2015b).

The main breeding area on LBI is along the main ridge between the Thumb and Mt Orau (Track 8). Monitoring work on black petrel was completed by Mike Imber in 1971-75, 1978/79 and 1981-84 in 22 study burrows (Imber 1987), in 1985-1988 in 60 study burrows (as part of the transfer of black petrel chicks from GBI to LBI; Imber *et al.* 2003) and from 1997-1999 in 97 study burrows. Limited burrow checks also occurred in 2000 and 2004. A two-year tracking project was also completed between 2007-2009 using some of the original Mike Imber burrows (Dr. Johanna Pierre, pers. comm., Bell *et al.* 2011, Bell *et al.* 2013). This study was a continuation of the survey and monitoring work begun in 2014/15 (Bell *et al.* 2015a) and will assist in identifying current population status of black petrels of LBI and determine the population trend by comparing it with Imber's earlier work.

2. OBJECTIVES

The main objective of this study was to estimate the population trend, fecundity and age-class survival of black petrels on LBI and to estimate the black petrel population size and describe the population trend by comparing the estimate to relevant existing data. The black petrel population monitoring was undertaken via burrow monitoring and the banding of

adults and fledglings to establish adult mortality, fecundity, breeding success, recruitment and age-class survival to describe the population trend.

In summary, the study objectives were to:

- Collect data that will allow estimation of the black petrel population size and describe the population trend by comparing the estimate to relevant existing data. Key tasks conducted under this objective were:
 - Identify the range of the black petrel population using automated acoustic recorders across the island.
 - Monitor the Mike Imber study burrows within the main breeding area and band all adults present in the burrows during December 2015 and January 2016 and band all remaining fledglings during April/May 2016.
 - Determine breeding success in the study burrows and record causes of breeding failure.
 - Monitor and re-survey the study area for new burrows and band and recapture as many breeding and non-breeding birds present as possible.
 - Capturing and banding as many birds as possible during the breeding season to determine juvenile (pre-breeder) survival, fecundity, age of first return to the natal colony, age of first breeding attempt, age of first successful breeding attempt and adult (breeder) survival.
 - Confirm the breeding status of adults during each visit to the colony (i.e. to monitor the study burrows at the beginning, middle and end of the breeding season), and where possible, identify the sex of the resident adult.
 - Determine a population estimate and trend by extrapolating from study burrows with additional information from the acoustic recordings and random transect and seabird-detector dog surveys.

3. METHODS

3.1 Study burrows

The study area (Track 8, between the lower Thumb and Mt Orau; Figure 1) was visited three times during the breeding season; 25 November to 2 December 2015, 11-25 January 2016 and 28 April to 19 May 2016.

During all visits, the numbered study burrows ($n = 149$, Figure 1) were either re-numbered from the historic Mike Imber burrows or randomly selected from those along the track system (i.e. within 5 m of either side). The historic Mike Imber study burrows were established between 1971 and 1997 (Imber 1987, Imber *et al.* 2003).

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 wood or a rock. Any occupying adult was removed from the burrow, banded (or the band number recorded if a recapture) 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.

Figure 1 Location of the black petrel (*Procellaria parkinsoni*) study burrows on Hauturu-o-Toi/Little Barrier Island, 2015/16.



All remaining fledgling chicks were banded during the April/May 2016 visit. 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™ or ArcMap™).

3.2 Surveys

3.2.1 Randomised transects

Thirty-six randomised transect surveys were completed in April and May 2016 (Figure 2). This transects were either along the main tracks or perpendicular to these tracks. These transects were completed using between two to four searchers.

Randomised GPS start points were selected for each transect and each transect followed the formed track. All transects were 200 m in length. A 4-m strip was searched by two people for burrows on either side of a centrally marked line along each transect. To maintain a consistent search effort, each transect was searched in 10-m lengths. To minimise the edge effect, burrows on the east or north side of the central line were counted if any part of the burrow entrance was within the 4-m strip, and burrows on the west or south side of the central line were counted only if the entire burrow entrance was within the 4-m strip.

Figure 2 Location of the randomised transects (and black petrel (*Procellaria parkinsoni*) burrows found along those transects) on Hauturu-o-Toi/Little Barrier Island, 2015/16.

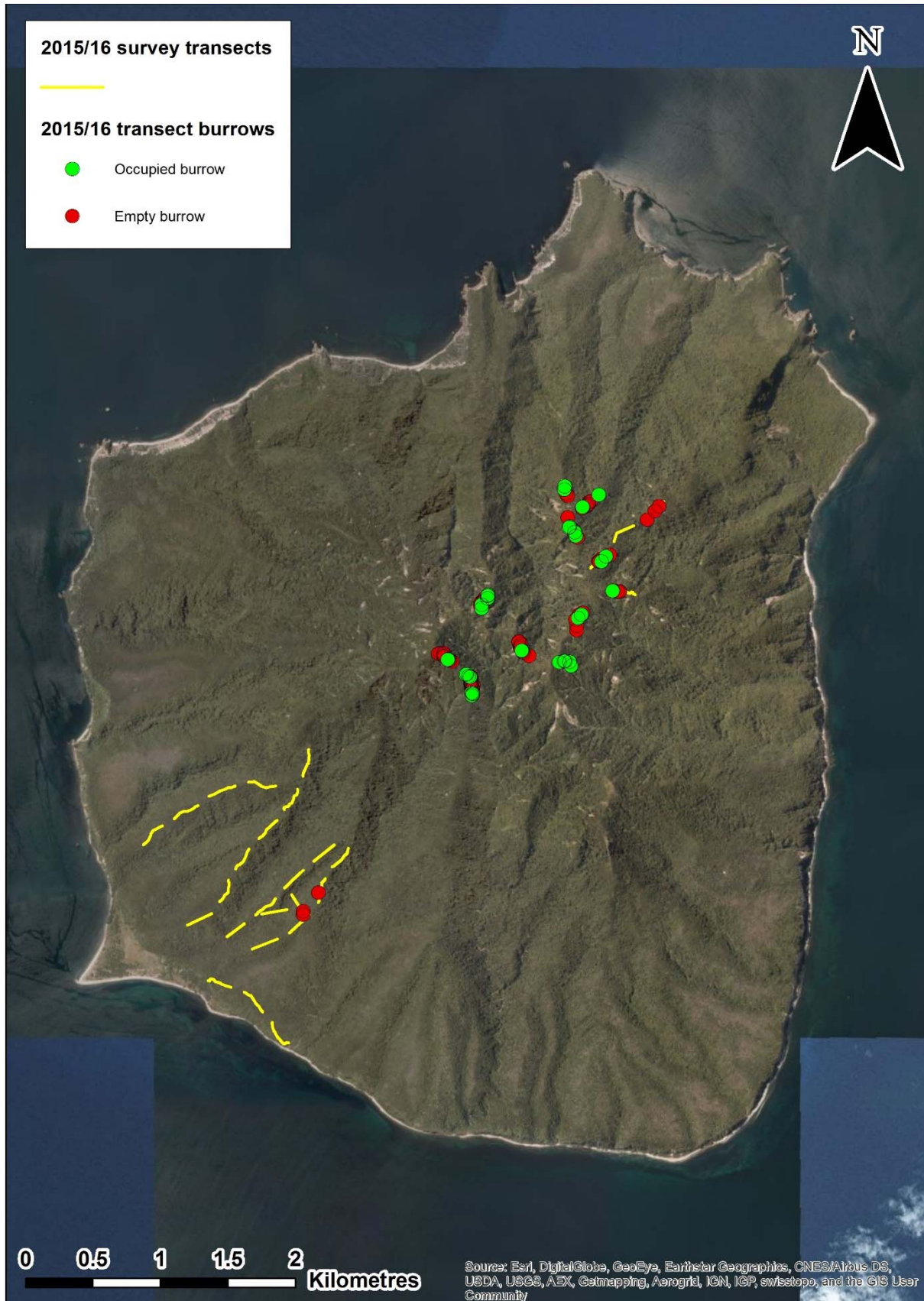
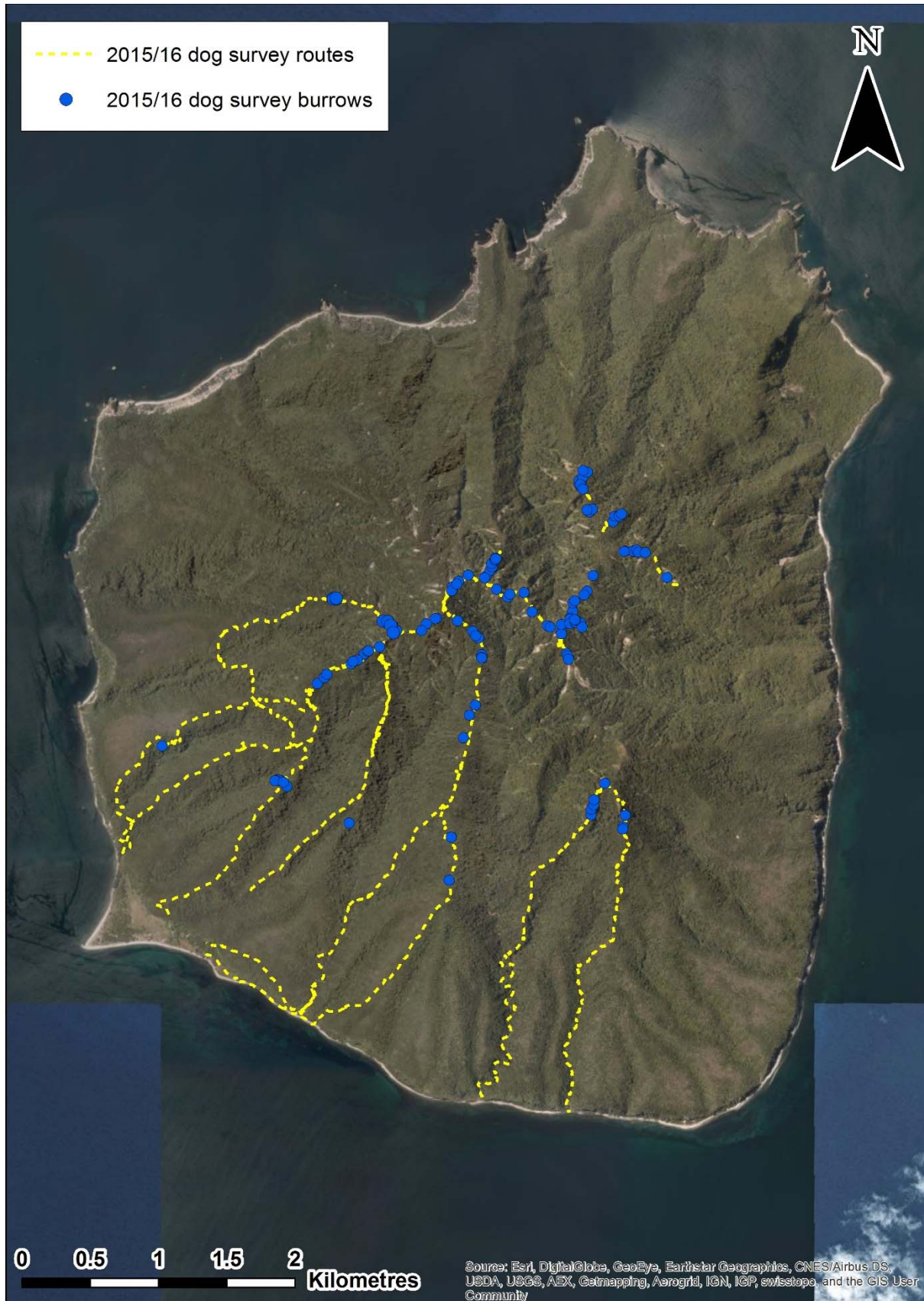


Figure 3 Location of seabird-detector dog surveys (and the black petrel (*Procellaria parkinsoni*) burrows found in those surveys) on Hauturu-o-Toi/Little Barrier Island, 2015/16.



Any burrows located within the search area was recorded (and its position was marked by GPS) and searched for the presence of an adult, egg or chick, The same procedure as outlined in Section 3.1 was followed for any bird caught in the transect burrow. Petrel sign (i.e. droppings) or burrows outside the width of each transect were noted. Details of vegetation (species and density), slope, aspect and general information on burrows were recorded.

3.2.2 Seabird-detector dog searches

Surveys of LBI were completed in April and May 2016 using a seabird-detector dog and two searchers (Figure 3). The dog-team followed the main tracks, but the search area was defined by the scenting of burrows with the dog leaving the track to indicate at occupied burrows (i.e. breeding burrows containing chicks or adults with chicks) or recently active burrows (i.e. where a chick had just fledged as shown by pinning feathers and fresh droppings). The dog could scent burrows up to 10 metres on either side of the track on calm days, with greater distances on the windward side of the track (up to 30 metres).

Any burrows located within the search area was recorded (and its position was marked by GPS) and searched for the presence of an adult, egg or chick, The same procedure as outlined in Section 3.1 was followed for any bird caught in the transect burrow. Petrel sign (i.e. droppings) or burrows outside the width of each transect were noted. Details of vegetation (species and density), slope, aspect and general information on burrows were recorded.

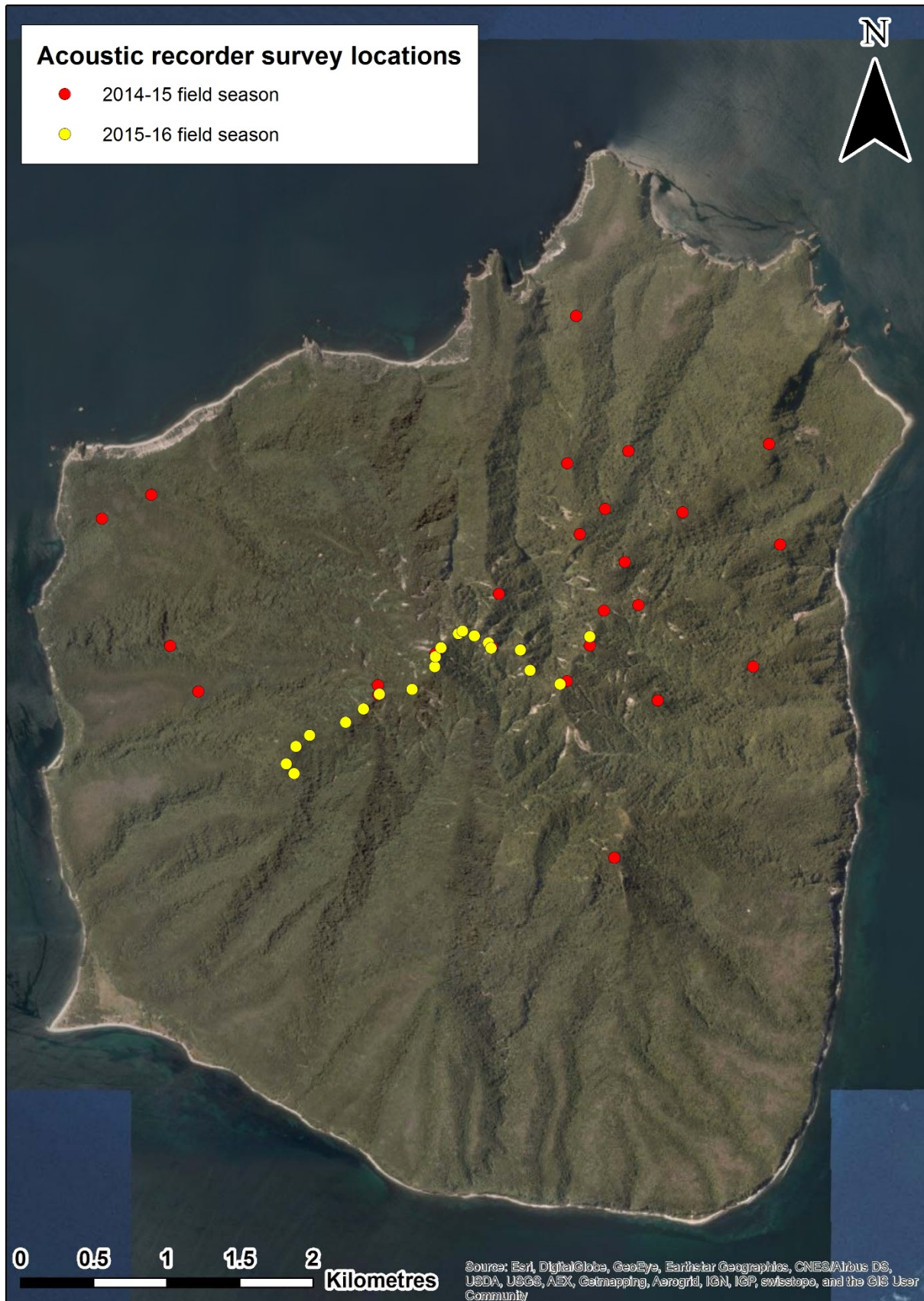
3.3 Automated acoustic recorder units

Twenty automated acoustic recorder units (ARU) were placed out across LBI from 1 December 2015 to 16 February 2016 (Figures 4 and 5). The devices were temporarily attached to a tree using soft cable ties (Figure 4). These devices were set up to record all sounds from one hour after dark (2145 hr NZST) and recorded for one hour.

Figure 4 Example of the automated acoustic recording unit deployed on Hauturu-o-Toi/Little Barrier Island, 2015/16.



Figure 5 Location of the automated acoustic devices deployed on Hauturu-o-Toi/Little Barrier Island during the 2014/15 and 2015/16 black petrel (*Procellaria parkinsoni*) breeding seasons.



4. RESULTS

4.1 Study burrows

Ninety-three of the 97 historic Mike Imber study burrows were located on LBI. The remaining four could not be located by searches by people or with the seabird detector dogs suggesting these burrows were no longer active. An addition 52 burrows were added to the study area. There are a total of 145 study burrows along Track 8 between the lower Thumb and Mt Orau. Of these, 81 contained breeding birds, 26 contained non-breeding birds and 38 were non-occupied or had been taken over by Cook's petrel (*Pterodroma cookii*) (Appendix 1). There were 12 failures which corresponds to a breeding success of 85.2%. Of the failures, 1 was a dead embryo, 3 were crushed eggs, 2 were infertile eggs, 2 disappeared eggs (between the January and April trips) and there were 4 dead chicks.

Using the 97 Mike Imber study burrows, the data collected in the 2014/15 and 2015/16 breeding seasons was compared to the 1996/97 breeding season (Table 1). There has been an apparent decline in breeding activity (by 3%) and an increase in non-breeding activity (by 4%) over the 19 years. The number of burrows taken over by Cook's petrels has increased by 15% over the 19 years, but the total number of non-occupied burrows has remained relatively stable (approximately 40%) despite increasing last year.

Table 1 Comparison in burrow occupancy and breeding success in the original 97 Mike Imber black petrel (*Procellaria parkinsoni*) study burrows on Hauturu-o-Toi/Little Barrier Island between the 1996/97, 2014/15 and 2015/16 breeding seasons.

Study burrow	1996/97	2014/15	2015/16
Breeding	39 (40.2%)	34 (35.1%)	36 (37.1%)
Non-breeding	16 (16.5%)	11 (11.3%)	20 (20.6%)
Occupied (black petrels only)	55 (56.7%)	45 (46.4%)	56 (57.7%)
Non-occupied (black petrels only)	37 (38.1%)	41 (42.3%)	21 (21.7%)
Non-occupied (total)	43 (44.3%)	52 (53.6%)	41 (42.3%)
Used by Cook's petrel	5 (5.2%)	11 (11.3%)	20 (20.6%)

4.2 Banding data

During the 2015/16 season, 112 adults were identified. Of these, 10 were already banded and 101 were banded this season (Appendix 1, Table 2). One female was banded as adult on GBI in 2000 and was subsequently recaptured there on two other occasions (2002 and 2003) before being caught on LBI this season (12 years later). One was a chick that was transferred from GBI in 1986 (Imber *et al.* 2003) and is now resident on LBI. Four males were recaptured in the same study burrows where originally banded in 1993, 1997, 1999 and 2008. Two females were recaptured in the same study burrows where originally banded in 2001 and 2007. The final two birds (a pair) had moved to a neighbouring burrow, but were still together since they were banded in 1997.

There were 81 chicks still present in the study burrows during the April visit and all were banded (Appendix 1, Table 2). An additional 51 chicks were banded in random burrows found during the surveys or on the surface when returning to the bunkhouse or Orau Hut.

Table 2 Banding, recapture and recovery data from black petrels (*Procellaria parkinsoni*) caught on Hauturu-o-Toi/Little Barrier Island in the 2015/16 breeding season.

	2014/15	2015/16
Recaptures of birds banded prior to 2014	3	10
Recaptures of birds banded in 2014/15	-	-
TOTAL RECAPTURES	3	10
Number of new-banded adults	0	102
TOTAL ADULTS	3	112
Number of new-banded chicks	56	132
TOTAL NUMBER OF BIRDS	59	144
Number of 'returned' chicks recaptured	0	0
BAND RECOVERIES FROM DEAD BIRDS	0	0

4.3 Acoustic monitoring

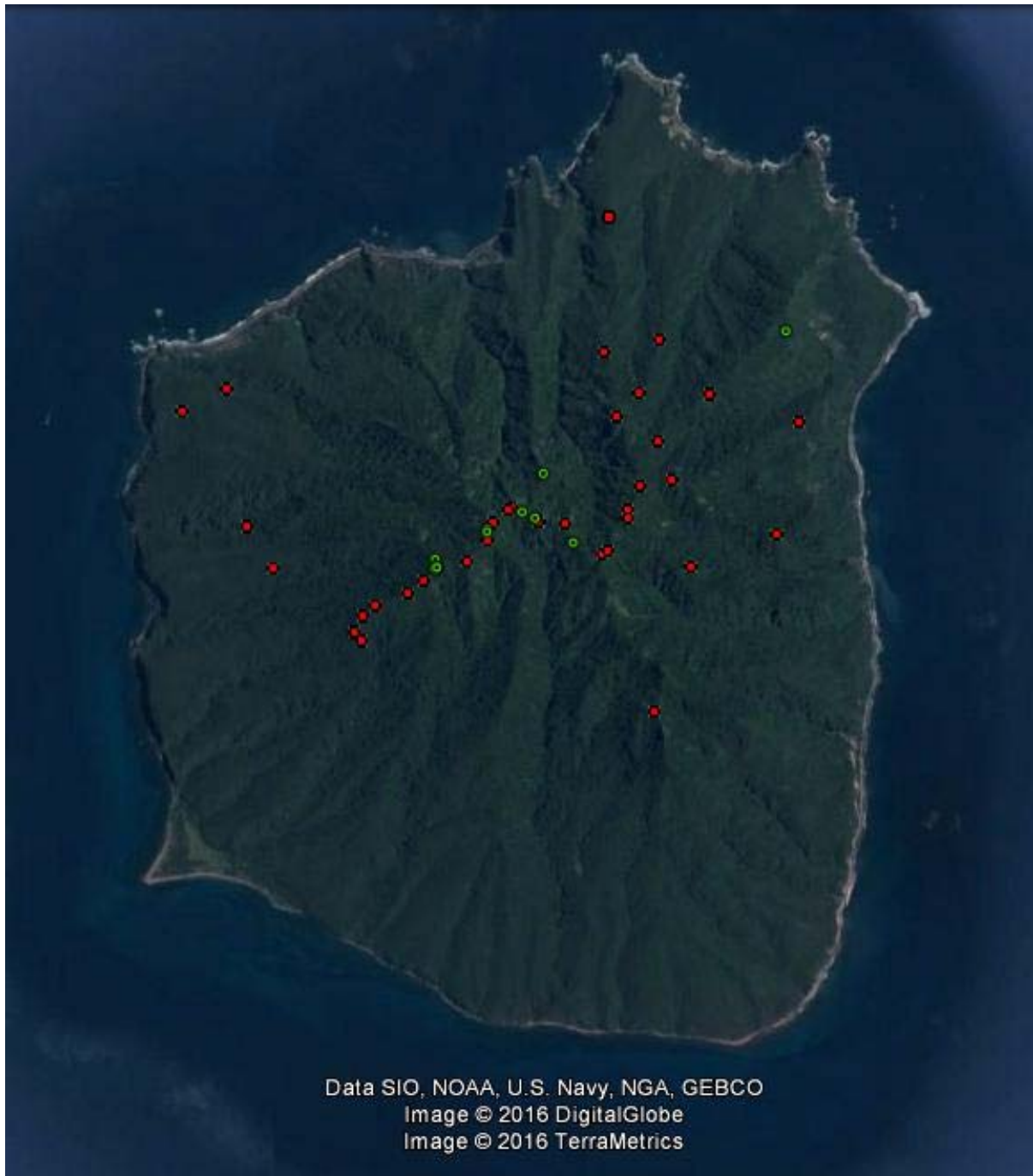
Twenty ARU were deployed on LBI between 1 December 2015 and 16 February 2016. This equates to a total of 940 recording nights and 940 recording hours (1 hour each night per device). Out of the total recording nights, only 722 hours of data were collected as LC4 did not function due to SD card corruption issues, and LC19 failed due to power issues (Table 3). Black petrel calls were recorded at five locations; near the Thumb, below the summit, near Track 7, midway along Track 8 and on Mt Kiriraukawa (Table 3 and Figure 6).

Table 3 Presence or absence of black petrel (*Procellaria parkinsoni*) calls recorded on automated acoustic recorders on Hauturu-o-Toi/Little Barrier Island, 2015/16.

Location	ARU	Outcome of recordings
Lower Thumb Track	LC1	No black petrel calls recorded
Lower Thumb Track	LC2	No black petrel calls recorded
Reischek Tree	LC3	No black petrel calls recorded
Track 8 (K27)	LC4	Failure (SD card corrupted)
Track 8 (False Thumb)	LC5	No black petrel calls recorded
Track 8 (near L121)	LC6	No black petrel calls recorded
Track 8 (Thumb Ladder)	LC7	Black petrel calls recorded (clacking recorded)
Track 8 (Woodpile)	LC9	No black petrel calls recorded
Track (near L126)	LC10	No black petrel calls recorded
Track 8 (just below summit)	LC11	Very faint black petrel calls recorded (i.e. distant)
Track 8 (near L48)	LC12	No black petrel calls recorded
Track 8 (near L55)	LC13	No black petrel calls recorded
Track 8 (Near Dobbie's bowl)	LC14	No black petrel calls recorded
Track 8 (near Track 7 junction)	LC15	Black petrel calls recorded (clacking recorded)
Track 8 (near L72)	LC16	Black petrel calls recorded (clacking recorded)
Track 8 (past L69)	LC17	No black petrel calls recorded
Track 8 (base of Mt Kiriraukawa)	LC18	No black petrel calls recorded
Track 8 (past L88)	LC19	Malfunction (battery failure)
Track 8 (Mt Kiriraukawa)	LC20	Black petrel calls recorded (clacking recorded)
Track 8 (Mt Oratere)	LC21	No black petrel calls recorded
Total	20	5

Figure 6 Location of the automated acoustic units on Hauturu-o-Toi/Little Barrier Island during 2014/15 and 2015/16 breeding seasons that either detected or did not detect black petrel (*Procellaria parkinsoni*) calls.

Where ● = ARU with black petrel calls detected and ● = ARU with no black petrel calls.



Calls were also heard at Orau Hut, the Orau Helipad and Mt Orotere while personnel were listening at night from Orau Hut and high points along Track 8 in December 2015 and January 2016.

Clacking started between 2153 at the earliest and 2233 at the latest. The call rate was only 0.02 clacks per minute.

4.4 Surveys

Thirty-six randomised transects and seabird detector dog surveys found a total of 223 burrows (Tables 4 and 5, Figure 7).

Most of these burrows were breeding burrows as chicks were present and where possible these chicks were banded. There were 50 burrows located in the randomised transects which had evidence of previous use, but were currently not occupied by black petrels. The seabird-detector dog surveys only found occupied burrows or burrows that had very recently been used by breeding or non-breeding birds as the dog does not indicate for non-occupied or disused burrows.

Table 4 Number of black petrel (*Procellaria parkinsoni*) burrows recorded on seabird-detector dog surveys on Hauturu-o-Toi/Little Barrier Island, 2015/16.

	Randomised transect burrows (found by people)	Randomised transect burrows (missed by people)	Burrows outside transect boundaries	Burrows found in other survey areas	Total
Breeding	20	7	13	82	121
Non-breeding	0	1	0	3	4
Total	20	8	13	85	126

Six transects (LT2, LT5, LT8, LT9, LT11 and LT17) were repeated using the seabird detector dogs to determine whether people were missing burrows and the resident chicks or adults. Eight additional (missed) burrows were found in four out of the six transects; 1 extra on LT2, 3 extra on LT5, 2 extra on LT8 and 2 extra on LT9. This showed that the dog was more accurate at determining the presence of chicks in a breeding burrow, but this could relate to the characteristics of some of the burrows (depth, location, number of bends, etc.) which meant people could not detect any chick present despite thoroughly searching via the entrance and recorded the burrow as unoccupied or as a non-breeding burrow if there was sign (such as droppings or feathers) present.

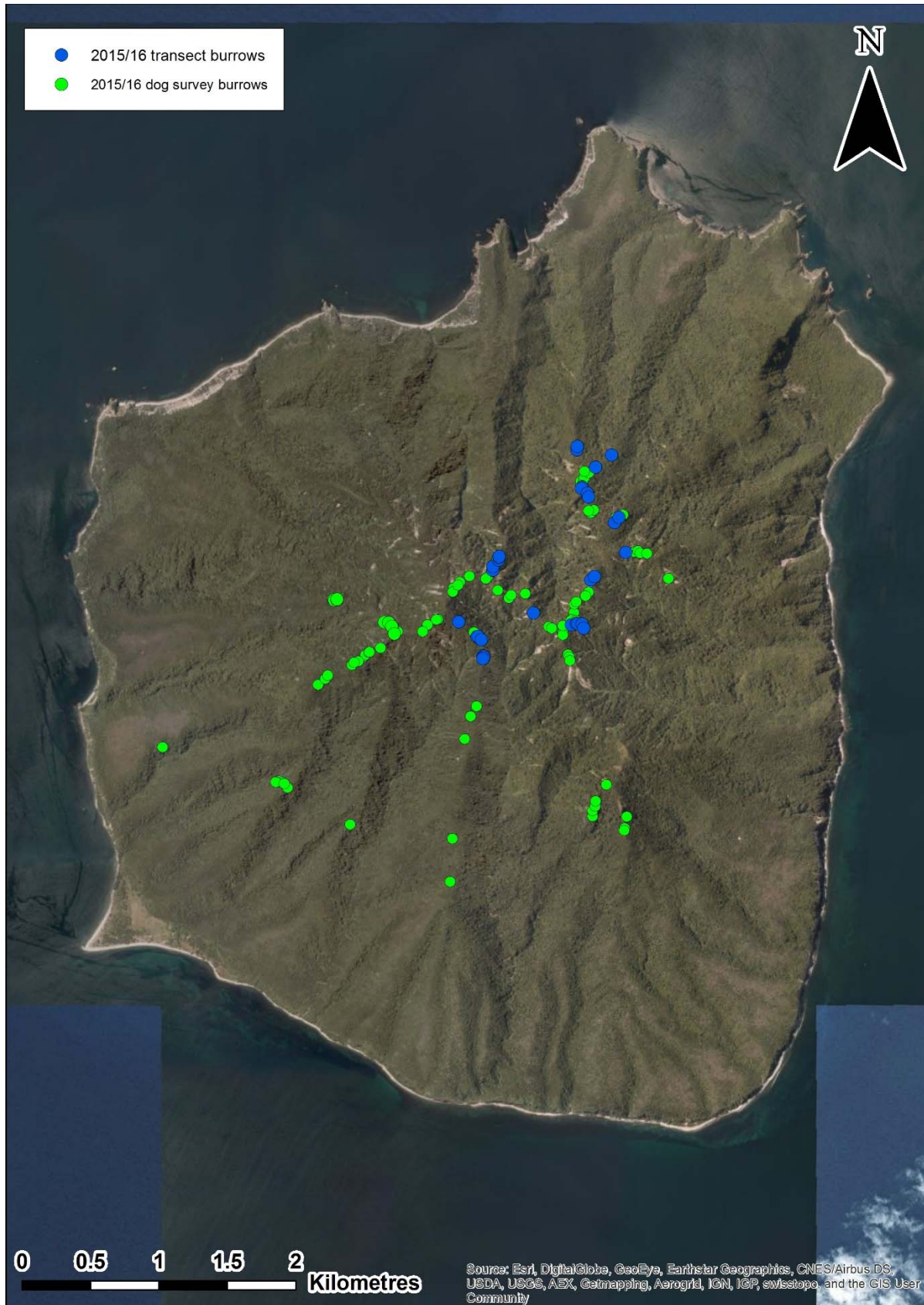
The majority of 170 breeding burrows were located above 500 metres above sea level with 11 burrows (6.5%) located between 250 and 280 metres a.s.l. and only one burrow (0.6%) found by the seabird-detector dog at 120 m a.s.l. with a chick present. The total area covered in the randomised transects was 5.76 ha and the total area covered by the seabird-detector dog was 72.9 ha. This relates to breeding burrow densities between 1.7 burrows per ha (dog) and 8.5 burrows per ha (people); 2.2 breeding burrows per ha (total).

Using the area above 500 metres (determined using ArcView™ as 281 ha), this would suggest the black petrel population on LBI is approximately 620 breeding pairs. However it is important to note that this area has not been assessed for habitat quality and certain sections within the area above 500 metres will not be available for black petrel burrows such as vertical cliffs or slips. Further assessment using GIS and ground surveys to quantify available habitat will be able to further clarify the number of breeding pairs on LBI.

Table 5 Number of black petrel (*Procellaria parkinsoni*) burrows recorded on randomised transects on Hauturu-o-Toi/Little Barrier Island, 2015/16.

Transect		Burrows			
		Non-occupied	Breeding	Non-breeding	Total
LT1	between Summit and Kiriraukawa	6	8	4	18
LT2	Mt Orau	4	4	1	9
LT3	Track 8 beyond Mt Orau	2	2	0	4
LT4	Top of Track 9	3	2	3	8
LT5	Track 10, from track 8 junction	1	2	3	6
LT6	Track 10, 100m below LT5	0	0	0	0
LT7	Track 10, 100m below LT6	1	0	2	3
LT8	Mt Ngarahu	2	1	1	4
LT9	Track 7	7	5	1	13
LT10	Mt Orotere	3	8	1	12
LT11	Track 13	0	7	0	7
LT12	Thumb Track, 100m asl	0	0	0	0
LT13	Thumb Track, 100m up from LT12	0	0	0	0
LT14	Thumb Track, 100m up from LT13	0	0	0	0
LT15	Thumb Track, 100m up from LT14	0	0	0	0
LT16	Thumb Track, 100m up from LT15	0	0	0	0
LT17	Top of Track 20	7	2	2	11
LT18	Track 20, 100m down from LT17	11	8	0	19
LT19	Waipawa Track, 100m asl	0	0	0	0
LT20	Waipawa Track, 100m up from LT19	0	0	0	0
LT21	Waipawa Track, 100m up from LT20	0	0	0	0
LT22	Waipawa Track, 100m up from LT21	0	0	0	0
LT23	above Waipawa/Thumb junction	0	0	0	0
LT24	Shag Track, bunkhouse end	0	0	0	0
LT25	Shag Track, 100m SE of LT24	0	0	0	0
LT26	Shag Track, 100m SE of LT25	0	0	0	0
LT27	Hamilton's Track, 100m asl	0	0	0	0
LT28	Hamilton's, 100m up from LT27	0	0	0	0
LT29	Hamilton's, 100m up from LT28	1	0	0	1
LT30	Hamilton's, 100m up from LT29	0	0	0	0
LT31	Valley Track, near Hamilton's junction	0	0	0	0
LT32	Valley Track, 100m down from LT31	0	0	0	0
LT33	Valley Track, 100m down from LT32	0	0	0	0
LT34	Valley Track, 100m down from LT33	0	0	0	0
LT35	Hamilton to Valley Track (310°)	2	0	0	2
LT36	Hamilton to Valley Track (230°)	0	0	0	0
Total		50	49	18	117

Figure 7 Location of the black petrel (*Procellaria parkinsoni*) burrows found during randomised transects and seabird-detector dog surveys on Hauturu-o-Toi/Little Barrier Island during the 2014/15 and 2015/16 breeding seasons.



5. DISCUSSION

In addition to this season, the black petrel population on Hauturu-o-Toi/Little Barrier Island has been monitored between 1971-75, 1978-79, 1981-88, 1997-1999, 2007-2009 and 2014/15 (Imber 1987, Imber *et al.* 2003, Bell *et al.* 2015a).

5.1 Burrow use by black petrels

In the 2015/16 breeding season, there were 69 breeding successes and 12 breeding failures in the 81 breeding burrows out of the 145 study burrows, equating to an overall breeding success rate of 85%. This breeding success is much higher than reported in the earlier studies on black petrels; 1977 (50%) and 1978 (60%) on Hauturu-o-Toi/Little Barrier Island (Imber 1987) and 1988/89 (62%) on Great Barrier/Aotea (Scofield 1989) and 61-84% on Great Barrier Island/Aotea (Bell *et al.* 2015b). This breeding success rate is also much higher when compared to many other seabird species such as Westland petrel, *Procellaria westlandica*, 39-50% (Freeman & Wilson 2002, Warham 1996). This is likely to be related to the predator-free status of LBI which means there are few land-based threats such as weather-related habitat loss or fire. Eight failures were at the egg stage and three of these may be related to inexperienced pairs crushing their own eggs or fights between two pairs over burrows causing the egg to be crushed. Four chicks died and appeared to have starved which could be related to poor foraging by the adults or the death of one adult as one parent cannot raise a chick alone.

Comparison between occupancy and breeding status within the historic Mike Imber study burrows suggests that the number of black petrels on Hauturu-o-Toi/Little Barrier Island may not have changed much in the 19 years between 1997 and 2016 with total occupancy of burrows between 56% and 58% in those two periods. However the number of non-occupied burrows having black petrels present has dropped by nearly 20% over the same period. The number of burrows taken over by Cook's petrel had also increased from 5% to 20% and this is likely to be a direct result of the large increase in Cook's petrel numbers on LBI over the past 10 years from 286,000 breeding pairs in 2007 (Rayner *et al.* 2007) to over 500,000 breeding pairs in 2015 (M. Rayner, Auckland Museum, pers. comm.). The increased number of burrows now being used by Cook's petrels could relate to the condition of some study burrows have become unsuitable for use by black petrels (without additional excavation by the birds). Reasons whether a burrow is used by black petrels 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.

5.2 Study burrows

Given that ten banded birds were recaptured in these historic Mike Imber burrows this season compared to three last season and that six of these birds were in the exact burrow that they were first captured in suggests that fidelity to burrows is high supporting the model results from GBI (Bell *et al.* 2015b). Increased capture effort of adults next season would give further information on burrow use, survival and site fidelity. Interestingly there has been an emigration event from LBI to GBI (a female now breeding on GBI; Bell *et al.* 2015b), another emigration event from GBI to LBI (a female now breeding on LBI) and 12 (4.8%) of the 250 chicks transferred between GBI and LBI between 1988 and 1990 have returned to their natal area on GBI (Imber *et al.* 2003). This suggests that birds from LBI may be attracted to GBI due

to the number of birds' resident there (and resulting noise early in the breeding season). This may be particularly important for females as they are attracted to calling males and do not appear to have such a high level of site fidelity until they are an established breeder.

It will be important to continue to monitor these LBI study burrows with a detailed mark-recapture programme to determine the adult and juvenile survival, site fidelity and recapture probabilities for black petrels on LBI and compare these data to that for GBI to determine if there are differences between the two colonies.

Immigration between the colonies has implications for population modelling work (as most models assume no immigration), and further surveys and mark-recapture work is needed to maximise the chances of recapturing known birds and returned fledglings. This also has implications for the recovery of the LBI population as pre-breeders are more likely to be attracted to GBI than LBI, slowing the population growth there. It is possible that the LBI population may not recover until GBI reaches carrying capacity; however until further information on the LBI for adult survival and recruitment is collected, this is difficult to assess. It is important that the black petrel population on LBI is monitored further to determine population dynamics, status and trends.

5.3 Acoustic recordings

Black petrels were only recorded by the ARUs at five locations and the clacking rate was much lower than recorded on GBI for the same period (0.02 clack per minute on LBI versus 5.5 clacks per minute on Mt Hobson/Hirakimata; Bell *et al.* 2016). This calling rate suggests that the population level of black petrels on LBI is significantly lower than that found on GBI. However, it does not mean that black petrels were not present in these areas as the majority of the ARUs were placed along the known high density black petrel area (i.e. along Track 8). It may be possible that the petrels call much later than those on GBI (whose activity starts at approximately 2115 hours at high density areas within the main colony on Mt Hobson/Hirakimata) and as a result were outside the recording time (2145-2245 hours) that was set on the ARUs or there were very few non-breeding birds within the range of the ARUs. It will be important to place ARU devices in other areas around LBI to assess the range of black petrels. It will also be important to place an ARU device in a known black petrel area to record call rates and levels for the whole night during the optimum non-breeding activity period (i.e. December) to determine whether recording times need to be set later to be able to detect black petrels on LBI. These start times, call rates and activity levels could then be related to GBI birds' start times, call rates and activity levels over the same period.

5.4 Population estimate

Both the ground surveys and ARUs recorded black petrel activity along the ridgelines and at high points across the island. There was limited activity at each site (i.e. few birds calling) suggesting that the total number of black petrels on LBI is low. It is important to place further acoustic monitoring devices out across the high points and other areas on LBI that have not been covered to date in order to identify other active black petrel areas that can be assessed by ground surveys as well as compared to recordings and surveys from GBI. Comparison with recordings taken on GBI suggested that the black petrel population on LBI is significantly lower and at lower densities than found on GBI. Further comparisons with GBI from recordings collected at other locations on LBI next season should be completed to confirm this result and obtain another assessment of the overall black petrel population on LBI.

The randomised ridge transects and seabird-detector dog surveys detected a total of 223 black petrel burrows (170 breeding burrows) across the island. The majority of these burrows were found above 500 metres a.s.l. with only 12 found below this altitude confirming that the distribution of black petrels on LBI are predominately restricted to the higher altitudes and steeper slopes. Given that most burrows were found above 500m (approximately 2 breeding burrows per ha), extrapolating to the island as a whole, the black petrel population for LBI is 620 breeding pairs. This is an increase of nearly 500 breeding pairs from the estimate of 50-100 pairs made by Imber during his study between 1970 and 1982 (Imber 1987) although Imber covered much less area of the island at the time of that survey. It is also important to note that this estimate does not take into account areas in this 'over 500 m asl' zone that are not suitable black petrel habitat such as slips or vertical bluffs and needs to be revised using detailed GIS mapping tools and ground-truthing.

The use of seabird detector dogs made the search time faster particularly for detecting active burrows (those with birds present), but having people also search for burrows meant empty or non-breeding burrows could also be identified and mapped. Additional transects will be completed in random locations outside the main ridgelines next season and further seabird detector-dog surveys will also be completed next season which will allow a more accurate population estimate for black petrels on LBI and colony boundaries to be determined.

On LBI, black petrels prefer the high-altitude habitat that is associated with steeper slopes and shorter distances to ridge tops, as found by Rayner et al. (2008) for the smaller Cook's petrel. Many of the historic black petrel burrows have been overtaken by Cook's petrel and the Cook's petrel numbers appear to have been increasing rapidly since the eradication of rats. The high rate of erosion and occurrence of slips on LBI may affect the ability of black petrels to maintain good breeding burrows compared to Cook's petrel as they require much larger burrows. Burrow characteristics on LBI are highly variable and a high number of birds nest in large caverns under fallen trees and cliffs rather than occupying the classic-dug seabird burrow as more often found on GBI (EAB, pers. obs.). Seabirds need good access to safe take-off points, free-draining soil and environmental stability (i.e. reduced erosion) when selecting burrows (Warham 1996) and this can be found along the ridges and high points on LBI.

6. RECOMMENDATIONS

The authors recommend that:

- Monitoring of the black petrel population (using the study burrows) is continued at Hauturu-o-Toi/Little Barrier Island up to, and including, the 2019/20 breeding season. This will ensure that 5 years of comparative data are collected to determine the population dynamics of black petrels, allowing us to develop a generational population model to determine survivorship, mortality and the effects of predation, fisheries interaction and other environmental factors.
- There are three visits to the Hauturu-o-Toi/Little Barrier Island colony; (i) November/December to allow a large number of birds to be banded or recaptured easily, as the birds are often outside the burrows during this period. A high rate of banding and recapture will enable the continuation of the mark-recapture programme; (ii) January/February to continue with the mark/recapture programme

and to confirm breeding status of the adults (and study burrows), and (iii) April/May to allow surviving chicks to be banded before they fledge.

- The study burrows should be checked for breeding status during every visit to the study area, to give a more accurate estimate of breeding success and determine sex of adults. This would also provide an opportunity to recapture returning birds banded as chicks.
- Acoustic recorder units should be deployed in 2016/17 to complete the coverage of the island to obtain information on the range and density of black petrels on Hauturu-o-Toi/Little Barrier Island.
- Seabird-detector surveys and randomised transects are undertaken in 2016/17 across the remaining areas on Hauturu-o-Toi/Little Barrier Island to provide a population estimate for the whole island.
- The exact limits of the Hauturu-o-Toi/Little Barrier Island black petrel colony or habitat should be established and the area calculated by a ground truth survey.

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9. APPENDICES

9.1 Results from the study of black petrel burrows ($n = 149$) on Hauturu-o-Toi/Little Barrier Island during the 2015/16 breeding year.

Table 6 Results from the study of black petrel burrows ($n = 149$) on Hauturu-o-Toi/Little Barrier Island, 2015/16.

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.

Burrow	Band		Outcome
1			Cook's
2			Cook's
3	41638	?	Chick (41172)
4	?	?	Chick (41174)
5			Empty
6			Cook's
7			Cook's
8	41211 (M)	41649 (F)	Non-Breeding
9			Empty
10	36753 (M)	41168 (F)	Non-Breeding
11	41212 (M)	41250 (F)	Chick (41179)
12			Empty
13			Cook's
14			Empty
15	41213 (M)	41632 (F)	Chick (41180)
16			Non-Breeding
17			Empty
18			Cook's
19			Cook's
20			Non-Breeding
21	41615 (M)	41630 (F)	Chick (411873)
22			NOT FOUND
23			Empty
24			Cook's
25			Empty
26			Empty
27	41648 (M)	36105 (F)	Chick (41184)
28	41215 (M)		Chick (41185)
29			Empty
30			Empty
31			Non-Breeding
32			Non-Breeding
33			Cook's
34	41629		Chick (41188)
35			Cook's
36	41199	41167	Non-Breeding
37	41644		Chick (41189)
38			Cook's

Burrow	Band		Outcome
39			Empty
40			Cook's
41			Cook's
42			Cook's
43	41613 (F)	41650 (M)	Crushed egg
44	41158		Chick (40291)
45			NOT FOUND
46			NOT FOUND
47			Empty
48			Empty
49			NOT FOUND
50	41238		Chick (40279)
51			Non-Breeding
52			Chick (40293)
53	41237	41156	Chick (40292)
54			Chick (40283)
55	28232 (M)	41616 (F)	Chick (40160)
56	41216 (M)	41160 (F)	Chick (already fledged)
57	41239	40159	Chick (40159)
58			Empty
59			Cook's
60			Chick (40295)
61	41617 (F)	41245 (M)	Chick (already fledged)
62			Cook's
63	41633 (M)		Non-Breeding
64	41217 (M)	41235 (F)	Dead chick
65			Dead chick
66	41218 (M)	41234 (F)	Dead chick
67	41225 (F)	41244 (M)	Non-Breeding
68			Non-Breeding
69	28631 (M)		Chick (40264)
70			Cook's
71	41623 (M)	41240 (F)	Non-Breeding
72			Non-Breeding
73	41625 (M)	41233 (F)	Chick (40299)
74	41618 (M)	41232 (F)	Chick (40265)
75	41241		Chick (40266)
76	41236		Chick (40296)
77			Empty
78			Non-Breeding
79	41153	41166	Non-Breeding
80			Non-Breeding
81			Cook's
82	41231		Chick (40280)
83	41152 (M)	41219 (F)	Infertile egg
84			Cook's
85	41242	41161	Chick (40268)
86	41224 (M)		Non-Breeding
87			Non-Breeding

Burrow	Band		Outcome
88			Cook's
89	41247 (M)	41220 (F)	Infertile egg
90	41627	41157	Chick (41197)
91	41229		Chick (41196)
92			Non-Breeding
93	28645 (M)	41151 (F)	Chick (41195)
94			Empty
95	41249 (M)	41243 (F)	Crushed egg
96	41155	41163	Non-Breeding
97	41228 (M)	41619 (F)	Chick (41194)
98		28650 (F)	Chick (41193)
99			Empty
100	41226	41636	Chick (41192)
101	41154		Chick (40296)
102	41223 (M)	41645 (F)	Non-Breeding
103	41248 (M)	41162 (F)	Non-Breeding
104	41647 (M)		Chick (40267)
105	41628 (M)	41246 (M?)	Non-Breeding
106	41624 (M)	41230 (M)	Non-Breeding
107			Empty
108			Non-Breeding
109	41631 (M)	41626 (F)	Dead chick
110	41222 (M)	41637	41227
111	41221 (M)	41620 (F)	Chick (41190)
112	41646 (M)	41621 (F)	Disappeared egg
113			Non-Breeding
114	41640		Chick (41178)
115	41641		Disappeared egg
116	28616 (M)	28633 (F)	Chick (41181)
117	41614 (M)		Chick (41176)
118	41208	41610	Chick (41169)
119	41209 (M)	25573 (F)	Chick (41170)
120			Chick (41171)
121	41639		Chick (41175)
122	41635		Chick (41173)
123	41642		Chick (41182)
124	41634 (M)	41210 (F)	Crushed egg
125	41214 (M)		Chick (41177)
126	41643	26937	Chick (41187)
127	41622 (M)	41164 (F)	Chick (41191)
128	41159		Chick (41186)
129			Chick (41198)
130			Chick (41200)
131			Chick (40252)
132			Chick (41198)
133	40271		Chick (40269)
134			Chick (40282)
135			Chick (40272)
136			Chick (40270)

Burrow	Band			Outcome
137				Chick (40298)
138				Chick (40263)
139				Chick (40278)
140				Chick (40276)
141				Chick (40294)
142				Chick (already fledged)
143				Chick (40153)
144				Chick (41254)
145				Chick (40193)
146				Chick (already fledged)
147				Chick (401947)
148				Chick (40158)
149				Chick (40196)