Flesh-footed shearwater – population study and foraging areas (POP2011-02)

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1 Abstract

This report describes the findings of a three-year study on flesh-footed shearwater *Puffinus carneipes* biology in New Zealand. The project focus was specifically to describe population monitoring and to define the at-sea distribution and habitat use by flesh-footed shearwaters and the potential for foraging birds to interact with fisheries in different regions from their breeding sites. The study was based at three breeding sites in northern and central New Zealand:

1. Lady Alice Island / Mauimua, Northland
2. Ohinau Island, Coromandel
3. Titi Island, Marlborough

In addition, the research used marked study burrows at Lady Alice Island / Mauimua, and demographic data from this and Kauwahaia Island, Te Henga / Bethells Beach, West Auckland to explore the estimation of vital rates for flesh-footed shearwaters in New Zealand. An additional banded population of birds was established at Ohinau Island, to enable mark-recapture studies to be undertaken in the future. Recommendations for extending these studies to estimate vital rates for the populations are set out. Birds were banded at Titi Island but due to the small size of the population at this site, and its relative inaccessibility, ongoing mark-recapture work is not recommended there.

The population sizes, nesting densities, and occupancy rates were estimated once for each of our study sites in the period 2012 – 2014. The colonies of flesh-footed shearwaters were mapped at each site.

We deployed GPS loggers on 97 flesh-footed shearwaters, mainly at Ohinau Island and describe their foraging distribution during incubation and chick-rearing. We used overlap analyses to examine where commercial fisheries and the birds were co-occurring. The main zones of overlap for this population were in the Bay of Plenty and East Cape areas, but with a significant patch of use near Mahia Peninsula. Fisheries overlap was most intense during early chick-rearing for bottom longline, trawl and setnet fisheries, and was fairly even throughout the breeding period for surface longline fishing.

Data from a variety of sources was used to examine the range of the species in the New Zealand zone throughout the year, and the species is most concentrated in north eastern North Island waters between Cape Reinga and Mahia Peninsula, and along the continental shelf and near the shelf break. Few birds are sighted south of Cook Strait, with only occasional records of individuals seen on the Chatham Rise or west of Cook Strait. Our GPS tracking of a few birds from Marlborough confirms this distribution. More foraging data from Northland breeding sites and from non-breeding periods are required to gain a comprehensive view of the species distribution.

2 Introduction

Flesh-footed shearwaters (*Puffinus carneipes*) breed on islands off Australia and New Zealand with a small outlying colony on Île Saint-Paul in the Indian Ocean. They have an estimated population of 650 000 individuals globally (Brooke 2004). They are currently listed by the IUCN with a conservation status of Least Concern, with stable population trends (BirdLife International 2013).

The flesh-footed shearwater is one of the most commonly reported species to be taken as fisheries bycatch in Australasia (Gales *et al*. 1998, Trebilco *et al*. 2010). New findings identify several significant populations may now be declining (Reid *et al*. 2013). Baker and Wise (2005) estimated that 1794–4486 flesh-footed shearwaters were incidentally killed in the Eastern Tuna and Billfish Fishery off the Eastern Coast of Australia. These birds were assumed to have originated from Lord Howe Island which is thought to hold 9–18% of the world's population (Brooke 2004). Baker and Wise (2005) suggest that the population would decrease by 50% in 55 years and by 80% in 120 years. Recent evidence collected at the breeding colonies of Lord Howe Island suggests that this population may well be decreasing, experiencing an annual breeding population decrease of around 1.3% (Reid *et al*. 2013).

Between 11–23% of the world population of flesh-footed shearwaters breeds in New Zealand (Taylor 2000), with an annual breeding population of 10 000 – 15 000 pairs (Waugh *et al*. 2013). In the recently published Conservation Status of New Zealand Birds, the status of the flesh-footed shearwater population in New Zealand has changed from “Not Threatened” to “Nationally Vulnerable”; their placement in this category is based on their suspected population declines (Robertson *et al*. 2013).

Recent survivorship analyses at two northern New Zealand breeding sites support this impression (Barbraud *et al*. in press). Within the New Zealand Exclusive Economic Zone (NZEEZ) the potential annual fatalities from risk assessment analyses are 523 –1090 individuals, a level which may threaten the viability of New Zealand’s flesh-footed shearwater populations (Richard & Abraham 2013, Ministry for Primary Industries 2013).

Furthermore, recreational fisheries seem to be a significant source of mortality in New Zealand. During a single month of beach surveys in late 2011, 64 carcasses were retrieved without any signs of oil contamination (surveys were being conducted to assess the impact of the *MV Rena* oil spill). Of the 15 individuals necropsied, all had sustained fatal injuries that were likely due to interactions with recreational fishers (Tennyson *et al*. 2012).

These statistics highlight the need to examine population trends of flesh-footed shearwaters within New Zealand. We conducted surveys on three signifcant flesh-footed shearwater breeding islands dispersed throughout New Zealand and compared our data with those previously collected by Baker *et al*. (2010).

We conducted field-based research, gathering data sets on population size, shearwater nesting density, burrow occupancy, and mapping of nesting areas to establish study design recommendations for ongoing work on flesh-footed shearwater population monitoring. We modelled the populations of flesh-footed shearwaters for two sites where multi-year datasets were available to assess the robustness of these datasets for estimating vital rates. We deployed locational loggers on breeding and non-breeding flesh-footed shearwaters, and used these and other data to examine their foraging behaviour, range, habitat use and overlap with fisheries.

2.1 Objectives

1. Develop a project design for a population monitoring programme suitable for estimating adult survival, juvenile survival, fecundity and age of first reproduction of flesh-footed shearwaters.
2. Provide recommendations on the extent of monitoring required to obtain robust estimates of adult survival, juvenile survival, fecundity and age of first reproduction of flesh-footed shearwaters.
3. Collect detailed data on the at-sea distribution and foraging behaviour of flesh-footed shearwaters.
4. Identify areas where flesh-footed shearwaters are a highest risk of interactions with fishing gear by analysing data collected in objective 3. In relation to spatial and temporal fishing effort.

3 Methods

Objectives 1&2 – Monitoring programme for estimating vital rates for shearwaters

3.1 Study sites and datasets:

To assist in understanding the multi-year and multi-site study, the sites and dates of each visit and data sets gathered at each are set out below. The location of each site is shown in Figure 1.

3.1.1 Sites and dates of visits

1. Lady Alice Island / Mauimua, Northland (35.89° S, 174.71° E): 28 Mar – 6 Apr 2012, 8 – 19 Dec 2012, 17 – 22 Jan 2014
2. Ohinau Island, Coromandel: (36.72° S 175.88° E): 11 – 14 Apr 2012[1], 19 Jan – 18 Feb 2014
3. Titi Island, Marlborough (40.95° S 174.14° E): 9 – 17 Jan 2012, 1 – 4 Jan 2013, 29 Jan 2013[2], 2 Feb 2013
4. Kauwahaia Island, Te Henga / Bethells Beach, West Auckland (36.54° S, 174.26° E): annual visits during 1989 to 2013

[1] The duration of this trip was reduced because of extreme weather conditions.
[2] This visit was planned to be multi-day, but was curtailed due to an accident on the vessel delivering staff to the site, a second one-day trip was instigated as soon as possible afterwards to recover GPS loggers from birds on 2 February 2013.

3.1.2 Colonies surveyed, transects completed

During each site visit, surveys were conducted to allow for estimation of colony footprint, burrow density and total count, and flesh-footed shearwater density, occupancy rates, and estimation of flesh-footed shearwater breeding populations sizes. The details of sampling during each visit are described in Table 1.

3.1.3 Demographic data assessed

Graeme Taylor and Andrea Booth generously supplied datasets gathered over several years to assist with analysis of vital rates for the shearwaters. The periods of study were:

1. Kauwahaia Island, Te Henga / Bethells Beach 1989/1990 – 2011/2012 (23 years, 102 individuals banded; Graeme Taylor datasets)
2. Lady Alice Island / Mauimua 1999/2000 – 2011/2012 (13 years, 593 individuals banded; Andrea Booth datasets).

3.1.4 Teams present on each visit

These are detailed in the annual reports for each season. In summary, at least one experienced Te Papa staff member (Susan Waugh, Colin Miskelly, Jean-Claude Stahl or Sarah Jamieson) was present on each field trip, along with 2-3 assistants. Iwi representatives were invited on each field trip. Ngati Wai Trust Board took up these opportunities, and sent iwi members on 2 field trips to Lady Alice Island / Mauimua.

A day visit in 2013 with Ngati Kuia at Titi Island, and a mainland based marae visit with Ngati Hei in 2014 were undertaken.

3.1.5 Develop a monitoring programmes

The project aims were to examine the distribution information about birds on Lady Alice / Mauimua, Ohinau and Titi islands, and identify potential study areas at these sites. Accessibility, density of burrows and representativeness factors, including size of colony were considered.

Study plots were established at Lady Alice / Mauimua Titi Island and Ohinau Island, with burrow mapping by GPS and hand-drawn maps. The occupancy of burrows and size of breeding population at each colony was assessed. Occupancy as assessed by burrow-scoping and through inspection of burrow contents through study hatches. Our assessment of impact of the study hatches on the nest outcomes was that there was no difference in rates of egg abandonment in nests with and without hatches fitted, comparing the burrow-scoped totals for the colonies and the study nests.

Objectives 3&4 – At sea distribution, behaviour and overlap with fishing of flesh-footed shearwaters.

Dates of visits are as for Objectives 1 & 2 above.

3.1.6 Devices deployed on flesh-footed shearwater

At each site, all accessible flesh-footed shearwater nests were used for tracking with GLS and/or GPS for each field season. The sites, dates of visits, and numbers of devices deployed at each time are listed below:

4. Lady Alice Island / Mauimua, Northland
    a. 28 Mar – 6 Apr 2012: 19 LOTEK GLS
    b. 8 – 19 Dec 2012: 16 GPS
    c. Dec 2010 – Dec 2011: 3 BAS GLS (deployed by Graeme Taylor & Andrea Booth)
5. Ohinau Island, Coromandel
    a. 11 – 14 Apr 2012: 4 GLS
    b. 19 Jan – 18 Feb 2014: 54 GPS
6. Titi Island, Marlborough
    a. 9 – 17 Jan 2012: 8 GPS
    b. 1 – 4 Jan 2013: 13 GPS

3.1.7 Datasets collected from GPS and GLS tracking

Data proved difficult to capture from the incubating shearwaters, on the one hand due to the small number of available birds at Titi Island, but also in large part due to the extended duration of foraging trips (7-10 days). This meant loggers deployed in the first 12 months of the programme gathered few tracks as birds remained in their burrows, and the batteries of their loggers were exhausted after a short time at sea.

As a result, it was decided to deploy GLS loggers, which could capture data over longer periods of time including to describe migration during non-breeding periods. Successful GPS tracking in 2014 captured 56 tracks in incubation and early chick-rearing.

1. Lady Alice Island / Mauimua, Northland
    a. 28 Mar – 6 Apr 2012: 3 GLS tracks
    b. 8 – 19 Dec 2012: 1 GPS track
    c. Dec 2010 – Dec 2011: 3 GLS tracks
2. Ohinau Island, Coromandel
    a. 11 – 14 Apr 2012: 0 GLS tracks
    b. 19 Jan – 18 Feb 2014: 56 GPS tracks[3];
3. Titi Island, Marlborough
    a. 9 – 17 Jan 2012: 1 tracks
    b. 1 – 4 Jan 2013: 4 tracks

Data for breeding season periods were sufficient to analyse incubation activity in January and early chick-rearing behaviour in February. Data from pre-laying, pre-laying exodus, and late-chick rearing periods were not collected. Some inference is considered appropriate for early incubation and later chick rearing, based on the January incubation period datasets, considering the similarity of activity for Lord Howe Island birds between these periods (Reid *et al*. 2012).

[3] Several of the loggers deployed resulted in multiple tracks, and some loggers gave no data due to birds staying for prolonged periods in their burrows. Hence the number of deployments and resulting tracks does not match exactly.

We did not deploy time-depth recorders as datasets using these devices had been collected by Graeme Taylor outside of this project.

3.1.8 At-sea datasets

Datasets for at-sea observations/species records held by Te Papa, and collected by fisheries observers were examined:

1. At-sea observations from the 1970s and 1980s from freight vessels moving between New Zealand ports and to Australian or more distant destinations (Te Papa unpublished data);
2. Te Papa collections records (Te Papa unpublished data);
3. Fisheries observer records as described by Richard *et al*. (2011a);
4. Fisheries data on shearwater captures from Ministry for Primary Industries databases.

3.1.9 Fisheries datasets

Fisheries catch-effort data were extracted from Ministry of Primary Industry databases to provide fishing effort for the periods of the year when flesh-footed shearwaters were breeding (December – May), and for the five split year periods from 2009-2010 until the summer of 2013-2014 when data was available until March 2014 only. Data were extracted where latitude and longitude of the fishery activity were recorded. Target species and primary fishing method for surface, bottom longline, setnet, trawl fisheries (combining midwater-, bottom- and paired- trawls) were requested. Latitude and longitude were analysed at a resolution of 0.1 decimal degrees.

3.2 Analysis

Objectives 1&2 – Monitoring programme for estimating vital rates for shearwaters

Analyses of population sizes, densities, and population distribution are set out in Appendix 1.

Vital rates were estimated for the two populations with long-term Capture-Mark-Recapture datasets, and methodologies for these analyses are set out in Appendix 2. This report content falls outside of the contracted research and is included to provide a comprehensive picture of the species biology to assist Department of Conservation in its management of the species and its' threats.

Objectives 3&4 – At sea distribution, behaviour and overlap with fishing of flesh-footed shearwaters.

Analyses methods for at-sea distribution, behaviour and overlap with vessels are set out in Appendix 3.

4 Results

Objectives 1&2 – Monitoring programme for estimating vital rates for shearwaters

The project addressed these objectives to develop a monitoring programme by conducting field programmes at the three breeding sites and through the use of existing data sets (GAT, A. Booth, unpublished data) listed in Methods. We assessed the suitability of the sites for future mark-recapture and population monitoring projects, and to describe the data necessary to estimate adult survival, juvenile survival, fecundity, and age of first reproduction of flesh-footed shearwaters, by analysis of existing datasets.

We set out our primary findings by the type of study and by site, below.

4.1 Lady Alice Island / Mauimua – mark recapture studies

This site has an existing banded population of birds, which were monitored annually until 2013, with good facilities at the site to conduct research programmes of moderate intensity (*e.g*., field hut, study colony in close proximity to field hut, relatively easy landing access, near-shore site).

The number of study nests available is suitably large (over 500 individuals banded) to enable robust estimation of annual adult survivorship for the flesh-footed shearwater population at the island.

The results of modelling on the mark-recapture data (A. Booth, Unpublished data, reported in Appendix 2) indicate a relatively high adult survival for burrow-caught birds (0.940 ± 0.087), and lower rates for surface caught birds (0.756 ± 0.027). Recapture rate probabilities were relatively low at 0.209 and 0.154 for burrow- and surface-caught birds respectively. Population growth rate (0.888 ± 0.016 per year, 0.852 – 0.916 95% CI for a population model of constant survival, time-dependent recapture probability and constant population growth rate) was able to be modelled using these survival rates, and age-at-first return information also collected at this site (average age of 6.2 years). These results suggest that the size of the study population is adequate to provide relatively robust estimation of vital rates, and ongoing work over the next few years at the site would increase the set of age-at-first–breeding and first-return data, as well as provide an increasingly robust dataset from which to model survivorship and population growth. Our analyses of this dataset indicated that it is necessary to gather data on both burrow-caught and surface caught birds to improve estimation accuracy. Without using surface-caught birds in the analysis, the population growth rate is further reduced (0.840 ± 0.080 (0.697 – 1.012 95% CI)). To further increase the robustness of results for this population, efforts to improve recapture rates for both surface- and burrow-caught birds are needed. This might involve improving the accessibility of study burrows, marking or adding inspection traps to a larger proportion of burrows in the study area, and increasing efforts to catch birds by longer visits or more intensive work in the colony over the time spent there.

Monitoring a larger number of study nests and banded individuals might be advisable, to reduce the standard errors of survivorship estimates, if this were feasible (*i.e.*, more nests were able to be accessed in the main study colony area).

Differential survival rates between burrow- and surface-caught estimated in our ancillary work on this dataset suggests a complex structure to the population, with some indication of skipping of breeding, as suggested by the low recapture rate of GLS logger equipped birds between years.

Juvenile survival and age-at-first breeding data for this population is beginning to become available, with the first birds banded as chicks being recaptured during the study, but not found among the breeding population. Further efforts to gather recruitment and juvenile survival data at this site are recommended, as the data available in 2012 were showing preliminary results only and the full recruitment of cohorts banded in the years 2000 – 2009 (n = 191 chicks banded) has yet to be achieved.

A similar modelling exercise was conducted on the 23 year dataset gathered at Kauwahaia Island (G. Taylor, unpublished data, reported in Appendix 2.). This population has been growing slowly over the study period from 1989 to 2012, from 9 breeding pairs to over 20 in recent years (modelled rates were 0.984 ± 0.009). For this population, in contrast to the Lady Alice Island / Mauimua population discussed above, recapture probabilities were high (0.880 for breeders and 0.197 for non-breeders). Annual average adult survival for both sexes was 0.931 ± 0.01. For this population a combination of high capture rate and long study period were sufficient to give a robust result, and these outcomes are only possible with a high consistency of research effort (consistent dates of visit, annual visits, access to a high proportion of individuals per year). This intensity of data collection may not be as easy to reproduce on an offshore island site as it was at Kauwahaia Island, which is accessible from mainland New Zealand on foot.

Advanced planning for parties aiming to work at this site will likely be required as there are relatively high numbers of other research or management activities on site, meaning the field hut and 'researcher-loading' maybe at capacity at critical times of year for a more intensive flesh-footed shearwater study.

A further complication with a long-term study of population vital rates at this site is the mixed-species nature of the colonies. Our work on population estimation and burrow densities at the site indicates that burrow density overall at the site may be increasing, while the occupancy rate by flesh-footed shearwater is stable.

The involvement of Ngati Wai iwi representatives in our field programmes opens a possibility that the iwi may have capability to conduct monitoring programmes in future years on the population.

4.2 Lady Alice Island / Mauimua – population monitoring studies

In addition to the aspects of the population and site noted above, the island has seven colonies that contain a varied proportion of flesh-footed shearwaters (Table 2), with between 5% and 20% of burrows in the colonies containing this species. The occurrence of other species in the same colonies creates a complex mix (See Table 1 in Appendix 1 for other species densities), and needs to be considered in any future population monitoring, especially as grey-faced petrels begin breeding in the autumn, and are known to evict flesh-footed shearwater chicks from burrows. Because of these factors, it is recommended to monitor all colonies for changes over time.

The island is relatively large, and access to all colonies requires a spell of good weather over 7 – 14 days (Figure 2).

The apparent intermittent breeding detected in our mark-recapture study suggests a complex pattern of activity for the species, either in response to climatic factors, or in our limited ability to detect birds at the site in unmarked or inaccessible burrows. Therefore, we recommend several consecutive years of data collection to estimate annual changes in proportion of breeding birds (through use of mark-recapture records from the study colony).

In our study, to estimate nesting density and occupancy we conducted 3 – 73 transects and inspected 30 – 50 nests at each colony (Table 1). Previous work and statistical advice in this area was suggested to estimate occupancy for only a sub-set of colonies and extrapolate across the whole island (Baker *et al*. 2010), or to estimate occupancy once for each colony (our study). Having analysed the data resulting from this method, however, we note that the variability observed between colonies was high. Advice from our statistical advisors (D. Sim) and researchers on other shearwater populations (S. Patrick, for Manx shearwaters) was to increase the number of independent estimates of burrow occupancy within colonies, with an optimum recommendation of a measure per transect (of *e.g.*, 7 – 10 burrows per transect), rather than per colony. This would further increase the robustness of the occupancy measures within and between colonies. Admittedly, burrowscoping is time-consuming and can also be difficult to do in fragile terrain, and hence there are trade-offs to be made between a comprehensive 'transect-by-transect' approach, as opposed to a 'whole-of-colony' approach. To increase burrowscoping effort more time would be required to coordinate with the teams doing transects, and to undertake more burrowscoping than we did. About 60 - 100 burrows per day were inspected with burrowscopes during our visits. This was possible as we already had a good knowledge of the colony layout and location of the flesh-footed shearwater colonies.

The accuracy of our burrowscoping work can be assessed by examining the numbers of burrows with unknown contents reported. Of 1244 individual nests inspected, 21 had unknown contents, or an average rate of 0.013 (s.d. 0.017) per burrow at each island.

4.3 Titi Island – mark recapture studies

During our work at this site, we established labelled study burrows, accessible with lids at Ongaonga colony only (Figure 3). About 15 burrow lids were fitted. Birds were readily accessible in some burrows and we fitted trap-lids into those that weren't. Twenty-six flesh-footed shearwaters were banded at Ongaonga colony, and had GPS tracking devices fitted for foraging studies.

One of the key aspects about this island site, to be borne in mind for developing future population studies, is that the flesh-footed shearwater population is small at c. 157 pairs (Table 2). It is only really feasible to study them in any numbers at two locations on the island with 5 – 15 flesh-footed shearwater nests accessible at each; however, both of these are relatively accessible.

Ongaonga colony has extremely friable soils, and hence moving around the colony poses a significant risk of collapse of burrows, should further intensive studies be considered.

A further small, dense group of flesh-footed shearwaters were located at Colony 2 (estimated at 56 pairs), but the total number of birds from accessible burrows did not lend itself to long-term monitoring projects (c. 10 burrows).

Camp colony, near the top of the island, close to camp, contained a very small number of flesh-footed shearwaters (less than 10 pairs) and was considered untenable for intensive studies, due to the very fragile nature of the soils, and high numbers of sooty shearwater and other species' burrows in this area.

4.4 Titi Island – population monitoring studies

The programme conducted to estimate burrow density, occupancy and breeding population size for flesh-footed shearwaters at Titi Island showed that these activities are feasible (Figure 3). As a means of measuring the responses of the species to pressures in the environment it is a worthwhile endeavour, as the Titi population is at the southern limit of the flesh-footed shearwater range in New Zealand, and will thus reflect expansion or contraction of the species range more markedly than sites central to its range.

A total population of 157 breeding pairs of flesh-footed shearwaters was estimated for the island (Table 2).

We planned to provide survey data over periods of 4 – 8 days, and timed our visits during the mid-incubation period (first 2 weeks of January). We were able to gather the required data to estimate the population size, provide comprehensive coverage of the colonies on the island, and prospect new areas to assess the flesh-footed shearwater population activity in these.

As with Lady Alice Island/ Mauimua, the mixed species colonies make this site complex to study, and if monitoring is planned to assess changes in the shearwater populations, annual surveys over 3 – 4 year periods are recommended.

Logistically, stays of more than one week are difficult, due to water restrictions at the site, and the need to camp near the top of the island, where flat ground is available. A day of moving gear and establishing camp is needed at each end of the study for a visit of this scale.

4.5 Ohinau Island – mark recapture studies

We were successful in establishing a new study colony of banded individuals and study nests at this site. Sixty-two birds were banded at the site during the study. Fifty breeding burrows were identified in 2012, and 37 were fitted with lids (or were otherwise accessible) in 2014. A further 12 burrows were monitored by burrow-scope in 2014 but not accessed with lids[4]. This represented a high proportion of the total number of burrows in the lower slopes of the main study colony, with all accessible breeding burrows being monitored. The study burrows were in areas of the colony that had consolidated soils, and hence could support the level of foot-traffic needed for frequent burrow inspections. The study colony extended up to the top of the island and around the southern flank of the landing gully, but was more fragile in these areas, and therefore not accessed, except for a single visit to estimate the colony perimeter and burrow density (Figure 4). A total of 236 breeding burrows was estimated for this colony in 2014. Should further mark-recapture work be required some extension of the number of study burrows would be possible, perhaps to include a further 20 burrows in neighbouring areas to those already established.

Nine of the fifty breeding burrows identified in 2012 were found to be empty in 2014. Fifteen nests marked in 2012 were not found in 2014. Of the four birds banded and fitted with GLS in 2012, none was recaptured in 2014 (one nest was not found, one was unused, two had unbanded birds). Skipping of breeding or low survivorship may explain these findings. This warrants further investigation, and the new banded population at the site provides a good basis for doing this.

[4] These burrows were located in rocky areas or were deep into the hillside, so no trap-doors could be fitted.

4.6 Ohinau Island – population monitoring studies

All areas of the island known to contain flesh-footed shearwater colonies were resurveyed, and we spent considerable effort defining the colony boundaries and population sizes (Figure 4).

The work conducted by Baker *et al*. 2010 covered all areas of the island to establish that flesh-footed shearwaters were nesting predominantly in the Mahoe forested slopes, with very few birds of this species detected in the coastal strips of flax, especially those in the south of the island.

Our work comparing the densities, occupancy rates and population sizes for the colonies with those of earlier surveys indicates a dynamic situation at the island, with a probable decline in breeding numbers to around 2100 breeding pairs in 2014 (Appendix 1).

The site readily lends itself to population monitoring studies, having relatively compact soils, and easy access from the mainland. Logistically it is a relatively easy site to work on, with flat areas for camping near the landing point, and close proximity to a town (Whitianga) for resupply of food, water, field workers and good cell-phone reception.

4.7 General recommendations – population monitoring

4.7.1 Choice of study sites:

The three sites we studied were selected because of a) the history of work undertaken at them; b) the relatively compact nature of the soils at all sites, meaning island-wide surveys and intensive work at some burrows could be completed; c) the relatively large populations for the two northern sites; d) to represent the Northland and Coromandel / Bay of Plenty populations as most other islands in those regions are too fragile to sustain several-week-long visits necessary to complete foraging and population studies. We recommend that for mark-recapture studies, ongoing work at Lady Alice Island / Mauimua and Ohinau Island be considered. For Titi Island, population surveys only are recommended.

The degree of representativeness of these sites for the flesh-footed shearwater populations in New Zealand needs to be assessed with punctual visits at some of the main centres of population for the species, *e.g.*, Whatupuke and Coppermine Islands (Chicken Islands group, Northland), Atiu Island / Middle Island (Mercury Islands, Coromandel) and Korapuki Island (Bay of Plenty). While it is considerably more difficult to establish a several-day or island wide survey on any of these sites, due to the complex terrain and/or fragile soils at each, a 'health-check' on the populations of flesh-footed shearwater by a short visit, to burrowscope 100 – 200 burrows, and run a number of transects to assess density for the populations at a representative area of the colonies would allow some assessment of population changes at each.

4.7.2 Timing of research

Scheduling of visits to conduct population monitoring should be targeted from c. 15 December – 15 January, when birds have laid eggs, but hatching has not commenced. Baker *et al*. 2010, and our own study collected the key information about the breeding population sizes during this 4 week period, and future studies need to attempt to use this timing. Logistically, it proved difficult to get into the field between 20 December and 9 January each year, due to lack of access to vessels or the quarantine facilities run by Department of Conservation, and this needs to be factored in to planning of future studies.

4.7.3 Survey effort

For each of the sites, visits of 5 – 10 days are recommended, to account for the size of the islands and to allow for bad weather. Our teams of 3 – 4 persons were able to survey each island in less than 5 working days at each site, including c. 125 - 300 burrows inspected and 7 – 10 colonies mapped and surveyed. A total survey length of c. 1000 – 1500 m was conducted at each island per season. In each of the three field seasons, we experienced delays in getting onto the islands due to bad weather, which reduced some of our planned visits by 2-3 days.

As noted above, an increase in the number of burrowscope ‘samples’ per colony is desirable, with possible trade-off between this and the number of transects per colony conducted.

Our teams spent a considerable effort defining the perimeter of colonies, as we identified the ‘area’ over which densities and occupancy rates were extrapolated as a key source of variability in the dataset. This was aided by prior knowledge of the location and ‘extent’ of each colony on an island, as a result of our own previous experience and that of other workers (*e.g.*, Baker *et al*. 2010; P. Gaze, pers. comm.; A. Booth pers. comm.).

4.7.4 Estimating occupancy

We surveyed close to 1300 burrows during the study. Only 1% of burrows had unknown occupants, and these were largely where an unguarded egg was present (mainly from Titi island in 2011). We consider, therefore that positive identification of burrow contents is occurring in almost 100% of cases in our work in flesh-footed shearwater colonies. This is likely because we dedicated effort to burrowscoping throughout the work, with one worker concentrating on this activity at each site. The burrow characteristics also assisted, as burrows tend to be straight, less than 2.5 m in length, and there are very few that have more than one entrance on the colonies we visited. Burrowscope technical improvements have occurred over time too, and the model of scope we used (Sextant Technology Taupe model, Sextant Technology

2014) allowed good visibility, ability to detect movement in the burrows, identify spider webs, insects, leaf matter, and to identify bird inhabitants to species level.

Objectives 3&4 – At sea distribution, behaviour and overlap with fishing of flesh-footed shearwaters.

Data were collected on foraging activity of flesh-footed shearwaters at our three study sites. The main data acquisition occurred at Ohinau Island, and despite considerable effort to deploy tracking devices, results from other sites were sparse. Hence we don't consider they are representative of the activity of the Titi Island and Lady Alice Island / Mauimua populations, and further data gathering is required. The main results of our research on the foraging behaviour of flesh-footed shearwater are reported in Appendix 3. Summary results are presented here. Data from 62 GPS loggers were collected across all sites, from a total of 97 deployments.

4.8 Areas exploited by foraging flesh-footed shearwaters

A body of data from incubation and early chick rearing from Ohinau Island showed that the birds are using both shelf and deep waters (Figure 5 and Figures 4 and 5 in Appendix 3). The main areas exploited were to the east of their breeding site, with intense areas of activity around eastern Coromandel Peninsula, the shelf-break in the Coromandel to Bay of Plenty areas, and off East Cape, and near Mahia Peninsula. Birds from Titi Island tracked during this period of the year used waters both west and east of the breeding site and appeared to stay on shelf waters to feed. The single track of a bird from Lady Alice Island / Mauimua showed it moving north to feed off of western Northland before the logger failed (not shown).

Data for the early chick rearing period (1 – 18 February) from Ohinau Island were more restricted in range with birds foraging over easterly waters in both shelf and deep-water areas, but with less intense activity along the southern flank of East Cape to the Wairarapa coast than during incubation. During chick-rearing (early February), the shearwaters continued to travel far to the east of the New Zealand mainland, as far east as 160°W.

Note that we chose to split the data representations for these periods by date, rather than in relation to the breeding activity of the individual birds tracked, to allow easy application of the results to any management activity.

4.9 Flesh-footed shearwater behaviour and relationship to marine environmental variables

We examined the travelling speed and tortuosity of the shearwater tracks, and found no signal in the data to indicate dedicated searching by birds during their foraging trips (areas with high turning rates and lower speeds). These results suggest that flesh-footed shearwaters are using a strategy of long distance, looping flights to encounter prey, and spending little time exploiting areas of upwelling or strong marine productivity. No overlap with seamounts (*e.g.*, Louisville Ridge, Chatham Rise seamounts) or other marine features were discernable.

There was no discernable difference in the distributions of Sea-Surface Temperature, Chlorophyll or Salinity for the foraging data between when birds travelled relatively slowly with sinuous tracks and when they travelled relatively fast and straight (Figure 7 in Appendix 3).

4.10 Flesh-footed shearwater activity in relation to fishing effort

Our empirical data are restricted to January and February for examining overlap between fishing activity and shearwater foraging areas. Our examination of other studies (principally T. Reid, unpublished thesis), suggests that it may be viable to estimate foraging zones for the species during early incubation (December) and late chick-rearing (March – May) on the basis of the January incubation period distribution data. The range of the species during the pre-laying exodus (late November to early December) is difficult to predict. We examined the potential overlap of birds with fisheries in four periods, December (Incubation), January (incubation), February (early chick-rearing), March – May (late chick-rearing) using tracking data from Ohinau Island and Titi Island to generate kernel density plots for these periods. We examined the potential overlap of the foraging activity with the effort by trawl, bottom longline, surface longline and setnet fisheries. Detailed results and by season / fishery plots are shown in figures 9 – 12 in Appendix 3.

For bottom longline fisheries, a fairly consistent level of overlap was estimated throughout the four periods (Figure 8 in Appendix 3). For the other fishing methods, overlap increased during early February compared to other periods. For bottom longline fisheries, areas of highest overlap were near the breeding site in eastern Coromandel, and off Mahia Peninsula. For surface longline, overlap was most intense off the shelf break and deep waters across the Bay of Plenty from Coromandel to East Cape. For both setnet and trawl fishing, the overlap was strongest on the shelf waters near the breeding site in Coromandel, in February for setnet and throughout the breeding season for trawl.

4.11 At-sea datasets

We used a variety of observational datasets collected at sea, to further define the range of the species throughout the year. The most informative of these was the container vessel 10-minute count dataset, which showed that birds were active in the New Zealand area in particular north of the sub-tropical convergence (from the Chatham rise, northwards) in the breeding season (December to March), with a strong concentration of bird sightings near to Bay of Plenty and Northland (Figure 6). In April and May, the number of observations diminished, and was focused in these same areas as earlier in the breeding season. The species was not observed during June – August in New Zealand or eastern Australian waters, confirming the exodus of birds in winter, as they migrate to northern hemisphere areas during these months (Rayner *et al.* 2011). Birds returned to areas north of Cook Strait from September to

November, with most sightings along the Bay of Plenty to Northland area of the North Island.

Bird specimens held in Te Papa collections provided information about the location, status (breeding, age, sex) of birds, where detailed data were recorded about their collection events. Of fifty-five specimens in the collection, most were collected from coastal areas or from known breeding sites. Only five flesh-footed shearwaters held by Te Papa, collected at sea could be used to describe distribution data which added to the picture of the sightings at-sea presented above (note that at two locations, two specimens were collected; Figure 7). Similarly, the observer records of birds captured at sea during fishing operations confirm the impression generated by our GPS tracking data that the species activity is centred around north eastern New Zealand from Northland to the Mahia Peninsula area (Figure 8).

4.12 Data collection problems

We encountered a number of challenges in gathering the tracking datasets described above. Our first season of data collection was hampered by poor weather and a 'late' start to the project[5], and this, combined with very long incubation periods (in excess of 7 days) meant that few of devices deployed were recovered from birds at Titi Island in January 2012. Similar problems were encountered at Lady Alice Island / Mauimua in December 2012, to the extent that only one GPS track was generated

[5] The project started in December 2011, and it was agreed that the 2011- 2012 season would be a 'pilot' season for the project.

from this part of the study. At the time of these deployments, the work conducted on flesh-footed shearwaters in Australia was not available, which would have indicated long distance travel for the species.

To reduce these problems, and to gather information about out-of-breeding distribution, we purchased 30 LOTEK brand GLS loggers and were able to deploy 23 on breeding flesh-footed shearwaters. These were deployed on all available flesh-footed shearwaters during chick-rearing at Lady Alice Island / Mauimua and Ohinau Island in March 2012 and April 2012 respectively. Unfortunately, the batch of loggers we were supplied with turned out to be faulty, and only 3 tracks were able to be recovered from the 12 loggers recovered from these birds. Low return rates for the loggered birds were also a problem, and despite multiple visits to Lady Alice Island / Mauimua in 2012, 2013 and 2014, and multiple attempts to visit Ohinau Island 2012 - 13 and 2014, few of the loggered birds were encountered. We have ongoing problems with the datasets downloaded from these loggers, and are continuing to work with the manufacturer to salvage the data to describe their northern hemisphere migration and breeding season activity. The lack of precision of the loggers around the equinoxes (March and September) reduce the picture of breeding and migration data that we can gather. These two months coincide with both the deployment of the loggers, and the return of birds to New Zealand following the austral winter moult in the North Pacific.

Another challenge for the study was the small number of birds available at several of the sites. At each locality, we had equipment to deploy loggers on 20 – 50 birds in any one visit. However, breeding birds were not available to be caught in these numbers at Lady Alice Island / Mauimua or Titi Island during incubation nor at Ohinau Island in April 2012 during chick-rearing.

We recommend that future foraging studies on the species be undertaken over periods in excess of 20 days, in order to capture representative datasets for any one period of the breeding season.

GPS logger configurations were set at 15 minute intervals, with power-save options implemented. After extensive testing, this proved the best compromise between battery-conservation and detail of behavioural data. Longer intervals between fixes (up to 1 h) did not significantly extend the total battery life possible with the model of I-Got-U loggers we deployed.

5 Discussion

The study was fruitful in developing demographic mark-recapture datasets, study sites for future research, and collect foraging data on flesh-footed shearwaters in northern and central New Zealand.

The species populations are increasingly well known, with recent surveys on most populations throughout New Zealand (Taylor 2000, Baker *et al.* 2010, Waugh *et al*. 2013, this study). Our analysis of island-wide population survey information indicates a probable decline for the population at Ohinau Island (Coromandel), but stable populations at Lady Alice Island / Mauimua (Northland) and Titi Island (Marlborough). Modelling of demographic information from Lady Alice Island / Mauimau indicated a potential decline in the study population, but with a recommendation for more intensive recapture efforts to improve estimation of survivorship.

Recent land-based conservation efforts may have mitigated some of the population impacts of potential fisheries mortality (Abraham and Richard 2013). Each of the three colonies studied has had their introduced mammals eradicated (kiore *Rattus exulans* were removed from Lady Alice Island/Mauimua Island in 1994, Kiore and rabbits *Oryctolagus cuniculus* were removed from Ohinau Island in 2005, Norway rats *R. norvegicus* were removed from Titi Island in 1970; Clout and Russell 2006). Moreover, there has been very limited muttonbird harvesting in these regions in modern time (Lyver *et al*. 2008, Gaze and Smith 2009). These efforts likely enhance shearwater reproductive output which may be countering some of the negative impacts fisheries mortalities could be having on the populations.

The population trend information at all our study sites is complex to interpret when considering the whole-of-island ecology. Where burrow density is increasing, but flesh-footed shearwater occupancy is stable or decreasing, it is possible that increases in the breeding populations of sympatric species is occurring. At each site, a larger and more aggressive burrowing species of seabird is present. The most numerous species nesting on Titi Island is sooty shearwater, while Little Penguins are also common. At the other two sites, grey-faced petrels are present in numbers, and are known to evict earlier-nesting and smaller species, such as flesh-footed shearwaters, when the petrels arrive to clean out burrows in April, when the shearwaters have unguarded chicks in their burrows. Even fully feathered adult-sized flesh-footed shearwater chicks are sometimes killed at this time of year. Grey-faced petrels have a deep powerful bill with a needle sharp hook.

We recommend ongoing monitoring of the Ohinau, Lady Alice Island/ Mauimua and Titi Island populations of flesh-footed shearwaters and other major populations (*e.g.*, Atiu / Middle Island, Karewa, and others in the Chickens Group) (Figure 1) to provide a more detailed picture of flesh-footed shearwater population changes.

The species assemblage and population dynamics at the sites are complex, with the potential for multiple factors, including possible less-than-annual breeding frequency, possible low survivorship, or poor attendance years, and competition between species for nesting habitat to be influencing population growth.

It is clear from our examination of mark-recapture datasets (Barbraud *et al.* in press, Appendix 2) that there is no room for complacency about the population trend of the species, with the population at Lady Alice Island / Mauimua modelled as decreasing (growth rate of 0.883 (0.852 – 0.916 95% CI), based on average annual survivorship estimates of 0.94 (± 0.087) for burrow-caught birds and 0.756 (± 0.027) for surface-caught birds. The datasets used in our analysis allowed us to begin to estimate age at first breeding at Lady Alice Island / Mauimua, and more effort is required there to make most use of the chick banding undertaken by A. Booth from

2000 to 2012. Breeding success estimates requires a significant investment of time at the study sites, with visits around hatching and prior to fledging recommended to estimate this parameter.

At both of the mark-recapture study sites we visited, the maximum number of accessible burrows was monitored in each breeding season, thus discussion of optimal sample sizes is somewhat moot. Further activity would have required a great deal more effort (*e.g.*, to set up study burrows in a separate colony). However, the standard-error on the survivorship estimates is less than 0.1 in both cases, and may be acceptable for most population modelling applications.

The foraging study has allowed for a first detailed picture of the areas exploited and kinds of habitat used by flesh-footed shearwaters in New Zealand waters, but our data were mainly gathered at Ohinau Island, which may represent the Mercury Islands cluster of populations well, but may not adequately represent the Northland populations. These data show that there is strong potential for interaction with fisheries of all main capture methods (surface longline, bottom longline, trawl and setnet) in the areas routinely exploited by the species from Ohinau Island.

The most intense overlap occurs with most of the fishing methods (bottom longline, trawl and setnet) during the period when the birds range area is restricted by the need to regularly feed small chicks, in early chick-rearing (*i.e.,* early February). This time of restricted foraging range coincides with periods when fisheries are active in the shelf- and slope- areas near the breeding sites in the Coromandel region.

Surface longline fishing mainly occurs further offshore than bottom longline, trawl or setnet fishing, and has a fairly even amount of overlap with the species range from Ohinau Island during the different parts of the breeding season.

Our examination of multiple at-sea sightings datasets confirms that the species range as described by GPS tracking from Ohinau Island and the small datasets from Marlborough, is fairly representative. In particular, there is a major concentration of activity in the zone between Mahia Peninsula and eastern Northland. Understanding the detailed movements of birds from key sites in Northland, such as Lady Alice Island / Mauimua, is necessary to improve our knowledge of how the large concentration of birds in that region use marine areas.

The exodus of birds from the New Zealand zone in June to August is confirmed from ship-borne sightings, although the occurrence of occasional fisheries capture records in this period suggests a few birds may remain in the zone at this time. Some outlier locations, *e.g.*, in waters south of Cook Strait have been indicated by the fisheries capture and Te Papa collections data, and lend an additional lens through which to examine species range. Further work to describe the movements of birds when they are not breeding is needed to provide quantitative data on their activity.

6 Recommendations

1. Ongoing population monitoring is recommended at the three sites we studied: Lady Alice Island / Mauimua, Ohinau Island and Titi Island. This should involve assessment of population size, nesting density, burrow occupancy and extent of colonies. Studies between 15 Dec and 15 Jan are recommended, for 3 -4 consecutive years. Work at Titi island is instrumental in demonstrating how the species, at the edge of its range is responding to pressures.

2. It would be beneficial to gather critical data (nest density and occupancy) at other breeding sites in Northern New Zealand. We recommend that these studies target Whatupuke Island and Coppermine Island (Chicken Islands group, Northland), Atiu Island / Middle Island (Mercury Islands, Coromandel) and Korapuki Island, Bay of Plenty for these studies due to the large sizes of populations at each. We recommend a one-day 'health-check' on the populations with the aim of inspecting 100 – 200 burrows by burrowscope, and running a number of transects to assess density for the populations at a representative area of the colony.

3. We recommend that further mark-recapture studies be focussed on Lady Alice Island / Mauimua and Ohinau Islands, with banded study populations established at both sites. The colony sizes in accessible areas at each site determine the size of the population that can be easily monitored. There is

always a trade-off between effort on the site (*e.g.*, number of personnel, number of areas visited) and impact on the site, and we feel we generated high quality data with a maximum of four researchers per site, for periods of 2 – 6 weeks, with minimal disturbance.

4. For Mark-Recapture studies at Lady Alice Island / Mauimua and Ohinau Island. Samples sizes of 50 or more study nests are practicable at both sites, but recapture efforts need to be consistent and recover a higher proportion of individuals (greater than 30% per annum) to provide robust survivorship statistics. In reality, the site characteristics (remote, and with logistical limitations) are most likely to be the limiting factors for sample size and ability to representatively describe the populations at these or other sites.

5. Breeding parameters (age-at-first reproduction, reproductive success) require long-term efforts and multiple visits per annum. At Lady Alice Island / Mauimua, recruitment information is most tenable to collect, with an average age of 6 years of birds recaptured to date.

6. We would not recommend further intensive mark-recapture studies at Titi Island, due to the small size of the population, its fragile soils, and low representativeness of the population compared to other larger breeding populations in the northern part of New Zealand. As this site lacks water sources and research support structures, it is more difficult to develop long-term studies there than at the other sites visited during the study.

7. Analysis of the transect survey method used in our studies indicates that GPS logged transects, combined with detailed perimeter mapping, and multiple occupancy samples within a colony provides robust, adaptable, and convenient assessment for the sites visited. This was facilitated by prior knowledge of the sites. Alterations to the method might be warranted where the locations of colonies are unknown (*e.g.*, more searches to locate colony areas, fewer transects). In any case, we recommend a higher level of burrowscoping (particularly to provide multiple occupancy estimates for each colony) than has been applied previously.

8. For the foraging data and analysis, we recommend ongoing research at Ohinau Island during December, and late chick-rearing (March – May), and further data collection at Lady Alice Island. It would be feasible to conduct further GPS tracking studies at Titi Island, where the small population provides information about the southerly range of the species, from a relatively accessible and easy-to-navigate site.

9. We recommend deployment of further devices to track non-breeding period activity.

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9 Figure headings

Figure 1. Islands with known extant flesh-footed shearwater breeding colonies. Bolded numbers indicate islands that were visited as part of this study. 1= Titi Island, 2= Te Henga/ Bethells Beach, 3= Karewa Island, 4= Atui/Middle Island, 5= Green Island, 6= Korapuki Island, 7= Double Island/Moturehu, 8= Ohinau Island, 9= West Chicken/Mauitaha Island, 10= Lady Alice Island, 11= Whatupuke Island, 12= Coppermine Island.

Figure 2. Lady Alice Island/Mauimua showing locations of flesh-footed shearwater colonies (yellow) and grey-faced petrel only colonies (green). Seven flesh-footed shearwater colonies were identified and surveyed during the project. Colony 1 is the study colony, and near the field hut and landing beach. Colonies at this site have numeric names only (1, 2, 3, 5, 6, 7a, 7b, 8, 9, and 10), corresponding to the same areas surveys by Baker and colleagues (2010).

Figure 3. Titi Island showing locations of flesh-footed shearwater colonies (yellow). Nine discrete colonies were identified and surveyed during the project. Colony names are 1a – Camp colony; 1b – Scout; 2 – Colony 2; 3a – 3 legged West; 3b – 3 legged East; 4 & 6 – Twin Sisters; 7 – Titoki; 9 – Ongaonga; 10 – Kitchen, numbers correspond to the areas identified by Baker and colleagues (2010).

Figure 4. Ohinau Island showing the perimeters of flesh-footed shearwater colonies surveyed during 2013-2014. Colony names are as follows 1 – Study Colony; 3 – Slot; 4 – Hilltop; 5 – South Colony; 6 – South Point; 8 – South of the Gully; 9a – Epic

Mealtime; 9b – Pohutakawa. South Point was not burrow-scoped. It would not likely increase the island population significantly due to its low burrow density (0.0115/m^2).

Figure 5. Breeding season locations of foraging trips for flesh-footed shearwaters tracked with GPS loggers from Ohinau and Titi Islands. The upper and lower figures represent kernelled density plots during the incubation period (January) and chick-rearing period (February), respectively. The dotted lines represent the 1000m bathymetry contour.

Figure 6. At sea data from 10 minute ship-borne counts summed across years (1970s – 1980s). Points are scaled by the number of flesh-footed shearwater seen at each point (red dots 1 – 200 birds), grey crosses are locations of observations where no flesh-footed shearwaters were observed. Starting with the figure in the upper left-hand corner and moving clockwise, incubation to early chick-rearing period (December to March), late chick-rearing period (April to May), winter (June to August), and return to the colony from migration and pre-laying period (September to November).

Figure 7. The collection sites of flesh-footed shearwaters that were gathered at sea that are now held by Te Papa.

Figure 8. Locations where flesh-footed shearwaters were caught as fisheries bycatch. a) incubation to early chick-rearing period (December to March; n = 113), b) late chick-rearing period (April to May; n = 43), c) winter (June to August; n =2), and d)

return to the colony from migration and pre-laying period (September to November; n = 66).

10 Table headings

Table 1. Details of flesh-footed shearwater surveys conducted during the breeding seasons of 2011-2012, 2012-2013, and 2013-2014.

Table 2. Density and population estimates of flesh-footed shearwater colonies at three islands surveyed during the study.

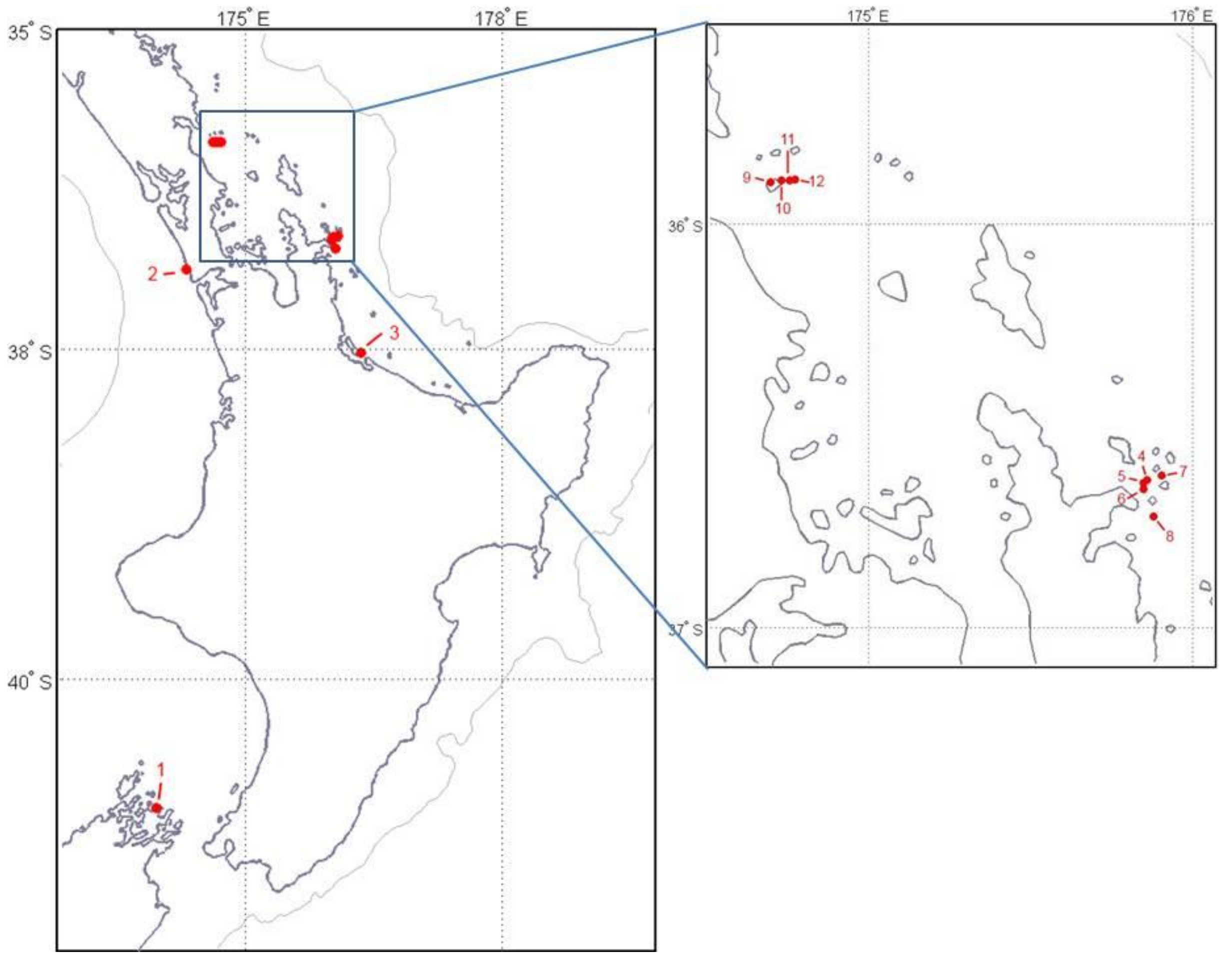

Figure 1

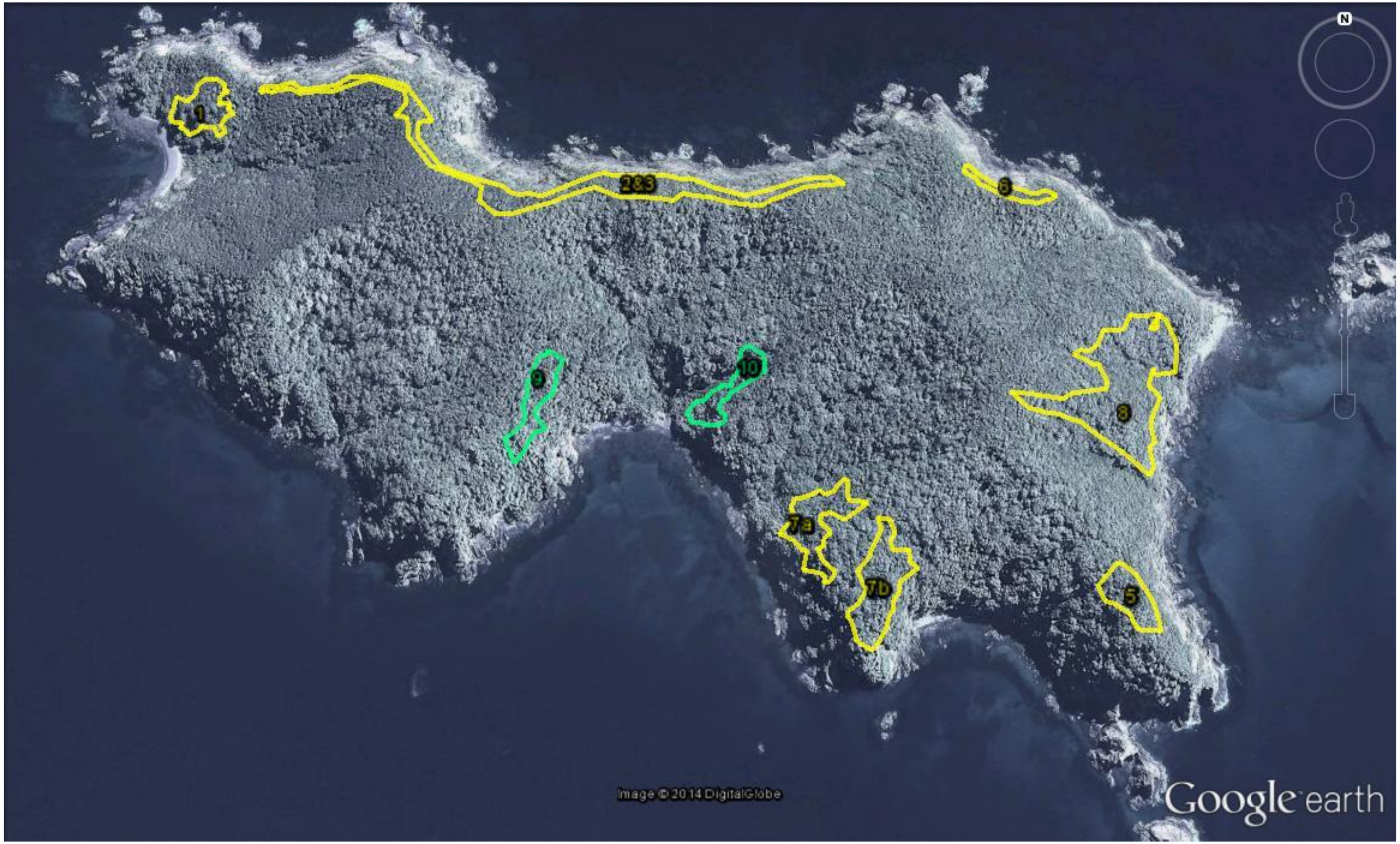

Figure 2

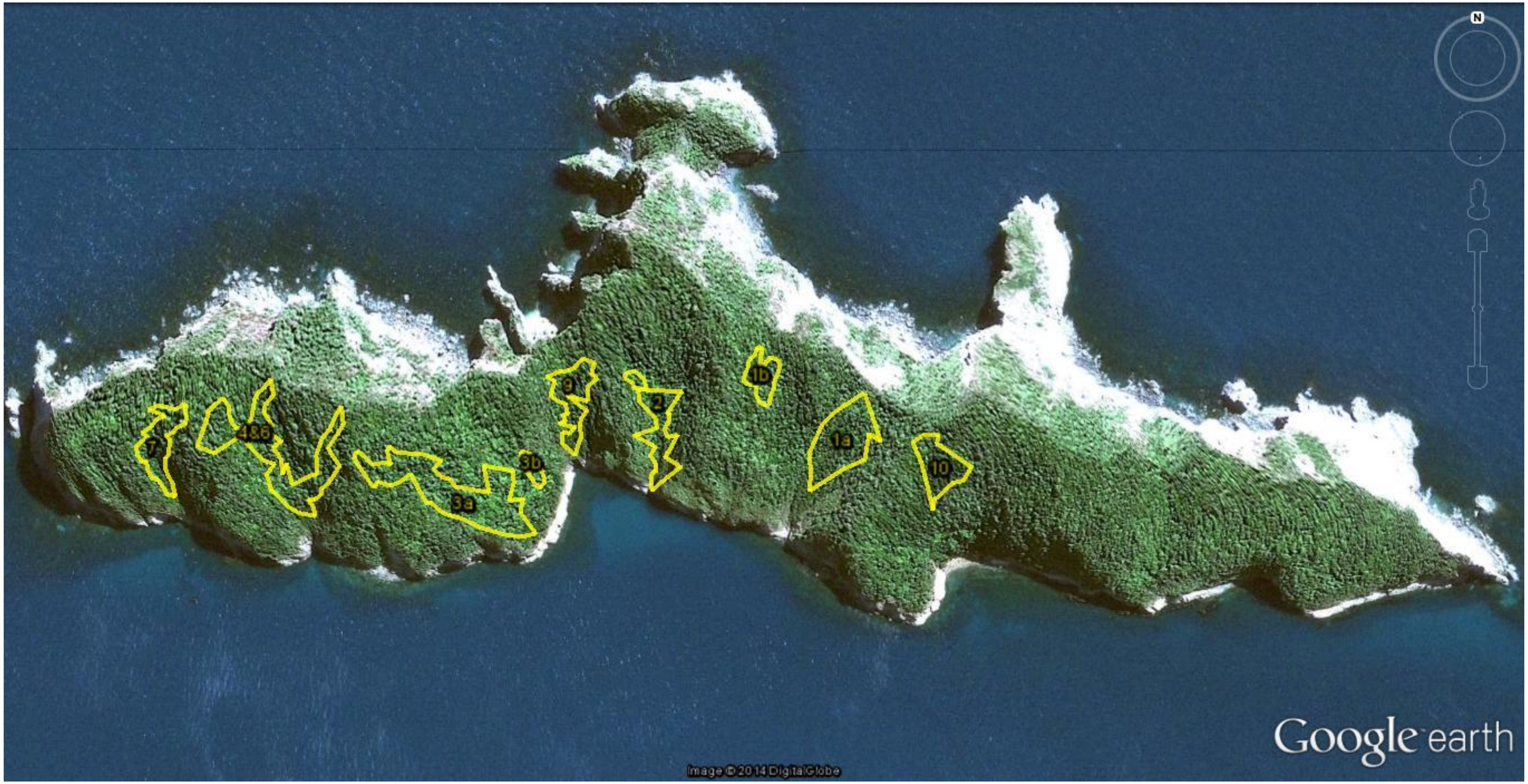

Figure 3


1
8
3
9a
4
5
9b
6
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2014 DigitalGlobe
Google earth

Figure 4

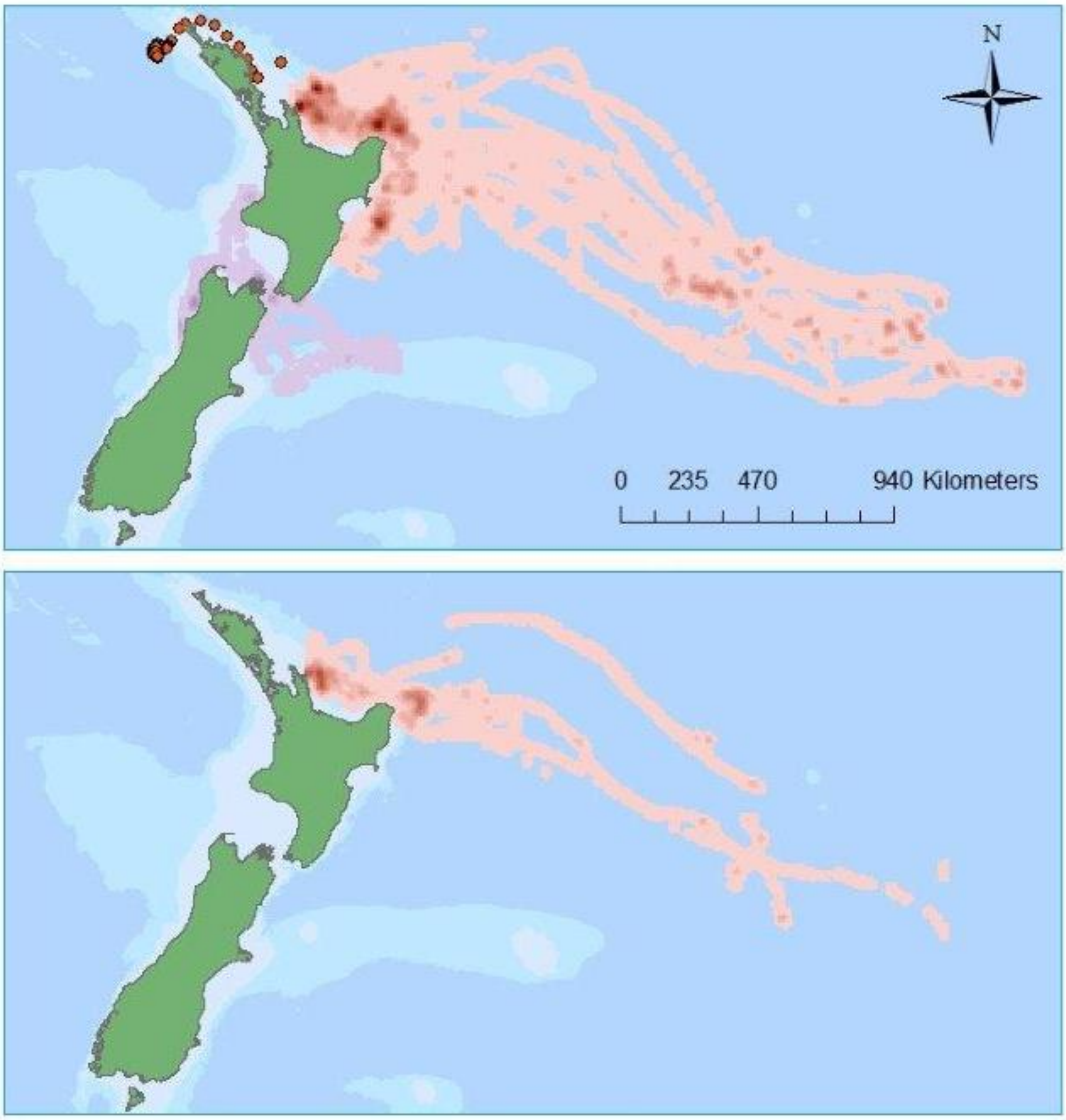

Figure 5

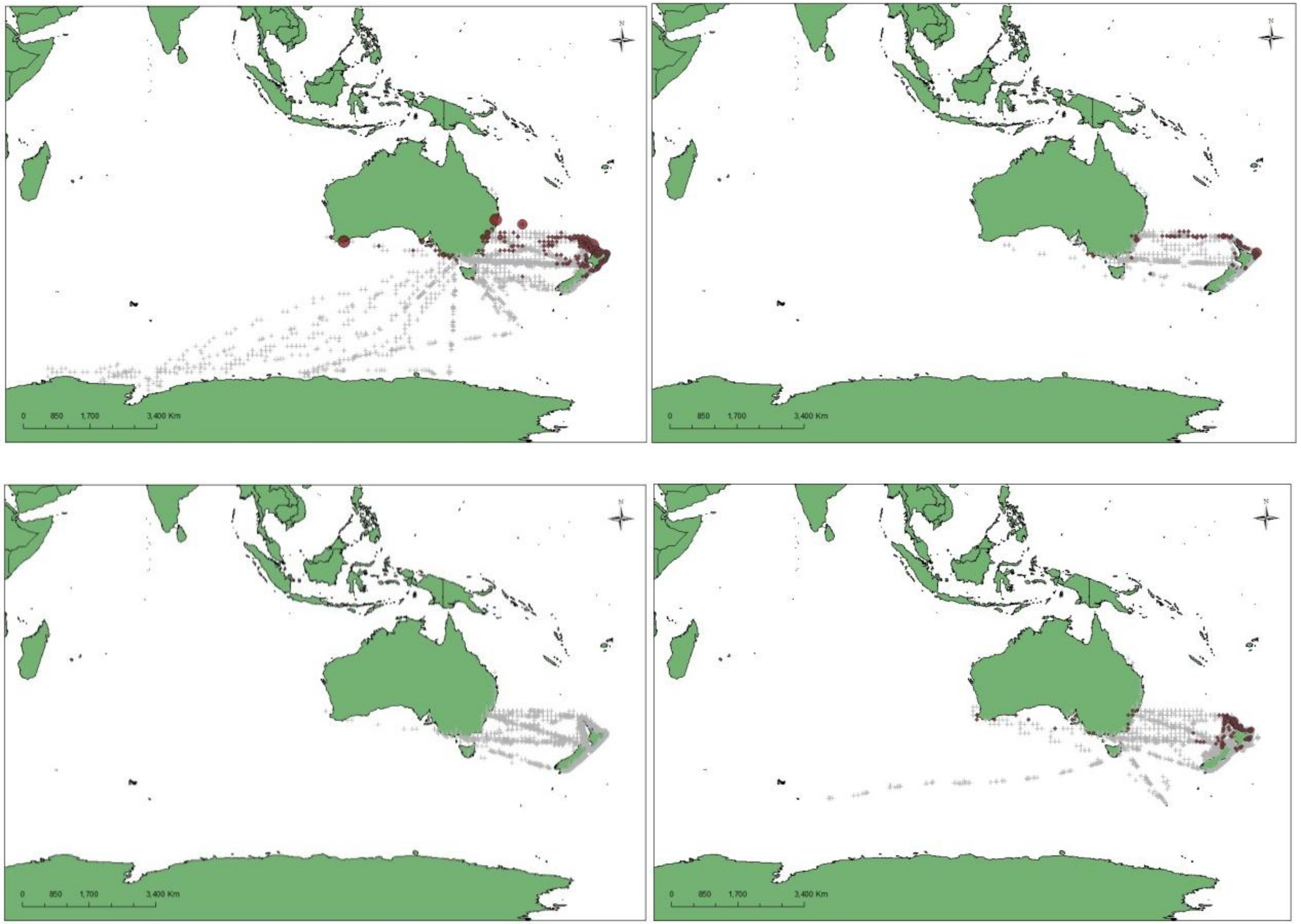
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Figure 6

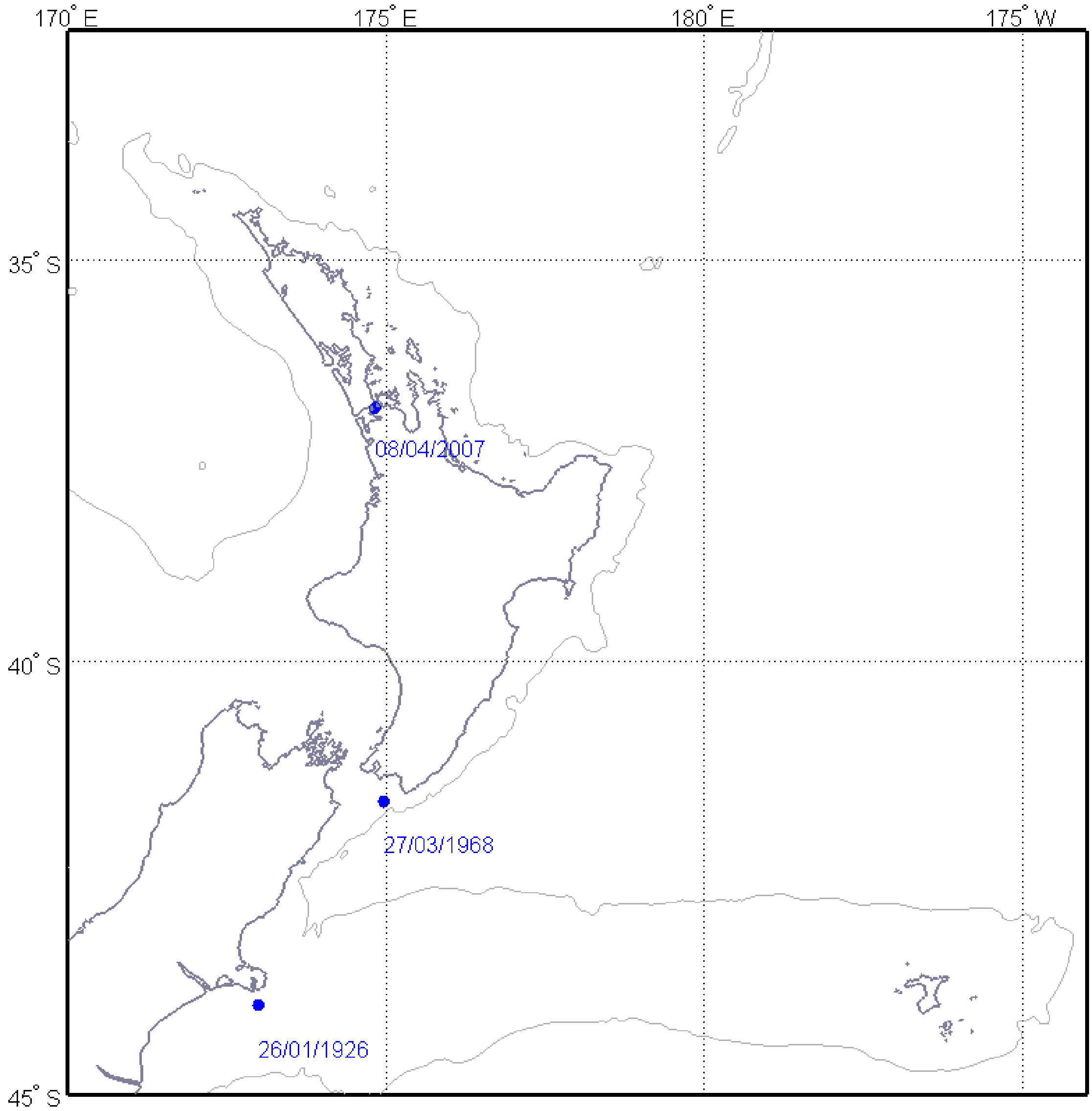

Figure 7

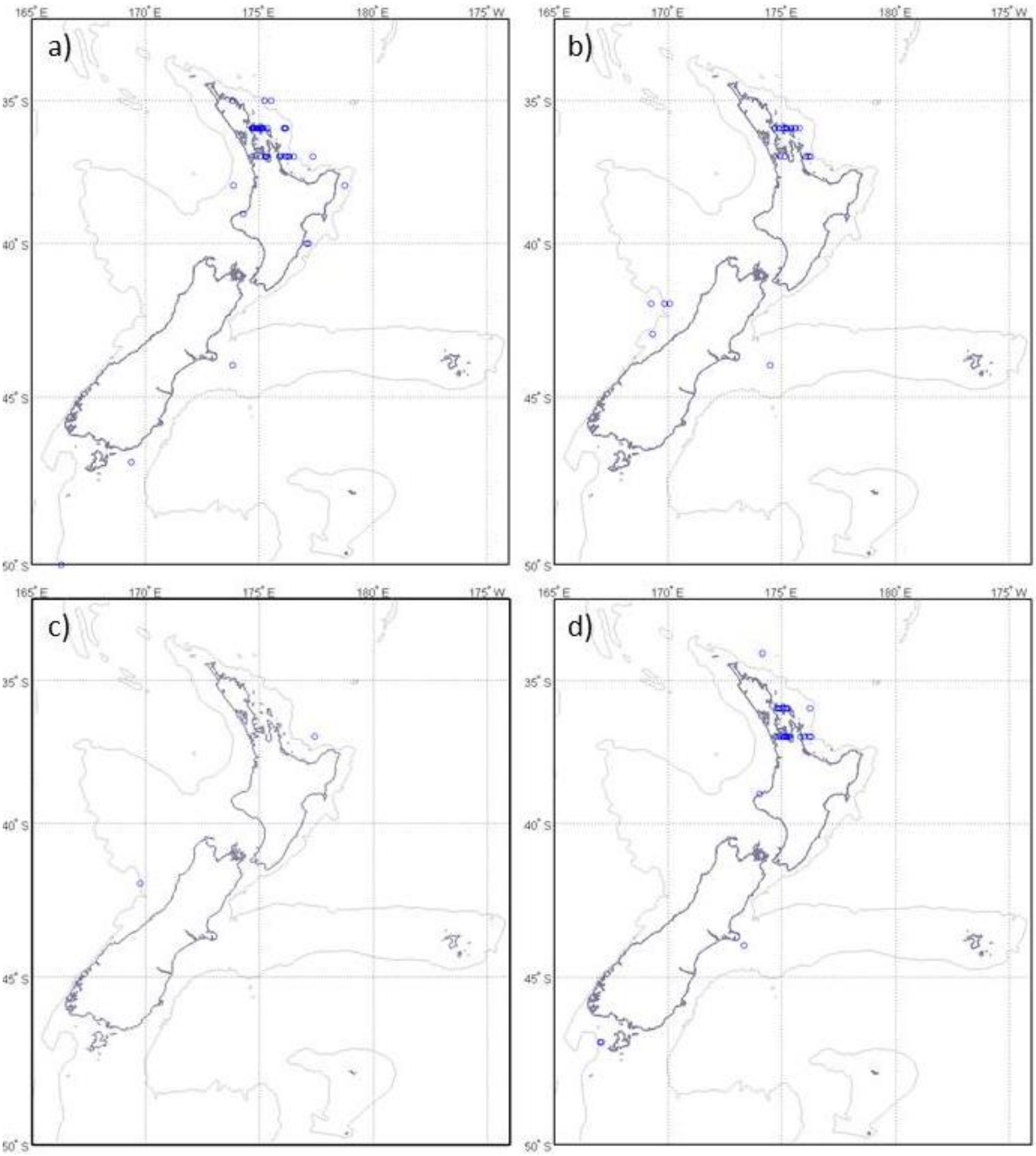

Figure 8

Table 1

Island	Area (ha)	Estimated population* (breeding pairs)	Dates	Total length of surveys (m; # of transects)	Burrows inspected
Lady Alice	155	921 (237–1605)	28 Mar–6 Apr 2012	1793 (39)	271
			8–19 Dec 2012	877 (14)	166
Ohinau	43	2071 (943–3200)	11–14 Apr 2012	1268 (26)	299
			18 Jan–18 Feb 2014	2617 (73)	399
Titi	32	337 (0–950)	9–17 Jan 2012	3238 (63)	136
			11–14 Jan 2013	134 (3)	142

* estimates ± 95% CI from Baker *et al*. 2010.

Table 2

Island (season)	Colony	Area	Estimated burrow density (m^{-2})	Estimated occupancy rate	Estimated # of occupied burrows
Lady Alice	1	7868	0.0685	0.1810	98
(2011-2012)	2&3	33722	0.0563	0.2069	393
	5	5545	0.0753	0.1333	56
	6	4287	0.0665	0.1167	47
	7a	8169	0.0742	0.0456	27
	7b*	10027	0.0836	0.0000	0
	8	33800	0.0306	0.0857	89
Ohinau	1	25163	0.1037	0.3379	882
(2013-2014)	3	592	0.0906	0.4839	26
	4	5455	0.1682	0.3438	315
	5	3790	0.2247	0.5122	436
	8	3270	0.1617	0.3448	182
	9a&b	11680	0.0710	0.3404	283
Titi	1a&b	2112	0.0625	0.0652	9
(2011-2012)	2	1373	0.1440	0.2587	56
	3*	3669	0.1093	0.0000	0
	4&6	3199	0.1043	0.0698	23
	7	1300	0.0823	0.2273	24
	9	1286	0.1612	0.2157	45

* plots were surveyed because previous work found some flesh-footed shearwaters