TĀKOKETAI/BLACK PETRELS ON AOTEA/GREAT BARRIER ISLAND

Key demographic parameters and population trends of black petrels (Procellaria parkinsoni) – 2022/23

WMIL Wildlife Management International

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Key demographic parameters and population trends of tākoketai/black petrels (*Procellaria parkinsoni*) on Aotea/Great Barrier Island: 2022/23

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Cover image: Banding an adult tākoketai/black petrel during night work on Aotea/Great Barrier Island (© Elizabeth Bell, WMIL, December 2022).

CONTENTS

EXECUTIVE SUMMARY

This report is part of the ongoing study of the tākoketai/black petrel, *Procellaria parkinsoni*, on Great Barrier Island/Aotea that began in the 1995/1996 breeding season.

During the 2022/23 breeding season 480 tākoketai/black petrel study burrows were intensively monitored within the Mt Hobson/Hirakimata study area on Aotea/Great Barrier Island.

There were 313 (65.2%) burrows occupied by breeding pairs, 64 (13.3%) occupied by non-breeding birds, and 103 (21.5%) were unoccupied. Overall, 191 chicks were produced from the study burrows representing a fledgling success rate of 61%, but 13 chicks were found to be below weight and smaller in size during the May chick banding trip, and most of these chicks were not expected to survive to fledging. This would further reduce breeding success to 56.9%.

Breeding success was impacted by weather events, specifically the Auckland flood event on 27 January 2023 and Cyclone Gabrielle between 12-16 February 2023. A number of burrows flooded, causing eggs to fail and small chicks to drown or chill and die, and foraging success of parents appeared to be reduced with 13 chicks being in poor condition by May prior to fledging.

Nine census grids were monitored within the study area and accounted for 197 of the inspected study burrows. Of these, 119 were occupied by breeding pairs (60.4%) and 68 chicks were produced representing a fledging success rate of 57.1%. Again 7 of these chicks were in poor condition and were not expected to fledge, reducing breeding success to 52.1%.

A total of 664 adults and 129 fledgling chicks were captured during the 2022/23 field season with 174 adults banded this season (including 52 from study burrows). Of the 129 fledgling chicks banded during the 2022/23 field season, 119 were banded in study burrows; 72 could not be banded due to torrential rain over the chick banding trip, and one had already fledged prior to the banding visit in May 2023.

There have been a total of 420 returned chicks recaptured at the colony since they were banded prior to fledging. Of these, 117 returned chicks were identified during the 2022/23 breeding season; 28 of which were caught for the first time at the colony. The majority of all 420 returned chicks were from the 2016/17 breeding season, followed by the 2013/14 cohort. Not all cohorts were represented as no returned chicks from the 1995/96, 1996/97 and 1997/98 cohorts were recaptured this season. Understanding the factors affecting return rates of chicks within the 35-ha study site is vital. It is important to determine whether it is related to low juvenile survival and/or recruitment or if it is simply due to a lack of detection. Understanding juvenile survival and recruitment is necessary for accurate demographic modelling and for species risk assessment modelling. Therefore, it is recommended that effort to obtain this data is completed with urgency.

Additional monitoring of pig and other predator occurrence and impact on black petrels on Cooper's Castle was undertaken this season. Eighteen black petrel burrows were identified within the boundaries of this study area; three were breeding sites and four sites were being visited by non-breeding birds. All other burrows were empty. Trail cameras were placed along pig pathways, walking tracks and outside active black petrel burrows. Footage confirmed feral pig, rat, and feral cat presence. While no interactions with black petrels were caught on camera at Cooper's Castle, there was one cat predation of an unbanded adult and one chick from a random, non-monitored burrow. There was one rat predation event at the study colony on Hirakimata this season. Introduced species still pose a threat to the black petrel population and it is imperative pest control measures continue.

*Key demographic parameters and population trends of tākoketai/black petrels (*Procellaria parkinsoni*) on Aotea/Great Barrier Island:*

1. INTRODUCTION

1.1 Introduction

Black petrels (*Procellaria parkinsoni*) are a medium–sized endemic seabird that only breeds on Te Hauturu–o–Toi/Little Barrier Island and Great Barrier Island/Aotea in the Hauraki Gulf of New Zealand. Black petrels are known by the name of tākoketai by Ngāti Rehua Ngāti Wai ki Aotea, tangata whenua and mana whenua of Great Barrier Island/Aotea. Black petrels are ranked as Nationally Vulnerable under the New Zealand Threat Classification System and Vulnerable on the IUCN Red List of Threatened Species (BirdLife International, 2020; Robertson et al., 2021). They are recognised as the seabird species that is at greatest risk of being adversely impacted by high rates of bycatch in commercial fisheries within New Zealand's Exclusive Economic Zone (Richard et al., 2020). Of the 179 observed captures of black petrel recorded between 2002 and 2020, 54.2% of captures occurred in bottom-longline fisheries, 27.9% in surface-longline fisheries and 17.9% in trawl fisheries (https://protectedspeciescaptures.nz/PSCv6/released/summary/; accessed 8/7/2023). Black petrels on Great Barrier Island/Aotea are also exposed to threats on land, principally depredation by cats (*Felis catus*), rats (*Rattus* spp.) and pigs (*Sus scrofa*) (Bell, 2013).

To monitor the ongoing population-level impacts of commercial fisheries on black petrels, it is necessary to quantify population parameters such as annual burrow occupancy rates, annual reproductive success as well as both adult and juvenile annual survival rates to create accurate assessments of population trends. To this end, a long-term research project aimed at quantifying these population parameters was initiated in 1995/96 (Bell & Sim, 1998). During this first season, three 40 m x 40 m study grids were set up within the largest known breeding colony on Mt Hobson/Hirakimata on Great Barrier Island/Aotea, and all burrows within the grids were marked and monitored. Additional burrows located within 10 m of the public walking tracks were also monitored. In 1998/99, the number of study grids was increased to six, and then to nine in 1999/00 (Bell & Sim, 2000a; Bell & Sim, 2000b). Over the years, additional burrows situated near the public walking tracks have continued to be added (Bell et al., 2022b), so that by the 2022/23 season a total of 480 study burrows were being monitored.

This report provides a summary of the results of this monitoring work on Great Barrier Island/Aotea in the 2022/23, with updates on the trends in several population parameters including both annual burrow occupancy and annual reproductive success.

1.2 Objectives

This project extends on demographic work funded by commercial fisheries levies and the Department of Conservation (DOC) and Ministry for Primary Industries/Fisheries New Zealand (MPI/FNZ) since 1996.

As black petrels are the species at highest risk from commercial fisheries in northern New Zealand, continuing research on this species is necessary to gather current rates of adult mortality, breeding success, juvenile survival and recruitment until suitable mitigation methods significantly reduce the capture risk to this species.

The objectives are:

a. To monitor the key demographic parameters at the breeding colony of this threatened seabird to reduce uncertainty or bias in estimates of risk from commercial fishing.
b. Conduct nocturnal searches of the Hirakimata/ Mt Hobson colony for recruits (i.e., birds banded as chicks returning to the colony to breed).
c. Capture black petrels at sea to determine the proportions of unbanded versus banded birds. This information will be used to assess if apparent low juvenile survival is biased by dispersal away from study colonies (Note: this objective is reported separately).

2. METHODS

2.1 Field methods

A network of 480 study burrows has been established within a c. 35-ha study area in the vicinity of Mt Hobson/Hirakimata on Great Barrier Island/Aotea (Figure 1). The colony residing around the Mt Hobson/Hirakimata summit represents the highest density of logistically accessible black petrels on Great Barrier Island/Aotea and was the reason underlying the establishment of the study site. Additionally, previous research programmes on black petrels that had taken place at Mt Hobson/Hirakimata before the establishment of WMIL's monitoring programme increases the importance of the site (Hunter et al. 2001; Imber, 1976; Imber, 1987; Imber et al., 2003a; Scofield, 1989). For instance, the first black petrel banded on Great Barrier Island/Aotea was banded in 1963 and the oldest bird currently resighted within the study is 35 years of age (i.e., banded as a chick) (WMIL, unpublished data).

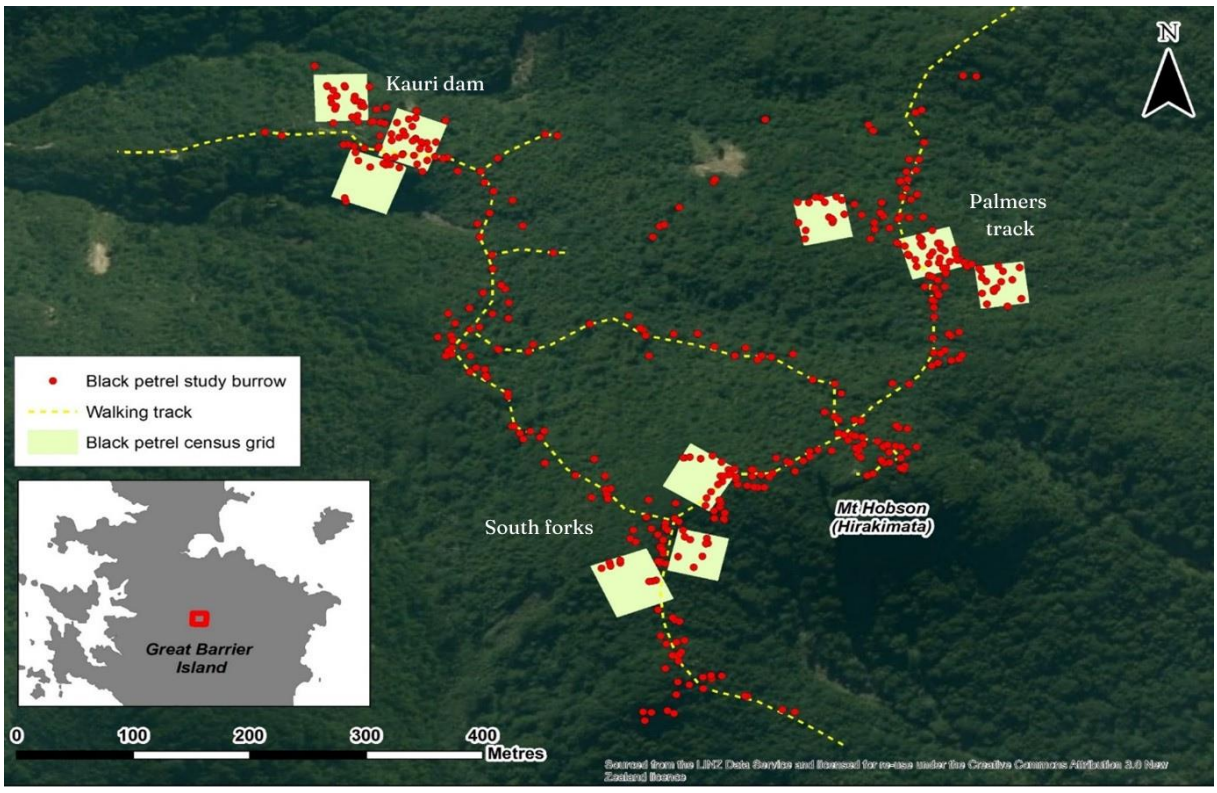

Figure 1: *Map of the 480 tākoketai/black petrel study burrows (red points) that have been established in the vicinity of Mt Hobson/Hirakimata on Great Barrier Island/Aotea. Yellow dashed lines are public walking tracks and highlighted squares are census grids (Kauri Dam, South Forks and Palmers Track).*

Study burrows (burrows where demographic data is recorded) have been progressively established over the past 28 years and to date include 197 burrows located within nine 40 m x 40 m census grids, plus a further 283 arbitrarily selected burrows situated within approximately 25 m of public walking tracks (Figure 1).

The first three census grids were established within previously known high density black petrel breeding habitat located over ridgelines in remnant (un-milled) podocarp broadleaf mixed forest. The boundaries of the second three and last three census grids were randomly selected within appropriate habitat hypothesised to maintain breeding populations (e.g., over ridgelines within either remnant forest or secondary re-growth forest (where kauri was only logged selectively in the past; Figure 1).

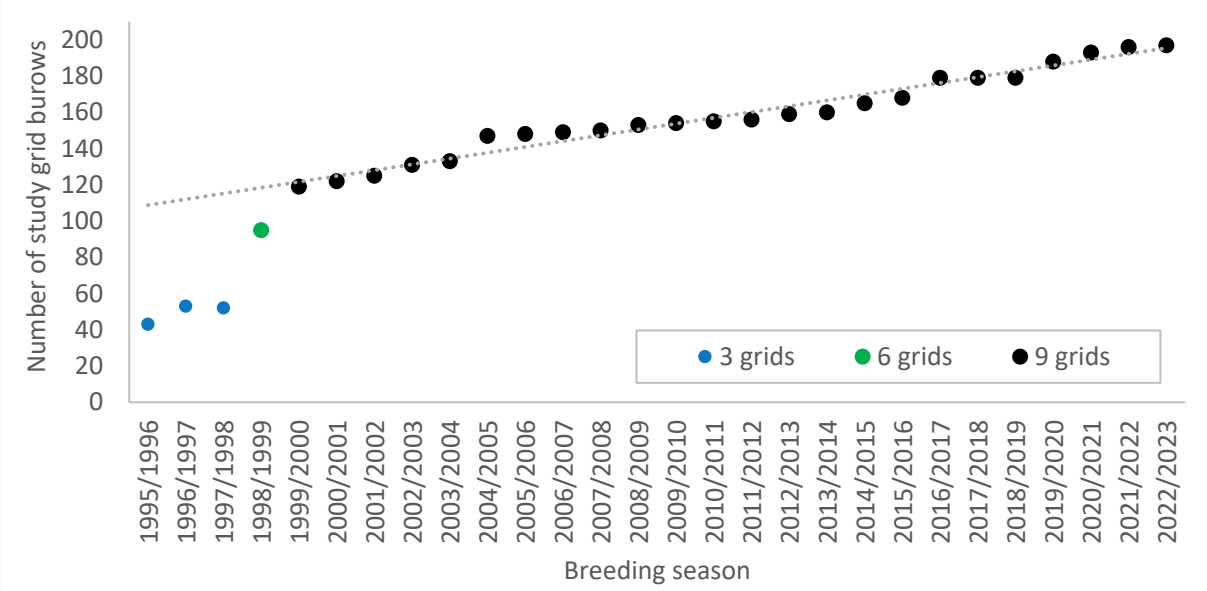

***Figure 2**: The total number of tākoketai/black petrel census grid burrows monitored each breeding season on Great Barrier Island/Aotea between 1995 to 2023.*

Census grid sizes at the start of the study were 100 m^2 in January 1996 and subsequently increased to 1600 m^2 by April 1996 during the chick fledging period. Being within the vicinity of public walking tracks allows faster traversing of the study site. The average distance from the centre of the nine census grid ranges between 1 to 61.7 m (mean distance is 25 m ± 17.4 m SD) from walking tracks. At the establishment of a census grid, an exhaustive grid-like search was conducted on foot by researchers traversing together in a line one metre apart within the grid boundaries. All occupied, empty, and potential (burrows in the process of being dug out) were recorded. On three separate occasions (December 2009, January 2010, and December 2015) further searches by a seabird detection dog was conducted in each census grid to identify any missed burrows. Burrow occupancy rates in the nine study grids likely provide the most consistent and representative measure of burrow occupancy across the study area, as they are unaffected by the occasional preferential addition of active breeding burrows to the study burrow network outside of the study grids that has occurred in previous years. For this reason, trends in burrow occupancy rates within the study grids provide the best measure of whether black petrel burrow occupancy is increasing or decreasing within the study area (Figure 2).

Up until the 2018/19 season, when burrows are found outside of census grids, they are automatically added into the study if they are found within c. 10 m of the public walking tracks, or if the burrow when found, contained a breeding adult that was previously banded as a chick. Currently any new burrows that are found are only added into the study if they are within the census grids (Figure 3) or contain a breeding adult that was previously banded as a chick.

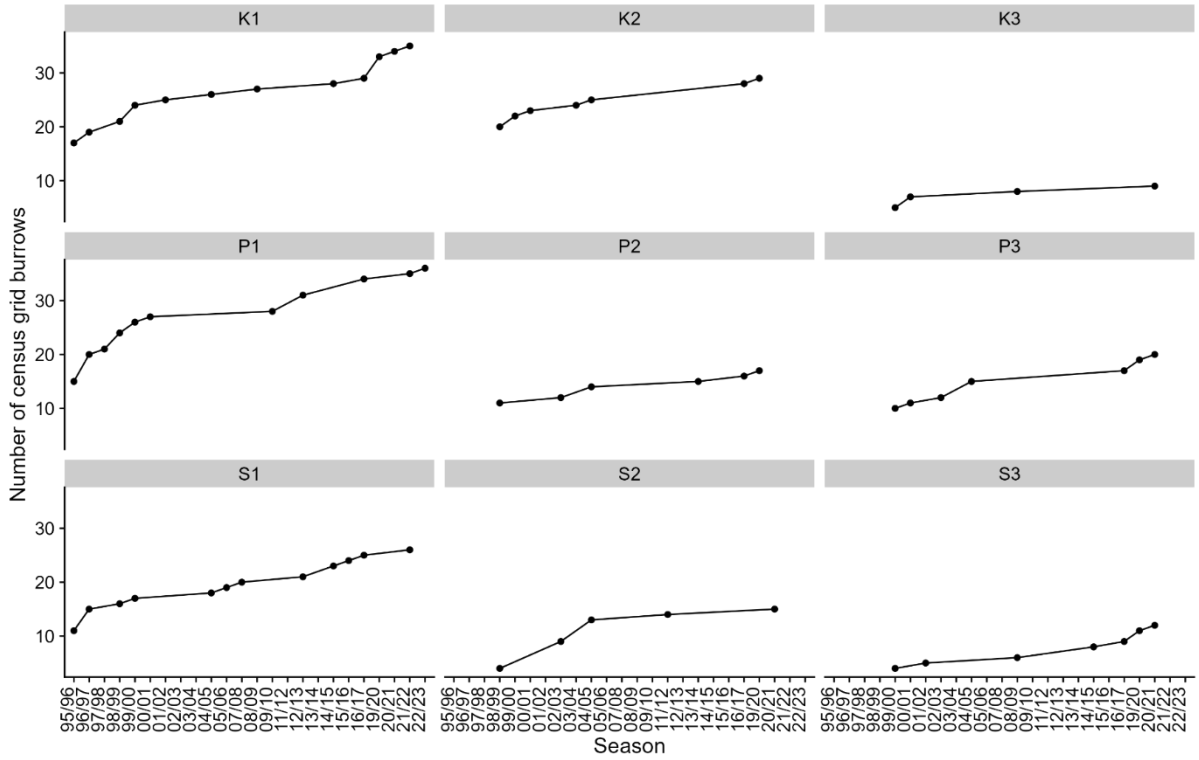

Figure 3: *The cumulative number of tākoketai/black petrel census grid burrows added to each census grid on Great Barrier Island/Aotea between 1995 to 2023 (Note: the first point for each study grid indicates when the study grid was first established).*

The additional 283 arbitrarily selected study burrows were found through a combination of haphazard searching and seabird detection dogs. Other burrows that are found further than c. 10 m from public walking tracks are noted and are often returned to in subsequent seasons in order to increase the number of banded birds into the study but data on breeding status and occupancy is not collected.

To facilitate accurate monitoring, 330 study burrows have had study hatches installed (68.8%), providing easier access to one or more chambers within the burrow and to reduce interaction time with the bird by the researchers. The effect of handler disturbances has not been investigated in black petrels, but it is hypothesised that black petrels are robust to handler disturbance, as offspring abandonment has not been observed following handling. Of these burrows with hatches installed, larger/internally complex burrows have had two (17 burrows, 5.2%) or three (10 burrows, 3%) hatches installed. While not formally quantified for this study, anecdotally, the time taken to retrieve the bird from the study burrow depends on several factors: the distance from the burrow entrance to the burrow chamber, the space within the chamber, the physical configuration/obstacles (e.g., tree roots) within the burrow, and the temperament of the bird. Depending on the internal complexity and accessibility of the bird within the burrow, retrieval of the bird may take between 1-30 min. The installation of hatches is aimed to reduce the time spent retrieving the bird by removing/ reducing the physical factors mentioned above.

The first visit to the Mt Hobson/Hirakimata study area occurred from 28 November to 5 December 2022 and was solely focused on identifying recruits (i.e., birds banded as chicks returning to the colony to breed). Timing of this trip was aimed at coinciding with the end of the pre-egg laying exodus and the start of the egg laying period when large numbers of birds would be returning to the island. The study burrows were monitored in two subsequent trips to the colony. The first trip occurred from 16 to 30 January 2023 and coincided with late incubation/hatching/early chick rearing (this trip was shortened due to Cyclone Gabrielle for staff safety). The second visit occurred from 27 April to 3 May 2023 and coincided with the late chick rearing/chick fledging period. The number and timing of trips to the colony each breeding season vary from year to year depending on additional project goals, but

at a minimum will contain two trips to cover the late incubation/hatching/early chick rearing and late chick rearing/fledging (Table 1).

Table 1: *Breeding cycle of tākoketai/black petrel on Great Barrier Island/Aotea (WMIL, unpublished data; also see Imber 1987).*

Breeding stage	Time period
Return to colony	10 October to 15 November
Pre-egg-laying exodus ('honeymoon')	15 October to 15 November
Egg laying	15 November to 31 December (peak 1-15 December)
Incubation	15 November to 28 February
Guard phase	10 January to 15 March (peak 1-15 February)
Chick rearing	15 January to 30 June
Fledgling	10 April to 30 June (peak 1-20 May)

To determine the breeding status and breeding outcome for each burrow, and to record the adult occupants of each burrow, each study burrow was checked at least twice during Trip 2. During each burrow check, any resident adults were removed from the burrow, and checked for bands. If banded, the band number of each bird was recorded, otherwise the bird was banded with an individually numbered size H stainless steel band. Unbanded adult petrels (regardless of breeding status) are assumed to be at least five years of age and are given an age estimate of 5 years. Before being returned to the burrow, a small mark was made on each bird's forehead using white correction fluid to provide a means of visually checking whether the same bird was still occupying the burrow during subsequent checks, without having to remove the bird to read its band. The presence of an egg or chick was also recorded. After each check, a palisade of twigs was erected over the burrow entrance to provide a quick means of checking for recent activity (i.e., arrivals and departures of parents switching incubation/brooding duties) during subsequent checks of the same burrow. During the final trip of each season (Trip 3), fledgling chicks found in the study burrows were extracted and banded. There were several instances of chicks from study burrows that were assumed to have fledged before they were able to be banded. We determined the fledged status of these empty burrows by the presence of down feathers and the dandruff-like substance produced by newly emerging flight feathers (i.e., flakes of waxy sheaths from the feather bases) in the burrow and burrow entrances.

For the two trips focused on assessing the burrow demographics the field team also spent several nights walking the public track system within the 35-ha study area, capturing any black petrels found on the ground. On a separate trip focused on recruitment the field team systematically searched the colony from dusk to dawn each night. For all night-work, captured birds were checked for bands, and any band numbers were recorded. If unbanded, a band was applied to the bird's leg, before being subsequently released. Before release, a small mark was made on each bird's forehead using white correction fluid to provide a means of visually checking whether a bird had already been captured, if encountered again on the same or another subsequent night.

2.2 Feral pig monitoring

This aspect of the work was undertaken in collaboration with University of Auckland Masters student Christine Mansford.

Feral pigs pose an inherent risk for black petrels on Great Barrier Island/Aotea (Bell, 2013). Not only do feral pigs destroy burrows, but they also predate eggs, chicks, and adults, causing major implications for seabird colonies (Russell, et al., 2020). In order to capture any potential interactions between feral pigs and black petrels, four LTL Acorn™ trail cameras was put in place along the Cooper's Castle track in January (*n*=2) and February (*n*=2) 2022, and seven were put in place along the Cooper's Castle Track(*n*=4), Hirakimata Track (*n*=2) and Windy Canyon Tracks (*n*=1) in April 2022. All these cameras remained in place until May 2023. Placement was determined at areas where there were obvious signs

of pig disturbance (i.e., scat, rooting or prints). Pig surveys for signs such as scats and wallows also served as a method to determine relative abundance of pigs as well as other predators. The SD cards were replaced and reviewed by either Christine Mansford (Auckland University) in December 2022 or WMIL staff in May 2023. The presence/absence of pigs (and other predators, specifically feral cats, and rats) was recorded. This work will be reported in detail as part of Christine's thesis.

Interviews with Iwi, hunters and community members were also undertaken by Christine to uncover any anecdotal evidence of pig/petrel interactions and pig abundance.

2.3 Data entry and analysis

All mark–recapture and breeding status data were entered into a Microsoft Access™ database at the completion of each trip. Microsoft Excel™ was used to calculate breeding occupancy and breeding success as percentages which was then compared to previous years. The statistical software R (R Core Team 2022) using the 'ggplot2' package (Wickham 2016) was also used to visualise a variety of demographic parameters (e.g., number of burrows within the study, the age distribution and mean age and its standard deviation, and number of birds banded as chicks re-sighted at the colony from each cohort).

3. RESULTS

3.1 Burrow occupancy and breeding success

The number of census grid burrows has continued to increase over time since 1995 (Figure 2 and 3). From the 1995/96 to 1997/98 breeding season, there were 43 to 53 census grid burrows across the three census grids, respectively. The total number of census grid burrows increased to 95 in the 1998/1999 breeding season with the incorporation of three more census grids. Following the addition of three more census grids in 1999/00, the total number of census grid burrows has steadily increased from 119 in 1999/00 to 197 in 2022/23, an increase of one burrow from the previous year (Figure 2 and 3). Some study burrows within the grids have been abandoned and are not used by breeding black petrels, but these burrows are still checked each season. Black petrel burrows are highly unlikely to be lost to other seabird species present on Great Barrier/Aotea. The only other burrow-nesting seabird that nests inland on Great Barrier Island/Aotea and overlaps with the habitat of black petrel is the Cook's petrel (*Pterodroma cookii*), approximately 65% smaller in size than the black petrel (Bell & Sim, 1998; Imber, et al., 2003b). However, due to sustained predation by mammalian predators, this species is at an extremely low density on Great Barrier Island/Aotea (Imber, et al., 2003b), and within the study site only seven Cook's petrel breeding burrows have ever been found.

Of the 480 study burrows (197 census burrows and 283 non-census study burrows) monitored during the 2022/23 breeding season, 313 (65.2%) were occupied by breeding birds, 64 (13.3%) were occupied by non-breeding birds and 103 (21.5%) were unoccupied (Table 2).

Of the 197 census grid burrows, there were 119 burrows occupied by breeding black petrels (60.4%), 0.9% lower than the 28-year average census grid breeding burrow occupancy rate of 61.3% (Table 2; Figure 4). Non-census study burrows breeding occupancy was 68.6% (194 out of 283 burrows), 1.7% lower than the 28-year average of 70.3% (Table 2; Figure 4).

Table 2: *Summary of breeding success of tākoketai/black petrels (percentage of breeding burrows that fledged a chick; number (#) of successful fledglings followed in parentheses) at Mt Hobson/Hirakimata on Great Barrier Island/Aotea between 1995 and 2023 within census grid burrows, non-census study burrows and all burrows combined. The number of census grid, non-census and total number of study burrows are the number of burrows where a breeding attempt was observed.*

Breeding season	Census grid burrows breeding success % (no. of chicks fledged)	Number of census grid burrows occupied by breeders % (total census grid burrows)	Non-census study burrows breeding success % (no. of chicks fledged)	No. of non-census burrows occupied by breeders % (total no. non-census burrows)	Total Breeding success % (No. of chicks fledge)	Total no. of study burrows occupied by breeders % (total no. study burrows)
2022/23	57.1% (68)	60.4% (197)	63.4% (123)	68.6% (283)	61.0% (191)	65.2% (480)
2021/22	77.3% (99)	65.3% (196)	70.9% (141)	70.3% (283)	73.4% (240)	68.3% (479)
2020/21	73.3% (85)	60.1% (196)	78.8% (160)	71.7% (2832)	76.8% (245)	67.0% (476)
2019/20	71.6% (78)	58.0% (188)	79.0% (143)	66.3% (273)	76.2% (221)	62.9% (461)
2018/19	69.6% (71)	57.3% (178)	76.5% (143)	69.5% (269)	74.0% (214)	64.7% (447)
2017/18	63.5% (61)	53.9% (178)	63.2% (115)	67.7% (269)	63.3% (176)	62.2% (447)
2016/17	67.0% (69)	57.9% (178)	67.4% (128)	69.6% (273)	67.2% (197)	65.0% (451)
2015/16	62.6% (67)	64.1% (167)	68.9% (126)	68.8% (266)	66.6% (193)	67.0% (433)
2014/15	68.3% (69)	61.6% (164)	70.0% (133)	70.9% (268)	69.4% (202)	67.4% (432)
2013/14	68.4% (65)	59.7% (159)	71.1% (1232)	65.3% (265)	70.1% (188)	63.2% (424)
2012/13	80.9% (72)	56.3% (158)	80.4% (152)	71.6% (264)	80.6% (224)	65.9% (422)
2011/12	80.2% (73)	58.7% (155)	54.9% (90)	65.1% (252)	63.9% (163)	62.7% (407)
2010/11	60.4% (58)	62.3% (154)	61.4% (105)	68.1% (251)	61.0% (163)	65.9% (405)
2009/10	72.4% (63)	56.9% (153)	73.5% (122)	65.9% (252)	73.1% (185)	62.4% (404)
2008/09	70.1% (68)	63.8% (152)	72.8% (126)	72.1% (240)	71.9% (194)	68.9% (392)
2007/08	71.3% (67)	62.7% (150)	80.6% (133)	72.7% (227)	77.2% (200)	68.7% (377)
2006/07	80.4% (78)	65.1% (149)	84.0% (136)	72.3% (224)	82.6% (214)	69.4% (373)
2005/06	69.9% (65)	62.8% (148)	61.2% (101)	75.3% (219)	64.3% (166)	70.3% (367)
2004/05	75.3% (64)	57.8% (147)	77.0% (114)	67.6% (219)	76.4% (178)	63.7% (366)
2003/04	80.8% (63)	58.6% (133)	62.4% (88)	71.9% (196)	68.9% (151)	66.6% (329)
2002/03	59.2% (45)	58.0% (131)	56.5% (70)	65.3% (190)	57.5% (115)	62.3% (321)
2001/02	76.5% (62)	64.8% (125)	65.8% (75)	69.5% (164)	70.3% (137)	67.5% (289)
2000/01	80.5% (62)	63.1% (122)	73.2% (71)	69.8% (139)	76.4% (133)	66.7% (261)
1999/00	66.3% (55)	69.7% (119)	78.6% (77)	73.1% (134)	72.9% (132)	71.5% (253)
1998/99	70.8% (46)	68.4% (95)	81.5% (66)	68.6% (118)	76.7% (112)	68.5% (213)
1997/98	77.1% (27)	67.3% (52)	81.4% (57)	70.7% (99)	80.0% (84)	69.5% (151)
1996/97	68.6% (24)	67.3% (52)	76.2% (48)	73.3% (86)	73.5% (72)	71.0% (138)
1995/96	87.0% (20)	53.5% (43)	92.3% (36)	86.7% (45)	90.3% (56)	70.5% (88)
Average	**71.7% (62)**	**61.3% (144)**	**72.2% (107)**	**70.3% (216)**	**72.0% (170)**	**66.6% (360)**

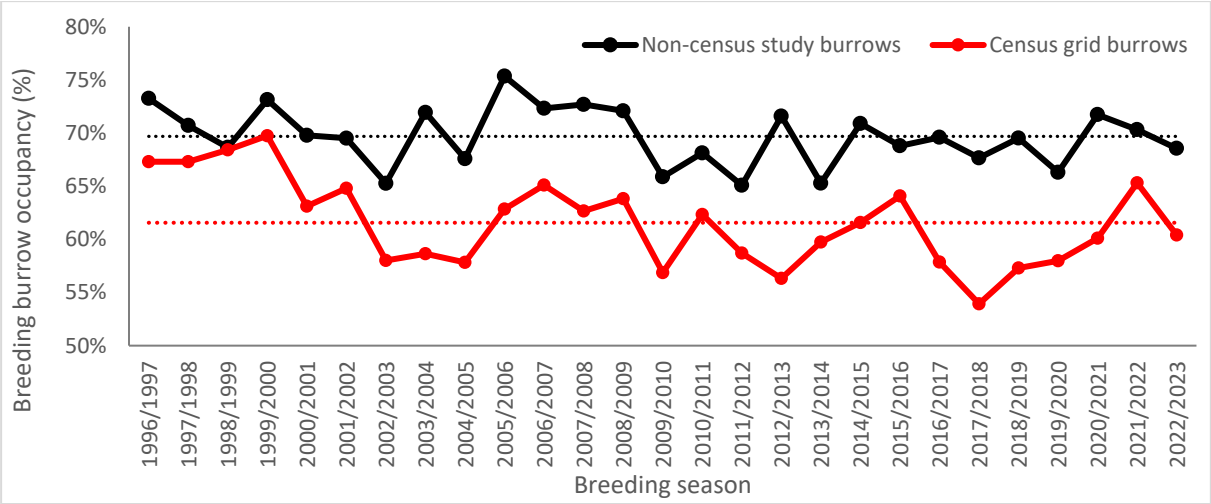

Figure 4: *Percentage of census grid burrows (n=197, red) and non-census study burrows (n=283, black) occupied by breeding tākoketai/black petrels at Mt Hobson/Hirakimata on Great Barrier Island/Aotea between 1996 and 2023 (dotted line represents the mean occupation of census grid burrows (red) and non-census study burrows (black) over 27 years by breeding black petrels).*

Of the 313 study burrows that were occupied by breeding birds during the 2022/23 breeding season, there were 122 breeding failures (39.0%) and 191 chicks were produced (61.0% breeding success; 11% lower than the 28-year average of 72%) (Table 2; Figure 6). There was significant rain events this season (665 mm between January 1 and February 28), and this caused flooding in a number of burrows affecting breeding success (Figure 5). The first heavy rainfall event (27 January; up to 299 mm in 24-hours) occurred at the peak hatching period which caused a number of small chicks to drown and pipping eggs to fail. These rainfall impacts (chick deaths and egg failures) came from the intensity of rain (volume that fell over short period) and the cumulative impacts of lighter falls throughout the period that did not allow the water to drain water. It was noted during the chick banding trip in May that a number (n=13) of chicks were underweight and smaller than normal; if all of these chicks do not fledge successfully, the overall breeding success would drop to 56.9% (this would be the lowest breeding success since monitoring began in 1995/96; Table 2).

Comparing rainfall to breeding success shows a weak pattern with more rainfall resulting in lower breeding success, but this is not consistent across the 28-year study (Figure 5).

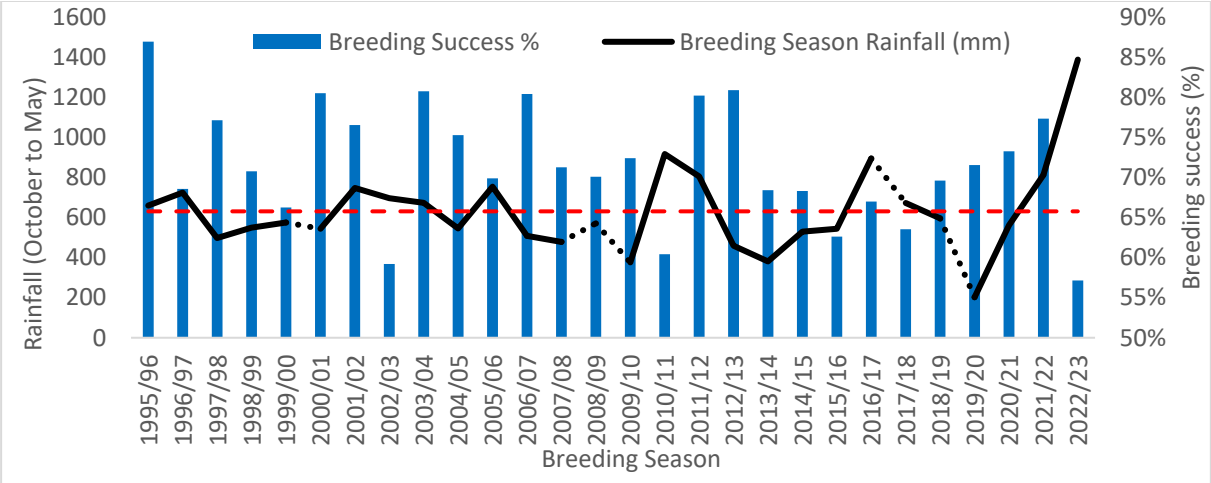

Figure 5: *Annual rainfall (black line; dotted sections are where data is limited and average across the period), average annual rainfall (red dashed line), and tākoketai/black petrel breeding success (blue bars) on Great Barrier Island/Aotea between 1996 and 2023.*

Causes of breeding failure in the 2022/23 breeding season included rat predation of an egg (*n*=1), eggs or chicks that disappeared from a breeding burrows (*n*=54), crushed eggs (*n*=26), infertile eggs (*n*=1), abandoned eggs (*n*=9), embryonic deaths (*n*=21) and chick deaths (*n*=10).

There was no cat predation within the study burrows this season, but cat predation continues to occur within the colony with one unbanded adult and one non-study burrow chick cat-predated carcasses being found near Mt Hobson/Hirakimata (EAB, pers. obs.). Table 3 provides a summary of cat predation events within the study burrows since 1995.

Table 3: *Number of tākoketai/black petrel chicks from study burrows, chicks from non-study burrows and adults predated by feral cats within the Mt Hobson/Hirakimata colony on Great Barrier Island/Aotea between 1995 and 2023.*

Season	Number of study burrow chicks predated	Number of non-study burrow chicks	Number of adults
1995/96	0	1	2
1996/97	0	1	1
1997/98	0	0	1
1998/99	2	1	2
1999/00	2	1	2
2000/01	1	1	1
2001/02	2	1	1
2002/03	3	4	2
2003/04	2	1	1
2004/05	0	0	1
2005/06	2	1	1
2006/07	0	1	0
2007/08	0	0	0
2008/09	0	1	0
2009/10	0	0	0
2010/11	1	0	0
2011/12	0	1	1
2012/13	0	1	0
2013/14	0	1	0
2014/15	0	1	0
2015/16	0	2	0
2016/17	2	3	2
2017/18	0	0	1
2018/19	0	1	1
2019/20	0	1	1
2020/21	0	1	1
2021/22	1	1	1
2022/23	0	1	1
Total	**18**	**28**	**24**
Average	**0.6**	**1.0**	**0.9**

Within the census grid burrows, there were 68 (57.1%) chicks produced during the 2022/23 season from 119 burrows where a breeding attempt occurred (14.6% lower than the 28-year average of 71.7%) (Figure 6, Table 2). As stated earlier, significant rain events caused flooding in a number of burrows causing chicks to drown and eggs to fail. There were also six very small, underweight chicks

recorded in May within the census grid burrows. If these chicks do not fledge successfully, breeding success within the census grids would drop to 52.1% (the lowest in the 28-year study).

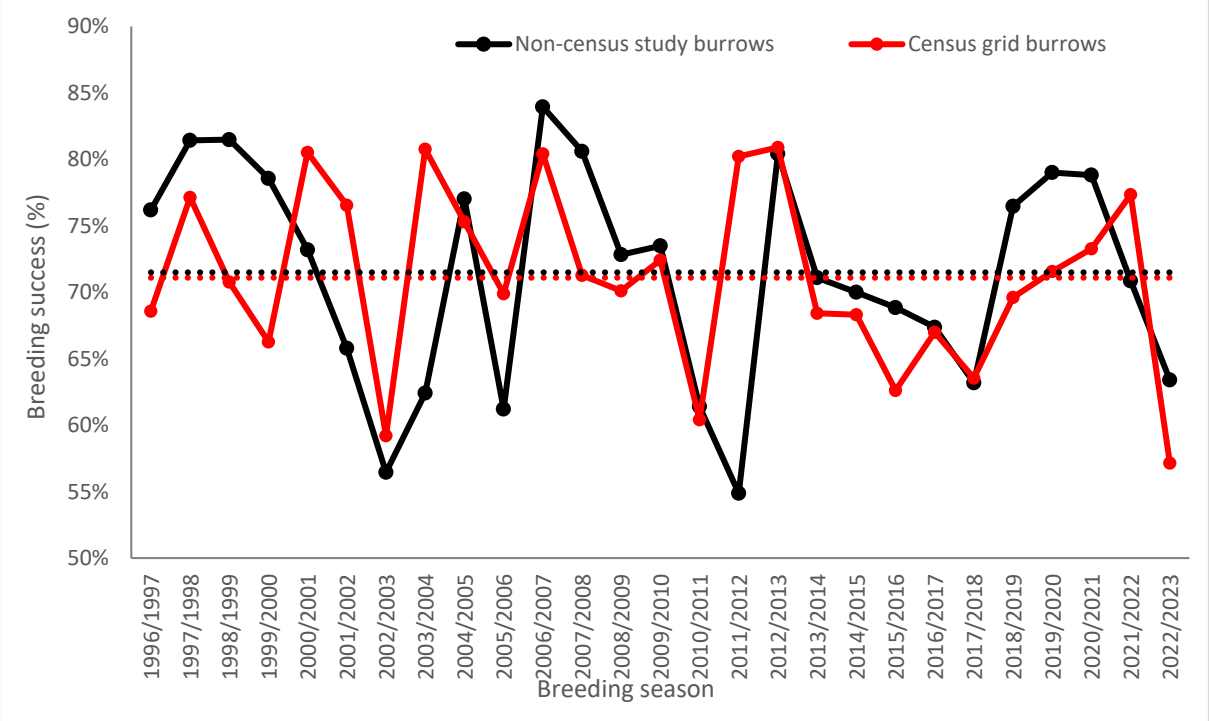

Figure 6: *Breeding success (percentage of breeding burrows that fledge a chick) of all tākoketai/black petrel non-census study burrows (n=283, black) and census grid burrows (n=197, red) at Mt Hobson/Hirakimata on Great Barrier Island/Aotea between 1996 and 2023 (the dotted line represents the mean breeding success of census burrows (red) and all study burrows (black) over 28 years).*

3.2 Population age structure

The estimated (banded as adults) and known (banded as chicks) age of black petrels breeding during the 2022/23 season that were located within the nine census grids ranged from 5 to 23 years and from 4 to 29 years, respectively (Figure 7). Similarly, the estimated and known age of breeding birds found in study burrows outside of the census grids both ranged from 6 to 24 and 5 to 32 respectively (Figure 7). Black petrels with estimated ages living inside and outside census grids were both skewed towards younger birds, both peaking at 8 years (Figure 7). The age distribution of black petrels with known ages were more evenly distributed across year groups both inside and outside the census grids.

Since monitoring began in 1995/96 the average known age of breeding black petrels within study burrows located inside and outside the census grids has slowly increased over time from an average age of 5 and 6 ± 1.4 years in 1995/96 to an average age of 11.86 ± 5.34 and 12.16 ± 5.48 years in the 2022/23 season, respectively (Figure 7). The steady increase in average age until the plateau observed from 1999/00 onwards is likely derived as an artefact of additional census grids that were established in 1998/99 (from 3 to 6 census grids) and 1999/00 (from 6 to 9 census grids). From 1999/00 onwards, the average age and its variation exhibited some fluctuation from season to season until 2008/09 where from thereafter appeared to have stabilised (Figure 7).

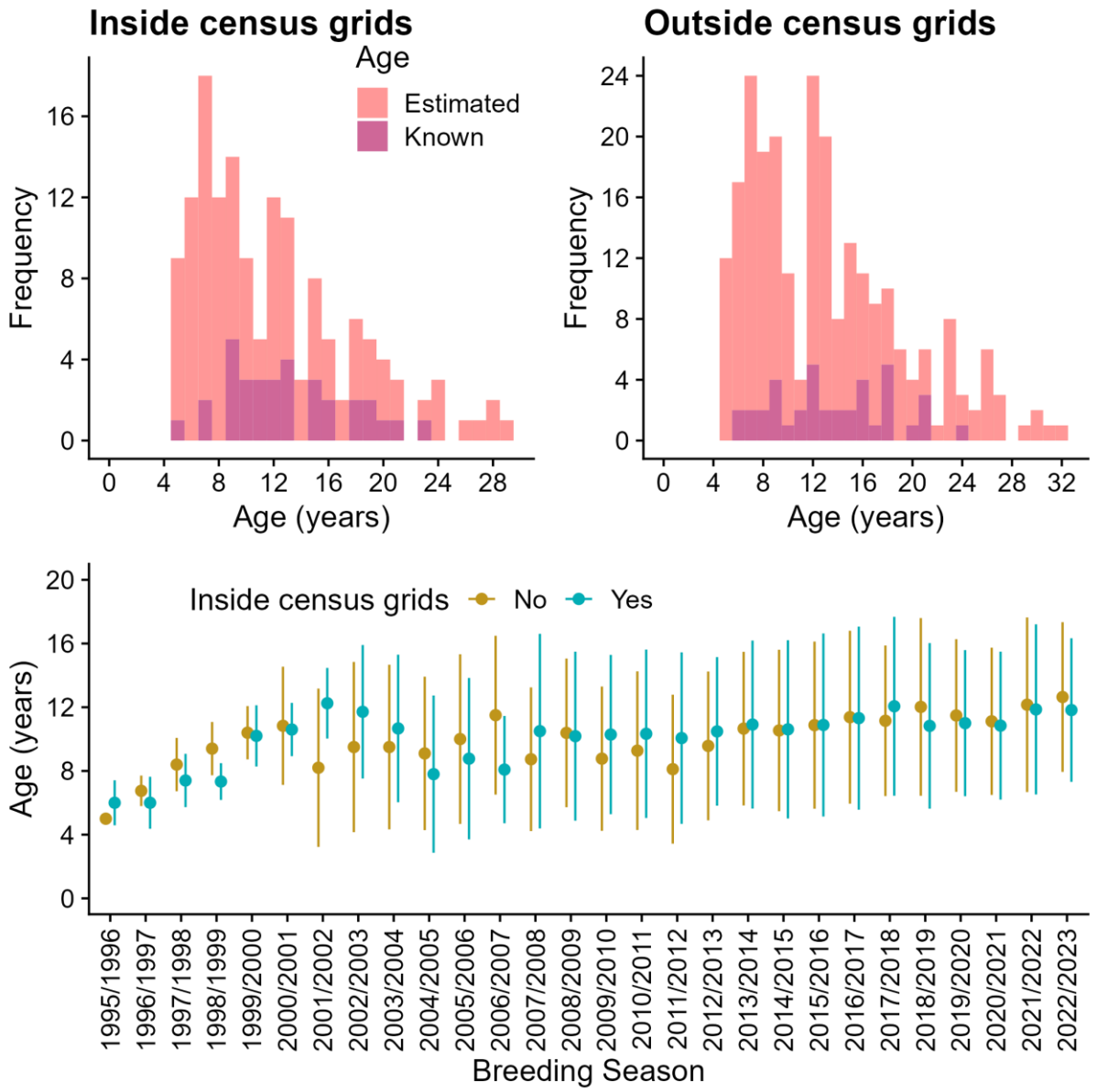

Figure 7: *The age distribution of the breeding tākoketai/black petrel adults studied at Mt Hobson/Hirakimata on Great Barrier Island/Aotea located within study burrows within (a) census grids and (b) outside census grids during the 2022/23 season. Birds banded as adults are assumed to be at least 5 years of age, and age is therefore estimated. Birds banded as chicks are of known age. c) the mean (± standard deviation) age of known age breeding tākoketai/black petrels per season between 1995/96 and 2022/23.*

3.3 Survival and status of returned chicks

A total of 664 adults and 129 fledgling chicks were captured during the 2022/23 season (Table 4 and Table 5). A total of 174 adults were banded during the 2022/23 season, of which 52 were captured in the study burrows (Table 4 and Table 5). Of the 129 fledgling chicks banded during the 2022/23 season, 119 were banded in the study burrows (Table 4). One chick from study burrows fledged prior to banding (i.e., evidence of down, pin feathers and droppings were obvious in the now-unoccupied burrow during the Trip 3 check). The remaining 72 chicks could not be banded due to torrential rain during the final days of the chick banding trip. The adults and fledgling chicks not banded in study burrows were located in either non-study burrows or were located on the forest floor during nocturnal searches. There were 61 adults banded during the recruitment trip in December.

Of the 626 parents occupying the 313 breeding study burrows during the 2022/23 breeding season, a total of 491 (78.4%) were captured and identified (102 burrows had both parents identified, 187 burrows had one parent identified and 24 burrows had no parents identified (either chicks alone or a failed breeding attempt before the January trip occurred). This is lower than normally achieved, due to the poor weather and January trip having to be shortened for safety reasons. Additionally, the percentage of parents captured within census grids was also low at 57.6% (a total of 137 of 238 parents were identified and captured within 119 census grid burrows where a breeding attempt took place; 39 burrows had both parents identified, 59 burrows had one parent identified and 7 burrows had no parents identified (either chicks alone or a failed breeding attempt before the January trip occurred). The majority of individuals that were not identified were adults whose breeding attempts had failed either prior to, or during Trip 2, and were therefore unlikely to be spending much time in their burrows during the rest of the season.

Table 4: *Summary of the number of tākoketai/black petrels captured, banded, re-captured adults and chicks (i.e., returned to the colony to breed) at Mt Hobson/Hirakimata on Great Barrier Island/Aotea between 1995 and 2023. Several fledglings located in study burrows had fledged before being banded, thus the number of fledglings banded may be less than the number fledged shown in Table 2. The total number of fledglings banded includes birds found either on the surface or in burrows not located within the study site (see Figure 1).*

Breeding season	Number of captures	Number of all adult recaptures	Number of adults banded	Number of fledglings banded in study burrows	Total number fledglings banded
2022/23	793	490	174	119	129
2021/22	999	638	107	227	254
2020/21	1103	703	136	233	264
2019/20	960	636	154	155	170
2018/19	898	562	122	201	214
2017/18	800	541	84	154	175
2016/17	1121	476	244	173	401
2015/16	978	617	177	171	184
2014/15	918	536	167	200	215
2013/14	860	539	120	185	201
2012/13	1021	546	249	212	226
2011/12	551	340	48	161	163
2010/11	685	457	83	139	145
2009/10	789	510	107	160	172
2008/09	875	489	183	191	203
2007/08	594	347	56	191	191
2006/07	672	371	85	210	216
2005/06	632	332	155	141	145
2004/05	650	330	135	177	185
2003/04	536	358	67	108	111
2002/03	637	392	182	60	63
2001/02	621	346	115	136	160
2000/01	555	320	98	128	137
1999/00	542	257	150	130	135
1998/99	404	158	130	111	116
1997/98	296	151	59	81	86
1996/97	300	51	180	67	69
1995/96	129	30	40	48	59

Table 5. *The number of tākoketai/black petrels captured, banded, re-captured adults and chicks (i.e., returned to the colony to breed) at Mt Hobson/Hirakimata on Great Barrier Island/Aotea between 1995 and 2023. The total number of fledglings banded includes birds found either on the surface or in burrows not located within the study site (see Figure 1).*

Season	No. banded	Pre -95	95/96	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	Not recaptured
1963/64	2																														2
1966/67	1	1																													0
1967/68	0																														0
1970/71	0																														0
1971/72	12	4																													6
1972/73	0																														0
1973/74	0																														0
1974/75	7																														0
1975/76	12	1		1																											10
1976/77	26																														26
1977/78	69	1	2																												67
1978/79	0																														0
1979/80	0																														0
1981/82	0																														0
1982/83	0																														0
1984/85	0																														0
1985/86	90	1	1	1	1	1	2	3	3	2	4	1	1							1	1	1	1	1		1					84
1986/87	125	1	1				2	1	1	1	1		1		2	1															120
1987/88	87	4	1	3	5	2	4	3	3	4	3	2	4	2	3	5	3	3	2	2	2	2	2	1	1	1	1	2	1	1	79
1988/89	122	7	3	6	5	5	6	7	5	5	4	6	3	6	4	4	3	3	2	3	2	2	2	1	1	2	1	1	1	1	107
1989/90	105	3	3	6	4	6	3	2	1	2	2	1	2	1	1	1	1	1		1											97
1991/92	99	6	3	11	7	6	7	7	10	8	6	7	7	5	3	3	2	2	2	2	2	2	1	1	1						74
1992/93	15	1	2	1		2	2	2	1	2	3	3	3	3	4	3	3	2	1	2	2	2	2								7
1994/95	24		2	1	1	2	2	2	2	3	1	1	1	1	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1		19
1995/96	100			15	14	14	17	15	13	15	13	8	12	13	7	8	9	9	5	5	6	4	3	3	3	2	2	2	1	2	71
1996/97	249				113	86	85	73	66	61	45	42	40	47	28	30	28	22	12	21	15	14	15	13	10	8	9	9	3	4	98
1997/98	144					32	32	30	33	30	19	14	18	13	13	17	14	11	12	10	9	5	5	5	5	4	5	5	3	2	49
1998/99	246						98	82	70	70	50	44	39	33	32	37	33	25	17	29	19	17	18	16	12	9	9	10	6	5	123
1999/00	246							85	78	67	51	52	52	37	31	39	31	32	20	22	17	15	20	11	9	7	7	6	5	3	157
2000/01	282								51	51	41	22	35	29	28	33	28	21	12	22	18	14	15	16	13	12	12	9	8	5	153
2001/02	265									62	40	24	21	19	20	27	23	15	16	21	19	16	17	16	18	8	9	9	9	14	168
2002/03	245										69	54	56	54	40	56	50	38	26	36	34	31	27	20	19	17	16	16	13	4	134
2003/04	177											21	31	23	21	26	25	24	15	23	19	15	17	15	17	15	15	14	9	9	123
2004/05	320												48	35	33	48	52	42	28	47	43	38	35	32	27	26	28	27	21	16	212
2005/06	251													45	36	49	45	35	23	35	28	27	25	16	15	15	10	12	12	4	159
2006/07	301														33	46	42	35	22	43	45	38	40	24	24	24	27	21	21	15	209
2007/08	247															29	20	19	18	32	23	23	20	12	14	16	15	13	10	13	185
2008/09	387																72	59	46	66	54	53	51	37	38	41	40	38	30	18	257
2009/10	278																	45	32	39	39	33	41	27	30	27	28	29	25	16	198
2010/11	228																		25	40	32	35	38	31	34	36	33	35	28	20	149
2011/12	211																			32	28	24	31	30	31	28	30	25	19	10	155
2012/13	475																				70	71	68	48	55	47	56	45	43	27	342
2013/14	321																					50	51	32	33	32	40	43	39	23	224
2014/15	382																						54	44	34	40	35	36	29	22	289
2015/16	362																							57	53	51	63	61	48	37	248
2016/17	602																								40	39	40	44	37	41	516
2017/18	258																									52	44	37	38	29	179
2018/19	336																										52	50	42	27	276
2019/20	321																											75	55	40	242

Season	No. banded	Pre -95	95/96	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	Not recaptured
2020/21	396																												64	42	64
2021/22	361																												107	40	254
2022/23	303																													174	129

The cumulative number of birds banded as chicks identified returning to the colony (as either breeding or non-breeding adults) has steadily increased over time (Figure 8). In the 2022/23 breeding season the cumulative number of returned adults recorded to date was 430, with 117 returned chicks recaptured at the colony this season. This includes 28 returned adults that had not been previously recorded since being banded as fledglings. Of those 28 returnees, most were found on the surface during nocturnal surveys during the December recruitment or January monitoring trip (*n*=19, 67.9%), with the remainder in study (*n*=8, 28.6%) or random, non-monitored (*n*=1, 3.6%) burrows.

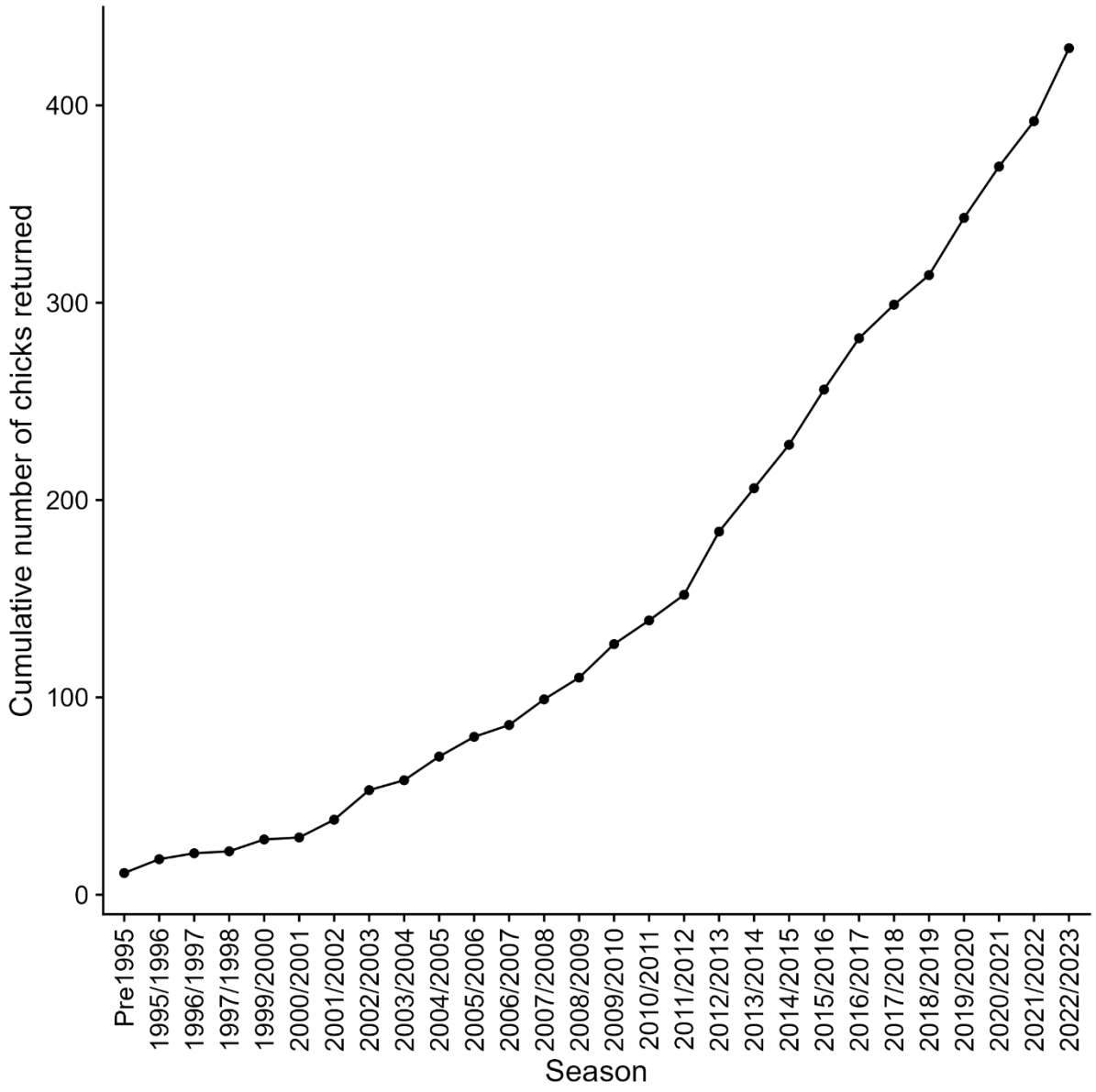

Figure 8: *The cumulative number of tākoketai/black petrel adults banded as chicks that have returned to the colony as adults at Mt Hobson/Hirakimata on Great Barrier Island/Aotea. Note: the time period before 1995 encompasses approximately 20 years of chicks banding records (1972-1992; e.g., the first returned chick was banded in 1972 and recaptured again in 1977).*

The median age of black petrels when first observed returning to the Hirakimata/Mt Hobson colony (regardless of breeding status) has fluctuated between 4.8 and 6.6 years since the 2002/03 breeding season (Bell, et al., 2022b). Between the 1995/96 and 2022/23 breeding seasons the mean age of first return was 6.5 ± 0.1 years, the mean age of first breeding attempt was 8.0 ± 0.2 years and the mean age of first successful breeding attempt was 8.4 ± 0.2 years.

Figure 9 shows the range of ages that black petrels have been when recaptured for the first time at the colony, as well as age of first-time breeders and first-time successful breeders.

The youngest returnee detected was observed at 1.6 years in the 2011/12 breeding season (Bell. et al., 2022a). During the 2022/23 breeding season, the median return age was 6.6 years (min and max range 3.7-34.7 years; Figure 9), which was similar to the previous 2021/2022 breeding season (median 6, min and max range 4-14 years; Bell, et al., 2022b).

Despite the ongoing bi-annual visits to the study colony since 1995/96 some birds can remain undetected for many years with the oldest black petrel recaptured for the first time since being banded as a chick occurred this season with a 34.7 year old being caught on the surface clacking outside a random, non-monitored burrow. Previously the oldest chick was caught during the 2011/12 breeding season at 26.6 years (Bell, et al., 2022b).

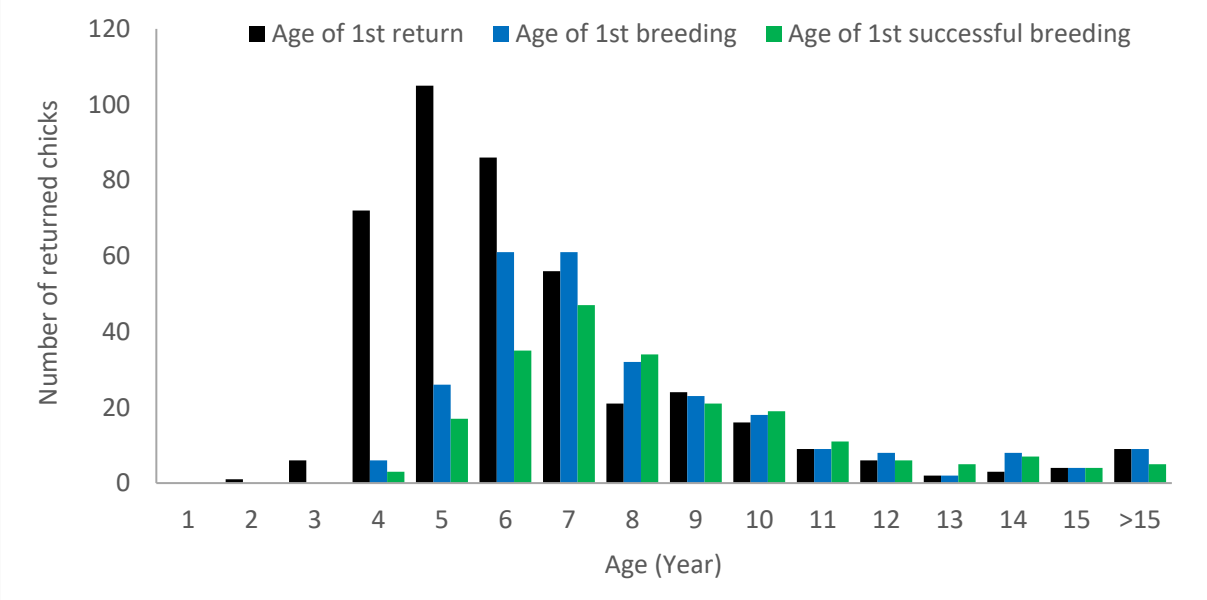

Figure 9: *The age of tākoketai/black petrel adults banded as chicks that have returned to the colony as adults when first returned (black bars), when first recorded breeding (blue bars) and first recorded successfully breeding (green bars) on Great Barrier Island/Aotea.*

Despite a similar number of chicks being banded each year prior to fledging, the percentage of chicks (from each cohort) returning to the colony at Mt Hobson/Hirakimata on Great Barrier Island/Aotea as adults is very low and fluctuates between 1.4-14.1% of chicks banded observed each year (Figure 10; Table 4 and 5).

Of the 117 adults first banded as chicks identified during the 2022/23 breeding season, the majority (*n*=16, 13.6%) of returned chicks were from the 2016/17 breeding season (8.1% of that cohort), followed by the 2013/14 cohort (*n*=12, 10.3%; or 6.4% of that cohort) (Figure 10).

Not all cohorts were represented as no returned chicks from the 1995/96, 1996/97 and 1997/98 cohorts were recaptured this season (Figure 10). There were three returned chicks from the 2018/19 cohort (all 4 years of age) recaptured this season (Figure 10). All cohorts from the 2019/2020 breeding season onwards are still expected to be at sea until 4 years of age.

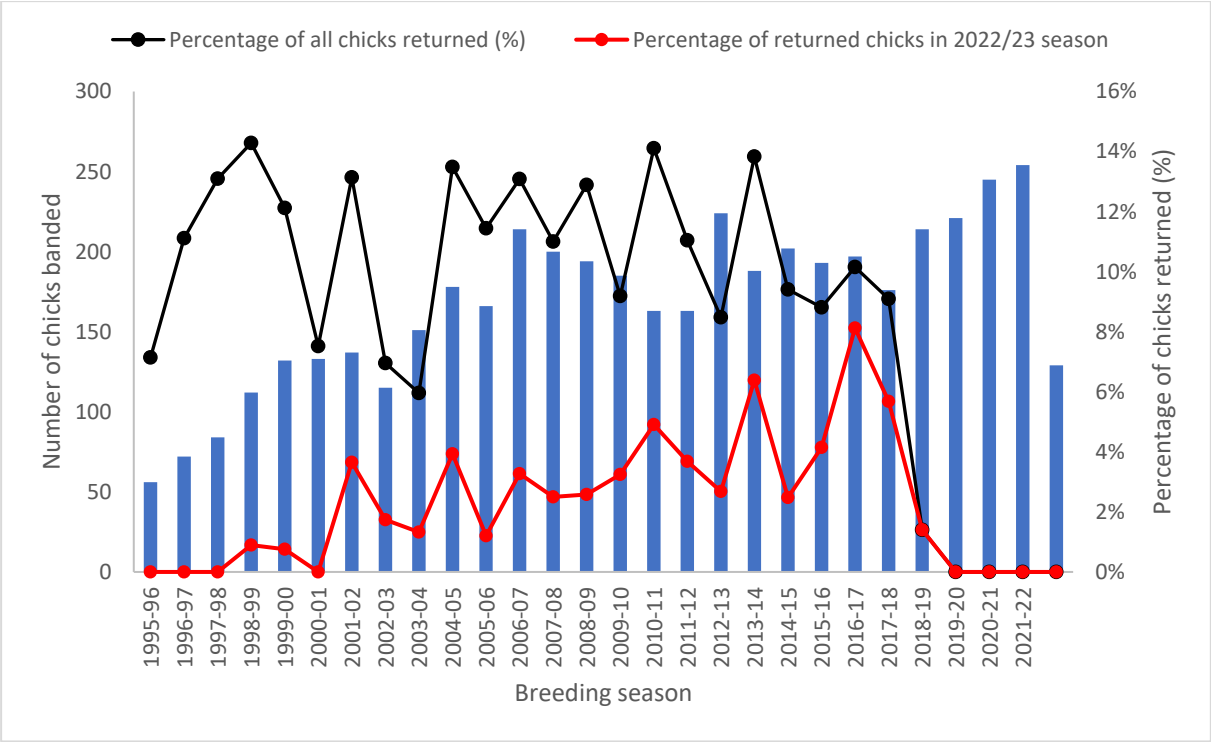

Figure 10: *The number of banded tākoketai/black petrel chicks per year (blue bars) overlayed with the percentage of banded chicks (black points and lines) from a particular breeding season cohort returning to the colony at Mt Hobson/Hirakimata on Great Barrier Island/Aotea as adults. Note: the number of chicks banded, and percentage returned before 1995 was intentionally not plotted. There were 589 chicks banded before 1995 and of these 5.9% have been re-observed as adults. Note: the left-hand side y-axis corresponds to the blue bars (number of chicks banded), whereas the right-hand side y-axis corresponds to the black (percentage of all returned chicks from a particular breeding season) and red line (percentage of returned chicks from a particular breeding season observed during the 2022/23 breeding season).*

The composition of each breeding seasons' cohort (i.e., the breeding season the chick hatched in) continues to vary each breeding season (Figure 11). Across the entirety of the study, the number of adults that were banded as chicks that subsequently returned to the colony as adults has increased steadily since the study's inception. Owing to the time lag between fledging and maturity, for the first five years of the study, only pre-1995 returned chicks are represented, which then steadily increase overtime (Figure 11). Likely changes in effort (e.g., increased night-work, multiple trips per year, usage of detection dogs, etc.) likely accounts for the dramatic increase in re-sightings from 2011/12 to 2012/13 where large proportions of the pre-1995, 2001/02, 2004/05 and 2005/06 birds were re-sighted.

Interestingly, despite the trip specifically undertaken in December to focus on recruitment, there was no significant increase in detections of returned chicks this season. It is apparent that pre-1995 birds are less likely to be recaptured at the colony, and the number of recaptures of returned chicks banded before 2000 are also declining (Figure 11).

A total of 181 birds were captured during the recruitment trip; 138 adults and 43 returned chicks. Of the 138 adults, 74 had been encountered before over the 28-year study, 52 were new to the study (banded this season) and 12 were seen for the first time since being banded in earlier seasons. Of the 43 returned chicks, 30 had been encountered before over the 28-year study and 13 had not been seen since they were chicks in their burrows. This capture rate equates to 22.6 birds caught per night over eight nights.

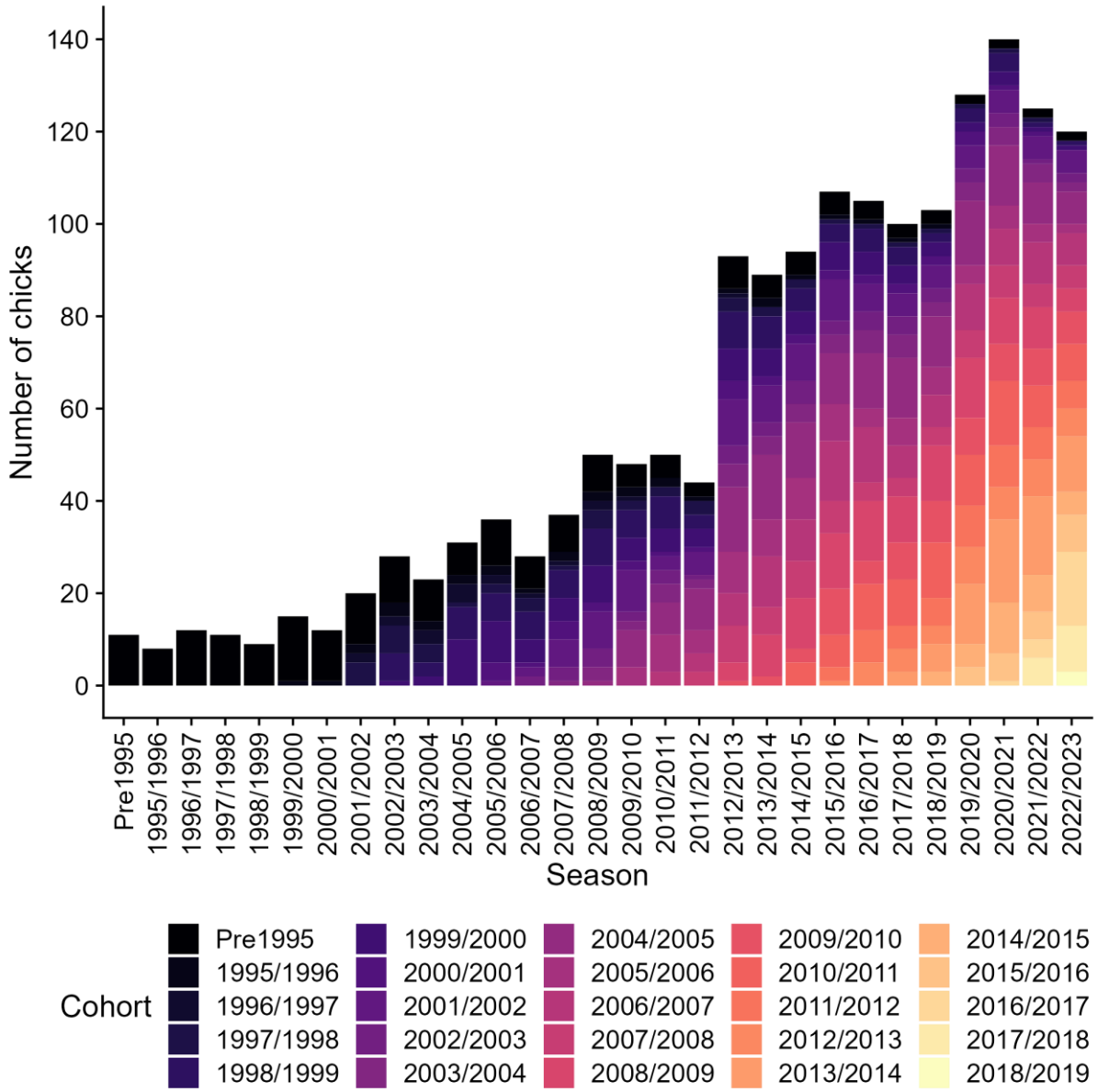

Figure 11: *The number of tākoketai/black petrel returned chicks (banded as chicks and re-observed as adults) at Mt Hobson/Hirakimata on Great Barrier Island/Aotea during each breeding season (from 1995/96 to 2022/23), categorised by the breeding season the bird was born in (i.e., breeding season cohort). Note: the time period before 1995 encompasses approximately 20 years of chicks banding records (1972–1992, e.g., the first returned chick was banded in 1972 and recorded again in 1977).*

Whilst the proportion of individuals representing different cohorts fluctuates from year to year, the proportion of individuals representing older cohorts tend to diminish over time as younger cohorts return to the breeding colony (Figure 12). For instance, in the 2021/22 breeding season, the pre-1995 cohort was represented by two individuals and cohorts from between 1995/96 to 2002/03 were each represented by single individuals. The time lag between a breeding season and the peak number of individuals being resighted at the colony average at 7.4 ± 2.4 (range 3 – 12) years after.

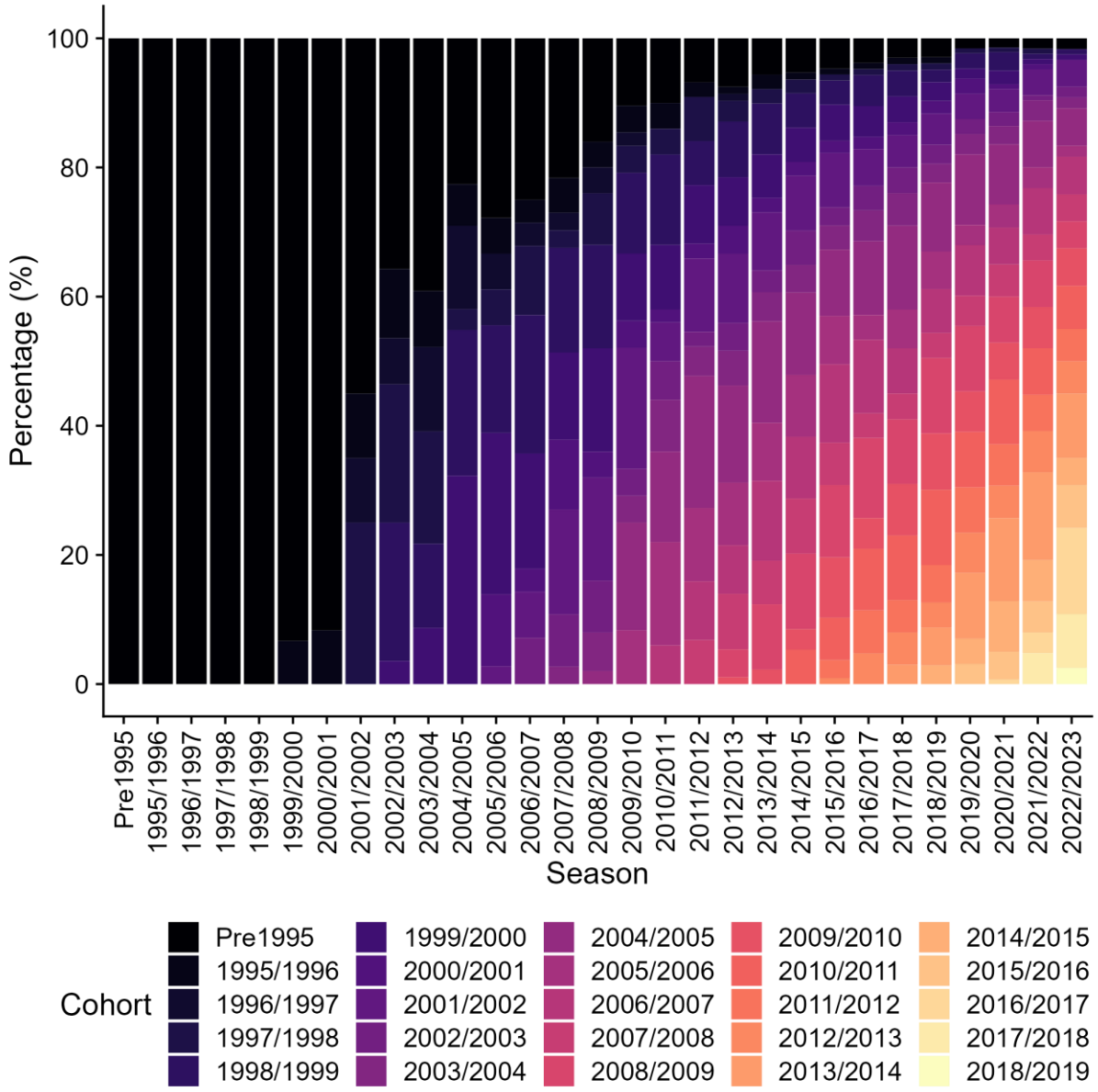

Figure 12: *The composition of each breeding seasons returned tākoketai/black petrel chicks - proportion of returned chicks (banded as chicks and re-observed as adults) at Mt Hobson/Hirakimata on Great Barrier Island/Aotea during each breeding season (from 1995/96 to 2022/23), categorised by the breeding season the bird was born in (i.e., breeding season cohort). Note: the time period before 1995 encompasses approximately 20 years of chicks banding records (1972–1992, e.g., the first returned chick was banded in 1972 and recorded again in 1977).*

Despite low numbers of individuals being resighted from older cohorts (including no returned chicks re-sighted from the 1995/96, 1996/97 and 1997/98 cohorts from the 2022/23 breeding season), the number of unique cohorts represented during each breeding season (by the presence of at least one individual) has continued to increase each year owing to the long life-expectancy and strong philopatric nature of black petrels (Figure 13). In the 2022/23 breeding season 20 different breeding season cohorts (since the study began) were represented (21 breeding seasons total if pre-1995 birds are classed as a single cohort; Figure 13).

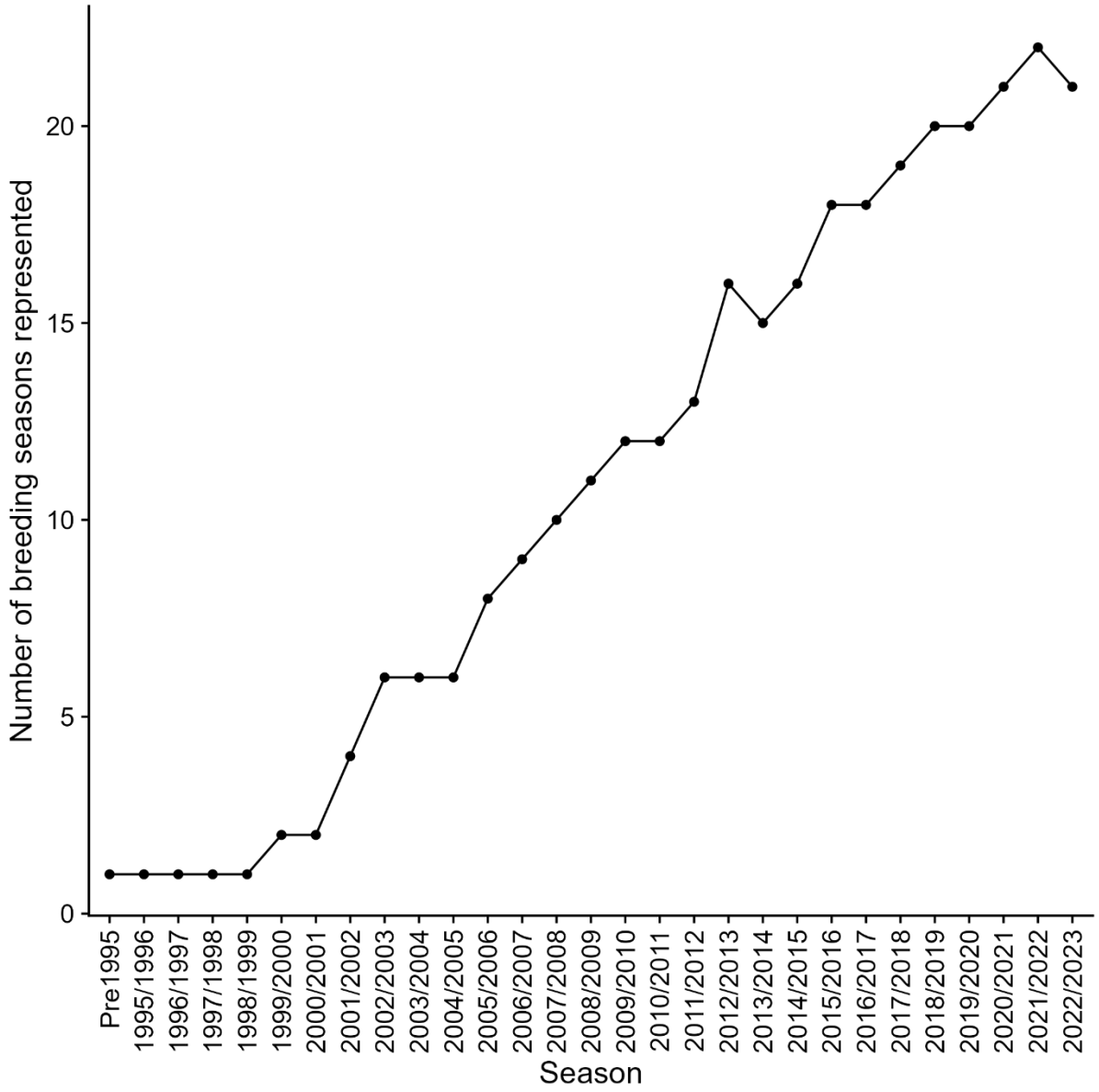

Figure 13: *The number of different breeding season cohorts represented by tākoketai/black petrel returned chicks (banded as chicks and re-observed as adults) at Mt/Hobson/Hirakimata on Great Barrier Island/Aotea during each breeding season (from 1995/1996 to 2022/23). Note: the time period before 1995 encompasses approximately 20 years of chicks banding records (1972–1992, e.g., the first returned chick was banded in 1972 and recorded again in 1977).*

3.4 Burrow turnover rate

Of the census grid burrows where we were able to identify both partner birds during the current season and previous breeding season (total of 36 census grid burrows), the turnover rate (% of one or both breeding partners changing from the previous season) within the census grid burrows has fluctuated over time but is following an overall downward trend over the breeding seasons. During the 2022/23 breeding season the turnover rate in the census grid burrows was 8.3% (Figure 14).

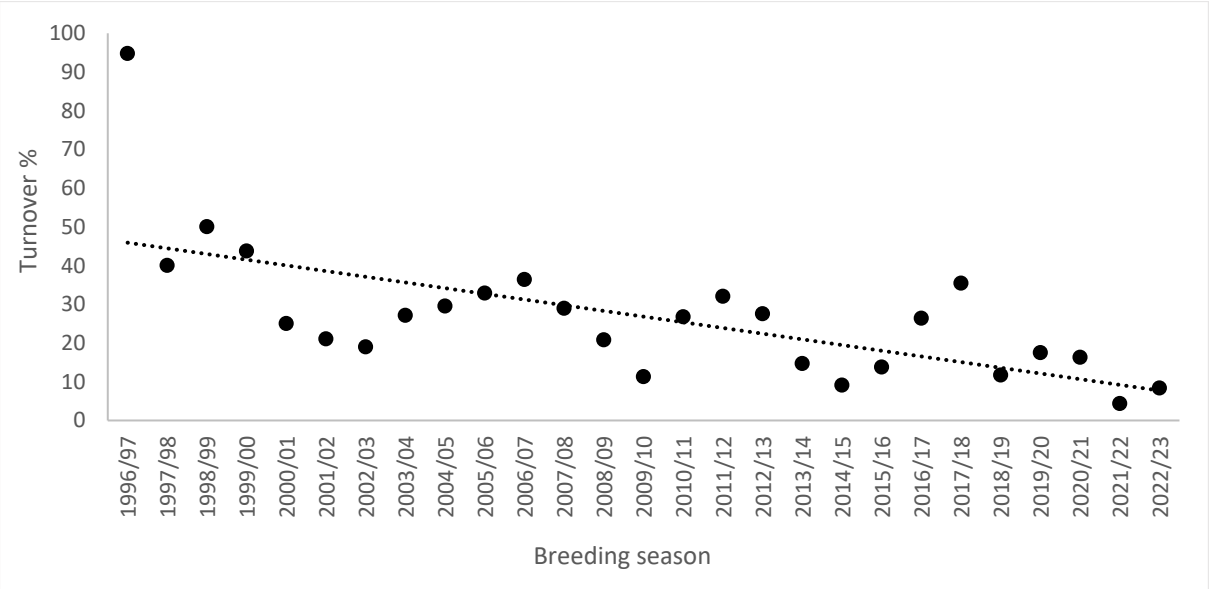

Figure 14: *The turnover rate within the census grid burrows between tākoketai/black petrel breeding seasons on Great Barrier Island/Aotea. This is the percentage of census grid burrows for which one or both breeding partners changed from the previous breeding season.*

The turnover rate from one partner changing from the previous season has fluctuated over the years, but it is also following a downward trend (Figure 15). In the current season, the turnover rate was 8.3%.

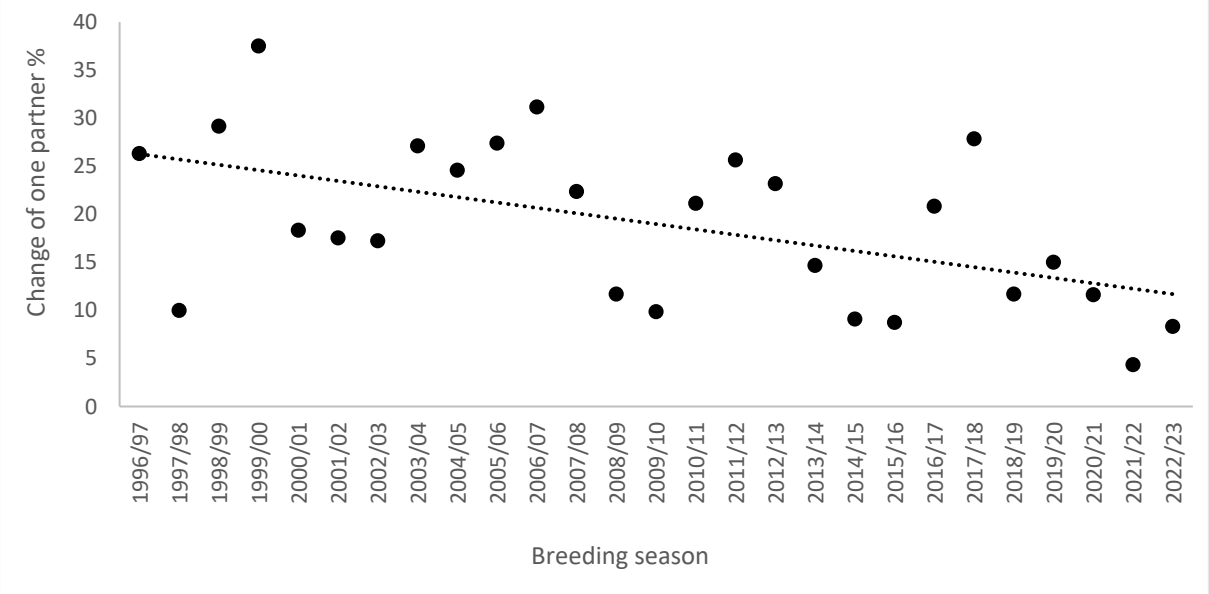

Figure 15: *The percentage of tākoketai/black petrel breeding census grid burrows on Great Barrier Island/Aotea where one partner changed from the previous breeding season.*

In breeding census grid burrows, the turnover rate of both partners from the previous breeding season has fluctuated over the years, but since the 1999/00 breeding season turnover of both breeding partners has been low (Figure 16). During the current 2022/23 season, we did not identify any burrows where there was a complete turnover in breeding pairs (Figure 16).

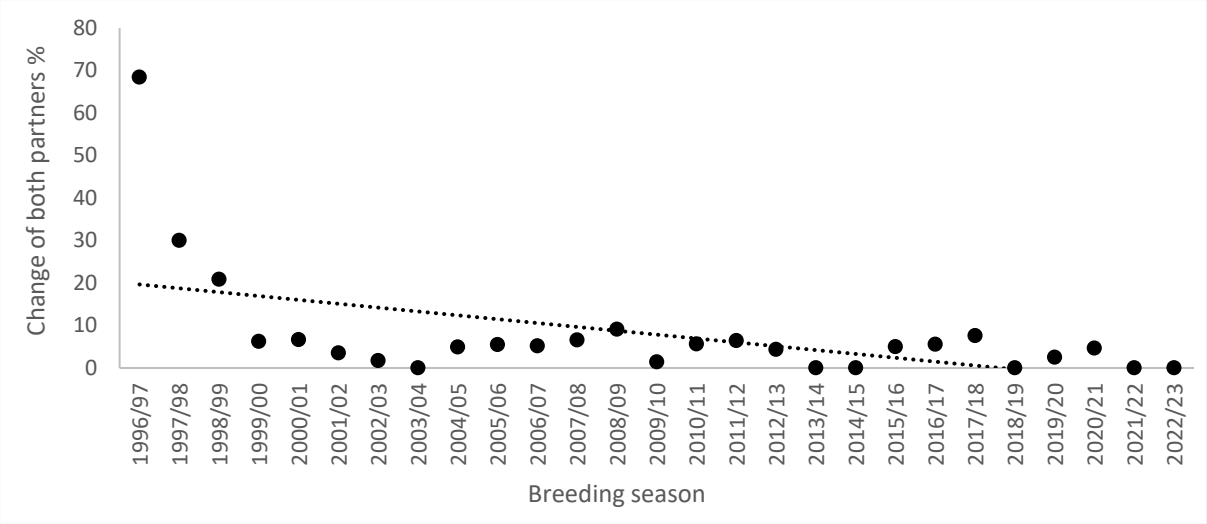

Figure 16: *The percentage of tākoketai/black petrel breeding census grid burrows on Great Barrier Island/Aotea where both partners changed in a burrow from the previous breeding season.*

3.5 Feral pigs and other predators

Across all eleven cameras, over this period (April 2022 to April 2023) a number of predators were recorded. One camera could not be recovered due to track conditions (following the extreme weather events). There were 364 incidents of predators over this time (Table 6; Figure 17). There were no interactions caught between black petrels and predators. Detailed analysis of the footage from all cameras will be reviewed at a later date by Christine as part of her thesis.

Figure 17: *Predators captured on film during the 2022/23 tākoketai/black petrel breeding season at Cooper's Castle on Great Barrier Island/Aotea. A) Feral pig, B) Rat, C) Mouse, and D) Feral cat.*

	Rat	Mouse	Pig	Cat	People	Bird	Total
Total images on all cameras combined	159	114	51	31	5	4	**364**
Percentage of cameras	43.7%	31.3%	14.0%	8.5%	1.4%	1.1%	

Table 6: *Number of predators and visitors seen across eleven trail cameras on Cooper's Castle on Great Barrier Island/Aotea between April 2022 and April 2023.*

4. DISCUSSION

The 2022/23 tākoketai/black petrel fledgling success rate on Great Barrier Island/Aotea was 61%; 11% lower than the 28-year average (72%). The fledgling success was even lower within census grids (57.1%). Much of this drop was likely to be the result of extreme weather at peak hatching (late January/early February) with nearly 60 eggs disappearing or having embryonic death and over 20 chicks dying this season. The 2022/23 season saw a decrease in breeding success, continuing the negative trend from last year's breeding season. Bell, et al. (2022a) hypothesised that age structure of the black petrel population might be contributing to an overall negative trend or difference between the census grid burrows and overall study burrows on Great Barrier Island/Aotea. Breeding success and reproductive performance in long-lived seabirds is affected by age, age at first reproduction, senescence, and experience (Aubry, et al., 2009; Limmer & Becker, 2010). The age distribution between burrows within and outside the census grids were similar, but there was some disparity between birds of known and estimated age (i.e., known ages were more uniformly distributed whereas estimated ages peaked towards younger birds (Bell, et al., 2022a). The oldest known aged bird still being caught at the colony is 34.7 (banded in 1988 by Dr. Mike Imber) as a non-breeder; this bird was caught for the first time this season. Another bird banded in 1989 (now 34 years old) was also caught again this season as a failed breeder; this bird has been caught every year since the 1995/96 breeding season. During the 2022/23 season three returned chicks were re-captured from the 2018/19 breeding season, at age 4, a year earlier than the typical return age. Future, in-depth modelling on the effect of age, age difference in pairs, experience on breeding success will be needed to understand this relationship in black petrels.

Rainfall (i.e., intensive volume over a short period on 27 January and cumulative lighter rainfall throughout the January/February period preventing water from draining) impacted on breeding success this season, with a number of burrows flooding causing chicks to drown and eggs failing to hatch. Comparison between rainfall and breeding success shows a weak pattern over time with more rainfall resulting in lower breeding success. However, this is not consistent across the 28-year study, and would need further investigation to determine whether particular areas of the colony are more at risk to rainfall events than others (e.g., burrows in flatter areas being more prone to flooding). It does appear that the tākoketai/black petrels are more resilient to rainfall events than other species such as toanui/flesh-footed shearwaters *Ardenna carneipes* having a very poor breeding season this year; on Ohinau Island toanui only had a 10% breeding success (the lowest record of breeding success on the island since records began in 2016) due to the extreme weather events (D. Burgin, WMIL, pers. comm.). This difference in resilience is most likely due to habitat differences (i.e., terrain and substrate), but as climate change extreme events increase in frequency, flooding events could occur more often, which in turn could significantly impact on tākoketai/black petrel breeding success and recruitment into the breeding population. Thirteen chicks were recorded underweight and small in May, and most of these are not expected to fledge. The parents of these chicks may be struggling to forage effectively reducing chick provisioning rates or amounts, or one parent may have died at sea in these storm events (particularly Cyclone Gabrielle) leaving only one parent to try to raise the chick. It will be important to identify all birds in study burrows next season to determine whether any birds have not returned following these weather events. Ongoing monitoring at the Great Barrier Island/Aotea colony is vital to continue to track population trends and determine impacts to the birds and colony.

There was no recorded instance of feral cat predation within the study burrows this season, but one unbanded adult and one non-study burrow chick was predated by feral cats this season. Live cage traps targeting feral cats are located around the Mt Hobson/Hirakimata summit and run prior to, and throughout the black petrel breeding season. The Tu Mai Taonga (https://www.tumaitaonga.nz/) project aims to protect and restore native species and ecosystems through feral cat removal and intensified rat control, initially in the Aotea Conservation Park and Northern Aotea area. The Tu Mai Taonga team are monitoring these cat traps across the study colony and surrounding area, and in conjunction with DOC, will target any feral cats that are reported within the tākoketai/black petrel study colony by the WMIL field team. There was one recorded instance of rat predation on an egg during the 2022/23 which was the same as the previous two seasons. Despite the low number of recorded rat predation incidences, rats, particularly kiore, remain a common sight within the area. A trial of Good Nature A-24 traps is currently underway at Mt Hobson/Hirakimata and tracking tunnel monitoring is showing a reduction in rat numbers across the summit area (S. Dwyer, DOC, pers. comm.). Work on Coopers Castle showed a number of predators in the areas including feral cats, rats, pigs and mice. Although there was no evidence of interaction with black petrels in the area, many of these predators were filmed close to or directly outside active black petrel breeding burrows. Investigation into possible deterrence methods of all predators, but specifically pigs and feral cats, is ongoing. The ongoing control of predators is important to reduce land-based threats for tākoketai/black petrels.

Cohorts of returned chicks appear to be mixed each breeding season, with no apparent dominating year group. The number of chicks banded each breeding season ranges from 59 (in 1995/96, when there were three census grids) to 254 (in 2021/22, when there are nine census grids). However to date, less than 9% of all black petrel chicks banded at the Great Barrier Island/Aotea study colony have been re-captured in subsequent field seasons. There is a real lack of understanding whether the low return rates relates either to low juvenile survival and/or recruitment or is purely due to a lack of detection of banded birds within the 35-ha study site. Survival effort estimates, especially juvenile survival and recruitment are vital for accurate population estimates and risk assessment modelling, and it is highly recommended that effort to obtain data to fill this knowledge gap for black petrels is completed with urgency.

The first specifically focused recruitment trip with a dedicated night banding team occurred this season. A total of 181 birds were captured during the recruitment trip; this capture rate equates to 22.6 birds caught per night over eight nights. Interestingly, despite the trip specifically undertaken to focus on recruitment, there was no significant increase in detections of returned chicks this season. Detection rates for pre-1995 birds at the colony is low as these birds age, and the number of recaptures of returned chicks banded before 2000 is also declining. As this was the first intensive monitoring session for recruitment, the number of new recaptures (13 out of 43 returned chicks were new) over 8-nights was good, but additional surveys should be factored into subsequent breeding seasons to increase the number of returned chicks being recaptured. A small team of personnel completed the recruitment trip, and if team size was increased, more ground at the colony could be covered, which in turn could increase the chance of recapturing returned chicks. Focusing recapture effort at launch sites as well as surveys throughout the colony area is also likely to increase recapture rates. A focused effort (i.e., number of hours at specific launch sites over a number of nights) to determine the rate of banded to new (unbanded) birds could also give an indication of population size and would be comparable between seasons.

In order to fill this urgent gap, it is recommended that additional methods (night banding team, focused nocturnal effort at launch sites, at-sea captures, conservation (seabird detection) dogs, and additional transect surveys within core areas) should be employed in unison with on the ground study burrow monitoring. The dedicated nocturnal monitoring should be repeated with a bigger team to locate and identify returned black petrel chicks within the current 35-ha study area. Black petrels are nocturnal and are highly vocal in the late evening. During the breeding season, un-paired males ‘clack’

(perform attraction calls) from or near their burrows to attract an un-paired female (Warham 1988). In addition, returning birds are easily located by the crashing sounds made through the forest canopy as they land to return to their burrows.

Another recommended method is the employment of seabird detection dogs to locate burrows occupied by breeding and non-breeding birds. Seabird detection dogs have been used successfully in the past within localised areas on Great Barrier Island/Aotea and Te Hauturu-o-Toi/Little Barrier Island (Bell, et al., 2016a; Bell, et al., 2016b). Expanding this effort into untapped and/or core breeding areas will help to identify black petrel hotspots and increase the probability of detecting returning birds. Previous experience with seabird detection dogs has found detection ability via scent of occupied or recently occupied burrows was 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; Bell, et al., 2016a). Black petrels carry a distinctive smell that is immediately apparent when handling, but because burrow entrances can often be cryptic and hidden within dense vegetation the scenting ability of trained seabird detection dogs confers a unique advantage over other methods (e.g., transect surveys) and makes their use as a highly effective tool to complement current methods.

At-sea captures is another highly effective method to catch large numbers of birds within short time periods; rafting birds can be caught by throwing a 1.8 m cast net and quickly pulled up onto the boat to be processed (Bugoni, et al., 2008; Roconi, et al., 2010). In 2022, WMIL staff conducted at-sea capture work within the Hauraki Gulf (locations off the coasts of Chicken/Marotere and Mokohinau Islands; Burgin, 2022). Over five at-sea expeditions (between April 2021 and March 2023), WMIL staff caught and banded 321 black petrels, of which 9 birds were recaptures (one from Hauturu and 8 from Aotea) (Burgin, 2022; Burgin, 2023). Much of these expeditions occurred between January and April, and the use of at-sea captures during the peak breeding season (November to January) will likely result in a higher volume of banded black petrels identified and incorporated into the study. There is possibility that at-sea captures may target birds that might not be able to be caught during burrow monitoring e.g., pre- or non-breeders (immature individuals or those that have failed to attract/find a mate) or birds that have a failed breeding attempt and have subsequently returned to sea. Like other *Procellaria*, black petrels are highly philopatric (Warham 1996), and are suspected to exhibit sexed biased dispersal within the colony site. Males are suspected of returning closer to their natal areas whereas females are suspected of dispersing farther afield. Some males have been documented usurping their father and occupying their natal burrow (unpublished WMIL data). Because of this, we suspect that the identified returned chicks are predominantly male, however genetic confirmation of sex identity is needed to establish this trend, which is lacking for most individuals. At-sea captures would therefore likely reduce the likelihood of sex-biased detection.

A combination of these recommendations such as night banding, at-sea captures, transect surveys, and conservation dogs will work to improve detection probability and more accurately determine survival effort estimates as well as juvenile survival and recruitment. The implementation of these methods is crucial for the survival, determining population trend, and management of this endangered species.

5. RECOMMENDATIONS

WMIL recommends that:

- Intensive population monitoring using the study burrows on Great Barrier Island/Aotea continues with three visits (i.e., at egg-laying (December); at chick hatching/chick guard in late January/early February and at chick fledging in late April/early May) per season to the colony to track population trends and determine impacts to the birds and colony.
- Multiple-night expeditions to focus on recruitment (i.e., nocturnal surveys to capture pre-breeders and returned chicks) to the Great Barrier Island/Aotea study colony continue to determine juvenile survival and recapture probabilities.

- Sexing of all tākoketai caught during the recruitment expedition and in the study burrows is completed to determine any sex biases and survival differences between sexes at the colony and within the study burrows.
- A focused, consistent and repeatable mark/recapture session (e.g., a 2-hour capture period at known launch sites) is completed over a number of nights to capture as many banded and unbanded birds as possible and that data are used to provide another population estimate as well as being compared to estimates obtained from at-sea captures and burrow monitoring.
- Transect surveys across the core tākoketai habitat (1000 ha around the summit) are undertaken to provide an updated population estimate for Great Barrier Island/Aotea.
- Satellite tracking of chicks to and in South American waters is undertaken to determine migration routes and foraging areas to estimate risk in these areas.
- The possibility of collaborative at-sea capture expeditions in Ecuador is investigated. Discussions between the Department of Conservation and New Zealand Government with Ecuadorian Government and researchers will have to be conducted to enable this type of collaborative work. At-sea work in Ecuador could determine the level of juvenile tākoketai presence in this area and risk within this area, and this mark/recapture work could provide another population estimate to compare with the New Zealand data.
- Further investigation to determine whether particular areas of the colony are more at risk to rainfall events than others (e.g., burrows in flatter areas being more prone to flooding) as a preliminary assessment on climate resilience.
- In-depth modelling on the effect of age, age difference in pairs, and experience on breeding success is completed to understand this relationship in tākoketai.
- Analysis of and comparison between breeding success in public and non-public access areas is completed to determine whether human disturbance is a factor at the Great Barrier Island/Aotea colony.
- Investigation into possible deterrence methods of all predators, but specifically pigs and feral cats, should be undertaken at Coopers Castle.

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7. REFERENCES

Aubry, L.M.; Koons, D.N.; Monnat, J.Y. & Cam, E. (2009). Consequences of recruitment decisions and heterogeneity on age-specific breeding success in a long-lived seabird. *Ecology* 90: 2491–2502.

Bell, E.A. (2013). Black petrel In: Miskelly, C.M. (ed.) *New Zealand Birds Online*. www.nzbirdsonline.org.nz (Accessed 6 May 2022).

Bell, E.A. & Sim, J.L. (1998). Survey and monitoring of black petrels on Great Barrier Island 1996. *Science for Conservation 77*. Department of Conservation, Wellington. 17p.

Bell, E.A. & Sim, J.L. (2000a). *Surveying and monitoring of black petrels on Great Barrier Island, 1998/99.* Published client report on contract 3089, funded by Conservation Services Levy. Department of Conservation, Wellington. 23p.

Bell, E.A. & Sim, J.L. (2000b). *Survey and monitoring of black petrels on Great Barrier Island, 1999/2000*. Published client report on contract 3018, funded by Conservation Services Levy. Department of Conservation, Wellington. 30 p. https://dxcprod.doc.govt.nz/globalassets/documents/science-and-technical/csl3018.pdf

Bell, E.; Lamb, S. & Ray, S. (2022a). Population trends and breeding population size of black petrels (Procellaria parkinsoni) — 2020/2021 operational report. *New Zealand Aquatic Environment and Biodiversity Report No. 280*. 43 p.

Bell, E.A.; Welch, M. & Lamb, S. (2022b). *Key demographic parameters and population trends of tākoketai/black petrels (Procellaria parkinsoni) on Aotea/Great Barrier Island: 2021/2022*. Unpublished Wildlife Management International Ltd. Technical Report to the Conservation Services Programme, Department of Conservation, Wellington

Bell, E.A.; Mischler, C.P.; MacArthur, N. & Sim, J.L. (2016a). *Black petrel (Procellaria parkinsoni) population study on Te Hauturu-o-Toi/Little Barrier Island, 2015/16*. (Unpublished report to the Conservation Services Programme, Department of Conservation, Wellington.) https://www.doc.govt.nz/Documents/conservation/marine-and-coastal/marine-conservation-services/reports/pop2015-01-black-petrel-lbi-final.pdf

Bell, E.A.; Mischler, C.P.; MacArthur, N.; Sim, J.L. & Scofield, P. (2016b). *Population parameters of the black petrels (Procellaria parkinsoni) on Great Barrier Island (Aotea Island), 2015/16*. (Unpublished report to the Conservation Services Programme, Department of Conservation, Wellington.) https://www.doc.govt.nz/Documents/conservation/marine-and-coastal/marine-conservation-services/reports/pop2015-01-black-petrel-gbi-final.pdf

Birdlife International (2020). *Species factsheet: Procellaria parkinsoni*. IUCN Red list for birds. Accessed from www.birdlife.org on 4 April 2020.

Bugoni, L.; Neves, T.S.; Peppes, F.V. & Furness, R.W. (2008). An effective method for trapping scavenging seabirds at sea. *Journal of Field Ornithology* 79: 308-313.

Burgin, D. 2022. *Summary report for at-sea capture work for tākoketai/black petrels 2022*. Unpublished Wildlife Management International Technical Report to the Department of Conservation, Wellington. 18p.

Burgin, D. 2023. *Preliminary report for at-sea capture work for tākoketai/black petrels 2023*. Unpublished Wildlife Management International Technical Report to the Department of Conservation, Wellington.

Hunter, C.; Fletcher, D. & Scofield. P. 2001. Preliminary modelling of black petrels (Procellaria parkinsoni) to assess population status. *DOC Science Internal Series 2*. Department of Conservation, Wellington, New Zealand. 42p.

Imber, M.J. (1976). Comparison of prey of the black Procellaria petrels of New Zealand. New Zealand *Journal of Marine and Freshwater Research* 10: 119–130.

Imber, M.J. (1987). Breeding ecology and conservation of the black petrel (Procellaria parkinsoni). *Notornis* 34: 19–39.

Imber, M.J.; McFadden, I; Bell, E.A. & Scofield, R.P. (2003a) Post-fledging migration, age of first return and recruitment, and results of inter-colony translocation of black petrels (*Procellaria parkinsoni*). *Notornis* 50, 183–190.

Imber, M.J.; West, J.A. & Cooper, W.J. (2003b). Cook's petrel (*Pterodroma cookii*): historic distribution, breeding biology, and effects of predators. *Notornis* 50, 221–230.

Limmer, B. & Becker, P.H. (2010). Improvement of reproductive performance with age and breeding experience depends on recruitment age in a long-lived seabird. *Oikos* 119: 500–507.

R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Richard, Y.; Abraham, E. & Berkenbusch, K. (2020). Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2016–17. *New Zealand Aquatic Environment and Biodiversity Report 237*. 57 p.

Robertson, H.A.; Baird, K.A.; Elliott, G.P.; Hitchmough, R.A.; McArthur, N.J.; Makan, T.D.; Miskelly, C.M.; O'Donnell, C.F.J.; Sagar, P.M.; Scofield, R.P.; Taylor, G.A. & Michel, P. (2021). Conservation status of birds in Aotearoa New Zealand, 2021. *New Zealand Threat Classification Series 36*. Department of Conservation, Wellington. 43 p.

Russell, J.C.; Horn, S.R.; Miskelly, C.M.; Sagar, R.L. & Taylor, R.H. (2020). Introduced land mammals and their impacts on the birds of the subantarctic Auckland Islands. *Notornis* 67(1): 247–268.

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

Warham, J. (1988). Vocalisations of Procellaria petrels. *Notornis* 35: 169–183.

Warham, J. (1996). *The behaviour, population biology and physiology of the petrels*. Academic Press, London. 613 pp.

Wickham, H. (2016). ggplot2: Elegant graphics for data analysis. Springer-Verlag, New York. https://ggplot2.tidyverse.org

8. APPENDICES

8.1.1 Summary of returned chick captures

Table 7: *Number of captures, age at first recapture, age at first breeding and age at first successful breeding for tākoketai/black petrels (*Procellaria parkinsoni*) banded as chicks and recaptured in the study site on Great Barrier Island/Aotea since the 1995/96 breeding season.*

Band	Sex	Date banded	No. of captures	Age of 1st return	Age of 1st breeding	Age of 1st successful breeding
13614	U	10-May-88	1	11		
13618	U	10-May-88	5	10	6	6
13638	U	11-May-88	4	18	16	17
21185	M	29-Apr-87	1	9		
22473	U	14-Mar-72	1	5		
22564	U	09-Apr-78	1	18	18	
23635	M	12-May-88	22	10	10	14
25525	M	15-Apr-99	10	7	8	10
25536	U	15-Apr-99	12	6	6	11
25546	M	16-Apr-99	10	5	5	11
25630	M	15-Apr-00	2	5		
25631	M	15-Apr-00	1	4		
25635	M	15-Apr-00	6	5	5	6
25637	U	15-Apr-00	1	5		
25648	U	15-Apr-00	4	4	5	8
25651	U	15-Apr-00	14	5	6	6
25658	M	15-Apr-00	1	5	5	5
25659	U	15-Apr-00	2	6	6	6
25661	M	15-Apr-00	14	9	9	13
25663	U	15-Apr-00	6	4	7	8
25664	U	15-Apr-00	9	3	6	10
25669	U	15-Apr-00	2	5	5	5
25673	M	15-Apr-00	16	5	7	7
25677	U	15-Apr-00	1	7	7	7
26924	U	04-May-86	1	6		
26955	U	07-May-86	6	24	24	24
26980	U	09-May-86	1	16	16	
26991	U	09-May-86	9	17	18	18
27032	U	29-Apr-87	2	7		
27058	U	30-Apr-87	7	14	14	14
27512	U	06-May-88	2	6		
27568	U	27-Apr-89	4	11	11	11
27604	M	27-Apr-89	27	7	7	8
27614	U	27-Apr-89	5	5		
27637	F	02-May-89	1	5		
27665	M	29-Apr-90	11	6	6	6
27666	U	29-Apr-90	4	4	7	7
27678	U	29-Apr-90	4	4	7	
27689	U	29-Apr-90	1	7	7	7
27702	F	29-Apr-90	13	6	6	6
27708	U	29-Apr-90	1	10		
27726	U	29-Apr-90	1	4		
27728	U	29-Apr-90	4	7	8	9

Band	Sex	Date banded	No. of captures	Age of 1st return	Age of 1st breeding	Age of 1st successful breeding
28085	U	02-Apr-01	1	5		
28089	U	02-Apr-01	1	15	15	
28572	U	06-Mar-92	23	4	4	4
29008	M	21-Apr-09	5	9	9	9
29018	U	21-Apr-09	3	7	7	7
29023	U	21-Apr-09	3	10	10	10
29027	U	21-Apr-09	1	5		
29047	U	21-Apr-09	8	6	7	7
29095	U	21-Apr-09	2	12	13	13
29098	U	21-Apr-09	3	4	7	7
29644	U	01-May-86	1	15		
29912	U	02-Apr-01	5	5	5	6
29927	M	02-Apr-01	10	9	12	12
29960	M	13/04/2000	8	9	9	9
29978	U	14-Apr-00	6	9	14	14
30161	U	12/04/2008	1	2		
30167	U	12-Apr-08	1	4		
30175	U	12-Apr-08	1	5		
30177	U	12/04/2008	1	3		
30807	F	29/04/1997	5	9	9	9
30908	U	08-Apr-96	1	7		
30924	U	12-Apr-96	9	6	6	6
30930	M	14-Apr-96	20	4	5	5
30934	U	15-Apr-96	1	18		
31076	U	31-Mar-98	1	5		
31080	U	31-Mar-98	1	4		
31081	U	31-Mar-98	2	4		
31082	U	31-Mar-98	1	4		
31089	U	31-Mar-98	9	5	6	9
31194	M	03-Apr-97	1	5	5	
31322	U	3/05/2006	1	3		
31324	U	03-May-06	8	7	7	7
31340	U	04-May-06	1	9	9	9
31345	U	04-May-06	1	6		
31366	U	01-Apr-98	20	5	6	6
31370	U	01-Apr-98	5	5	8	
31377	U	02-Apr-98	1	4		
31382	U	02-Apr-98	5	4	5	5
31383	U	02-Apr-98	1	6		
31389	U	02-Apr-98	1	17	17	17
31405	U	03-Apr-97	3	6	7	7
31406	U	03-Apr-97	1	5		
31413	U	05-Apr-97	1	8	8	8
31415	U	05-Apr-97	2	7		
31422	U	05-Apr-97	1	16	16	
31424	U	05-Apr-97	5	6	8	8
31474	U	17-Apr-99	1	4		
31476	U	17-Apr-99	2	4	6	
31478	U	17-Apr-99	3	10	10	
31490	U	18-Apr-99	1	4		
31491	U	18-Apr-99	1	7		
31494	U	18-Apr-99	15	6	9	10

Band	Sex	Date banded	No. of captures	Age of 1st return	Age of 1st breeding	Age of 1st successful breeding
31495	M	18-Apr-99	17	4	5	5
31498	U	18-Apr-99	4	6	6	6
31527	U	18-Apr-99	1	4		
31537	U	19-Apr-99	6	8	8	8
31542	U	19-Apr-99	17	4	6	7
31546	U	19-Apr-99	1	9		
31956	U	02-Apr-01	2	7		
32063	U	05-Apr-01	1	5		
32073	U	05-Apr-01	2	6	19	
32091	U	02-Apr-01	1	7		
32099	U	02-Apr-01	13	5	8	8
32100	U	02-Apr-01	1	12	12	
32915	U	21-Apr-02	3	6	6	6
32921	U	21-Apr-02	1	11	11	11
32927	U	21-Apr-02	8	6	6	6
32957	F	21-Apr-02	10	5	6	7
32960	U	21-Apr-02	1	14	14	14
32979	U	21-Apr-02	1	5		
32980	M	21-Apr-02	11	4	11	11
32985	U	21-Apr-02	10	11	11	11
32995	M	21-Apr-02	10	11	11	13
33003	U	22-Apr-02	6	7	7	7
33015	U	22-Apr-02	4	6	14	
33035	U	22-Apr-02	13	6	7	7
33052	M	22-Apr-02	15	6	6	6
33055	U	22-Apr-02	1	8	8	8
33067	U	22-Apr-02	1	8		
33068	U	22-Apr-02	2	7	8	
33071	U	22-Apr-02	2	11	14	
33088	U	22-Apr-02	1	3		
33208	M	15/05/2003	4	5	7	
33218	U	16-May-03	2	5	6	
33225	U	16-May-03	1	4		
33226	U	16-May-03	1	12	12	
33244	M	16-May-03	10	6	10	10
33246	U	16-May-03	9	10	10	10
33248	U	16-May-03	10	6	8	8
33276	U	08-May-04	10	7	7	7
33335	U	08-May-04	2	5	7	
33369	U	09-May-04	9	9	8	8
33375	U	09-May-04	13	5	5	5
33376	U	09-May-04	2	8	8	
33380	U	09-May-04	1	4		
33389	M	09-May-04	10	6	6	6
33397	U	09-May-04	1	5		
33508	U	02-May-06	9	7	7	7
33518	U	02-May-06	1	4		
33528	U	02-May-06	9	7	7	7
33530	U	02-May-06	7	5	6	6
33540	F	02-May-06	11	4	7	7
33543	U	02-May-06	1	5		
33546	U	02-May-06	1	7	7	

Band	Sex	Date banded	No. of captures	Age of 1st return	Age of 1st breeding	Age of 1st successful breeding
33550	U	02-May-06	3	4	5	5
33575	U	03-May-06	11	5	5	5
33581	U	03-May-06	7	5	6	15
33584	U	03-May-06	1	9		
33589	F	03-May-06	5	5	5	5
33591	U	03-May-06	1	5		
33596	U	03-May-06	2	5	6	
33737	U	16-May-03	11	7	7	7
34273	U	27-Apr-05	9	7	7	7
34276	U	27-Apr-05	4	5	8	8
34278	U	27-Apr-05	4	12	12	12
34299	U	27-Apr-05	6	7	7	7
34304	U	27-Apr-05	10	8	8	8
34308	U	27-Apr-05	1	10	10	10
34317	U	27-Apr-05	9	8	8	8
34320	U	27-Apr-05	12	5	8	8
34338	U	27-Apr-05	12	5	6	6
34349	U	27-Apr-05	5	7		
34435	U	24-Apr-07	1	7	7	7
34445	U	24-Apr-07	1	15	15	15
34505	U	24-Apr-07	5	6	6	6
34513	U	24-Apr-07	1	9	9	
34520	U	24-Apr-07	5	5	12	12
34525	U	24-Apr-07	1	10	10	10
34527	M	24-Apr-07	10	6	6	13
34528	U	24-Apr-07	4	12	12	12
34535	U	24-Apr-07	5	9	9	9
34550	U	24-Apr-07	2	8	10	
34553	U	24-Apr-07	2	7	8	8
34573	U	24-Apr-07	2	16	16	16
34574	U	25-Apr-07	2	4		
34580	U	25-Apr-07	11	5	6	6
34599	U	25-Apr-07	1	6		
34600	U	25-Apr-07	3	5	7	
34607	U	25-Apr-07	1	10	10	
34610	U	25-Apr-07	4	7	11	
34612	U	25-Apr-07	4	9	14	14
34615	M	25-Apr-07	8	7	9	10
34621	M	25-Apr-07	5	4	9	9
34624	U	25-Apr-07	1	6		
34626	U	25-Apr-07	1	9		
34645	U	26-Apr-07	4	10	15	15
34655	U	26-Apr-07	1	9	9	
34660	U	26-Apr-07	7	4	5	5
34687	U	26-Apr-07	8	7	8	8
34698	U	26-Apr-07	2	7		
34713	M	10-May-04	6	13	13	13
34804	U	27-Apr-05	2	4	5	5
34808	U	28-Apr-05	1	8		
34820	U	28-Apr-05	11	6	6	10
34828	U	28-Apr-05	1	5		
34836	U	28-Apr-05	10	6	7	10

Band	Sex	Date banded	No. of captures	Age of 1st return	Age of 1st breeding	Age of 1st successful breeding
34837	U	28-Apr-05	6	9	14	14
34843	M	28-Apr-05	10	5	6	6
34867	U	22-Feb-05	1	7	7	7
34886	U	26-Apr-05	5	7	7	8
34891	U	27-Apr-05	1	15		
34895	U	27-Apr-05	3	14	15	15
34901	U	28-Apr-05	11	5	7	7
34903	M	28-Apr-05	13	5	7	7
34916	U	28-Apr-05	1	9	9	
34994	U	02-May-06	1	10	10	
35101	U	21-Apr-09	6	6	6	7
35130	U	22-Apr-09	1	8	8	
35131	M	22-Apr-09	7	5	10	11
35151	M	23-Apr-09	5	7	7	8
35160	U	23-Apr-09	4	5	6	6
35166	U	24-Apr-09	1	11	11	11
35180	U	24-Apr-09	2	7	7	7
35186	U	24-Apr-09	3	4	6	
35187	M	24-Apr-09	7	5	6	6
35188	M	24-Apr-09	7	6	6	7
35189	U	24-Apr-09	1	4		
35193	U	24-Apr-09	7	5	6	6
35311	U	6/05/2010	1	6	6	6
35313	U	06-May-10	7	6	6	9
35315	M	06-May-10	7	6	7	7
35316	U	06-May-10	2	6	7	7
35345	M	07-May-10	3	7	9	
35360	U	22-Apr-09	9	5	6	6
35361	U	22-Apr-09	8	5	6	6
35380	U	22-Apr-09	1	5		
35392	U	23-Apr-09	3	6	7	
35397	U	23-Apr-09	1	4	4	4
35399	M	23-Apr-09	5	8	10	10
35419	F	06-May-11	5	5	7	7
35421	U	06-May-11	2	8	8	
35436	U	06-May-11	1	5	5	
35439	U	06-May-11	2	4	6	
35444	U	06-May-11	2	5	7	
35450	M	06-May-11	3	7	10	
35459	F	06-May-11	6	5	8	10
35460	M	06-May-11	5	7	7	7
35466	U	06-May-11	2	5		
35481	U	06-May-11	3	5	10	11
35485	U	07-May-11	4	8	9	9
35489	U	07-May-11	2	4		
35490	U	07-May-11	2	4	5	
35493	U	07-May-11	3	5	5	5
35516	M	09-May-10	5	8	9	10
35518	U	09-May-10	2	4	6	6
35521	U	09-May-10	5	6	6	9
35571	U	08-May-10	1	3		
35574	U	08-May-10	7	5	6	10

Band	Sex	Date banded	No. of captures	Age of 1st return	Age of 1st breeding	Age of 1st successful breeding
35584	U	08-May-10	1	6		
35597	M	08-May-10	5	9	9	9
36112	M	10-Apr-08	4	5	10	10
36115	U	10-Apr-08	2	7	8	8
36118	M	10-Apr-08	4	5	7	
36124	U	10-Apr-08	3	8	8	8
36139	M	11-Apr-08	9	6	7	
36140	U	11-Apr-08	1	5		
36147	U	11-Apr-08	3	5		
36209	M	11-Apr-08	4	10	10	10
36213	U	11-Apr-08	6	9	9	10
36216	U	11-Apr-08	1	4		
36233	U	11-Apr-08	2	6	7	
36241	U	11-Apr-08	1	5		
36247	U	11-Apr-08	3	12	14	14
36248	U	11-Apr-08	1	7		
36270	U	12-Apr-08	1	13		
36271	U	12-Apr-08	1	7		
36277	U	12-Apr-08	2	7		
36290	U	13-Apr-08	9	5	6	7
36294	U	13-Apr-08	1	6	6	
36401	U	07-May-11	1	10		
36411	M	07-May-11	5	7	7	7
36419	M	08-May-11	6	6	7	7
36426	U	08-May-11	5	5	6	8
36427	U	08-May-11	1	4	12	12
36430	U	08-May-11	2	10	11	11
36431	U	08-May-11	4	7	7	9
36440	U	08-May-11	6	6	7	7
36441	U	08-May-11	6	4	9	9
36455	U	07-May-10	3	6	9	9
36470	U	07-May-10	1	6		
36474	U	07-May-10	1	4		
36476	U	07-May-10	1	5		
36495	U	08-May-10	6	6	6	8
36904	U	27-Apr-12	4	6	8	8
36906	U	27-Apr-12	2	11	11	11
36911	U	27-Apr-12	1	4		
36918	U	27-Apr-12	2	5		
36925	M	27-Apr-12	6	5	5	7
36930	U	27-Apr-12	5	5	7	8
36953	U	29-Apr-12	1	5		
36957	U	29-Apr-12	6	5	8	9
36968	U	29-Apr-12	1	8		
36994	U	28-Apr-12	4	4	8	8
37605	U	28-Apr-12	3	7	7	8
37606	U	28-Apr-12	1	6		
37615	F	28-Apr-12	5	6	6	8
37616	U	28-Apr-12	1	5		
37636	U	28-Apr-12	1	5		
37638	U	28-Apr-12	1	4		
37648	U	28-Apr-12	1	9	9	

Band	Sex	Date banded	No. of captures	Age of 1st return	Age of 1st breeding	Age of 1st successful breeding
37659	U	29-Apr-12	3	8	8	8
38574	U	26-Apr-13	3	5	5	5
38582	U	26-Apr-13	2	10	10	
38592	U	26-Apr-13	1	7	7	7
38609	U	29-Apr-13	4	6	6	7
38654	U	27-Apr-13	1	9	9	9
38655	U	27-Apr-13	2	3		
38661	U	27-Apr-13	4	4	4	4
38668	U	27-Apr-13	1	9		
38672	U	27-Apr-13	1	4		
38694	U	28-Apr-13	2	10		
38760	U	28-Apr-13	5	5	6	6
38777	U	28-Apr-13	2	4		
38780	U	28-Apr-13	2	7	7	7
38795	U	28-Apr-13	1	9		
38844	U	27-Apr-13	2	5	10	10
38847	U	26-Apr-13	1	8	8	8
38899	U	25-Apr-14	3	6	6	8
38969	U	26-Apr-14	2	4		
38979	M	26-Apr-14	1	6		
38983	U	26-Apr-14	3	6	7	7
38994	U	26-Apr-14	1	7		
39011	U	27-Apr-13	1	7		
39022	U	27-Apr-13	2	7	8	8
39044	U	27-Apr-13	5	4	6	9
39053	U	27-Apr-14	1	5		
39059	U	27-Apr-14	2	7	7	7
39063	U	27-Apr-14	3	6	6	6
39065	U	27-Apr-14	2	7	7	
39067	U	27-Apr-14	1	7		
39078	U	27-Apr-14	2	5	7	
39088	U	27-Apr-14	1	4	4	
39310	U	25-Apr-14	3	6	6	6
39311	U	25-Apr-14	4	5	5	5
39318	U	25-Apr-14	3	6	6	6
39323	U	25-Apr-14	3	6	6	6
39340	U	25-Apr-14	2	5		
39343	U	25-Apr-14	3	6	6	9
39460	U	27-Apr-14	4	5	5	5
39465	U	27-Apr-14	2	4		
39478	U	27-Apr-14	2	7	8	8
39480	U	27-Apr-14	1	8	9	9
39481	U	28-Apr-14	3	6	7	7
39484	U	28-Apr-14	1	5		
39491	U	28-Apr-14	1	8	9	9
39654	U	23-Apr-15	1	6		
39674	U	23-Apr-15	1	4		
39683	U	23-Apr-15	2	4		
39691	U	23-Apr-15	2	5	5	5
39692	U	23-Apr-15	2	6	7	7
39714	M	25-Apr-15	2	6	8	8
39721	U	23-Apr-15	1	6		

Band	Sex	Date banded	No. of captures	Age of 1st return	Age of 1st breeding	Age of 1st successful breeding
39735	U	23-Apr-15	2	6	6	6
40202	U	01-May-18	1	5	5	5
40235	U	02-May-18	1	4		
40237	U	02-May-18	1	4	4	
40239	U	03-May-18	1	4		
40320	U	08-May-18	1	4		
40344	U	08-May-18	1	5		
41303	U	25-Apr-15	2	7	8	8
41313	U	25-Apr-15	1	6		
41316	U	25-Apr-15	2	5	7	7
41317	U	25-Apr-15	1	4		
41334	U	25-Apr-15	1	7	7	7
41342	U	25-Apr-15	2	6	6	6
41343	U	25-Apr-15	4	5	7	7
41357	U	25-Apr-15	1	5		
41399	U	26-Apr-15	1	6		
41400	U	26-Apr-15	1	8		
41490	U	05-May-16	2	5		
41507	U	11-May-88	17	11	12	12
41653	U	06-May-16	1	7		
41654	U	06-May-16	1	6	7	7
41656	U	06-May-16	1	6		
41691	U	07-May-16	1	5		
41713	U	07-May-17	1	6		
41732	U	07-May-17	1	5		
41738	U	07-May-17	1	6		
41902	U	10-May-16	1	4		
41912	U	08-May-16	1	4		
41918	U	08-May-16	1	7	7	
41923	U	08-May-16	1	4		
41932	U	08-May-16	1	6		
41992	U	08-May-16	2	5	6	6
42000	U	08-May-16	1	5		
42037	M	07-May-16	2	4	6	
42042	U	07-May-16	1	6		
42050	U	07-May-16	1	4	4	
42053	M	13-May-17	1	6		
42624	U	13-May-17	1	4		
42724	U	07-May-17	1	5	5	
42824	M	05-May-17	1	6		
42838	U	05-May-17	1	6		
42956	U	05-May-17	1	6		
42962	U	05-May-17	2	5		
42965	U	05-May-17	1	5		
42966	U	05-May-17	1	6		
42970	M	05-May-17	1	6		
42979	U	06-May-17	1	6		
42999	U	07-May-17	1	6		
43018	U	08-May-17	1	6		
43022	U	08-May-17	1	6		
43025	U	10-May-17	1	6		
43026	U	10-May-17	1	6		

Band	Sex	Date banded	No. of captures	Age of 1st return	Age of 1st breeding	Age of 1st successful breeding
43043	U	10-May-17	1	6	6	6
43123	U	03-May-18	1	5		
43129	U	03-May-18	1	5		
43135	U	04-May-18	1	5		
43139	U	05-May-18	1	5		
43268	U	02-May-29	1	4		
43352	U	08-May-18	1	4		
43355	U	09-May-18	1	4		
43375	U	09-May-18	1	4		
43382	U	16-May-18	1	4		
43390	U	17-May-18	1	5		
43433	U	05-May-19	1	4		
43451	U	03-May-19	1	4		
Mean (±SEM)			**3.7 ± 0.2**	**6.5 ± 0.1**	**8.0 ± 0.2**	**8.4 ± 0.2**