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An assessment of recent population trends of flesh-footed shearwaters (*Puffinus carneipes*) breeding in New Zealand

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Abstract Flesh-footed shearwaters (*Puffinus carneipes*) are considered to be one of New Zealand's seabird species that is most heavily impacted by both commercial and recreational fisheries, yet they have an IUCN ranking of "Least Concern". To resolve this contradiction we conducted surveys on 3 large breeding colonies and compared our results to historical data. We found that the burrow density on the most northerly island (Lady Alice Island/Mauimua) has increased since the last set of surveys; however the density of flesh-footed shearwaters nests has remained stable. At the largest colony we surveyed (Ohinau Island), the density of burrows has remained stable, while the density of nests has declined. At New Zealand's most southerly colony (Titi Island), both burrow and nest densities have remained stable. Our results suggest that the status of flesh-footed shearwaters populations in New Zealand is variable with 2 populations that are stable and 1 that is declining. Nevertheless, due to the short time period between our surveys and the historical data, repeated surveys in the future are needed to determine if further declines in the largest colony warrant a reassessment of the status of this species.

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INTRODUCTION

Seabirds are one of the apex predators of the world's oceans. Due to the inherent challenges of monitoring the health of the marine ecosystem, seabirds are often used as proxy indicators of events and processes occurring within our oceans (Cairns 1987; Piatt *et al.* 2007). Examining seabird population trends and behaviours can reveal shifts in the marine food web and oceanographic conditions (Weimerskirch *et al.* 2003; Montevecchi 2007). Unfortunately, seabird populations are not faring well relative to other birds; they are currently the most threatened group of birds on the planet (Croxall *et al.* 2012). Of the 339 extant species recently reviewed, 29% are threatened (*i.e.*, categorised as Vulnerable, Endangered, or Critical by the IUCN) and a further 10% of species are classified as Near Threatened (Croxall *et al.* 2012). Furthermore, 52% of those for which there is adequate information were shown to have downward population trends (Croxall *et al.* 2012). The principal threats to seabirds include fisheries (both bycatch and overfishing; Waugh *et al.* 2008; Bertrand *et al.* 2012), alien invasive species (Major *et al.* 2006; Jones *et al.* 2008), pollution (Derraik 2002; Mallory & Braune 2012), and human disturbance (Priddel *et al.* 2006; Carey 2009). The flesh-footed shearwater, *Puffinus carneipes*, is

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exposed to many of these threats (Priddel *et al.* 2006; Hutton *et al.* 2008; Richard *et al.* 2011) and a review of their conservation status may be warranted.

Flesh-footed shearwaters are large shearwaters that spend their non-breeding season in the pelagic waters of the Indian and Pacific Oceans. They breed on islands of Australia and New Zealand with a small outlying colony on Île Saint-Paul in the Indian Ocean. They have an estimated world population of 650,000 individuals (Brooke 2004) and are currently listed with a conservation status of Least Concern with stable population trends (BirdLife International 2012). Such a ranking may need to be reconsidered in the light of information that they are one of the most commonly reported species to be taken as fisheries bycatch (Gales *et al.* 1998; Trebilco *et al.* 2010) and new findings that 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). Their results suggest that the population could decrease by 50% in 55 years and by 80% in 120 years under current rates of mortality (Baker & Wise 2005). Recent evidence collected at the breeding colonies of Lord Howe Island has confirmed that this population is experiencing an annual breeding population decrease of 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). Recently the status of flesh-footed shearwaters 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 2 northern New Zealand breeding sites support this impression (Barbraud *et al.* 2014). Within the New Zealand Exclusive Economic Zone (NZEEZ), 1079–1769 individuals are estimated to be killed in commercial fisheries bycatch each year; such levels may threaten the viability of flesh-footed shearwaters in New Zealand (Richard *et al.* 2011). 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).

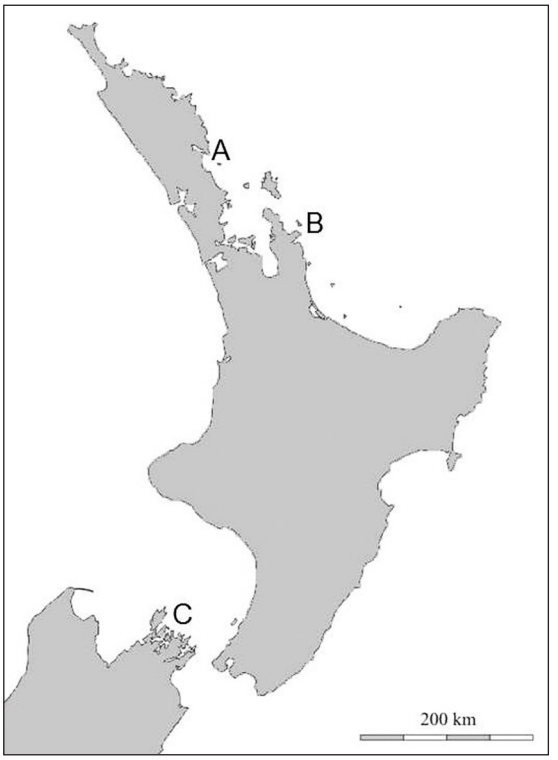

Fig. 1. Colonies where flesh-footed shearwater surveys were conducted between 2011–2014. (A = Lady Alice Island/Mauimua Island, B = Ohinau Island, C = Titi Island).

These statistics highlight the need to examine population trends of flesh-footed shearwaters within New Zealand. We conducted surveys on 3 major flesh-footed shearwater breeding islands across New Zealand and compared our data with those previously collected by Baker *et al.* (2010). We also report densities of other sympatric burrowing seabird species recorded in our surveys: little penguin (*Eudyptula minor*), grey-faced petrel (*Pterodroma macroptera*), Pycroft's petrel (*P. pycrofti*), sooty shearwater (*Puffinus griseus*), and little shearwater (*P. assimilis*).

METHODS

Surveys

Surveys were conducted on Lady Alice Island/Mauimua Island (Hen and Chicken Islands Nature Reserve, Northland; 35.89° S, 174.71° E), Ohinau Island (Mercury Islands Group, Coromandel; 36.72° S, 175.88° E), and Titi Island (Marlborough Sounds; 40.95° S, 174.13° E) during the breeding seasons of 2012–2013, 2013–2014, and 2011–2012, respectively (Fig. 1). These data were compared to those collected

by Baker *et al.* (2010) on Lady Alice Island/Mauimua from 2007-2008, and Ohinau and Titi Islands from 2008-2009. The surveys of both studies were timed to ensure they occurred while the birds were in mid incubation (December-January; Table 1).

On each island we surveyed as many flesh-footed shearwaters colonies as we could locate. Although colonies have multiple-species present, burrows are predominantly used by flesh-footed shearwaters or sooty shearwaters during the period we sampled. Burrow density is used to estimate the overall number of birds likely to be present on the island, with the correction factor of burrow occupancy, to adjust for the numbers of nesting birds, empty burrows, or other species using burrows (*e.g.*, moulting penguins, non-breeding petrels). We ran straight-line transects along the gradient of each colony (usually between 20–100 m in length). As the surveyor walked along the slope they counted all burrow entrances within a meter of their track that would be suitable for nesting flesh-footed shearwaters (*i.e.*, >20 cm long and an entrance >14 x 8 cm; Waugh *et al.* 2003). Using a handheld GPS unit (GPSMAP 60CSx, Garmin Ltd.), the coordinates from the start and end points of each transect were recorded; these were later used to calculate the length of each transect (BaseCamp, Ver. 4.1.0, Garmin Ltd.). Transects were spaced ~20 m apart.

The perimeter of each colony was recorded with a handheld GPS unit. A subsample of burrows in each colony was examined using a burrowscope to determine whether they were occupied and if so, by which species (Taupe Burrowscope, Sextant Technology Ltd., Wellington, New Zealand). A total of 3624 m were surveyed and the occupancies of 583 burrows were determined using a burrowscope (Table 1). These methods were similar to those used by Baker *et al.* (2010) when conducting flesh-footed shearwater surveys. We used the coordinates of Baker *et al.* (2010) to locate each colony, however, we independently constructed perimeters, thus we analysed burrow and nest density data rather than count data, to mitigate differences in colony perimeter locations.

Statistical methods

To determine whether burrow density and flesh-footed shearwater occupancy rates of burrows changed between sampling periods, we used weighted permutation analysis of variance, with time, plot, and time by plot interaction as factors. Permutation ANOVAs were used because neither burrow densities, nor flesh-footed shearwater nest densities, were normally distributed. In this method, the time "labels" for the observations (either "historical" or "recent") were permuted 5000 times within each plot. The number of transects observed at each time point within each plot was held constant for each permutation. An F statistic for the effect of time was calculated for each permutation, thus generating 5000 observations of an F statistic, and 5000 estimates of the β-coefficient of time under the null hypothesis of no time effect. The β-coefficient is equivalent to the overall change between sampling periods. The P-value for the β-coefficient of time was calculated as the proportion of permutation β-coefficients equal to or more extreme than the observed coefficient. In addition, because each plot had a different area, the regression was weighted by the area of each plot as measured by our team. The analysis was programmed in RStudio using the *lm* subroutine in the package *lmPerm* (Wheeler 2010; R Core Team 2012).

RESULTS

The density of burrows on Lady Alice Island/Mauimua Island significantly increased during the 5 years between surveys, while the number of nesting flesh-footed shearwaters remained constant (burrows: + 0.0352/m^2, F = 9.82, P = 0.0072; nests: +0.0032/m^2, F = 9.82, P = 0.150). During the 2012-2013 season we located 7 flesh-footed shearwater colonies on the island. Within these colonies, the median densities of burrows and flesh-footed shearwater nests were 0.1239/m^2 (interquartile range [IQR]: 0.0833 – 0.1818) and 0.0167/m^2 (IQR: 0.0071 – 0.0270), respectively. We estimated a total of 5617 burrows with a nesting population of 710 pairs.

The density of burrows on Ohinau Island remained stable during the 5 years between surveys, however the number of flesh-footed shearwaters nesting on the island significantly decreased (burrows: +0.0024/m^2, F = 0.262, P = 0.860; nests: -0.0103/m^2, F = 1.998, P = 0.016). During the 2013-2014 season, we located 6 flesh-footed shearwater breeding colonies. The estimated median densities of burrows and nests within these colonies were 0.1667/m^2 (IQR: 0.1100 – 0.3330) and 0.0859/m^2 (0.0451 – 0.1139), respectively. Within these colonies we estimated a total burrow count of 5790 with a nesting population of 2124 flesh-footed shearwater pairs.

On Titi Island both burrows and nests densities remained stable during the 3 years between surveys (burrows: -0.0194/m^2, F = 0.002, P = 0.531; nests: -0.0055/m^2, F = 0.179, P = 0.135). During the 2011-2012 season, we located 6 flesh-footed shearwater colonies. The median burrow and nest densities of these colonies were 0.2093/m^2 (IQR: 0.1189 – 0.2883) and 0.0121/m^2 (IQR: 0.0000 – 0.0434), respectively. Together, these colonies contained an estimated total of 1379 burrows and 157 breeding pairs.

Table 1. Details of surveys conducted on a selection of flesh-footed shearwaters colonies in New Zealand.

Colony	Area (ha)	Dates	Total length of surveys (m)	Burrows inspected	No. of burrows occupied by flesh-footed shearwaters
Lady Alice Island/Mauimua Island (35.89° S, 174.71° E)	155	8–19 December 2012	877	166	23
Ohinau Island (36.72° S, 175.88° E)	43	18 January–18 February 2014	1594	292	106
Titi Island (40.95° S, 174.13° E)	32	9–17 January 2012	1153	125	13

Table 2. The densities of species nesting sympatrically with flesh-footed shearwaters. Presented are data (number of occupied burrows, followed by median density, and interquartile range (nests/m^2)) from all major flesh-footed shearwater colonies on each island, including colonies that were not included in the statistical analysis due to lacking comparable historical data.

	No. colonies surveyed (burrows examined)	little penguin	grey-faced petrel	Pycroft's petrel	flesh-footed shearwater	sooty shearwater	little shearwater	tuatara*
Lady Alice/ Mauimua 2012–2013	7 (369)	6 0 (0.0000-0.0027)	52 0.0123 (0.0062-0.0274)	18 0.0025 (0.0090-0.0088)	56 0.0167 (0.0071-0.0270)	1 0 (n/a)	2 0 (n/a)	25 0.0079 (0.0024-0.0128)
Ohinau 2013–2014	6 (399)	0 (n/a)	0 (n/a)	0 (n/a)	147 0.0859 (0.0450-0.1139)	0 (n/a)	0 (n/a)	0 (n/a)
Titi 2011–2012	6 (241)	11 0.0036 (0.0000–0.0213)	0 (n/a)	0 (n/a)	32 0.0122 (0.0000-0.0430)	56 0.0676 (0.0105–0.0908)	0 (n/a)	5 0.0000 (0.0000–0.0032)

* Tuatara were not observed breeding in the burrows. They were simply occupying the burrows, occasionally alongside a nesting seabird.

Lady Alice Island/Mauimua had the most diverse seabird community with 5 other species located in the study colonies (Table 2). The most depauperate community was on Ohinau Island, as there were no sympatric congeners nesting within the study plots, although signs of little and fluttering shearwaters (*P. gavia*) nesting outside the plots were observed and a Pycroft's petrel was seen inspecting burrows. All species were present in lower numbers than the flesh-footed shearwaters with the exception of sooty shearwaters on Titi Island (Table 2). Tuatara were regularly found in the burrows on Lady Alice and Titi Islands; they are not present on Ohinau Island (Table 2).

DISCUSSION

Due to concerns regarding the numerous threats facing flesh-footed shearwater populations, we carried out surveys on 3 major breeding colonies across the shearwater's breeding range within New Zealand. We found that burrow densities have significantly increased on Lady Alice Island/Mauimua, however the density of nesting flesh-footed shearwater has remained stable. On Ohinau Island the density of burrows has remained constant while the density of flesh-footed shearwater nests has significantly declined, and on Titi Island burrow and nest densities have remained constant. This geographically limited population decline was unexpected, as recent work has shown they sustain significant mortality from both commercial and local fisheries (Richard *et al.* 2011; Tennyson *et al.* 2012).

The lack of a general decline in flesh-footed shearwaters may be due to recent land-based conservation efforts that may have mitigated some of the population impacts of fisheries mortality. Each of the 3 colonies has had their introduced mammals eradicated (kiore [*Rattus exulans*] were

removed from Lady Alice Island/Mauimua in 1994, kiore and rabbits [*Oryctolagus cuniculus*] were removed from Ohinau Island in 2005, and Norway rats [*R. norvegicus*] were removed from Titi Island in 1970; Clout & Russell 2006). Moreover, there has been limited muttonbird harvesting in these regions in modern times (Lyver *et al.* 2008; Gaze & 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.

At first glance, the result that the population breeding on Lady Alice Island/Mauimua is stable was somewhat unexpected for 2 reasons. Firstly, we found that the density of burrows significantly increased over time. It is possible that this increase is due to an increase in the flesh-footed shearwater population that was not detected during our surveys, however Lady Alice Island/Mauimua has the highest diversity of sympatric breeding seabirds, thus it is more likely that the increase in burrow density was due to activities of other species of burrow-nesting seabirds. Secondly, Barbraud *et al.* (2014) conducted a survival analysis on a 13 year data set of marked individuals captured at a single colony on Lady Alice Island/Mauimua and a found contrasting trend. Specifically, they found that the population growth rate of all marked birds was 0.883 ± 0.016 (*SE*) which equates to an annual decrease of 16%.

The fact that the population nesting on Ohinau Island has significantly declined is of concern. Ohinau Island is one of the largest breeding colonies within New Zealand (Waugh *et al.* 2013), and losing a colony of this size would have serious ramifications to the country's entire population. Furthermore, the 2 other largest flesh-footed shearwater breeding sites of New Zealand are within 100 km of Ohinau Island (Atiu Island/Middle Island and Karewa Island; Waugh *et al.* 2013). If the downward trend observed on Ohinau is an indication to what is occurring on other islands within the region, this could have consequences for the global population.

The strength of our analyses is that they provide the first assessments of flesh-footed shearwater population trends over a wide geographical range within New Zealand, however, their weakness is that they are based on surveys conducted over 2 points in time only. Many seabirds do not breed every year (*i.e.*, they are intermittent breeders). For example, ~14% of the breeding population of short-tailed shearwaters (*Puffinus tenuirostris*, a close relative to the flesh-footed shearwater) does not breed each season (Bradley *et al.* 2000). It is likely that flesh-footed shearwaters are also intermittent breeders. Gaze (2000) reports large discrepancies in the composition of the shearwater community nesting on Titi Island with the ratio of sooty shearwater to flesh-footed shearwater varying from 1:1 to 0:6 between years, further supporting our hypothesis that flesh-footed shearwaters are intermittent breeders. Such high variation in the proportion of birds attempting to breed per year limits our ability to draw strong of conclusions from our short time series.

In conclusion, our results suggest that flesh-footed shearwater populations may be faring reasonably well. However, we feel that due to the short time scale covered in our analysis, it would be prudent to conduct more surveys in the future before reassessing their conservation status. More surveys would allow us to draw stronger conclusions regarding population trends and ideally be able to tease apart why different populations appear to be on different trajectories. Furthermore, the conflicting trends of burrow and nest densities in our study suggest that rapid surveys (*i.e.*, burrow counts during short island visits) may be of little value in monitoring flesh-footed shearwater populations and that burrow occupancy data will be essential to defining their population trends.

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