Flesh-footed shearwater population monitoring and estimates: 2020/21 season

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EXECUTIVE SUMMARY

This report covers the findings from the third and final year of flesh-footed shearwater (*Ardenna carneipes*) research under Conservation Services Programme project POP2018-04. Here we report on the ongoing population monitoring of flesh-footed shearwaters on Ohinau and Lady Alice Islands and three updated flesh-footed shearwater population estimates: Coppermine, Whatupuke and Taranga Islands.

During the 2020/21 season we monitored 270 and 290 study burrows on Ohinau and Lady Alice Islands respectively. The breeding success (burrows with an egg that produce a chick that is likely to survive to fledging) on Ohinau Island was 58%, similar to the 62% measured in the 2018/19 season. Breeding success on Lady Alice Island was 48%, which was also similar to the 52% measured in 2018/19. There were no detectable differences in breeding success between study and burrowscope (control) burrows indicating no impact of handler disturbance. We were able to identify 80% of the birds in breeding study burrows on Ohinau Island and 75% in burrows on Lady Alice Island. An additional 315 and 148 flesh-footed shearwaters were banded on Ohinau and Lady Alice Island respectively.

Burrow transects were carried out on Coppermine and Whatupuke Islands to gather data for an updated population estimate each island. Taranga was also surveyed to confirm the presence/absence of flesh-footed shearwaters on the island. We estimate that there are a total of 2,869 (2,142 – 3,597, 95% CI) occupied burrows on Coppermine Island and 1125 (647 – 1,603, 95% CI) occupied burrows on Whatupuke Island. No flesh-footed shearwaters were detected on Taranga and this confirms they are absent from the island.

KEY OBJECTIVES & OUTPUTS

This research was carried out as part of the Conservation Services Programme (CSP), flesh-footed shearwater research project (POP2018-04). The key objectives we were funded by Department of Conservation to complete were (strikethrough text indicates objectives that have been completed; bold text indicates objectives undertaken in the 2020/21 season):

1. ~~To estimate the current population size of flesh-footed shearwaters at Motumahanga Island, Taranaki.~~
2. **To obtain updated estimates of the population size of flesh-footed shearwaters nesting at the Chicken Islands** (~~Lady Alice~~, **Whatupuke and Coppermine Islands**)
3. **To estimate key demographic parameters of flesh-footed shearwater at Lady Alice and Ohinau Island.**
4. ~~To carry out simultaneous tracking of flesh-footed shearwaters at Lady Alice (Hauraki Gulf) and Ohinau Islands (Bay of Plenty) in one breeding season during the incubation and early chick rearing period.~~
5. **To describe the breeding phenology, particularly egg-laying dates at two breeding sites (Lady Alice and Ohinau Islands) to assess if inter-annual and site variation exists.**

Objective 1 was completed in full in the 2018/19 season. Objective 2 was partially completed with the Lady Alice Island population estimate completed in the 2018/19 season (Crowe & Bell 2019). Objective 3 was completed but is an ongoing objective, so is reported here and will be reported on again next season. Objective 4 was completed in 2019/20 and reported on in Crowe (2020). Objective 5 was completed in 2020/21 and is reported on here.

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1. Population Monitoring on Ohinau and Lady Alice Islands

1.1 INTRODUCTION

Flesh-footed shearwaters (*Ardenna carneipes*) breed on islands off the coast of northern New Zealand, Australia and on St Paul Island (Île Saint-Paul) in the Indian Ocean. Populations are thought to be in decline both in New Zealand and globally (Waugh et al. 2013; Lavers 2015). Under the New Zealand threat classification system, the decline of flesh-footed shearwaters has been recognised, and as such the species is now ranked as "Nationally Vulnerable" (Robertson et al. 2017). This decline has been attributed primarily to bycatch in commercial fisheries and recreational fisheries. Flesh-footed shearwaters are reported to be one of the most commonly caught species in New Zealand long-line fishing and are also prone to being caught in trawl fisheries (Robertson et al. 2004; Abraham & Thompson 2011). It is estimated that between 496 and 1,020 flesh-footed shearwaters are killed annually in commercial fisheries (Richard et al. 2020). Looking at the causes of seabird mortality in the Bay of Plenty, Tennyson et al. (2012) found that all fifteen necropsied flesh-footed shearwaters had been killed in fishing-related activities. Most of these deaths were attributed to physical trauma such as broken wings, crushed skulls and stab wounds, while two of the birds contained hooks used in recreational fishing.

While the population of flesh-footed shearwaters on Lord Howe Island in Australia has been relatively well studied (Reid 2010), long-term studies measuring demographic parameters for New Zealand populations of this species have been based on small sample sizes (Barbraud et al. 2014). Long-term studies help with gaining a better understanding of demographic parameters such as adult survival, recruitment, age at first return and age at first breeding. This will consequently help provide more accurate population trends, and thus aid in future management decisions for the species, particularly in light of the myriad threats this and many other seabird species face (Croxall et al. 2012).

The possible decline of flesh-footed shearwaters coupled with a general lack of demographic and population estimates particularly in New Zealand (Taylor 2000), has warranted the establishment of a long-term population study. In addition to this, the need to update old population estimates, or survey islands for which robust estimates do not exist, is fundamental to the conservation management of the species. Two islands in northern New Zealand – Mauimua/Lady Alice Island (hereafter Lady Alice Island) and Ohinau Island - were both identified by Waugh *et al.* (2014) as suitable sites for such long-term studies due to being relatively easy to access and having large colony sizes. Both of these colonies have now been monitored intensively by Wildlife Management International (WMIL) staff for five consecutive seasons from 2016/17 – 2020/21, and this report focuses on the most recent 2020/21 season.

1.2 METHODS

1.2.1 Study Sites and Dates

Ohinau Island

Ohinau Island (Mercury Islands Group, 36.73°S, 175.88°E) is a 43 ha island located off the east coast of Coromandel Peninsula. The island is owned by local iwi, Ngati Hei, and co-managed with the Department of Conservation. There are 12 flesh-footed shearwater colonies on Ohinau Island, of which five contain study burrows (Camp, Camp South, South of Gully, Hilltop and Pohutukawa; Figure 1). These study burrows have been monitored intensively since 2016 (Mischler 2016; Crowe *et al.* 2017; Crowe 2018; Crowe & Bell 2019; Crowe 2020). There are an estimated total of 4,007 (3,044 – 4,791) occupied burrows on the island (Crowe 2018). A team of two personnel was based on the island during the following dates:

- **Trip 1**: 30 November 2020 – 21 December 2020; checking all study burrows to determine breeding status, identify adult birds breeding in all burrows and band/recapture adult birds seen on the surface at night.
- **Trip 2:** 29 April 2021 – 5 May 2021; checking all study burrows to determine breeding success and banding all chicks in burrows.

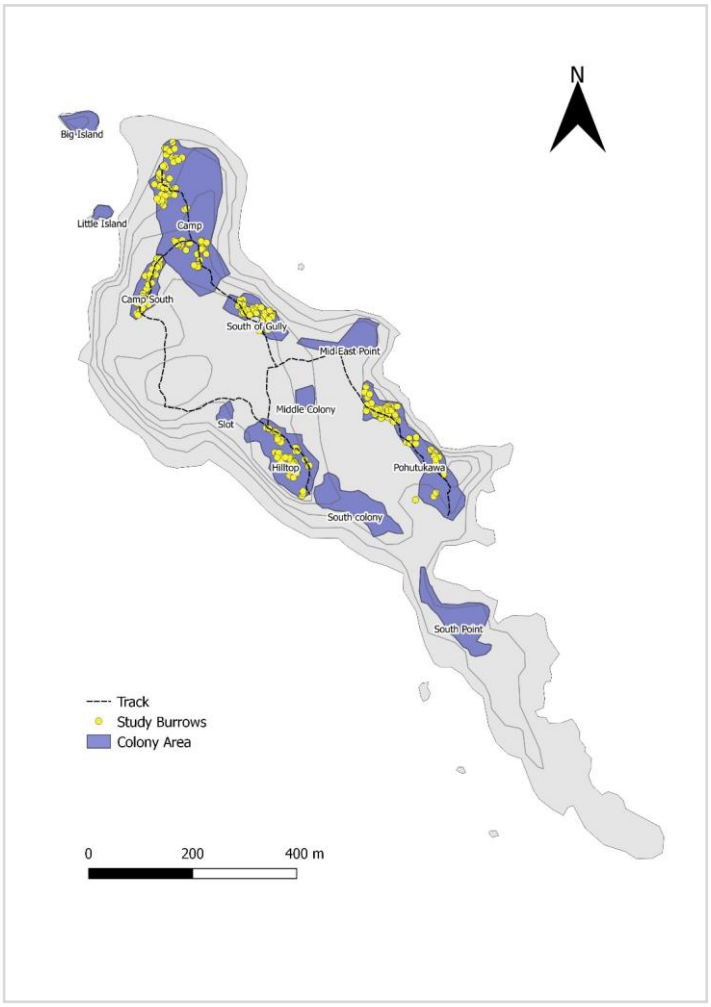

Figure 1 - Map of Ohinau Island showing the location of all flesh-footed shearwater colonies and all marked study burrows.

Lady Alice Island

Lady Alice Island (Hen and Chickens Group, 35.89°S, 174.72°E) is a 155 ha Nature Reserve located 40km southeast of Whangarei (Figure 2). The most recent, accurate population survey estimates a total of 3217 (2180- 4255, 95% CI) occupied flesh-footed shearwater burrows on the island (Crowe & Bell 2019). Seven main colonies on Lady Alice Island have been identified (Figure 3). The current study focused on in the LA1 colony which has been monitored to varying degrees for 13 seasons between 1999 and 2012 and intensively since 2016 (Barbraud *et al.* 2014; Crowe *et al.* 2017; Crowe 2018). A team of two personnel was based on the island during the following dates:

- **Trip 1:** 30 November 2020 – 21 December 2020; checking all study burrows to determine breeding status, identify adult birds breeding in all burrows and band/recapture adult birds seen on the surface at night.
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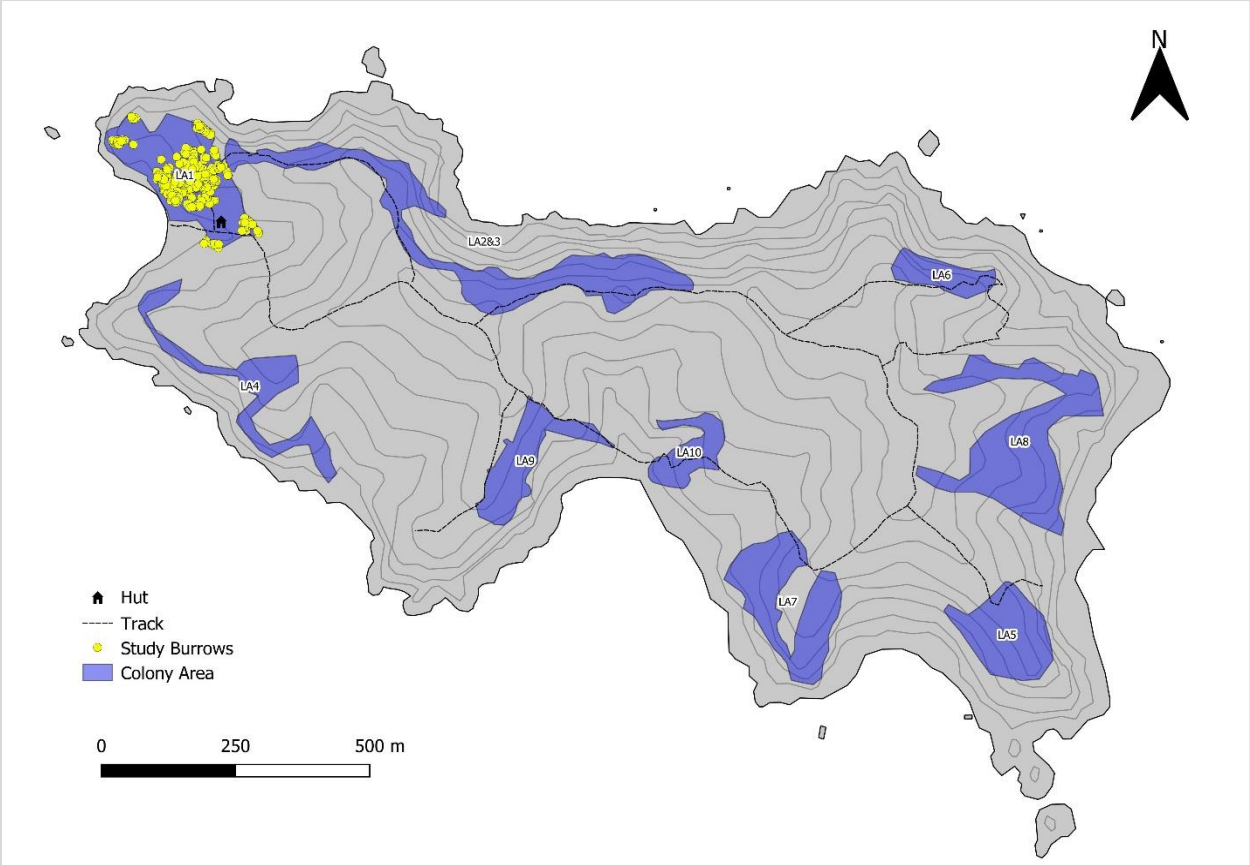

Figure 2 - Map of Lady Alice Island showing the location of study burrows and all known flesh-footed shearwater colonies.

1.2.2 Field Methods

December Trips

Each study burrow was checked every second day from 1 December to 20 December 2020 to determine egg-laying dates. All birds found in these burrows were banded or had their band number checked and recorded. The sex of the bird was determined (or confirmed) by cloacal examination. If sex was determined as male, the laying date was recorded as the day previous, as females typically return to sea quickly after laying, with males taking the first long incubation shift. Birds found in burrows were marked with correction fluid to prevent unnecessary handling during future burrow checks, then placed back in their burrow. To reduce disturbance on incubating birds, mobile phones were held down the burrow to video the occupants and check for correction fluid on the head.

Once an egg was found in a burrow and both partners were banded and identified, the burrow was no longer checked for the duration of the trip. This helped minimise disturbance to the birds and the burrow. Empty and non-breeding burrows were checked all the way up until the day we departed each island.

For burrows that had failed (i.e. due to a broken egg) before we were able to identify both partners, we removed the failed egg and replaced it with a wooden 'dummy' egg. On many occasions this proved to be successful, with the partner bird often found incubating the 'dummy' egg. Once the bird was banded, or had its band number confirmed, the 'dummy' egg was removed.

Burrowscope burrows were checked only once during the trip. This was carried out on 18 or 19 December after all breeding birds were expected to have laid (Bell et al. 2017). The burrowscope was fed down the entrance of the burrow until a bird was seen and then confirmed to be incubating an egg. If no bird was seen after a thorough search, the burrow was recorded as being empty. No hatches were dug in to burrowscope burrows.

Night work was carried out to increase the total number of banded birds and to recapture banded birds. Night work was primarily carried out between 21:00 and 01:00. Adults were caught using a hand-net and were banded, marked with correction fluid and the capture location was recorded.

Māhoe die-off/nightshade growth

During the trip to Ohinau Island in December, we discovered that in some areas of the island, the dominant canopy species māhoe (*Melicytus ramiflorus*) had died off and this had caused nightshade (*Solanum* sp.) to grow in the understory. Most areas with māhoe had some die-off and nightshade growth and some areas, particularly the northwest facing slopes around Camp Colony, had extensive die-off and thick nightshade growth (Figure 3). The māhoe die-off was likely caused by the drought conditions that were experienced in the previous summer (2019/20) in northern parts of the North Island (NIWA 2020). During two 3-week trips in each of January and February 2020, there was zero rainfall on Ohinau Island (P. Crowe pers. obs.).

Figure 3 - The extent of some of the māhoe die-off and nightshade growth in Camp Colony, Ohinau Island, December 2020.

To assess the impact of nightshade growth on breeding, we assigned a rating to each of our study burrows (Table 1). All ratings were discussed and agreed on by both observers. Nightshade rating was assigned to each burrow prior to the first check meaning that we had no prior knowledge of the breeding status of each burrow (breeding, non-breeding or empty). A chi-square test was used to determine if there was any difference in breeding status rates for burrows with different nightshade ratings.

Table 1 - Descriptions of the nightshade rating that each study burrow was given to assess the impact of nightshade on occupancy and breeding success.

Rating	Description
0	Burrow entrance and surrounding area not affected
1	A small amount of nightshade around entrance and surrounding area
2	A moderate amount of nightshade around entrance and surrounding area
3	Burrow entrance and surrounding area completely covered with nightshade

April-May Trips

At the end of April/start of May, both islands were revisited, to check study burrows again. All study burrows were checked, regardless of their status in December. Chicks found in burrows were banded, weighed and had wing length measurements taken, before then being placed back in their burrows. All chicks banded were marked with correction fluid on their head to prevent unnecessary recapture when undertaking night banding. Breeding success is defined here as burrows with an egg that produce a chick that is likely to survive to fledging. Because chicks fledge in early May (Priddel et al. 2006), burrows with chicks during this trip were assumed to have bred successfully. Where possible, the cause of failed breeding attempts was recorded. Empty burrows were checked thoroughly to make sure there was no sign of a chick or egg.

All burrowscope burrows were checked again in the April/May trip. Chicks were extracted where possible by hand or leg hook to be banded and have measurements taken (as above), before being placed back in their burrow. Empty burrows and failed burrows were confirmed using the burrowscope and/or probing the burrow with a stick.

Night work on these trips was primarily aimed at catching any chicks coming out of burrows to exercise and preparing to fledge. Chicks were banded, weighed and had wing length measurements taken. They were also marked with correction fluid and the capture location was recorded. There was no apparent preferred time for chicks to be on the surface, so catching took place at any time after dark. Some adults were still present on the islands at this point and were also captured. Adults were either banded, or their band number taken, marked with correction fluid and released at the same location they were captured.

1.3 RESULTS

1.3.1 Occupancy

Ohinau Island

A total of 270 study burrows were monitored during this season on Ohinau Island (Table 2). This consisted of 261 burrows monitored in the previous season and nine new burrows. Twelve additional burrows were retired because they had collapsed, and had not had any flesh-footed shearwater activity in the previous two seasons.

Of the 270 study burrows, 76% (*n* = 204) were breeding burrows and 12% (*n* = 32) were non-breeding burrows. The remaining burrows were empty or held other species. A total of 80% (327 of 408) of birds in breeding study burrows were identified. We were able to successfully identify both partners for 63% (*n* = 128) of these breeding burrows (Table 2). 35% (*n* = 71) of breeding burrows had only one partner identified while the remaining five burrows (2%) had neither partner identified. Two of these burrows had eggs laid in them but no bird was ever found to be incubating, while the other three had no egg, but ultimately had a chick during the April/May burrow checks, indicating a bird that laid after we had departed the island or another chamber was discovered in April/May.

There was no significant differences in breeding occupancy between the four nightshade rating groups (Pearson Chi-Square, $\chi^2_3 = 5.34$, $p = 0.15$). However, when comparing breeding occupancy rates only for burrows scored with a nightshade rating of zero with those that had a nightshade rating of three, there was a significant difference (Pearson Chi-Square, $\chi^2_1 = 5.13$, $p < 0.05$). On average, 79% of burrows scored with a nightshade rating of zero were occupied breeding burrows compared to just 65% of burrows with a nightshade rating of three (Figure 4). There were no significant differences between any other two groups.

Table 2 - Breakdown of burrow status for all study burrows on Ohinau and Lady Alice Islands 2020/21 season.

Burrow Status	**Ohinau Island**	**Lady Alice Island**
Breeding		
- 0 partners	5	5
- 1 partner	71	72
- 2 partners	128	89
Total breeding burrows	**204**	**166**
Non-breeding		
- 1 bird	21	14
- 2 birds	11	4
Total flesh-footed shearwater burrows	**236**	**184**
Other species		
- Little Penguin		7
- Grey-faced Petrel (chick in Dec)	1	23
- Little Shearwater		2
- Sooty Shearwater		3
Empty	33	71
Total Study Burrows	**270**	**290**
New Retired	12	1
Previously Retired	6	10
Total Retired Burrows	**18**	**11**

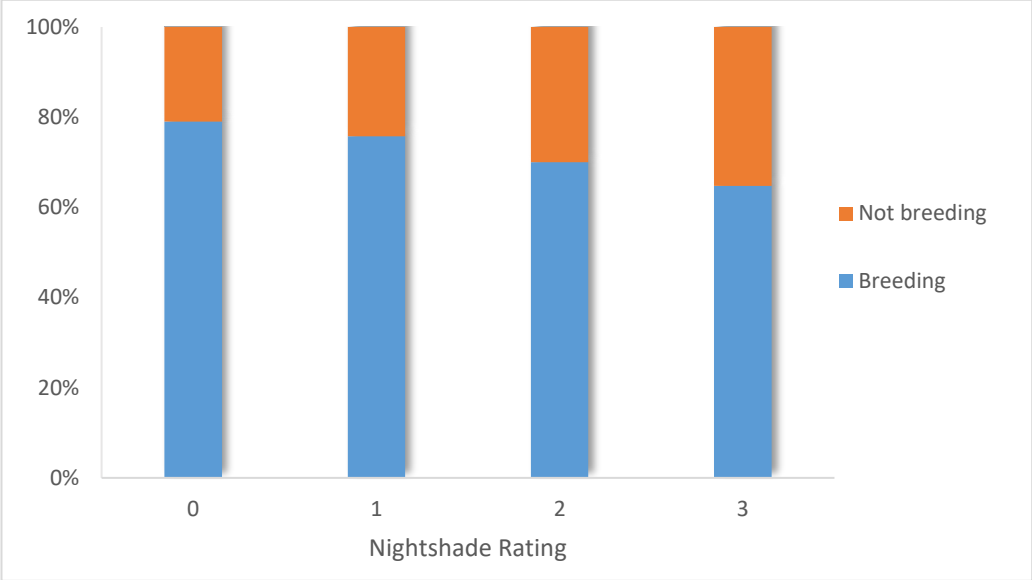

Figure 4 – Comparison of nightshade growth around burrows (nightshade rating) and breeding occupancy on Ohinau Island.

Lady Alice Island

A total of 290 study burrows were monitored on Lady Alice Island this season (Table 1.1). This consisted of 287 burrows monitored in the 2019/20 season, one new burrow and two formally retired burrows becoming active again. One additional burrow was retired because it had collapsed.

Occupancy was low on Lady Alice Island this season with only 54% (*n* = 166) of the 290 study burrows being breeding burrows and 6% (*n* = 18) being non-breeding burrows. The number of true empty burrows (no flesh-footed shearwaters or any other seabird species observed in the burrow) was not much higher this season (24%) compared to the 2019/20 season (23%) whereas the number of other species in study burrows was much higher. Twenty-three of all study burrows (8%) contained a grey-faced petrel chick in December compared to just five burrows (2%) in the 2019/20 season. Little penguin, little shearwater and sooty shearwater numbers were also higher.

A total of 75% (250 of 332) of birds in breeding study burrows were identified. We were able to identify both partners in 54% (*n* = 89) of breeding burrows. 43% (*n* = 72) of breeding burrows had only one partner identified and the remaining 6% (*n* = 5) had no partners identified. These burrows either had a cold egg present with no adults during checks or had no egg but ultimately had a chick during the April/May burrow checks, indicating a bird that laid after we had departed the island.

1.3.2 Breeding Success

Study Burrows

Breeding success for Ohinau Island was 58% (*n* = 118) while on Lady Alice Island it was 48% (*n* = 79). The difference in breeding success between the two islands was significant (Pearson Chi-Square, χ^2_1 = 3.86, p = 0.05). It appears more burrows failed during the incubation stage rather than the chick-rearing stage on both islands, however, there is a large degree of uncertainty, as the cause of burrow failure could not be determined in the majority of cases (Table 3).

Table 3 - Summary of breeding outcomes for study burrows and burrowscope burrows on Ohinau and Lady Alice Islands

	Ohinau		**Lady Alice**	
	Study Burrows (*n*= 270)	**Burrowscope (*n* = 41)**	**Study Burrows (*n* = 290)**	**Burrowscope (*n* = 43)**
Breeding Burrows	204	33	166	34
Breeding success	118 (58%)	23 (70%)	79 (48%)	19 (56%)
Failed, pre-hatching	27 (13%)	0 (0%)	11 (7%)	0 (0%)
Failed, post-hatching	11 (5%)	1 (3%)	4 (2%)	2 (6%)
Failed, unknown reason	48 (24%)	9 (27%)	72 (43%)	13 (38%)

There was no difference in breeding success between the groups with different nightshade ratings (Pearson Chi-Square, χ^2_3 = 2.13, p = 0.55; Figure 4). There were also no differences between any two particular groups.

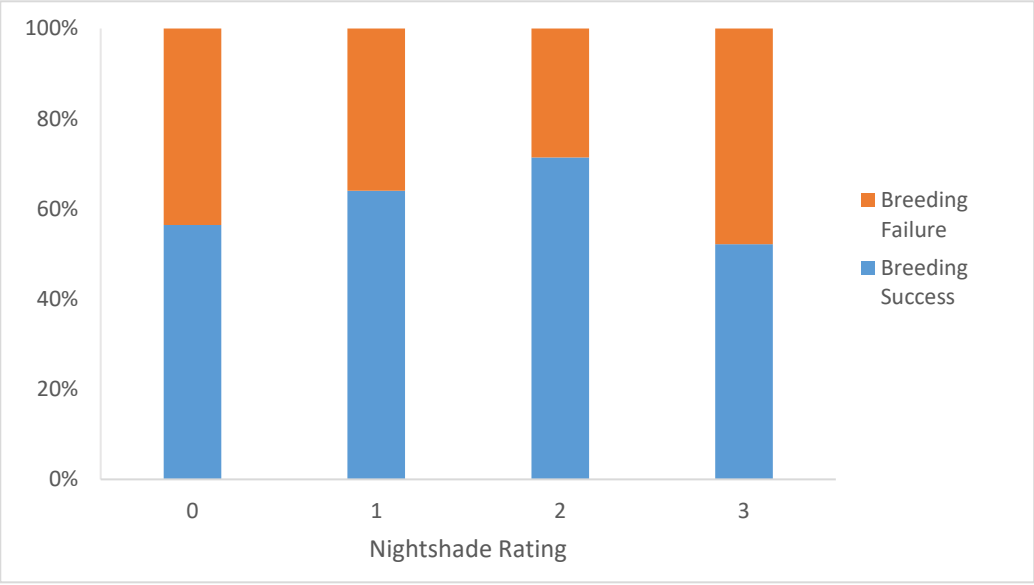

Figure 5 - Comparison of nightshade growth around burrows (nightshade rating) and breeding success on Ohinau Island.

The average breeding success for all burrows combined (study and burrowscope) since 2016 is 59% for Ohinau Island and 51% for Lady Alice Island. Breeding success has been higher on Ohinau Island in all seasons apart from the 2016/17 season when it was marginally lower (Figure 6).

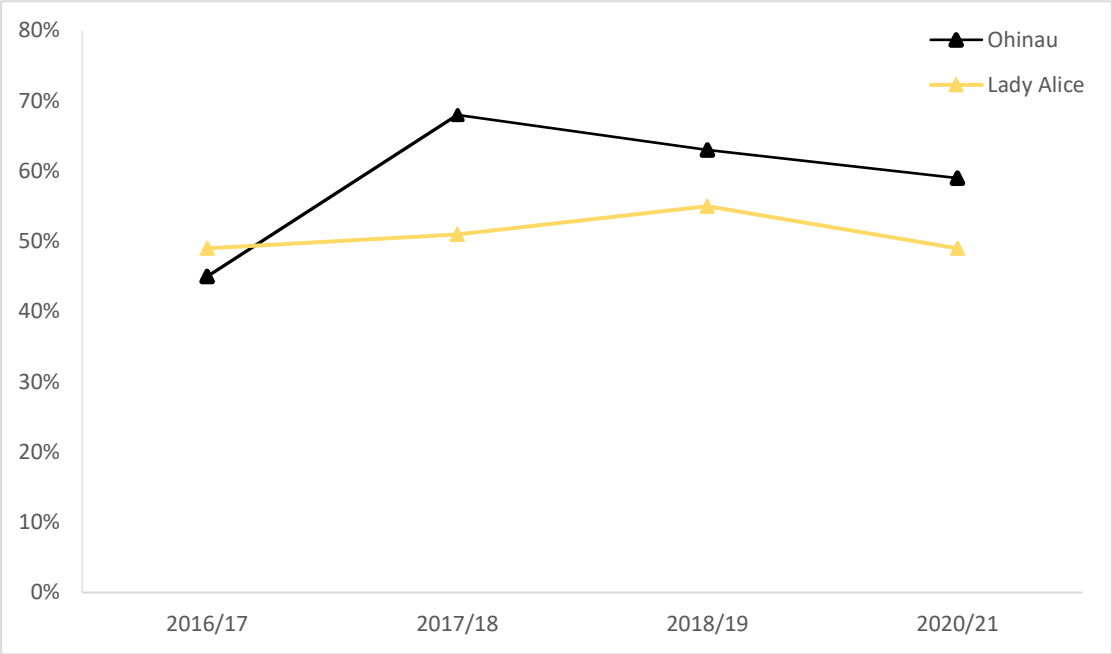

Figure 6 - Breeding success for all burrows (study and burrowscope combined) for Lady Alice and Ohinau Islands since 2016/17. Breeding success was undetermined for the 2019/20 season.

Burrowscope Burrows

Breeding success in Ohinau Island burrowscope burrows was 70% compared to 58% in study burrows, however, this difference was not significant indicating that there is little or no impact of handler disturbance (Pearson Chi-Square, $\chi^2_1 = 1.65$**,** $p = 0.19$). On Lady Alice Island, breeding success in burrowscope burrows was 56% compared with 48% in study burrows (Pearson Chi-Square, $\chi^2_1 = 0.78$, $p = 0.38$).

1.3.3 Egg-laying dates

Of the 204 breeding burrows on Ohinau Island we were able to determine the egg laying dates of 195 burrows (96%). We were able to determine the laying dates of the same percentage of burrows (96%; 159 of 166) on Lady Alice. As our trip to Ohinau Island during the 2018/19 season occurred in December also, we inherently determined the egg laying dates of the study burrows and so they are included here in the analyses for comparison. During December 2018 on Ohinau Island we determined the egg laying dates of 192 of 209 (92%) study burrows.

Egg laying is highly synchronised both within and between islands and between seasons (Figure 7). The first egg on Lady Alice Island was laid on 2 December and on Ohinau Island on 3 December. The last egg on Ohinau Island was laid on 18 December and on Lady Alice on 19 December. In 2018 on Ohinau Island, one bird laid on the 20 December. There is an indication that some birds lay after 20 December as some burrows with no egg in December ended up having a chick (typically a very downy chick) present in April/May, however this number is likely to be very small.

Egg laying peaks between 8 and 12 December with over 50% of all eggs laid over the course of those 5 days on each island. Over 90% of eggs are laid over the 12 day period between 5 and 16 December. For the 2020/21 season, both islands peaked on 10 December with 13% of all eggs being laid on this day.

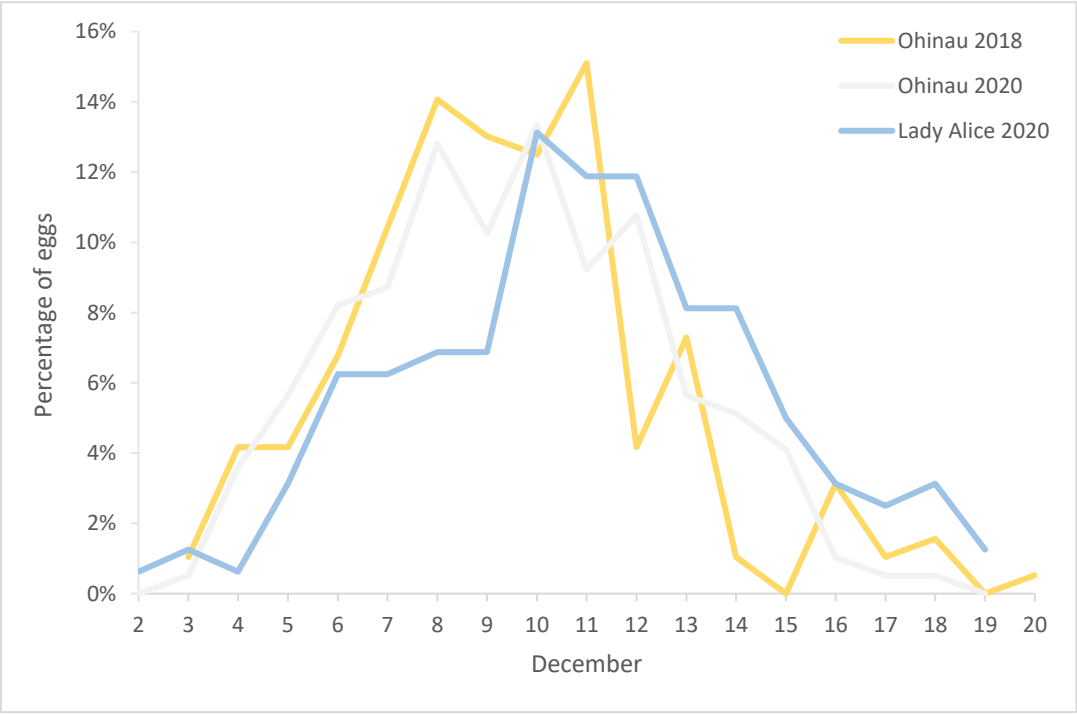

Figure 7 - Egg laying dates on Lady Alice and Ohinau Islands for the 2020 Season. Laying dates on Ohinau Island in 2018 are included here in the analyses for comparison.

1.3.4 Banded Birds

During the 2020/21 season, 148 birds were banded on Lady Alice Island and 315 birds were banded on Ohinau Island (Table 4). In total, 3875 flesh-footed shearwaters have been banded across both islands during this study.

Table 4 - Number of flesh-footed shearwaters banded on both islands in the past six seasons.

Ohinau	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	Total
Adult	90	528	182	210	470	188	1668
Chick	267	133	131	453	0*	127	1111
Total	357	661	313	663	470	315	**2779**

Lady Alice	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	Total
Adult	0	285	163	102	118	38	706
Chick	0	94	83	103	0*	110	390
Total	0	379	246	205	118	148	**1096**

No April/May trip to band chicks prior to fledging due to COVID-19

Total birds banded during study	**3875**

1.3.5 Recaptured Birds

On Ohinau Island, 76% (*n* = 247) of banded birds identified as breeding this season were also breeding in 2019/20. Of these birds, 94% (*n* = 232) were found breeding in the same burrow, while the remaining 6% of birds (*n* = 15) were breeding in a different burrow. The fifteen birds consisted of five pairs and five individual birds shifting burrows. Previous seasons have shown that only 1% or 2% of birds move burrows on Ohinau Island (Crowe & Bell 2019; Crowe 2020). The māhoe die-off/nightshade growth likely contributed to more birds shifting burrows with 60% of shifting birds' former burrows being scored a three on the nightshade rating scale.

In all cases of birds shifting burrows, they only moved to a nearby burrow, usually within 10m of their previous burrow. However, some birds have been known to move 50m between burrows previously (G. Taylor pers. comm.). No individuals have been recorded moving between colonies on the same island at any time in this study.

On Lady Alice Island, 71% (*n* = 186) of banded birds identified as breeding this season were breeding last season. Of these birds, 88% (*n* = 164) were found breeding in the same burrow, while 12% (*n* = 22) of breeding birds were breeding in a different burrow. Both of these results are similar to the previous season where 72% of all birds bred in consecutive seasons and 10% of these birds shifted burrows.

A total of 789 (193 chicks, 596 adults) flesh-footed shearwaters were banded between 2000 and 2009 on Lady Alice Island (Andrea Booth unpublished dataset; Barbraud et al. 2014). Of these, 10% (*n* = 19) of chicks and 15% (*n* = 92) of adults have been recaptured in the previous five seasons on Lady Alice Island. There were no new recaptures of any of the 789 birds this season. Thirty-eight of the 111 recaptures were birds that were banded as adults in 2000. Sixteen of these birds were recaptured during the 2020/21 season, making these birds at least 26 years old now. The oldest known-age birds breeding in the colony on Lady Alice Island are two birds banded as chicks in 2000 making these birds 21 years old.

Of the 1480 adults that had been banded on Ohinau Island as part of this study from 2015-20, 46% (*n* = 680) have been recaptured again. For Lady Alice Island the result is higher with 63% (*n* = 430) of the 680 banded adults having been recaptured.

Two birds that were banded as chicks as part of the 2015/16 Ohinau Island cohort were recaptured this season. This is in addition to the five that were caught in the previous (2019/20) season. One bird has been caught both years. The age at first return of these two birds is five years old. Both of these birds were recaptured on the surface at night-time and both were in the same colonies that they fledged from and mostly within the same immediate area as their natal burrow. In total, 2.6% (*n* = 7) of the 267 chicks banded on Ohinau Island in 2015/16 have been recaptured so far.

No chicks from the 2016/17 cohort on either Ohinau or Lady Alice Island were recaptured this season.

Management of Records of Banded Birds, Study Burrows and Transect Data

Copies of the field records of all newly banded birds during our trips and any previously banded birds have been deposited with the Marine Species and Threats team, Department of Conservation, Wellington. Banding schedule records have also been sent to the National Bird Banding Scheme managed by Department of Conservation, Wellington.

A list of all study burrows tagged on both islands and the GPS locations of each site, plus maps and relevant photos, have been deposited with the Marine Species and Threats team, Department of Conservation.

1.4 DISCUSSION

1.4.1 Occupancy

The number of study burrows currently being monitored is at a suitable number and, provided occupancy rates remain approximately the same, few burrows will need to be added in future seasons to maintain a sample of 200 breeding burrows per island. Occupancy rates were lower on Lady Alice this season and we suggest that the reason for lower occupancy on Lady Alice Island was due to a larger number of study burrows being occupied by other seabird species. The decision was made not to add additional study burrows to get to the target of 200 breeding study burrows as the number (currently 290) in the network of study burrows is normally sufficient to get to that target. This will be monitored in forthcoming seasons and, if necessary, additional study burrows will be added. Burrows that have collapsed, are continually occupied by a different species, or remain inactive for multiple seasons, will be retired.

Occupancy rates on Ohinau Island remained relatively stable and 200 breeding study burrows was achieved with adding only a handful of new burrows. This was a surprising result as a large number

study burrows on Ohinau Island were significantly impacted by the māhoe die-off/nightshade growth and these burrows showed a lower occupancy rate. However, occupancy as a whole across the entire island remained similar to previous seasons.

Ohinau Island had a higher percentage of breeding birds shift burrows this season (6% cf. 1-2% in previous seasons) which was possibly due to the nightshade growth making it difficult or impossible for birds to get to their previous burrows and so choosing to occupy another nearby burrow. We observed many birds on the surface at night time in December amongst the nightshade and most were not on the ground but instead suspended up in the nightshade. Historically, Lady Alice Island has always had a much higher percentage (10-12%) of breeding birds shift burrows when compared to Ohinau Island. This is likely to be a result of the LA1 colony on Lady Alice Island being more heterospecific with other seabird species often occupying study burrows and causing more flesh-footed shearwater pairs to shift to a nearby burrow.

1.4.2 Breeding Success

On Ohinau Island, breeding success this season was 58%, down from the 62% measured in the 2018/19 season and 68% measured in the 2017/18 season. While it is slightly lower, breeding success is still within a range that would be expected for this species in a predator-free environment. On Woody Island, Western Australia, breeding success for flesh-footed shearwaters was measured as 40% and 53% for two consecutive seasons (Powell *et al.* 2007). Priddel *et al.* (2006) observed a 50% breeding success rate during the 2002/03 breeding season on Lord Howe Island, Eastern Australia. Reid *et al.* (2013) incorporated data from the literature with their own field studies on Lord Howe Island, and estimated breeding success for the 2008/09 season to be 60%. Both Lord Howe and Woody Islands have Ship Rats (*Rattus rattus*) present which are known to predate the eggs and young of several species of burrowing Procellariiformes (Moors and Atkinson 1984).

The breeding success on Lady Alice was only 48% which is the lowest measurement in study burrows since the study began in 2016/17. It is, however, only 4% lower than the highest measurement of breeding success on Lady Alice Island (52% in 2017/18 and 2018/19) and as such is a fairly typical measurement of breeding success. Breeding success has been considerably lower than Ohinau Island for the majority of seasons, and lower than would be expected for this species in a predator-free environment. Previous seasons have had notable climate-related explanations such as floods or La Niña seasons which may have impacted birds breeding on Lady Alice Island to greater degree than those breeding on Ohinau Island. Grey-faced petrels are likely to cause at least some breeding failures on Lady Alice, but this factor is equally, or more pronounced, on Ohinau Island. Only one of our study burrows with grey-faced petrels present in April contained a flesh-footed shearwater chick. Many grey-faced petrels were observed on the surface at night time on both islands, and there was evidence of chicks having been killed by them. Grey-faced petrels are known to evict the unguarded chicks of flesh-footed shearwaters when they arrive to clean out burrows in April (Barbraud *et al*. 2014, Waugh *et al*. 2014).

On both islands there are a small percentage of burrows (typically <2%) that have a chick present in April/May that had no egg in December. It is assumed that birds breeding in these burrows laid after we departed the island prior to Christmas, however, it is also possible that some or all of the chicks present in these burrows had actually been displaced from their natal burrow by a grey-faced petrel or other seabird. Going by the assumption that these birds laid after our departure, there are also an unknown number of birds that lay after we depart the islands in December but fail (and leave no evidence of a breeding attempt) prior to our visit in April/May. This is a limitation of only having two

visits to the island per breeding season but is pertinent only to when the summer visits is in December. As all birds are expected to have laid by the end of December, field trips to the islands in January should not be subject to this limitation and any chick found in a burrow that did not have an egg in January can be assumed to have been displaced from a different burrow.

Breeding success observed in burrowscope burrows was not significantly higher to that observed in study burrows on both islands. However, this marks the second consecutive season where breeding success measured in burrowscope burrows has been 8% or higher than in study burrows on both islands including 18% on Lady Alice Island in 2018/19 (Crowe 2019). We believe that this indicates that there is possibly some impact of handler disturbance and anecdotal evidence of birds (P. Crowe *pers. obs.;* G. Taylor *pers comm.*). This warrants further investigation and increasing the sample size of burrowscope burrows (see Section 4) will give greater statistical power to detect true differences in the breeding success of study and burrowscope burrows. As birds have to be handled to record band numbers, our handling impact cannot be avoided but we will aim to minimise disturbance as much as possible by using phones to check for changeover/marked birds, only handling birds when we need to, and for as short a period of time as possible. Any use of breeding success estimates in population modelling should use the burrowscope measurements as these are likely to be more representative measurements of breeding success for the population as a whole.

Flesh-footed shearwater pairs breeding in burrows with no nightshade growth were no more likely to succeed in their breeding attempt than those more impacted by nightshade growth. Hand-pulling of weeds from around study burrows in December likely contributed to this as it allowed birds to more easily access their burrows. However, during the trip to Ohinau Island in April/May we arrived to discover that the areas cleared of nightshade had been replaced with dense growth of inkweed (*Phytolacca octandra*). The inkweed likely started growing from January onwards and would have had the greatest impact on birds during chick-rearing. The best explanation for why this did not significantly impact breeding success is that birds were able to adjust and had figured out how to get to their burrow as the inkweed grew. The area that we cleared around the study burrows back in December also remained slightly more open than surrounding areas and this likely gave birds a slight path to their burrows (D. Burgin pers. obs.).

1.4.3 Egg-laying Dates

Egg laying for flesh-footed shearwaters is between 2 and 20 December and peaks between 8 and 12 December with over 50% of all eggs laid over the course of those 5 days on each island. The first egg laid at the Bethells Beach flesh-footed shearwater colony in 2020 was 3 December (G. Taylor pers. comm.). All of these results are practically identical to Bell *et al.* (2017) who recorded egg-laying between 3 and 19 December in 2016 on both Ohinau and Lady Alice Islands. Bell *et al.* (2017) reported peak laying on 10 December which was the same result here in 2020 for both islands. These results show that egg-laying for flesh-footed shearwaters in New Zealand is highly syncronised and very little variation exists between islands and between breeding seasons.

1.4.4 Banded Birds

A total of 315 birds consisting of 188 adults and 127 chicks were banded on Ohinau Island this season. The number of adults banded has remained consistently high across all seasons with most birds encountered on the surface at night-time being unbanded. The majority of birds caught at night-time

on Ohinau Island are caught on or just off the main track which goes up through Camp Colony. Most birds encountered in existing study burrows are already banded.

The number of newly banded adults on Lady Alice Island has diminished slightly and this is because the majority of the birds encountered in study burrows, or on the surface at night time, are now banded. A total of 110 flesh-footed shearwater chicks were banded from the LA1 colony this season which represents the highest total banded in a single cohort for the island. Most of these birds came from study burrows or random burrows within the colony and very few chicks were encountered on the surface at night time.

1.4.5 Recaptured Birds

One of the main aims of the December trip was to focus effort at the start of the trips on recapturing birds on the surface at night time. Previous trips to these islands just prior to the commencement of egg laying have proved highly successful with large numbers of breeders and non-breeders encountered on the surface at night-time. The result this season was the opposite with very few birds seen and caught during this same period. The reason for the lack of birds at this time this season is unknown. The majority of the birds encountered on the surface at night-time came towards the end of the trip (14-19 December) which seemed to coincide with the first incubation changeover.

Discrepancies between total recapture rates of banded adults (surface- and burrow-caught) on both islands most likely has two contributing factors. Firstly, a larger percentage of birds are banded on the surface on Ohinau Island. Surface banded birds have a lower recapture probability as they have a higher proportion of young and non-breeding birds who are more transient than burrow-caught birds (Barbraud et al. 2014). Secondly, all banding and recapturing effort on Lady Alice Island is concentrated within one relatively small area (the LA1 colony) whereas, on Ohinau Island, effort is spread over the island through multiple colonies.

The proportion of chicks banded between 2000 and 2009 that have returned to Lady Alice Island (10%) is very similar to the 8% return rate reported by Bell *et al.* (2016) in the black petrel population on Aotea/Great Barrier Island over a 20-year period. While this estimate of recruitment is extremely low and suggests a low juvenile survival rate, it is based on a small sample size and is probably a reflection of the detectability of returned chicks, more so than survival. Three percent (n = 7) of chicks from the first cohort (2015/16) of the current study have now been recaptured on Ohinau Island. All of these individuals are most likely non-breeders as they have all been caught on the surface at night-time.

No birds from any later cohorts have been recaptured on either island yet, but this was partly expected as birds do not generally start to return to their natal colonies until an average of 6 years old (Barbraud *et al.* 2014). We anticipate that a larger number of birds from the 2015/16 cohort and a smaller number from later cohorts will be recaptured in the forthcoming seasons. An even smaller number of these may be detected breeding within the study burrows.

2. Population Estimates for Coppermine, Whatupuke and Taranga/Hen Island

2.1 INTODUCTION

There is a strong need to update older population estimates for flesh-footed shearwaters and survey islands for which robust estimates do not exist in order to ascertain the decline of flesh-footed shearwaters in New Zealand (Taylor 2000). This is fundamental to the conservation management of the species. During the 2020/21 season population estimates were undertaken on the remaining Marotere/Chicken islands; Mauipa/Coppermine (hereafter Coppermine), Whatupuke and Taranga/Hen (hereafter Taranga) Island, to update previous estimates calculated (Baker et al. 2010).

2.2 METHODS

2.2.1 Study Sites and Dates

Coppermine Island

Coppermine Island (Chickens Group, 35.89°S, 174.77°E) is an 80 ha Nature Reserve directly east of Whatupuke Island. The most recent, accurate population survey carried out in 2008 and 2009 estimated a total of 1425 (1059-1791 95% CI) occupied flesh-footed shearwater burrows on the island amongst four colonies, all situated on the western half of the island (Figure 8; Baker *et al.* 2010). A team of two personnel was based on the island from 12 to 16 January 2021.

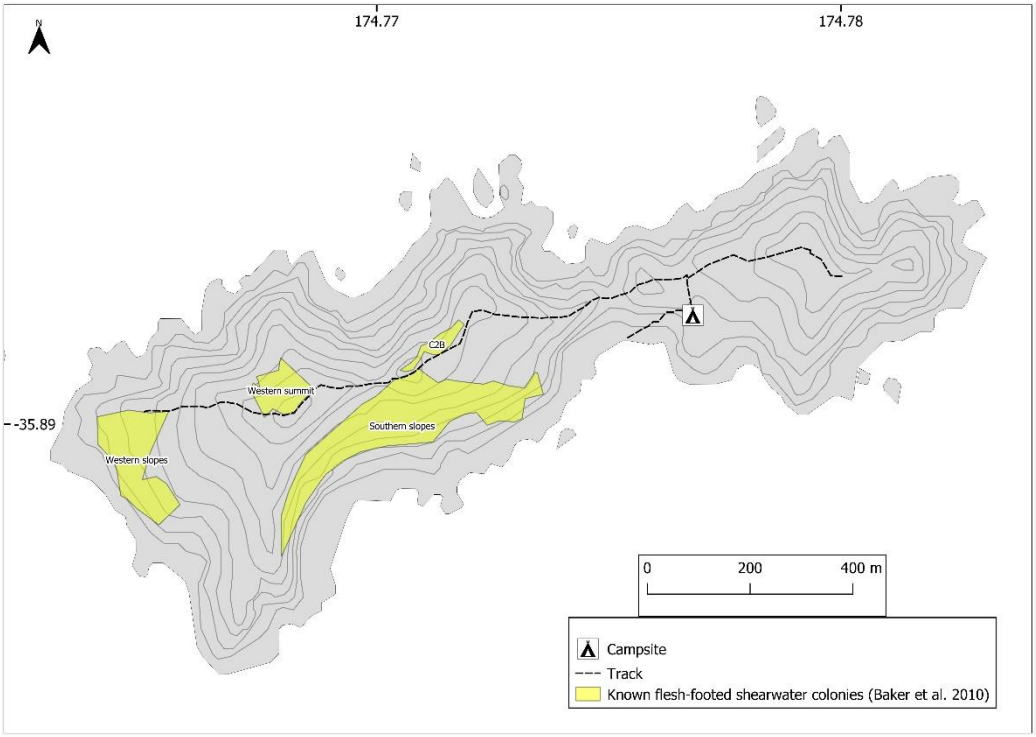

Figure 8 - Map of Coppermine Island showing the size and location of all known flesh-footed shearwater colonies prior to the population estimate presented here.

Whatupuke Island

Whatupuke (Chickens Group, 35.89°S, 174.75°E) is a 102 ha Nature Reserve directly east of Lady Alice Island. The most recent, accurate population survey in 2008 estimated a total of 1,210 (36 – 2384, 95% CI) flesh-footed shearwater burrows on the island (Baker *et al.* 2010). There were three known flesh-footed shearwater colonies on the island with the vast majority (1012; 573-1452 95% CI) of those being in the Eastern Slopes colony (Figure 9; Baker *et al.* 2010).

A team of two personnel was based on Whatupuke between 16 and 22 January 2021.

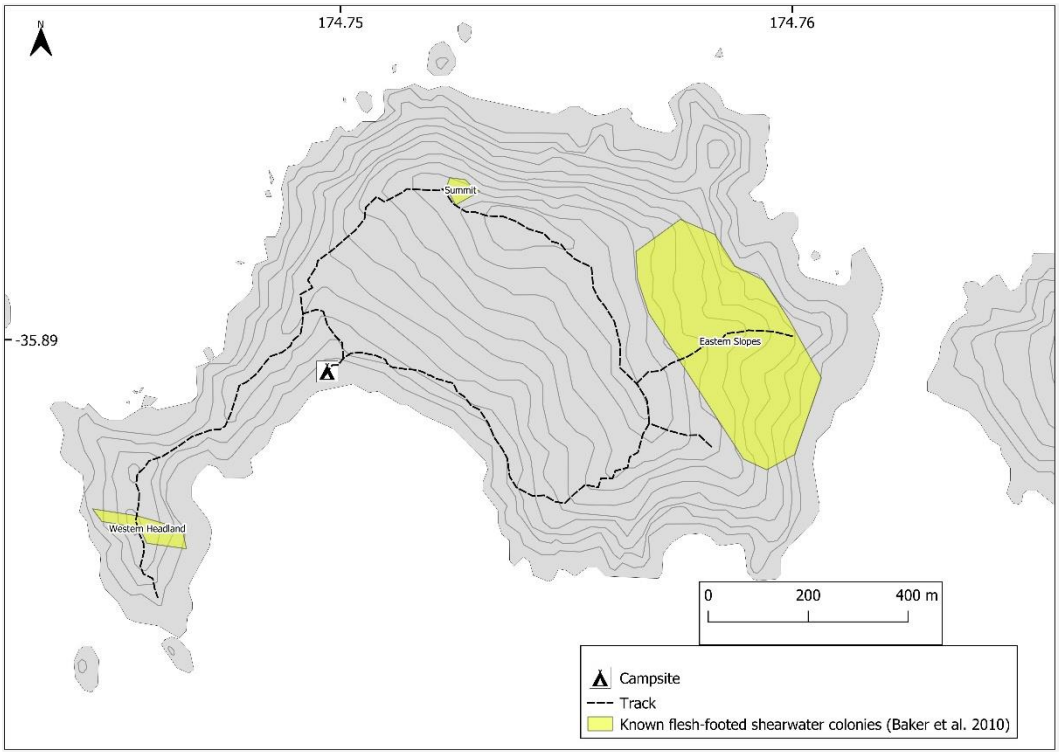

Figure 9 - Map of Whatupuke Island showing the size and location of all known flesh-footed shearwater colonies prior to the population estimate presented here.

Taranga Island

Taranga (Hen and Chickens Group, 35.96°S, 174.72°E) is a 475 ha Nature Reserve located approximately approximately 40km southeast of Whangarei and 7km south of the Chicken Islands. Together they are colloquially known as the Hen and Chicken Islands. There are no known flesh-footed shearwater colonies on the island (Figure 10). During historic surveys of Taranga, there have been very few or no flesh-footed shearwater burrows detected (Skegg 1964; Waugh *et al.* 2013).

A team of two personnel was based on the island from 22 to 28 January 2021.

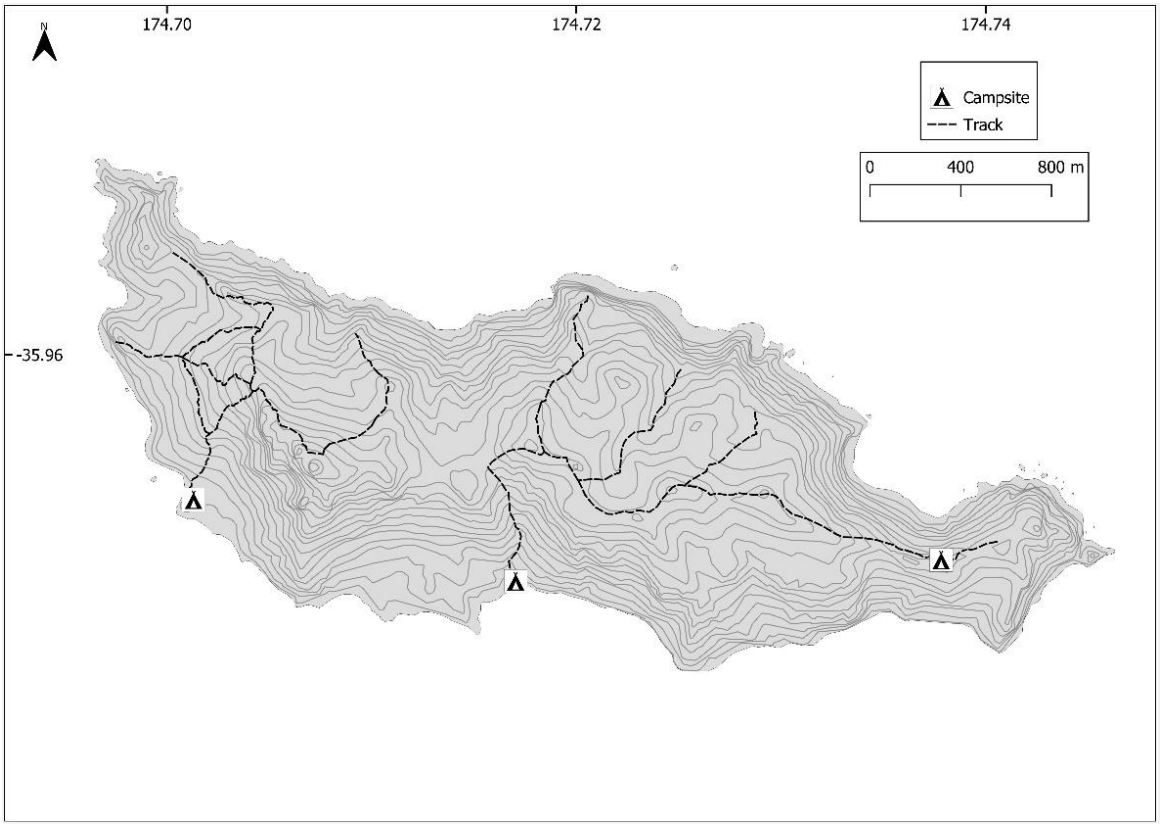

Figure 10 - Map of Taranga Island showing the locations of campsites and access tracks.

2.2.2 Field Methods

Coppermine and Whatupuke

Transect start points and bearings (transect direction) were randomly generated using QGIS version 3.16 within known flesh-footed shearwater colonies on Whatupuke and Coppermine Islands based on colony boundaries mapped by Baker *et al*. (2010). A tape was run out for 30 m from the start point on the generated bearing. The same method was used as described in Bell & Boyle (2017) for Middle Island, Ohinau Island (Crowe 2018) and Lady Alice Island (Crowe & Bell 2019). Burrows were searched for in a 2 m strip to the right hand side of the tape i.e. each 30 m transect covered 60 m^2. Following Waugh *et al.* (2003) and Baker *et al.* (2010) burrows were classified by the size of the entrance (small or large), with large burrows defined as burrows >20 cm long, with an entrance size >14 x 8 cm. A sample of burrows within each colony were burrowscoped to determine the contents of each burrow and generate an occupancy estimate for each colony. In most cases this was either all burrows encountered on transects or at least 30 burrows. Great care was taken when examining burrows to accurately determine the contents of each burrow. The species, breeding status, presence/absence of tuatara and any other observations were recorded. If the observer could not confidently determine the contents (or lack thereof) of the burrow then it was recorded as unknown and was excluded from the occupancy estimation. A single person carried out each transect but each transect was walked two or three times to ensure counts were accurate and no burrows were missed.

A number of areas on Coppermine and Whatupuke were highlighted as “search areas” that we deemed to potentially have flesh-footed shearwater colonies. Potential colony areas were identified by examining aerial photographs, topographic maps and literature searches especially of historic visits to the islands. We then conducted ground searches in these areas looking for highly-burrowed areas.

Searches yielded two additional flesh-footed shearwater colonies on Whatupuke and one on Coppermine. On Whatupuke we were able to generate (following the above methodology) and conduct a number of transects within these colonies while on Coppermine, time restrictions meant we were not able to conduct transects, and as such the burrow density and occupancy rates for this colony (Northern Slopes) were assumed from what we considered to be the most similar colony which was the Western Summit. A number of burrows in the Northern Slopes colony were burrowscoped to confirm there were flesh-footed shearwaters present and breeding in burrows within the colony.

The boundaries of all colonies were mapped using a Garmin 64st hand-held GPS. To calculate the surface area of each colony, an eight metre resolution Digital Elevation Model (DEM) was downloaded from the LINZ Data Service website and a slope raster layer was created. A spatial join between each mapped colony polygon and the slope raster then calculates the average slope in radians within that colony. The 3D surface area for each colony is then calculated as:

[3D] Surface Area = [2D] Planimetric Area / cosine (Slope Angle in radians)

This is the same method used in Cuthbert (2019) to calculate colony areas for Hutton's shearwater.

Mean burrow density and 95% confidence interval for each colony was calculated using the transect data and multiplied by the 3D surface area to give an estimate of the total number of burrows in each colony. The measured occupancy rate for each colony was then applied to give an estimate of the total number of occupied flesh-footed shearwater burrows within that colony.

Taranga Island

With no known flesh-footed shearwaters colonies on Taranga Island, the methodology for surveying the island was different to that of Whatupuke and Coppermine. Flesh-footed shearwaters are very vocal at night-time both in flight over breeding grounds and on the ground at colonies, consequently much of the survey work focused on listening out for birds calling at night-time. Listening for birds was undertaken from good vantage points along the main ridge of Taranga that looked down over the spurs and valleys below. Counts were conducted from dark (generally about 20:30) until approximately 01:00. All species heard were recorded along with counts or estimates for each species at 30-minute intervals.

Ground searches for burrows were also conducted during the daytime in areas where we had either heard seabirds calling during a previous night's survey or in other areas that we deemed as potentially good habitat. Potential habitat was determined from historic records of flesh-footed shearwaters on the island, aerial photos, vegetation type (especially māhoe and taupata) and from information provided by local DOC staff. Any burrowed areas found were mapped and all burrows within the area were burrowscoped to determine what species was occupying each burrow.

Both of the established DOC campsites are on the southern side of the island down by the coast and most field work/research carried out on the island is conducted from one of these two base camps. Therefore, we invested most of our time listening and searching for flesh-footed shearwaters on the northern side and eastern end of the island.

2.3 RESULTS

2.3.1 Coppermine Island

We carried out a total of 99 thirty-metre transects across four colonies on Coppermine Island between 12 and 15 January 2021. One additional colony was found meaning there are now five known colonies on Coppermine (Figure 11). All transects were 30m long with the exception of four transects that had to be shortened due to steep and unsafe terrain. A further eleven transects were abandoned because of steep and unsafe terrain or because they fell outside of colony boundaries.

Occupancy rates were fairly consistent across the colonies, but burrow density was highly variable (Table 5). For this reason we stratified data into colonies and extrapolated the burrow density and occupancy data to get a population estimate for each colony. The population estimate for all colonies on Coppermine is 2869 occupied burrows (2142 – 3597, 95% CI).

A description of each colony is provided below and a summary of all transect data can be found in Table 5.

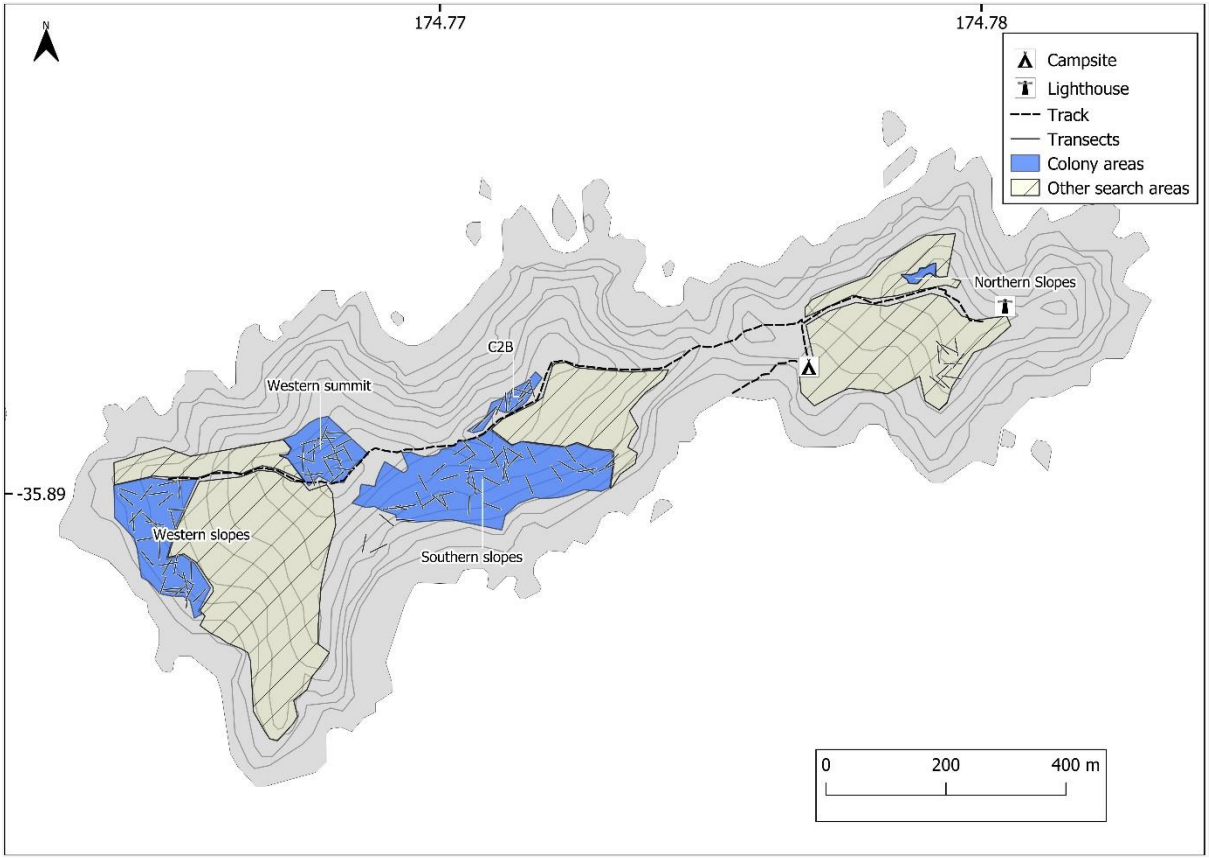

Figure 11 - Map of Coppermine Island showing the current extent of flesh-footed shearwater colonies as mapped in 2021, additional areas searched and locations of transects.

Western Slopes

A moderate-sized colony at the western end of the island facing towards Whatupuke Island. Burrows appear mainly in clusters, especially at the southern end, with only scattered burrows in between clusters. We found the colony area mapped by Baker *et al.* (2010) to be very accurate, apart from a small area to the southwestern end of the colony that we mapped no burrows and therefore deemed not part of the colony. The northern and southern boundaries are well-defined by small ridgelines.

Fairly open understory with main vegetation being pohutukawa, puriri, māhoe and karaka. The colony runs close to the coastline in places and ends where the bush become scrubby in other places.

No other seabird species were detected in any of the burrows that were burrowscoped.

Western Summit

A fairly dense colony that runs from the main ridgeline down to the north where the terrain drops off steeply. The colony is comprised mainly of māhoe with emergent pohutukawa. At the bottom (north) end where the terrain drops steeply, it is mainly taupata scrub with large pohutukawa. The terrain was too steep and soil to loose and friable to search safely, but burrows may continue down below the mapped boundary. The eastern boundary is sharply defined, and burrows stop where the forest turns to kaunuka.

No other seabird species were detected in any of the burrows that were burrowscoped.

C2B

This colony is by far the most densely burrowed colony on Coppermine Island. It is on the north-facing slopes running from the ridgeline down to a steep drop-off. We could not safely explore below the drop-off, but it appeared there were at least some burrows below. The soil is very loose in places and the colony as a whole is fragile. The vegetation is short, dense taupata scrub and māhoe, most of which had died off making the colony quite weedy (see section 1.2.2 Māhoe die-off/nightshade growth above). Flesh-footed shearwater occupancy was the highest recorded on Coppermine Island (58%).

One burrow was occupied by a breeding sooty shearwater.

Southern Slopes

The largest colony on Coppermine Island. The colony runs from the main ridge, or from a bluff just below the ridge down close to the ocean or where terrain becomes too steep. The top (north) half of the colony consisted primarily of puriri and māhoe while the bottom (south) half is dominated by pohutukawa. Burrows are relatively dense across the whole colony but are most numerous at the top end of the colony. The eastern end of the colony ends where the vegetation turns scrubby. The west and southwest boundaries of the colony end where the terrain turns very steep and to bluffs. Baker *et al.* (2010) had the colony stretching far to the southwest to the next ridge, however, our groundtruthing showed the colony did not go this far. Forty percent of burrows checked were occupied by breeding flesh-footed shearwaters which was the lowest occupancy measured in a colony on Coppermine Island but is still a relatively high measure.

One burrow was occupied by a breeding Pycroft's petrel.

Northern Slopes

A small, north facing colony at the eastern end of the island. This colony was found when searching for additional colonies that had not been previously reported. The colony is located just below where the forest changes from kanuka to pohutukawa and above the coastal cliffs. It is a relatively open burrowed area. A number of burrows in the Northern Slopes colony were burrowscoped to confirm there were breeding flesh-footed shearwaters present but time restrictions meant we were not able to conduct transects. As such the burrow density and occupancy rates for this colony (Northern Slopes) were assumed from what we considered to be the most similar colony which was the Western Summit.

Other search areas

Two areas searched by Baker *et al.* (2010) named C1 (eastern end of island near the lighthouse) and C2A (between Southern Slopes and C2B) were also searched by us and showed up very few or no

burrows. We carried out 10 transects in a section of the C1 search area that Baker *et al.* (2010) found a small number of burrows and these transects yielded only one burrow (Figure 12).

We also searched the ridge and surrounding area between the southern and western slopes colonies which turned up no burrows. Any areas that were safely accessible by foot at the eastern end of the island around the campsite and lighthouse were also searched with no burrows found.

2.3.2 Whatupuke Island

We carried out a total of 120 thirty-metre transects across five colonies on Whatupuke Island between 16 and 21 January 2021 (Figure 12). Twenty of these transects ultimately were excluded from the analysis because they ended up falling outside of the mapped colony areas. Thus 100 transects were included in the analysis. All transects were 30m long with the exception of four transects that had to be shortened due to steep and unsafe terrain.

Burrow density was variable and occupancy rates were highly variable across the colonies (Table 5). For this reason we stratified data into colonies and extrapolated the burrow density and occupancy data to get a population estimate for each colony. The population estimate for all colonies combined on Whatupuke is 1125 (647 – 1603, 95% CI) occupied burrows.

A description of each colony is provided below and a summary of all transect data can be found in Table 5.

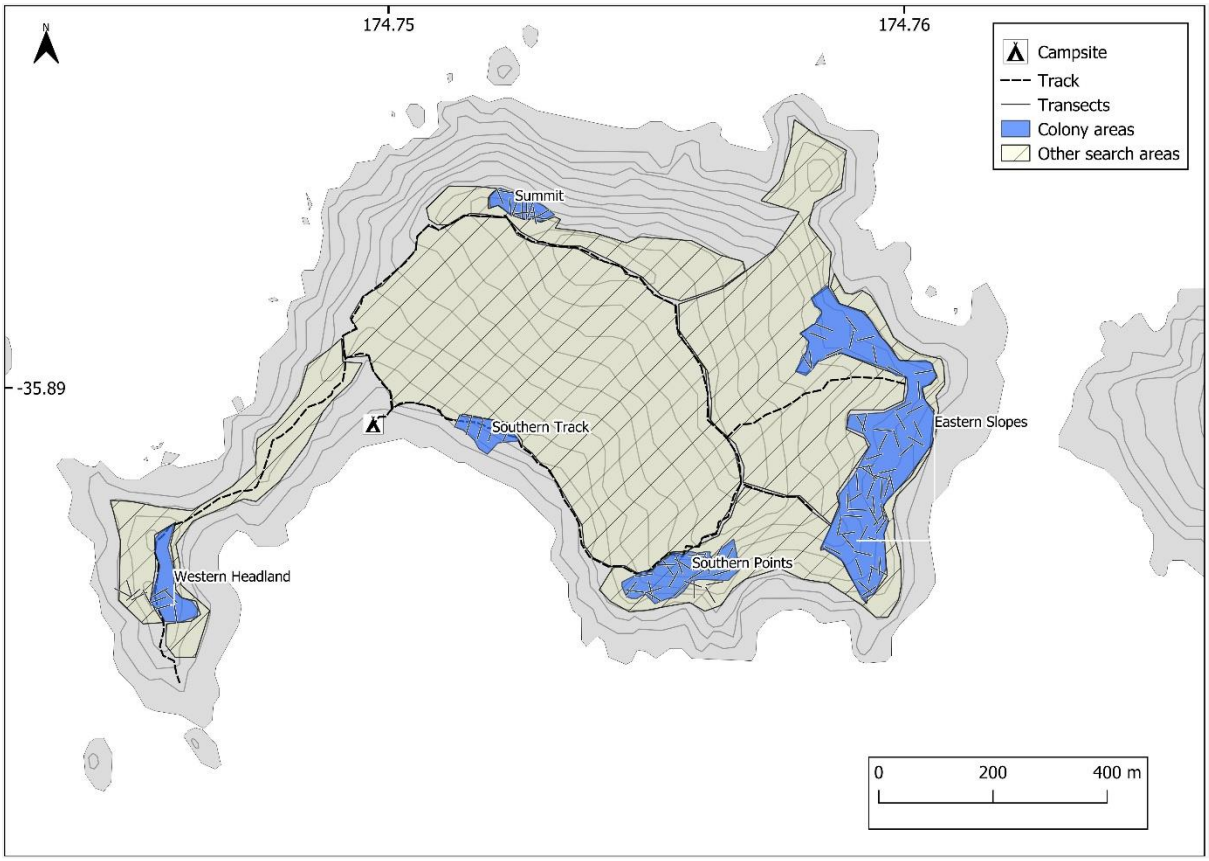

Figure 12 - Map of Whatupuke Island showing the current extent of flesh-footed shearwater colonies as mapped in 2021, additional areas searched and locations of transects.

Summit

A small, fairly densely burrowed colony on the north facing side of Whatupuke. Mainly pohutukawa and taupata scrub. Soft soil and steep terrain making the colony very fragile. The northern boundary is dictated by where we could safely traverse. Some burrows could be seen below this, but it turns to near vertical cliffs not long after this.

Baker *et al.* (2010) had the summit colony running from the ridge down to an arbitrary steep area. We discovered that there were no burrows in this flat area along the ridge and burrows only begun where the terrain became steeper and soil became more suitable for burrowing. The majority of our original random transects missed the actual colony so the colony was remapped and new transects generated. Any original transects that landed within the newly mapped colony were still included in the analysis to increase the sample size.

No other seabird species were detected in any of the burrows that were burrowscoped.

Western Headland

This is a small colony on the east facing slopes of the western headland. The colony stretches from the ridgeline down to where terrain becomes unsuitably steep. The vegetation is primarily pohutukawa and is quite rocky in places. Baker *et al.* (2010) had mapped the colony going up and over the ridge to the western side of the island also. We found that there were no burrows on western side and this side consisted of kanuka and a quite dense understory of Gahnia which is usually unsuitable for burrowing. Occupancy was measure at 53% which was the highest on the island and burrows were in moderate-density.

There were also a few scattered burrows along the isthmus leading out to the headland but not significant enough to warrant inclusion in the colony.

No other seabird species were detected in any of the burrows that were burrowscoped.

Eastern Slopes

Eastern Slopes is the largest colony with approximately half of all occupied flesh-footed shearwater burrows on Whatupuke Island. We found burrow density and occupancy to be fairly low but the total area of the colony means it houses the largest number of flesh-footed shearwaters. Burrows are present mainly in clusters with only scattered burrows in between clusters. Clusters were primarily just down from any small ridges or spurs in the colony and also in patches where māhoe was the dominant tree species.

The colony area mapped by Baker *et al.* (2010) had the colony going much higher up towards the ridge and further to the north. We found these areas to be either kanuka forest with dense undergrowth of gahnia or nikau palm forest, both of which usually result in unsuitable burrowing substrate. We did find it stretched further to the south than what was mapped by Baker *et al.* (2010). The eastern boundary of the colony is defined primarily by where the terrain becomes too steep for burrowing.

Five percent (n = 6) of burrows were occupied by other seabird species with four of these being Pycroft's petrels and two sooty shearwater.

Southern Points

This was one of two new colonies found that had not been previously identified as a colony. The colony is of moderate size and there are a large number of burrows within this colony, but occupancy rate is low and therefore only 145 flesh-footed shearwater pairs are estimated to breed in this colony.

The colony is between two spurs on the south-facing slopes at the southern end of the island. Most of the area is relatively open forest. Burrows are present mainly in clusters with only scattered burrows in between clusters. Clusters were primarily just down from any small ridges or spurs in the colony.

Four percent (*n* = 3) of burrows were occupied by other seabird species with two of these being Pycroft's petrels and one sooty shearwater.

Southern Track

This was the second of two new colonies found that had not been identified as a colony during the previous estimates. The colony is on the south facing slopes not far from the Whatupuke campsite and is intersected by the southern coastal track. It is very similar structure to the southern point's colony – open understory and fairly densely burrowed but low occupancy of flesh-footed shearwaters.

This colony was discovered on our last day on the island so time restrictions meant we did not carry out randomised transects. Instead we ran five 30m transects north-south at approximately 20m spacing across the colony.

One burrow was found to contain a fluttering shearwater chick.

Other search areas

The south face of Whatupuke encompassed by the loop track is the largest and most obvious area that we searched for other flesh-footed shearwater colonies. Baker *et al.* (2010) named this area W1A and carried out transects that yielded very few burrows. We also found only a very small number of burrows in this area, all of which were checked and were either empty or contained tuatara.

As mentioned above, the eastern slopes colony was re-mapped and all accessible areas around the colony were searched for burrows. The small headland to the northeast end of the island is accessible from the eastern slopes colony and we searched around this area for burrows. This area is mainly pohutukawa and more open areas with flax. There are a few scattered burrows (of which a few burrowscoped contained breeding flesh-footed shearwaters) but no concentrations or clusters of burrows and so we deemed this area not significant enough to warrant being a colony.

Areas along the northern and western ridges that were safe to traverse were searched and we found that most of these areas were thick vegetation with few or no burrows. The majority of the northern and western sides of Whatupuke are too steep to safely search on foot but are unlikely to support any significant number of flesh-footed shearwater.

Table 5 – Summary of transect data and population estimates for all colonies on Coppermine and Whatupuke Islands.

Island	Colony	Dates Surveyed	Area sampled (m^2)	Large burrows counted	Burrow density (burrows/m^2)	No. Burrows burrowscoped	Occupancy Rate	Colony Area (m^2)	Estimated Occupied Burrows	Lower 95% CI	Upper 95% CI
Coppermine	**Western Slopes**	*14 January 2021*	1778	76	0.043	41	0.50	21514	460	292	628
	Western Summit	*12 January 2021*	1200	105	0.088	53	0.50	11189	490	366	613
	C2B	*12, 14 January 2021*	548	84	0.153	26	0.58	3097	274	191	357
	Southern Slopes	*13, 15 January 2021*	2340	174	0.074	60	0.40	53623	1609	1266	1952
	Northern Slopes*	*15 January 2021*	-	-	0.088	-	0.50	847	37	28	46
Whatupuke	**Summit**	*16, 21 January 2021*	626	42	0.067	40	0.51	4368	150	59	242
	Western Headland	*18 January 2021*	300	18	0.060	18	0.53	6793	216	43	388
	Eastern Slopes	*17, 19-21 January 2021*	3450	140	0.041	130	0.25	58003	579	431	727
	Southern Points	*19 January 2021*	1232	79	0.064	79	0.16	14297	145	94	195
	Southern Track	*21 January 2021*	300	20	0.067	20	0.11	4992	35	20	50
	*No transects carried out in this colony. Burrow Density and Occupancy Rate assumed from the structurally similar colony, Western Summit										
	Coppermine Total	***12-15 January 2021***	**5866**	**439**		**180**		**90270**	**2869**	**2142**	**3597**
	Whatupuke Total	***16-21 January 2021***	**5908**	**299**		**287**		**88453**	**1125**	**647**	**1603**

2.3.3 Taranga/Hen Island

With no known flesh-footed shearwater colonies on the island we did not carry out randomised transect sampling. Instead, we focussed on night work listening and looking out for seabirds coming in at night time. We spent six nights out on Taranga/Hen Island listening from various vantage points. Five of the six points were along the main ridge and covered the entire north face of Taranga/Hen Island plus Stead Bay on the western side of the island (Figure 14). The remaining listening spot (number 6) was from the coast at Wahine Campsite and covered part of the south-facing slopes.

All listening spots were great vantage points with most overlooking multiple ridges/valleys/faces. We found that sound travelled very well up these valleys and we were able to detect birds calling from all the way down near the coast (Figure 13). All nights were calm except 24 and 26 January when there was a gusty southwest wind. Most nights were also clear and well-lit by a 2/3 moon – full moon so some seabirds could also be seen circling over the island.

During all night listening, no flesh-footed shearwaters were heard (Table 6). Also, notably, no sooty shearwaters were heard. Pycroft's petrel were observed at all listening sites with a maximum count in any half-hour period of four birds. Fluttering shearwater were observed at three listening sites but a maximum of one bird seen or heard during a 30-minute period. At listening spot 3 we had a fluttering shearwater land next to us and enter an otherwise unoccupied burrow. From the campsite and fly camps along the ridge we were able to hear along the south-facing slopes. One little shearwater was heard at the far Eastern camp site.

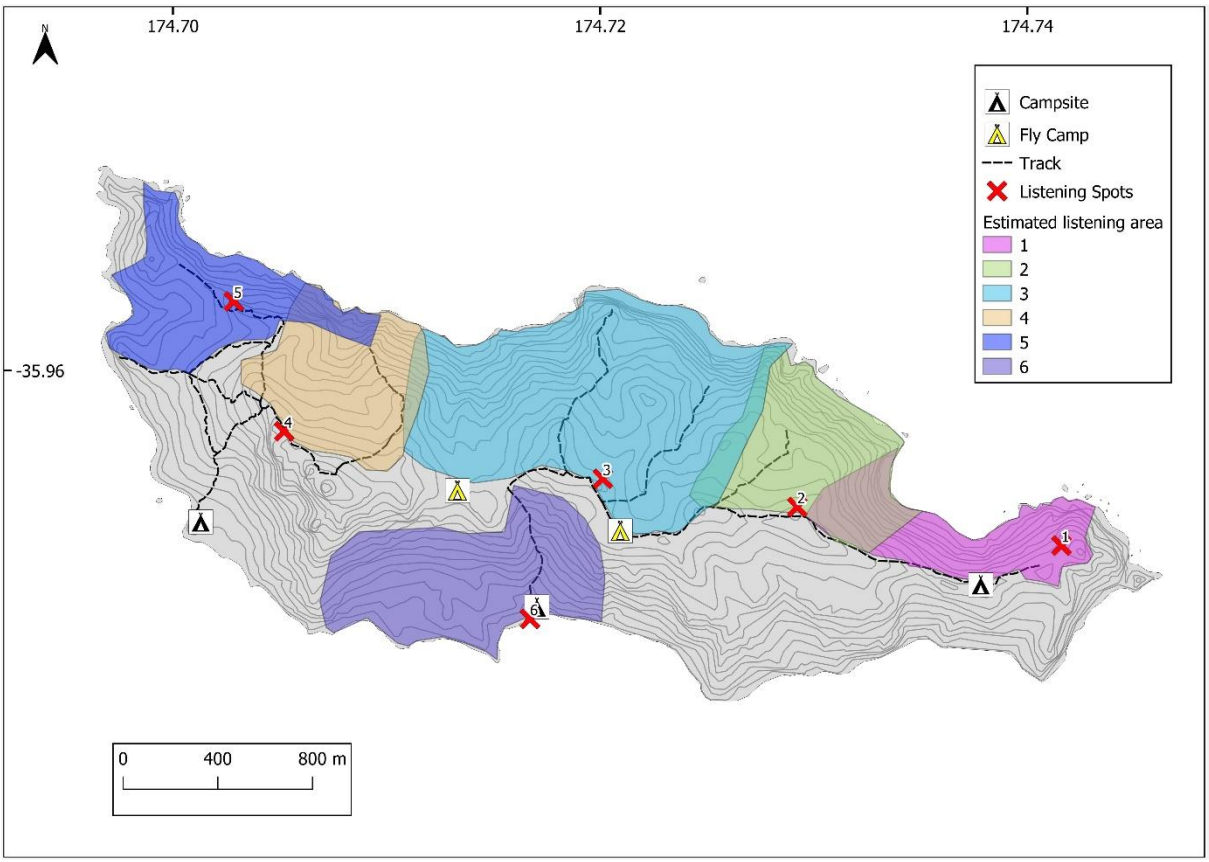

Figure 13. Map of Taranga/Hen Island showing campsites and listening spots. Shaded areas indicate the estimated area covered from each of the listening spots. Note that there is some overlap in estimated areas covered from listening points and this is indicated by areas of slightly darker shading.

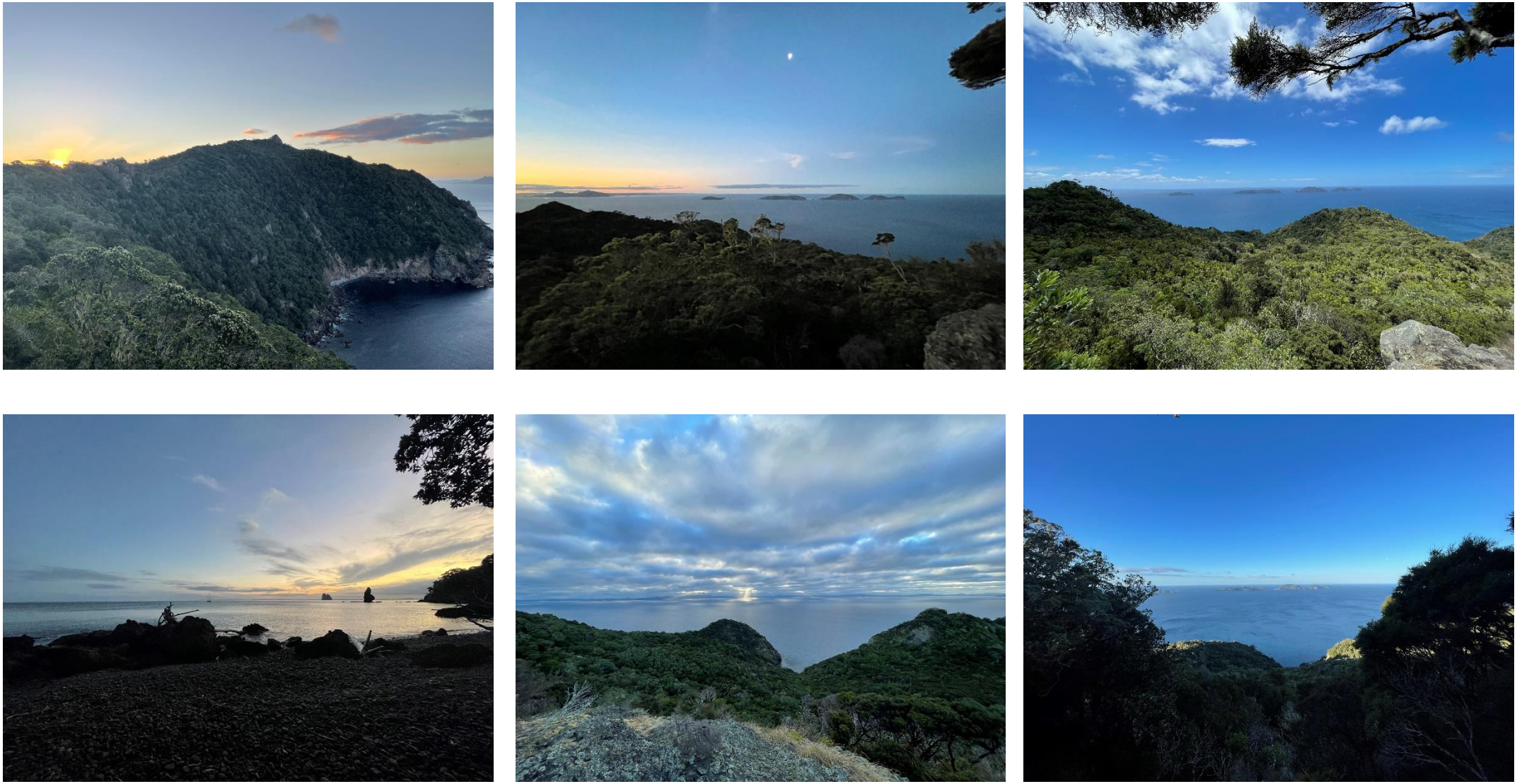

Figure 14 - Photos from the six night count listening locations. Clockwise from top left: (1) looking west from the eastern-most high point; (2) looking north towards the chicken/marotere islands; (3) from Baldy's knob looking north towards the chicken/marotere islands; (4) looking north from listening spot near balancing rock; (5) looking west from Moran Lookout; and (6) looking south from Wahine beach/campsite.

Table 6 - Results from the night-time bird counts on Taranga Island. Figures shown are the maximum count recorded on any 30-minute count throughout the night.

Listening Spot	Date	Flesh-footed shearwater	Pycroft's Petrel	Fluttering Shearwater	Little Spotted Kiwi	Morepork	Kaka
1	22/01/2021	0	1	0	1	3	3
2	23/01/2021	0	2	0	3	3	3
3	24/01/2021	0	2	1	3	4	4
4	25/01/2021	0	3	1	2	3	3
5	26/01/2021	0	3	0	4	4	4
6	27/01/2021	0	4	1	2	0	1

Ground searches for burrows were also conducted during the daytime in areas where we had either heard seabirds calling during a previous night's survey or in other areas that we deemed as potential good habitat. Ground searches turned up several burrowed areas across the island as well as dead and live birds (Figure 15). However, no flesh-footed shearwaters were found in any burrows. Where possible we tried to determine what was likely to occupy the burrows, but the vast majority of burrows checked were found to be empty with no evidence of any seabird. Three small colonies along the main ridge we deemed to be grey-faced petrel colonies while one colony at the eastern end of the island was determined to be a mix of fluttering shearwater and grey-faced petrel. A single Pycroft's petrel burrow containing a young chick was found at the eastern end of the island near this colony. Two Pycroft's petrel adults were found on the surface at night-time at the western end of the island. These birds were seen while walking back to our campsite after night counts. One dead little shearwater chick was found near our fly camp in the middle of the island.

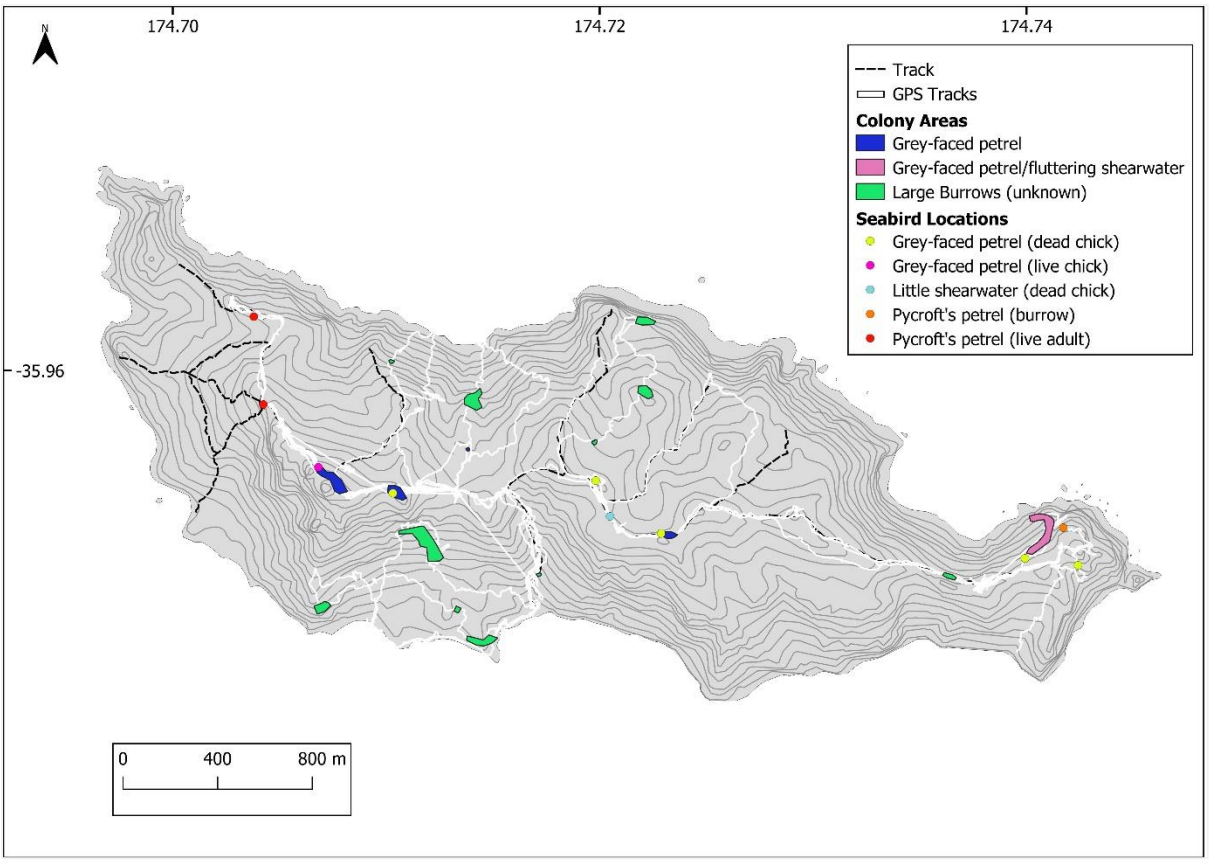

Figure 15 - Map of Taranga showing the area covered during daytime ground searches, mapped areas of any colonies found, and locations of dead and live seabirds found.

2.4 DISCUSSION

We have designed the survey methodology to reduce potential errors following recommendations from Wolfaardt & Phillips (2013), and Parker & Rexer-Huber (2015). A random sampling design within known colonies was used to remove any sample bias. The open nature of the forest floor in colonies on Coppermine and Whatupuke, and using two experienced observers walking and counting burrows on transects multiple times, removed errors around burrow and occupant detection probability, as well as observer bias. The surveys were carried out as early as logistically possible in January, after egg laying was complete (Bell et al. 2017). As such, errors around estimating burrow occupancy would have been low, with only burrows failing during early incubation and retaining no sign of a failed breeding attempt being misidentified as a non-occupied burrow.

2.4.1 Coppermine Island

The population estimate presented here for Coppermine Island is twice as large as the previous estimate carried out by Baker *et al.* (2010). The primary reason for the discrepancy between the current estimate and the Baker *et al.* (2010) estimate is simply the total area calculated for each of the colonies. For example, the area we calculated for the southern slopes colony was 53,623m² compared to Baker *et al.* (2010) who calculated it as 13,529m². We calculated the three-dimensional surface area for all colonies to extrapolate transect data as opposed to using the two-dimensional

calculations. As most of the flesh-footed shearwater colonies are on steep terrain, the three-dimensional approach is more applicable and gives a more accurate estimate.

Unlike estimates on Ohinau, Lady Alice and Whatupuke Islands where we found discrepancies in the mapped colony areas, we found the colony areas mapped by Baker *et al.* (2010) for Coppermine Island to be very similar to what we mapped this season (Crowe 2018; Crowe & Bell 2019). There did not appear to be any retraction or expansion of colonies on the island. The only significant change was in the Southern Slopes colony where we found that the colony did not stretch as far to the southwest as previously mapped. Baker *et al*. (2010) did not run transects in this area and we discovered that this whole area was near-vertical rocky bluffs that would harbour very few or no burrows so excluded it from the mapped colony. We also found burrow density and occupancy measurements across all colonies to be remarkably similar between the two studies. This suggests that there has not been a true increase in population but instead a sampling/analysis-related increase.

2.4.2 Whatupuke Island

Unlike all other recent flesh-footed shearwater population estimates, the estimate presented here for Whatupuke Island (1125 [647 – 1603, 95% CI] occupied burrows) is very similar to the previous estimate by Baker *et al.* (2010) of 1210 (36 – 2384, 95% CI) occupied burrows. This is despite identifying two previously unknown colonies at the south end of the island. The primary reason for a similar total estimate here is that we found the largest colony, eastern slopes, to be significantly smaller than previously thought. The area mapped by Baker *et al.* (2010) for the eastern slopes colony was found to be an overestimate with much of the upper (western) section of the previously-mapped colony containing no burrows and being unsuitable burrowing habitat. We found a discrepancy for all colony areas mapped by Baker *et al* (2010) compared with what we found on the ground in 2021. This is in contrast to Coppermine Island where we found the colony boundaries to be remarkably similar to the previous estimate thirteen years ago. We also found that our measure of burrow density was higher for most of the colonies on Whatupuke and this is due to better defined colony boundaries that exclude areas of very few or no burrows. Occupancy rates between the two estimates were comparable. We suggest the reason for differences in burrow density and colony areas is the amount of effort spent on each island during the surveys between 2008 and 2009. Baker *et al*. (2010) spent only two days on Whatupuke compared with 17 days spent on Coppermine.

Large numbers of burrows with low occupancy rates in the three colonies at the southern and eastern end of Whatupuke (southern track, southern point and eastern slopes) suggest that these are primarily the colonies of a different seabird species. All three of these had some summer-breeding species (Pycroft's petrel, sooty and fluttering shearwater) but the majority of burrows were empty which suggests that a winter-breeding species such as grey-faced petrel may occupy these burrows in the winter and spring. It is estimated that more than 5000 pairs of grey-faced petrels occupy Whatupuke (Taylor 2000). This is similar to what we have found on Lady Alice Island where flesh-footed shearwaters seem to occupy colonies on the western and northern sides of the island while grey-faced petrels primarily occupy the southern and eastern sides (Crowe & Bell 2019).

2.4.3 Taranga Island

The majority of the seabird surveys and studies on Taranga Island have focused on the western and southern sides of the island, so our focus was to predominantly cover the eastern and northern sides of the islands. Most of Taranga Island is very steep and inaccessible on foot, with this in mind undertaking night work to listen for calling flesh-footed shearwaters was a useful method as we are confident that if flesh-footed shearwaters were present in the areas we surveyed we would have

detected them. On our trips to Coppermine and Whatupuke in the days prior to visiting Taranga Island, flesh-footed shearwaters (and occasional Pycroft's petrel, little and fluttering shearwaters) could be heard calling in flight over the islands all night every night, and these calls were distinctly lacking on Taranga Island.

Ground searches for burrows also confirmed the absence of flesh-footed shearwaters on the island. While we located the occasional patch of burrows on Taranga Island, the vast majority of these were empty in January. As such, Taranga Island appears to be a breeding grounds for species breeding earlier in the year, namely grey-faced petrel, little shearwater and fluttering shearwater.

It appears that the small population that may have been present in the 1960s (Skegg 1964) is no longer present and as such the population of flesh-footed shearwaters on Taranga Island should be considered zero.

3. POP2018-04 Review and Summary

Here we provide a brief summary of the outputs from the previous three seasons of project POP2018-04: flesh-footed shearwater research. This has been broken down into three main objectives: population monitoring; tracking and; population estimates. Note that this project was a continuation of POP2015-02: flesh-footed shearwater various locations populations project and so some information is also presented from that project. Further details can be found within previous annual reports.

3.1 POPULATION MONITORING

Since the 2018/19 season, between 250 and 300 study burrows have been monitored on Ohinau and Lady Alice Islands. This number of study burrows has generally been sufficient to get at least 200 breeding burrows and record a robust estimate of occupancy and breeding success. In addition to the study burrows, at least 30 breeding burrowscope (control) burrows have been monitored each season to record the impact (if any) of handler disturbance on breeding success. The average breeding success for all burrows since 2016 is 59% for Ohinau Island and 51% for Lady Alice Island. During the past two seasons, there has been a suggestion of handler disturbance causing decreased breeding success, therefore the measurement of breeding success of burrowscope burrows should be used as the quotient for any population modelling as these are more representative measurements of breeding success for the population as a whole.

Since 2015/16 a total of 2779 flesh-footed shearwaters (1668 adults and 1111 chicks) have been banded on Ohinau Island and 1096 (706 adults and 390 chicks) on Lady Alice Island. Only seven birds banded as chicks have been recaptured so far. All seven of these birds were banded as part of the first (2015/16) Ohinau Island cohort. Five were recaptured during the 2019/20 season and two during the 2020/21 season making the age at first return of these birds four and five years respectively.

The egg-laying dates of flesh-footed shearwaters were determined for Ohinau and Lady Alice Islands in December 2016 and December 2020 as well as Ohinau Island only in December 2018. The results of these analyses show that flesh-footed shearwaters lay between 2 and 20 December with peak laying from 8 – 12 December. Egg-laying is highly synchronised within colonies, between colonies and between breeding seasons.

3.2 GPS TRACKING

During the 2019/20 season, breeding flesh-footed shearwaters were tracked simultaneously on Ohinau and Lady Alice Islands during the incubation and chick-rearing stages. On Ohinau Island, GPS devices were deployed on 26 individuals during incubation and 27 individuals during chick-rearing and this yielded 21 tracks and 50 tracks respectively. On Lady Alice Island, GPS devices were deployed on 29 individuals during incubation and 34 individuals during chick-rearing and this yielded 20 tracks and 55 tracks respectively.

The average length of incubation foraging trips was 11.8 days and 4665 km for Ohinau Island birds and 16.6 days and 4734 km for Lady Alice Island birds. Lady Alice birds undertook significantly longer trips in respect to duration. The average length of foraging trips during chick-rearing was 3.1 days and 1205 km for Ohinau birds, and was 4.8 days and 1536 km for Lady Alice birds. There was considerable variation in all aspects of foraging trips during chick-rearing which is likely due to a dual-foraging strategy.

There was considerable overlap of foraging areas between Ohinau and Lady Alice birds indicating that birds from different populations mix at sea during the breeding season (Figure 16). All birds from Ohinau Island foraged either down the east coast of the North Island or out towards the Louisville Ridge. During incubation, nearly half of Lady Alice birds foraged in the same locations while the remaining birds foraged inshore off the West Coast of the North Island or offshore in the Tasman Sea. During chick-rearing, areas closer to each of the colonies had greater importance but birds still utilised some of the more distant foraging locations identified during incubation in order to maintain their own body weight and condition. Overall, more time was spent foraging in pelagic (> 50km offshore) than inshore waters (<50km).

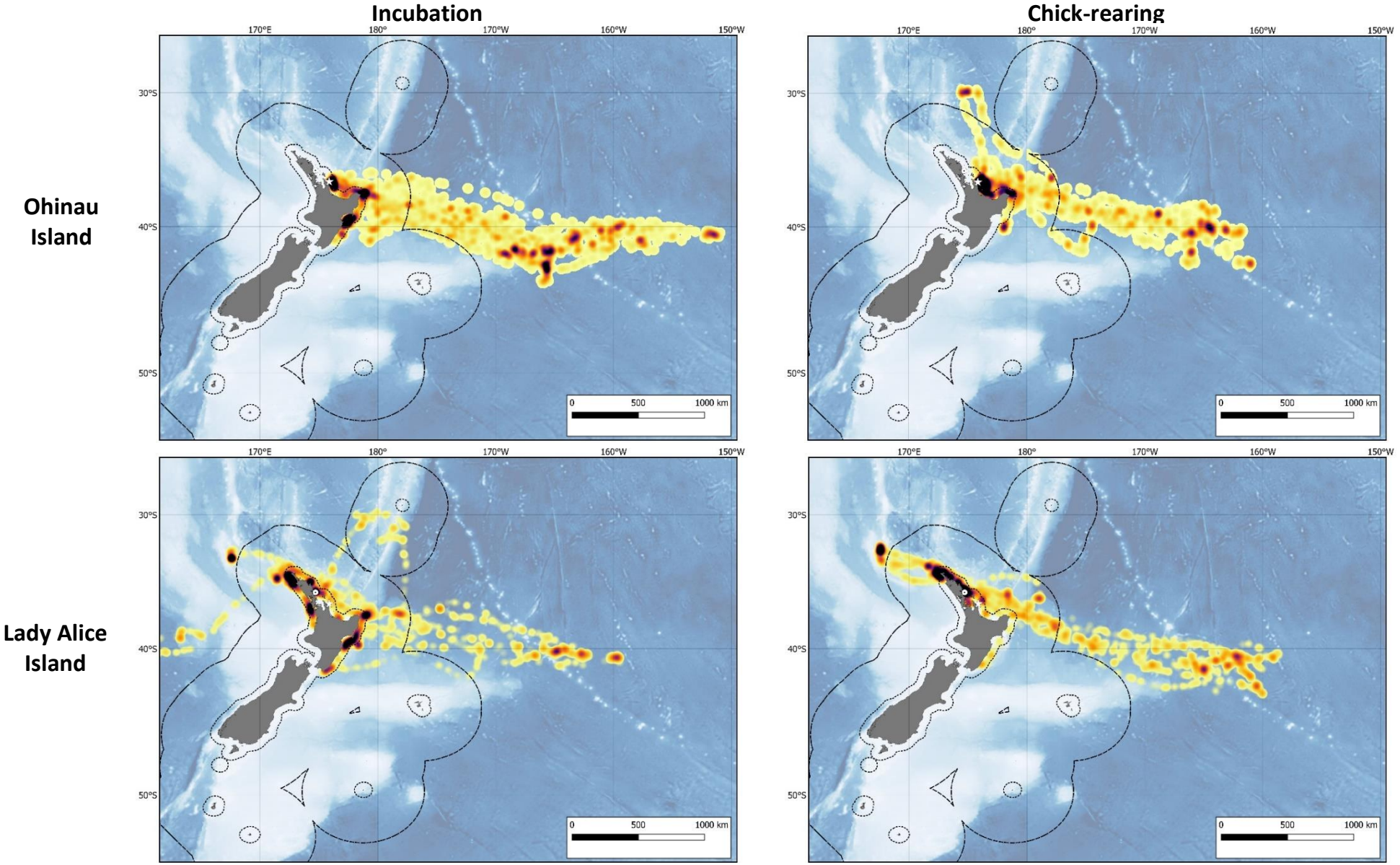

Figure 16 - Kernel density maps of all flesh-footed shearwater foraging points from the 2019/20 season separated by island and breeding stage. Darker areas represent a greater concentration of foraging activity. The location of Ohinau Island is shown as a white star and Lady Alice Island a white circle. Dotted black line indicates the 50km break and dashed black line indicates the New Zealand EEZ.

Tracking of juveniles using solar Platform Transmitter Terminals (PTTs) was undertaken in 2019 with mixed success. While some interesting and informative tracking data was collected, most of the devices stopped transmitting after approximately 3-4 weeks when they were expected to last for several months. Most birds showed rapid flight north from Ohinau Island to the Pacific Ocean but then slowed down and appeared to settle into an area north of Fiji and southeast of Tarawa (Kiribati) (Figure 17). Once they reached this general area, each device began to fail, and GPS tracks stopped being transmitted. The exact cause of this remains unknown but we speculate that most, if not all, birds died due to foraging inexperience or as fisheries bycatch. We think it is unlikely the devices failed, or fell off, as battery levels were full on most devices at the point of last transmission and the attachment method was very secure. A similar study which tracked juvenile and adult Scopoli's shearwaters (*Calonectris diomedea*) simultaneously found that most juvenile tracking devices failed after less than six days while all adult devices lasted longer than 50 days (Afán *et al.* 2019). The authors attributed this to a high mortality rate in juveniles caused by inexperience and vulnerability to bycatch in fisheries.

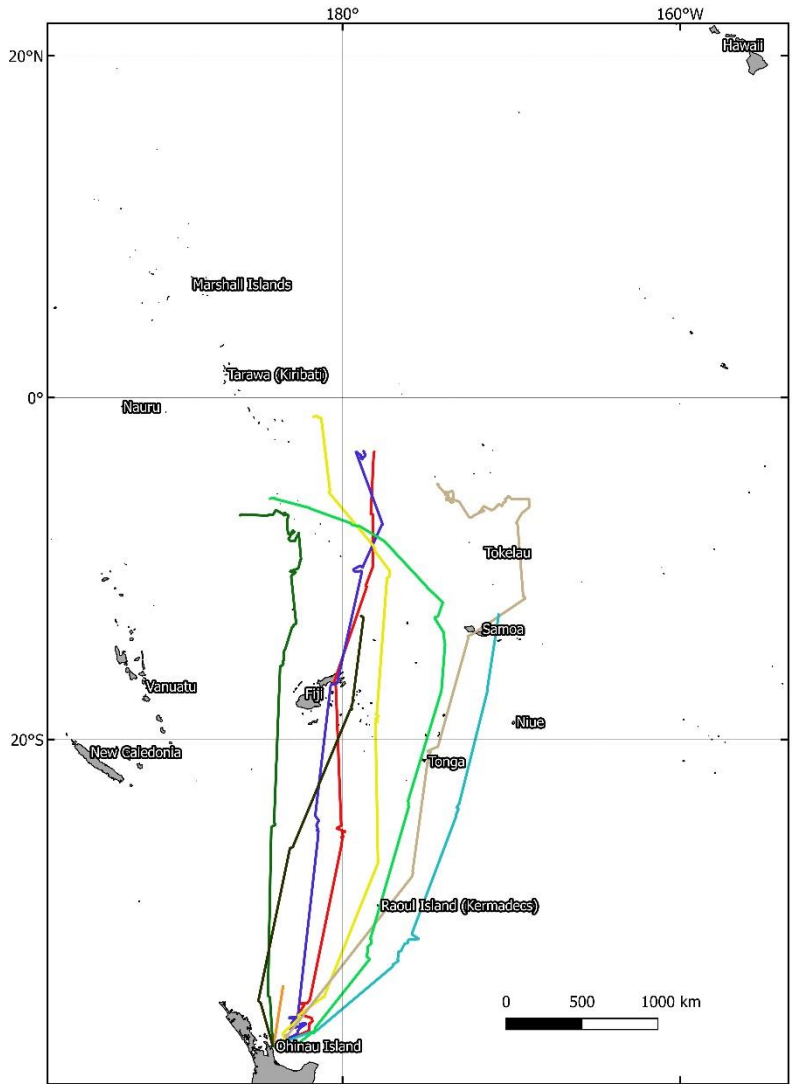

Figure 17 – Map showing the GPS tracks of all flesh-footed shearwater juveniles tracked from Ohinau Island in 2019.

3.3 POPULATION ESTIMATES

Five of the seven islands surveyed over the past five years; Middle, Ohinau, Lady Alice, Coppermine and Motumahanga Islands, have all shown substantial increases from previous estimates (Table 7). These five estimates have accounted for an additional 8,800 flesh-footed shearwater breeding pairs, which represents a 59-88% increase on the 10,000 – 15,000 estimate given by Waugh et al. (2013) for the number of breeding pairs within New Zealand. The increases are counter to the general consensus that populations are decreasing due to bycatch pressure from commercial and recreational fisheries. While some changes such as Motumahanga Island correspond to a true increase in population size, it is incredibly important to note that most of the others are likely to be a result of more in-depth and higher-quality sampling and analysis techniques giving a more accurate estimate of population sizes compared to previous estimates. The same rational applies to Whatupuke, which saw a small decrease in population size between this estimate and the previous estimate. The remaining island, Taranga, has seen no change and we have confirmed that flesh-footed shearwaters are absent from this island.

Table 7 – Summary of population estimates completed over the past five years with comparison to previous estimates.

		Current Estimate			Previous Estimate			
Island Group	**Island**	**Year**	**Estimated Occupied Burrows**	**95% Confidence Interval**	**Year**	**Estimated Occupied Burrows**	**95% Confidence Interval**	**Difference**
Mercury Islands	Middle Island	2017	5822	2400 - 9244	2003	3000	N/A	2822
	Ohinau Island	2018	4007	3044 - 4791	2009	2071	943 - 3200	1936
Sugarloaf Islands	Motumahanga Island	2019	562	N/A	1989	100	N/A	462
Hen & Chicken Islands	Lady Alice Island	2019	3217	2180 - 4255	2007-09	921	237 - 1605	2296
	Whatupuke Island	2021	1125	647 - 1603	2008	1210	36 - 2384	-124
	Coppermine Island	2021	2869	2142 - 3597	2008-09	1425	1059 - 1791	1444
	Taranga/Hen Island	2021	0	N/A	1991	0	N/A	0

4. Conclusions and Recommendations

Most of the population estimates conducted over the past five years have shown substantial changes to previous estimates. With this in mind, surveys of other flesh-footed shearwater breeding colonies to update population estimates are warranted.

- **We recommend that the following islands be considered for surveys to update population estimates:**
    - **Titi Island, Marlborough Sounds**
    - **Green Island, Mercury Islands**
    - **Mauitaha, Hen and Chicken Islands**
    - **Wareware and Muriwhenua Islands, Hen and Chicken Islands**

There are challenges associated with surveying some of these islands, most notably Green Island being particularly fragile and so would require a modified sampling technique similar to that carried out on Middle Island (Bell & Boyle 2017). Green Island has a large number of diving petrels and so it would be interesting to see if there has been similar displacement of diving petrels by flesh-footed shearwaters, as seen on Motumahanga Island (Crowe & Bell 2019). Titi Island should be surveyed as it is the southern-most breeding population of flesh-footed shearwaters and may be exposed to different factors influencing population dynamics. Access to Mauitaha would require explicit permission from Ngātiwai. Wareware and Muriwhenua Islands have historically only had fluttering shearwaters noted as breeding on them (Waugh *et al.* 2014). However, given their locality to nearby flesh-footed shearwater colonies, plus comments about flesh-footed shearwaters being present received from experienced local DOC staff (N. Forrester pers. comm.), consideration for a survey is warranted. Karewa Island (Bay of Plenty) holds a significant population of flesh-footed shearwaters and has not been surveyed since 2010, but is extremely fragile and currently under treaty negotiations so should not be considered.

As the biggest current quantifiable threat to the population viability of flesh-footed shearwaters is adult mortality associated with commercial longline and trawl fisheries, the tracking data collected during the 2019/20 season can be used to improve estimates of the at-sea distribution and habitat use of adult flesh-footed shearwaters during the breeding season. These improved estimates can then be used to improve spatially-explicit models of bycatch risk and be used to help determine mitigation measures to help reduce the incidence of bycatch of flesh-footed shearwaters. Further tracking of juvenile birds post-fledging may help to determine juvenile mortality in the first month after fledging and better understand the low recruitment rates that have been recorded on Lady Alice Island so far.

- **We recommend that a simultaneous sample of 10 juvenile and 10 adult flesh-footed shearwaters be tracked using PTTs in April/May to determine migration routes, and any differences between adult and juvenile mortality during this period.**

By sampling both adults and juveniles simultaneously we will be able to determine differences in foraging distribution and behaviour, but also whether juveniles are particularly vulnerable to mortality events during their first few months at sea as suspected by other work (Afán et al. 2019).

The number of study burrows on Ohinau and Lady Alice Islands are a suitable number for long-term demographic monitoring. Significant effort has been put in to banding flesh-footed shearwaters on

both islands since 2016 with over 1,500 chicks and 2,3000 adults having been banded across both islands. Recapture efforts of breeding adults and non-breeders need to be consistently large scale to provide a robust mark-recapture dataset and the large banding effort will help to achieve this.

We recommend that:

- **Population monitoring on Ohinau and Lady Alice Islands be continued with 200 breeding study burrows monitored annually.**
- **The number of burrowscope only burrows monitored annually be increased from 30 to 50 on each island.**
- **A survival analysis be undertaken to estimate adult survival on each island.**
- **There is continued, focussed effort to band and recapture as many flesh-footed shearwaters on the surface and in burrows on both islands.**

The last two seasons have indicated that our handling of adults in study burrows may be having some level of impact. To further test this and determine if the impact is significant, we recommend that the number of burrowscope burrows be increased to 50 on each island. A significant mark/recapture dataset has been collected and an attempt should be made to analyse this data and obtain an estimate of adult survival. A concerted effort to continue to band and recapture birds on both islands will allow more robust estimates of age at first return and adult survival to be made, estimate juvenile survival and age at first return, and measure changes in these demographic parameters over time.

We anticipate that the māhoe and inkweed growth around study burrows on Ohinau Island will be an ongoing issue for at least the next few seasons until the māhoe regrows to form a new canopy and shade out the weedy areas. This needs to be taken into account for logistics as at least two days will be required at the start of each trip to hand-pull weeds from around study burrows (with great care not to damage burrows) to allow easier observer access for burrow checks.

5. Acknowledgements

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