



Flesh-footed shearwater population monitoring on Ohinau and Lady Alice Islands, 2017/18 report



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Executive Summary

This report covers the final year in the population monitoring of flesh-footed shearwaters (*Puffinus carneipes*) on Ohinau and Lady Alice Islands carried out under Conservation Services Programme project POP2015-02. During the 2017/18 breeding season we monitored 228 and 230 study burrows on Ohinau and Lady Alice Islands respectively. The breeding success on Ohinau Island was 68% this season, up from 51% in the previous season. Breeding success on Lady Alice remained relatively low at 52% compared to 50% in the previous season. The difference in breeding success between the two islands this season is possibly due to the effect that La Niña had on the different foraging areas exploited by each of the populations. 98% of breeding burrows on Lady Alice Island and 88% of breeding burrows on Ohinau had both partners identified. 81% of birds that bred in 2016/17 bred again this season indicating most birds breed annually. A total of 1956 flesh-footed shearwaters have now been banded of both islands during the previous three breeding seasons. A population survey was conducted for Ohinau Island and there are an estimated 4007 occupied burrows, nearly twice as many as the previous two estimates conducted in the last 10 years. A population survey was also carried out for the LA1 colony on Lady Alice Island and there was an estimated 867 occupied burrows, eight times that which was estimated almost ten years ago. Further population surveys of other islands inhabited by flesh-footed shearwaters are warranted and monitoring of the populations on Ohinau and Lady Alice islands should continue.

1. Introduction

Flesh-footed shearwater populations are in decline both in New Zealand and globally. Under the New Zealand threat classification, 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 prone to being caught in trawl fisheries (Abraham & Thompson 2011). It is estimated that between 1,079 and 1,769 flesh-footed shearwaters are killed annually by commercial fishermen (Richard *et al.* 2011). 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 by recreational fishermen.

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 are lacking. Long-term studies help to gain a better understanding of demographic parameters such as adult survival, age at first breeding, fecundity and recruitment. This will then help provide more accurate population trends and thus aid in future management decisions for the species.

The decline of flesh-footed shearwaters coupled with a general lack of demographic parameter measurements, particularly in New Zealand, has warranted the establishment of a long-term population monitoring study. 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 relatively large colony sizes. As such they were selected as study sites for the current study.

1.1 Previous studies on islands

1.1.1 Ohinau Island

Previous field studies of flesh-footed shearwaters have been carried out on both Ohinau and Lady Alice Islands. GPS tracking work was carried out on Ohinau Island in 2012 with approximately 50 burrows being marked and 62 adult birds banded (Waugh *et al.* 2014). In April 2016, Wildlife Management International Limited (WMIL) continued on Ohinau Island by conducting preliminary work for the current study by finding and marking burrows containing flesh-footed shearwater chicks. We expanded the number of marked burrows to 218 and banded a further 357 individuals (Mischler 2016). In 2016/17 the first full breeding season on Ohinau Island was monitored by WMIL with 229 burrows being monitored and an observed breeding success of 50.7%. A total of 661 birds, including both adults and chicks, were banded.

1.1.2 Lady Alice Island

Flesh-footed shearwaters were monitored on Lady Alice Island for 13 consecutive seasons starting from 2000 - 2013 with 596 adults and 193 chicks banded (Andrea Booth unpublished dataset, Barbraud *et al.* 2014). Waugh *et al.* (2014) conducted GPS tracking of flesh-footed shearwaters in 2012 on the island, however, this was not overly successful. Work was not carried out by WMIL on Lady Alice Island during the first year of the current study due to access complications. In 2016/17 the first full breeding season of this study was monitored by WMIL. A total of 179 burrows were monitored and a very similar breeding success rate of 50.4% to that of Ohinau Island in the same season was measured. A total of 379 flesh-footed shearwaters were banded.

1.2 Key Objective and Outputs

This research was carried out as part of the Flesh-footed Shearwater: Various Locations Population Project (POP2015-02). The key objective we were funded to complete was:

Objective 2: To estimate key demographic parameters of flesh-footed shearwater at Lady Alice Island/Mauimua and Ohinau Islands.

To meet this objective, the following outputs were to be delivered in 2017/18:

- Establish and identify the partners in up to 200 study burrows on each island.
- Determine the sex of birds in study burrows by DNA sexing of feathers
- Determine the breeding success of all study burrows and where possible record cause of burrow failure.
- Monitor ≥ 30 burrowscope burrows on both islands to determine if there was any effect of handler disturbance on breeding success.
- Band as many adults on the surface at night to increase the banded population of flesh-footed shearwaters.
- Band all chicks in study burrows prior to fledging.
- Band as many chicks on the surface prior to fledging to increase the number of banded chicks each season.
- Record details of any recaptured banded birds.

1.3 Population Estimates for Ohinau and Lady Alice Islands

In addition to the above outputs, we made the decision to carry out population estimates for Ohinau Island and the LA1 colony on Lady Alice Island. The rationale for this is that the most recent estimate for the Lady Alice colony (LA1) published by Baker *et al.* (2010) was 105 (98 – 113, 95% CI) occupied burrows yet in the previous season we monitored 158 occupied burrows in the same colony (Crowe *et al.* 2017). On Ohinau Island the sheer number of birds that were seen, heard and banded on the surface at night time over the previous two seasons led us to speculate that there may be a larger population than the most recent and commonly cited figure of 2,071 (943 – 3200, 95% CI) occupied burrows.

2. Methods

2.1 Study Sites and Dates

2.1.1 Ohinau Island

Ohinau Island (Mercury Islands Group, 36.73°S, 175.88°E) is a 43ha island located off the east coast of Coromandel Peninsula (Figure 1). The island is owned by local iwi Ngati Hei and co-managed with the Department of Conservation. There are an estimated 2,071 (943 – 3200, 95% CI) occupied flesh-footed shearwater burrows on the island (Baker *et al.* 2010). Burrows are distributed over the entire island in eight sub-colonies (Figure 2). We continued to focus our study on five of these sub-colonies (Camp, Camp South, South of Gully, Hilltop and Pohutukawa) and left the other three undisturbed. A team of two personnel was based on the island during the following dates:

- **Trip 1:** 18 December 2017 – 2 January 2018; 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. Carrying out burrow transects for population estimate.
- **Trip 2:** 26 April 2018 – 1 May 2018; checking all study burrows to determine breeding success and band all chicks. Mapping individual colony outlines using GPS.

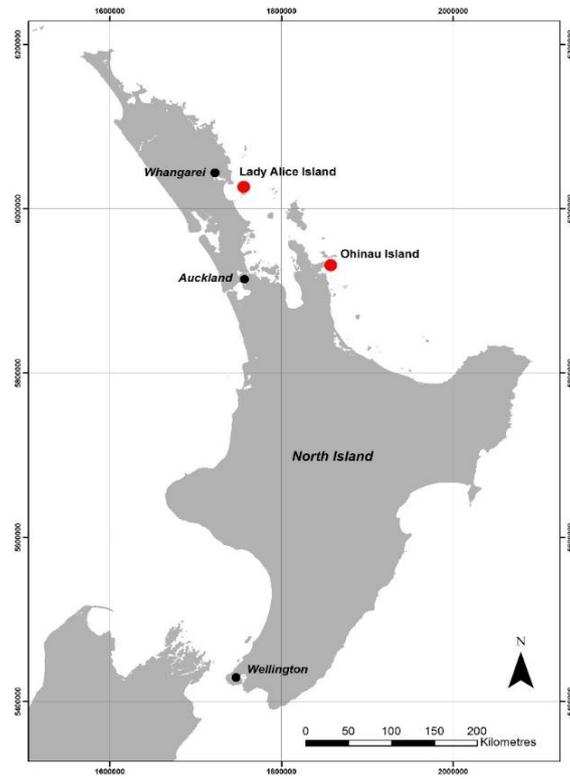


Figure 1. Locations of Lady Alice and Ohinau Islands

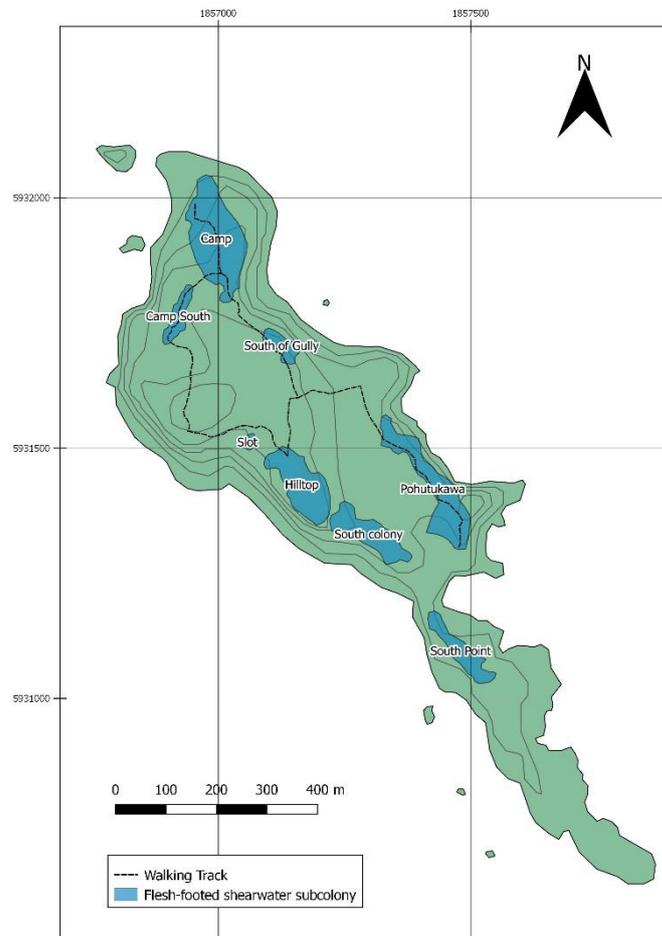


Figure 2. Location of flesh-footed shearwater colonies, Ohinau Island

2.1.2 Lady Alice Island

Lady Alice Island / Mauimua (Hen and Chickens Group, 35.89°S, 174.72°E) is a 155 ha Nature Reserve located 40km southeast of Whangarei (Figure 1). There are an estimated 921 (237- 1,605, 95% CI) occupied flesh-footed shearwater burrows on the island (Baker *et al.* 2010). Seven main sub-colonies on Lady Alice Island have been identified (Figure 3). This study focussed on in the LA1 colony which has been monitored for 13 seasons between 1999 and 2012 (Barbraud *et al.* 2014). A team of two personnel was based on the island during the following dates:

- **Trip 1:** 6 January 2018 – 2 February 2018; 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. Carrying out burrow transects for population estimate and mapping the LA1 colony boundary. We were concurrently conducting GPS tracking of some birds as part of a different objective for this project. The results of this work are reported in Crowe (2018).
- **Trip 2:** 20 April 2018 – 24 April 2018; checking all study burrows to determine breeding success and band all chicks.

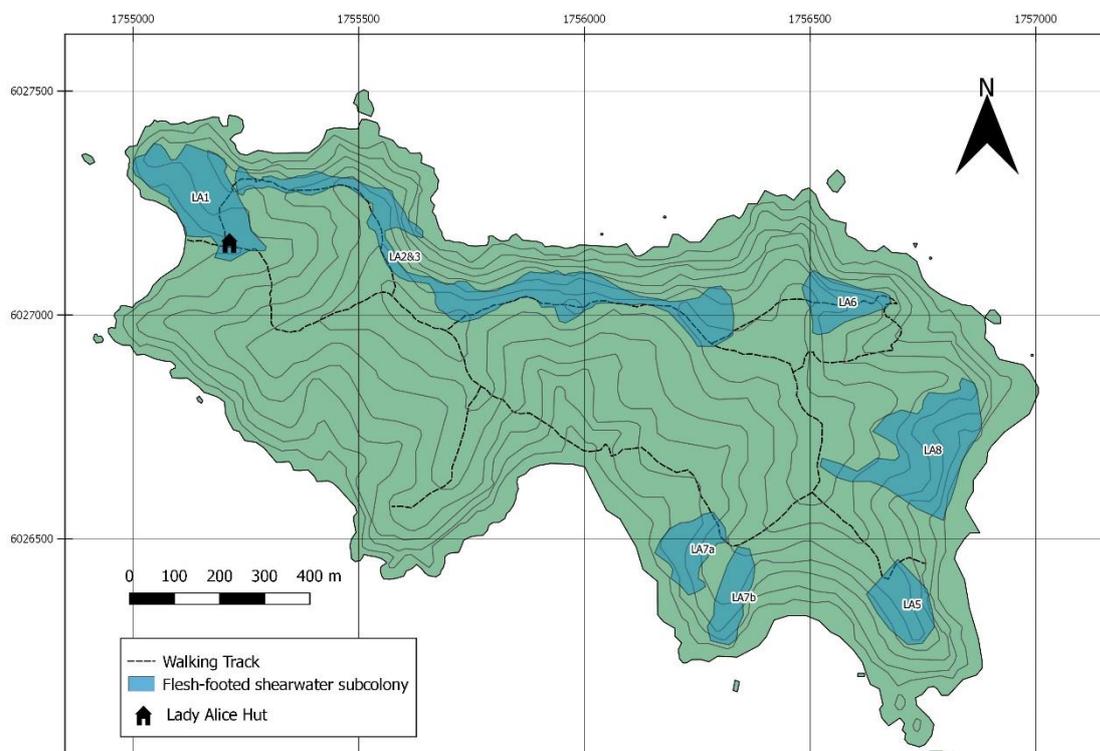


Figure 3. Location of flesh-footed shearwater colonies, Lady Alice Island. All burrows monitored in this study were situated in LA1 colony

2.2 Burrow Monitoring

Each study burrow was checked approximately every 4 – 5 days. The first check was very thorough to search for a bird and/or an egg to determine the breeding status of each burrow. All birds found in these burrows were banded and had wing length, head and bill length, minimum bill depth and weight measured. We also took a sample of two breast feathers from those birds that we did not know the sex of to allow for DNA sexing. Only one bird from each burrow was sexed and the partner

bird was assumed to be the opposite sex. All birds found in burrows were marked with correction fluid to prevent unnecessary handling during future burrow checks then placed back in their burrow.

If no bird was present in the burrow, it was searched thoroughly for a sign of a failed breeding attempt such as egg shell fragments. Empty burrows were all checked at least once more at a later date to confirm they were indeed empty. 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 burrow.

For burrows that had failed (such as 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 as the partner bird was 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 after 20 December on Ohinau Island after all breeding birds should have laid (Bell *et al.* 2017) and within the first three days on Lady Alice Island to minimise the number of burrows that fail in the early stages of incubation. The burrowscope was fed down the mouth of the burrow until a bird was seen and confirmed 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.

At the end of April, both islands were revisited and all burrows were checked. All study burrows were checked regardless of their status in December. Chicks found in burrows were banded, weighed and had wing length measured then placed back in their burrows. Because chicks fledged in early May (Priddel *et al.* 2006), burrows with chicks during this time 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 trip. Chicks were removed where possible by hand or leg hook to be banded and have measurements taken (as above) then placed back in their burrow. Empty burrows and failed burrows were confirmed using a burrowscope or/and burrow probing with a stick.

2.3 Night Work

2.3.1 December & January Trip

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 01:00 and dawn. Adults were caught using a hand-net and were banded, marked with correction fluid and the capture location was recorded. Take-off “runs” were targeted during the pre-dawn exodus as this is where we would see a large number of birds funnelling in to a relatively small area to take off.

2.3.2 April Trip

Night work on this trip primarily aimed to catch any chicks coming out of burrows exercising and preparing to fledge. Chicks were banded, weighed and had wing length measured. There was no apparent preferred time for chicks to be on the surface so catching took place at any time after dark. Chicks seemed to spend very little time on the surface and therefore not many were caught. Some

adults were still present on the islands at this point and were also captured. Adults were banded and weighed to determine post-breeding weights.

2.4 Population Estimates for Ohinau and Lady Alice Islands

Transect start points and bearing (transect direction) were randomly generated within the colonies. A tape was run out for 20m from the start point on the generated bearing. The same method was used as that in Bell & Boyle (2017) for Middle Island / Atiu. Burrows were searched for in a 2m strip to the right hand side of the tape i.e. each transect covered 40m². Transects were done in pairs with one person searching for and counting burrows, while the other checked the contents of each burrow using a burrowscope.

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, then 'clipped' using a shapefile containing a polygon describing the boundary of each colony. The resulting clipped DEM was then used to create a Triangular Irregular Network (TIN) describing the 3D surface of the colony, and the 3D surface areas of the TIN were calculated using the Surface Volume tool in ArcMap 10™.

3. Results

3.1 Study Burrows

Ohinau Island			
	Study	Burrowscope	Total
2015/16	186	32	218
2016/17	229	36	265
2017/18	228	44	272

Lady Alice Island			
	Study	Burrowscope	Total
2015/16	0	0	0
2016/17	198*	30	228
2017/18	230	36	266

*97 of these burrows were monitored between 1999 and 2012

Table 1. Number of study burrows monitored on Ohinau and Lady Alice Islands over the past three seasons

3.1.1 Ohinau Island

A total of 228 study burrows were monitored during this season on Ohinau Island (Table 1). This consisted of 227 burrows monitored in the previous season and one new burrow.

Of the 228 study burrows, 78% ($n = 179$) were breeding burrows and 4% ($n = 9$) were non-breeding burrows. The rest were empty or held other species. We were able to successfully identify both partners for 89% ($n = 159$) of these breeding burrows (Table 2). 10% ($n = 17$) of breeding burrows had only one partner identified while the remaining three burrows had neither partner identified. One of these burrows contained an abandoned egg right from the first burrow check while the other two were burrows that had been extended by the occupants and the nest chamber had become inaccessible. Both of these were confirmed with the burrowscope but adult birds could not be extracted.

3.1.2 Lady Alice Island

A total of 230 study burrows were monitored on Lady Alice Island this season (Table 1). Of these burrows, 70% ($n = 162$) were breeding burrows and 5% ($n = 11$) were non-breeding burrows. We were able to identify both partners in 98% ($n = 159$) of breeding burrows, with the remaining 2% ($n = 3$) having only one partner identified (Table 2).

Burrow Status	Ohinau Island	Lady Alice Island
Breeding		
- 0 partners	3	
- 1 partner	17	3
- 2 partners	159	159
Non-breeding		
Adult/s Alone		
- 1 bird	8	7
- 2 birds	1	4
Total with flesh-footed shearwaters	188	173
Other species		
- Little Penguin		5
- Grey-faced Petrel (chick in Dec/Jan)	1	4
- Pycroft's Petrel		2
- Little Shearwater		
- Sooty Shearwater		3
Collapsed	3	2
Empty	36	41
Total Burrows	228	230

Table 2. Breakdown of burrow status for all study burrows on Ohinau and Lady Alice islands

3.2 Breeding Success

Breeding success is defined here as burrows that produced a chick that is likely to survive to fledging.

3.2.1 Study Burrows

Twenty-four breeding burrows were excluded from the breeding success data analysis on Lady Alice Island. These were the 24 burrows that had birds fitted with GPS and GLS devices to track their foraging movements during the incubation period. When the breeding success was looked for these burrows alone, it was found they had a breeding success of just 13% ($n = 3$) indicating that our tracking of these individuals had an effect on their breeding success and thus were excluded from our overall estimate of breeding success.

Breeding success for Lady Alice Island was 52% ($n = 72$) while on Ohinau Island it was 68% ($n = 121$). There was a significant difference in breeding success between the two islands (Pearson Chi-Square, $\chi^2_1 = 7.78$, $p < 0.01$). It appears more burrows failed during the egg stage than chick stage, however, there is a fair degree of uncertainty here as the cause of burrow failure could not be determined in many cases (Table 3).

	Ohinau		Lady Alice	
	Study Burrows ($n = 228$)	Burrowscope ($n = 44$)	Study Burrows ($n = 206^*$)	Burrowscope ($n = 35$)
Breeding Burrows	179	31	138	31
Breeding success	121 (68%)	21 (68%)	72 (52%)	14 (45%)
Failed, pre-hatching	27 (15%)	3 (10%)	42 (30%)	3 (10%)
Failed, post-hatching	2 (1%)	0 (0%)	4 (3%)	2 (6%)
Failed, unknown reason	29 (16%)	7 (23%)	20 (14%)	12 (39%)

*24 burrows with tracked birds excluded from analysis

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

The breeding success on Ohinau Island was also significantly higher this season than the previous season (Pearson Chi-Square, $\chi^2_1 = 11.31$, $p < 0.01$; Figure 4). There was no significant difference in the breeding success between seasons on Lady Alice Island (Pearson Chi-Square, $\chi^2_1 = 0.08$, $p = 0.77$).

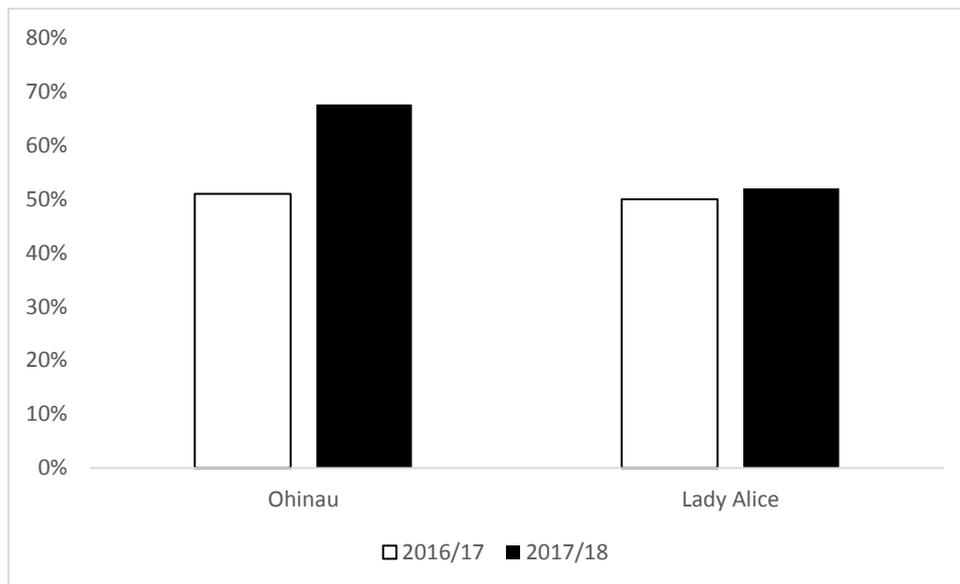


Figure 4. Bar graph showing the breeding success of study burrows on Ohinau and Lady Alice Islands for the current and previous breeding seasons

Grey-faced petrels were present in six burrows on Ohinau Island and thirteen burrows on Lady Alice Island in April. One burrow on Lady Alice Island contained a dead chick with injuries consistent with grey-faced petrel attacks (bald and bleeding head or any piercing to the body). No burrows with grey-faced petrels present also contained a live flesh-footed shearwater chick.

3.2.2 Burrowscope Burrows

Breeding success in burrowscope burrows was the same as the study burrows on Ohinau Island (68%, $n = 21$) and lower on Lady Alice Island (45%, $n = 14$) (Table 3). This indicates that our manipulation of burrows by digging hatches plus handling and banding of birds inside study burrows is not having an effect on their breeding success.

3.3 Banded Birds

This season a total of 313 birds were banded on Ohinau Island and 246 birds were banded on Lady Alice Island (Table 4). Both these numbers have dropped off considerably from the previous seasons' banding totals and this is most likely a product of now having the vast majority of birds in our study burrows banded. Many more of the birds seen on the surface at night time are also banded. For both islands and years combined, 1956 flesh-footed shearwaters have been banded in this study.

Ohinau	2015/16	2016/17	2017/18	Total
Adult	90	528	182	800
Chick	267	133	131	531
Total	357	661	313	1331

Lady Alice	2015/16	2016/17	2017/18	Total
Adult	0	285	163	448
Chick	0	94	83	177
Total	0	379	246	625

			Total banded during this study	1956
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Table 4. Number of flesh-footed shearwaters banded during the three years of this study

3.3.1 Management of Records of Banded Birds and Study Burrows

Copies of the field records of all birds newly banded 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 deposited with 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.

3.4 Recaptured Birds

On Ohinau Island, 81% ($n = 255$) of birds that were identified as breeding last season were found to be breeding again this season. Of these birds, 98% ($n = 249$) were found breeding in the same burrow while the remaining 2% of birds ($n = 6$) were breeding in a different burrow. In all cases of birds shifting burrows, they only moved to a nearby burrow, usually within 10m of their previous burrow.

The result for Lady Alice Island was identical to that of Ohinau with 81% ($n = 162$) of breeding birds found in the 2016/17 season found breeding again this season. A further 2.5% ($n = 5$) of birds breeding in 2016/17 were recaptured on the surface or found in non-breeding burrows meaning an absolute minimum adult survival rate of 83.5%. However, there was more shuffling of burrows on Lady Alice Island with 10% ($n = 17$) of birds moving burrows while the remaining 90% ($n = 145$) of birds remained breeding in the same burrow.

A total of 789 (193 chicks, 596 adults) flesh-footed shearwaters were banded between 2000 – 2009 on Lady Alice Island (Andrea Booth unpublished dataset, Barbraud *et al.* 2014). Of these, 9% ($n = 18$) of chicks and 14% ($n = 82$) of adults have been recaptured in the previous two seasons on Lady Alice Island. Thirty-six of the 100 recaptures were birds that were banded as adults in 2000 making these birds at least 23 years old now.

3.5 Population Estimates

3.5.1 Ohinau Island

We carried out a total of 70 transects in 8 different colonies between 29 December 2017 and 01 January 2018. All but one transect (which came to a cliff edge) were 20m long. A total of 247 burrows were counted on transects, of which 242 had the contents checked using a burrowscope. The average occupancy for all burrows checked was found to be 0.461.

When mapping the colony boundaries, it was found that multiple colonies covered a larger area than previously thought while the 'Camp' and 'Camp South' colonies were one continuous colony. Four additional colonies were also found (Figure 5). Extrapolating the burrow densities recorded on transects, there are an estimated 8688 burrows on Ohinau Island with an estimated 4007 (3044 – 4791, 95% CI) being occupied flesh-footed shearwater burrows (Table 5).



Figure 5. Map of Ohinau Island showing the current extent of each colony (red) overlapped by the previously known extent (blue).

	Ohinau Island	Lady Alice "LA1" Colony
Total transects	70	68
Transect survey area (m ²)	2775	2720
Total burrows counted	247	124
Burrows with contents checked	242	124
Occupancy	0.4612	0.4878
Burrow density (burrows/m ²)	0.0890	0.0456
Calculated Area (m ²)	97609	39000
Potential Burrows	8688	1778
Estimated Occupied Burrows	4007	867
95% confidence interval	3044 - 4791	628 - 1107

Table 5. Results from the population surveys for Ohinau Island and the “LA1” colony on Lady Alice Island

3.5.2 Lady Alice Island

A total of 68 transects were conducted between 16 January 2018 and 21 January 2018. Two transects were not completed as they ended up on the rocky coastline. All transects were located in the ‘LA1’ study colony which we mapped partially in the previous season and was known to be spread out over a much larger area than the Baker *et al.* (2010) population estimate (Figure 6).

There were 124 burrows found on transects, of which all had their contents checked using the burrowscope. The average occupancy was 0.488. Extrapolating the burrow density out, there are an estimated 1778 burrows in the LA1 colony of which 867 (628 – 1107, 95% CI) are occupied by flesh-footed shearwaters (Table 5).

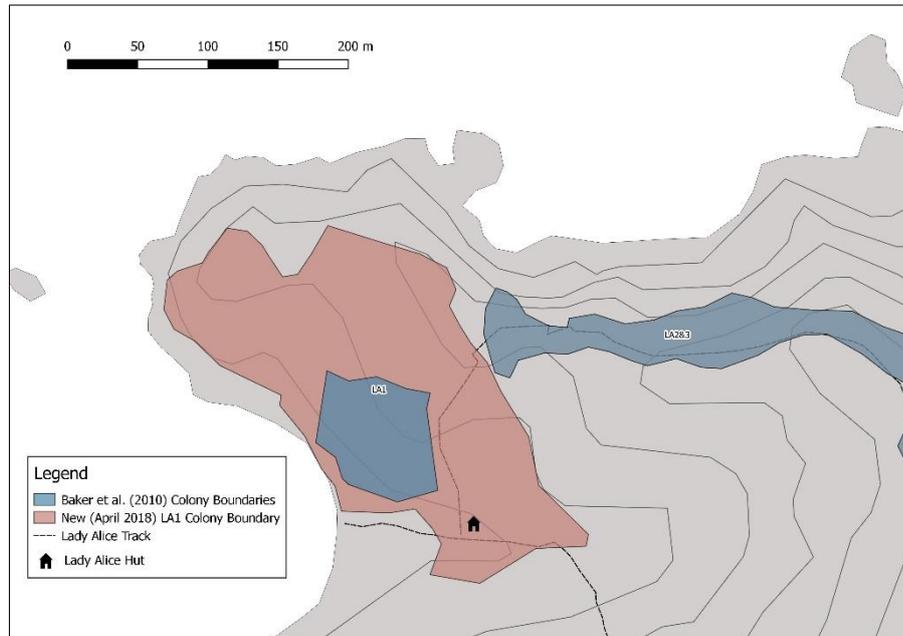


Figure 6. Map showing the current extent of the LA1 Colony on Lady Alice Island compared to that mapped by Baker *et al.* (2010)

4. Discussion

4.1 Study Burrows

Both Lady Alice and Ohinau Islands have proved to be great locations for long-term demographic studies of flesh-footed shearwaters. They are both readily accessible from the mainland with a good campsite on Ohinau Island and hut on Lady Alice Island. The track network, open vegetation, and mostly compact soils on both islands means moving around and between burrows is easy.

A suitable number of study burrows has been reached for both islands and provided the occupancy rate remains stable between years then no new study burrows will need to be added.

4.2 Breeding Success

The breeding success of 68% on Ohinau Island this season is more like what should 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 also 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).

As Lady Alice Island is also predator-free, the breeding success of 52% this season suggests that there must be other factors resulting in the poor breeding success. In the 2016/17 season, the measured breeding success on Lady Alice was similarly low (50%) and we suggested this was due to a significant wet weather event resulting in many burrows flooding. This was backed up by the poor breeding success on Ohinau Island which was similarly affected by the same weather event (Crowe

et al. 2017). For the current season, we suggest the observed difference in breeding success is possibly due to the different foraging areas exploited by each population and the effect that La Niña had on each of these areas. Flesh-footed shearwaters from Lady Alice Island tend to forage north of the island up to Cape Reinga and then around off the west coast of the North Island in the Tasman Sea (Kirk *et al.* 2017; Crowe 2018). Birds from Ohinau Island have a more easterly distribution, foraging mainly off the North Islands' east coast between Coromandel Peninsula and East Cape, and also far to the east of New Zealand as far as 160°W (Waugh *et al.* 2014). Sea surface temperatures (SST) were between 2°C and 4°C above average this season with some areas off the west coast of New Zealand that were 6-7°C above average (Niwa 2018). Higher SST and calmer weather associated with La Niña events means less mixing of cooler nutrient rich subsurface waters with warmer surface waters and results in less productive waters. This can then have a bottom-up effect on the food chain and result in negative impacts on seabird population dynamics (Oro 2014).

Part of spending a greater amount time on Lady Alice Island meant that we were able to detect the cause of burrow failure in more cases. During the April burrow checks, there is often no obvious sign (such as a dead chick or broken egg) of burrow failures. Burrows are often cleaned out by other species such as grey-faced petrels or by non-breeding individuals prospecting potential burrows and any evidence of burrow failure is lost. On Lady Alice Island it was evident that there were considerably more failures during incubation than chick-rearing and this was largely due to burrow abandonment. It was not unusual for some of our burrows on Lady Alice Island to have an egg unoccupied in a burrow for a period of 6 – 8 days before a partner returned from the sea to incubate the egg (if at all). None of these burrows bred successfully and it is unlikely that any of the eggs hatched. The longest chilling period we were able to detect for an egg that subsequently hatched was three days. This is the same maximum length of chilling detected by Powell (2004) in long-term study on Woody Island, Western Australia.

The high rate of egg abandonment on Lady Alice Island again most likely comes down to foraging. If the foraging areas typically utilised by flesh-footed shearwaters from this colony have poor productivity then this means the bird is having to spend longer at sea to build up the body condition necessary for its next incubation shift. Meanwhile its partner that is incubating for longer than normal reaches a critical point in body condition where it has to abandon the burrow and head to sea to forage for itself.

Grey-faced petrels are also likely to be the cause of some breeding failures on both islands. None of our study burrows with grey-faced petrels present in April contained flesh-footed shearwater chicks. 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). More than twice as many grey-faced petrels were found in burrows during the April trip on Lady Alice Island this season compared to the previous season.

4.3 Banded Birds

With nearly 2000 individuals now banded from both islands, a significant proportion of the flesh-footed shearwater population in New Zealand has been banded. This will help for future mark-recapture studies and determining adult survival models. Importantly, we have banded over 700 chicks which are known-age birds and thus have a large sample size to determine age at first return and age at first breeding, two factors not understood well or with inferences made from small sample sizes.

4.4 Recaptured Birds

The proportion of chicks that were banded between 2000 – 2009 that have returned to Lady Alice (9%) is very similar to the 8% return rate reported by Bell *et al.* (2016) in the black petrel population on Great Barrier Island / Aotea over a 20 year period. While this estimate of recruitment is extremely low and suggests a low juvenile survival rate, it is probably more a reflection on the detectability of returned chicks, more so than survival. Future work on both these islands should focus on night work to recapture surface birds to increase the number of chicks recaptured which will help to develop more robust population modelling.

4.5 Population Estimates

4.5.1 Ohinau Island

The population estimate presented here is considerably larger than the most recent estimate by Jamieson & Waugh (2015) of 2124 breeding pairs. It is also larger than the commonly cited estimate by Baker *et al.* (2010) of 2071 occupied burrows. The population survey by Jamieson & Waugh (2015) yielded a relatively low occupancy of burrows and they suggested this represented a decline in the number of birds nesting on the island. However, this survey was conducted between 18 January and 18 February 2014 which is 1-2 months after egg laying has finished (Bell *et al.* 2017). Many burrows are likely to have failed over this period and thus occupancy will be underestimated. As we conducted our survey in the two weeks following the conclusion of egg-laying, our measurement of occupancy is a better representation of actual occupancy.

4.5.2 Lady Alice Island

Our population estimate for the LA1 colony on Lady Alice Island is not only eight times that of the Baker *et al.* (2010) estimate (867 vs 105) but is not far off the 921 occupied burrows estimated for the entire island. The primary reason for the large discrepancy between the two estimates is simply the total area mapped for the colony. Our estimates for burrow occupancy and burrow density were relatively similar but calculated area for the colony was eight times larger (39000m² vs 4709m²). Part of this comes down to spending a large amount of time on the island and thus gaining an understanding of the extent of the colonies through seeing and hearing birds at night and searching for burrows during the day. Our population estimate for the LA1 colony is larger than the Jamieson & Waugh (2015) estimate for the entire Lady Alice Island (710 pairs). Again, the timing of the Jamieson & Waugh (2015) survey was an issue with the survey beginning before peak laying for flesh-footed shearwaters and finishing just as laying had ended. This would have resulted in an underestimation of occupancy and so population estimate.

5. Conclusions and Recommendations

We suggest that monitoring of flesh-footed shearwaters on both islands should continue. We have found from this project that it takes about two seasons to set up a suitable number of study burrows and identify the individuals breeding in those burrows. Multiple seasons of breeding success data will be important for working out what “normal” success levels are and thus help for population modelling. With a large portion of birds on both islands banded, more focus can be put on to recapturing banded birds and developing robust estimates for adult survival. At least three more years will be required before a number of chicks banded in the first season on Ohinau Island will likely return to breed.

Burrowscope (control) burrows could be incorporated in with the study burrows on both islands for future monitoring. As we have two full seasons of comparable data indicating that there is no effect of handler disturbance on breeding success. Incorporating the burrowscope burrows to study burrows would involve digging inspection hatches (where necessary) and banding adults during the incubation period.

The results of the population estimates presented here for Ohinau Island and the LA1 Colony means there is scope for resurveying some or all of the other islands with flesh-footed shearwater populations. It has now been approximately ten years since the first detailed population estimates were conducted by Baker *et al.* (2010). The timing of surveys will be an important factor to consider as we have found the timing can greatly affect the measured rate of occupancy.

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8. Appendices

8.1 Other bird species observed on Ohinau and Lady Alice Islands

Regular bird counts were completed on both islands and the results uploaded to eBird (www.ebird.org/content/newzealand/). Below is a summary of these observations.

Species	Ohinau Island	Lady Alice Island
Flesh-footed Shearwater	Hundreds of birds on surface in December. 5-10 adults seen per night in April	Hundreds of birds on surface in December. 5-10 adults seen per night in April
Sooty Shearwater	One adult banded in burrow (non-breeding). One more seen	A few birds found in burrows and one or two birds seen or heard most nights.
Fluttering Shearwater	One heard calling from a burrow south of Camp	Heard calling most nights in January. Occasionally seen on surface
Buller's Shearwater	None observed	Commonly seen flying off the coast
Little Shearwater	Seen up to four on surface most nights in December.	Up to 3 birds seen most nights in January
Diving Petrel	A few dead fledglings seen. No live birds seen	None observed
Pycroft's Petrel	Not common. Five adults banded and one active burrow found	Lots seen on surface and in burrows
Grey-faced Petrel	3 chicks present in burrows in December. Several dead fledglings around island. Very common in April with 26 individuals seen on surface one night and multiple birds in burrows	A few chicks in burrows in December, very common in April on the surface and in burrows
Little Penguin	None observed but footprints seen on beach one morning	Common in burrows and on surface at night
White-faced storm petrel	None observed	Seen offshore usually around fishing vessels
Fairy Prion	None observed	Seen on boat ride to island and occasionally offshore
Pied Shag	Up to 30 individuals roosting in bay near camp each day	Up to 40 birds roosting in bay near camp each day
Little Shag	One bird seen one day	None Observed

White-faced Heron	None Observed	None observed
Reef Heron	One seen on rocks with shags in April trip	One seen from beach one day
Variable Oystercatcher	Two near landing beach one day	A pair seen sometimes at West Bay
Black-backed Gull	Nesting on flat island. Up to 30 offshore and a few around beach	Seen offshore and on beach near camp
Red-billed Gull	A few seen offshore	Large numbers seen offshore, a few birds on beach each day
Australasian Gannet	Small numbers feeding close to shore. More offshore	Common offshore
Caspian Tern	One seen feeding daily near island	1-2 birds seen offshore
White-fronted tern	Up to 15 offshore most days	Some birds seen offshore
Kereru	Up to two seen around Pohutukawa colony	Usually at least one around camp
Bellbird	Very common throughout whole island	Abundant
Tui	Up to 2 regularly heard at Pohutukawa colony	Abundant
Saddleback	None observed	Common
Tomtit	None observed	One bird heard down the eastern side of island
Fantail	Common, seen most days	Common
Kaka	Heard calling on one day	2-5 birds seen each day
Morepork	Heard only one night	Common
Kingfisher	Common throughout island	Common
Silvereye	Very common throughout whole island	Common
Welcome Swallow	Common, seen most days	Common
Grey Warbler	Common throughout island	Common
Shining Cuckoo	Heard calling about 3 times in December	Common
Australasian Harrier	Up to two individuals seen most days	2-3 birds seen each day
Dunnock	Very common throughout whole island	Common
House Sparrow	Small flocks heard around camp	None observed
Blackbird	Common throughout island	1-2 birds seen each day
Starling	Heard most days throughout island	Common
Chaffinch	Singing daily, mainly at camp	Common