Flesh-footed shearwater population monitoring and at-sea distribution: 2019/20 season

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Flesh-footed shearwater population monitoring and at-sea distribution: 2019/20 season

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Cover Image: banded flesh-footed shearwater (*Puffinus carneipes*) at night time on Ohinau Island. Photo credit: Kaila Ritchie.

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Abstract

This report covers the findings from the second of three years' flesh-footed shearwater (*Puffinus 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 the results of GPS tracking of breeding birds from both islands.

During the 2019/20 breeding seasons we monitored 274 and 288 study burrows on Ohinau and Lady Alice Islands respectively. A total of 216 study burrows on Ohinau Island were breeding and we were able to identify 408 of the 432 (94%) partners occupying these study burrows. On Lady Alice Island, 202 study burrows were breeding and 358 of 404 (89%) of partners occupying these study burrows were identified. We were unable to determine breeding success for the 2019/20 season but the rate of failure during incubation in January was similar to the 2018/19 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. 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.

1. Population Monitoring on Ohinau and Lady Alice Islands

1.1 Introduction

Flesh-footed shearwaters (*Puffinus carneipes*) breed on islands off the coast of northern New Zealand, Australia and on St Paul Island 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 prone to being caught in trawl fisheries (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 to gain a better understanding of demographic parameters such as adult survival, age at first return, age at first breeding and recruitment. Consequentially, this will help provide more accurate population trends, and thus aid in future management decisions for conservation of the species.

The possible decline of flesh-footed shearwaters coupled with a general lack of demographic parameter measurements, particularly in New Zealand, has generated the establishment of a long-term population monitoring study. Two islands in northern New Zealand - 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 four consecutive seasons from 2016/17 – 2019/20, and this section of the report focuses on the most recent 2019/20 season.

1.1.1 Key Objective and 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 2019/20 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 Island/Mauimua 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 is reported on here.

1.2 Methods

1.2.1 Study Sites and Dates

Figure 1.1: Locations of Ohinau and Lady Alice Islands.

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. The island is owned by local iwi, Ngāti 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 1.2). These study burrows have been monitored extensively since 2016 (Mischler 2016; Crowe et al. 2017; Crowe 2018a; Crowe & Bell 2019). There are an estimated total of 4,007 occupied burrows on the island (Crowe 2018a). A team of 2-3 personnel was based on the island during the following dates:

- **Trip 1:** 3 January 2020 – 27 January 2020; checking all study burrows to determine breeding status, identify adult birds breeding in all burrows, band/recapture adult birds seen on the surface at night and GPS track adult birds to determine the at-sea movements during the incubation period.
- **Trip 2:** 10 February 2020 – 28 February 2020; primarily GPS tracking of adult birds to determine the at-sea distribution during the chick-rearing stage but also banding and recapturing adult birds seen on the surface at night.

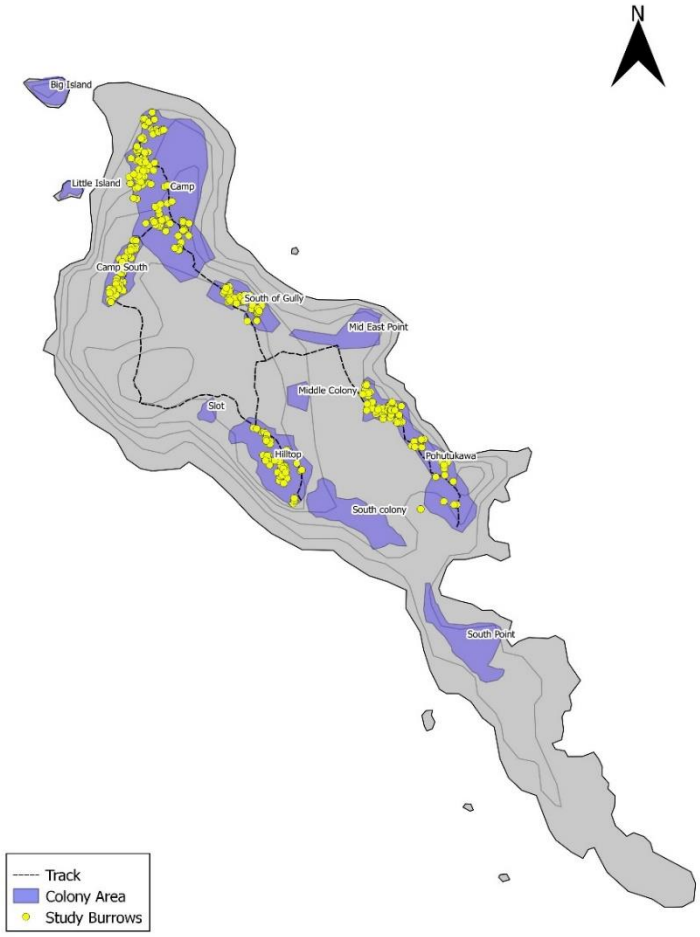

Figure 1.2: Map of Ohinau Island showing the location of all flesh-footed shearwater colonies and all marked study burrows.

Lady Alice Island

Lady Alice Island/Mauimua (Chickens/Marotere Islands, 35.89°S, 174.72°E) is a 155 ha Nature Reserve located 40km southeast of Whangarei (Figure 1.2). The most recent population survey estimates a total of 3217 occupied flesh-footed shearwater burrows on the island (Crowe & Bell 2019). Seven main colonies on Lady Alice Island have been identified (Figure 1.3). The current study focusses on 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 2018a; Crowe & Bell 2019). A team of 2-4 personnel was based on the island during the following dates:

- **Trip 1:** 7 January 2020 – 2 February 2020; checking all study burrows to determine breeding status, identify adult birds breeding in all burrows, band/recapture adult birds seen on the surface at night and GPS track adult birds to determine the at-sea movements during the incubation period.
- **Trip 2:** 17 February 2020 – 8 March 2020; primarily GPS tracking of adult birds to determine the at-sea distribution during the chick-rearing stage but also banding and recapturing adult birds seen on the surface at night.

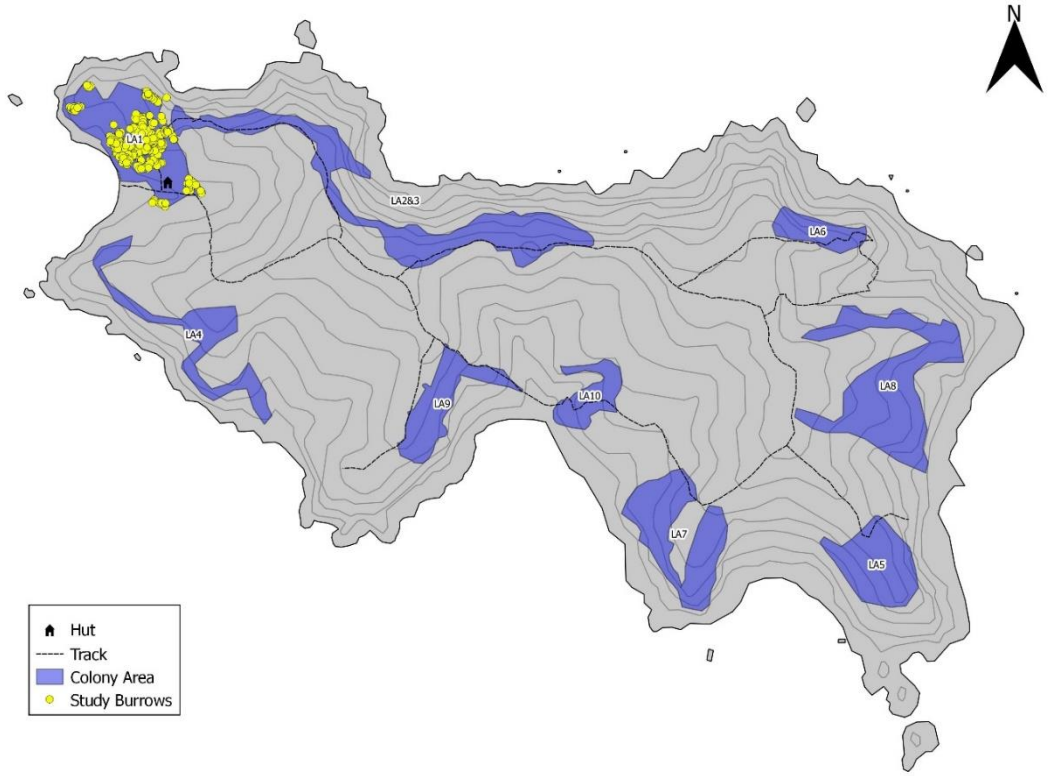

Figure 1.3: Map of Lady Alice Island showing the location of study burrows and all known flesh-footed shearwater colonies.

1.2.2 Field Methods

Each study burrow was checked every 5 – 7 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 some had measurements for wing length, head and bill length, minimum bill depth and weight taken. We also took a sample of two breast feathers to allow for DNA sexing of birds whose sex was not already known. 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. To reduce disturbance on incubating birds, mobile phones were held down the burrow through the entrance or hatch and used to video, under flashlight, the occupant. If correction fluid could be seen on the head of the bird then it was not removed from the burrow, and if no correction fluid was visible, the bird was removed and checked.

If no bird was present in the burrow, it was searched thoroughly for any evidence of a failed breeding attempt, such as egg shell fragments. Burrows deemed to be empty were all checked at least once more at a later date to confirm they were empty. Once an egg was found in a burrow and both partners were banded and identified, the burrow was left undisturbed for the remainder of the trip. This helped minimise disturbance to the birds and the 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 some 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 January trip. This was carried out as early as feasible during the trip to minimize 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 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 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 funnel in to a relatively small area to take off.

1.3 Results

Ohinau Island

A total of 274 study burrows were monitored during this season on Ohinau Island (Table 1). This consisted of 243 burrows monitored in the previous season and 31 new burrows. Four additional burrows were retired because they had collapsed, and had not had any flesh-footed shearwater activity in the previous two seasons.

Of the 274 study burrows, 79% (*n* = 216) were breeding burrows and 5% (*n* = 13) were non-breeding burrows. The remaining burrows were empty or held other species. A total of 94% (408 of 432) of birds in breeding study burrows were identified. We were able to successfully identify both partners for 90% (*n* = 195) of these breeding burrows (Table 1). 8% (*n* = 18) of breeding burrows had only one partner identified while the remaining three burrows 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 one had been extended by the occupants and the nest chamber had become inaccessible. This was confirmed with the burrowscope, but adult birds could not be extracted.

Lady Alice Island

A total of 288 study burrows were monitored on Lady Alice Island this season (Table 1.1). This consisted of 260 burrows monitored in the 2018/19 season and 28 new burrows. Four additional burrows were retired because they had collapsed, the entrance was too small for flesh-footed shearwaters, or there had been no activity in the burrow for the previous two seasons.

Of the 288 burrows, 70% (*n* = 202) were breeding burrows and 3% (*n* = 10) were non-breeding burrows. The remaining burrows were empty or held other species. A total of 89% (358 of 404) of birds in breeding study burrows were identified. We were able to identify both partners in 79% (*n* = 160) of breeding burrows. Nineteen percent (*n* = 38) of breeding burrows had only one partner identified and the remaining four burrows had no partners identified. These burrows had an egg present during the first check, but subsequent checks did not reveal any flesh-footed shearwaters in that burrow.

1.3.1 Burrow Occupancy and Breeding Success

Due to work and travel restrictions due to the COVID-19 pandemic, both Ohinau and Lady Alice islands could not be visited at the end of April/start of May. This meant that breeding success for the 2019/20 season was undetermined and no chicks were banded prior to fledging. 7% (*n* = 15) of breeding attempts on Ohinau Island and 9% (*n* = 18) of breeding attempts on Lady Alice Island had failed prior

to hatching. This is a very similar result to the 2018/19 season where 8% and 10% of breeding attempts failed prior to hatching on Ohinau and Lady Alice Island respectively.

Table 1.1.: Status of all study burrows monitored on Ohinau and Lady Alice Islands during the 2019/20 season.

Burrow Status	**Ohinau Island**	**Lady Alice Island**
Breeding		
- 0 partners	3	4
- 1 partner	18	38
- 2 partners	195	160
Total breeding burrows	216	202
Non-breeding		
- 1 bird	10	7
- 2 birds	3	3
Total flesh-footed shearwater burrows	229	212
Other species		
- *Little Penguin*		4
- *Grey-faced Petrel* (chick in January)	1	5
- *Sooty Shearwater*		1
Empty	44	66
Total Study Burrows	274	288
Retired	6	13

1.3.2 Banded Birds

During the 2019/20 season, 118 birds were banded on Lady Alice Island and 470 birds were banded on Ohinau Island (Table 1.2). With no trips to the islands in April/May, all birds banded this season were adults. In total, 3412 flesh-footed shearwaters have been banded during this study.

Table 1.2.: Number of flesh-footed shearwaters banded on both islands in the past five seasons.

Ohinau	2015/16	2016/17	2017/18	2018/19	2019/20	Total
Adult	90	528	182	210	470	1480
Chick	267	133	131	453	0*	984
Total	357	661	313	663	470	**2464**

Lady Alice	2015/16	2016/17	2017/18	2018/19	2019/20	Total
Adult	0	285	163	102	118	668
Chick	0	94	83	103	0*	280
Total	0	379	246	205	118	**948**

*No April/May trip to band chicks prior to fledging

Total banded during this study	**3412**

1.3.3 Recaptured Birds

The results for recaptured breeding adults were nearly identical to what was observed on both islands during the 2018/19 and 2017/18 seasons.

On Ohinau Island, 76% (*n* = 288) of birds that were identified as breeding last season were found to be breeding again this season. Of these birds, 99% (*n* = 284) were found breeding in the same burrow, while the remaining 1% of birds (*n* = 4) 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. However, some birds have been known to move 50m between burrows previously (G. Taylor pers. comm.).

On Lady Alice Island, 72% (*n* = 271) of breeding birds found in the 2018/19 season were found breeding again this season. The exact same result as the last two season was found with 90% of these being in the same burrow, and the remaining 10% found in a different study burrow.

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 four seasons on Lady Alice Island. Thirty-eight of the 111 recaptures were birds that were banded as adults in 2000. Twenty-four of these birds were recaptured this season, making these birds at least 25 years old now.

Of the 1010 adults that had been banded as part of this study from 2015-19, 52% (*n* = 529) have been recaptured again. For Lady Alice Island the result is higher with 67% (*n* = 370) of the 550 banded adults having been recaptured.

Five birds that were banded as chicks as part of the 2015/16 Ohinau Island cohort were recaptured this season. This marks the first lot of known-age birds to return and makes the age-at-first-return of these birds four years old. All of these birds were recaptured on the surface at night-time. All were in the same colonies that they fledged from and mostly within the same immediate area as their natal burrow.

No chicks have yet been recaptured that were banded at the Lady Alice colony as part of this study.

1.3.4 Management of Records of Banded Birds, Study Burrows and GPS 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.

All raw GPS data and associated GLS data from tracking of breeding adults have been deposited with the Marine Species and Threats team, Department of Conservation.

1.4 Discussion

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 the upcoming season. The majority of burrows are occupied by the same pair from season to season, and so occupancy of these marked study burrows has remained consistent. While there are a greater number of study burrows on Lady Alice Island, the birds that breed in these burrows show a tendency to shift around more than the birds on Ohinau Island. We will continue to target burrows closely, as birds that move burrows between seasons do not appear to move a great distance.

Burrows that have collapsed, are continually occupied by a different species, or remain inactive for multiple seasons, will be retired and new burrows will be added if required, to reach 200 study burrows per island. As the birds that shift burrows typically only move <10m from their former burrow, we will focus on adding burrows that are within this distance of the current network of study burrows.

While we could not determine breeding success in the 2019/20 season, a similar proportion of burrows failed prior to hatching as in the 2018/19 season and so it could be speculated that breeding

success would be similar to that of the 2018/19, with Lady Alice Island being around 50% and Ohinau around 60%.

Around 75% of flesh-footed shearwaters that bred in the 2018/19 season also bred this season. This is down marginally from the 80% and 81% observed in the two seasons prior. This indicates that flesh-footed shearwaters are mostly annual breeders. The true percentage of annual breeders is probably higher, as up to 10% of breeding birds have been shown to shift burrows between seasons.

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 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 based on a small sample size and is probably a reflection of the detectability of returned chicks, more so than survival. With five chicks having now been recaptured from the first cohort of the current study, we will continue to focus on night work to recapture surface birds and increase our sample size. Demographic parameters such as adult and juvenile survival rates can then be calculated by modelling mark/recapture data. The probability of recapture is situation- (surface or burrow) and age-dependent and most likely increases with age, up to a certain point (Barbraud et al. 2014). As such, we would expect to recapture a larger number of birds from the 2015/16 chick cohort next season and a small number of birds from the 2016/17 chick cohort.

2. GPS Tracking of Breeding Flesh-footed Shearwaters on Ohinau and Lady Alice Islands.

2.1 Introduction

Flesh-footed shearwaters are recognised as one seabird species that is at the greatest risk of being adversely impacted by unsustainably high rates of bycatch in commercial fisheries (Richard et al. 2020). To adequately manage this threat, a spatially-explicit model of bycatch risk is required, incorporating measures of fishing effort, fishing method and flesh-footed shearwater at-sea distribution and habitat use (Richard, et al., 2017). Foraging distributions and strategies can be highly variable between colonies of the same species, between individuals within the same colony and between breeding stages or years (Ainley et al. 2004; Bearhop et al. 2006; Ochi et al. 2009). As such, it is important to have fine-scale GPS data that covers all of these variables.

In the last ten years there have been multiple tracking studies on flesh-footed shearwaters to determine the at-sea distribution of breeding birds. In 2014, tracking of breeding birds during the incubation and chick-rearing periods occurred on Ohinau Island and yielded a large number of tracks (Waugh et al. 2014). This work showed that adults from Ohinau Island foraged mainly inshore off the east coast of New Zealand and offshore east of the Chatham Rise towards the Louisville Ridge.

Tracking of birds from the Lady Alice colony was carried out as part of the same Waugh et al. (2014) study but only one track was obtained. This provided justification for further tracking on Lady Alice Island to determine the at-sea distribution of birds from a Hauraki Gulf colony. Successful GPS tracking of breeding flesh-footed shearwaters on Lady Alice Island was carried out in 2017 and 2018 during chick-rearing and incubation respectively (Kirk et al. 2017; Crowe 2018b). The results showed that breeding adults from Lady Alice Island utilised foraging areas mainly to the north and west of the North Island but also had some overlap with Ohinau Island birds off to the east of the North Island. The 2018 season was considered a La Niña season, which typically result in poor oceanic productivity, and as a result the observed foraging distribution may have resulted from atypical foraging behaviour of tracked birds.

While tracking birds from both colonies has been overall successful, it has led to questions of whether observed differences in foraging areas is due to seasonal/annual variation in foraging behaviour or whether different colonies truly utilise different foraging areas. Here we address the problem of inter-colony, intra- and inter-seasonal variation by GPS tracking breeding adults on Ohinau Island and Lady Alice Island simultaneously during both breeding stages (incubation and chick-rearing) within the same year.

2.2 Methods

2.2.1 Field Methods

Tracking took place on Ohinau and Lady Alice islands during January (incubation period) and February (chick-rearing period) 2020. A selection of study burrows on both islands were fitted with a one-way flap, or 'burrowgate'. We targeted burrows that had an entrance considered suitable to house a burrowgate (Figure 2.1). During incubation, the deployment of a burrowgate on a burrow allowed the partner of an incubating bird to enter the burrow at changeover but would prevent the departing partner from leaving the burrow. Where both partners were captured inside the burrow, the departing bird was weighed and a GPS and saltwater immersion logger were attached. During chick-rearing, adult birds would typically make brief visits to their breeding burrows at night to feed their chick and would be captured in the burrow. All burrows which had burrowgates fitted were checked multiple times per night and a final check prior to dawn ensured that no birds were trapped inside the burrow for the following day.

Figure 2.1: A burrow on Ohinau Island with a burrowgate fitted to the entrance.

Some birds on Lady Alice Island were captured on the surface at night time. We focussed our effort primarily on an area known as the "take off tree". In this spot birds "funnel" down from burrows higher up into a small area where they either climb a large karaka (*Corynocarpus laevigatus*) tree or access a natural path down to the coast where they depart the island (M. Bell, P. Crowe pers. comm.). Birds with correction fluid on their head, identifying them as birds from our study burrows, were targeted and caught.

All birds intercepted either in their burrow or on the surface were fitted with a GiPSy-5™ GPS device (manufactured by TechnoSmart™ Europe) and an Intigeo-C330™ GLS device (manufactured by

Migrate Technology™). The GPS devices were programmed to record one position fix every 5 minutes. The GLS devices were programmed to record saltwater immersion every 30 seconds and then this data was "binned" every five minutes to give a count of between 0 and 10 corresponding to the number of 30-second intervals that were "wet" (defined as a conductivity score of >63; the "wet count"). For example, if the bird stayed on the water for the entire five minutes, the wet count was 10. If the GLS device was wet for only 30 seconds the recorded wet count was one.

The GiPSy 5™ GPS devices were sealed in heat-shrink plastic tubing to prevent saltwater damage. The GPS devices were attached to the dorsal mantle feathers on the birds back using five strips of waterproof Tesa tape® and superglue (Figure 2.2). GLS devices were attached to each birds' metal leg band using two small, plastic cable ties. Attachments typically took less than 15 minutes. Once the devices had been attached, the bird was placed back in its burrow and the burrowgate was removed to allow the bird to depart that night.

Figure 2.2: Flesh-footed shearwater with a GPS attached to its back.

Each bird was weighed before being fitted with GPS and GLS devices and weighed again when the devices were retrieved to obtain information on body condition and to assess the impact of carrying the devices.

GPS devices weighed either 15g or 17g (including heat shrink and tape). Where practical we fitted lighter birds (600-680g) with a 15g device and heavier birds (≥680g) with a 17g device. During incubation – when adult birds' are typically at their lightest – device weight was, on average, 2.4% (range 2.2% - 2.6%) of the birds' body mass. During chick-rearing – when adult birds' weight can be highly variable – device weight averaged 2.3% (range 1.9% - 2.6%) of the birds' body weight. All birds were well below the 3% of body mass threshold suggested by Phillips et al. (2003) for device attachment to Procellariiform birds and 127 of 143 total deployments (both islands, both stages) were

below the 2.5% threshold we proposed to mitigate potential negative impacts (see AEC353 and Crowe 2018b).

Retrieving loggers during incubation was straightforward as burrows were being checked every 4-5 days as part of the demographic study. Care was taken to not disturb the burrow too often and where possible the burrow was checked using a phone to check the incubating birds head for correction fluid or back for a GPS. Some searching for tracked birds on the surface occurred, mainly in the two hours after dark when birds were arriving on the island and the two hours before dawn exodus. This was primarily aimed at getting tracked birds whose burrows had failed but may still be returning to the island and spending time on the surface rather than in a burrow.

To retrieve loggers during chick-rearing we utilised the burrowgates again to intercept birds on their subsequent visit to their burrow. Removing devices from birds typically took less than 5 minutes.

In addition to the GPS tracking carried out during the incubation and chick rearing stages, a total of 59 (31 on Ohinau Island and 28 on Lady Alice Island) GLS devices were deployed on breeding adults prior to our departure from the islands in late February/early March. We intend to retrieve these in December 2020 once these birds had completed their annual migration to the north Pacific and back. These GLS devices were programmed to sample ambient light levels every five minutes (used for geolocation) as well as temperature, conductivity and wet/dry data.

2.2.2 Data entry and analysis

Data was downloaded from both devices every time loggers were retrieved from a bird. In a few cases the GPS loggers failed or were not retrieved and these are noted in the table in Appendix 7.2. The GPS device data was first cleaned to remove any clear outlying points that resulted from a poor satellite fix or a device malfunction. Any data recorded by the devices both pre-deployment and post-removal were also removed. Wet count data collected from the GLS devices were classified into one of three behaviour types, using a classification method previously used to determine the at-sea behaviour of flesh-footed shearwaters and black petrels (Procellaria parkinsoni) from tracking data (Kirk, et al., 2017; Crowe, 2018; Bell et al. 2019). Flight was classified as positions with a wet count of zero or one (mostly dry), resting/rafting positions had a wet count of nine or ten (mostly wet) and foraging behaviour was classified as positions with an intermediate wet count of between two and eight inclusive. Each GPS location was then paired with the corresponding behaviour type in Microsoft Excel by matching the time/date stamps recorded by each device. For birds which we could not determine the trip length from the GPS data, the GLS data was used to approximate the departure and/or return time. All means are presented with ± standard deviation.

To assess the relative rates of inshore (<50km offshore) versus pelagic (>50km offshore) foraging trips, a 50km polygon was plotted around the coast of New Zealand. We then calculated the percentage of points that fell within the 50km polygon (shelf) and the percentage that fell outside (pelagic) for each colony and each breeding period. As all GPS devices recorded a fix at 5-minute intervals, each point represents the same sampling period and so the number of points inside and outside the 50km can be considered a measure of the relative amount time spent inshore versus pelagic.

Spatial analyses were carried out using QGIS version 2.18. To generate the kernel density maps from the GPS data, a smoothing parameter (radius) of 100km was used and applied to a 2km x 2km grid over the entire extent of the tracking data.

2.3 Results

2.3.1 Control Birds and Impact of Tracking

As our April/May trips to Ohinau and Lady Alice Islands were cancelled due to the COVID-19 pandemic, we were not able to determine the breeding success of any burrows and thus compare breeding success between burrows with tracked birds and control burrows without tracked birds.

On Ohinau Island during incubation, tracked birds gained on average 126g (±44g SD, n = 20) of body mass. This represents an average increase of 20% body weight per foraging trip or an average increase of 1.8% of body mass per day. On Lady Alice Island during incubation, tracked birds gained on average 100g (±40g SD, n = 16) of body mass. This represents an average increase of 17% body weight per foraging trip or an average increase of 1.1% of body mass per day. When birds tracked from both islands are combined, the average body weight change was 19% which is significantly larger than the 12% observed when tracking birds during the same breeding period in 2018 (two-sample t-test, t_{27} = 2.15, $p < 0.05$).

During chick-rearing, weights of adults birds were highly variable and depended on whether the adult was foraging primarily for itself (weight increase) or for its chick (weight decrease). On Ohinau Island, tracked birds gained an average of 15g per deployment which equates to an average increase of 0.4% of body weight per day (±3.5%, n = 39). Control birds lost an average of 12g per foraging trip which equates to an average decrease of 0.8% of body weight per day (±3.8%, n = 48). There was no significant difference between tracked and control birds indicating that our manipulation during chick-rearing did not adversly impact the foraging behaviour or foraging ability of tracked birds (two-sample t-test, t_{87} = 1.56, p = 0.12).

On Lady Alice Island, tracked birds lost an average of 9g per foraging trip which equates to an average loss of 0.3% of body weight per day (±4.2%, n = 39). Control birds lost an average of 24g per foraging trip which equates to an an average loss of 1.7% of body weight per day (±5.0%, n = 33). There was no significant difference between tracked birds and control birds (two-sample t-test, t_{61} = 1.19, p = 0.12).

2.3.2 Ohinau Island

Incubation

We deployed devices on 26 adult flesh-footed shearwaters (17 male, 8 female, 1 unknown) in January 2020. Each bird was from a different burrow i.e. we did not track both the male and female from a pair. Two individuals were not recaptured in January or February and so these devices were not retrieved. One bird returned with no GPS device attached and two returned with water logged devices which yielded no data. Of the remaining 21 birds, all but two had GPS tracks of the entire foraging trip. A summary of all GPS deployments is presented in Appendix 6.1 of this report.

The average trip duration for birds tracked from Ohinau during incubation was 11.8 days (± 2.5 days, n = 23, range 6 – 16 days). The majority of trips were 11 or 12 days in duration (Figure 2.3). For birds that we were able to obtain complete tracks, the average distance travelled on each trip was 4665 km (± 2016 km, n = 19, range 970 – 8928 km). This equates to an average of 394 km (± 130 km, n = 21, range 162 – 595 km) travelled per bird per day. The average maximum range from Ohinau Island was 1352 km (± 823 km, n = 21, range 70 – 2901 km). There was no discernible difference between males and females in distribution, duration or distance of trips.

Adults undertaking foraging trips during incubation on Ohinau Island could roughly be split in to one of two categories: birds who foraged off the east coast of the North Island and birds who foraged

either east or west of the Louisville Ridge. Seven of the twenty-one birds foraged inshore off the east coast. Their foraging was highly concentrated around Hawke's Bay but did stretch from East Cape to the Wairarapa coast. Thirteen of the twenty-one tracked birds foraged around the Louisville Ridge. Figure 2.4A shows several darker spots to the east and west of the Louisville Ridge with each of these darker spots representing one or two individuals' concentrated foraging area.

One of the remaining two birds visited and foraged in both of these locations during the same foraging trip while the other (67097) exhibited a strange behaviour and carried out short 1-2 day foraging trips along the shelf break east of Ohinau Island. This birds' partner remained in the burrow incubating until they switched over after 6 days.

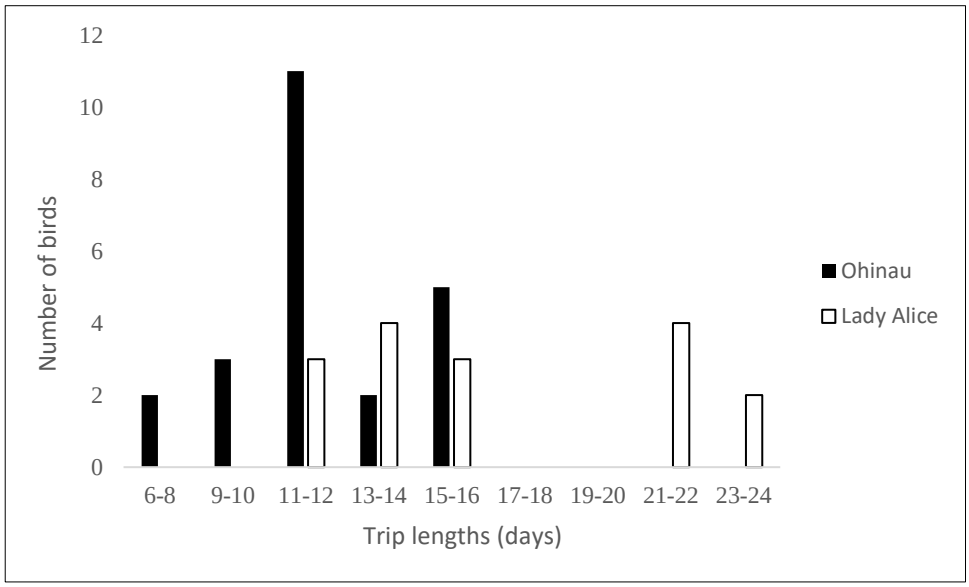

Figure 2.3: **Number of days of each foraging trip for flesh-footed shearwaters tracked during incubation on Ohinau and Lady Alice Islands in January 2020.**

Chick-rearing

A total of 27 adult flesh-footed shearwaters (11 male, 16 female) were GPS tracked from 20 different burrows in February 2020. Seven burrows had both the male and female birds tracked. There were a total of 44 GPS deployments on the 27 birds. Of these 44 deployments, 39 were subsequently retrieved. The remaining five devices will be shed by the birds during the next moult. A summary of all GPS deployments is presented in Appendix 6.2 of this report. One of the GPS devices suffered water damage and no GPS data were retrieved. The remaining 38 retrievals yielded complete tracks of 50 seperate foraging trips.

Foraging trips during chick-rearing varied in all aspects. The average trip duration was 3.1 days (± 3.2 days, *n* = 51, range 1 – 12 days) with the majority of trips (71%, *n* = 36) being one or two days long (Figure 2.7). The average distance travelled on each trip was 1205 km (± 1725 km, *n* = 50, range 970 – 8928 km). This equates to an average of 274 km (± 160 km, *n* = 50, range 64 – 639 km) travelled per bird per day. The average maximum range from Ohinau Island during chick-rearing was 409 km (± 629 km, *n* = 50, range 16 – 2087 km). There was no discernible difference between males and females in distribution, duration or distance of trips.

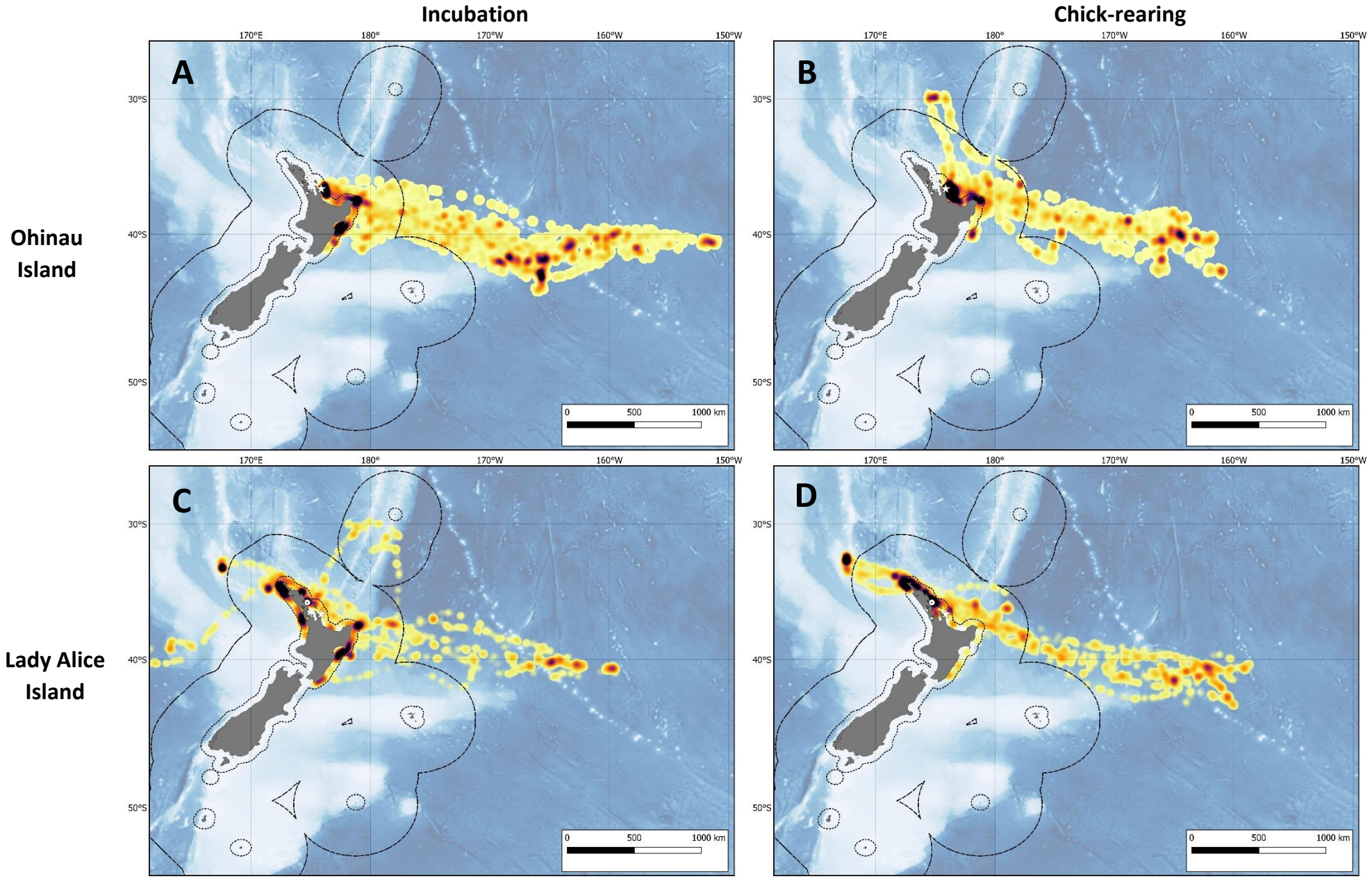

Figure 2.4: Kernel density maps of all flesh-footed shearwater foraging points separated by island and breeding stage. Darker areas represent a greater concentration of foraging activity. The location of Ohinau Island is shown as a white star and Lady Alice Island a white circle. Dotted black line indicates the 50km break and dashed black line indicates the New Zealand EEZ.

During chick-rearing, Ohinau Island birds exploited similar foraging areas to where they did during incubation (Figure 2.4B) but there were some subtle differences. Areas more local to Ohinau Island, such as Bay of Plenty, appeared to become more important while the area around Hawke's Bay became less important. Individuals that were tracked multiple times generally exhibited a dual foraging strategy; undertaking one or two short (1 – 3 days), chick-provisioning, trips followed by one longer (≥4 days) trip to maintain their own body weight and condition (Figure 2.5). Short trips were mostly inshore around the Bay of Plenty while long trips were out to around the Louisville Ridge, akin to those foraging trips during incubation (Figure 2.6).

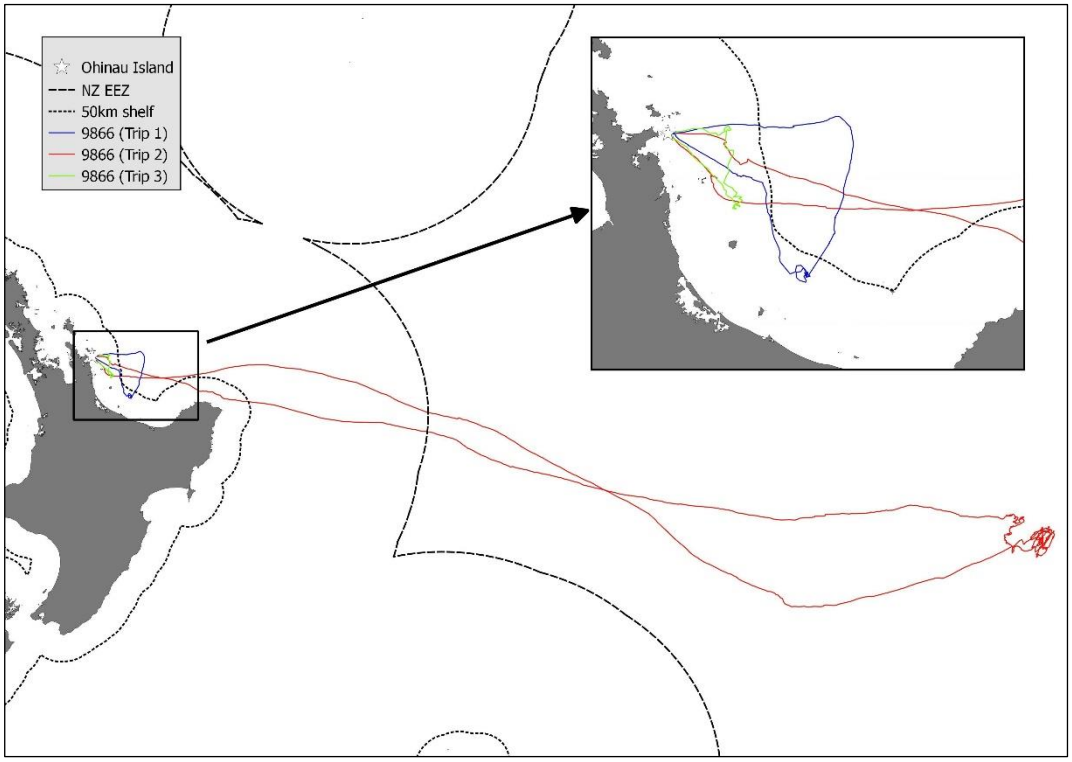

Figure 2.5: **GPS tracks of a bird tracked from Ohinau Island for three separate foraging trips exemplifying a dual-foraging strategy. The location of Ohinau Island is shown as a white star. Dotted black line indicates the 50km break and dashed black line indicates the New Zealand EEZ.**

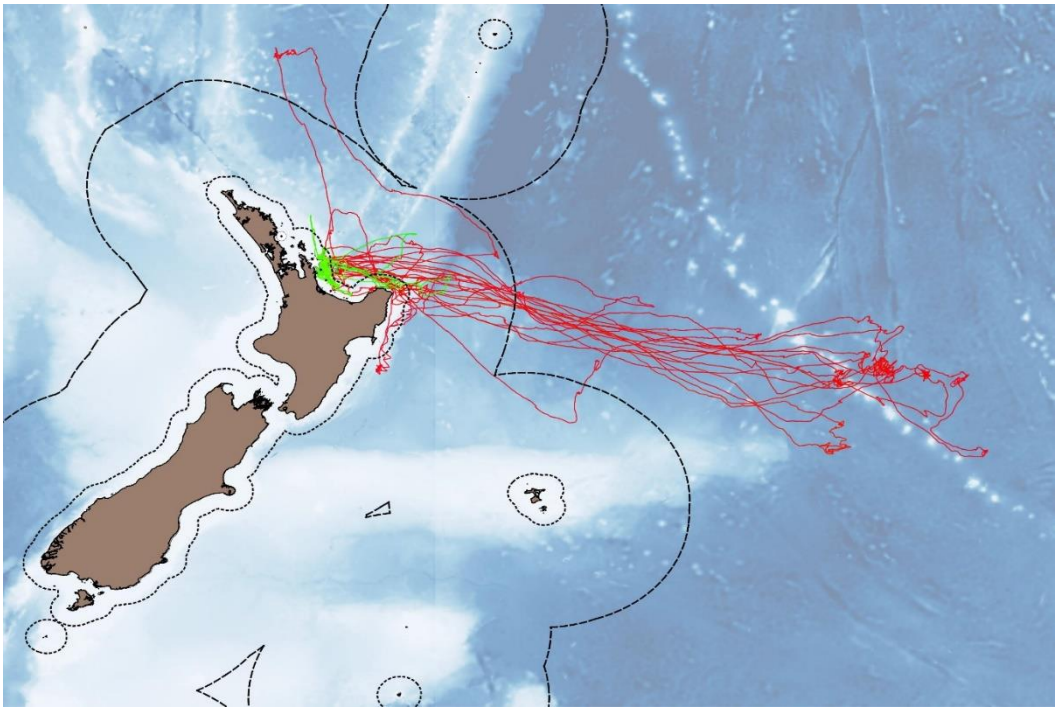

Figure 2.6: **All GPS tracks from Ohinau Island during the chick-rearing period. Short foraging trips (1–3 days) are represented by green tracks and long foraging trips (≥4 days) are represented by red tracks. The location of Ohinau Island is shown as a white star. Dotted black line indicates the 50km break and dashed black line indicates the New Zealand EEZ.**

2.3.3 Lady Alice Island

Incubation

We deployed devices on 29 adult flesh-footed shearwaters (17 male, 10 female, 2 unknown) during incubation in January 2020. Each bird was from a different burrow i.e. we did not track both the male and female from a pair. Two birds had not departed the island after three days and so had their devices removed. Seven individuals were not recaptured in January or February and so these devices were not retrieved. Of the 20 devices retrieved, 17 were complete tracks and 3 were incomplete tracks. Four of the complete tracks were discarded from our analyses below, as they were believed to represent non-natural foraging trips in response to being handled and having loggers attached. All discarded tracks were three days in length and were of birds who had temporarily abandoned their nest before returning and resuming incubating.

Birds tracked from Lady Alice during incubation had an average trip length of 16.6 days (± 4.6 days, n = 16, range 11 – 23 days) which was significantly longer than birds tracked from Ohinau Island during the same period (two-sample t-test, t_{21} = 3.73, p < 0.01). For birds that we were able to obtain complete tracks, the average distance travelled on each trip was 4734 km (± 2132 km, n = 16, range 2300 – 8955 km). The average maximum range from Lady Alice Island was 944 km (± 709 km, n = 15, range 249 – 2335 km). There was no discernible difference between males and females in distribution, duration or distance of trips.

The spatial distribution of Lady Alice Island birds foraging during incubation was variable but tracked birds could roughly be split in to two groups. The first group of birds (*n* = 7) followed a similar foraging distribution to Ohinau Island birds tracked during the same period, heading either east out towards the Louisville Ridge or south along the east coast of the North Island between East Cape and Wairarapa. The second group of birds (*n* = 9) went north from Lady Alice Island and foraged inshore off the West Coast of the North Island or offshore in the Tasman Sea (Figure 2.4C).

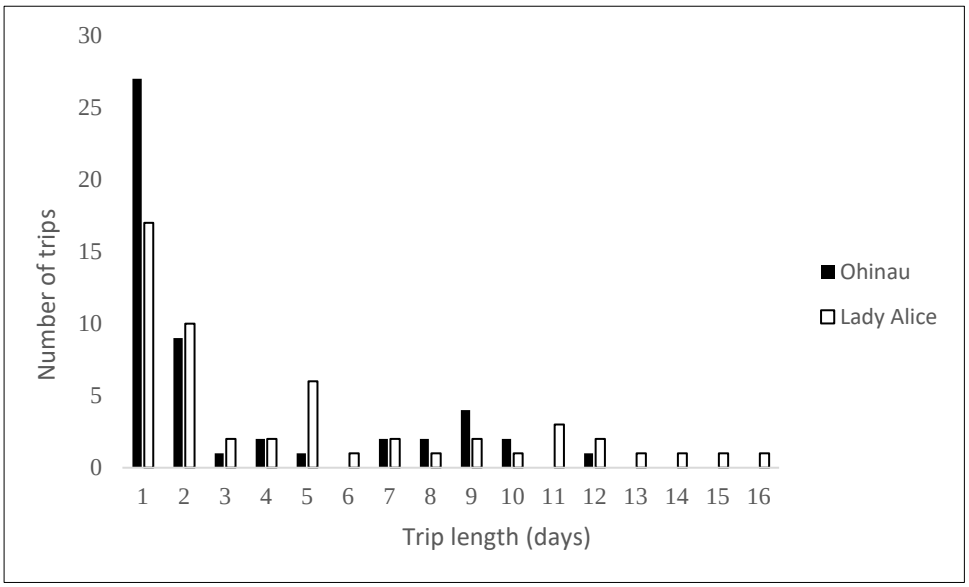

Figure 2.7: Number of days of each foraging trip for flesh-footed shearwaters tracked during the chick-rearing period on Ohinau and Lady Alice Islands in February 2020.

Chick-rearing

A total of 34 adult flesh-footed shearwaters (18 male, 16 female) were GPS tracked from 22 different burrows in February 2020. Twelve burrows had both the male and female birds tracked while the remaining ten burrows had either the male or female tracked. There were a total of 43 GPS deployments on the 34 birds. Of these 43 deployments, 41 were subsequently retrieved. The remaining two devices will be shed by the birds during the next moult. A summary of all GPS deployments is presented in Appendix 6.4 of this report. The 41 devices retrieved yielded 50 complete tracks and 3 incomplete GPS tracks of seperate foraging trips.

Foraging trips during chick-rearing varied in all aspects. The average trip duration was 4.8 days (± 4.4 days, *n* = 53, range 1 – 16 days) which was significantly longer than birds tracked from Ohinau Island during the same period (two-sample t-test, t_{95} = 2.16, $p < 0.05$). 51% of trips (*n* = 27) were one or two days long (Figure 2.7). The average distance travelled on each trip was 1536 km (± 1826 km, *n* = 49, range 85 – 6547 km). This equates to an average of 308 km (± 28 km, *n* = 53, range 64 – 639 km) travelled per bird per day. The average maximum range from Lady Alice Island during chick-rearing was 477 km (± 694 km, *n* = 49, range 12 – 2381 km). There was no discernible difference between males and females in distribution, duration or distance of trips.

During chick-rearing, Lady Alice Island birds exploited many similar foraging areas to where they did during incubation (Figure 2.4D). There was a nearly-continuous, inshore, foraging "hotspot" stretching from Little Barrier Island in the Hauraki Gulf all the way up to Cape Reinga and around to 90-mile beach. A dual foraging strategy was evident again in individuals tracked multiple times. During short foraging trips (1 – 3 days) all birds remained on the eastern side of the North Island and the majority of these trips were spent foraging around inshore areas (Figure 2.8). During long foraging trips (≥4 days), the majority of birds ventured further afield going to either Three Kings Islands/90 Mile Beach, West Norfolk Ridge or out towards Louisville Ridge (Figure 2.4D). Like Ohinau Island birds tracked during the same period, the foraging area down the east coast of the North Island was less important during chick-rearing with only one individual carrying out a long foraging trip down the east coast to the Wairarapa.

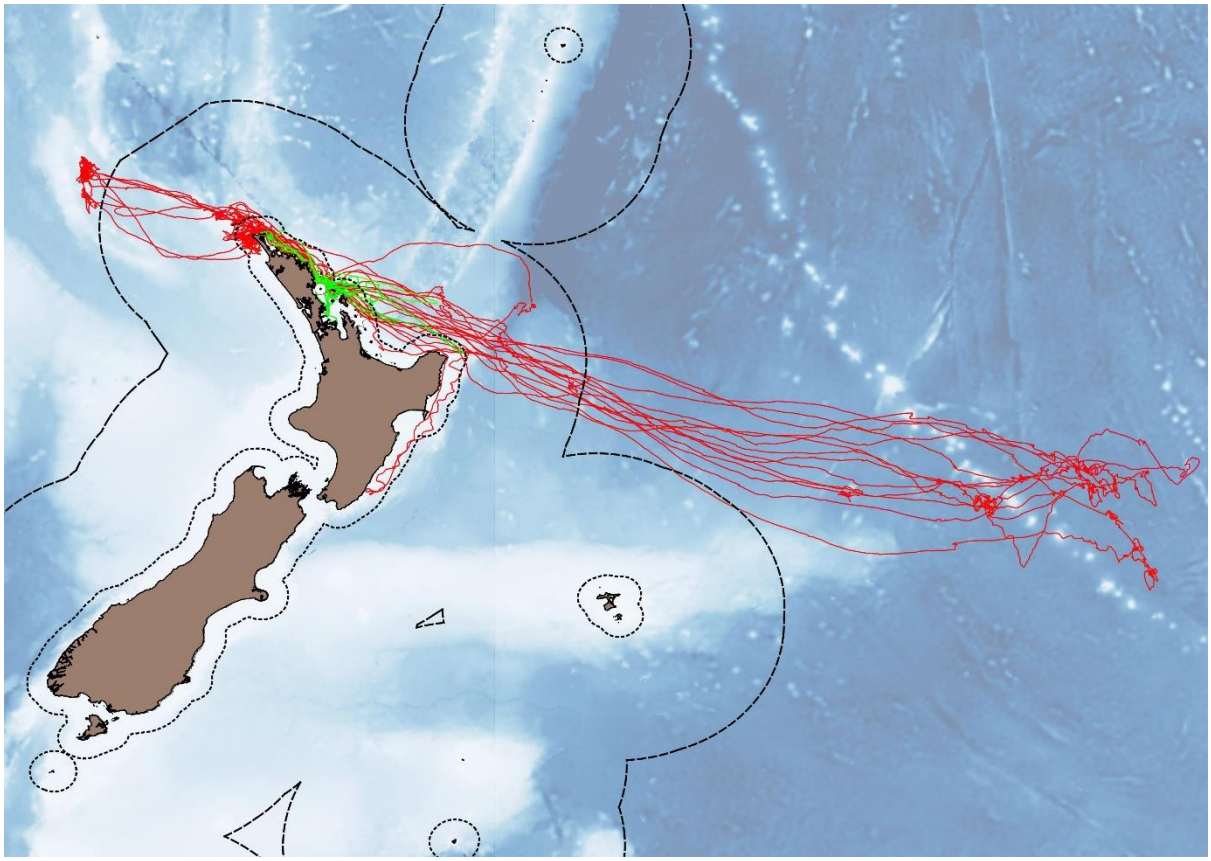

Figure 2.8: **All GPS tracks from Lady Alice Island during the chick-rearing period. Short foraging trips (1 – 3 days) are represented by green tracks and long foraging trips (≥4 days) are represented by red tracks. The location of Lady Alice Island is shown as a white circle. Dotted black line indicates the 50km break and dashed black line indicates the New Zealand EEZ.**

2.3.4 At-sea Behaviour

The classification method used here to determine behaviour type is very simple, however visual inspection of Figure 2.9 demonstrates that using these thresholds of saltwater immersion can effectively distinguish between flying, resting (or rafting) and foraging. When each track is broken

down in this way, most birds appear to depart their breeding colony and undertake a direct and rapid flight to a specific (perhaps known) location where they then spend several days flying around at a slower pace foraging and spending time resting or rafting on the water surface. They may visit several other locations to forage and rest before undertaking a similarly rapid and direct flight back to their breeding colony.

There were some small differences in at sea-sea behaviour between islands and breeding stages, however, none of these differences were significant (Table 2.1). The total time spent foraging was highly consistent with 12-14% of total time spent foraging during both breeding stages and at both locations. We found no significant relationship between individual foraging effort (time) and change in body weight for either island or breeding stage.

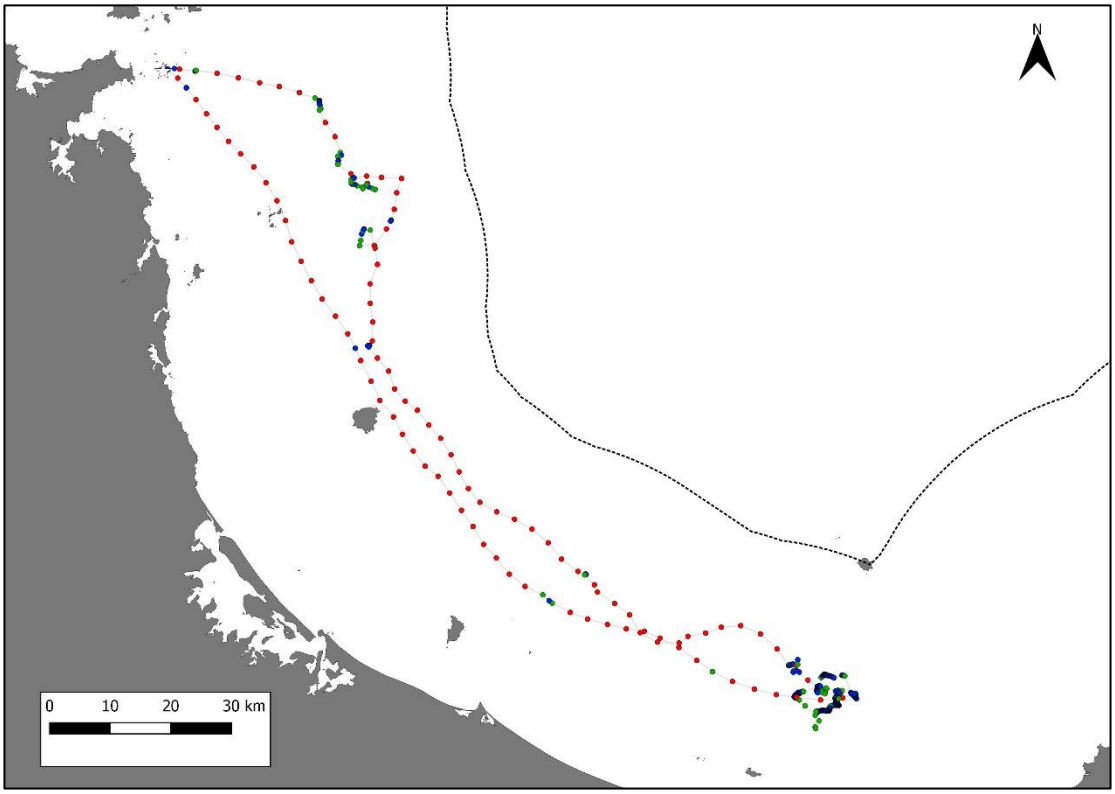

Figure 2.9: **An example of a flesh-footed shearwater foraging trip with each GPS point classified as one of the three behaviour types: flight (red); rest (blue); or foraging (green). The location of Ohinau Island is shown as a white star. Dotted black line indicates the 50km break.**

Table 2.1: Mean (± Standard Deviation) proportion of time spent performing each of the three behaviour types for the two different breeding stages and islands.

		Flight	Rest	Forage
Ohinau	Incubation (*n* = 24)	48% (±13%)	40% (±12%)	12% (±3%)
	Chick-rearing (*n* = 50)	37% (±21%)	49% (±18%)	14% (±6%)
Lady Alice	Incubation (*n* = 16)	38% (±13%)	50% (±12%)	12% (±2%)
	Chick-rearing (*n* = 52)	42% (±14%)	46% (±12%)	12% (±4%)

On Ohinau Island, more time was spent in pelagic waters than inshore during both breeding stages (Table 2.2). On Lady Alice Island, more time was spent in pelagic waters during chick-rearing but a greater amount of time was spent foraging inshore during the incubation stage.

Table 2.2: Total proportion of time spent inshore versus pelagic for each island and breeding period. Note: this is all GPS points for all birds from each island and breeding period combined.

		Inshore (< 50km)	Pelagic (> 50km)
Ohinau	Incubation	37%	63%
	Chick-rearing	33%	67%
Lady Alice	Incubation	54%	46%
	Chick-rearing	40%	60%

2.4 Discussion

While we could not determine if there was an impact on the breeding success of burrows with tracking manipulation, there was no apparent impact of tracking on the individual birds' body weight or condition. During incubation, all tracked birds gained on average 19% of their body weight on foraging trips. While this is not at the 25% level increase of birds observed at Bethell's Beach (G. Taylor pers. comm.), it was significantly greater than what was observed when tracking birds during the same period in 2018 (Crowe 2018b). Reducing the weight of the GPS devices and lowering the maximum device-body weight threshold to 2.5% appears to have alleviated the negative impacts that we encountered during tracking in 2018.

Individuals from Lady Alice Island had incubation foraging trip durations 4.8 days longer than individuals from Ohinau Island. However, they had remarkably similar average distance travelled (4734km Lady Alice; 4665km Ohinau Island). This is reflected by the behavioural analysis where birds from Lady Alice Island spent 10% more time than Ohinau Island birds resting/rafting on the water surface. Lady Alice birds also had significantly longer trip durations during chick-rearing, spending an additional 1.6 days away from the colony on average. It is unclear why Lady Alice Island birds spent more time away during incubation but during chick-rearing it is probably due to the timing of the field trips with the field team on Lady Alice Island beginning tracking one week later than the field team on Ohinau Island. Egg-laying is highly synchronised between colonies and so eggs are likely to be hatching at the same times, around late January-early February (Bell et al. 2017). Like most Procellariforms, flesh-footed shearwater chicks are fed on most nights in the early stages after hatching but as the chick grows, the period between feeding increases (Marchant & Higgins 1990).

Birds tracked from Lady Alice and Ohinau Island showed considerable overlap in foraging distribution during both breeding stages illustrating that birds from different breeding colonies do mix at sea. Approximately half of birds tracked from Lady Alice Island during the incubation period foraged in the same areas as birds tracked from Ohinau Island. The remaining birds foraged mainly on the west coast of the North Island from Manukau Harbour to Cape Reinga and on the West Norfolk Ridge. These areas were identified as foraging hotspots during previous GPS tracking of breeding birds from Lady Alice Island (Kirk et al. 2017; Crowe 2018b). The West Norfolk Ridge location has also been identified as an important foraging location for breeding Black Petrels (Bell et al. 2019). Both black petrels and flesh-footed shearwaters are known to follow fishing boats, and this area is frequented by many commercial fishing vessels (Friesen et al. 2017; Global Fishing Watch 2020).

The area around Louisville Ridge is highly important to flesh-footed shearwaters from both colonies during both breeding periods. The Louisville Ridge is unique in the southwest Pacific region as the only feature between the New Zealand Plateau and the East Pacific Rise that penetrates the upper bathyal zone (Grecian et al. 2016). The eastward flowing deep water currents in South Pacific hit these seamounts and this creates an upwelling of cool, nutrient-rich water from the sea floor which feeds phytoplankton growth (Genin & Dower 2007). In turn, this has a bottom-up effect, attracting zooplankton and ultimately fuelling higher trophic levels like fish and top predators such as seabirds. This area has been shown to be immensely important for an array of seabirds during breeding- and non-breeding seasons including Antipodean Wandering Albatross (*Diomedea antipodensis*; Walker & Elliott 2006), broad-billed prions (*Pachyptila vittata*; Grecian et al. 2016), and Chatham Island petrel (*Pterodroma axillaris*; Rayner et al. 2012) and Chatham Island taiko (*Pt. magentae*; G. Taylor pers. comm.). This area is also heavily targeted by commercial fisheries (Global Fishing Watch, 2020) and as such has implications for conservation management.

During chick-rearing, inshore foraging areas more local to each of the breeding colonies had greater importance. Ohinau Island birds generally foraged inshore to the east and south while Lady Alice foraged to the north. When combined, there is a near-continuous foraging hotspot stretching inshore from 90-mile beach around Cape Reinga and down the east coast to East Cape. This result is contradictory to the total amount of time spent over inshore seas where Ohinau and Lady Alice birds spent 33% and 40% of their time respectively. This contradiction is explained by the dual foraging strategy where chick-provisioning trips are typically very short (1-3 days) and concentrated locally to an area approximately 100km radius from the breeding colony. These short trips are interchanged with longer, self-provisioning, trips of 4-16 days aimed to maintain the adults own body weight and condition. The ratio of chick-provisioning trips to self-provisioning trips seems to vary and is likely dependent on the chick's age and body condition of the adult.

Birds tracked from Ohinau Island followed a nearly identical foraging distribution to individuals tracked in January and February 2014 (Waugh et al. 2014). This suggests that foraging areas can remain consistent between breeding seasons and there is possibly minimal variation in areas being exploited by flesh-footed shearwaters.

3. Conclusions and Recommendations

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 new tracking data presented here 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 at-sea distribution data will be retrieved from up to 59 GLS's carried by adults during the 2020 non-breeding season.

In the upcoming 2020/21, population estimates will be carried out on Whatupuke and Coppermine Islands (Objective 2). The four islands that we have already surveyed; Middle, Ohinau, Lady Alice and Motumahanga Islands, have all shown substantial increases from previous estimates. These estimates have accounted for an additional 7500 breeding pairs, which represents at least a 50% increase on the 10,000 – 15,000 estimate given by Waugh et al. (2013). The population estimates for Coppermine and Whatupuke Islands will provide greater insight into the trends of flesh-footed shearwaters breeding in New Zealand.

As much time as practical will continue to be invested in to recapturing birds on the surface at night-time on Ohinau and Lady Alice Islands. For the coming season, field teams will be established on each island prior to the commencement of egg laying (i.e. from the end of November). This has been found to be the most active period for flesh-footed shearwaters on the islands with immense numbers of breeders and non-breeders present on the surface at night-time. On the same trip we will determine the egg-laying dates for all study burrows on both islands and draw comparisons to the 2016/17 season when this was last measured simultaneously for both islands (Objective 5).

4. Acknowledgements

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6. Appendices

6.1 Summary of GPS deployments on Ohinau Island during incubation (Jan 2020)

Burrow	Band	Sex	Trip Length (days)	GPS Track (days)	Complete Track?	Trip Distance (km)	Max Range from Colony	Flight	Rest	Forage	Δ Weight (g)	Δ Body Mass (%)	% Body Mass change per day	Notes
CC05	67679	F	8	8	Y	2169	354	30%	55%	15%	40	6%	0.75%	
CC45	54548	M	15	15	Y	7393	1753	60%	31%	9%	120	20%	1.33%	
CC48	64008	F	13	13	Y	3616	918	35%	54%	11%	170	25%	1.92%	
CS02	67097	M	6	6	Y	970	70	25%	62%	13%	110	17%	2.91%	Bird returned to island some nights
CS08	67017	F	14	14	Y	3615	549	28%	61%	11%	115	19%	1.37%	
CS27	67025	F	11	11	Y	5977	2101	63%	27%	10%	170	28%	2.58%	
CS54	64005	M	12	12	Y	2970	381	35%	56%	10%	160	25%	2.08%	
HT02	66932	F	9	8	N	3475	1446	57%	27%	15%	105	18%	2.01%	
HT11	66106	F	15	15	Y	8928	2901	61%	26%	13%	190	32%	2.15%	
HT22	64017	F	11	11	Y	6237	2364	61%	30%	9%	105	17%	1.50%	
HT30	67009	M	11	11	Y	5037	1737	50%	39%	11%	160	26%	2.40%	
HT37	67562	M	11	11	Y	2496	291	28%	57%	15%	110	16%	1.47%	
HT39	67553	M	11	0	N			65%	25%	10%	160	27%	2.49%	GPS water logged, no data
HT46	66278	M	10	10	Y	2478	320	37%	47%	16%	105	17%	1.72%	
HT49	64019	U			N									Did not return
PK11	66563	M	12	12	Y	4758	1733	50%	40%	10%	90	15%	1.23%	
PK16	66218	M	10	10	Y	2768	374	36%	48%	17%	10	2%	0.15%	
PK24	67039	M			N									Did not return
PK41	67087	M	11	11	Y	5638	1763	68%	23%	10%	155	24%	2.22%	
PK60	66601	M	11	11	Y	5456	2094	58%	35%	8%	135	20%	1.83%	
PK62	67461	M	13+	13	N	5102	1670	55%	33%	13%				Device retrieved in Feb; GPS died before return
SG02	66234	M	16	0	N			52%	37%	11%				Device retrieved in Feb; GPS water logged, no data
SG03	66269	M	12	12	Y	5013	1732	54%	38%	8%	120	20%	1.64%	
SG05	67600	F	12	12	Y	7006	2468	61%	29%	9%	180	30%	2.50%	
SG16	66118	M	15	15	Y	6101	1369	58%	28%	14%				Device retrieved in Feb
SG37	66273	M	16	0	N			36%	55%	10%				Bird recaptured in Feb; device lost

6.2 Summary of GPS deployments on Ohinau Island during chick-rearing (Feb 2020)

Burrow	Band	Sex	Trip Number	Trip Length (days)	GPS Track (days)	Complete Track?	Trip Distance (km)	Max Range from Colony	Flight	Rest	Forage	Δ Weight (g)	Δ Body Mass (%)	% Body Mass change per day	Notes
CC51	9864	F	1	1	1	Y	183	63	19%	59%	22%	-10	-1%	-1.45%	
CC56	9866	F	1	1	1	Y	362	110	40%	44%	16%	-15	-2%	-2.38%	
			2	9	9	Y	4734	1761	64%	29%	7%	85	14%	1.38%	
			3	1	1	Y	180	56	43%	46%	11%				
CC62	9867	M	1	1	1	Y	174	49	29%	47%	24%	45	7%	2.42%	
			2	2	2	Y	438	160	19%	68%	13%				
CC63	9875	F	1	1	1	Y	64	16	4%	76%	20%	20	3%	3.13%	
			2	1	1	Y	124	30				-45	-7%	-6.77%	GLS failed
	9900	M	1	5	5	Y	1612	336	44%	44%	12%	-35	-5%	-1.06%	
			2	3	3	Y	471	130	15%	66%	18%	5	1%	0.27%	
CC64	9862	F	1	1	1	Y	177	49	27%	42%	32%	0	0%	0.00%	
			2	1	1	Y	191	67	21%	54%	25%				
			3	14+		N									Did not return
	15056	M	1	1	1	Y	202	51	30%	51%	19%	-45	-5%	-5.26%	
			2	2	2	Y	356	77	24%	61%	15%	35	5%	2.41%	
CC65	9873	F	1	1	1	Y	232	80	18%	61%	21%	55	9%	9.32%	
			2	9	9	Y	4722	1801	65%	28%	8%	-10	-2%	-0.17%	
CC66	9621	F	1	1	1	Y	156	60	15%	66%	19%	-15	-2%	-2.38%	
			2	2	2	Y	1135	421	84%	6%	10%				
			3	1	1	Y	360	168	60%	30%	10%	25	4%	4.07%	
			4	11+		N									Did not return
	66300	M	1	4	4	Y	924	244	29%	59%	12%	-5	-1%	-0.18%	
			2	1	1	Y	257	62	50%	42%	8%				
CC57	67273	F	1	4	4	Y	1921	586	65%	26%	10%	-5	-1%	-0.20%	
			2	10	10	Y	3972	1376	52%	38%	10%	150	25%	2.24%	
			3	1	1	Y	118	40	52%	38%	10%				
	67319	M	1	1	1	Y	160	44	17%	69%	14%	-15	-2%	-2.19%	

CC54	9874	F	1	1	1	Y	205	62	27%	58%	15%	-10	-1%	-1.49%	
			2	9	9	Y	5634	2087	68%	24%	8%	10	2%	0.17%	
CC52	9899	F	1	2	2	Y	652	283	35%	57%	8%	15	2%	1.23%	
CC59	54409	M	1	1	1	Y	217	74	16%	76%	8%	-25	-3%	-1.74%	
			2	1	1	Y	104	37	12%	76%	12%				
CC61	9868	M	1	1	1	Y	149	46	21%	67%	12%	-70	-10%	-3.29%	
			2	2	2	Y	274	67	16%	70%	14%				
			3	1	1	Y	113	28	20%	56%	24%	-5	-1%	-0.26%	
			4	1	1	Y	233	65	57%	26%	17%				
			5	1	1	Y	230	51	46%	33%	20%				
			6	11+		N									
CC55	9865	F	1	8	8	Y	4319	1706	59%	34%	6%	85	14%	1.71%	
CC60	9869	F	1	1	1	Y	141	56	23%	62%	16%	-80	-11%	-2.78%	
			2	1	1	Y	141	53	11%	72%	17%				
			3	2	2	Y	488	111	39%	48%	13%				
			4	13+											Did not return
CC67	9876	F	1	7	7	Y	4159	1667	72%	21%	7%	110	18%	2.58%	
	9884	M	1	1	1	Y	163	54	46%	41%	13%	-45	-6%	-6.04%	
			2	12+											Did not return
CC68	9872	M	1	2	2	Y	984	332	62%	27%	11%	-20	-3%	-1.52%	
			2	12	12	Y	3757	788	38%	52%	9%	30	5%	0.40%	
CC69	9871	F	1	9	9	Y	4941	1806	65%	25%	10%	35	5%	0.61%	
CC70	9863	F	1	10	10	Y	4071	1046	57%	36%	7%	5	1%	0.08%	
CC71	9878	F	1	2	2	Y	260	63	13%	75%	13%	125	20%	9.77%	
			2	7	0	N			50%	43%	7%	95	14%	2.04%	GPS waterlogged, no data
	66761	M	1	8	8	Y	5108	1946	69%	23%	8%	15	2%	0.30%	
CC72	9870	F	1	1	1	Y	216	74	17%	63%	19%	45	8%	7.50%	
			2	1	1	Y	92	30	9%	78%	14%	-20	-3%	-3.03%	
	9891	M	1	2	2	Y	351	83	16%	69%	15%	60	8%	4.05%	

6.3 Summary of GPS deployments on Lady Alice Island during incubation (Jan 2020)

Burrow	Band	Sex	Trip Length (days)	GPS Track (days)	Complete Track?	Trip Distance (km)	Max Range from Colony	Flight	Rest	Forage	Δ Weight (g)	Δ Body Mass (%)	% Body Mass change per day	Notes
A1	57204	U	22	22	Y	7524	1987	49%	40%	11%	80	14%	0.63%	
D1	55738	M			N									Bird never returned
D5	59556	M	14	14	Y	2914	393	28%	58%	14%	105	17%	1.24%	
D8	59525	F	22	22	Y	8955	2094	56%	34%	10%	80	14%	0.63%	
D12	55740	M	13	13	Y	2925	527	31%	58%	11%	135	22%	1.66%	
E3	57276	F		3	N									Not considered "normal" foraging trip. Tracks not included in analysis
E4	55662	M			N									Bird never returned
E5	53650	M	15	15	Y	3234	489	26%	62%	11%	130	21%	1.41%	
E14	54174	M	16	16	Y	3154	511	30%	59%	11%	130	21%	1.29%	
E16	55730	M	23	23	Y	7957	902	51%	38%	12%	140	23%	1.01%	
F2	54190	M	23	21	N	4171	310	30%	55%	15%	50	8%	0.33%	
G2	55844	U			N									Bird never returned
G4	57283	M		3	N									Not considered "normal" foraging trip. Tracks not included in analysis
G5	53987	M			N									Bird did not depart. Device Removed
G6	55715	M			N									Bird never returned
G25	59534	F			N									Bird did not depart. Device Removed
H5	53760	F	11	11	Y	3476	752	52%	35%	13%	10	1%	0.14%	
H6	53958	M	22	22	Y	4109	323	22%	64%	14%	160	25%	1.15%	
H9	59559	M	16	16	Y	3453	249	25%	62%	13%	80	13%	0.82%	
H17	55650	M	11	11	Y	2300	318	22%	62%	16%	100	17%	1.52%	
H25	50118	F	13	3	N	1055	743	37%	50%	13%	85	14%	1.09%	
I3	55820	F		3	N									Not considered "normal" foraging trip. Tracks not included in analysis
I9	55670	M												Bird never returned
I11	59558	F	13	13	Y	5336	1339	52%	37%	11%	130	21%	1.64%	
I13	56094	M												Bird never returned
J4	57381	F		3	N									Not considered "normal" foraging trip. Tracks not included in analysis
J19	57127	F	11	11	Y	6204	2335	60%	32%	9%	140	24%	2.19%	
J22	57194	M												Bird never returned
J55	57196	F	21	17	N	5246	1626	39%	51%	11%	50	8%	0.40%	

6.4 Summary of GPS deployments on Lady Alice Island during chick-rearing (Feb 2020)

Burrow	Band	Sex	Trip Number	Trip Length (days)	GPS Track (days)	Complete Track?	Trip Distance (km)	Max Range from Colony	Flight	Rest	Forage	Δ Weight (g)	Δ Body Mass (%)	% Body Mass change per day	Notes
D3	57401	F	1	1	1	Y	694	322	67%	24%	9%	-5	-1%	-0.05%	
			2	15	5	N	2225	1948	56%	36%	8%				
D6	46083	M	1	9	9	Y	2263	321	41%	47%	11%	-150	-20%	-1.84%	
			2	2	2	Y	314	22	35%	53%	12%				
M1	55860	F	1	2	2	Y	542	182	51%	38%	11%	-60	-9%	-0.59%	
			2	11	11	Y	3809	757	48%	43%	9%				
			3	2	2	Y	551	39	50%	42%	8%				
M5	55858	F	1	2	2	Y	419	79	30%	53%	17%	-70	-10%	-5.19%	
			2	8	8	Y	2812	759	46%	45%	9%	30	5%	0.62%	
	57382	M	1	18+		N									Did not return
M14	55765	M	1	5	5	Y	1499	332	36%	52%	12%	40	6%	1.23%	
			2	5	5	Y	2057	373	46%	42%	12%	-75	-11%	-2.17%	
M16	55859	F	1	11	11	Y	5527	2284	56%	35%	10%	55	9%	0.79%	
	57511	M	1	9	3	N	695	290	32%	56%	11%	15	3%	0.28%	
N2	54180	M	1	5	5	Y	2362	608	51%	38%	11%	110	15%	3.06%	
N4	56087	M	1	10	6	N	2018	1542	47%	45%	8%	15	2%	0.24%	
	57129	F	1	1	1	Y	315	42	45%	43%	12%	50	8%	4.13%	
			2	1	1	Y	179	42	26%	48%	26%				
			3	13+		N									Did not return
N5	55868	M	1	2	2	Y	298	15	37%	52%	12%	80	13%	4.17%	
			2	1	1	Y	216	17	38%	53%	10%				
	55891	F	1	1	1	Y	285	56	54%	31%	15%	-90	-13%	-13.04%	
			2	1	1	Y	199	58	22%	69%	9%	0	0%	0.00%	
N7	55863	M	1	2	2	Y	724	232	53%	36%	10%	-135	-17%	-1.24%	
			2	2	2	Y	701	235	46%	43%	11%				
			3	5	5	Y	1409	297	39%	49%	13%				
			4	1	1	Y	180	28	26%	54%	20%				
			5	4	4	Y	1130	250	31%	57%	12%				

N9	55865	M	1	12	12	Y	5645	2050	53%	39%	8%	-35	-5%	-0.41%	
	57394	F	1	1	1	Y	264	76	31%	58%	11%	-45	-7%	-0.59%	
			2	11	11	Y	5783	2381	53%	40%	8%				
N14	57146	F	1	1	1	Y	484	205	54%	35%	10%	-10	-2%	-1.64%	
	57200	M	1	1	1	Y	189	16	37%	45%	18%	-25	-4%	-3.79%	
P1	57161	F	1	1	1	Y	283	109	65%	28%	7%	-10	-1%	-0.74%	
			2	1	1	Y	459	171	54%	34%	12%				
	57395	M	1	5	5	Y	1097	174	32%	53%	15%	-45	-7%	-1.35%	
P4	57164	M	1	13	13	Y	5532	2188				40	6%	0.50%	GLS failed, no behaviour
	57203	F	1	1	1	Y	125	29	24%	68%	8%	-15	-2%	-2.42%	
			2	14	14	Y	5902	2146	50%	41%	10%	5	1%	0.05%	
P10	57534	M	1	12	1	N	203	33	52%	37%	11%	-10	-1%	-0.12%	
P12	57451	F	1	6	6	Y	1723	352	42%	50%	9%	-15	-2%	-0.38%	
	57513	M	1	1	1	Y	109	17	9%	73%	18%	110	17%	16.67%	
			2	2	2	Y	238	33	23%	69%	8%	-125	-16%	-8.12%	
P13	57516	M	1	3	3	Y	637	120	38%	51%	11%	-40	-6%	-1.99%	
P15	57453	F	1	16	16	Y	6547	2324	48%	44%	8%	80	14%	0.86%	
	57532	M	1	2	2	Y	539	106	34%	43%	23%	10	2%	0.84%	
P17	57479	M	1	7	7	Y	2528	775	51%	40%	9%	15	2%	0.32%	
	57538	F	1	4	4	Y	1681	591	48%	40%	12%	5	1%	0.20%	
Q2	57541	F	1	2	2	Y	982	434	72%	21%	8%	-10	-2%	-0.79%	
			2	1	1	Y	261	106	38%	55%	7%	-10	-2%	-1.61%	
Q4	57484	M	1	3	3	Y	408	43	19%	62%	19%	-45	-6%	-1.61%	
			2	1	1	Y	184	36	32%	46%	22%				
	57540	F	1	1	1	Y	85	12	15%	62%	23%	10	2%	1.67%	
Q5	57539	F	1	7	7	Y	2820	777	65%	24%	11%	-10	-2%	-0.13%	
			2	5	5	Y	2263	771	59%	32%	9%				

6.5 Maps of all GPS tracks by island and breeding stage