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Population trends, at-sea distribution, and breeding population size of black petrels (*Procellaria parkinsoni*) on Great Barrier Island/Aotea: 2019–2020 operational report

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EXECUTIVE SUMMARY

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During the 2019–2020 breeding season, 458 study burrows were monitored within the Mt Hobson/Hirakimata study area on Great Barrier Island/Aotea. In 2019–2020, 289 (63.1%) were occupied by breeding pairs, 97 (21.2%) were occupied by non-breeding birds, and 72 (15.7%) were unoccupied.

The 58.5% of study grid burrows occupied by breeding pairs during the 2019–2020 breeding season was 2.8% lower than the 25-year average of 61.3%. Fledging success in 2019–2020 was 76.5% which is higher than the 25-year average for black petrels breeding within the Mt Hobson/Hirakimata study area on Aotea/Great Barrier Island.

Remote Argos Avian Transmitters (TAV) were deployed on ten adult black petrels to track their at-sea foraging distribution during the pre-laying exodus stage. Six of ten individuals with devices ultimately ended up breeding. Pre-laying exodus foraging trips were 30 days long on average. The distribution of foraging trips was highly variable between individuals with birds ranging far to the east, west, and north of Great Barrier Island/Aotea. Additional tracks were recorded during the incubation stage and multiple tracks were recorded for the four non-breeding individuals. Breeding black petrels made significantly longer trips and ranged further than non-breeding black petrels. This result has inherent impacts on assessing and managing the risk of black petrel bycatch in commercial fisheries because black petrels from different life stages may be impacted differently, depending on the location of the fisheries.

During the 2019–2020 breeding season, distance sampling was used to estimate burrow density and the number of breeding black petrels within areas stratified into medium-grade habitat near Mt Hobson/Hirakimata. Distance sampling within Glenfern Sanctuary showed that this area was not medium-grade habitat with only 2 burrows (both unoccupied) detected in the 50 transects completed in this area. Further stratification of the medium-grade habitat followed the transect surveys across the core area around Mt Hobson/Hirakimata, which resulted in the medium-grade habitat being determined to be above 300 m above sea level (asl) with a calculated total area of 833 hectares (ha). A total of 131 line transects were surveyed within the core medium-grade habitat above 300 m asl, and 115 black petrel burrows were detected. Of these burrows, 46.96% were being used as breeding burrows during the 2019–2020 breeding season. By fitting a burrow detection function to these data, an average breeding burrow density of 3.757 burrows/ha within this 833-ha area was calculated, yielding a total estimated population size of 3130 breeding pairs, or 6260 breeding birds. Remaining areas of suitable medium-grade habitat on Great Barrier Island/Aotea need to be surveyed to create black petrel burrow density estimates and provide an accurate population size for breeding black petrels on Great Barrier Island/Aotea.

[1] All authors: Wildlife Management International Ltd, Blenheim, New Zealand.

1. POPULATION TRENDS OF BLACK PETRELS ON GREAT BARRIER ISLAND/AOTEA

1.1 Introduction

Black petrels (*Procellaria parkinsoni*) are medium–sized endemic seabirds that only breed 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 takoketai by Ngāti Rehua Ngāti Wai ki Aotea, the 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 (Robertson et al. 2017, BirdLife International 2020). 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. 2017). Of the 160 observed captures of black petrel recorded between 2002 and 2018, 57.5% of captures occurred in bottom-longline fisheries, 24.4% in surface-longline fisheries, and 18.1% in trawl fisheries (https://psc.dragonfly.co.nz/2019v1; accessed 27/03/2020). 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 adult 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 1995–1996 (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 1998–1999, the number of study grids was increased to six, and then to nine in 1999–2000 (Bell & Sim 2000a, Bell & Sim 2000b). Over the years, additional burrows situated near the public walking tracks have continued to be added, so that by the 2019–2020 season a total of 458 study burrows were being monitored (Bell et al. 2017).

This section of the report provides a summary of the results of this monitoring work in 2019–2020, with updates on the trends in several population parameters including both annual burrow occupancy and annual reproductive success.

1.2 Methods

1.2.1 Field methods

A network of 458 study burrows has been established within a 35-ha study area in the vicinity of Mt Hobson/Hirakimata on Great Barrier Island/Aotea (Figure 1). These burrows have been progressively established over the past 25 years and include 188 burrows located within nine 40 m x 40 m study grids, plus a further 269 arbitrarily-selected burrows situated within 10 m of public walking tracks. To facilitate accurate monitoring, many of these study burrows have had study hatches installed, providing easier access to one or more chambers within the burrow.

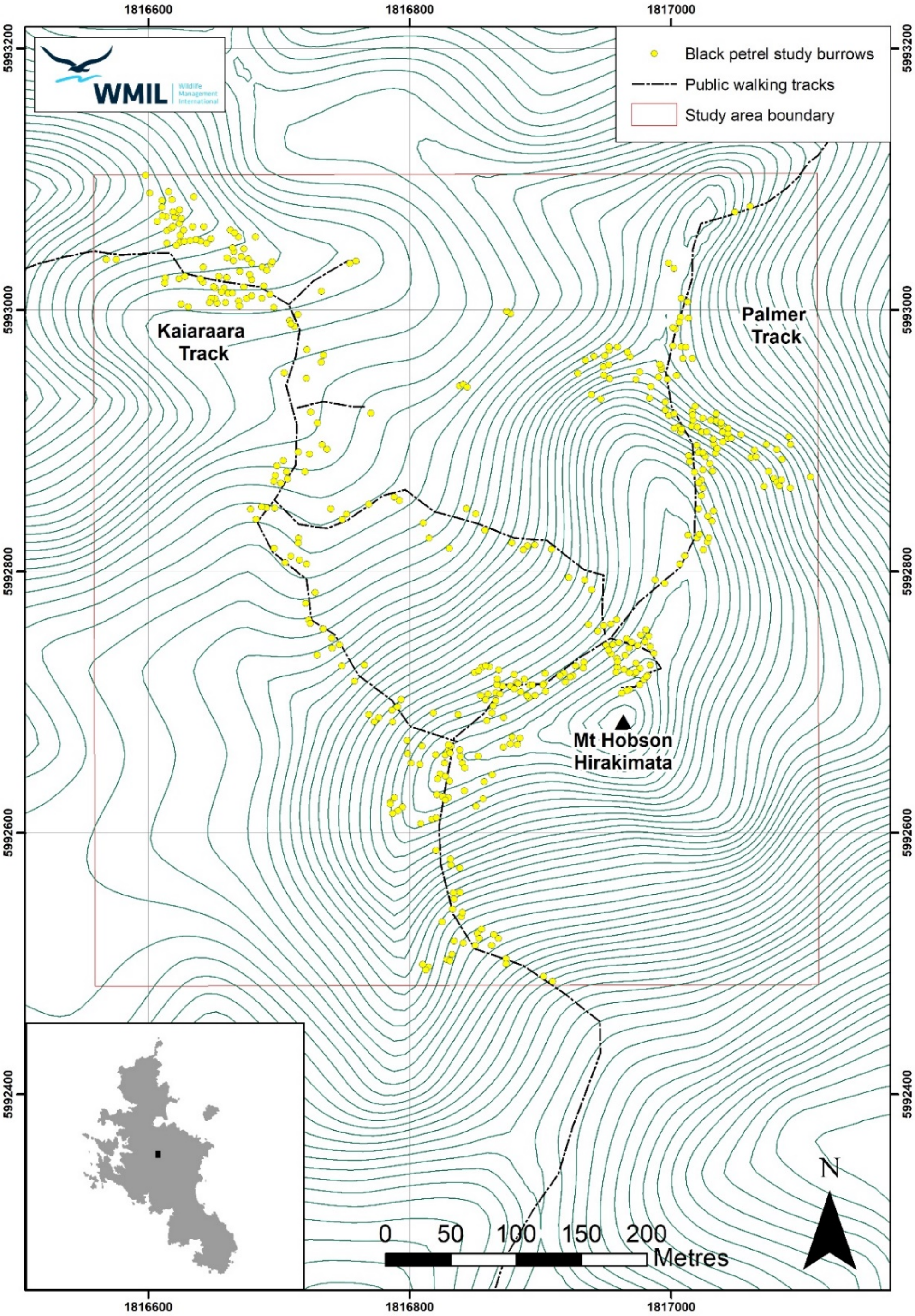

Figure 1: Map of the 458 black petrel study burrows that have been established in the vicinity of Mt Hobson/Hirakimata, Great Barrier Island/Aotea.

During the 2019–2020 field season, study burrows were monitored during four visits to the Mt Hobson/Hirakimata study area, carried out between 29 December 2019 to 31 January 2020 (trip 1); 6 February to 28 February 2020 (trip 2); 14 May to 19 May 2020 (trip 3); and 21 October to 28 October 2020 (trip 4). These visits roughly coincided with late incubation/hatching/early chick rearing (trip 1); mid chick rearing (trip 2); late chick rearing/fledging (trip 3); and pre-laying exodus (trip 4) phases of the black petrel breeding season. The chick rearing/fledgling trip was later than usual due to COVID-19 restrictions.

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 1.

During each burrow check, any resident adults were carefully removed from the burrow and checked for bands. If already banded from a previous trip, the band number of each bird was recorded; otherwise the bird was banded with an individually numbered size H stainless steel band. Before being returned to the burrow, a small vertical 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, thus not having to handle the bird again. 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 during subsequent checks of the same burrow, also further reducing unnecessary handling. During the final trip of each season, fledgling chicks found in the study burrows were extracted and banded.

During each trip, the field team spent several nights walking the public track system within the 35-ha study area, capturing any black petrels found on the ground. These birds were checked for bands, and any band numbers were recorded. If unbanded, a band was applied to the bird's leg. Before release, a small horizontal 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.

1.2.2 Data entry and analysis

All mark–recapture and breeding status data were entered into a Microsoft Access™ database at the completion of each trip. Data analysis and visualisation were performed using Microsoft Excel™.

1.3 Results

1.3.1 Burrow occupancy and breeding success

Of the 458 study burrows monitored during the 2019–2020 breeding season, 289 (63.1%) were occupied by breeding birds, 97 (21.2%) were occupied by non–breeding birds, and 72 (15.7%) were unoccupied.

In the nine grid squares the number of census grid burrows has increased over time since 1995, although there was a loss of one burrow between the 1996/1997 and 1997/1998 seasons. For the first breeding season in 1995/1996 there were 43 study grid burrows (in three grids combined) and 188 in the 2019–2020 season (in nine grids combined), with grid census burrows either remaining the same or increasing by 1 and up to 43 per season (Figure 2). Some study burrows within the grids have collapsed and are not used by breeding black petrels, but these burrows are still checked each season in case new birds have begun to re-dig these burrows.

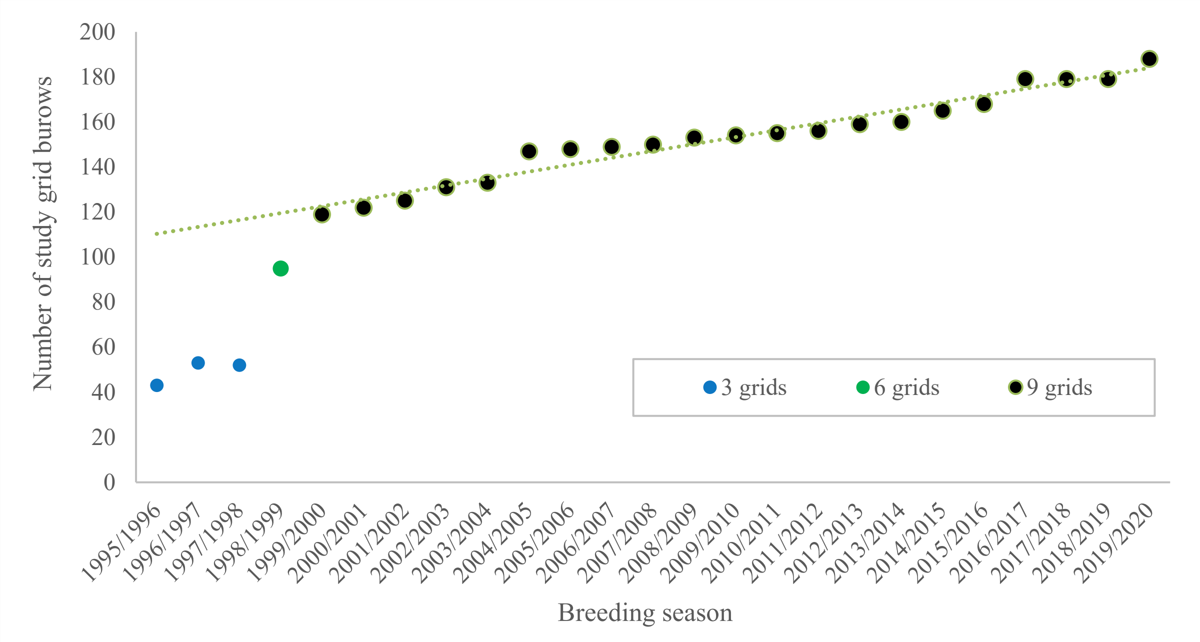

Figure 2: The total number of census grid study burrows monitored each breeding season between 1995 to 2020.

Burrow occupancy rates in the nine study grids likely provide the most consistent and representative measure of burrow occupancy across the study area, because they are unaffected by the occasional preferential addition of active breeding burrows to the study burrow network outside 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 or not black petrel burrow occupancy is increasing or decreasing within the study area. In the 2019–2020 breeding season, in the 188 study burrows within the study grids, the mean percentage of study grid burrows occupied by breeding black petrels was 58.5%, 2.8% less than the 25–year average study grid burrow occupancy rate of 61.3% (Figure 3).

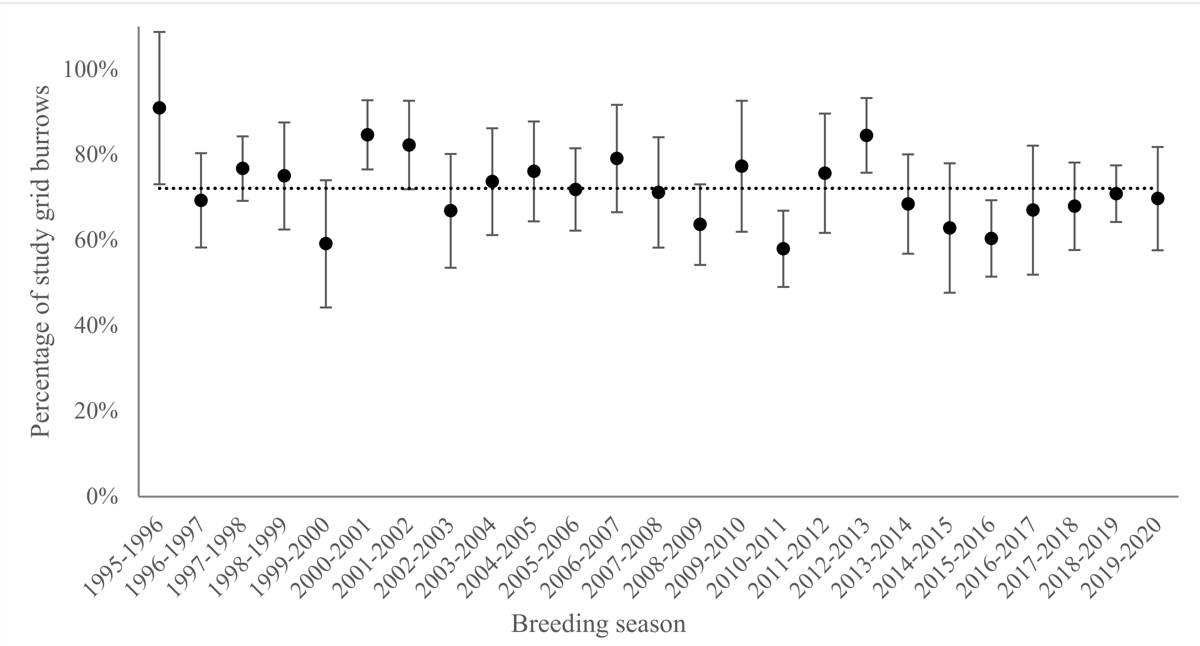

Figure 3: Mean percentage of study grid burrows occupied by breeding black petrels at Mt Hobson/Hirakimata on Great Barrier Island/Aotea between 1995 and 2020 (error bars represent 95% confidence intervals and dotted line represents the 25-year mean of 61.3%).

From the 289 study burrows that were occupied by breeding birds during the 2019–2020 breeding season, 221 chicks were produced, representing a 76.5% fledging success rate. Among the 289 breeding burrows, there were 68 breeding failures, representing a failure rate of 23.5%. Causes of breeding failure included eggs or chicks that disappeared from burrows, eggs being abandoned or crushed, and chicks dying.

The breeding success rate observed during the 2019–2020 season (76.5%) was 4.2% more than the 25-year average of 72.3% (Figure 4).

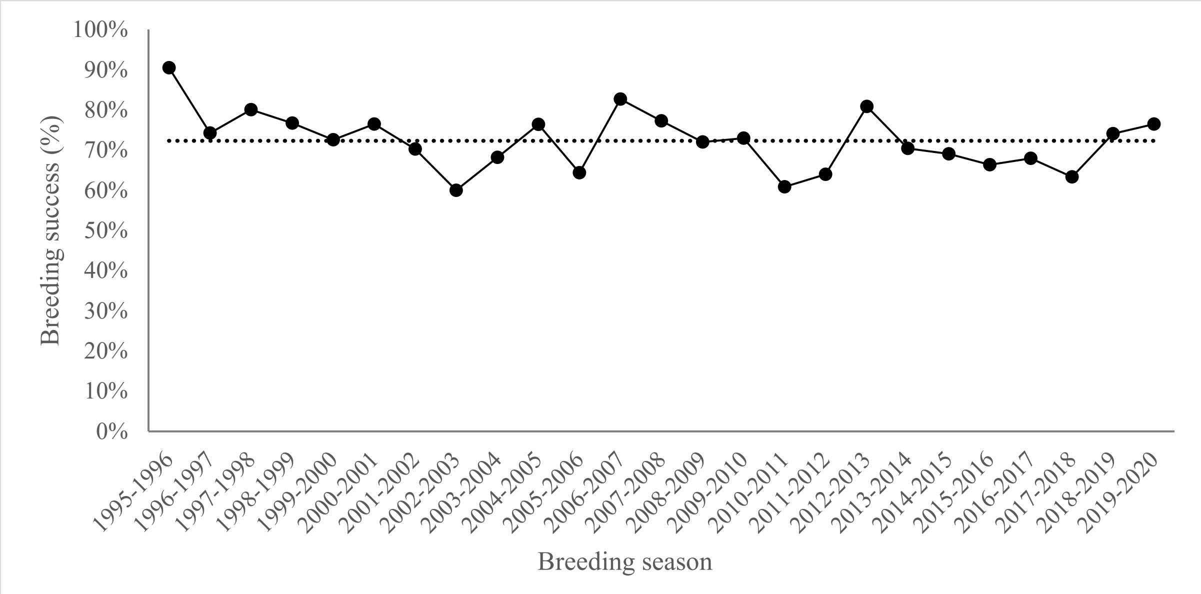

Figure 4: Mean breeding success (percentage of breeding burrows that fledge a chick) among black petrel study burrows at Mt Hobson/Hirakimata on Great Barrier Island/Aotea between 1995 and 2020 (the dotted line represents the 25-year mean of 72.3%).

1.3.2 Adult and juvenile survival

In total, 792 adults and 168 fledgling chicks were captured during the 2019–2020 field season. A total of 153 adults were banded during the 2019–2020 field season, of which 99 were captured in the study burrows. Of the 168 fledgling chicks banded during the 2019–2020 field season, 156 were banded in the study burrows. Due to COVID-19 restrictions, the chick banding trip was later than usual, and a number of chicks had fledged before the chick banding trip took place and could not be banded.

Of the 578 parents occupying the 289 breeding burrows during the 2019–2020 breeding season, 566 (97.9%) were captured and identified. The majority of individuals that were not identified were adults with breeding attempts that had failed, either prior to, or during, the first field trip of the season and were therefore unlikely to be spending much time in their burrows at that time.

During the 2019–2020 breeding season, 641 recaptures were recorded, including 127 returned chicks (99 of which have been banded by Wildlife Management International Ltd. (WMIL) since 1995). Fifteen were chicks that had been caught for the first time since being banded as fledglings (all banded by WMIL since 1995). A total of 336 returned chicks have now been recaptured at the Mt Hobson/Hirakimata colony.

1.3.3 Burrow turnover rate

The turnover rate (% of one or both breeding partners changing from the previous season) has fluctuated over time but is following an overall downward trend over the breeding seasons in grid study burrows (Figure 5). During the 2019–2020 breeding season the turnover rate was 17.5%.

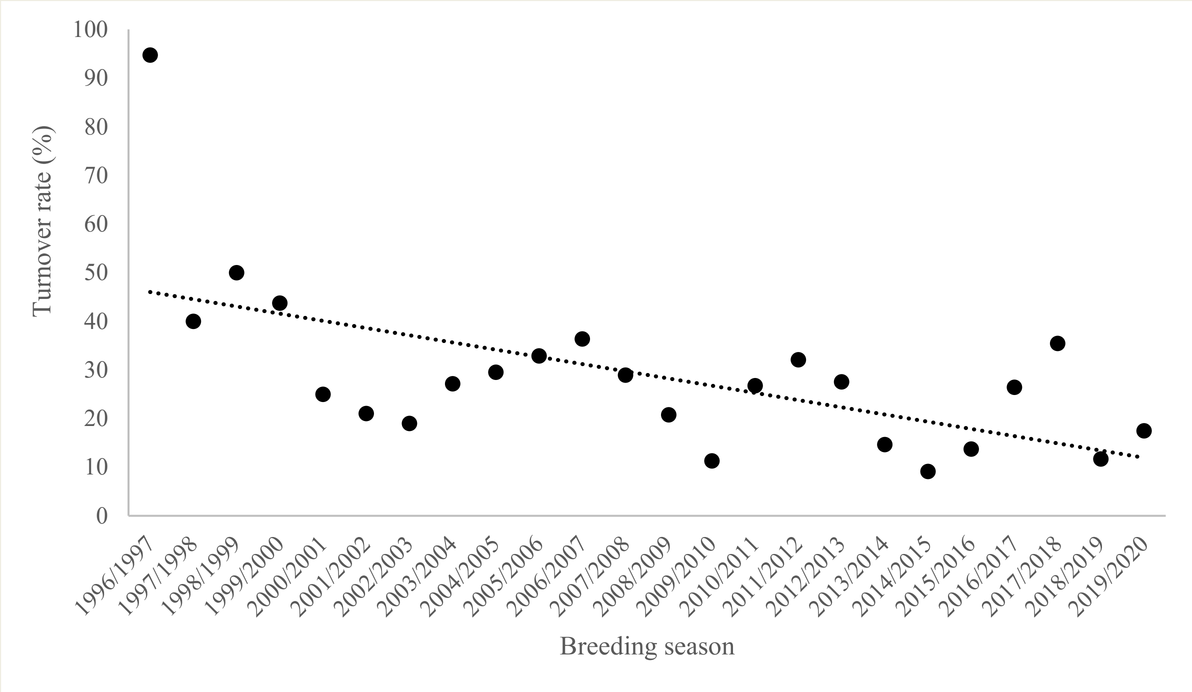

Figure 5: The turnover rate (i.e., the percentage of one or both breeding partners changed) in study grid burrows between breeding seasons on Great Barrier Island/Aotea.

In study grid breeding burrows, the turnover rate of one partner from the previous breeding season has fluctuated over the years but is following an overall downward trend (Figure 6).

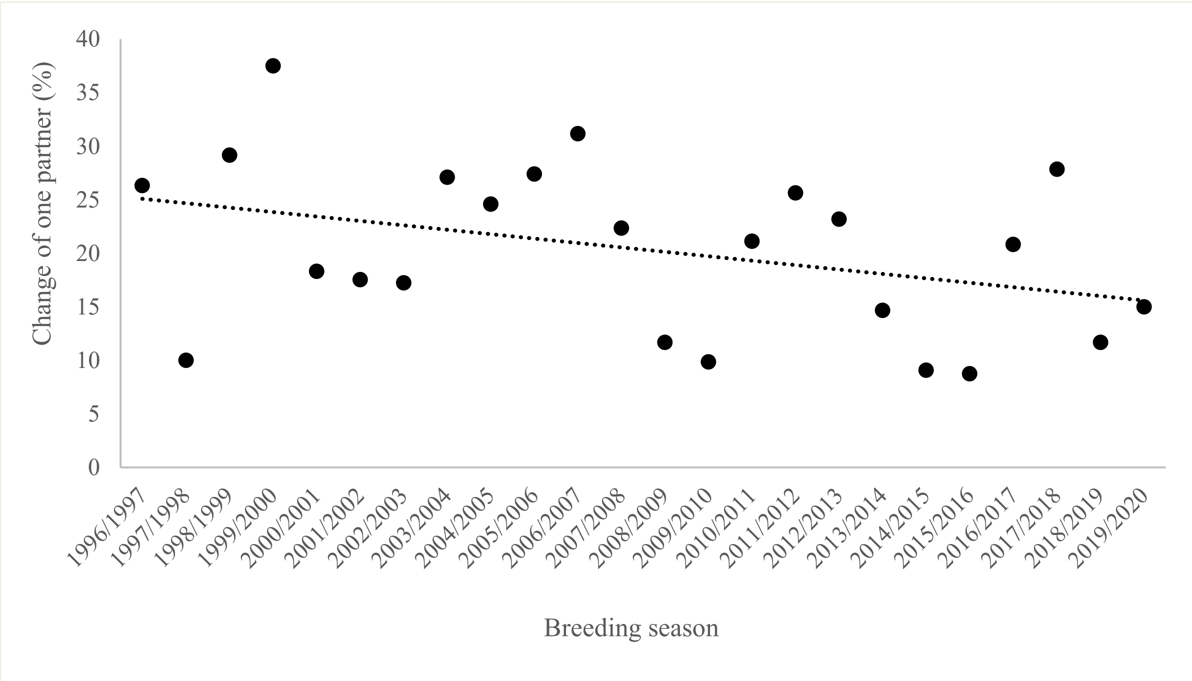

Figure 6: The percentage of study grid breeding burrows where one partner was a different bird than that seen in the previous breeding season on Great Barrier Island/Aotea.

In study grid breeding burrows, the turnover rate of both partners from the previous breeding season has fluctuated over the years (between 0 and 68.4%), but since the 1999–2000 breeding season turnover of both breeding partners has been low (between 0 and 9.1%) (Figure 7).

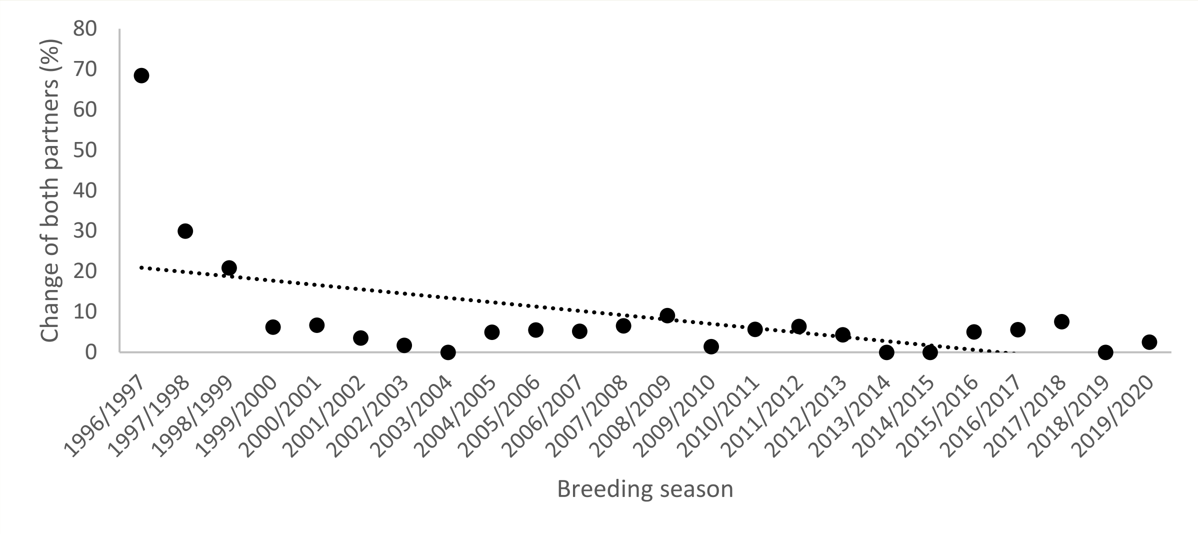

Figure 7: The percentage of breeding grid study burrows where both partners changed in a burrow from the previous breeding season.

1.4 Discussion

The 2019–2020 breeding season saw the fledgling success increase to 76.5% which is higher than the 25-year average for black petrels breeding on Great Barrier Island/Aotea. Due to COVID-19 restrictions the chick banding trip for the 2019/2020 breeding season was later than usual therefore fewer chicks were able to be banded. However, those banded in burrows were in good condition with only four small, under-sized chicks.

A total of 336 chicks have been recaptured at the colony since the 1995–1996 breeding season. The majority of these chicks were banded by WMIL, with only 29 chicks banded prior to this (1972–1992 by other researchers). The oldest known-aged bird still being caught at the colony is 32 years old (banded in 1988 by Dr. Mike Imber). Over 4250 chicks have been banded at the Great Barrier Island/Aotea study colony, but with less than 8% recaptured at the colony to date, there is a real lack of understanding whether this relates to juvenile survival and recruitment or is purely due to lack of effort to locate banded birds within the 35-ha study site. Survival estimates, especially for juvenile survival and recruitment, are vital for accurate population estimation and risk assessment modelling. It is highly recommended that effort to obtain data to fill this knowledge gap for black petrels is completed with urgency.

2. SATELLITE TRACKING OF ADULT BLACK PETRELS

2.1 Introduction

Black petrels are recognised as the seabird species that is at the greatest risk of being adversely impacted by unsustainably high rates of bycatch in commercial fisheries both within, and beyond, New Zealand's Exclusive Economic Zone (Richard & Abraham 2013). To adequately manage this threat, a spatially explicit model of bycatch risk is required, incorporating measures of fishing effort, fishing method, and black petrel at-sea distribution and habitat use (Richard et al. 2017). Models of the at-sea distribution of black petrels have been generated using a combination of remote tracking data and at-sea counts carried out by both fisheries observers and recreational birdwatchers (Abraham et al. 2015). However, these data do not yet adequately describe the at-sea distribution of black petrels at all life stages, nor do they adequately describe inter-annual variation in at-sea distribution in response to changes in sea surface temperatures and other environmental variables (Richard et al. 2017).

Tracking work using Global Positioning System (GPS) loggers was carried out on adult black petrels for the first time in 2006. During this time, GPS devices were successfully deployed on nine breeding black petrels during the chick-rearing stage on Great Barrier Island/Aotea. This work showed that birds travelled up to 1128 km from the colony during chick provisioning trips, between 248 and 2396 km per trip, spending a significant amount of time foraging in the vicinity of the continental shelf off the north–east coast of the northern North Island (Freeman et al. 2010).

Since then, tracking of breeding black petrels took place in 2010, 2012, 2013, 2018, and 2019 and this work has demonstrated that there is a great deal of individual and inter-annual variability in at-sea habitat use and foraging behaviour. In 2018 and 2019, GPS devices were deployed on adult black petrels during chick rearing and incubation periods on Great Barrier Island/Aotea. During incubation foraging trips, birds travelled an average distance of 4383 km and these trips were an average of 10.7 days long. Chick rearing foraging trips were an average of 3633 km and an average of 8.6 days long. Females were also found to forage further offshore and for longer periods of time compared to males (Bell et al. 2019). These tracking studies have shown that many foraging trips were to the outer Hauraki Gulf, coastal waters off Northland, East Cape, and Hawke's Bay, but foraging hotspots were also identified far offshore along the Norfolk and Kermadec ridges, Hikurangi Plateau, in the Tasman Sea, and in pelagic waters to the north and east of the Chatham Rise (Bell et al. 2011, Bell et al. 2013, Bell et al. 2019).

Global Location Sensor (GLS) devices have also been deployed on adult birds migrating to wintering grounds in the eastern Pacific during their non-breeding season. These tracking data have shown that these birds spent a great deal of time within a relatively small area of the eastern Pacific, off the coasts of Ecuador/Peru and the Galapagos Islands (Bell et al. 2011, Bell et al. 2019).

The only stage of the adult black petrel annual life cycle that has remained entirely unknown is the pre-egg laying exodus period. This phase of the breeding season follows a period onshore at the breeding colony when pair bond re-establishment and mating occur but precedes egg laying. During this pre-egg laying exodus period, both the female and male depart to sea on long foraging trips to highly productive areas to build up their body weight and condition and, for females, to feed up for egg production (Warham 1996, Quillfeldt et al. 2019). As soon as the female returns from the pre-laying exodus, she lays a single egg. The female typically departs shortly after, once the male has returned; the male takes the first long incubation shift.

In October 2020 a sample of black petrels from the Mt Hobson/Hirakimata breeding colony on Great Barrier Island/Aotea were tracked using Argos Avian Transmitters (TAV) and in this section of the report, the main findings from tracking black petrels during the pre-egg laying exodus period are presented.

2.2 Methods

2.2.1 Field methods

Ten adults which were known to have bred previously were caught in their burrows between 24 October and 28 October 2020, when birds had returned to the colony at the beginning of the breeding season. All study burrows being monitored on Mt Hobson/Hirakimata were checked at least once, and only adult birds which were known to have bred in the same burrow were fitted with a satellite tracking device (Table 1).

All birds intercepted were fitted with a Telonics Inc. remote satellite transmitter (TAV-2617) device. The satellite devices were programmed on a 4 hours on/30 hours off schedule to maximise battery life while giving a greater overview of pre-laying exodus location and behaviour. The four hours that a device was on typically generated between 15 and 20 location fixes.

The satellite devices were attached to the dorsal mantle feathers of each bird using 6 lengths of marine Tesa™ tape and super glue. The combined weight of devices and tape was between 14 and 18 g and did not exceed 3% of a bird's body weight (Phillips et al. 2003).

Each bird was weighed before being fitted with a satellite device. Two breast feathers were also collected from each bird, to enable each bird's sex to be determined from DNA testing. Devices took on average 9 minutes to attach and no individual was handled for greater than 15 minutes in total (including weighing the bird).

2.2.2 Data entry and analysis

Tracking data were downloaded on a regular basis following deployment from the Argos website (https://www.argos-system.org). All location data were first cleaned to remove any duplicate fixes and clear outlying points that resulted from a poor satellite fix or a device malfunction. Any data recorded by the devices both pre-deployment and post-removal were also removed.

Tracking data from each individual was split into separate foraging trips. The time/date stamp was compared to burrow check data from the January 2021 trip to determine the foraging trip type (pre-egg laying exodus trip, incubation foraging trip, or non-breeding foraging trip). The time/date stamp was also used to determine when a bird was likely in a burrow incubating an egg, indicated by a long period (7+ days) with no satellite transmission, followed by a recommencement of satellite transmission.

Data sorting and grooming were carried out in Microsoft Excel, and mapping and spatial analyses were carried out using QGIS version 3.6. Because transmitters were programmed on a 4 hours on/30 hours off schedule, GPS fixes were intermittent, and any distances calculated are almost certainly underestimates. Therefore, any distances stated in the results should be considered absolute minimum values.

Table 1: Summary of satellite transmitter deployments on adult black petrels on Great Barrier Island/Aotea in 2020–2021.

Band	Burrow	Sex	Breeding status (2020–2021 season)	January 2021 burrow status	Weight on (g)	Weight off (g)	Δ weight (g)	Date on (NZ)	Date off (NZ)	Date of last transmission (NZ)	Days with device on	Days transmitting
H29823	267	Male	Breeder	Chick	760	760	0	27/10/2020	8/01/2021	1/01/2021	73	66
H32025	331	Male	Non-breeder	–	770	720	-50	23/10/2020	19/01/2021	17/12/2020	88	55
H34843	80	Male	Breeder	Failed (rat predation)	780	660	-120	27/10/2020	9/01/2021	22/12/2020	74	56
H35450	460	Male	Breeder	Egg	710	800	90	27/10/2020	18/01/2021	14/01/2021	83	79
H44164		Female			710	680	-30	27/10/2020	9/01/2021	27/12/2020	74	61
H36139	189	Male	Non-breeder	–	790	–	N/A	24/10/2020	*Not recaptured*	26/01/2021	N/A	94
H37574	134	Female	Non-breeder	–	800	–	N/A	27/10/2020	*Not recaptured*	1/01/2021	N/A	66
H37591	321	Female	Breeder	Chick	760	630	-130	23/10/2020	28/01/2021	21/01/2021	97	90
H38885	303	Male	Non-breeder	–	780	–	N/A	24/10/2020	*Not recaptured*	14/01/2021	N/A	82
H39602	73	Male	Breeder	Egg	760	850	90	27/10/2020	20/01/2021	1/01/2021	85	66
				Average	762	729	-21				82	71.5

2.3 Results

2.3.1 Pre-egg laying exodus

Ten individuals (7 males, 3 females) from nine different burrows were satellite-tracked between 23 October 2020 and 26 January 2021. Satellite transmitters were attached to 11 different birds, but one was removed because the burrow entrance was too tight for the bird to enter/exit the burrow. This device was redeployed on another individual of the same sex. Three individuals with devices attached were not recaptured during the January 2021 field visit to Great Barrier Island/Aotea, and the devices being carried by these birds were not retrieved. These devices will drop off as the tape wears or will be shed naturally by the birds during their subsequent moult.

For birds that were recaptured on Great Barrier Island/Aotea, the average number of days carrying a transmitter was 82 (±8 days SD, n = 7, range: 73–97 days). Black petrels carrying a transmitter lost on average 21 g of body weight (±83 g SD, n = 7, range: -130 g to +90 g) but this varied greatly between individuals (see Table 1). The average number of days the devices transmitted for was 72 (±13 days n = 10, range: 55–94).

Pre-egg laying exodus foraging trips were carried out between late October and early December. Five of six individuals tracked during this breeding phase carried out a single foraging trip lasting between 31 and 45 days, and the remaining bird carried out two foraging trips, one lasting 28 days and the other 5 days (Table 2). Trips were on average 30 days (±11 days SD, n = 7) long. The average distance travelled on pre-egg laying exodus foraging trips was 6275 km (±3962 km SD, n = 7, range: 299–13 077 km). The average maximum range from the breeding colony on Mt Hobson/Hirakimata on Great Barrier Island/Aotea on foraging trips was 1705 km (±1399 km SD, n = 7, range: 152–4651 km).

The location of pre-egg laying exodus foraging trips varied greatly between individuals. Birds foraged north, west, and east of northern New Zealand (Figure 8). Five of six black petrels foraged far offshore and spent the majority of their time outside the New Zealand Exclusive Economic Zone (EEZ). Of these five, three (H44164, H37591, H39602) went far to the west towards Australia and spent most of their time foraging along the Lord Howe Rise and in the Tasman Sea (Figure 9). H29823 went north of Great Barrier Island/Aotea and foraged mainly in the South Fiji Basin and along the edge of the Kermadec Ridge, inside the New Zealand EEZ. H34843 went over 4500 km east and appeared to spend most of its time foraging along a seamount approximately 500 km southeast of Rapa iti (French Polynesia). The 13 077 km travelled by H34843 during its exodus is the longest distance recorded on a foraging trip during the breeding season by any black petrel. Its maximum range of 4651 km is also the furthest recorded distance from the breeding colony on Great Barrier Island/Aotea ever recorded. The remaining black petrel (H35450) spent the majority of its two pre-laying exodus foraging trips foraging along the shelf break between the Cavalli Islands in the north and Bay of Plenty in the south. Most of the time it was along the shelf break east of Coromandel Peninsula. This bird was found in burrow 460 at the same time as its partner (H44164) and there was no overlap between the two birds in their at-sea distribution during the pre-laying exodus period.

Although both females did go west towards Australia and forage in the Tasman Sea, there does not appear to be any difference in foraging distribution between sexes because one male followed a similar foraging pattern to the two females. The remaining males foraged far out east, north past the Kermadec Islands and inshore off the coast of the North Island. No significant differences in trip distance, range, or duration were found between sexes.

Table 2: Summary of foraging trips carried out by breeding adult black petrels on Great Barrier Island/Aotea (GBI) in 2020–2021.

Band number	Sex	Trip type	Trip number	Complete track (Y/N)	Distance (km)	Max. range from GBI (km)	Trip duration (Days)	Start date (NZST)	End date (NZST)
H29823	Male	Exodus	1	Y	5 051	1 191	33	23/10/2020	25/11/2020
		Incubation	2	Y	7 990	2 503	23	10/12/2020	01/01/2021
H34843	Male	Exodus	1	Y	13 077	4 651	33	23/10/2020	25/11/2020
		Incubation	2	N	1 571	802	17	5/12/2020	22/12/2020
H35450	Male	Exodus	1	Y	2 241	238	28	26/10/2020	21/11/2020
			2	Y	299	152	5	30/11/2020	5/12/2020
		Incubation	3	Y	840	254	8	6/01/2021	14/01/2021
H44164	Female	Exodus	1	Y	8 282	1 915	38	23/10/2020	30/11/2020
		Incubation	2	N	4 084	1 205	20	7/12/2020	27/12/2020
H37591	Female	Exodus	1	Y	6 229	2 102	31	26/10/2020	26/11/2020
		Incubation	2	Y	5 715	2 128	25	27/11/2020	22/12/2020
			3	N	3 427	1 492	15	6/01/2021	21/01/2021
H39602	Male	Exodus	1	Y	8 744	1 686	45	23/10/2020	7/12/2020
		Incubation	2	N	2 714	1 054	11	21/12/2020	01/01/2021

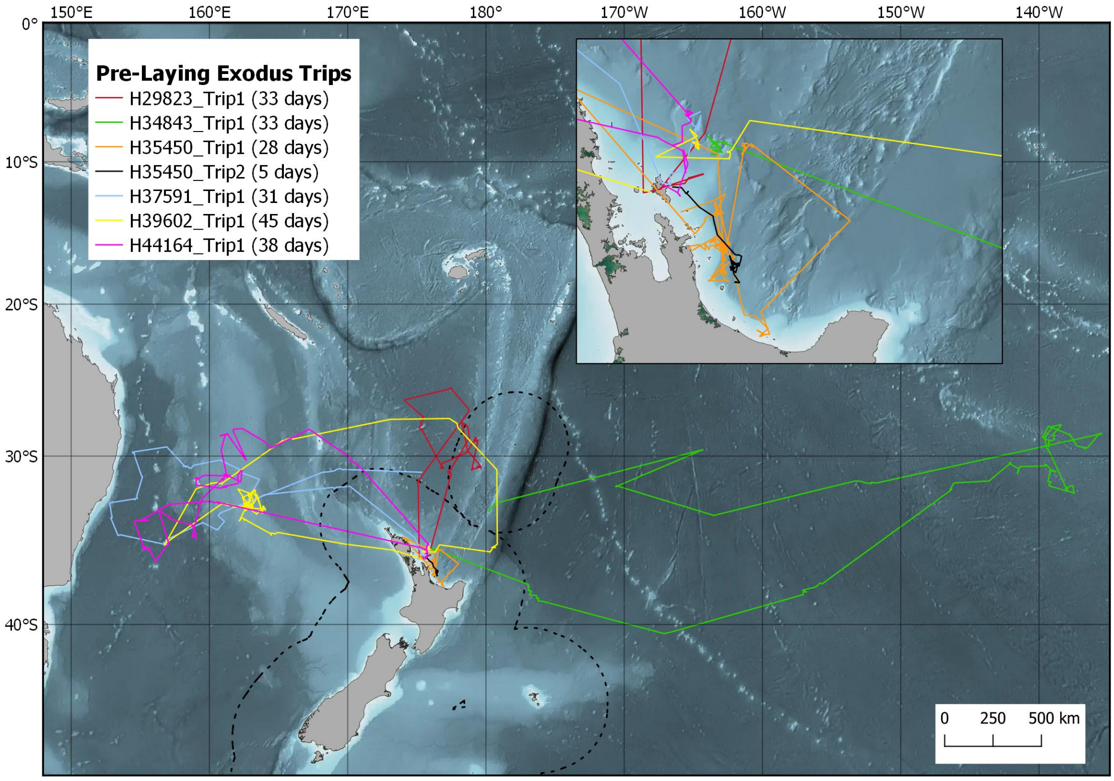

Figure 8: **All pre-laying exodus foraging trips of black petrels tracked from Great Barrier Island/Aotea between October and December 2020. The black dashed line represents the boundary of the New Zealand Exclusive Economic Zone.**

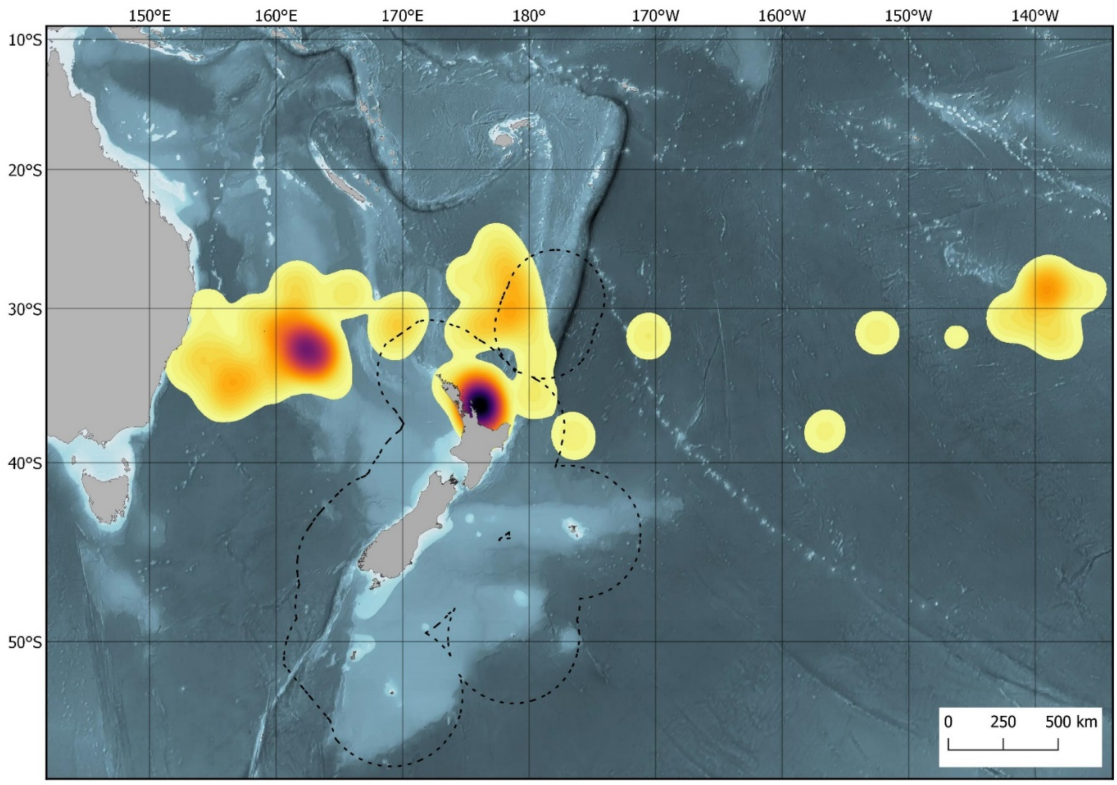

Figure 9: **Kernel density map for all black petrel GPS points recorded during pre-egg laying exodus trips between October and December 2020. Darker areas represent greater concentrations of black petrel activity. The black dashed line represents the boundary of the New Zealand Exclusive Economic Zone.**

2.3.2 Incubation

Incubation foraging trips were carried out between December 2020 and January 2021. All six black petrels that were tracked during the pre-laying exodus stage also yielded tracks during the incubation stage. In total, there were seven tracks from the incubation stage, of which, three were complete tracks. The remaining tracks were all incomplete due to the batteries in the satellite transmitters running out before the bird had returned to Great Barrier Island/Aotea. Complete trips lasted for between 8 and 25 days and each individual travelled between 840 km and 7990 km.

The location of incubation foraging trips varied greatly between individuals but showed a similar pattern to the spatial distribution of tracks during the pre-laying exodus stage (Figure 10). Two black petrels (H37591, H44164) carried out three trips out west towards Australia and foraged in the Tasman Sea, Lord Howe Rise, New Caledonia Trough, and Norfolk Ridge. One individual (H34843) went north and foraged along the Kermadec Ridge. H39602 went southeast to the Hikurangi Plateau whereas H29823 went 2500 km east past the Louisville Seamount to forage. The remaining black petrel (H35450) mainly foraged inshore along the shelf break in the Bay of Plenty.

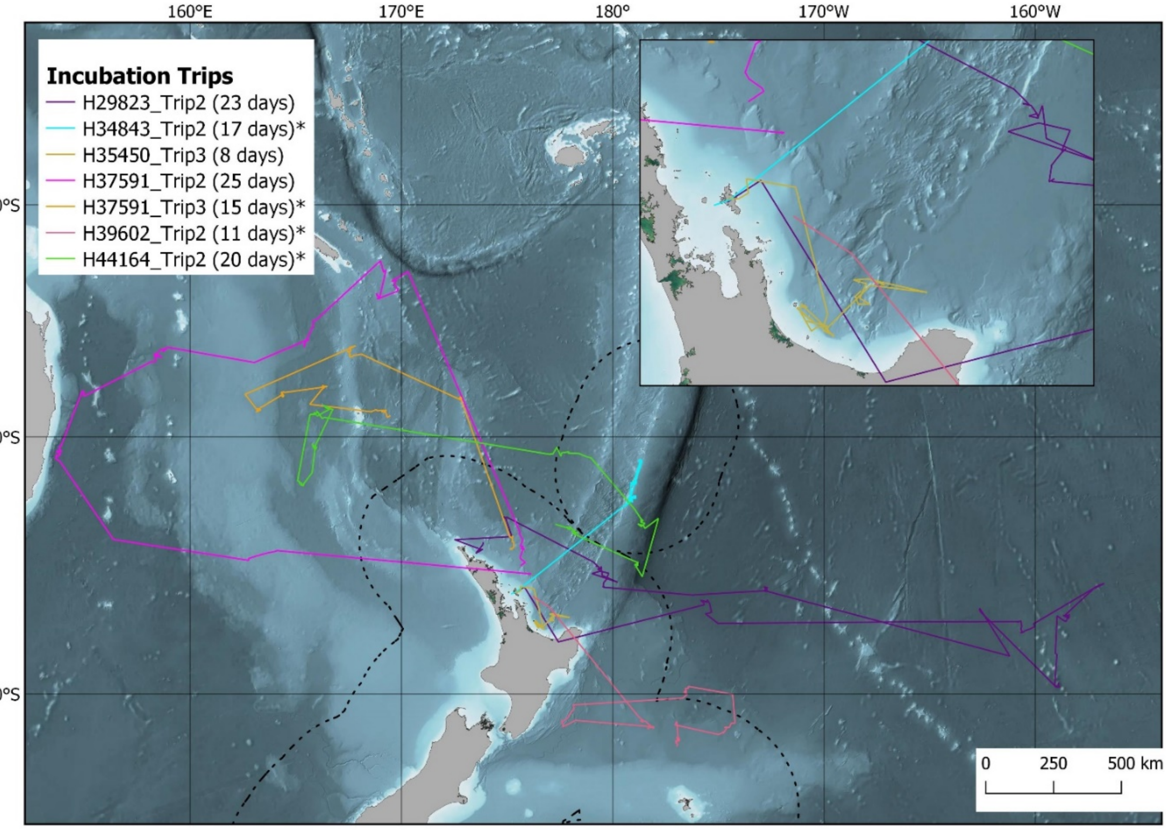

Figure 10: All foraging trips of black petrels tracked from Aotea/Great Barrier Island during the incubation stage between December 2020 and January 2021. The black dashed line represents the boundary of the New Zealand Exclusive Economic Zone.

2.3.3 Non-breeding birds

Of the ten black petrels with satellite transmitters attached in late October 2020, four ended up not breeding at the Mt Hobson/Hirakimata study colony during the 2020–2021 breeding season. These four black petrels consisted of three males and one female.

Tracks of non-breeding black petrel foraging trips were recorded between late October 2020 and late January 2021. The four black petrels tracked yielded 23 tracks of which 19 were complete tracks (Table 3).

Table 3: Summary of foraging trips carried out by non-breeding adult black petrels on Great Barrier Island/Aotea (GBI) in 2020–2021.

Band number	Sex	Trip type	Trip number	Complete track (Y/N)	Distance (km)	Max. range from GBI (km)	Trip duration (Days)	Start date (NZST)	End date (NZST)
H36139	Male	Non-breeding	1	Y	127	75	3	26/10/2020	28/10/2020
			2	Y	1 312	207	11	30/10/2020	10/11/2020
			3	Y	408	93	10	12/11/2020	22/11/2020
			4	Y	1 026	291	10	25/11/2020	5/12/2020
			5	Y	718	123	10	5/12/2020	15/12/2020
			6	Y	334	101	5	15/12/2020	20/12/2020
			7	Y	454	123	5	20/12/2020	25/12/2020
			8	Y	619	133	10	25/12/2020	4/01/2021
			9	Y	660	105	10	4/01/2021	14/01/2021
			10	N	2 257	1 428	13	14/01/2021	26/01/2021
H37574	Female	Non-breeding	1	Y	278	135	3	23/10/2020	26/10/2020
			2	Y	194	80	3	28/10/2020	31/10/2020
			3	Y	6 094	2 039	25	31/10/2020	25/11/2020
			4	Y	268	110	5	25/11/2020	30/11/2020
			5	Y	1 393	516	8	2/12/2020	10/12/2020
			6	Y	1 599	560	8	12/12/2020	20/12/2020
			7	N	3 460	1 308	11	21/12/2020	01/01/2021
H38885	Male	Non-breeding	1	Y	377	127	3	28/10/2020	31/10/2020
			2	Y	7 546	943	38	31/10/2020	7/12/2020
			3	Y	5 213	814	28	10/12/2020	6/01/2021
			4	N	1 746	681	5	9/01/2021	14/01/2021
H32025	Male	Non-breeding	1	Y	6 192	1 274	38	26/10/2020	2/12/2020
			2	N	1 637	823	13	5/12/2020	17/12/2020

The average distance travelled on non-breeding foraging trips was 1832 km (±2354 km SD, *n* = 19, range: 127–6192 km). The average maximum range from the colony at Mt Hobson/Hirakimata on Great Barrier Island/Aotea for non-breeding foraging trips was 413 km (±510 km SD, *n* = 19, range: 75–2039 km). Trip durations were highly variable but lasted on average 12 days (±11 days SD, *n* = 19, range: 3–38 days).

Non-breeding birds undertook significantly shorter foraging trips in all aspects (distance, range, and duration) when compared to foraging trips by breeding birds (Table 4). Most of the non-breeding birds remained within the New Zealand EEZ for the majority of their foraging trips (Figure 11). On trips within the New Zealand EEZ, black petrels exploited shelf breaks southeast and north of Great Barrier Island/Aotea. Other foraging areas exploited include Norfolk/West Norfolk Ridge, South Fiji Basin, Kermadec Ridge, and east to the Louisville Seamount and beyond. One non-breeding bird (H32025) was seen at sea by a longline fishing boat on the West Norfolk Ridge at a location known as Wanganella Banks (32.59° S, 167.49° E; see Appendix).

Table 4: Comparison between non-breeding and breeding black petrel foraging trip means from Great Barrier Island/Aotea (*n* indicates numbers of trips for which there were complete GPS tracks to generate the means).

	n	Distance (km)	Maximum range (km)	Trip duration (days)
Non-breeding	19	1 832	413	12
Breeding	10	5 847	1 682	27

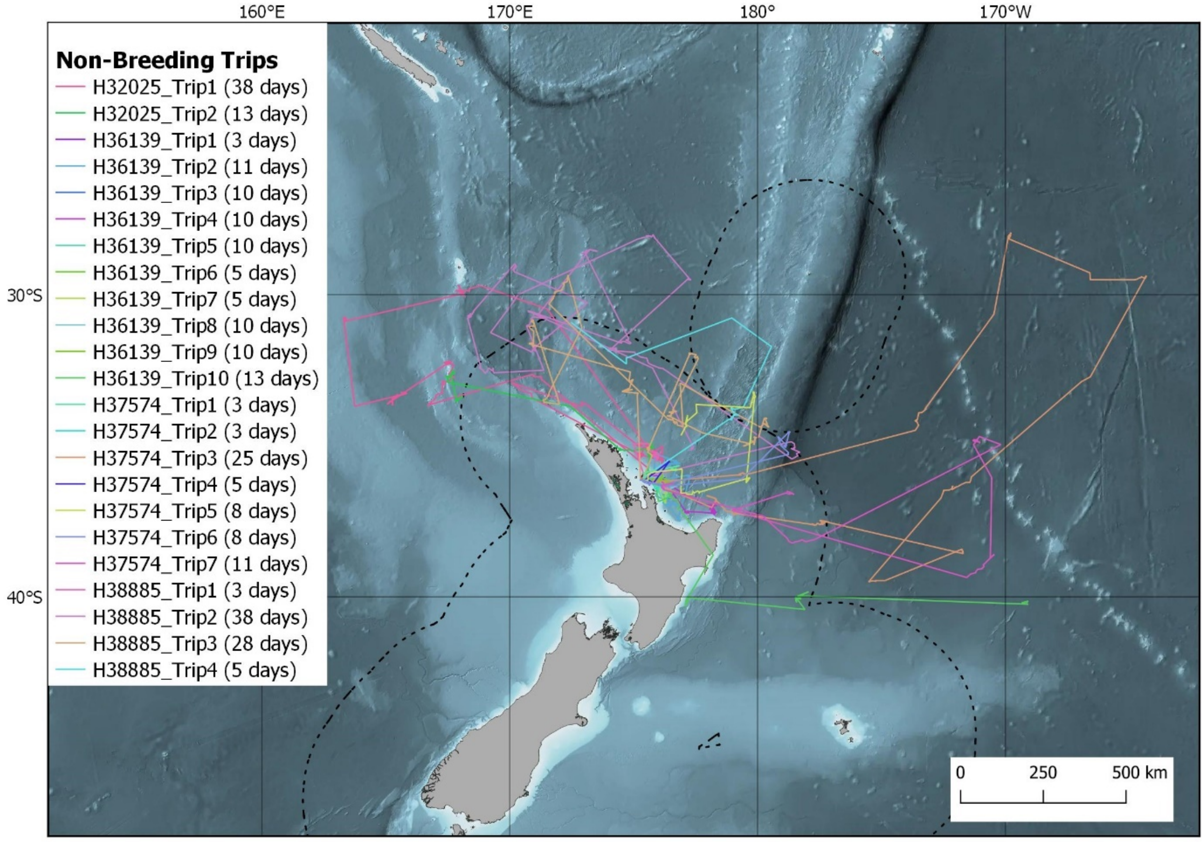

Figure 11: All foraging trips by non-breeding black petrels tracked from Great Barrier Island/Aotea between October 2020 and January 2021. The black dashed line represents the boundary of the New Zealand Exclusive Economic Zone.

2.4 Discussion

The Telonics Inc. TAV-2617 remote satellite transmitters functioned well, averaging 72 days of transmitting (versus a 74 day average as stated by Telonics). The attachment method surpassed expectations with devices and tape remaining intact until removed by the field team in January 2020. Devices remained on for between 55 and 94 days, far exceeding the of 30–40 days that the tape can generally be expected to hold given the exposure it faces to seawater, sun, wind, and pecking/preening by the bird.

Despite only deploying satellite transmitters on black petrels that had known recent breeding history in study burrows at the Mt Hobson/Hirakimata colony on Great Barrier Island/Aotea, only 60% of individuals tracked ultimately ended up breeding. This was, however, somewhat expected with 67% of burrows at the Mt Hobson/Hirakimata colony being occupied by breeding adults annually (Bell et al. 2017). Tracking data from non-breeding birds also hold value and non-breeding birds are significantly under-represented in black petrel tracking datasets.

Although the average change in weight for birds carrying transmitters was -21 g, this does not necessarily indicate that the tracking manipulation had an adverse impact on the wellbeing of the black petrels. Transmitters were removed from individuals as soon as they were found back in their burrow during normal burrow checks; however, the bird may have been in the burrow incubating its egg for some time prior to the burrow being checked. Similarly, the bird may have just arrived back and begun its incubation stint. This is supported by a large standard deviation (±83 g) associated with the mean and also a large range (-130 g to +90 g). Another measure of adverse effects of a tracking manipulation is the impact on breeding success and the satellite tracking this season did not appear to have an adverse effect. Breeding success in only one burrow with a tracked bird had failed by the time the field team left Great Barrier Island/Aotea in February 2021; this failure was determined to be due to rat predation and was not due to abandonment by either of the breeding birds. Two of the six burrows with tracked birds had chicks and the remaining three were still incubating their egg.

The tracking data presented here provide the first detailed account of the at-sea distribution of black petrels during the pre-egg laying exodus stage of the breeding season. These tracking data confirms that substantial variation in at-sea habitat use occurs between individual birds, and that there is substantial inter-annual variability in foraging behaviour. New foraging locations such as the South Fiji Basin and far to the east near Rapa Iti (French Polynesia) have been identified and some familiar foraging locations were again exploited by black petrels. One factor that seems to be consistent with tracking studies on black petrels is the importance of shelf breaks for foraging as shown during tracking studies in the 2017–2018 and 2018–2019 breeding seasons (McArthur et al. 2018, Bell et al. 2019). Freeman et al. (2010) found a significant relationship between bathymetry and black petrel foraging movements. Shelf breaks are commonly considered important for foraging procellariforms because associated upwellings often cause high productivity (Phillips et al. 2006, Studwell et al. 2017).

Black petrels tracked in this study visited a number of foraging hotspots identified during tracking studies carried out in previous years, including along the Lord Howe Rise, Norfolk and Kermadec ridges, Hikurangi Plateau, in the Tasman Sea, and in waters north of the Chatham Rise (Bell et al. 2019). The Norfolk/West Norfolk Ridge (approximately 167.6° E, 32.8° S) just outside the New Zealand EEZ, identified here as a key foraging spot for breeding birds during the pre-egg laying exodus stage and also non-breeding birds, has also been identified as a key foraging location for black petrels during both incubation and chick-rearing. This same area has also recently been identified as a key foraging area for adult flesh-footed shearwaters (*Puffinus carneipes)* during both the incubation and chick-rearing stages in multiple years of GPS tracking (Kirk et al. 2017, Crowe 2018, Crowe 2020). Both black petrels and flesh-footed shearwaters are known to follow fishing boats, and this area is frequented by many commercial fishing vessels (Gaskin et al. 2016, Global Fishing Watch 2020), also evidenced by the photo in the Appendix that was taken from a commercial fishing boat.

No significant differences in trip distance, range, duration, or foraging distribution were found between sexes. This is different to what has been found with black petrels at other breeding stages, with females tending to forage further away from Great Barrier Island/Aotea and males staying closer to the island and foraging at more inshore locations (Bell et al. 2019). The tracking results from the pre-egg laying exodus presented here are based on a very small ($n = 6$) sample size and, perhaps a more substantial sample size (such as the 25+ given by Bell et al. 2019), a pattern of differences in foraging behaviour and distribution between male and female black petrels may emerge.

Breeding and non-breeding birds showed significant differences in foraging trip distance, range, duration, and distribution. Breeding black petrels generally spent a longer time away from the colony and foraged much further offshore whereas non-breeding birds made shorter trips and foraged relatively closer to Great Barrier Island/Aotea. This result has inherent impacts on assessing and managing the risk of black petrel bycatch in commercial fisheries because black petrels from different life stages may be impacted differently depending on the location of the fisheries. When night searches have been completed within the study area, higher numbers of non-breeders have been captured on the surface at night throughout the breeding season compared with breeding birds (E. Bell, pers. obs.) and this may relate to the fact that non-breeding birds are not tied to the colony (i.e., an egg or chick) and can spend more time out of burrows and/or at-sea foraging.

The biggest current quantifiable threat to the population viability of black petrels is adult mortality associated with commercial longline and trawl fisheries These new tracking data can be used to improve models of the at-sea distribution and habitat use of adult black petrels during both the breeding and non-breeding seasons. These improved estimates can then be used to improve spatially explicit models of bycatch risk and to help determine mitigation measures to reduce the incidence of bycatch of black petrels.

Although the tracking data presented here provide a great first insight into black petrel behaviour and distribution during the pre-egg laying exodus stage, there are certain limitations to the dataset. The remote satellite transmitters had to be programmed to a 4 hours on/30 hours off schedule to maximise battery life and get ‘complete’ tracks. As such, the devices spent most of the time off and analysis of the spatial data (at times) required some subjective decisions on when one foraging trip ended, and another began. This was particularly difficult for individuals who were foraging close to Great Barrier Island/Aotea because it was often unclear if the individual had returned to the island or not.

Even though the devices were on, satellite fixes were not at regular and reliable intervals; therefore, the sampling period was highly variable within and between individuals. This makes presenting data using kernel density analysis problematic and, as such, care should be taken not to draw too many inferences from the kernel density map. It is strongly recommended that future tracking during the pre-egg laying exodus stage would have devices programmed to be on more frequently. This would reduce the number of days of battery life but would increase the spatial resolution of data. Full tracks of the pre-laying exodus would likely still be obtained because devices could be programmed to operate for up to 45 days (the longest exodus trip we recorded here). Alternatively, archival GPS devices could be used instead of remote satellite transmitting devices. Archival devices are significantly cheaper and could be programmed to last for 45+ days and still record tracks with fine spatial resolution. The downside of archival GPS devices is that they must be retrieved to obtain the data and any data will be lost on any devices not retrieved. However, given 70% (all six breeding birds and one non-breeding bird) of the remote satellite transmitters were retrieved, this is unlikely to be a significant issue.

3. DISTANCE SAMPLING TO ESTIMATE BLACK PETREL BURROW DENSITY AND BREEDING POPULATION SIZE IN MEDIUM-GRADE HABITAT

3.1 Introduction

An accurate estimate of the global population size of black petrels, and in particular the number of mature breeding pairs, is a key piece of information required to inform the conservation management of this threatened seabird. For example, to assign an appropriate New Zealand Threat Classification ranking to this species, accurate estimates of both black petrel population size and population trend are required (Townsend et al. 2008). Similarly, Fisheries New Zealand regularly assesses the risk posed by commercial fisheries to New Zealand seabird species, as required by the National Plan of Action (NPOA) to reduce the incidental catch of seabirds within New Zealand's Exclusive Economic Zone (Fisheries New Zealand 2020). The current risk assessment method includes the calculation of a Population Sustainability Threshold, which in turn requires accurate estimates of a number of population demographic parameters, including an estimate of the total number of breeding pairs in a seabird population (Richard et al. 2017).

Earlier analyses to estimate the black petrel breeding population size on Great Barrier Island/Aotea have had varying results. One estimate was derived from the extrapolation of burrow densities of the study grids to calculate the total number of burrows present in a 35-ha black petrel study area near the summit of Great Barrier Island/Aotea (Bell & Sim 2005). These density estimates have varied considerably from year to year, and it is unclear how accurate these estimates are relative to the true size of the black petrel breeding population because the study grids have been intentionally situated in sites with relatively high burrow densities, so are likely to overestimate the average burrow density of the 35-ha study area. Black petrels are also known to breed outside the study area, both elsewhere on Great Barrier Island/Aotea and on Te Hauturu-o-Toi/Little Barrier Island, with relatively little breeding population estimate data available from these locations (Bell & Sim 2005, Richard et al. 2017).

Another method used random, four metre fixed-width strip transect sampling throughout the 35-ha study area on Great Barrier Island/Aotea, both with and without a *post-hoc* stratification of the study area into zones of high-, medium-, low-, and zero-burrow densities (Bell et al. 2007). Although providing a more representative picture of burrow density across the 35-ha study area, this method includes a critical assumption that all burrows within the fixed-width strips are detected; this has been shown to be incorrect based on a comparison of fixed-width transects carried out by both a human field team and a seabird detector dog on Te Hauturu-o-Toi/Little Barrier Island in 2016 (Bell et al. 2016). Stratification was also prone to error, due to chance encounters of localised concentrations of burrows in areas of low- or medium-grade black petrel habitat; or localised gaps in burrow distribution in areas of high-grade black petrel habitat leading to incorrect 'zoning' during the *post-hoc* stratification process.

Richard & Abraham (2015) used fisheries bycatch data and a Bayesian modelling approach to create an estimate of the total number of breeding black petrels on both Great Barrier Island/Aotea and on Te Hauturu-o-Toi/Little Barrier Island using the transect survey results from the 35-ha study area on Great Barrier Island/Aotea to determine a lower limit for a constructed prior probability distribution, and at-sea survey results from South American waters to determine an upper limit for this prior distribution. The resulting breeding population estimate of 2750 breeding pairs (5500 breeding birds) is the estimate currently being used for the NPOA risk assessment for black petrels (Richard et al. 2017, Richard et al. 2020). However, Richard et al. (2017) acknowledged that the black petrel population size is still "not well known" due to uncertainty regarding the proportion of breeding adults that breed in any particular year, changes in the actual population size of black petrels, and uncertainty from the sampling processes used on Great Barrier Island/Aotea and Te Hauturu-o-Toi/Little Barrier Island. Richard et al. (2017) recommended that a demographic model to estimate the size of the black petrel breeding population, including an estimate of the number of black petrels that breed in suitable habitats on Great Barrier Island/Aotea outside the 35-ha study area at Hirakimata/Mt Hobson, and on Hauturu/Little Barrier Island, be developed.

Due to the large size of both Great Barrier Island/Aotea and Te Hauturu-o-Toi/Little Barrier Island, and rugged terrain and dense vegetation, the use of randomly-located grids or fixed-width strip transects would not be feasible. As such, a trial using distance sampling to generate an estimate of occupied black petrel breeding burrow density within the 108-ha high-grade habitat on Great Barrier Island/Aotea was completed during the 2018–2019 breeding season (Bell et al. 2019).

Distance sampling is a simple and cost-effective method for estimating the absolute density of objects within a particular sampling area (Buckland et al. 2001). Distances are recorded from points or line transects to the objects of interest (in this case, black petrel burrows), and the resulting distribution of distances is used to model how detection probability declines with increasing distance from the point or line transect (Buckland et al. 2001). However, to generate unbiased estimates of density, five key assumptions need to be met:

1) that the probability of detecting objects of interest situated on the survey line or point is 100% and declines outwards from the survey line (detection gradient/detection function);
2) that the lines or points sampled are randomly distributed in relation to the objects of interest;
3) that detections are independent from one another;
4) that measurements are exact; and
5) that objects are detected at their initial locations.

The trial within the high-grade habitat demonstrated that distance sampling provided a more robust and cost-effective alternative to the use of grids or fixed-width strip transects to estimate black petrel breeding burrow density and breeding population size on Great Barrier Island/Aotea. It produced an estimated density of 14.1 breeding burrows per ha, or a total of 1532 breeding burrows (and 3064 breeding adults) within the 108-ha survey area (Bell et al. 2019).

This section of the report covers the extension into the first section of the medium-grade habitat on Great Barrier Island/Aotea.

3.2 Methods

3.2.1 Habitat stratification

Breeding black petrels are unevenly distributed across Great Barrier Island/Aotea, with significantly higher densities of breeding birds found on high-altitude ridges under mature, unlogged, and unburnt native forest than at lower altitudes or in other vegetation types on the island (Marchant & Higgins 1990, WMIL unpublished data). Great Barrier Island/Aotea was stratified into high-, medium-, and low-grade black petrel habitat strata using all existing data on the presence and location of black petrel breeding burrows on the island using ArcMap version 10.6.1, with overlaid map layers describing altitude, vegetation type, and the presence and absence of feral pigs (a major threat to burrow-nesting shorebirds on land, e.g., Cuthbert 2002). The relationship between these three habitat variables and the densities of known black petrel burrows on the island were used to create definitions of high-, medium-, and low-grade black petrel habitat strata on Great Barrier Island/Aotea as described in Table 5.

The boundaries of these three habitat strata were mapped using ArcMap, according to the criteria outlined in Table 5 (Figure 12). The medium-grade habitat was separated into two areas to allow for a two-year survey timeframe; the core area surrounding Mt Hobson/Hirakimata and Glenfern Sanctuary to be completed in 2019–2020 (Figures 13 and 14) and the remaining areas (Northern Block, Te Ahumata/White Cliffs, Tramline, The Needles, Windy Hill and Ruahine) to be completed in 2020-2021.

The random start points and compass bearings were generated for 173 100-m long line transects within the core medium-grade habitat stratum (Figure 13) and 50 100-m long line transects within the Glenfern Sanctuary medium-grade habitat stratum (Figure 14).

Table 5: Definitions of high-, medium-, and low-grade habitat strata for black petrels on Great Barrier Island/Aotea. Altitude is given as metres above sea level (asl).

Habitat stratum	Vegetation type	Altitude (metres asl)	Feral pigs	Total Area (ha)	Example sites
High-grade	Mature Forest	>400	Absent	108	Hirakimata/Mt Hobson Mt Heale
Medium-grade	Mature Forest	>400	Present	3 207	Te Paparahi Block
		250–400	Present		
		<250	Absent		Glenfern Sanctuary
	Shrubland	>250	Present		
		<250	Absent		Glenfern Sanctuary
Low-grade	Mature Forest	<250	Present	24 520	
	Shrubland	<250	Present		
	Other*	<250	Present		Okupu

*Includes settlements, farms, etc.

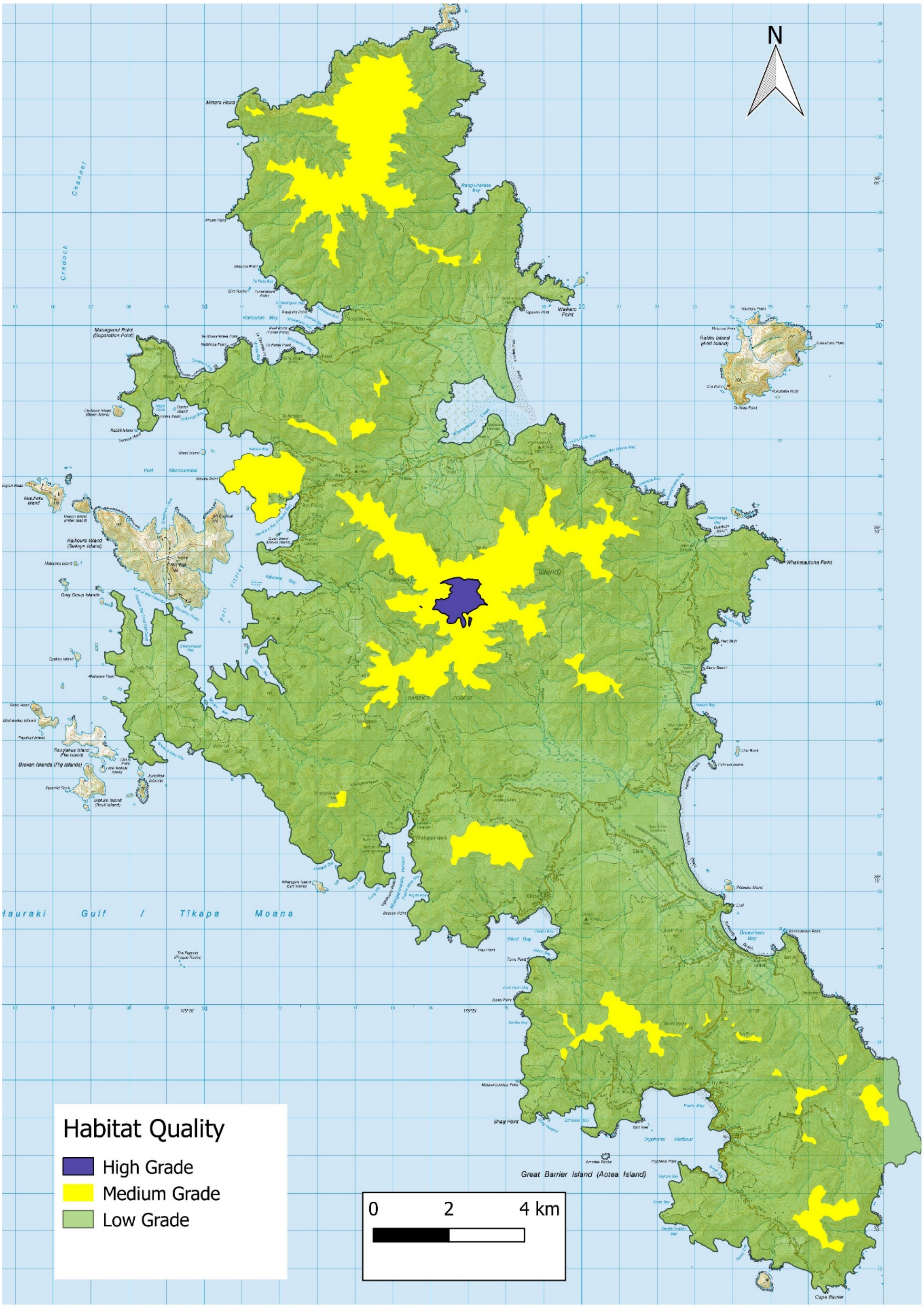

Figure 12: Habitat stratum on Great Barrier Island/Aotea as generated by information in Table 5 (i.e., existing presence of black petrel burrows, vegetation type, altitude, presence of feral pigs).

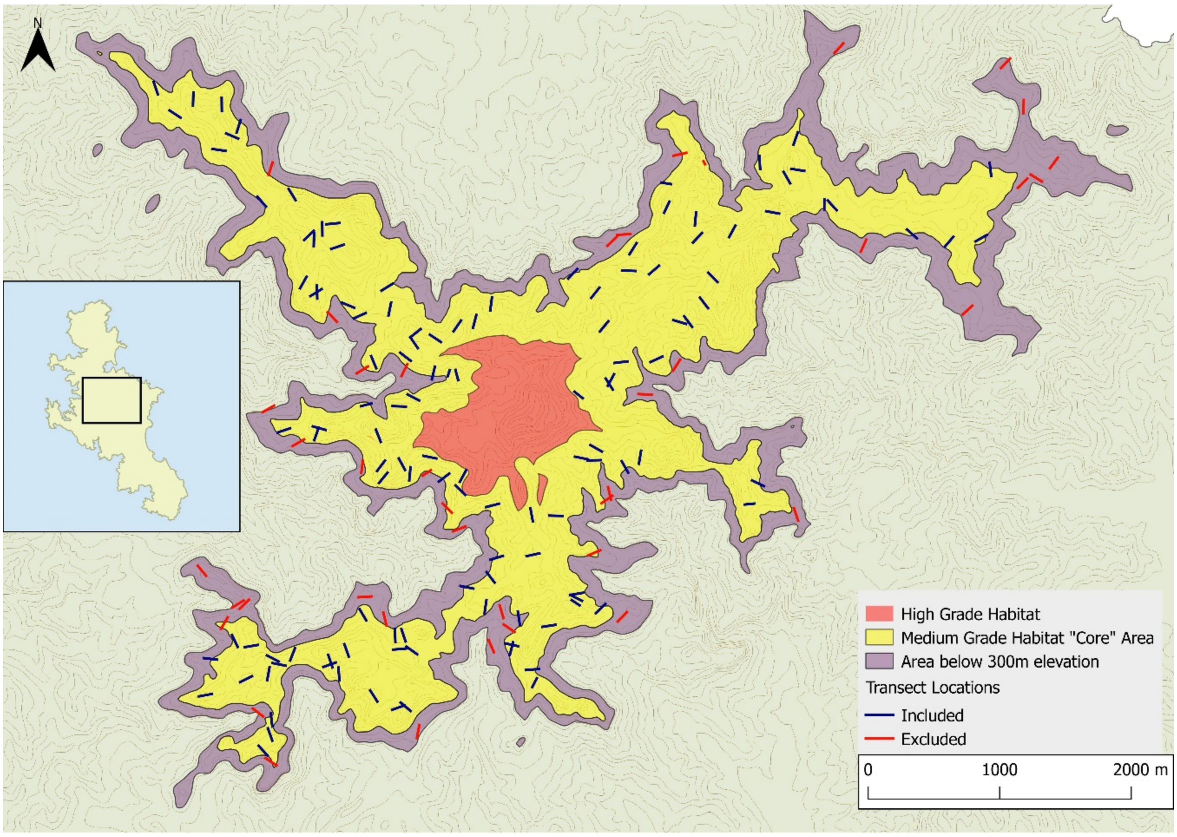

Figure 13: Medium-grade habitat stratum line transects surveyed in the core area on Great Barrier Island/Aotea in January and February 2021.

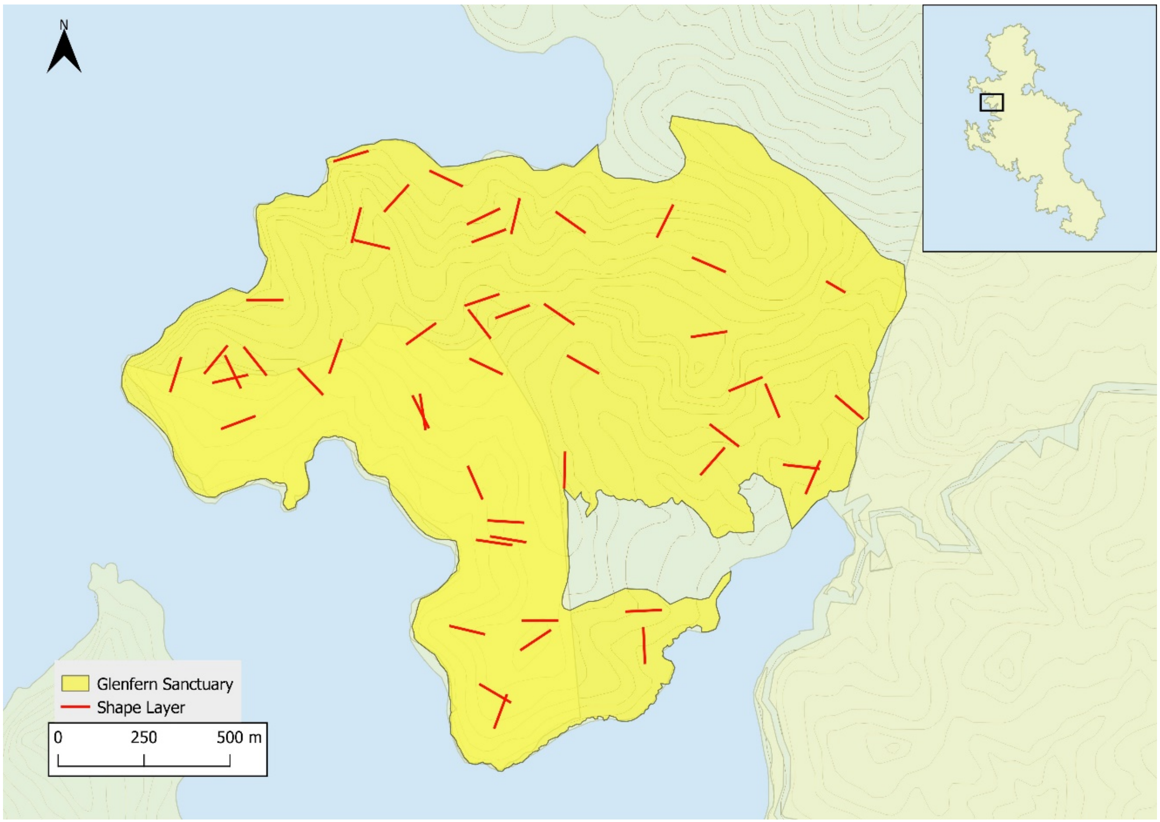

Figure 14: Medium-grade habitat stratum line transects surveyed in Glenfern Sanctuary on Great Barrier Island/Aotea in January and February 2021.

3.2.2 Line transect surveys

A team of two fieldworkers navigated to the start location of each randomly generated transect using a handheld Garmin GPS. One fieldworker then laid out a tape measure along the pre-defined compass bearing for the transect, before a second fieldworker slowly walked along the tape measure, scanning the ground for black petrel burrows. Burrows were detected either by directly sighting burrow entrances, or via the detection of visual cues indicating the likely presence of a burrow. These cues included signs of fresh digging, the presence of a semi-circular mound of soil or sticks in front of a burrow entrance, and/or the presence of fresh guano, eggshell remains, or fresh feathers. Once a potential burrow or a cue had been detected, one of the fieldworkers inspected the potential burrow or searched within a 2-m radius of the cue, to confirm whether or not a black petrel burrow was present. Once a black petrel burrow was confirmed, it was carefully checked to determine whether it was being, or had been used, as a breeding burrow during the current season. Burrows were checked manually, either by reaching an arm, smart-phone camera, or stick into the nest chamber, either via the burrow entrance or through a small inspection hole dug directly into the nest chamber. Burrows were recorded as being current breeding burrows based of the presence of incubating adults or lone chicks, or of fresh egg or chick remains. Once confirmed, the perpendicular distance of each burrow from the transect was measured to the nearest 0.1 m using a tape measure. Extreme care was taken to ignore any burrows detected by either fieldworker whenever they were not standing at the tape measure.

Wherever possible, the full 100-m length of each transect was surveyed, in 20-m increments. However, several transects were truncated either where they crossed the boundary of the medium-grade stratum, or because the fieldworkers encountered hazardous terrain such as cliffs and bluffs. A total of 173 transects, comprising a total length of 23.997 km, were surveyed (see Figure 13) in the core area around Mt Hobson/Hirakimata, and a total of 50 transects, comprising a total length of 4.9579 km, were surveyed in Glenfern Sanctuary (see Figure 14).

3.2.3 Data analysis

Line transect data were entered into Microsoft Excel, and histograms of the perpendicular distance data were created to examine whether the assumptions underlying the distance sampling methodology had been met, and to identify an appropriate distance at which to truncate these distance data (Figure 15). The distance data were modelled using the Conventional Distance Sampling Engine in Distance 7.2 (Thomas et al. 2010), which allows detection probability to be estimated as a function of distance from the transect line. In this analysis each burrow detection was treated as a single object and this dataset was truncated at a perpendicular distance of >15.0 m to reduce any disproportionate effect of outliers on both model fit and model selection (Buckland et al. 2001).

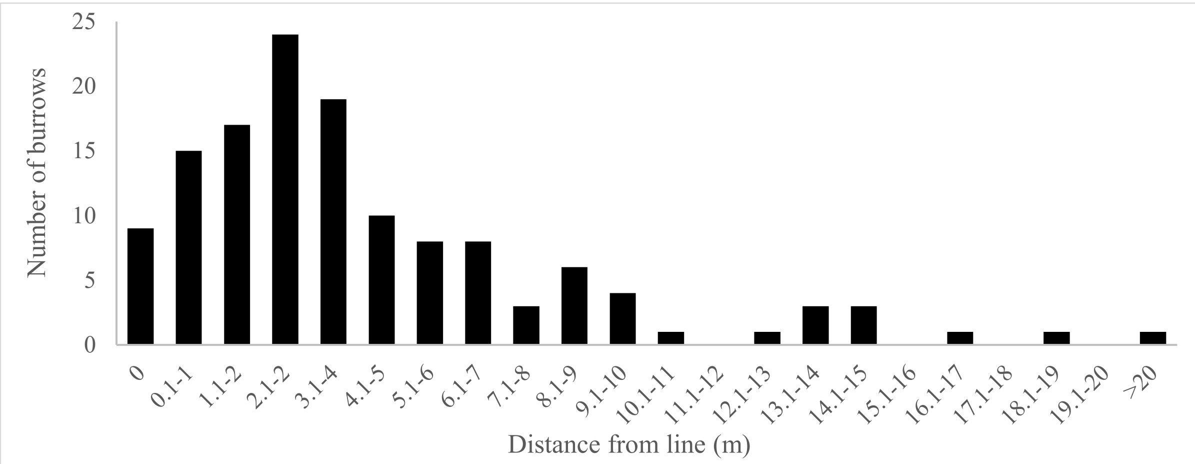

Figure 15: Distribution of burrow detection distances for all black petrel burrows detected by fieldworkers in the core medium-grade habitat during this distance sample transect survey on Great Barrier Island/ Aotea in 2019–2020.

Four alternative detection models were fitted to these data: the uniform key function with a cosine or simple polynomial adjustment term, and the half-normal key function with a cosine or hermite polynomial adjustment term. The detection model with the lowest AIC_c (Akaike Information Criterion) value was selected and this model was used to generate an estimate of the number of black petrel burrows present per hectare in the medium-grade habitat stratum.

An 8-m resolution Digital Elevation Model of Great Barrier Island/Aotea from the LINZ Data Service website at https://data.linz.govt.nz/ was used to create a Triangular Irregular Network (TIN) describing the 3D surface of Great Barrier Island/Aotea using the 'Raster to TIN' tool in ArcMap. This TIN was 'clipped' using a shapefile describing the boundary of the medium-grade black petrel habitat defined in Table 5 and Figures 12, 13, and 14, and the 3D surface area of the medium-grade black petrel habitat on Great Barrier Island/Aotea was determined using ArcMap's 'Surface Volume' tool. Lastly, the estimate of the number of burrows present per hectare was multiplied by the 3D surface area of the medium-grade habitat stratum, to generate an estimate of the number of breeding pairs, and breeding adults, present within this habitat stratum.

3.3 Results

A total of 142 burrows were detected during this medium-grade habitat survey: 140 in the core area above 250 m asl and two in Glenfern Sanctuary (see Figures 13 and 14). The lack of burrows in Glenfern Sanctuary, and the fact that both burrows that were detected were unoccupied, suggested that this area could not be classed as medium-grade habitat and was excluded from the distance sample model.

Of the 173 transects within the core habitat around Mt Hobson/Hirakimata, an assessment of burrow detection, occupancy rates, and habitat variables (slope, vegetation, pig activity, etc.) showed that the habitat under 300 m asl also could not be classified as medium-grade black petrel habitat. All transects below 300 m (n=41) were also excluded from the distance sample model. Figure 13 shows both included and excluded transects within the core medium-grade habitat. This core area around Mt Hobson/Hirakimata was recalculated above 300 m asl and determined to be a total of 833 ha of medium-grade black petrel habitat.

A total of 131 transects were surveyed in the core area above 300 m asl and 115 burrows were detected along these transects in the core medium-grade habitat.

Of the 115 burrows detected in the core medium-grade habitat above 250 m asl, a total of 54 burrows were determined to have been used as breeding burrows during the 2019–2020 breeding season and a further 61 burrows were either unoccupied, or occupied by non-breeding birds, providing a breeding burrow occupancy rate of 0.4696 within this medium-grade habitat stratum.

The four detection functions fitted to these line transect data all provided a reasonable fit to the data, but the model using the uniform key function with a cosine adjustment term had the lowest AIC value (standard error = 2.3114; coefficient of variation = 17.43), so this model was used to generate estimates of burrow detection probability and burrow density (Figure 16).

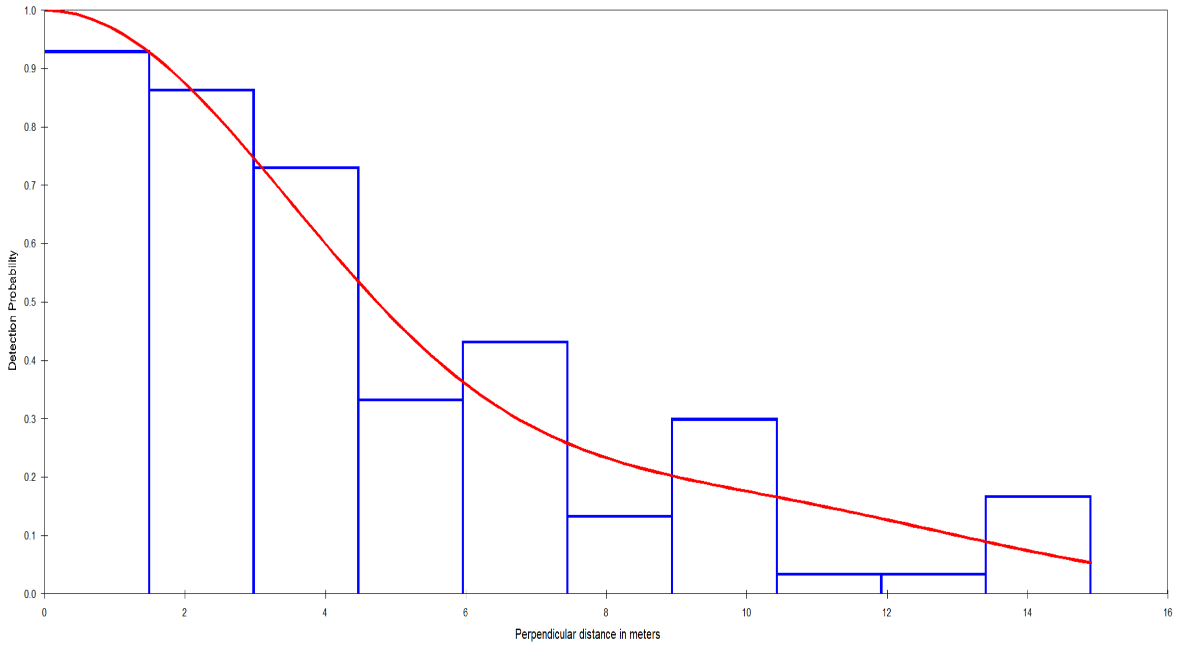

Figure 16: Detection probability and distribution of perpendicular burrow detection distances (histogram) for black petrel burrows detected during this line transect survey. The red line represents the uniform cosine detection function fitted to these data, from which burrow detection probabilities and burrow density estimates were generated.

According to this model, the total density of black petrel burrows in the medium-grade habitat stratum is 8.0005 burrows/ha (5.6891–11.251 burrows/ha, 95% confidence limits). By multiplying this by the proportion of these burrows used for breeding during the 2019–2020 breeding season, the density of breeding burrows (0.4696) in the medium-grade habitat stratum was 3.757 burrows/ha (2.6716–5.2835 burrows/ha, 95% confidence limits) during the 2019–2020 breeding season. When multiplied by the total area of the core medium-grade habitat stratum (833 ha), this yields an estimate of 3130 black petrel breeding pairs (2225–4401 breeding pairs, 95% confidence limits) present in the medium-grade habitat stratum, or 6260 breeding adults (4450–8802 breeding adults, 95% confidence limits).

3.4 Discussion

Following on from the high-grade survey completed in 2018–2019, distance sampling proved to be a robust method to estimate black petrel breeding burrow density and breeding population size on Great Barrier Island/Aotea with all the key assumptions being met.

Within the 833-ha core medium-grade habitat on Great Barrier Island/Aotea, the number of breeding black petrels was estimated at 6260 adults. When combined with the population estimate for black petrels within the 108-ha high-grade habitat (3064 breeding adults, Bell et al. 2019), this suggests that it is likely that there are an estimated 10 000 breeding birds within the core habitat surrounding Mt Hobson/Hirakimata on Great Barrier Island/Aotea breeding each year. The number breeding may vary slightly from year to year as shown by the variation in occupancy rate across the survey areas (0.51 for high-grade habitat, 0.47 for medium-grade habitat, and 0.63 for the study burrows). The population estimate is likely to alter as clarification and updated stratification of habitat types are completed. This population estimate of breeding black petrels within medium-grade habitat is also likely to change as the remaining medium-grade habitat survey across Great Barrier Island/Aotea is completed.

Further work could be done to examine variation in breeding population estimates within habitat grades, by repeating surveys with the high-grade and core medium-grade habitat around Mt Hobson/Hirakimata. There appears to be a lower breeding occupancy rate between the high- and medium-grade habitat compared with the study burrows and this suggests that there may be a further habitat separation (preference), particularly within the high-grade habitat, by black petrels on Great Barrier Island/Aotea.

The estimate of 6260 breeding adults within 833 ha of occupied core medium-grade breeding habitat on Great Barrier Island/Aotea when combined with the estimate from the high-grade habitat has almost doubled the Richard et al. (2017) estimate of 5500 black petrels breeding on both Great Barrier Island/Aotea and Te Hauturu-o-Toi/Little Barrier Island which is used to inform the NPOA risk assessment for this species. To further improve the accuracy of the global breeding population estimate for black petrels used to inform the NPOA risk assessment for this species, distance sampling should be undertaken in the remaining medium-grade black petrel habitat on Great Barrier Island/Aotea as well as on Te Hauturu-o-Toi/Little Barrier Island. Including burrow density estimates for these remaining occupied habitats on both islands into the population demographic model recommended by Richard et al. (2020) will allow Fisheries New Zealand to produce the most robust and accurate global population estimate of this species and, in turn, will eliminate or minimise several sources of uncertainty inherent in many of the previous population estimates that have been generated to date.

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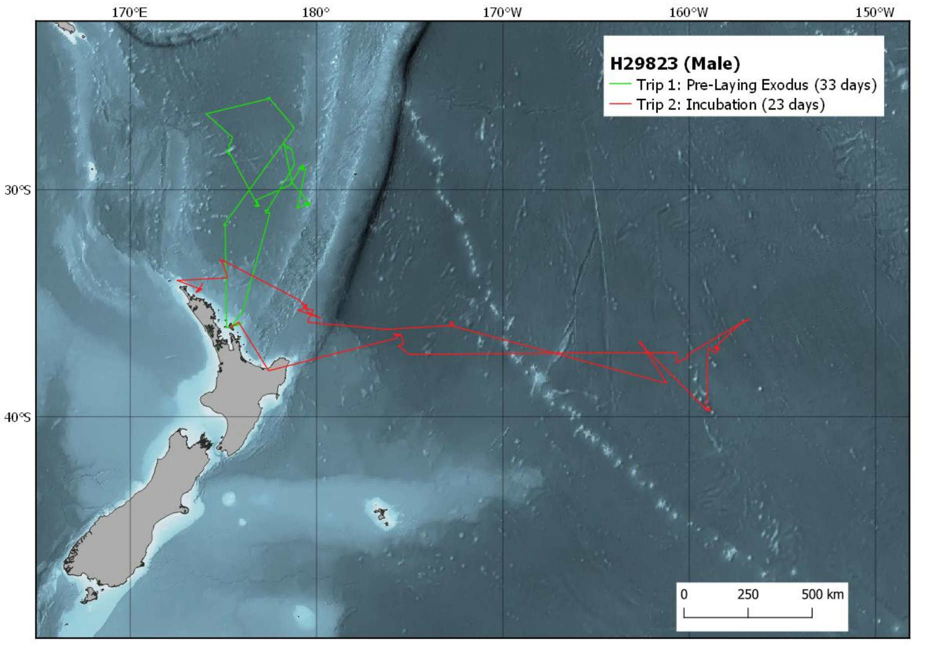
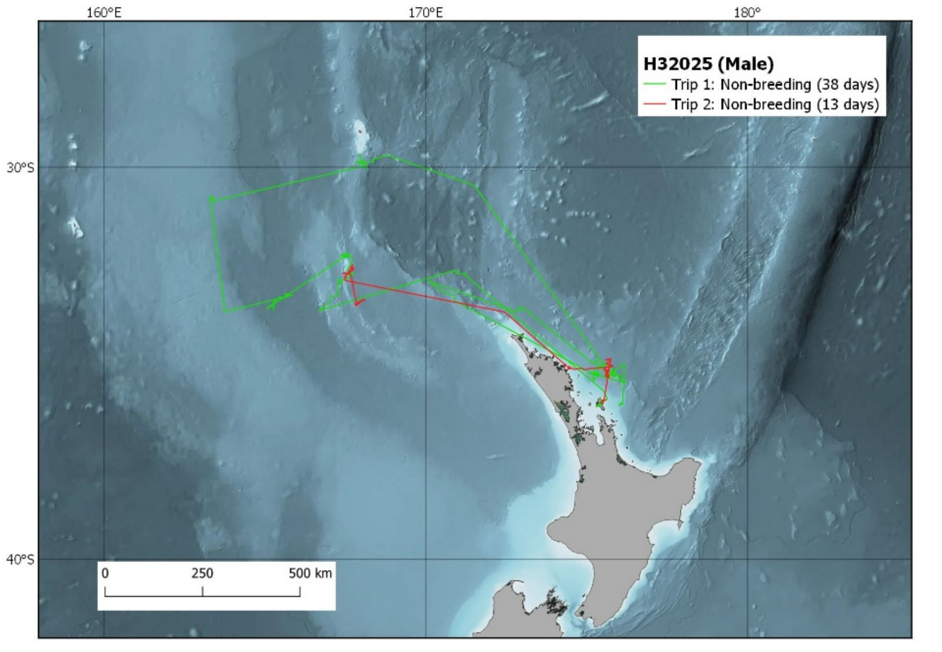
6. APPENDIX

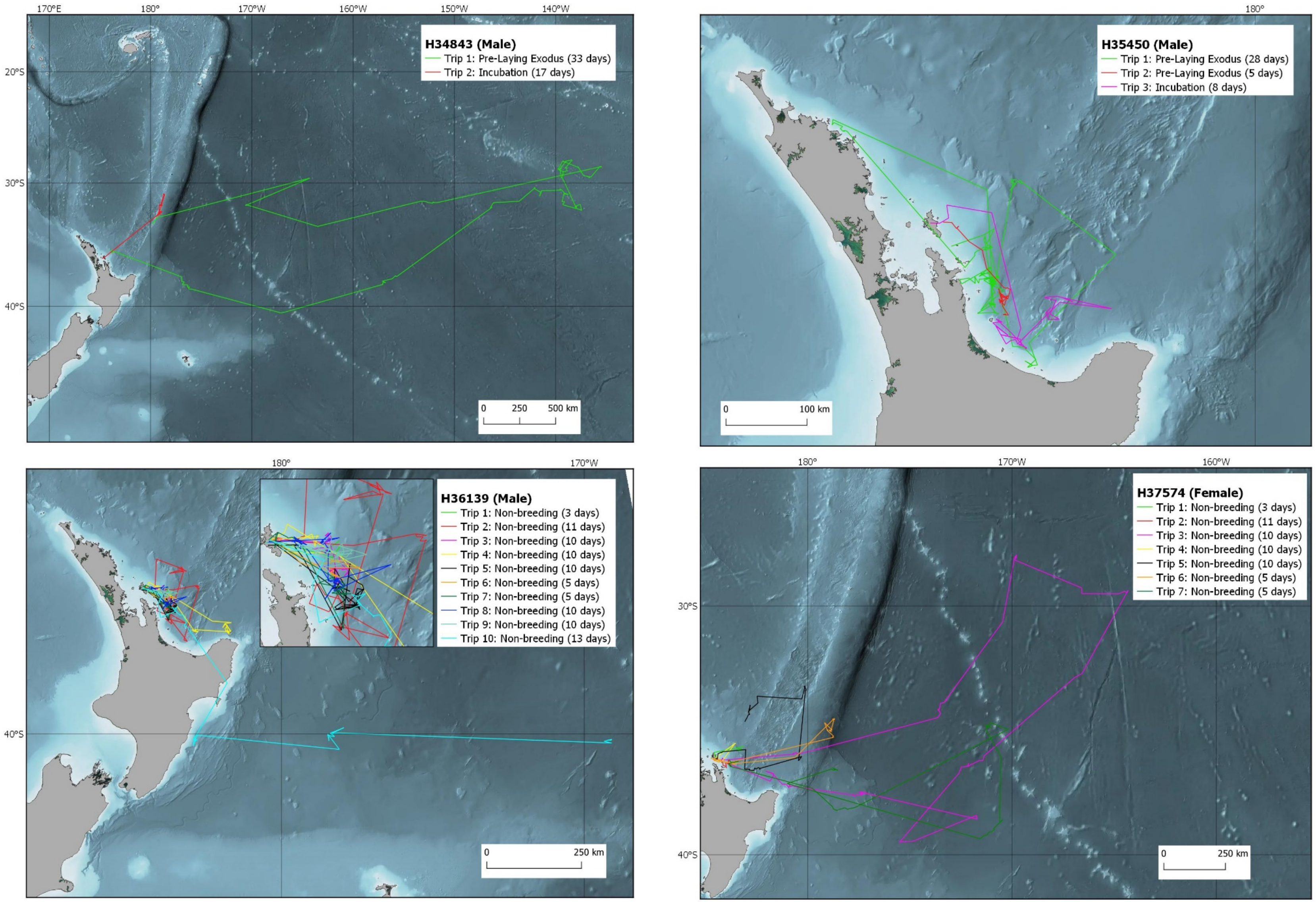
Black petrel wearing an Argo satellite transmitter (TAV2617) device seen at sea by fishermen on West Norfolk Ridge.

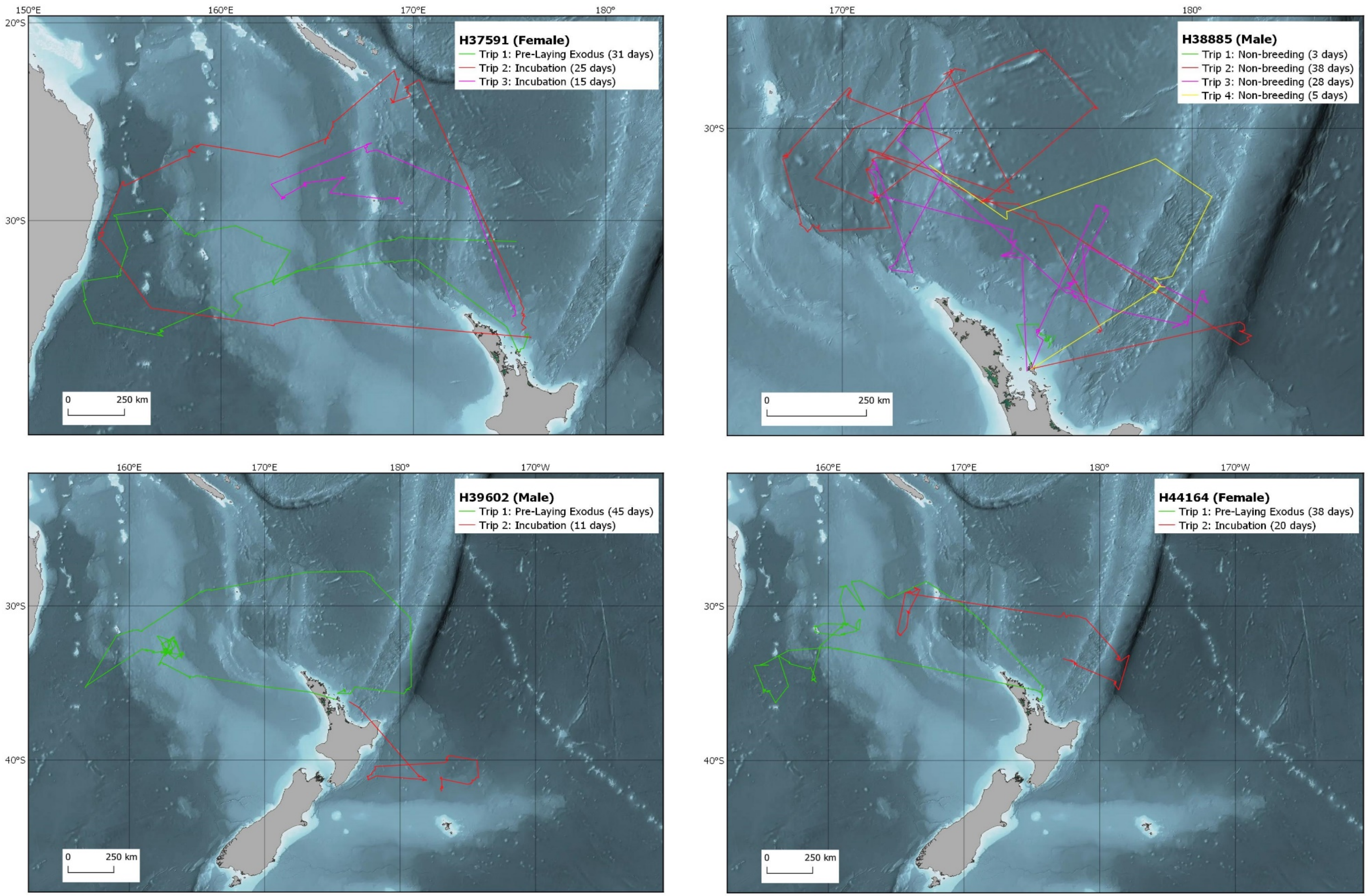
Individual GPS tracks: October 2020 – January 2021.

All tracks from breeding (pre-laying exodus and incubation stages) and non-breeding black petrels. Note that the scale differs for some figures. (Continued over next two pages)






H34843 (Male)
Trip 1: Pre-Laying Exodus (33 days)
Trip 2: Incubation (17 days)
170°E
180°
170°W
160°W
150°W
140°W
20°S
30°S
40°S
0 250 500 km
H35450 (Male)
Trip 1: Pre-Laying Exodus (28 days)
Trip 2: Pre-Laying Exodus (5 days)
Trip 3: Incubation (8 days)
180°
0 100 km
H36139 (Male)
Trip 1: Non-breeding (3 days)
Trip 2: Non-breeding (11 days)
Trip 3: Non-breeding (10 days)
Trip 4: Non-breeding (10 days)
Trip 5: Non-breeding (10 days)
Trip 6: Non-breeding (5 days)
Trip 7: Non-breeding (5 days)
Trip 8: Non-breeding (10 days)
Trip 9: Non-breeding (10 days)
Trip 10: Non-breeding (13 days)
180°
170°W
40°S
0 250 km
H37574 (Female)
Trip 1: Non-breeding (3 days)
Trip 2: Non-breeding (11 days)
Trip 3: Non-breeding (10 days)
Trip 4: Non-breeding (10 days)
Trip 5: Non-breeding (10 days)
Trip 6: Non-breeding (5 days)
Trip 7: Non-breeding (5 days)
180°
170°W
160°W
30°S
40°S
0 250 km


H37591 (Female)
Trip 1: Pre-Laying Exodus (31 days)
Trip 2: Incubation (25 days)
Trip 3: Incubation (15 days)
150°E
160°E
170°E
180°
20°S
30°S
0 250 km
H38885 (Male)
Trip 1: Non-breeding (3 days)
Trip 2: Non-breeding (38 days)
Trip 3: Non-breeding (28 days)
Trip 4: Non-breeding (5 days)
170°E
180°
30°S
0 250 km
H39602 (Male)
Trip 1: Pre-Laying Exodus (45 days)
Trip 2: Incubation (11 days)
160°E
170°E
180°
170°W
30°S
40°S
0 250 km
H44164 (Female)
Trip 1: Pre-Laying Exodus (38 days)
Trip 2: Incubation (20 days)
160°E
170°E
180°
170°W
30°S
40°S
0 250 km