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Population estimation of the New Zealand storm petrel (*Fregetta maoriana*) from mark-recapture techniques at Hauturu/Little Barrier Island and from at-sea resightings of banded birds

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Abstract: Between 2014 and 2018 a mark-recapture/ resighting study was conducted to ascertain the size of the population of New Zealand storm petrel (Fregatta maoriana) at their breeding grounds on Hauturu, Little Barrier Island, New Zealand. A total of 415 New Zealand storm petrels were captured and marked with individual colour bands using acoustic playback and night-time spotlighting on Hauturu. Two mark-recapture models were developed using the recaptures of banded birds on land and the at-sea resightings of banded birds attracted to burley on the Hauraki Gulf near Hauturu. The landbased model suggests a current population of 994 (range 446–2,116) individuals whereas the at-sea model suggests an estimate of 1,630 (range 624-3,758) individuals. The discrepancy between these models likely lies in the bias of on-land captures towards juvenile birds constituting >50% of birds caught. We consider the at-sea model most representative of total population size. Logistic population growth models anchored by on-land and at-sea population estimates suggest pre-rat eradication populations of New Zealand storm petrel of 323 and 788 individuals respectively.

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Keywords: New Zealand storm petrel, population estimate, spotlighting, Hauturu, Little Barrier Island, *Fregetta*

INTRODUCTION

The New Zealand storm petrel (Fregetta maoriana) (hereafter NZSP) is classified as "Threatened -Nationally Vulnerable" under the New Zealand Threat Classification Scheme (Robertson et al. 2017) and as "Critically Endangered" by the International Union for the Conservation of Nature (BirdLife International 2018). Endemic to New Zealand, the species was considered extinct until sighted at sea in northern New Zealand in 2003 (Flood 2003; Saville et al. 2003; Stephenson et al. 2008a). A ten-year research programme resulted in the discovery of the species' only known breeding site on Te Hauturu o Toi, Little Barrier Island (36°16'S, 175°06'E), in 2013 (hereafter Hauturu) (see Rayner et al. 2015 for overview). To date four NZSP breeding burrows have been discovered by using either telemetry or a trained seabird detecting dog and two chicks have been banded (Rayner et al. 2015). This population has been presumed to be expanding following the 2004 eradication of kiore (*Rattus exulans*), a likely predator of storm petrel eggs, chicks, and adults. The 1980 eradication of feral cats (Felis catus) would have removed a predator of adult birds and fledglings (Rayner et al. 2007).

A critical next stage in the conservation management of this poorly known seabird is understanding the distribution, size, and trajectory of this population following predator removal. However, the breeding habitat and behaviour of NZSP present challenges for population census. The small number of discovered New Zealand storm petrel nests on Hauturu lie 700-1,500 m inland under mature mixed conifer-broadleaf forest, including hard beech (Fuscospora truncata) and kauri (Agathis australis). The terrain in this area is steep with fragile slopes consisting of deep leaf litter and fragile rock scree. NZSP nests are in natural fissures and holes in this terrain, difficult to see, and likely easily damaged by field workers moving in the area. The behaviour of NZSP on land is also extremely cryptic. Birds are strictly nocturnal over the breeding site to the point where they show moonlight avoidance behaviour; visiting the colony before and after moon rise and set (Rayner et al. 2015). Accordingly, typical census techniques used for seabird population estimates, such as counts of birds or burrows at the colony, are not suitable and would damage areas where nesting sites have been found (Rayner et al. 2008; Rayner et al. 2015).

Mark-recapture presents a non-typical solution to the census of cryptic seabird populations and has been used with a variety of storm petrel taxa (Sydeman et al. 1998; Insley et al. 2014). This technique involves the marking of a subset of a population and later recapturing or resighting a new subset with the proportion of marked individuals allowing for estimation of the total population size. A variety of techniques have been used for capturing Procellariiformes on the wing including call playback (Insley et al. 2014), the use of mist nets (Becker et al. 2016), and spotlighting (Crockett 1994; Gummer et al. 2015). In 2014, we investigated the utility of using these three techniques to catch NZSP on Hauturu, concluding that a combination of call playback and spotlighting represented the best approach for a mark-recapture census (Ismar et al. 2015). Here we report the results of a five-year mark-recapture programme, using a combination of land- and sea-based mark-recapture and resighting, in order to quantify the population size of NZSP on Hauturu. In addition, we present a simple logistic model to estimate the growth trajectory of this population following presumed ecological release from rat predation in 2004.

METHODS On land capture

NZSP are active at their breeding sites beginning in September with incubation conducted between February and April over a period of 40 days and chicks fledging in June and July following a chick rearing period of 60 days (Rayner et al. 2015). We conducted field work on Hauturu over the course of five summer seasons: 2014 (18 Feb-2 Mar), 2015 (9-19 Feb), 2016 (8-15 Jan, 2-12 Feb, 1-5 Mar), 2017 (1 Feb-3 Mar), and 2018 (9-18 Feb). Our primary capture site was an area of clear grassland close to the likely flight path of NZSP approaching the valley containing known breeding burrows discovered in 2013 (Ismar et al. 2015; Rayner et al. 2015). Two other capture sites were used for a small number of nights over the five years: 1) several hundred metres away by the island's bunkhouse, which was used on three nights in February 2017 due to inclement weather at the main capture site; 2) on one night captures were attempted with hand-held torches on the far eastern coast of Hauturu, about five kilometres distant, in an attempt to investigate the distribution of NZSP around the island. The primary capture location presented the open space required for efficient use of hand-held spotlights and for the positioning of a generator that powered a flood light (500 W halogen). The flood light was positioned in the centre of the capture area with a baffle cone to direct light upwards in the sky so as not to impact the night vision of field workers (Fig. 1). Our previous research had demonstrated the extreme aversion of NZSP to moonlight over land (Rayner et al. 2015). Accordingly, most field trips were based around the new moon, with capture attempts finishing earlier or starting later in the night to account for moon rise and set.

A typical capture/recapture session began with the floodlight being turned on and a playback speaker (FOXPRO NX3) turned on playing a NZSP call previously recorded at a known breeding site (see Ismar *et al.* 2015). When a NZSP was attracted and sighted in the flood light, field workers used two Ledlenser X21 (2000 lumen) LED torches, as well as headlamps, to attempt to disorientate the storm petrel to bring it to ground in the long grass (Fig. 1).

Recaptured birds were marked with a thin stripe of white correction fluid (Liquid paper®) on the centre of the head and banded with a unique four-band combination consisting of one numbered metal New Zealand Department of Conservation stainless steel B size (4.0 mm) leg band and a three-colour combination of Darvic® leg band sequence (Fig. 1). The breeding status of captured birds was assessed through evaluation of brood patch moult following the protocols of (Rayner *et al.* 2013) (0 = fully downy to 4 = fully bare, and R = refeathering).

In the 2014 season processed captured birds were allowed to recuperate in a cardboard bird box away from light and noise and then released on the coast. From 2015 to 2018 captured birds were released into a trial NZSP colony consisting of 50 artificial plywood nest boxes, with 6 cm diameter



Figure 1. A. Capture site on Hauturu showing spotlight and time-lapsed New Zealand storm petrel descending before its capture (Photograph: Edin Whitehead). Inset showing banded NZSP in hand (Photograph: Andre Raine). B. Banded NZSP observed and photographed during at-sea resighting surveys (Photograph: Edin Whitehead). C. Close up of banded NZSP at sea with band number of bird legible at high resolution (Photograph: Edin Whitehead).

Novacoil plastic drainage pipe entrance tunnels, and a sound playback system playing NZSP calls. The aim was to encourage the birds to anchor to the site for future nesting, in addition to the birds leaving scent in nest boxes at the trial colony to encourage other birds to stay. Birds were left to depart the nest boxes on their own accord before the following morning, although on occasion birds spent the following day in the box before leaving the subsequent night.

At-sea resighting

In 2016-2018 we conducted boat-based at-sea surveys for both unmarked and banded NZSP between January and March. This research was conducted at known locations where birds had been captured during our previous research programme (2006–2013) into the breeding location of the species including Northwest Reef (10 km north of Hauturu) and Simpsons Rock in the Mokohinau group, (36°00'26.93"S, 175°07'09.08"E) (see Stephenson et al. 2008b; Rayner et al. 2013; Rayner *et al.* 2015). During each resighting session, a sea anchor was deployed allowing the boat to drift slowly. Subsequently, a bait of frozen salmon burley in a mesh bag was deployed on a rope behind the boat as per Rayner et al. (2013). Observers on the boat used binoculars to observe any NZSP approaching the burley (typically within <50 m of observers) and identify birds possessing metal and colour band combinations. High-resolution digital photography was also used to record and confirm band combinations (Fig. 1). Birds were only added to the count of banded individuals if they could be individually identified by their unique metal and colour band sequence. Numbers of unmarked NZSP were also recorded at each location per timed session.

Mark-recapture estimates

Population size (*N*) was estimated based on the following mark-recapture equation:

 $N = n^* M / m,$

where n is the number of NZSP caught on-land or sighted at-sea in session i,

M the number of NZSP banded prior to capture/ resigning session *i*,

and m the number of banded NZSP recaptured or resignted in the same session.

This mark-recapture equation was applied to all on-land capture and at-sea resighting sessions that yielded banded NZSP; the mean of all estimates for N was taken to represent the average population estimate of the respective study year, and minimum and maximum values of estimates were used as conservative indicators of confidence.

Population growth modelling

We used simple logistic population growth models, to calculate seasonal population size change and size at the time of rat eradication in 2004. Models



Figure 2. Sightings of New Zealand storm petrels per hour spotlighting and playback effort on Hauturu, across the prospecting, mating, and early incubation stages in breeding seasons 2014–2018. Julian day represents days passed since the beginning of the calendar new year.

were based upon mark-recapture population estimates and presumed population parameters including: reproductive success of 0.7 per storm petrel nest and season based on Pelagodroma *marina* breeding in the Hauraki Gulf (see Rayner et al. 2017); post-fledging survival to adulthood of 0.5, annual adult survival of 0.91 and age at first breeding of four years (based on Fregetta tropica; Beck & Brown 1971). The reproductive rate r was calculated as a product of the factors of successful recruitment probability from a nest in a given year and eventual recruitment probability of fledglings into the breeding population. We assumed a static population prior to rat eradication in 2004 and for 2003 (pre-rat eradication) estimates we averaged the results of individual models for mark-recapture on land (2015-2017) and boat-based surveys (2016–2018). Our population model describes the population size N in the year i+1 based on the population size in the previous year i, and the numbers of fledglings from four years prior to the estimate (i-3) by the following formula:

 $N_{i+1} = r * N_{i-3}/2 + s * N_i$

We used the averaged model for estimates based upon land-based mark-recapture (2015–2017) and at-sea resightings (2016–2018).

RESULTS

Between 2014 and 2018, 399 field hours (91 field nights) of field work were conducted during which $6.4 \pm 1.5 \text{ SE} (0-20.7)$ sightings of NZSP per hour were made at the spotlighting site on Hauturu. There was a significant difference in sightings between years (Welch ANOVA $F_4 = 11.2$; P = < 0.0001; Fig. 2) with sightings per hour in 2015 ($11.12 \pm 5.8 \text{ SE}$) and 2018 ($8.7 \pm 2.7 \text{ SE}$) being consistently different from sightings in 2014 ($3.3 \pm 0.9 \text{ SE}$), 2016 ($3.8 \pm 0.8 \text{ SE}$) and 2017 ($3.7 \pm 0.6 \text{ SE}$; Wilcoxon comparisons all < 0.001), but not from each other (Wilcoxon P = 0.2). Across years sightings of NZSP per unit effort on Hauturu peaked in mid-February (Fig. 2).

In total, we captured, banded and released 415 NZSP. Over half of all birds captured (52%) had brood patches with no down shed (score 0) with the remainder being evenly distributed between brood patch scores of 1–4 (Fig. 3). No refeathering of the brood patch was observed.

We recaptured a total of 14 NZSP on land in 2015, 2016, and 2017 (Table 1). No banded birds were recaptured in 2018. These data provided a population estimate from averaged annual models of 994 (range 446–2,116) individuals (Table 1). We conducted a total of 21 hrs. of boat-based surveys in 2016 (10 hrs.), 2017 (7 hrs), and 2018 (4 hrs.) during which we were able to identify 20 NZSP by their unique band combinations (Table 1) providing a population estimate from averaged annual models of 1,630 (range 624–3,758) individuals (Table 1).

Our logistic growth models using on-land mark-recapture and at-sea resightings indicate a 2004 pre-rat eradication population of 323 and 788 NZSP individuals with averaged annual population growth rates (2004–2020), following rat eradication (Fig. 4), of $6.0 \pm 0.2\%$ and $5.1 \pm 0.2\%$.

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Figure 3. Brood patch score proportions (0 = fully downy to 4 = fully bare, and R = refeathering) of New Zealand storm petrels captured at sea in February 2012 (filled bars; n = 19) (Rayner *et al.* 2013) compared with scores of birds captured through spotlighting and playback on Hauturu (January–March, 2014–2018) (unfilled bars; mean \pm SE, see Table 1 for sample sizes).



Figure 4. Estimates of New Zealand storm petrel population size trajectory on Hauturu between 2004 rat eradication and 2025. Models are anchored by and based on averaged mark-recapture calculations from land captures (2015–2017, dashed line), at sea resightings (2016–2018, solid line), and presumed population breeding and life history parameters (see methods).

Year	Location	Annual captures on land, and total sightings at-sea	Annual resightings/ recaptures	Population size, mean (min–max)
2014	Hauturu	40	0	
2015	Hauturu	114	6	704 (502–924)
2016	Hauturu	92	4	1,001 (732–1,405)
2017	Hauturu	114	4	1,276 (105–4,018)
2018	Hauturu	57	0	
	Model average			994 (446–2,116)
2016	At-sea	82	7	1,931 (1,040–4,158)
2017	At-sea	120	12	2,250 (409–4,499)
2018	At-sea	37	1	708 (424–2,616)
	Model average			1,630 (624–3,758)

Table 1. New Zealand storm petrel population estimates based on mark-recapture calculations from land-based captures 2015–2017 and on resighting of banded versus unbanded birds at sea 2016–2018.

DISCUSSION

Our five-year study provides the first population data for the NZSP suggesting a population size of fewer than two thousand individuals of this Threatened - Nationally Vulnerable seabird (Robertson et al. 2017). Our use of mark-recapture provided a useful alternative to census methods involving counts of burrows and/or burrow occupancy which were not possible in the fragile habitat supporting a cryptic population of unknown distribution. The capture of birds for markrecapture was challenging, especially given the size of the available habitat on Hauturu. Techniques such as mist-netting, used on storm petrels breeding on islands an order of magnitude smaller than Hauturu (Sydeman et al. 1998; Insley et al. 2014), proved unsuccessful as a result of the low densities of flying NZSP. However, a combination of acoustic lures and floodlights proved ideal for drawing in NZSP to then be captured with handheld spotlights (Ismar *et al.* 2015). This technique would be suitable for other studies seeking to capture storm petrels in large landscape situations.

Sightings in our study support previous assertions of a February activity peak for NZSP over Hauturu, associated with estimated peak laying for the species (Ismar *et al.* 2015; Rayner *et al.* 2015), though a study weakness was that capture sessions did not extend beyond March to the known June chick fledging period. Interannual variation in NZSP sightings at the capture site were intriguing and we believe related to inter-seasonal differences in the timing of capture trips, moon phase, and prevailing weather conditions. Overall, NZSP were more likely to be sighted in greater numbers on moonless nights with cloud cover and/or light rain

conditions (Rayner *et al.* 2015) as has been observed in other small Procellariiformes that seek to minimize predation risk during nocturnal activity over land (Yutaka 1986; Mougeot & Bretagnolle 2000).

Of interest is the difference between the landbased and at-sea based components of our study which yielded different population results. Landand sea-based mark-recapture/resighting are important tools for the population assessment of Procellariiformes (Gummer et al. 2015; Rowe et al. 2018) including storm petrels (Zuberogoitia et al. 2007; Insley et al. 2014; Becker et al. 2016), but have inherent biases that can skew population estimates. On land the use of sound playback lures is known to bias capture rates towards pre-breeding individuals more attracted by the sound cues of conspecifics and/or more susceptible to the disorientation of flood lights. This is the case with NZSP (Ismar et al. 2015). Across the four years of our study over 50% of the birds had a downy brood patch (Ismar *et al.* 2015) at a time of year when breeding NZSP are either losing down in preparation for incubation (February) and/or sitting on eggs (March) (Rayner et al. 2015). The hypothesis that our on-land captures were dominated by young NZSP is supported by the remarkable recapture of a NZSP in March 2016 which had been banded as a chick two years earlier in May 2014; it had a fully downy brood patch (score 0) at the time of capture.

Capture bias over land towards a smaller pool of pre-breeding NZSP explains the smaller population size estimate for on land compared with at sea. NZSP visiting the burley oil slick likely have less demographic imbalance, as supported by the wide spread of brood scores from birds caught using scent-based burley attraction and a net gun during previous studies (Fig. 3) (Rayner *et al.* 2013). We thus consider the at-sea population estimate more representative of the total NZSP population on Hauturu and the land-based estimate a good indicator of the juvenile component of the population. However, caution must be exercised given the low recapture rates and the fact that our models could not account for changes in recapture rates on land as birds age. Regardless the current data provide a useful baseline for the ongoing monitoring of the population growth rate of NZSP on Hauturu using the same census techniques.

Our simple logistic growth models of the NZSP population based on mark-recapture estimates and generic storm petrel demographic parameters indicate the likely population expansion of NZSP from a potential low of between 300 and 800 individuals following the eradication of kiore from Hauturu. Before their eradication, kiore were likely a major predator of NZSP storm petrel eggs, chicks and adults (Booth 1995; Taylor 2000; Rayner et al. 2007) and may have experienced an ecological release of their population following the removal of feral cats, also a likely storm petrel predator, from Hauturu in 1980 – this may have further impacted a declining NZSP population (see Rayner et al. [2007, 2015] for discussion). The current data suggest that the 2004 eradication of kiore from Hauturu unknowingly prevented the continued decline of a relict NZSP population headed towards extinction.

The results of our study suggest that NZSP remain qualified as Threatened – Nationally Vulnerable under the New Zealand threat classification scheme by having a small increasing population of 250–1,000 mature individuals (Robertson *et al.* 2017). The species is also vulnerable as it only breeds at one location. Future census work for NZSP should focus on repeating night-time counts of NZSP at the current study site on Hauturu to provide a comparative data set by which to assess ongoing population recovery. This study should be conducted in February, and/or March, five years after the completion of field work in the current study.

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LITERATURE CITED

- Beck, J.R.; Brown, D.W. 1971. The breeding biology of the black-bellied storm-petrel *Fregetta tropica*. *Ibis* 113: 73–90.
- Becker, B.H.; Carter, H.R.; Henderson, R.P.; Weinstein, A.M.; Parker, M.W. 2016. Status and monitoring of ashy storm petrels *Oceanodroma homochroa* at Point Reyes national seashore, 2012–2015. *Marine Ornithology* 44: 63–70.
- BirdLife International 2018. *Fregetta maoriana. The IUCN Red List of Threatened Species* 2018: e.T22728808A132659638. doi: 10.2305/IUCN. UK.2018-2.RLTS.T22728808A132659638.en Accessed: 26 March 2020.
- Booth, A. 1995. The little shearwater in the 1994 breeding season on Lady Alice Island: breeding success, and timing and causes of breeding failure. *Conservation Advisory Science Notes No.* 115. Wellington, Department of Conservation.
- Crockett, D.E. 1994. Rediscovery of Chatham Island taiko Pterodroma magentae. Notornis 41: 49–60.
- Flood, R. 2003. The New Zealand storm petrel is not extinct. *Birding World* 16: 479–483.
- Gummer, H.; Taylor, G.; Wilson, K.-J.; Rayner, M.J. 2015. Recovery of the endangered Chatham petrel (*Pterodroma axillaris*): a review of conservation management techniques from 1990 to 2010. *Global Ecology and Conservation* 3: 310–323.
- Insley, H.; Hounsome, M.; Mayhew, P.; Elliott, S. 2014. Mark–recapture and playback surveys reveal a steep decline of European storm petrels *Hydrobates pelagicus* at the largest colony in western Scotland. *Ringing & Migration* 29: 29–36.

- Ismar, S.M.H.; Gaskin, C.P.; Fitzgerald, N.B.; Taylor, G.A.; Tennyson, A.J.D.; Rayner, M.J. 2015. Evaluating on-land capture methods for monitoring a recently rediscovered seabird, the New Zealand Storm-Petrel *Fregetta maoriana*. *Marine Ornithology* 43: 255–258.
- Mougeot, F.; Bretagnolle, V. 2000. Predation risk and moonlight avoidance in nocturnal seabirds. *Journal of Avian Biology* 31: 376–386.
- Rayner, M.J.; Hauber, M.E.; Imber, M.J.; Stamp, R.K.; Clout, M.N. 2007. Spatial heterogeneity of mesopredator release within an oceanic island system. *Proceedings of the National Academy of Sciences of the United States of America* 104: 20862– 20865.
- Rayner, M.J.; Parker, K.A.; Imber, M.J. 2008. Population census of Cook's petrel *Pterodroma cookii* breeding on Codfish Island (New Zealand) and the global conservation status of the species. *Bird Conservation International 18*: 211–218.
- Rayner, M.J.; Gaskin, C.P.; Stephenson, B.M.; Fitzgerald, N.B.; Landers, T.J.; Robertson, B.C.; Scofield, P.R.; Ismar, S.M.H.; Imber, M.J. 2013. Brood patch observations indicate likely breeding provenance and timetable in New Zealand storm petrel (*Pealeornis maoriana*). *Marine Ornithology* 41: 107–111.
- Rayner, M.J.; Gaskin, C.P.; Fitzgerald, N.B.; Baird, K.A.; Berg, M.M.; Boyle, D.; Joyce, L.; Landers, T.J.; Loh, G.G.; Maturin, S.; Perrimen, L.; Scofield, R.P.; Simm, J.; Southey, I.; Taylor, G.A.; Tennyson, A.J.D.; Robertson, B.C.; Young, M.; Walle, R.; Ismar, S.M.H. 2015. Using miniaturized radiotelemetry to discover the breeding grounds of the endangered New Zealand Storm Petrel *Fregetta maoriana. Ibis* 157(4): 754–766.
- Rayner, M.J.; Young, M.K.; Gaskin, C.G.; Mitchel, C.; Brunton, D.H. 2017. The breeding biology of northern white-faced storm petrels (*Pelagodroma marina maoriana*) and results of an in-situ chick translocation. *Notornis* 64: 76–86.
- Robertson, H.A.; Baird, K.; Dowding, J.E.; Elliott, G.P.; Hitchmough, R.A.; Miskelly, C. M.;

McArthur, N.; O'Donnell, C.F.J.; Sagar, P.M.; Scofield, R.P.; Taylor, G.A. 2017. Conservation status of New Zealand birds, 2016. *New Zealand Threat Classification Series* 19. Wellington, Department of Conservation. 23 p.

- Rowe, L.K.; Scofield, R.P.; Taylor, G.A.; Barker, R.J. 2018. An estimate of the Hutton's shearwater (*Puffinus huttoni*) population in the Kaikōura region using colour-marking in 2002 and 2014. *Notornis* 65: 196–201.
- Saville, S.; Stephenson, B.; Southey, I. 2003. A possible sighting of an 'extinct bird' the New Zealand storm petrel. *Birding World* 16: 173–175.
- Stephenson, B.M.; Flood, R.; Thomas, B.; Saville, S. 2008a. Rediscovery of the New Zealand storm petrel (*Pealeornis maoriana* Mathews 1932): two sightings that revised our knowledge of storm petrels. *Notornis* 55: 77–83.
- Stephenson, B.M.; Gaskin, C.P.; Griffiths, R.; Jamieson, H.; Baird, K.A.; Palma, R.L.; Imber, M.J. 2008b. The New Zealand storm-petrel (*Pealeornis maoriana* Mathews, 1932): first live capture and species assessment of an enigmatic seabird. *Notornis* 55: 191–206.
- Sydeman, W.J.; Nur, N.; McLaren, E.B.; McChesny, G.J. 1998. Status and trends of the ashy-faced storm petrel on Southeast Farallon Island, California, based upon capture-recapture analyses. *The Condor* 100: 438–447.
- Taylor, G. 2000. Action plan for seabird conservation in New Zealand, part a: threatened seabirds. *Threatened Species Occasional Publication 16*. Wellington, NZ, New Zealand Department of Conservation.
- Yutaka, W. 1986. Moonlight avoidance behavior in Leach's storm-petrels as a defense against slatybacked gulls. *The Auk 103(1)*: 14–22.
- Zuberogoitia, I.; Azkona, A.; Castillo, I.; Zabala, J.; Martínez, J.A.; Etxezarreta, J. 2007. Population size estimation and metapopulation relationships of storm petrels *Hydrobates pelagicus* in the Gulf of Biscay. *Ringing & Migration* 23: 252–254.

Post-translocation dispersal and home range establishment of roroa (great spotted kiwi, *Apteryx haastii*): need for longterm monitoring and a flexible management strategy

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Abstract: Between 2010 and 2016, the community group Friends of Flora Inc., in partnership with the Department of Conservation, translocated 44 roroa (*Apteryx haastii*) to the Flora Stream area in Kahurangi National Park, New Zealand. Each kiwi was fitted with a VHF transmitter and their subsequent locations were monitored for two to eight years by radio-telemetry. Monitoring showed that short to medium term translocation goals relating to survival and home range establishment were met. Dispersal occurred for 9 to 878 days prior to home ranges being established. This post-translocation monitoring was used to inform management decisions to extend predator control from 5,000 to 9,000 ha and to retrieve four of the kiwi that dispersed outside the project area. At the end of the study, 68% of the translocated kiwi were known to have home ranges within the trapped area. The study illustrates the benefit of long-term post-translocation monitoring and a flexible approach to deal with unforeseen dispersal.

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Key Words: roroa, great spotted kiwi, Apteryx haastii, translocation, dispersal, home range, community group

INTRODUCTION

Kiwi are endemic to New Zealand. Roroa (great spotted kiwi, *Apteryx haastii*) are classified as Vulnerable by the IUCN (BirdLife International 2020) and nationally Vulnerable by the Department of Conservation (DOC) (Robertson *et al.* 2017). Kiwi of all ages are vulnerable to predation by nonnative ferrets (*Mustela putorius furo*) and dogs (*Canis familiaris*) (Robertson *et al.* 2011) and young kiwi and kiwi eggs are vulnerable to predation by other mustelids (McLennan *et al.* 1996). Translocations have been used as a conservation tool for kiwi to supplement long-term predator management. They can be used for range re-establishment, genetic management, and advocacy (Germano *et al.* 2018).

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Effective post-release monitoring is necessary to determine both short- and long-term success of translocations and reasons for failure (Parker et al. 2013; IUCN/SSC 2013). Roroa pose particular challenges for intensive monitoring; they are nocturnal, sensitive to disturbance, and live at low density in mainly remote, mountainous terrain (McLennan & McCann 2002; Heather & Robertson 2015). Miskelly & Powlesland (2013) reported 62 kiwi conservation translocations, excluding reinforcements. Only four of these were of roroa: to Te Hauturu-o-Toi in 1915; Rotoiti, Nelson Lakes National Park in 2004 and again in 2006; and the Flora Stream area, Kahurangi National Park. In addition, there were roroa translocations to the Nina Valley, Lewis Pass between 2011 and 2015 (S. Yong pers. comm.).

There are anecdotal reports of kiwi from the project area dating back to the 1970s and 1980s. Sub-fossil remains of large kiwi have been found in cave systems at Hodge Creek in the Flora area (Worthy 1997), but the bones of roroa and 'brown' kiwi, which were also present historically, overlap in size (Worthy & Holdaway 2002). Roroa were still present on Mt Arthur in 1994 (Worthy & Holdaway 1994), although McLennan & McCann (2002) suggest reports may have related to a single female translocated from Karamea. Roroa are found in the adjacent Cobb Valley albeit with low call rates (Toy et al. in prep.). However, in a 2011 survey of the area between the Flora and the Cobb, no kiwi were detected in 1,579 hours of acoustic recording (Friends of Flora, unpubl. data). It was assumed that predation by dogs and non-native stoats (Mustela *erminea*) caused the loss of roroa from the project area and that habitat conditions are otherwise suitable for roroa.

Roroa were translocated in accordance with the long-term goal of the Kiwi Recovery Plan 'to restore and, wherever possible, enhance the current abundance, distribution and genetic diversity of all kiwi taxa' (Holzapfel *et al.* 2008). The project area was chosen because it has more intensive predator control than much of the roroa range, it was recently occupied by roroa, and it has comparatively easy access, enabling monitoring and public engagement. Between 2010 and 2016, four wild-to-wild translocations of adult and subadult kiwi were performed. Forty-four kiwi were translocated, meeting the recommendation of more than 40 founders when establishing a new kiwi population (Sporle 2013; DOC translocation proposal 2016). The project is a partnership between DOC and Friends of Flora and aims to achieve a sustainable population of roroa. Each translocation and its follow-up monitoring were approved by the Kiwi Recovery Group and DOC and were undertaken in accordance with best practice at that time (Robertson & Colbourne 2003). Posttranslocation fieldwork was performed by Friends of Flora volunteers working with two part-time, contracted ecologists accredited to handle kiwi. Operational targets included successful transfer and establishment, defined as more than 50% of the transferred kiwi establishing home ranges within the project area within 12 months of release. Longerterm conservation goals included: a self-sustaining population be established with roroa successfully breeding and young birds forming new pairs within the protected area within 10 years; roroa are common within the Flora Stream area, and juvenile kiwi moving into adjacent areas within 50 years (DOC translocation proposals 2010, 2013, 2016).

Here, we summarise eight years of posttranslocation monitoring of dispersal, home-range establishment, and pairing. Breeding success, the long-term measure of a sustainable population will be discussed separately (Toy & Toy *in prep*.).

METHODS

The Flora Stream lies to the north of Tu Ao Wharepapa (Mt Arthur) in the Upper Takaka River catchment, (41°10'S, 172°41'E; Fig. 1). The project area covers approximately 10,000 ha ranging from 700 to 1,500 m altitude. Rainfall for the Mt Arthur Ecological District is between 1,500 and 4,000 mm/annum, wetter towards the west (McEwan 1987). Silver beech (Lophozonia menziesii) is the predominant canopy species with red beech (Fuscospora fusca) at lower altitudes and mountain beech (Fuscospora cliffortioides) at higher altitudes. Above the tree line there are areas of *Olearia*, *Dracophyllum* and *Hebe* spp. shrubland and extensive Chionochloa spp. grasslands (Toy 2016). The geology is predominantly sedimentary with areas of tertiary limestone and igneous rock, with marble mainly in the south (Rattenbury *et al.* 1998).

The area was gazetted as part of Kahurangi National Park in 1996. It is managed by the community group Friends of Flora Inc. and DOC with the aim of restoring and enhancing the biodiversity values of the area. Stoat trapping was started in 2001 and the network of traps has been expanded to cover about 9,000 ha by 2020 (Fig. 1). Traplines are spaced approximately 1 km apart with double set DOC150 traps at 100 m intervals along the lines. Traps are serviced approximately monthly. The area adjoins the Cobb Valley in which the community group Friends of Cobb have trapped stoats since 2006. The project area is on the edge of a much larger block that has received four aerial applications of sodium fluoroacetate (1080) for control of rats (*Rattus* spp.) or brushtail possums (Trichosurus vulpecula). Secondary poisoning of mustelids occurs from such applications (Parliamentary Commissioner for the Environment 2011). The threat from dogs has declined since a permit is required to bring a dog into a National Park.

In the Flora, roroa daytime roosts are most commonly underground 'burrows' which are naturally occurring cavities, or occasionally above ground 'shelters' in hollow logs or under ferns or overhangs. For the purpose of this paper, 'burrow' is used to refer to both underground burrows and above ground shelters.

Translocation

Forty one adult and three sub-adult kiwi were translocated into the Flora from four separate source sites in NW Nelson: Clark River (40°56'S, 172°32'E); New Creek (41°48'S, 171°55'E); Upper Roaring Lion



Figure 1. Location of the Flora Stream project area in relation to the translocation source sites, and the expansion of stoat trapping in the Flora between 2001 and 2020.

River (41°03'S, 172°26'E); South Gouland (40°56'S, 172°20'E) (Table 1; Fig. 1). Multiple translocations were performed for logistical reasons, to reduce the impact on source site kiwi populations, and to maximise genetic diversity of the new population. We attempted to translocate established pairs of roroa. Each translocated kiwi was named by local iwi and fitted with a unique alpha-numeric metal band and a leg-mounted GSK diagnostic v2.0 VHF transmitter (Wildtech and Sirtrack). In each translocation all kiwi were released in the same general area. In the first two translocations, known partners were released into burrows within a few metres of each other. On four occasions in subsequent translocations, partners of known pairs were released in the same burrow.

Four kiwi that dispersed outside the trapped area were retrieved and released a second time within the area.

Post-release monitoring

We aimed to locate all translocated kiwi the day after release, then twice a week for two months and thereafter at about fortnightly intervals. Monitoring continued until May 2018 when achievement of operational targets relating to dispersal, pair formation, and location of home ranges within the project area had been demonstrated. Transmitters were then removed. Monitoring finished earlier for kiwi that died, disappeared or whose transmitter failed or fell off (monitoring truncated). Dispersal monitoring was truncated for the four kiwi that were retrieved.

TR4 receivers (Telonics[™]) and 3-element folding Yagi aerials (Sirtrack Ltd) were used to locate kiwi. Teams of volunteers trained in radio-telemetry took bearings (Silva mod 15 mirror compass) of the strongest signal direction from multiple locations whose co-ordinates were recorded. Usually, bearings were taken from three or more locations; hill tops and ridge lines were preferred to maximise coverage. As the project area covers 10,000 ha of deep valleys, individual bearings were frequently taken more than 2 km from the kiwi. The location of each kiwi was estimated by manual triangulation of bearings plotted using MapToaster Topo NZ[™]. This enabled signal strength, topography and locations from which a signal could not be detected, to be taken into account. Each triangulation was subjectively attributed an indication of accuracy taking account of the number of bearings taken, the strength of the VHF signal, the degree to which the bearings converged and the topography. Shortrange and ridge-top bearings were considered better quality than long-distance bearings and those taken in gullies where signals may 'bounce'.

 Table 1. Source site, translocation date and number of roroa translocated to the Flora.

C	D	Number of adults (sub-adults)			
Source site	Date	Paired	Single males	Single females	
Clark River	May 2010	10	1 (1)	0	
New Creek	March 2013	8	1	3	
Roaring Lion	May 2013	4	3	1	
South Gouland	April 2016	8	1 (1)	1 (1)	

Aerial surveillance was undertaken when a kiwi could not be located by monitoring teams on the ground.

Telemetry accuracy was tested by comparison of triangulated positions with exact locations determined by tracking-to-burrow (n = 87). To minimise disturbance to the kiwi, we limited tracking-to-burrow to an annual transmitter change and installation of cameras outside nest burrows. The accuracy test covered the range of topography encountered in the project area as well as a range of volunteers undertaking telemetry. The mean difference between triangulated locations and known kiwi burrows was 186 m (n = 87, 95% *CL* ± 31 m).

Monitoring of night movements

Most telemetry estimated the position of daytime roosts. At night, kiwi may move to areas in which they do not roost. We monitored kiwi night movements on 13 occasions spread over five years, with teams taking bearings of any kiwi within range every 20 minutes throughout the night. Bearings were taken from two to four fixed locations; observers did not move location during the night. Bearings taken at night are approximate as the signal volume fluctuates as the kiwi moves. The accuracy of night-time triangulations could not be quantified.

Analysis

A dispersal range was calculated for each kiwi for the period from release until it settled into a home range or until monitoring ended if earlier. A kiwi was identified as settling in a home range if it paired and remained in an area for more than six months or, for a single kiwi, if it remained in an area for more than a year. Single kiwi were identified *post-hoc* as taking longer to settle than kiwi in pairs, hence the difference in definition. Dispersal ranges were calculated as minimum convex polygons (MCP) using Ranges 9 v2.02 (www.anatrack.com). MCP were used rather than kernel density estimates to enable comparison with previous studies and to avoid emphasis on nest sites. Tracking resolution was set to 186 m, as determined in the triangulation accuracy test giving a buffer of 93 m around the outermost locations.

Before home range analyses, poor quality triangulations (11% of the total) were discarded leaving 3,751 locations which were mapped. Forty-two high-quality triangulations located a kiwi in areas remote from all other locations for that kiwi; these were considered outliers, *sensu* Burt (1943) and were excluded from home range analyses. Incremental area analyses (IAA) were performed on the remaining locations for each kiwi using Ranges 9 v2.02. Home ranges were only calculated if IAA curves reached an asymptote. Home ranges were calculated for individuals and for pairs.

To investigate movements over time, annual IAA and home range analyses were performed for each kiwi. These analyses used 1 July as the start of the annual period to align with the start of the roroa breeding season (Heather & Robertson 2015). A multi-year home range covering the period of monitoring was also calculated for each kiwi.

RESULTS

Dispersal phase

Monitoring of 28 roroa continued until they established a home range; the monitoring of the other 16 was truncated. The dispersal phase was very variable; kiwi that established a home range dispersed for between 9 and 878 days before settling and covered between 33 and 1,745 ha (Fig. 2; Appendix 1). Kiwi whose monitoring was truncated (Appendix 2) dispersed over a greater area (t = 4.568, df = 40, P = 4.6E-05 and for longer (t = 2.203, df = 29, P = 0.036), than those that established home ranges (Table 2). The maximum straight-line distance an individual kiwi moved from its release site was 9.8 km (Appendices 1 and 2) but its dispersal route will have been longer. Dispersal of some kiwi appeared unidirectional but others moved back and forth. Six kiwi paused in an area for up to 11 months before moving.

Dispersal of kiwi in established pairs that stayed together through the translocation was of significantly shorter duration (t = 2.459, df = 25, P = 0.021) and covered a significantly smaller area (t = 3.317, df = 26, P = 0.0027) than the dispersal of kiwi that formed new pairs in the project area. However, only three of 11 translocated pairs that were monitored until they established a home range stayed together. Of the four pairs in which the partners were released in the same burrow only one pair stayed together. The dispersal phase of kiwi in translocated pairs that separated was not

significantly different in duration (t = 0.193, df = 20, P = 0.85) or area (t = 0.725, df = 20, P = 0.48) from kiwi translocated without a partner.

Pairing

Pairs were assumed to have formed when male and female kiwi overlapped their home range or bred. Nine kiwi formed transitory associations during the dispersal phase, including two comprised of same sex birds. By the end of radio-telemetry monitoring, 34 of the translocated kiwi had paired, four had not and monitoring of six was truncated too soon to tell. Four kiwi are known to have paired with non-translocated kiwi, one with an immigrant, most likely from the Cobb Valley, and three with offspring of translocated birds. Seven of the pairs comprised partners from different source sites. Five kiwi changed partners during the project, three of them after they had bred. The members of one of the pairs that separated after release occupied adjacent home ranges with new partners.

Home Ranges

Thirty-nine kiwi established home ranges, the areas of 30 of these were quantified (Appendix 3). The IAA of the home ranges of the seven kiwi monitored for eight years show an asymptote after 3.5–5.8 years. Eighty-five percent of annual home



Figure 2. Illustration of variability in roroa posttranslocation dispersal in the Flora Stream project area. Te Manu-huna had the smallest dispersal range (solid red) and he settled in a home range after nine days (dashed red). Tahi had the largest dispersal range (solid black) and he took 878 days to settle in a home range (dashed black). Release locations shown as spots. Inset shows location of these ranges in relation to the trapped area in 2020 (shaded grey).

Table 2. Duration and extent of	f post-translocation dispers	al of roroa in the Flo	ora Stream project a	area in relation to:
whether dispersal monitoring v	vas completed or truncated;	translocation status ((single or as a pair)	and persistence of
pairs post-translocation.				

Dispersal monitoring	Translocation as a pair or single kiwi and persistence of the pair post-translocation	Mean duration of dispersal (days)	Mean dispersal area (ha)	Maximum dispersal (km)	Number kiwi
Completed	Translocated with partner, pair persisted post-translocation	84	117	2.5	6
	Translocated with partner, pair separated post-translocation	216	445	6.0	16
	Translocated without partner	197	316	4.4	6
Truncated		311	973	9.8	16

range IAA plots reached an asymptote, on average after 15 locations (n = 114; 95% *CL* ± 0.98; range 4–27). Home ranges were not calculated if IAA did not reach an asymptote.

Multi-year home ranges for individual kiwi varied from 29 to 475 ha ($\bar{x} = 142$, n = 29, 95% *CL* ± 38 ha). Mean annual home ranges varied from 26 to 126 ha (Appendix 3). The ratio between the size of the multi-year home range and the mean annual home range, an indicator of inter-annual home range movement, ranged from 1.2 to 3.8 ($\bar{x} = 2.1$; n = 23; 95% *CL* ± 0.31).

The size of both multi-year and annual home ranges varied between different regions of the project area (Fig. 3). Independent one-way ANOVA analyses with *post-hoc* testing using Tukey's correction showed the Flora annual home ranges were significantly larger than those in Ghost Creek (P = 0.019) and Deep Creek (P < 0.001) but Ghost Creek and Deep Creek home ranges were not significantly different in size (P = 0.21). Multi-year home ranges were significantly larger in the Flora



Figure 3. Mean area with 95% *CL* of multi-year (2-7 years) and annual home ranges in three regions of the project area: Flora Stream; Deep Creek; and Ghost Creek.

than in Ghost Creek (P = 0.013), but not Deep Creek (P = 0.057) and there was no significant difference between Ghost Creek and Deep Creek (P = 0.81).

The sizes of annual home ranges of single and paired kiwi were not significantly different ($\overline{x} \pm 95\%$ *CL* single kiwi 91 ± 13 ha, *n* = 10; paired kiwi 78 ± 7.5 ha, *n* = 104; *t* = 2.000, df = 18, *P* = 0.061).

Members of a pair had almost the same multiyear home range (Fig. 4). The multi-year home ranges of kiwi in adjacent pairs sometimes slightly overlapped (Fig. 4), but there was no concurrent overlap. Half the kiwi that settled into a home range were occasionally located roosting up to 2.4 km outside it.



Figure 4. Distribution of multi-year home ranges of roroa present in the project area (trapped area shaded grey on inset) at the end of radio-telemetry monitoring. Red = females, black = males, stars = kiwi known to be present but without a transmitter.

Commonly, annual home ranges moved incrementally (e.g. Fig. 5a), but on six occasions movement was to an adjacent area (e.g. Fig. 5b), and once a pair separated and established new home ranges with new partners 6.2 km from their original partners. Intra-annual movement sometimes coincided with breeding activity (particularly following predation of egg or chick), occasionally followed handling, but often was unexplained.





Figure 5. Examples of how home ranges of individual roroa move from year to year in the Flora Stream project area (trapped area shaded grey on inset). (A) shows incremental shifts by 'Hoire'; (B) shows movement to an adjacent area by 'Aorere'.

Three female kiwi from a later translocation appropriated all or part of the home range of kiwi from earlier translocations. By the end of the radiotelemetry monitoring, mapped home ranges were spread over approximately 5,000 ha. Last known locations of kiwi whose monitoring was truncated were dispersed over 10,000 ha. All but one of the home ranges were within 1 km of another pair (Fig. 6). There was one instance of two single females sharing a home range, although they were never found in a burrow together.

All night monitoring was carried out over five years on 13 occasions during December to May. Periods of non-breeding, incubation and up to two months after chick hatch were covered. Sixteen kiwi were monitored, up to six on any one night, giving a total of 69 nights of kiwi activity. On 24 occasions a kiwi moved outside the annual home range estimated from daytime roosts, usually into space between adjoining pairs' annual home ranges. The maximum distance outside the home range was about 600 m, the average foray length was 200 m. Seven incursions into another pair's home range were observed, all less than 100 m. Kiwi remained within detection range all night on 31 occasions. The percentage of the annual home range covered by these kiwi varied from less than 5% to about 60%,



Figure 6. Home range locations of roroa monitored to the end of the project, and the last known positions of other translocated kiwi, in relation to the trapped area shown shaded grey. Stars = release locations; solid polygons = quantified annual home ranges of pairs unless annotated with 's' for single; dashed circles = approximate home ranges identified by calling of roroa pairs without transmitters; spots = last known locations of other roroa, excluding kiwi who died. Colours indicate origin of roroa pre-translocation as per legend; graded colour = pairs of mixed origin.

but was less than 25% on 24 occasions. Eleven kiwi monitored through the night more than once in a year, covered different parts of their home range on different nights.

DISCUSSION

Translocation targets and goals

Monitoring should enable managers to assess whether translocation objectives are being met, and adjust management of the population (IUCN/ SSC 2013). Forty-four roroa were translocated into the Flora Stream area without death or injury. One year after translocation, 26 kiwi (59%) were known to have established home ranges within the project area exceeding the short-term translocation target of 50%. A further 11 kiwi (25%) were within the project area but had yet to establish a home range.

Eight years after the first translocation, the trapped area had been increased to accommodate dispersal of the kiwi. Thirty kiwi (68%) were known still to be in the project area, six had dispersed outside it, five had disappeared with their last tracked location being within the project area, and three had died. One of the kiwi that died did so three years after translocation due to emaciation consistent with starvation and/or old age; the other two died during dispersal, one in a tomo (sinkhole) and one stuck in a burrow. Twenty-eight (93%) of the kiwi remaining in the project area were known to have a partner, at least two of the pairs involved kiwi hatched in the Flora.

Dispersal was variable which may reflect individual responses to a novel, stressful situation (Parker *et al.* 2012). Many variables in translocation methods could have contributed to the dispersal response: source site altitude and habitat; method of capture; length of holding period; method of transfer; time of year; release location. Of the roroa that dispersed outside the project area, one did so after it appeared to have settled and paired, but the rest were single birds dispersing soon after translocation.

The long-term conservation goals for this project relate to the establishment of a self-sustaining population. This requires that recruitment exceeds mortality, and that the effective population size is sufficient to avoid inbreeding depression and ensure genetic variation is sufficient to enable survival and adaptation in the face of environmental change (IUCN/SSC 2013; Taylor *et al.* 2017). To reduce the likelihood of inbreeding depression, we sourced roroa from four sites in NW Nelson. Subsequent pairing of roroa from different source sites occurred. Translocations from different source sites could lead to outbreeding depression, a risk that is difficult to quantify for a long-lived species (IUCN/SSG 2013) such as roroa (Robertson et al. 2005). In general, the risk of inbreeding depression is seen as greater than the risk of outbreeding depression (Ralls et al. 2018) and, in addition, it appears likely that the conditions needed for outbreeding depression (Frankham et al. 2011; Frankham 2015) are not present in roroa. Translocation from multiple source sites was therefore deemed appropriate. There is new evidence of genetic variation across the range of roroa that may be explained by isolation by distance (H. Taylor *pers. comm.*), suggesting that roroa caught closer together will be more genetically similar to one another than those caught at extremes of the species' range, but that this is part of a genetic continuum rather than specific adaptation to differing environments (H. Taylor & K. Ramstad, In, Germano et al. 2018). Breeding success and effective population size in the Flora stream area are discussed separately (Toy & Toy in prep.).

The study area lies on the eastern edge of the range of roroa in NW Nelson (Germano et al. 2018). The translocations were performed assuming that the habitat would be suitable given the recent occupation of the area by roroa, and the ongoing intensive predator control. Establishment of home ranges and breeding by the translocated kiwi support this assumption. However, past occupancy may not indicate current or future suitability (IUCN/SSC 2013) and it is rarely possible to understand what makes habitat suitable (Osborne & Seddon 2012). Certainly, habitat suitability involves more than predator control. To demonstrate that the Flora population is sustainable under changing environmental conditions (e.g. summer drought) requires continued monitoring. Acoustic recorders are being used to monitor call rates and to indicate changes in population distribution. This will show if the long-term translocation outcome of dispersal into adjacent areas has been met and whether additional predator control is necessary. Other methods will be necessary to show if carrying capacity has been reached and genetic diversity is adequate.

Informing management decisions

Monitoring showed kiwi were establishing home ranges outside the trapped area. Trapping was extended to cover an additional 4,000 ha in the Deep Creek, Ghost Creek and Grecian River areas to encompass this dispersal. Frequent monitoring also enabled retrieval of four roroa that dispersed further away where they were vulnerable to predation. All paired within the project area after their second release. Six kiwi that dispersed outside the project area and could not be retrieved likely remain part of the functional translocated population as they moved to adjacent areas.

Translocation lessons learned

Learning from monitoring will benefit the design of future translocations. Long-term post-translocation monitoring is recognised as good practice (Parker et al. 2013; IUCN/SSC 2013), but what constitutes long-term cannot be specified a priori and must be reviewed in response to monitoring results. This study showed that roroa can settle in a stable home range after nine days, but they can also take nearly 2.5 years. Annual home ranges shifted and, as a result, multi-year home range expansion for some kiwi continued for six years which may result from translocation, but could be normal for a relatively low-density population. The longer an animal is followed, the more space it will likely use, which can translate into larger home-range estimates (Fieberg & Börger 2012). Retrieval of kiwi or expansion of a predator control area may be of great benefit during the dispersal phase, but are unlikely to be justified by subsequent home range expansion. Therefore, we conclude that, in relation to dispersal, radio-telemetry monitoring should continue until stable home ranges are demonstrated to have established, which in the Flora Stream area took more than 2.5 years. However, since our translocation objectives also related to breeding outcomes, longer monitoring was necessary (Toy & Toy in prep.). To maximize the effectiveness of the translocation, all kiwi should be monitored since dispersal is very variable between individuals.

Le Gouar et al. (2012) recommend that release strategies should be designed to minimise adverse effects associated with post-release dispersal. We tried three approaches: releasing known pairs in the same burrow to minimise dispersal; releasing kiwi from successive translocations in areas without resident kiwi to reduce the likelihood of territorial clashes with previously released kiwi; and releasing kiwi in clusters to limit dispersal by acoustic anchoring. Our sample size was too small to test these ideas but we observed that one of four pairs released in the same burrow persisted, compared with two of seven released in separate nearby burrows. We conclude that there is no advantage to releasing in the same burrow. We did not determine what keeps pairs together, but if they did stay together they established home ranges more quickly and nearer to the release site than if they formed new pairs. Gasson (2005) reported similar findings in roroa translocated as part of the Rotoiti Nature Recovery Project.

In each translocation, we released kiwi in clusters in areas without resident kiwi. We found dispersal was variable, but later translocations caused little disruption to home ranges of previously released kiwi. Some kiwi dispersed several kilometres before establishing a home range, but of 17 pairs that established home ranges, all except one settled within 1 km of at least one other pair. Roroa calls of both sexes are audible from more than 1 km away in good conditions (McLennan & McCann 1991; RT & ST *pers. obs.*). This suggests there was acoustic anchoring. Roroa translocated to Rotoiti also established home ranges within calling range of each other (Gasson 2005) although they dispersed shorter distances than we observed in the Flora, which might be due to the presence of physical barriers at Rotoiti. Acoustic anchoring has been investigated as part of translocation protocols for other New Zealand birds: North Island kokako (*Callaeas wilsoni*) (Molles *et al.* 2008), and North Island Robin (*Petroica longipes*) (Bradley *et al.* 2011).

Home ranges established over a larger area than was predicted prior to the translocations. Currently, the trapped area is about 9,000 ha, similar to the 10,000 ha minimum area required for long-term kiwi persistence (Brown et al. 2015), but much of the trapped area is unoccupied. Understanding habitat and range requirements is a complex issue (Powell & Mitchell 2012; Osborne & Seddon 2012) but is clearly fundamental to translocation success. In the project area, several kiwi from later translocations established home ranges in areas through which kiwi in earlier translocations had dispersed, suggesting the habitat was suitable for roroa, but unknown factors discouraged the previously released kiwi from settling there. Home ranges in the Flora region of the project area are larger than those in Deep Creek or Ghost Creek. The reason for this might relate to resource availability. More detailed monitoring of night-time habitat use might be informative but suitable technology, such as GPS tags (Kie *et al.* 2010), is not yet available for kiwi.

Almost everything we currently know about home range for any kiwi species is based on daytime roosts, but this information may underestimate the actual home range size since kiwi's knowledge of habitat quality may extend beyond the home range estimated from their daytime roosts. Burt (1943) describes a home range as the area traversed by an individual in its normal activities of feeding, sheltering and breeding. He states that occasional movements outside the area should not be considered as part of the home range. Powell & Mitchell (2012) suggest regular but infrequent movements to a place should be assessed in the context of all that is known about the species. They suggest that an animal keeps an up-to-date cognitive map of the status of resources and where to meet its requirements. Such a map may enable kiwi to respond to events such as incursions by other kiwi into their home range or unusual weather conditions that affect their fitness. Our night-time monitoring and two dropped transmitters showed that kiwi regularly moved outside the home range estimated from daytime roosts. McLennan & McCann (1991) and Gasson (2005) also identified nocturnal use of habitat in which roroa did not roost. Ultimately, home ranges will be dynamic as animals respond to changes in environment and neighbours (Fieberg & Börger 2012). The fact that multi-year home ranges in the project area are substantially larger than annual home ranges reflects this. Changes to home range also occur within a year. Our annual home range estimations were made using locations made throughout the year. Other roroa studies, (Keye *et al.* 2011; Jahn *et al.* 2013) were restricted to a few months duration. This may contribute to our annual home range estimates being larger than those found in these other studies.

The extent and nature of the terrain in the project area necessitated long-distance bearings and included areas prone to 'bouncing' signals and non-detection, all factors that increase the size of the error polygon (Harris et al. 1990). As a result, we had a large buffer in the MCP analyses compared to Jahn et al. (2013) who did close-approach telemetry resulting in an 18 m triangulation error. Running our MCP analyses using the minimum 1 m triangulation error permitted in Ranges 9 v2.02 negates our large triangulation error and gives a mean annual home range of 42 ha. That this is larger than the 20–34 ha mean home range size reported in other studies by Jahn et al. (2013), suggests that our large home ranges are not just a consequence of triangulation error but also reflect our all-season, multi-year monitoring.

Large home range size could be a feature of a low-density and/or translocated population. Opportunity for incremental and more major movements of home range, would be more limited in a higher density, established population. However, if large home ranges are a symptom of translocated kiwi's unfamiliarity with a new area, they might be expected to decrease over time, but this did not occur. If larger home range size is a feature of low-density populations, this should be included when modelling population size.

'Post release monitoring is often viewed as difficult and expensive, and even optional' (Parker et al. 2013). The ability of community groups to deliver such an effort has been questioned (Galbraith et al. 2016). The intensity and duration of posttranslocation monitoring in this study is unusual following kiwi translocations (P. Jahn *pers. comm.*). It was needed to trigger management required to achieve the translocation targets and goals. Transmitters were then removed and intensive monitoring ceased. The project has shown that with training, support and leadership, volunteers can provide the long-term commitment and carry out the tasks necessary for long-term post-translocation monitoring at manageable cost. Annual acoustic monitoring is underway in the Flora, but to understand whether long-term goals are met, other more intensive methods such as territory mapping and genetic analysis will be required.

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Home Ranges were calculated using Anatrak Ranges 9 ©. Maps were drawn using QGIS 2.18.17 Open Source Geospatial Foundation Project, using data sourced from the LINZ Data Service licensed for reuse under CC BY 4.0. This paper was greatly improved following comments received from Peter Jahn, Helen Taylor, Jen Germano, Craig Symes and an anonymous reviewer – thank you.

LITERATURE CITED

- BirdLife International 2020. Species factsheet: *Apteryx haastii*. Downloaded from http:// www.birdlife.org on 23 June 2020.
- Bradley, D.W.; Ninnes, C.E.; Valderrama, S.V.; Waas, J.R. 2011. Does 'acoustic anchoring' reduce posttranslocation dispersal of North Island robins? *Wildlife Research* 38: 69–76.
- Brown, K.; Elliott, G.; Innes, J.; Kemp, J. 2015. Ship rat, stoat and possum control on mainland New Zealand: an overview of techniques, successes and challenges. Wellington, Department of Conservation.
- Burt, W.H. 1943. Territoriality and home range concepts as applied to mammals. *Journal of Mammalogy* 24: 346–352.
- Fieberg, J.; Börger, L. 2012. Could you please phrase "home range" as a question? *Journal of Mammalogy* 93: 890–902.
- Frankham, R. 2015. Genetic rescue of small inbred

populations: meta-analysis reveals large and consistent benefits of gene flow. *Molecular Ecology* 24: 2610–2618.

- Frankham, R.I.; Ballou, J.D.; Eldridge, M.D.; Lacy, R.C.; Ralls, K.; Dudash, M.R.; Fenster, C.B. 2011. Predicting the probability of outbreeding depression. *Conservation Biology* 25: 465–475.
- Galbraith, M.; Bollard-Breen, B.; Towns, D.R. 2016. The community-conservation conundrum: is citizen science the answer? *Land* 5: 37, 16p. doi: 10.3390/land5040037
- Gasson, P.A. 2005. Translocation of great spotted kiwi/ roa (Apteryx haastii) to Rotoiti Nature Recovery Project. Nelson, Department of Conservation.
- Germano, J.; Barlow, S.; Castro, I.; Colbourne, R.; Cox, M.; Gillies, C.; Hackwell, K.; Harawira, J.; Reuben, A.; Robertson, H.; Scrimgeour, J.; Sporle, W.; Yong, S. 2018. *Kiwi Recovery Plan* 2018-2028. Threatened Species Recovery Plan 64. Wellington, Department of Conservation.
- Harris, S.; Cresswell, W.J.; Forde, P.G.; Trewhella, W.J.; Woollard, T.; Wray, S. 1990. Home-range analysis using radio-tracking data – a review of problems and techniques particularly as applied to the study of mammals. *Mammal Review* 20: 97–123.
- Heather, B.D.; Robertson, H.A.D. 2015. *The field guide to the birds of New Zealand* Revised Edition. Auckland, New Zealand, Penguin Random House.
- Holzapfel, S.; Robertson, H.; McLennan, J.A.; Sporle, W.; Hackwell, K.; Impey, M. 2008. *Kiwi* (Apteryx *spp.*) recovery plan 2008–2018. Threatened Species Recovery Plan 60. Wellington, Department of Conservation.
- IUCN/SSC 2013. Guidelines for reintroductions and other conservation translocations. v1.0. Gland, Switzerland, IUCN Species Survival Commission.
- Jahn, P.; Harper, G.A.; Gilchrist, J. 2013. Home range sharing in family units of great spotted kiwi (*Apteryx haastii*) at Nelson Lakes National Park. *Notornis* 60: 201–209.
- Keye, C.; Roschak, C.; Ross, J. 2011. Summer home range size and population density of great spotted kiwi (*Apteryx haastii*) in the North Branch of the Hurunui River, New Zealand. *Notornis* 58: 22–30.
- Kie, J.G.; Matthiopoulos, J.; Fieberg, J.; Powell, R.A.; Cagnacci, F.; Mitchell, M.S.; Guaillard, J.M.; Moorcroft, P.R. 2010. The home-range concept: are traditional estimators still relevant with modern telemetry technology? *Philosophical Transactions of the Royal Society, B. Biological Sciences* 365: 2221–2231.
- Le Gouar, P.; Mihoub, J.B.; Sarrazin, F. 2012. Dispersal and habitat selection, behavioural and spatial constraints for animal translocations. *In*: Ewen,

J.G.; Armstrong, D.P.; Parker, K.A.; Seddon P.J. (eds). Reintroduction Biology: integrating science and management. Oxford, Wiley Blackwell.

- McEwan, W.M. 1987 (ed.). Ecological regions and districts of New Zealand. Third revised edition in four 1:500 000 maps. Wellington, Department of Conservation.
- McLennan, J.A.; McCann, A.J. 1991. *Ecology of great spotted kiwi* Apteryx haastii. DOC Investigation No. 509. DSIR Land Resources Contract Report No. 91/48.
- McLennan, J.A.; McCann, A.J. 2002. Genetic variability, distribution and abundance of great spotted kiwi (*Apteryx haastii*). In: Overmars, F. (ed.). Some early 1990s studies in kiwi (Apteryx spp.) genetics and management. Science & Research Internal Report 191. Wellington, Department of Conservation.
- McLennan, J.A.; Potter, M.A.; Robertson, H.A.; Wake, G.C.; Colbourne, R.; Dew, L.; Joyce, L.; McCann, A.J.; Miles, J.; Miller, P.J.; Reid, J. 1996. Role of predation in the decline of kiwi, *Apteryx* spp., in New Zealand. *New Zealand Journal of Ecology* 20: 27–35.
- Miskelly, C.M; Powlesland, R.G. 2013. Conservation translocations of New Zealand birds, 1863–2012. *Notornis* 60: 3–28.
- Molles, L.E.; Calcott, A.; Peters, D.; Delamare, G.; Hudson, J.; Innes, J.; Flux, I.; Waas, J. 2008. 'Acoustic anchoring' and the successful translocation of North Island kokako (*Callaeas cineras wilsoni*) to a New Zealand mainland site within continuous forest. *Notornis* 55: 57–68.
- Osborne, P.E.; Seddon, P.J. 2012. Selecting suitable habitats for reintroductions: variation, change and the role of species distribution modelling. *In*: Ewen, J.G.; Armstrong, D.P.; Parker, K.A.; Seddon P.J. (*eds*). *Reintroduction Biology: integrating science and management*. Oxford, Wiley Blackwell.
- Parker, K.A.; Dickens, M.J.; Clarke, R.H.; Lovegrove, T.G. 2012. The theory and practice of catching, holding, moving and releasing animals. *In*: Ewen, J.G.; Armstrong, D.P.; Parker, K.A.; Seddon P.J. (*eds*). *Reintroduction Biology: integrating science and management*. Oxford, Wiley Blackwell.
- Parker, K.A.; Ewen, J.G.; Seddon, P. J.; Armstrong, D.P. 2013. Post-release monitoring of bird translocations: why is it important and how do we do it? *Notornis* 60: 85–92.
- Parliamentary Commissioner for the Environment 2011. Evaluating the use of 1080: Predators, poisons and silent forests. <u>www.pce.parliament.nz</u> [viewed 17 April 2020].
- Powell, R.A.; Mitchell, M.S. 2012. What is a home range? *Journal of Mammalogy* 93: 948–958.
- Ralls, K.; Ballou, J.D.; Dudash, M.R.; Eldridge,

M.D.B.; Fenster, C.B.; Lacy, R.C.; Sunnucks, P.; Frankham, R. 2018. Call for a paradigm shift in the genetic management of fragmented populations. *Conservation Letters* 11: 1–6.

- Rattenbury, M.S.; Cooper, R.A.; Johnstone, M.R. 1998. *Geology of the Nelson area*. Institute of Nuclear and Geological Sciences 1:250,000 geological map 9.
- Robertson, H.A.; Baird, K.; Dowding, J.E.; Elliott, G.P.; Hitchmough, R.A.; Miskelly, C.M.; McArthur, N.; O'Donnell, C.F.J; Sagar, P.M.; Scofield; R.P.; Taylor, G.A. 2017. Conservation status of New Zealand birds, 2016. New Zealand Threat Classification Series 19. Wellington, Department of Conservation. 27pp.
- Robertson, H.; Colbourne, R. 2003. *Kiwi Best Practice Manual*. Wellington, Department of Conservation.
- Robertson, H.A; Colbourne, R.M.; Graham, P.J.; Miller, P.J.; Pierce, R.J. 2011. Experimental management of brown kiwi, *Apteryx mantelli* in central Northland, New Zealand. *Bird Conservation International* 21: 207–220.
- Robertson, H.A.; McLennan, J.A.; Colbourne, R.M.; McCann, A.J. 2005. Population status of great

spotted kiwi (*Apteryx haastii*) near Saxon Hut, Heaphy Track, New Zealand. *Notornis* 52: 27–33.

- Sporle, W. 2013. A guide to establishing a new kiwi population. Kiwis for Kiwi.
- Taylor, H.R.; Colbourne, R.M.; Robertson, H.A.; Nelson, N.J.; Allendorf, F.W.; Ramstad, K.M. 2017. Cryptic inbreeding depression in a growing population of a long-lived species. *Molecular Ecology* 26: 799–813.
- Toy, S. 2016. *Biodiversity treasures of the Flora*. Report for Friends of Flora and the Department of Conservation.
- Worthy, T.H. 1997. Fossil deposits in the Hodges Creek Cave System, on the northern foothills of Mt Arthur, Nelson, South Island, New Zealand. *Notornis* 44: 111–124.
- Worthy, T.H.; Holdaway, R.N. 1994. Quaternary fossil faunas from caves in Takaka Valley and on Takaka Hill, northwest Nelson, South Island, New Zealand. *Journal of the Royal Society of New Zealand* 24: 297–391.
- Worthy, T.H.; Holdaway, R.N. 2002. *The lost world of the moa. Prehistoric life in New Zealand.* Canterbury University Press.

Persistence of pre- translocation pairs	Kiwi name	Duration (days)	Area (ha)	Maximum dispersal distance (km)	Number of contributing locations
Pair persisted	Hoire	77	96	1.3	9
	Ngutu-roa	9	39	0.5	6
	Poai	100	91	1.6	11
	Rameka	184	304	2.5	13
	Te Manu-huna	9	33	0.4	6
	Waiharakeke	122	138	1.9	11
Pair separated	Anatori	122	206	1.8	15
	Aorere	122	116	1.5	11
	Mangarakau	28	317	2.1	8
	Pakawau	170	149	1.4	20
	Parapara	34	169	3.8	3
	Pikopiko	186	494	2.2	16
	Puponga	18	229	2.8	7
	Rata	12	101	2.2	6
	Tahi	878	1,745	6.0	58
	Tai Tapu	47	187	2.7	12
	Te Kau	255	620	2.8	23
	Te Rae	194	515	3.3	25
	Toru	450	685	3.9	43
	Waru	148	500	3.0	20
	Whakahihi	396	494	4.0	30
	Whitu	398	588	3.5	36
Translocated	Patoto	239	319	2.0	23
without partner	Rakopi	170	142	1.5	15
	Те Нари	483	849	4.4	31
	Toro-Ngangara	69	171	1.9	9
	Turimawiwi	150	286	3.0	20
	Whakangangahu	69	127	1.9	10

Appendix 1. Duration and extent of post-translocation dispersal for roroa in the Flora Stream project area monitored throughout the dispersal period. Kiwi are grouped based on whether pre-translocation pairs persisted or separated.

Kiwi name	Duration days)	Area (ha)	Maximum dispersal distance (km)	Number of contributing locations	Reason for truncated monitoring
Waikaki	>171	141	1.3	22	Died
Rima	>337	790	3.0	36	Died
Pohara	>535	1,880	5.1	30	Disappeared
Rototai	>82	180	2.0	5	Disappeared
Awaroa	>254	890	2.8	24	Dropped transmitter
Waewae-rakua	>350	867	5.7	18	Dropped transmitter
Anaweka	>537	1,044	6.1	55	Dropped transmitter
Ono	>738	1,314	7.7	52	Dropped transmitter
Opau	>253	196	2.7	28	Dropped transmitter
Whariwharangi	>299	833	2.5	26	Dropped transmitter
Iwa	>83	1,340	8.3	7	Retrieved
Korowhiti	>261	1,645	6.5	19	Retrieved
Rua	>361	1,455	7.8	19	Retrieved
Totaranui	>97	373	4.5	10	Retrieved
Kuikui kuini	>226	2,108	9.8	16	Transmitter died
Wha	>398	520	8.5	17	Transmitter died

Appendix 2. Duration and extent of post-translocation dispersal in the Flora Stream project area for kiwi whose monitoring was truncated during the dispersal period.

Appendix 3. Size of multi-year and annual home ranges of kiwi in the Flora Stream project area (2010-2018). Areas and number of triangulated locations are shown only for home range estimates that reached an asymptote in the IAA. Aorere and Rakopi's multi-year home ranges covered both the Flora and Ghost Creek regions, so were not included. Ratio multi-year home range to annual home range (HR:HRann) was not calculated where there was only one HRann contributing year.

Region of project area	Kiwi name	Multi-year home range (HR)		Annual home r	Ratio	
		Area (ha)	Number of contributing locations	Mean area (ha)	Number of contributing years	HR:HRann
Flora	Anatori	218	194	86	6	2.5
	Aorere	-	-	43	1	-
	Korowhiti	134	70	102	2	1.3
	Mangarakau	124	52	103	2	1.2
	Pakawau	199	182	75	8	2.7
	Parapara	157	174	88	6	1.8
	Patoto	126	54	90	3	1.4
	Pikopiko	228	182	82	7	2.8
	Puponga	73	15	73	1	-
	Rakopi	-	-	50	1	-
	Rameka	404	177	117	6	3.5
	Totaranui	159	203	89	7	1.8
	Waiharakeke	475	194	126	8	3.8
Deep Creek	Hoire	48	104	26	5	1.9
	Ngutu-roa	157	78	76	4	2.1
	Poai	65	104	33	5	2.0
	Te Kau	244	84	75	4	3.3
	Te Manu-huna	101	90	72	3	1.4
	Toro-Ngangara	65	34	47	2	1.4
	Turimawiwi	127	28	93	2	1.4
	Waru	79	17	79	1	-
	Whakangangahu	137	97	48	4	2.9
Ghost Creek	Aorere	-	-	105	5	-
	Iwa	88	88	51	3	1.7
	Rakopi	-	-	122	3	-
	Rata	132	38	78	2	1.7
	Rua	38	16	38	1	-
	Tai Tapu	113	37	68	2	1.7
	Te Hapu	63	10	63	1	-
	Toro-Ngangara	165	52	79	2	2.1
	Toru	29	15	29	1	-
	Whakahihi	85	77	41	4	2.1
	Whitu	80	57	35	3	2.3

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Individual variation in the foraging behaviour of two New Zealand foliage-gleaning birds

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Abstract: The foraging behaviour of two foliage gleaning birds, rifleman and grey warbler (henceforth warbler), was studied at Kowhai bush, Kaikoura, with the aims of exploring behavioural variation by individual pairs, and broader patterns of foraging behaviour for each species. Data on six foraging variables were collected from individually identifiable birds of known breeding status at the time of sampling. A total of 1,632 samples were taken during the spring/summer period of 1987/8. Data analysis explored foraging behaviour in relation to species, sex, and breeding stage. Individual pairs of riflemen exhibited significant variation in behaviour, indicating behavioural specialisation that I term a "foraging personality" identified as an emergent characteristic of each pair. Riflemen showed greater within-pair variation than warblers. The similarities and differences in foraging behaviour between the two species are described and are linked to their behavioural ecology. Analyses are presented in relation to the problem of data independence when repeated samples are taken from one individual.

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Keywords: Rifleman, Acanthisitta chloris, Grey Warbler, Gerygone igata, foraging personality, feeding behaviour

INTRODUCTION

Behavioural flexibility in relation to current environmental conditions, varying physiological demands or morphological variation makes evolutionary sense, and presumably influences survival. Flexibility in foraging behaviour by bird species has been found in a wide range of contexts. Two bark-foraging species, nuthatch (*Sitta europaea*) and Eurasian tree creeper (*Certhia familiaris*), showed significant between-year variation in the proportion of time spent foraging on beech (*Fagus sylvatica*) (Adamik & Korňan 2004). Coal tits (*Parus ater*) and common starlings (*Sturnus vulgaris*) adjusted their foraging behaviour in relation to the presence or absence of snow (Maccarone 1987; Brotons 1997), and wind for the coal tits

Received 7 April 2020; accepted 30 May 2020 Correspondence: tawakix@hotmail.com (Lens 1996). Gustaffson (1988) linked individual differences in foraging behaviour of coal tits to size, wing morphology and age. Foraging behaviour of gray-breasted jays (Aphelocoma ultramarina) is affected by age, dominance status, and learning opportunities (McKean 1990). Mixed-species flocks of migrant North American warblers and nonmigrant Australasian warblers both adjusted their foraging behaviour in relation to drought (Bell & Ford 1990; Newell et al. 2014), and forest type (Tarbox *et al.* 2018). Numerous other examples are documented in these papers. Most relevant here is that these examples are reported in relation to species or populations; flexibility in foraging behaviour by individual passerine birds is only rarely reported (e.g. Greenberg 1990; Whelan 2001; Aplin *et al.* 2014) and is presumably rarely studied. However, as a principle, behavioural flexibility has been reported across a wide variety of taxa, and is

clearly an important factor influencing behavioural outcomes (Lea *et al.* 2020).

The theoretical context of most research on bird foraging has been variously described as niche (or resource) partitioning, guild structure, foraging specialisation, ecological (or behavioural) plasticity, or species flexibility (e.g. Holmes & Robinson 1988; Bell & Ford 1990; Greenberg 1990; Martin & Carr 1990; McNally 1994; Somasundaram & Vijayan 2008; Mansor & Mohd Sah 2012). More recent research has shifted towards the conservation/ applied science context, where birds are used as bioindicators (e.g. Virkkala 2016). Recognising that individual variation is a key factor underlying all of this research, researchers have recently begun to use the notion of personality when referring to the expression of different behaviours under the same conditions (Aplin et al. 2014). By extension, some authors now refer to personality as an emergent property of groups of animals (e.g. Planas-Sitjà et al. 2015).

Using an experimental approach with three closely-related species of American warblers, Whelan (2001) described what he called "distinct foraging microhabitats". Under controlled conditions, each species foraged from different surfaces within the artificial forest and adjusted their foraging behaviour in relation to current foraging location. Whelan showed that leaf dispersion has the strongest influence on prey capture location, and distance to prey determines prey capture manoeuvre. A key finding is that he demonstrated significant variation in the location and behaviour of individual birds of the same species foraging under the same conditions. Furthermore, Whelan (1989) showed that the learning rate of warblers varies at both individual and species levels. These (wild-caught) birds therefore demonstrated individual preferences, different learning outcomes, and behavioural specialisation, in a standardised context. Those results are entirely consistent with the notion of personality as used in recent literature, although Whelan (1989) did not use the word.

It therefore seems likely that individual behavioural variation makes a fundamental, albeit rarely studied, contribution to the patterns documented in many ecological studies of passerine birds. Understanding that variation should help to explain the broader patterns of behaviour described in much research on foraging behaviour (Martin & Carr 1990; Lea *et al.* 2020).

Research designed to explore phenotypic variation in behaviour necessarily requires longterm data gathered from identifiable individuals, usually as a series of samples. A statistical issue that immediately arises is independence of data. Multiple samples taken from one individual increase the final sample size considerably, potentially making the data more representative of behaviour and enabling more fine-scaled analyses if reasonable independence of samples can be assumed. The issues for birds have been addressed in detail in Bell *et al.* (1990), Heijl *et al.* (1990), and Recher & Gebski (1990). Multiple samples were taken in this study, which includes two analyses addressing the question of whether the data can be treated as independent measures for statistical analysis.

An additional analytical problem is that sampling of bird behaviour almost inevitably results in a mix of continuous (e.g. height) and categorial (e.g. perch type) variables, complicating any attempt to combine variables into a single analysis that captures the diversity of foraging behaviour for comparative purposes. Treating variables separately can result in multiple statistical analyses, and associated type II errors. The present study was descriptive, and the approach taken was therefore to use exploratory quantitative techniques to search for broad patterns in the data, and use a minimum of inferential analyses to test trends apparent in the data.

This study explored the foraging behaviour of two foliage gleaning bird species in relation to sex, stage of breeding, and individual variation. The aims were: i) to explore behavioural differences within and between breeding pairs, ii) to document behavioural variability during different stages of the nesting cycle, and iii) to compare the behaviour of the two species.

METHODS

Birds were studied in a small, mostly isolated, forest, 7 km inland from the small coastal tourist town of Kaikoura, eastern South Island, New Zealand (173°37'E, 42°23'S). The forest was mostly Kunzea ericoides (kanuka, Myrtaceae) existing as secondary re-growth on a flood plain adjacent to a small river (a more detailed description is in Gill 1980b). The original forest was cleared for farming, and then allowed to revert to forest for flood control purposes about 30 years before this study. Most of the trees were similar in height at 5–7 m, which is a mature size for this early-stage forest coloniser, although it can grow considerably (http://www.nzpcn.org.nz/flora_details. taller aspx?ID=885). The canopy was closed but not dense, and the relatively low and consistent canopy height supported human observation of these tiny birds. The area was occasionally grazed by cattle, ensuring minimal undergrowth and easy access for researchers throughout the forest. There was little leaf litter or fallen branches on the forest floor, allowing researchers to move silently in any direction. Both bird species are relatively tolerant of human presence and tend to move through the forest at a speed approximating a human walking pace. Thus, individual birds could usually be followed reliably for 10–30 minutes, enabling repeated sampling of foraging and reliable finding and monitoring of nests. The main study area of about 1 km² was marked out in a 25x25 m grid, enabling easy monitoring of location, although marked birds (and researchers) sometimes moved beyond the gridded area.

The data reported here were collected in the (southern) spring and summer of 1987/8. The data were lost in a computer crash in 1989. However, paper records were retained and were recently reentered. For most analyses, the data were linked to breeding stage, identified as BL (building/laying), IN (incubation), FN (feeding nestlings), and FF (feeding fledglings). Each of these stages was about three weeks long, although nests could fail at any time, and re-nesting could begin while fledglings were still being fed. Data collection began in late August and continued until mid-January. Breeding stage for every pair was checked at least weekly.

Study species

(Acanthisitta chloris, titipounamu, Rifleman Acanthisittidae) and grey warbler (Gerygone igata, riroriro, Acanthizidae, henceforth warblers) are the two smallest bird species in New Zealand (Anderson, 2013; Withers, 2013). Both are endemic species, with the rifleman being one of two surviving species in an endemic suboscine family. Warblers are the only mainland New Zealand representative of an Australasian group (including the Philippines, Thailand, Indonesia, and New Guinea) containing the gerygones (about 20 species), thornbills (about 12 species), and some others (https://carolinabirds. org/index.html).

Male riflemen are 10–15% smaller by weight than female riflemen and both warbler sexes. Both species are active foliage gleaners, thus are easily located due to continuous movement and regular calling (riflemen) or singing (male warblers). Demographic and behavioural detail for both species are summarised in Table 1 (references therein, and personal observations). Riflemen are dimorphic (males are green, females are brown), but sex in warblers can only be distinguished by behaviour: female warblers sing rarely, do all nest building and incubation, and are generally much quieter and less conspicuous than males. Female and male riflemen are similarly conspicuous and vocal, routinely giving contact calls as they forage. Mate guarding behaviour by males of both species early in the breeding season allowed pair-identification, and sex assignment for warblers. During the BL phase of the breeding season, male warblers sit 1.0–1.5 m

below females as they forage, and move wherever the female goes (= guarding). Other male activities include singing patrols (moving and foraging as they sing), occasional intensive chase interactions with other males, and accompanying the female when she is off the nest during incubation. Once eggs hatch, males provision nestlings and fledglings (Gill 1982a), including doing all provisioning if the female initiates a new nest. Male riflemen participate fully at all stages of the breeding cycle, including provisioning females to support egg production, and doing most nest building (Sherley 1985, 1989). One study of foraging of non-breeding riflemen identified differences in perch use by males and females, but no differences in activity budget or prey capture rate (Lill 1991). Gill (1980b) reported that non-breeding warblers fed mostly in the upper part of the forest, they were always upright when perched, and 40% of their foraging behaviour was hover gleaning.

Most birds were individually colour-banded. Capture was primarily with mist nets, although a few riflemen were captured using a hand net near a nest box. No birds were injured during capture and banding, and no nests were abandoned as a result of our activities. Content of nests was only checked if it was known that no bird was present, with most determination of nesting stage achieved using bird behaviour (e.g. carrying nest material or food; returning to the nest secretively and without food). The species studied form long-term pair bonds and are sedentary (Gill 1982a; Sherley 1985), thus, any unbanded birds could be identified by their association with a mate and/or a nest. I did not record foraging data from unbanded birds that could not be linked to a nest and/or a banded mate at the time of sampling.

Research methodology was approved by the Animal Ethics Committee of the Department of Zoology at Canterbury University. Bird banding was conducted under licence from the Department of Conservation.

Warblers build an enclosed pendulous nest, generally in a dense clump of vegetation in the upper half of trees in this study area. Riflemen are hole nesters, building a ball nest with a side entrance. In this study, most rifleman nests were in nest boxes. Thus, riflemen nests were protected from predators, but warbler nests were not. Warblers are also parasitized by the shining bronze cuckoo (*Chalcites lucidus*) (Gill 1982b; McLean & Rhodes 1991; Briskie 2007; Thorogood *et al.* 2017). Some of the data used here were from birds feeding a cuckoo chick, including one nest from which both a warbler and a cuckoo chick were successfully fledged (the female fed the warbler fledgling and the male fed the cuckoo fledgling).

Characteristic	Rifleman* [#]	Warbler ^{+#}
Clutch size	$4.4 \pm s.d. 0.4$	3–5 (mode 4)
Egg size	19% female weight	23% female weight
Laying rate	2-day intervals	2-day intervals
Incubation period	$19.6 \pm s.d. 0.8 \text{ days}$	17–21 (19.5) days
Nestling period	$24.0 \pm s.d. \ 1.2 \ days$	15–19 (17.2) days
Female weight	7.0 <u>+</u> s.d. 0.7, N=20	6.4 (combined gender)
Male weight	5.6 <u>+</u> s.d. 0.3, N=33	6.4 (combined gender)
Male guards female	Yes	Yes
Male provisions female	Yes (pre-lay and lay only)	No
Male builds nest	Yes (> female)	No (may follow female)
Male incubates	Yes (> female during day)	No
Male feeds chicks	Yes (> female)	Yes
Helping behaviour	Yes (uncommon)	No
Male aggression	Yes (neighbour disputes)	Yes (neighbour disp.)
Female aggression	Yes (neighbour disputes)	No
Male territorial singing	No	Yes (very persistent)

Table 1. Demographic characteristics of rifleman and grey warbler

*Rifleman: Sherley (1985, 1989, 1990a, 1990b)

⁺Warbler: Gill (1980a, 1980b, 1982a)

[#]Personal Observations

Sampling foraging

All data were collected when there was good weather with little wind and no rain. Movement and binoculars were essential for following birds closely, and rain, or movement of vegetation due to wind, made sampling too difficult.

After a bird was identified, I waited for it to peck at a food item and immediately started a stop watch. The bird was then observed continuously until the next peck in order to obtain the inter-peck time interval and the distance moved between peck locations, estimated as the pathway distance travelled in decimetre units. Recorded for the second peck site were: perch site, peck substrate, feeding behaviour, height of bird, and height of canopy directly over the bird (as estimates). Using the inter-peck interval data reported here, an average of 15 seconds would have elapsed from when the bird was first seen, and the data recorded for the first foraging event. A tree marked in metre units was used for training for height estimation; path estimation of distance moved was practiced using a measuring tape.

Height was analysed as relative height (bird/ canopy = relative position of the bird in the tree) rather than the more usual absolute height. Thus, the position of the bird in the tree was estimated very precisely, effectively by using top down as well as bottom up estimates for the two heights.

The birds moved continuously and could disappear from direct view at any time. To minimise bias towards short inter-peck time intervals, I continued the sample if the bird was out of sight for less than three seconds. If the bird was unseen for more than three seconds, no data were recorded and another timed sample was initiated from the next peck seen. If the bird was lost completely, the time and travel distance when it was lost were recorded and I recorded the foraging details of the *first* peck; no inter-peck rate was available for that record, but a distance moved was. I recorded up to five samples from one individual bird on one day. Minimum time interval between samples was initially set at five minutes, but was reduced to two minutes once preliminary data had been collected (peck rate for both species was around 6/min, birds were opportunistic in their use of feeding method and location, and birds could easily move through the entire height of the forest in two minutes). If working with a pair, individuals were alternated in order to maximise the time between samples taken from one individual. If <5 samples were obtained during one session with a bird, then the balance could be taken later in the day. A few instances of >5 samples from one bird in one day were found in the data (maximum 8); these were mostly due to two samplers working separately and encountering the bird at different times (all samples were accepted).

Peck rate and distance moved were recorded and reported as continuous variables. If a bird made multiple pecks at the substrate (e.g. due to finding a resting swarm of flying insects, or taking scale insects), the number of pecks was counted and divided into the inter-peck time interval. Peck rate was converted to pecks per minute. Movement rate was calculated using the distance moved and time interval between pecks, converted to metres/min; values >60 m/min were removed from the data as they indicated a fast flight not linked to foraging.

The two height measures were recorded as continuous variables, but reported as a discrete (ordinal) variable: proportion of total samples recorded at relative heights between 0 (ground) and 1 (top of canopy). Relative height was then analysed using six categories: 0–0.1, >0.1–0.3, >0.3–0.5, >0.5–0.7, >0.7–0.9, >0.9.

Perch substrate, peck site and feeding behaviour were recorded as categorical (nominal) variables. Categories were:

Perch substrate: i) Ground, Trunk (stem of tree from ground), ii) Large Branch (side branch off trunk with a thickness >25 mm), iii) Small Branch (side branch <25 mm but too thick for the birds to disturb), iv) Twig (branchlet with leaves directly attached, < 10 mm thick), v) Leaf (including leaf petioles), vi) Dead Wood.

Peck site: i) Ground (including ground vegetation such as low grass), ii) Litter (or other loose ground vegetation), iii) Moss (mostly on ground, occasionally on trees), iv) Lichen (on trees), v) Bark (bark on *K. ericoides* is loose and stringy and may strip off naturally to expose bare wood), vi) Dead wood, vii) Leaf (including leaf petioles), viii) Flower, Air, Web (spider), ix) Hole (cavity in the wood), x) Knot (site on trunk or large branch where a branch had been lost), xi) Trunk or Branch (large or small) were recorded only if there was no bark at the peck site.

Feeding Behaviour: A peck at the substrate (glean) was divided into: i) Upright glean (bird standing upright), ii) Downside glean (bird feeding on underside of perch; the distinction effectively gives the exposed and shaded sides of the substrate), iii) Hover glean (the bird hovers to inspect vegetation and takes a prey item off the substrate while hovering), iv) Probe (bird pokes its beak into a hole), or v) Lunge (the bird jumps or flies to grab a previously sighted resting prey item; it may stop at the peck site or continue on, but it does not hover and the prey item was on the substrate when taken). Non-gleaning behaviour included vi) Flush

(the bird's activities disturb a sedentary prey item that flies or falls, which is then taken in the air), vii) Hawk (the bird attacks a flying prey item that was not flushed), and viii) Provision (male feeds female).

If the bird caught flying prey that was not flushed (= Hawk), then the jump-off perch was recorded and the peck site was recorded as "Air".

Analysis

Data summaries

Levels of analysis supported by the data included: i) within and between-pairs, ii) between-breeding stage (both species), iii) between sexes (within species), and iv) between-species. To be included in i), a minimum of 5 samples was required for both members of the pair for all four stages of breeding (= minimum 20 total samples per individual). To be included in analyses for ii), iii), and iv), a minimum of three samples for an individual was required. For all analyses, each sample was treated as an independent measure of foraging behaviour.

Between-pair variation in behaviour: within-pair data

The aim of the between-pair analysis was to capture variation in the behaviour of individual birds working together as a pair. Hence each pair was treated as a nominal individual. For each behavioural variable, the data for females and males were collapsed to create one index value for each breeding stage that assessed the scale of behavioural difference within a pair for each breeding-stage/variable combination. To produce the index, all six behavioural variables were converted into categorical variables, each with exactly six categories. Some combining of minor categories was required for the three categorical variables (described in Results). For continuous variables, the categories were defined to ensure a reasonably even spread of data across categories. The data were indexed using the formula:

$$\Sigma I_{BS} = [(F_C/N_F) - (M_C/N_M)]^* ((N_F + N_M)/10)$$

Where I_{BS} = Index value for Breeding Stage

F = Female, M = Male

C = behaviour category count

 N_x = sample size for the breeding stage for the specified sex

10 is a constant that reduces the scale of the final index to a number close to 1, without affecting its relative value.

A key characteristic of this formula is that behaviour categories with higher counts have a higher proportional representation in the final index value relative to categories with lower counts, compensating for the problem that categories with low counts (and therefore lower reliability) could dominate the overall index when Ns are small. Low counts (including zeros) are expected for some categories due to the nature of the behaviour being sampled. Modelling indicated that those counts could bias the result if a simpler index such as a percentage was used (e.g. with a total N of 5, one observation enters the data as 20%; with a total N of 20, two observations enter the data as 10%).

Thus, for each pair, six indexed values (one for each sampled behaviour) were calculated for each of the four breeding stages. The formula delivers a value where 0 = no difference between female and male, positive values mean F>M, negative values mean M>F, and larger values indicate a bigger difference between female and male. The upper and lower bounds are open as they depend on sample size, but modelling indicated that they were likely to range between 3 and -3 in this data set: the biggest calculated index values were 2.08 for riflemen and 2.94 for warblers. The sum of the six values is always zero because females and males are contributing equally to the data, so negative values were converted to positive in the index. A final data set indexing the behavioural differences for a pair with complete data contained 24 values: (4 x breeding stage) x (6 x behaviour category). For riflemen, seven pairs had sufficient data; for warblers one pair had sufficient data. One rifleman pair with complete data in the first three stages, but data for only the male in the FF stage, was included by using an estimate of the missing female datum (thus total N = 8). N's per individual rifleman ranged from 35–60.

The complete analysis was therefore only possible for riflemen, but between-species comparison was achieved using a more limited data set. Ten warbler pairs had enough data for at least one stage of the breeding cycle to support a partial analysis, allowing a visual review but not a statistical analysis. To compare directly with riflemen, the complete indexed rifleman data set for eight pairs was subsampled to match the partial warbler data set. Exclusion of some rifleman data was achieved by matching pairs of warblers and riflemen using a randomly assigned pair number, and then eliminating any rifleman breeding stage result for which the equivalent warbler analysis was missing. For example, if five warbler pairs had data available for FN, then only the five matched indexed rifleman values for FN were used. Two warbler pairs with indexed results for only one breeding stage were eliminated to match the warbler N to the rifleman N of 8. Thus, for the between-species comparison of gender variation within pairs, sample size and data availability were equivalent for the two species, enabling use of ANOVA.

Sex and species comparisons: all data

All individuals with <3 samples were removed from the data set, leaving for riflemen: 16 females and 17 males, and for warblers: 15 females and 14 males. Variable structure was 2 x species, 2 x gender, 4 x breeding stage, and 6 x foraging behaviour (= 96 in total). Patterns in the data were initially identified visually, and then reviewed using hierarchical cluster analysis in SPSS to confirm the visual conclusions. The original plan to use followup statistical analysis to check the significance of major differences was abandoned when it became apparent that relationships amongst the many elements of the data were complex. There were few obvious differences and a great deal of overlap, potentially resulting in a large number of statistical tests. Thus, the analysis is primarily visual, with 95% confidence intervals plotted on the graphs wherever appropriate as an indication of statistical distinctiveness.

Independence of data

Two analyses were conducted to check whether a series of five samples taken from one individual at one time could be treated as (reasonably) independent in the overall analysis. The checks were conducted on continuous variables only (peck rate, distance moved, height), as these supported analyses that explored variance.

In the first analysis, I looked at mean and variance for each variable across the 5-sample sequence for all birds in the data set of each species. This analysis explores patterns in the sequence, with the prediction that if the birds are responding to the observer, then there will be detectable trends in the sequence (such as moving higher, moving more quickly, or pecking at a slower rate).

In the second analysis, I predicted that if the five samples taken from one individual were correlated (= not independent), then the variance of those samples should, on average, be smaller than the variance for five randomly chosen values from the full data set. Here, I extracted the first available sequence of five samples for all females in the BL breeding stage category (riflemen) and for all males in the FN category (warblers). For rifleman, 14 females satisfied the criterion, giving 70 samples; for warblers 12 males satisfied the criterion, so I included two repeat sets from two male individuals in order to match N with riflemen.

The two species were analysed separately. Samples ordered by bird were paired against themselves (i.e. two identical columns were created). Order of the second column was then randomised (with replacement), creating a paired data set where each sequence of five samples for one bird was paired with five randomly selected samples from the full data set (of 70 samples). The mean/ variance ratio of each sequence of five samples was then calculated, giving 14 pairs of ratios (individual:random). These 14 were compared using a paired t-test, where it was predicted that a ratio calculated using the data from one bird would, on average, be larger (because the variance of a set of correlated data should be smaller), than the ratio calculated from five samples chosen randomly from the same data set. The test was bootstrapped 20 times, giving 20 t values for each behaviour for each species (= 120 t-tests). The scale and distribution of the t values is of primary interest rather than their possible significance, although significant t values would support the prediction.

RESULTS

There are three sections in the Results. First, is an analysis of within-pair foraging behaviour of pairs of birds, using the summarising index that treats each pair as an individual. Second, is a broad descriptive analysis of the foraging behaviour of the two species using all of the data broken down by species, sex, and breeding stage. Third, is an analysis of the issue of data independence for multiple samples taken from the same individual bird. The acronyms for breeding stage codes are: BL (building/laying), IN (incubation), FN (feeding nestlings) and FF (feeding fledglings). A total of 1,632 observations were obtained, of which 978 from 33 birds (riflemen) and 529 from 29 birds (warblers) with 3+ samples were accepted for the analysis of foraging behaviour. Sample range per rifleman was 3–60 (= 19.6 \pm s.d. 10.7), and per warbler was 3–40 (= 17.5 \pm s.d. 11.3). Actual sample sizes in some analyses were slightly reduced due to occasional missing elements in the data.

Within-pair variation in foraging behaviour

There was significant variation in within-pair behaviour among rifleman pairs (2-way repeated measures ANOVA, Fig. 1), with both behaviour ($F_5 = 3.3$, P = 0.007) and breeding stage ($F_3 = 7.1$, P < 0.001) being significant. The interaction was not significant ($F_{15} = 1.5$, P = 0.1). Sex differences were generally strongest during BL, whereas they were most variable during IN. Most similar in terms of pattern were pairs 14 and 1, and pairs 5 and 3 (the estimated value for FF for pair 5 was not plotted). Sex difference through the breeding cycle was least variable for pairs 13 and 6, indicated by strongly overlapping 95% confidence intervals; for all other pairs sex difference had non-overlapping 95% CIs.

The broad results from this analysis are, i) that each pair had a unique pattern of sex difference through the breeding cycle, and ii) there was considerable variability in foraging behaviour by individual pairs.



Figure 1. Difference in the foraging behaviour of paired female and male riflemen at four different stages of the nesting cycle (see Methods, paragraph 2), indexed using six standardised behavioural variables collapsed into one value for the pair (formula in Methods). Higher values indicate a greater difference in foraging behaviour within the pair. Bars are index means for the pair \pm 95% confidence intervals (N per bar = 12 = 6 lumped behavioural variables for both sexes). The pairs are organised along the x-axis by increasing overall dissimilarity.

Because more limited data were available for warblers and bars were not as directly comparable as in Fig. 1, the warbler version of Fig. 1 was plotted as two separate graphs with the primary aim of comparing between species (Fig. 2a,b). Sex difference between warbler pairs was relatively small, with six of the ten pairs having very similar index values (black bars in Fig. 2a). The warbler data were matched with rifleman data (see Methods) to create a statistically comparable data set for eight pairs from each species. There was significant variation in sex difference between warblers and riflemen, both between species (2-way repeated measures ANOVA, $F_{11} = 9.9$, P = 0.003, Fig. 2a) and among the breeding stages ($F_3 = 6.4$, P = 0.001, Fig. 2b). The interaction was not significant. The main source of the between-species difference was in the BL and IN stages, with riflemen having bigger within-pair differences in behaviour at both stages.

Comparative foraging behaviour

These summaries are based on visual inspection of the data and describe general comparative trends. Ns are warbler, female:male, BL, 77:88; IN, 32:42; FN, 86:110; FF, 49:61; rifleman, female:male, BL, 224:171; IN, 91:87; FN, 92:80; FF, 68:60. In the figures, Y axes were standardised for within-species sex comparison, but may be different between-species.

The most obvious differences between the two species were, i) the wider height range and associated differences in perch types and peck sites (especially use of trunks and bark) used by riflemen relative to warblers, ii) the exclusive and frequent use of hover gleaning by warblers, iii) provisioning of female riflemen by males during BL, and iv) the high peck and movement rates for female warblers during IN. The most obvious general similarity was the similar movement rates by both species.



Figure 2. Difference in the foraging behaviour of paired birds of two species in the breeding season indexed using six standardised behavioural variables averaged across available data for the pair (formula in Methods). Each warbler pair is matched to equivalent data from a randomly selected rifleman pair. Higher values indicate a greater difference in foraging behaviour within the pair. Bars are mean index values using all available data from any stage of the breeding season (a), or averaged across pairs with available data in each breeding stage (\pm 95% CI) (b).

Height

Riflemen foraged throughout the full height distribution in the forest whereas warblers spent relatively more time in the upper part of the forest (Fig. 3). Female warblers foraged most frequently in the canopy, especially when IN and FF, and tended to forage lower during BL. Male warblers generally foraged lower than females, although they rarely used the bottom third of the forest, and they moved higher when FF. Rifleman males foraged more than females in the canopy when IN, FN and FF, whereas during BL males foraged more than females in the bottom half of the forest.



Figure 3. Relative foraging heights used by two bird species organised by sex and stage of the breeding season. Bars are frequencies of height index categories converted to %. Rifleman N = 978, warbler N = 529. BL = building/laying, IN = incubation, FN = feeding nestlings, FF = feeding fledglings.



Figure 4. Pecking and movement rates of two bird species organised by sex and stage of the breeding season. Bars are mean \pm 95% CI. See Figure 3 for sample sizes and acronyms.
Peck rate

With the exception of female warblers during IN, riflemen generally pecked at higher rates than warblers (Fig. 4). Female warblers pecked at higher rates than male warblers during all breeding stages, and at a very high rate during IN. Female riflemen pecked at lower rates than males during BL, IN and FF.

Movement rate

Both species moved at similar rates at all stages of the breeding cycle (Fig. 4). Variability was slightly higher for warblers than for riflemen both through the breeding cycle and between sexes, with female warblers moving at the slowest rate during BL and FF, and the fastest rate during IN.

Perch substrate

Riflemen used all available perch substrates, with an emphasis on trunks and twigs, whereas warblers used twigs and leaves almost exclusively (Fig. 5). Male riflemen used twigs more than trunks, whereas females used trunks more than twigs. Female warblers used twigs and leaves even more exclusively than males. Use of twigs increased and use of leaves declined through the breeding cycle for both species. Although neither species foraged frequently on the ground, riflemen used the ground more than warblers.

Peck site

Warblers pecked primarily at leaves, whereas riflemen pecked predominantly at bark (females) or equally at bark and leaves (males) (Fig. 6). Use of leaves increased through the breeding cycle for both species and genders. Male warblers used a more diverse array of peck sites than females (particularly bark), whereas both rifleman sexes used a similar array of peck sites. Female riflemen used leaves at a much lower rate than males in the BL stage.



Figure 5. Perch substrates used by two bird species organised by sex and stage of the breeding season. Bars are counts for each category converted to %. GR = ground, TR = trunk, LB = large branch, SB = small branch, TW = twig, LF = leaf, DW = dead wood. See Figure 3 for sample sizes and acronyms.

Feeding method

Foliage gleaning was the primary foraging method for both species (Fig. 7). However, of the types of foliage gleaning identified, riflemen primarily used upright gleaning; they used lunging, downside gleaning and probing at relatively low frequencies, and used hover gleaning very rarely. For rifleman, courtship feed (5.4%, BL, females only) and flush (0.9% IN, 1.0% FN, males only) were left off the graph to maintain comparability with warblers. Warblers used similar frequencies of upright gleaning and lunging, slightly lower frequencies of hover gleaning, and did not probe or provision the female. Riflemen used downside gleaning more than warblers, whereas warblers used flushing more than riflemen. Both genders of both species used hawking at relatively low rates. In relation to the breeding cycle: during BL upright gleaning was the most used foraging technique by female and male riflemen and female warblers, whereas male warblers used lunging most; lunging and hover gleaning were used more frequently by female warblers during IN and to a lesser extent during FF; male riflemen used lunging and hawking more during IN and FF; male warblers used hover gleaning more when FN and FF.

Cluster analysis generates a dendrogram that represents the relative relationships between variables. Variables that are more similar in terms of standardised data will connect more strongly, identified by links and groupings in the diagram. Here, it was predicted that variables would cluster by species and sex (within species). No prediction was made for clustering by breeding stage. The predictions were incorrect with the reality being far more complex. The following general patterns were identified by visual inspection of the links in the dendrogram (Appendix 1):



Figure 6. Peck sites used by two bird species organised by sex and stage of the breeding season. Bars are counts for each category converted to %. Some minor (and linked) categories were combined for rifleman. LF = leaf, TW = twig, BK = bark, KN = knot, DW = dead wood, GR = ground, LT = litter (on ground), MS = moss, LI = lichen (on trees), WEB = spider's web, FL = flower, TR = trunk, LB = large branch. See Figure 3 for sample sizes and acronyms.

- Peck rate for female warblers during IN clustered on its own as the variable most different from all others.
- Species did not cluster distinctively.
- Genders did not cluster distinctively.
- Breeding stage did not cluster distinctively.
- Most variables clustered together to some extent, usually with a few exceptions (such as peck rate for female warblers during incubation, as above).
- Relative height for both species clustered together very strongly.
- Perch substrate and peck site clustered together strongly (for both species).
- Travel rate and peck rate clustered together strongly (for both species).

Overall. the cluster analysis indicates considerable overlap in the foraging behaviour of riflemen and warblers. They were distinguished breeding-stage/gender/species by specific combinations summarised at the beginning of the results, such as feeding at lower heights (riflemen), using unique feeding methods (warblers - hover glean), or feeding predominantly on leaves in the canopy (female warblers). But none of the three independent variables clustered strongly together.

The three continuous variables (peck rate, movement rate, height) were further investigated using factor analysis to see if there were unique groupings (factors) in the data. No clearer outcome was found (analysis not presented), supporting the broader interpretations of the cluster analysis.

Independence of data in the 5-sample sequence

Analysis of the five-sample sequence indicated strong overlap and no clear trends when all data were inspected (Fig. 8). For riflemen: *pecking rate* increased for the first three pecks then decreased,



Figure 7. Feeding methods used by two bird species organised by gender and stage of the breeding season. Bars are counts for each category converted to %. UG = upright glean, LU = lunge, DG = downside glean, HK = hawk, HG = hover glean, FL = flush, PR = probe. See Figure 3 for sample sizes and acronyms.

with samples 3, 4 and 5 bracketing sample 1; movement rate decreased for the first three pecks then increased, although the first sample was slightly bigger than the other four; *height* had a slight trend downward. All 95% CIs overlapped strongly in all three graphs. Repeated measures, 2-way ANOVA using all three variables indicated no significant variation in the sequence of five samples (F_4 = 1.02, P = 0.4). For warblers: pecking rate decreased then increased; *movement rate* was very similar; for *height*, the first sample was lower than the others, with samples 2 and 3 higher and samples 4 and 5 intermediate. Height for warblers was the variable where 95% confidence intervals overlapped least, with the data suggesting that warblers moved higher after the first sample was taken. However, repeated measures, 2-way ANOVA using all three variables indicated no significant variation in the sequence of five samples ($F_4 = 1.08$, P = 0.38). While it is not appropriate to draw conclusions from nonsignificant results, the results for both species do not support a conclusion that there are trends or patterns in the 5-sample sequences of behaviour.

Six bootstrap procedures were run (giving 120 t values from three behaviours x two species x 20 runs). Small t values were found on all 120 t-tests, with no test approaching significance (at P = 0.05, t_{13} = 1.77). Warbler: *peck rate*, t range = 0.31–0.93,

median = 0.75; movement rate, t range = 0.03-0.79, median = 0.27; height, t range = -0.19-0.18, median = 0.04. Rifleman: peck rate, t range = 0.10-0.93, median = 0.67; movement rate, t range = 0.10-0.32, median = 0.21; height, t range = -0.18-0.75, median = 0.16. In contrast to the result in Figure 3 for warblers, warbler height in the bootstrap procedure showed the least difference of the three variables.

Results from the boot-strapping analyses support a conclusion of reasonable independence in the 5-sample series. However, the test was structured to deliver positive t-test values if variance in the data for one individual was smaller than variance in the data selected randomly. If the two sets of variances were truly similar, then the ratio of positive:negative t values would be close to 1:1. They were not: just two of the 120 test results were negative, indicating slightly reduced variance for the within-individual data relative to the randomly selected data.

Taken together, the results from both analyses indicate few trends in the data, and that the variance was slightly lower for data taken from one individual relative to randomised data from all individuals. The conclusion that data taken in a 5-sample sequence were reasonably independent is supported.



Figure 8. Patterns in the 5-sample sequence for continuous foraging behaviours for female riflemen (IN) and male warblers (FN). Bars are mean + 95% CI, N = 14 sample sequences.

DISCUSSION

Even when working intensively with individually identifiable small birds, it is difficult to detect the variation in behaviour amongst individuals that is documented here. Whelan (2001) referred to the distinctive foraging behaviour of individual birds as foraging microhabitats, but I believe that the principle of a "foraging personality" might be better applied to these birds. In a conceptually similar approach, Snijders et al. (2014) referred to exploration behaviour as a known personality trait in great tits (Parus major). Certainly, rifleman pairs showed unique foraging personalities as an emergent property of distinct individual patterns of behaviour within the pair. Such differences could reflect microhabitat variation in a complex environment, for example due to variation in soil quality or local-scale differences in invertebrate prey availability. However, the forest was homogeneous and even-aged, ground vegetation was heavily browsed and occasionally flooded, and the spatial scale was small (about 1 km²). Both bird species lived in the study area at similar densities, yet riflemen demonstrated considerably more withinpair behavioural variability than warblers. The behavioural differences appear to reflect individual preferences, foraging specialisation, or learned differences in patterns of behaviour, rather than micro-scale, environmentally-driven behavioural variation.

The notion of a group-based (in this case, a pair) personality has considerable traction in the biological literature. Although not referring specifically to groups, Wolf & Weissing (2012) argued that personality differences should be treated as a key dimension of intraspecific variation in order to better understand ecological-evolutionary links. Aplin et al. (2014), Farine & Sheldon (2015), and Herbert-Reid (2017) discussed the principle of emergent group behaviour (= "group personality") based on the personalities of the individuals making up a group, and concluded that this is a real phenomenon needing further research. Further resolution is also needed of the links between learned outcomes, phenotypic consistency, and behavioural flexibility (a discussion of these relationships is in Lea *et al.* 2020).

In this study, although pairs exhibited distinct foraging personalities, individual birds also exhibited flexibility by adjusting their foraging behaviour to the differing demands of each breeding stage. Although almost every rifleman pair had a unique pattern of behavioural difference, the whole-season summary in Figure 2b suggests that behavioural difference decreased after the BL stage (when males and females contribute more equally to parental care). However, that result is not so evident in the more detailed analysis in Figure 1. There is an additional possibility, not addressed here, that each member of a pair adjusts its behaviour in relation to the foraging preferences (or personality) of its mate. Clearly, the relationships are complex and dynamic, and are not yet clearly understood.

The variation documented through the breeding stages shown for both species presumably reflects the changing demands of parental care requirements, along with variation in prey type and availability through time as temperatures warmed through the spring. Incubating female warblers in particular switched to relatively high-energy lunging and hover gleaning as their main feeding methods. They moved fast and pecked at very high rates, likely reflecting urgency to return to the nest and the energy costs of incubation. Despite the energetic costs of nest building and manufacturing eggs, during the BL period females moved at a more similar pace to the post-incubation period when males shared parental care and demands on the female were more similar to those of males. Even without taking data, an observer can easily identify incubating female warblers because of the urgency with which they move, and sample sizes for females were low in part because they were difficult to follow. It seems likely that the IN period is the most energetically demanding for them. In contrast, for rifleman, peck and movement rates of females and males were not distinctive during IN relative to the other breeding stages, likely because both sexes incubate. There were differences: incubating female and male riflemen used different feeding sites and substrates, with males foraging higher than females. However, the differences were no stronger than were found during other breeding stages. Part of the explanation for those differences may lie in the female/male size difference for rifleman (Lill 1991).

Distinctive behaviour in relation to breeding was also noticeable in riflemen, although during the BL stage and for a different reason. Female riflemen became noticeably sluggish when they were due to lay, due presumably to the weight of the large egg. Although obvious to an observer, that change cannot be seen in the data because it occurred for just a few hours each second day during the laying of 4–5 eggs. Female warblers also carry a large egg and lay every second day (Table 1), but do not become noticeably sluggish. The likely key difference is provisioning of female riflemen by males (Sherley 1989). Female riflemen can sit quietly while waiting to be fed, whereas female warblers cannot.

Although this analysis identifies considerable variability in the foraging behaviour of individual birds/pairs, the broader analysis of foraging behaviour also indicates considerable flexibility in response by each species to the demands of different stages of the breeding season. Overall, it is clear that these birds respond to the current demands of the breeding cycle, presumably with further adjustment in relation to environmental conditions (Recher *et al.* 1996; Cueto & Lopez de Casenave 2002). Thus, it seems that all three aspects: individual preferences, flexibility in response to current environmental conditions, and the demands of each breeding stage, will act in concert to influence behavioural outcomes at any moment. Snapshots (samples) of foraging behaviour designed to explore ecological outcomes should attempt to take account of that variability if they are to genuinely capture the factors influencing bird foraging.

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LITERATURE CITED

- Adamik, P.; Korňan, M. 2004. Foraging ecology of two bark foraging passerine birds in an oldgrowth temperate forest. *Ornis Fennica* 81: 13–22.
- Anderson, M.G. 2013. Grey warbler. In: Miskelly, C.M. (ed.) New Zealand Birds Online. <www. nzbirdsonline.org.nz> Accessed: 12 June 2020.
- Aplin, L.M.; Farine, D.R.; Mann, R.P.; Sheldon, B.C. 2014. Individual-level personality influences social foraging and collective behaviour in wild birds. *Proceedings of the Royal Society B 281*: 20141016. doi: 10.1098/rspb.2014.1016
- Bell, H.L.; Ford, H.A. 1990. The influence of food shortage on interspecific niche overlap and foraging behavior of three species of Australian warblers (Acanthizidae). *Studies in Avian Biology* 13: 381–388.
- Briskie, J.V. 2007. Direct observations of shining cuckoos (*Chrysococcyx lucidus*) parasitising and depredating grey warbler (*Gerygone igata*) nests. *Notornis* 54: 15–19.
- Brotons, L. 1997. Changes in foraging behaviour of the coal tit *Parus ater* due to snow cover. *Ardea* 85: 249–257.
- Cueto, V.R.; Lopez de Casenave, J. 2002. Foraging behaviour and microhabitat use of birds inhabiting coastal woodlands in eastcentral

Argentina. *The Wilson Bulletin* 114: 342–348. doi: 10.1676/0043-5643(2002)114[0342:FBAMUO]2.0 .CO;2

- Farine, D.R.; Sheldon, B.C. 2015. Selection for territory acquisition is modulated by social network structure in a wild songbird. *Journal of Evolutionary Biology* 2(8): 547–556. doi: 10.1111/ jeb.12587
- Gilĺ, B.J. 1980a. Breeding of the grey warbler with special reference to brood-parasitism by the shining cuckoo. Unpubl. PhD thesis, University of Canterbury, New Zealand.
- Gill, B.J. 1980b. Abundance, feeding, and morphology of passerine birds at Kowhai Bush, Kaikoura, New Zealand. *New Zealand Journal of Zoology* 7: 235–246. doi: 10.1080/03014223.1980.10423781
- Gill, B.J. 1982a. Breeding of the grey warbler Gerygone igata at Kaikoura, New Zealand. Ibis 124: 123–147. doi: 10.1111/j.1474-919X.1982. tb03752.x
- Gill, B.J. 1982b. The Grey Warbler's care of nestlings: a comparison between unparasitised broods and those comprising a Shining Bronze-Cuckoo. *Emu* 82: 177–181. doi: 10.1071/MU9820177
- Greenberg, R. 1990. Ecological plasticity, neophobia, and resource use in birds. *Studies in Avian Biology* 13: 431–437.
- Gustaffson, L. 1988. Foraging behaviour of individual coal tits, *Parus ater*, in relation to their age, sex and morphology. *Animal Behaviour 36*: 696–704. doi: 10.1016/S0003-3472(88)80152-0
- Herbert-Read, J.E. 2017. Social behaviour: the personalities of groups. *Current Biology* 27(18): PR1015-R1017. doi: 10.1016/j.cub.2017.07.042
- Holmes, R.T.; Robinson, S.K. 1988. Spatial patterns, foraging tactics, and diets of ground-foraging birds in a northern hardwoods forest. *Wilson Bulletin* 100: 377–394.
- Hejl, S.J.; Verner, J.; Bell, G.W. 1990. Sequential versus initial observations in studies of avian foraging. *Studies in Avian Biology* 13: 166–173.
- Lea, S.E.G.; Chow, P.K.Y.; Leaver, L.A.; McLaren, I.P.L. 2020. Behavioral flexibility: a review, a model, and some exploratory tests. *Learning and Behavior* 48: 173-187. doi: 10.3758/s13420-020-00421-w
- Lens, L. 1996. Wind stress affects foraging site competition between Crested Tits and Willow Tits. *Journal of Avian Biology* 27: 41–47.
- Lill, A. 1991. Behavioural energetics of overwintering in the rifleman, *Acanthisitta chloris. Australian Journal of Zoology* 39: 643–654. doi: 10.1071/ ZO9910643
- Maccarone, A.D. 1987. Effect of snow cover on starling activity and foraging patterns. *Wilson Bulletin* 99: 94–97.
- Martin, T.E.; Carr, J.R. 1990. Plasticity of foraging maneuvers of migratory warblers: multiple

selection periods for niches? *Studies in Avian Biology* 13: 353–359.

- McKean, L.M. 1990. Differences in the foraging behavior of individual gray-breasted jay flock members. *Studies in Avian Biology* 13: 284–287.
- McLean, I.G.; Rhodes, G.I. 1991. Enemy recognition in birds. pp. 173–211 In: Power, D.M. (ed.) Current Ornithology, vol. 8. New York, Plenum.
- MacNally, R. 1994. Habitat specific guild structure of forest birds in southeastern Australia: a regional scale perspective. *Journal of Animal Ecology* 63: 988–1001.
- Mansor, M.S.; Mohd Sah, S.A. 2012. Foraging patterns reveal niche separation in tropical insectivorous birds. *Acta Ornithologica* 47: 27–36. doi: 10.3161/000164512X653890
- Newell, F.J.; Beachy, T-A.; Rodewald, A.D.; Rengifo, C.G.; Ausprey, I.J.; Rodewald, P.G. 2014. Foraging behaviour of migrant warblers in mixed-species flocks in Venezuelan shade coffee: interspecific differences, tree species selection, and effects of drought. *Journal of Field Ornithology* 85: 135–151.
- Planas-Sitjà, I.; Deneubourg, J-L.; Gibon, C.; Sempo, G. 2015. Group personality during collective decision-making: a multi-level approach. *Proceedings of the Royal Society* 282: 20142515. doi: 10.1098/rspb.2014.2515
- Recher, H.; Gebski, V. 1990. Analysis of the foraging ecology of eucalypt forest birds: sequential versus single-point observations. *Studies in Avian Biology* 13: 174–180.
- Recher, H.; Major, J.D.; Ganesh, S. 1996. Seasonality of canopy invertebrate communities in eucalypt forests of eastern and western Australia. *Australian Journal of Ecology* 21: 64–80. doi: 10.1111/j.1442-9993.1996.tb00586.x
- Sherley, G.H. 1985. The breeding system of the South Island Rifleman (*Acanthasitta chloris*) at Kowhai Bush, Kaikoura, New Zealand. Unpubl. PhD thesis, University of Canterbury, New Zealand.
- Sherley. G.H. 1989. Benefits of courtship-feeding in Riflemen (*Acanthisitta chloris*). *Behaviour 109*: 303–318.

- Sherley, G.H. 1990a. Relative costs and benefits of co-operative breeding to Riflemen (*Acanthisitta chloris*) parents. *Behaviour* 112: 1–22.
- Sherley, G.H. 1990b. Relative parental effort during incubation in riflemen (*Acanthisitta chloris*). *New Zealand Journal of Zoology* 17: 289–294.
- Snijders, L.; van Rooij, E. P.; Burt, J. M.; Hinde, C. A.; van Oers, K.; Naguib, M. 2014. Social networking in territorial great tits: slow explorers have the least central social network positions. *Animal Behaviour* 98: 95–102. doi: 10.1016/j.anbehav.2014.09.029
- Somasundaram, S.; Vijayan, L. 2008. Foraging behaviour and guild structure of birds in the montane wet temperate forest of the Palni Hills, South India. *Podoces* 3: 79–91.
- Tarbox, B.C.; Robinson, S.K.; Loiselle, B.; Flory, S.L. 2018. Flocking ecology and foraging behaviour of insectivorous birds inform management of Andean silvopastures for conservation. *The Condor* 120: 787–802. doi: 10.1650/ CONDOR-18-1.1
- Thorogood, R.; Kilner, R.M.; Rasmussen, J.L. 2017. Grey gerygone hosts are not egg rejectors, but shining bronze-cuckoos lay cryptic eggs. *The Auk* 134: 340-349. doi: 10.1642/AUK-16-128.1
- Virkkala, R. 2016. Long-term decline of southern boreal forest birds: consequence of habitat alteration or climate change? *Biodiversity Conservation* 25: 151-167. doi: 10.1007/s10531-015-1043-0
- Whelan, C.J. 1989. An experimental test of prey distribution learning in two paruline warblers. *The Condor 91*: 113–119.
- Whelan, C.J. 2001. Foliage structure influences foraging of insectivorous forest birds: an experimental study. *Ecology* 82: 219–231.
- Withers, S. 2013 [updated 2018]. Rifleman. In: Miskelly, C.M. (ed.) New Zealand Birds Online. <www.nzbirdsonline.org.nz> Accessed: 12 June 2020.
- Wolf, M.; Wessing, F.J. 2012. Animal personalities: consequences for ecology and evolution. *Trends in Ecology and Evolution* 27: 452–461. doi: 10.1016/j.tree.2012.05.001



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Breeding petrels of Breaksea and Dusky Sounds, Fiordland; responses to three decades of predator control

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Abstract: Twenty-four breeding colonies of three petrel species were found on 18 of 26 islands surveyed in Breaksea Sound/Te Puaitaha, Fiordland National Park, New Zealand, in November 2017 and December 2019. All vegetated islands within Breaksea Sound were surveyed, along with 20 islands in Dusky Sound/Tamatea that were not included in an initial survey in November 2016 (eight of these additional Dusky Sound islands had breeding petrels, including three with broad-billed prions *Pachyptila vittata*). Sooty shearwater (*Ardenna grisea*) was the most widespread and abundant species in Breaksea Sound, with an estimated 6,950 burrows on 14 islands, while broad-billed prions were breeding on seven islands (2,100 burrows estimated). We record the first evidence of mottled petrels (*Pterdroma inexpectata*) breeding in Breaksea Sound, which is now their northernmost breeding location. Burrow occupancy rates were not assessed for any of the species. Most of the islands in Breaksea Sound had previously been surveyed during 1974 to 1986, before Norway rats (*Rattus norvegicus*) were eradicated from Hāwea and Breaksea Islands, and stoats (*Mustela erminea*) controlled to near zero density on Resolution Island and adjacent islands (including the inner Gilbert Islands and Entry Island). Following pest mammal control or eradication, broad-billed prions have colonised at least four additional sites. Sooty shearwaters were found at five sites in Breaksea Sound where they had not been recorded in 1980–83, and at one site they had increased by more than 50-fold since rat eradication. When combined with data from the 2016 and 2017 surveys, more than 75,700 petrel burrows are estimated to be present in southern Fiordland.

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Key words: Breaksea Island; breeding; colony; Fiordland; petrel; predation; prion; rat; seabird; shearwater; stoat

INTRODUCTION

Breaksea Island/Te Au Moana (170 ha) and nearby Hāwea Island (9 ha) in outer Breaksea Sound/

Received 20 April 2020; accepted 12 May 2020 *Correspondence: colin.miskelly@tepapa.govt.nz Te Puaitaha, Fiordland, were among the first sites in New Zealand where rats were successfully eradicated, in 1988 and 1986 respectively (Taylor & Thomas 1989, 1993). The presence of Norway rats (*Rattus norvegicus*) on these two islands up until their eradication indicates that Breaksea and Hāwea Islands were among the few islands in Fiordland that were not reached by stoats (Mustela erminea) (Taylor & Tilley 1984). Stoats apparently extirpated Norway rats on 20,887 ha Resolution Island / Tau Moana and the numerous islands off its north coast (Fig. 1; and see Taylor 1978 and Miskelly et al. 2017a). Following control of stoats to almost zero density on Resolution Island since 2008 (Edge et al. 2011), all the islands in Breaksea Sound west of (and including) Entry Island are now effectively free of predatory mammals. Stoats were eradicated from Anchor Island in Dusky Sound in 2001 (Elliott et al. 2010; Edge et al. 2011), resulting in all the smaller islands surrounding Anchor Island being free of all introduced mammal species since then (Wildland Consultants & DOC 2016; Department of Conservation 2017).



Figure 1. Breaksea and Dusky Sounds, Fiordland, showing the locations of the more detailed maps that follow (A = Breaksea Sound, B = Anchor Island and surrounding islands), and petrel colony data for six islands lying outside these two core study areas. Symbol sizes denote colony size, with the large triangle showing a site with an estimated 3,000 broad-billed prion burrows and 60 sooty shearwater burrows, and the small triangle a site with an estimated 600 broad-billed prion burrows and at least one sooty shearwater burrow. Crosses show four islands visited with no evidence of breeding petrels being found.

Before these pioneering rat and stoat eradication efforts were initiated, ecological surveys were undertaken on most islands in Breaksea Sound, to determine the distribution of pest mammals and their impacts on native fauna. The surveys were undertaken between 1974 and 1986 by Fiordland National Park staff and scientists from Ecology Division, Department of Scientific and Industrial Research (DSIR), and were summarised in a series of unpublished reports (Morrison 1975, 1982, 1983, 1984; Thomas 1975; Taylor *et al.* 1986) and island survey forms held by the Te Anau Department of Conservation (DOC) office. Information on burrow-nesting petrels contained in the reports was summarised in Appendix 2 of Miskelly *et al.* (2017b). These reports provide an invaluable benchmark for assessing changes in the distribution and abundance of burrow-nesting petrels (and other fauna) since predatory mammals were eradicated.

Two species of burrow-nesting petrels were known to breed on islands in Breaksea Sound, with sooty shearwaters (Ardenna grisea) on at least seven islands, and broad-billed prions (Pachyptila vittata) on two islands and attempting to colonise a third (Taylor 2000; Jamieson et al. 2016; Miskelly et al. 2017b). In March 1986, Norway rats caused complete failure of sooty shearwater breeding attempts assessed on Breaksea and Hawea Islands, and they preved on broad-billed prions attempting to colonise Hāwea Island (Taylor & Thomas 1989; Taylor 2000). Stoats killed large numbers of adult prions at colonies they could reach (Bruce Thomas quoted in Taylor 2000). Our 2019 survey provided the first opportunity to assess how these seabird populations had responded to rat eradication, and to search for evidence of them expanding onto nearby islands where they have been protected from rat predation since 1986 or 1988, and stoat predation since 2008.

METHODS

A boat-based survey of islands in Breaksea Sound/ Te Puaitaha (45.59°S, 166.67°E), Fiordland National Park, south-west New Zealand, was undertaken between 9 and 12 December 2019, with a primary focus of locating petrel breeding colonies and estimating their size. The team then shifted to nearby Dusky Sound/Tamatea (45.77°S, 166.55°E) 12–14 December and surveyed islands that had not been included in a previous survey of 59 islands there in November 2016 (Miskelly et al. 2017b). Information from three additional islands in Dusky Sound, an islet off the outer coast of Resolution Island, and an islet just north of Breaksea Sound was collected on 25 and 26 November 2017, on the way back from a similar survey in Chalky Inlet/ Taiari and Preservation Inlet/Rakituma to the south (Miskelly et al. 2019a).

The timing of the three surveys was chosen to maximise the chance of locating the three petrel species known to breed in Fiordland (sooty shearwater, broad-billed prion, and mottled petrel *Pterodroma inexpectata*). Other petrel species that could potentially breed in Fiordland (including

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fairy prion *Pachyptila turtur*, common diving petrel *Pelecanoides urinatrix*, and grey-backed storm petrel *Garrodia nereis*) would also be attending breeding colonies at this time of year if present (Marchant & Higgins 1990; Miskelly *et al.* 2019a). For the 2019 survey, priority was given to islands where rats had been readicated or stoats controlled, and sites where breeding petrels had been reported previously.

Landings were made from a small inflatable dinghy, with 2–8 team members landing on each island for between 5 min and 5 h 10 min (mean =60 min; Appendix 1). Forty-nine islands (additional to the 2016 survey) were landed on and surveyed for the presence of burrow-nesting petrels. Few of the islands had individual names on available maps and charts (where most are named as clusters of islands), and so we created names/numbers for them, usually numbering islands in each cluster from west to east. A central latitude and longitude reference point for each island is provided in Appendix 1, along with the reference number for each island used by DOC, from a GIS database of 713 islands in Dusky and Breaksea Sounds created by Wildlands Consultants (see Wildland Consultants & DOC 2016).

Island areas were obtained from the DOC GIS database. Distance from the sea for each seabird breeding colony was estimated from Google Earth, as a straight-line distance from the nearest portion of a line between outer headlands at the fiord entrance. Where multiple colonies occurred on large islands, this measurement was estimated for the most seaward colony detected.

Information on predator control history, effort, and trapping results on islands in Dusky Sound was provided by Pete McMurtrie (DOC, Te Anau). There are currently 4,971 'DOC 150' stoat traps set in Breaksea and Dusky Sounds (3,571 on Resolution Island), which are checked 3 times per annum.

Petrel burrow entrances were searched for and counted on each island during walk-through surveys. The proportion of each island surveyed was estimated, with the estimated number of burrows on each island based on the actual count extrapolated to allow for areas not surveyed. Where we found burrows to be confined to a portion of the island, we estimated the proportion of the colony (rather than the entire island) that we surveyed. Only burrows that appeared to be in use were included in counts, and the limited time spent on each island meant that we were unable to obtain estimates of burrow occupancy (e.g. through use of a burrowscope; Parker & Rexer-Huber 2020). The exclusion of 'disused' burrows that were filled with leaf litter or covered with cobwebs may have meant that some active burrows were overlooked; however, none of the three petrel species recorded breeding on Fiordland islands are known to

deliberately conceal or block burrow entrances.

The petrel species present were identified by any of: adults or chicks extracted from burrows or seen on the colony surface or in collapsed burrows; vocalisations from birds inside burrows; corpses, feathers, or failed eggs on the colony surface; burrow location, and burrow entrance size. Any intact eggs were measured (length x maximum width; to the nearest 0.1 mm, using Vernier callipers) as a guide to species identification (cf. measurements in Marchant & Higgins 1990). The few mottled petrel burrows found were identified by their 'medium' size (about 10–12 cm wide), and white droppings at two of the three sites (prion droppings are typically stained pink by carotenoids and undigested carapaces from their crustacean diet).

Data on petrel breeding sites from 1974–1986 island survey reports held by the DOC Te Anau office are summarised where relevant in the tables and text.

Taxonomy and nomenclature follow Gill *et al.* (2010), apart from where we follow Heidrech *et al.* (1998) in referring sooty shearwater to the genus *Ardenna*.

RESULTS

Evidence of breeding petrels was found on 18 islands in or near Breaksea Sound, on one islet off the outer coast of Resolution Island, and on eight additional islands in Dusky Sound that were not included in the 2016 survey. These 27 breeding islands ranged in size from 0.1 to 153 ha, and were up to 16 km from the open sea (Tables 1–3, Figs 1–5).

Sooty shearwater (Ardenna grisea)

The sooty shearwater was the most widespread and abundant breeding petrel in both Breaksea Sound and Dusky Sound, with an estimated 6,950 burrows on 14 islands in Breaksea Sound and an additional 790 burrows at eight previously unsurveyed sites in Dusky Sound (Table 1). Burrows were found mainly under forest on ridges and spurs facing the sea, or close to sea level (but still under forest).

The largest colonies in Breaksea Sound were on Hāwea and Breaksea Islands (5,400 and 800 burrows estimated respectively), with more than 100 burrows estimated to be present on each of Entry Island and two of the inner Gilbert Islands. Sooty shearwaters had been recorded at all five of these sites between 1974 and 1986 (Table 1), but at that time their breeding success was close to zero in the presence of Norway rats on Hāwea and Breaksea Islands (G. Taylor, *pers. obs*, Apr 1986).

The largest sooty shearwater colonies were within 5 km of the entrance to Breaksea Sound, with a few isolated burrows up to 15 km from the open

sea (Table 1, Fig. 2). The five easternmost sites were new breeding locations, but only 1–4 burrows were found at each of these sites. 'North-west Resolution islet' was also a new breeding location, with 40 burrows estimated to be present (Table 1).

Within Dusky Sound, we did not find petrel burrows on any of the inner Many Islands (close to Luncheon Cove on the south coast of Anchor Island), but there were 200 and 500 sooty shearwater burrows estimated on two islets south of Passage Island (Table 1, Fig. 3). We did not find sooty shearwater burrows on three islets north-east of Passage Island [islets 6 to 8], where a few active burrows were found on each islet on 8 Nov 1986 (Kim Morrison, *pers. comm.* to CMM, 21 Jan 2020).



Figure 2. Distribution of known sooty shearwater colonies within Breaksea Sound (see Fig. 1 for broader location). Circle sizes denote colony size, with the very large circle showing the estimated 5,400 burrows on Hāwea Island, large circles 130–800 burrows, and medium circles 20–75 burrows estimated. Small circles denote sites with fewer than four burrows found. Crosses show islands visited with no evidence of sooty shearwaters being found.



Figure 3. Distribution of known sooty shearwater colonies on and around Anchor Island, Dusky Sound (see Fig. 1 for broader location). The two rectangles enclose sites surveyed in 2019, with the remaining sites surveyed in 2016 (see Fig. 4 in Miskelly *et al.* 2017b). Circle sizes denote colony size, with large circles showing colonies with 1,000–2,500 burrows, medium circles 10–400 burrows, and small circles 1–5 burrows estimated. Crosses show islands visited with no evidence of sooty shearwaters being found.

Broad-billed prion (Pachyptila vittata)

Broad-billed prions, or evidence of their presence, were found at seven sites in or near Breaksea Sound, on one islet off the outer coast of Resolution Island. and on three additional islets in Dusky Sound (Table 2, and Figs 1, 4 & 5). All 11 sites occupied by broad-billed prions in 2017 and 2019 had been surveyed during 1981–86, with prions recorded at seven of the sites (Table 2). The four new sites were all within 4.5 km of known breeding locations on Wairaki Island and 'Inner Gilbert 1', with the new colonies on the south-eastern point of Breaksea Island and the western end of 'Inner Gilbert 2' being only 200-600 m from known colonies. All the Breaksea Sound colonies were within 3.5 km of the open sea (Table 2, Fig. 4). Colonies were under shrubs (Veronica elliptica, Dracophyllum longifolium, or Olearia oporina), often under a dense ground cover of Asplenium obtusatum fern.

Broad-billed prions were listed as a breeding species on Hāwea Island (in the presence of Norway rats) by Taylor & Thomas (1989), but the evidence for their presence was a few pairs attempting to colonise 'The Hump' (an islet just off the south-west coast). We estimated 1,200 burrows to be present on Hāwea Island in December 2019, 33 years after rats were eradicated.

Broad-billed prion chicks were found on two small islets south-west of Passage Island, Dusky Sound, in December 1986 (Kim Morrison, *pers. comm.* to CMM, 15 Nov 2018). We confirmed their ongoing presence at both sites in December 2019, with corpses of fledglings found on both islets (Table 2, Fig. 5).

Mottled petrel (Pterodroma inexpectata)

We found active burrows believed to be of mottled petrels on three islands in Breaksea Sound, 4–16 km from the open sea (Table 3, Fig. 4). Burrows were under podocarp/southern rātā (*Metrosideros umbellata*) forest, close to the shore. We did not observe live birds, corpses, feathers or eggs at any of the sites, and so were unable to confirm the presence of mottled petrels.

At least four medium-sized burrows and the distinctive vermiculated ventral feathers of mottled petrels were found on 'Passage Islet 1' in Dusky Sound (Table 3, Fig. 5). This is the only site in Fiordland where three species of petrels have been found breeding sympatrically (and the first site in Fiordland where mottled petrels and broad-billed prions have been found together).



Figure 4. Distribution of broad-billed prion colonies (triangles) and mottled petrel colonies (circles) surveyed in Breaksea Sound in 2019 (see Fig. 1 for broader location). For broad-billed prion, triangle sizes denote colony size, with the large triangle showing the estimated 1,200 burrows on Hāwea Island, medium triangles showing colonies with 90–700 burrows, and small triangles 10–50 burrows estimated. The three mottled petrel sites each had 5–25 burrows estimated. Crosses show islands visited with no evidence of either species being found.



Figure 5. Distribution of broad-billed prion colonies (triangles) and mottled petrel colonies (circles) on and around Anchor Island, Dusky Sound (see Fig. 1 for broader location). The two rectangles enclose sites surveyed in 2019, with the remaining sites surveyed in 2016 (see Fig. 1 in Miskelly *et al.* 2017b). Symbol sizes denote estimated colony sizes. For broad-billed prions, large triangles show colonies with 160–400 burrows, and small triangles show two colonies both with 35 burrows estimated. For mottled petrels, large circles show colonies with 100–700 burrows, and the small circle a site with 10 burrows estimated. Crosses show islands visited with no evidence of either species being found.



Figure 6. Segregation of breeding colonies of three species of petrels on 176 islands in southern Fiordland (from Breaksea Sound south to Preservation Inlet) based on island size (log scale ha) and distance from the open sea. Red squares = sooty shearwater; green circles = broad-billed prion; blue triangles = mottled petrel; black crosses = islands surveyed without breeding petrels being found. Symbol sizes are proportional to colony size: large symbols = 1,000 to 9,000 burrows; medium symbols = 100 to 900 burrows; small symbols = 1 to 90 burrows. Solid symbols show petrel colonies surveyed in 2019 (these are superimposed on 2016 & 2017 data, as presented in Fig. 4 in Miskelly *et al.* 2019a).

See Appendix 1 for island locatic	ons and search	effort.						
Island name	Water body	ISLAND	Area (ha)	Distance from sea (km)	Evidence	Count	Estimate	1974–1986
Roof-top stack	Breaksea	669	0.3	0	not found	0	0	active burrows, Oct 1981
Breaksea I	Breaksea	J.	152.9	0.0	burrows, adult on egg	199	800	many burrows, Feb 1984
Hāwea I	Breaksea	13	8.2	2.1	burrows, adults on eggs	270	5,400	40–100 burrows, Apr 1986
NW Resolution islet	Breaksea	661	0.9	0.3	burrows, adult on egg	18	40	not recorded, Oct 1981
Inner Gilbert 1	Breaksea	666	0.6	3.2	burrows, 4 eggs, adult	$0.5/\mathrm{m}^2$	200	6 chicks banded, Apr 1986
Inner Gilbert 2	Breaksea	110	24.7	3.5	burrows, adult & eggs	129	250	burrows present, Dec 1974
Inner Gilbert 5	Breaksea	111	5.8	4.0	burrows, adult confirmed	9	25	a few burrows, Dec 1974
Inner Gilbert 7	Breaksea	112	4.6	4.5	burrows, fresh egg, adult calling	18	75	burrows present, Dec 1974
Inner Gilbert 7 SW islet	Breaksea	part112	0.1	4.5	burrow	1	1	no data
Entry Island	Breaksea	27	38.5	4.9	burrows, droppings	43	130	a few burrows, Mar 1979
Harbour Is (large)	Breaksea	102	48.2	11.5	burrows	ŝ	3+	not recorded, Feb 1983
Harbour Is (small)	Breaksea	103	7.8	11.9	burrow	1	$^{1+}$	not recorded, Sep 1985
John Islands (large)	Breaksea	100	45.1	12.9	burrows	4	20	not recorded, Feb 1983
John Islands (small)	Breaksea	101	10.6	15.1	burrows at east end	Э	Э	not recorded, Oct 1981
John Islet (west)	Breaksea	701	1.1	15.6	burrow	1	1^+	not recorded, Oct 1981
Five Finger Pen. stack	Outer coast	619	2.5	0	burrows, adult on egg	Э	60	not recorded, Dec 1986
Luncheon Cove pen., Anchor I	Dusky	21	1136.6	6.1	burrow, calls from 2 sites at night	1	4+	not recorded
Prove Island	Dusky	11	8.1	8.8	burrow	1	1^+	not recorded, Dec 1986
Passage Island	Dusky	71	16.4	9.5	burrows	10	20	not recorded, Sep 1985
Passage Islet 1	Dusky	323	0.2	8.3	burrows, dead fledgling, droppings	17	35	1 chick, 100+ burrows, Dec 1986
Passage Islet 2	Dusky	70	0.2	9.0	burrows; 2 corpses, feathers	35	35	1 chick, burrows, Dec 1986
Passage Islet 3	Dusky	69	0.7	9.2	burrows, egg, droppings, feathers	143	200	no data
Passage Islet 4	Dusky	68	0.8	9.1	burrows, warm egg, adult in burrow	248	500	no data
Passage Islet 6	Dusky	no no.	0.2	10.0	2 inactive burrows	0	0	a few burrows, Nov 1986
South Dusky stack	Dusky	253	0.6	3.6	burrow and skull	1	1^{+}	not recorded, Dec 1986

Table 1. Evidence for sooty shearwater presence on islands in Breaksea Sound in December 2019 and Dusky Sound in November 2017 and December 2019, with the estimated number of burrows on each island. ID ISLAND is the Department of Conservation Dusky + Breaksea Sound island database reference no. for each island.

Table 2 . Evidence for br estimated number of bu See Appendix 1 for islar	oad-billed prio urrows on each nd locations an	n presence on i island. ID ISL≜ d search effort.	slands in ND is th	ι Breaksea Soun ιe Department σ	d in December 2019 and Dusl of Conservation Dusky + Bree	ky Sound ir aksea Soun	ı Novemb d island d	er 2017 and December 2019, with the latabase reference no. for each island.
Island name	Water body	ID ISLAND	Area (ha)	Distance from sea (km)	Evidence	Count	Estimate	1974–1986
Roof-top stack	Breaksea	669	0.3	0	burrows, 2 chicks, falcon kill	16	25	not recorded Oct 1981
Breaksea Island	Breaksea	IJ	152.9	2.3	burrows, 5 with white feathers	50	50+	not recorded 1974–1986
Wairaki Island	Breaksea	12	2.2	1.7	burrows, 1 chick	4	20	c.50 burrows, Apr 1986
Hāwea Island	Breaksea	13	8.2	2.1	burrows, feathers, down, feather scale	60	1,200	4 adults banded, Apr 1986; 19 burrows in use, Dec 1986
NW Resolution islet	Breaksea	661	0.9	0.3	burrows, chick, falcon kill	45	06	not recorded Oct 1981
Inner Gilbert 1	Breaksea	666	6.0	3.2	burrows, 2 chicks	$0.5/{ m m}^2$	700	abundant, Apr 1986
Inner Gilbert 2	Breaksea	110	24.7	3.5	white feathers and down	10	10 +	not recorded 1974–1983
Five Finger Pen. stack	Outer coast	619	2.5	0	burrows, 4 chicks, falcon kill	151	3,000	1 chick, burrows common, Dec 1986
Passage Islet 1	Dusky	323	0.2	8.3	burrows, dead fledgling, droppings	17	35	1 chick, 100+ burrows, Dec 1986
Passage Islet 2	Dusky	70	0.2	9.0	burrows; 2 corpses, feathers	35	35	1 chick, burrows, Dec 1986
South Dusky stack	Dusky	253	0.6	3.6	burrows, chicks, skull	177	600	1 chick & 3 eggs, Dec 1986
Table 3. Evidence for n island. ID ISLAND is th search effort.	nottled petrel p e Department c	rresence on isla of Conservation	nds in B1 Dusky +	reaksea Sound . - Breaksea Soun	and Dusky Sound in Deceml d island database reference n	ber 2019, w 10. for each	ith the es island. See	timated number of burrows on each e Appendix 1 for island locations and
Island name	Water body	ID ISLAND	Area (ha)	Distance from sea (km)	Evidence	Count]	Estimate	1974–1986
Inner Gilbert 5	Breaksea	111	5.8	4.3	burrows, dropping	9	25	not recorded, Dec 1974
John Islet (north)	Breaksea	702	0.4	16.0	burrow, dropping	1	∧ Ю	not recorded, Oct 1981
John Islet (south)	Breaksea	700	0.2	16.0	burrows	2	8	not recorded, Oct 1981
Passage Islet 1	Dusky	323	0.2	8.5	burrows, feathers	4	10	not recorded, Dec 1986
Passage Islet 6	Dusky	no no.	0.2	10.0	old burrows	ю	0	not recorded, Dec 1986
Payet Passage islet	Dusky	420	1.5	0.2	not found	0	0	heard in burrows. May 1980

Breeding petrels of Breaksea Sound

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Table 4. Summary of known petrel colonies in coastal Fiordland. A = number of colonies by species and location; B = estimated number of burrows.

A. Islands/colonies	Sooty shearwater	Mottled petrel	Broad-billed prion	Total
Milford to Doubtful	9	0	1	10
Breaksea Sound	14	3	7	24
Outer Resolution	1	0	1	2
Dusky Sound	44	13	5	62
Chalky Inlet	14	3	8	25
Preservation Inlet	11	2	1	14
Total	84	21	22	127
B. Burrows				
Milford to Doubtful	unknown	0	unknown	unknown
Breaksea Sound	6,950	38	2,125	9,113
Outer Resolution	60	0	3,000	3,060
Dusky Sound	22,189	5,510	1,230	28,929
Chalky Inlet	14,979	290	9,700	24,969
Preservation Inlet	8,446	950	240	9,636
Total	52,624	6,788	16,295	75,707

Status and spatial segregation of petrel breeding colonies in southern Fiordland

The three surveys undertaken between 2016 and 2019 located 127 breeding colonies of three petrel species on 107 islands in southern Fiordland (data herein and in Miskelly *et al.* 2017b & 2019a). The most abundant and widespread species was sooty shearwater, with more than 52,000 burrows estimated, on 84 islands (Table 4). There were an estimated 16,300 broad-billed prion burrows on 22 islands, and *c.* 6,800 mottled petrel burrows on 21 islands (Table 4).

The sooty shearwater colonies surveyed in 2019 had similar physical characteristics to those found in 2016 and 2017, with the larger colonies found on medium to large islands (0.5 to 150 ha) and within 9 km of the open sea (Fig. 6). The mottled petrel colonies found in 2019 were all small in size (<30 burrows), and mainly fitted the pattern found previously, occurring on islands less than a hectare in size and more than 9 km from the open sea (Fig. 6).

Broad-billed prion colonies found in 2016 and 2017 were almost all on tiny islands (less than a hectare) and within 5 km of the open sea. Those found in 2019 included colonies on much larger islands (up to 150 ha) and on two islets that were more than 9 km from the open sea (Table 2, Fig. 6).

DISCUSSION

Regional significance of Breaksea Sound and Dusky Sound petrel colonies

Breaksea Sound holds about 19% of the known petrel colonies in Fiordland and about 12% of the known burrows (Table 4). Dusky Sound has far more islands than the other sounds; partly as a consequence, it holds about 49% of known Fiordland petrel colonies, and about 38% of the known burrows. When combined with islets off the outer coast of Resolution Island, the islands in the interlinked Breaksea and Dusky Sounds hold about 69% of the known petrel colonies in Fiordland, and about 54% of the known burrows (Table 4).

Dusky Sound is the stronghold for mottled petrels within Fiordland, with more than 80% of the known burrows. In contrast, Chalky Inlet is currently the Fiordland stronghold for broadbilled prions (60% of known burrows), while sooty shearwaters are more evenly distributed throughout (Table 4).

National significance of Fiordland petrel colonies As recently as 2016, Fiordland was considered a region where almost nothing was known about breeding petrel numbers and distribution (Taylor 2000; Waugh *et al.* 2013; Jamieson *et al.* 2016; Wildland Consultants & Department of Conservation 2016). While estimates of burrow numbers are not yet available for at least ten Fiordland petrel colonies north of Breaksea Sound (Table 4), it is now apparent that Fiordland holds substantial populations of three petrel species (Miskelly *et al.* 2017b, 2019a, Table 4 herein). All three species have wider breeding distributions, including on islands around Stewart Island and at the Snares Islands/ Tini Heke (Waugh *et al.* 2013; Jamieson *et al.* 2016; Miskelly *et al.* 2019b).

It is not possible to convert our burrow counts and estimates into breeding population estimates as we did not attempt to estimate rates of burrow occupancy. However, the burrow estimates reported here provide an 'order of magnitude' guide to the importance of Fiordland for breeding petrels. Both sooty shearwater and mottled petrel have much larger populations south of Foveaux Strait. Several of the larger sooty shearwater colonies exceed the entire known Fiordland population: colonies on Whenua Hou/Codfish Island, Taukihepa/Big South Cape Island, Putauhinu Island, Poutama Island, and the Snares Islands all exceed 170,000 pairs or burrows (Lyver 2000; Newman et al. 2009; Waugh *et al.* 2013). Similarly, at least three more southern mottled petrel colonies (of 10,000–160,000 pairs each, on Whenua Hou/Codfish Island, Taukihepa/Big South Cape Island, and Snares Islands) all exceed the entire known Fiordland population (Warham et al. 1977; Scott et al. 2009; Miskelly et al. 2019b).

Broad-billed prion colony sizes on islands around Stewart Island/Rakiura remain poorly known (Taylor 2000; Jamieson et al. 2016), with the largest known New Zealand colony (340,000+ pairs) reported from Rangatira Island in the Chatham Islands (West & Nilsson 1994). Fiordland holds the next-largest reported colony (7,500 burrows estimated on an islet in Chalky Inlet; Miskelly et al. 2019a), but it is likely that other larger colonies are as yet unreported or under-estimated, either in Fiordland or around Stewart Island. An estimated 200,000 broad-billed prions were killed during a storm in July 2011, which apparently did not impact the Rangatira Island colony (Tennyson & Miskelly 2011; Jamieson et al. 2016). This implies that the birds that died were from colonies in Fiordland, around Stewart Island, and/or at the Snares Islands, and yet none of these colonies individually or collectively are known to be large enough to contribute more than a tiny proportion to mortality of this magnitude.

Although relatively small compared to the vast colonies found elsewhere, Fiordland petrel colonies have considerable historical, ecological, and conservation significance. Anchor Island in Dusky Sound is considered the type locality for the broadbilled prion, which was the first New Zealand bird

to be given a binomial name (as Procellaria vittata by Forster 1777; see Mathews & Hallstrom 1943 for restriction of the type locality). The four small broadbilled prion colonies surviving on islets around Anchor Island are remnants of the 'innumerable ... blue Petrils' (i.e. broad-billed prions) that Captain Cook and his naturalists encountered on Anchor Island and the adjacent Seal Islands in 1773 (Hoare 1982; Medway 2011). Prions and other petrels clearly bred in vast colonies in coastal Fiordland before the introduction of predatory mammals, and would have influenced the structure of vegetation communities through input of marine-sourced nutrients, burrowing activity, trampling, and the transportation of leaf litter and ground vegetation underground as nest lining (Warham 1990; Smith *et al.* 2011). The surviving colonies on small islands throughout Fiordland are therefore microcosms of this pre-human environment, where seabirds play an important role as ecosystem engineers (Smith *et* al. 2011; Ellis et al. 2011; Kolb et al. 2011), as well as being rare examples of sites where petrels continue to nest under tall podocarp forest. The remaining colonies should also provide source populations for the recolonisation of adjacent larger islands and the mainland if these sites can be cleared of predatory mammals (Wildland Consultants & DOC 2016; Department of Conservation 2017). An additional conservation and potential research benefit of sooty shearwater colonies on islands within Fiordland National Park is that, along with the Snares Islands and Whenua Hou/Codfish Island, they provide sanctuaries where the shearwaters are protected from the annual harvest of their young (as tītī/ muttonbirds) that occurs at most of their colonies around Stewart Island and in Foveaux Strait (Newman et al. 2009).

Response of petrels to rat and stoat eradications

The most notable finding of the 2019 survey was the discovery of broad-billed prions breeding at sites previously occupied by rats (Breaksea and Hāwea Islands), and at two sites formerly accessible to stoats, where prions had not been found in earlier surveys (Inner Gilbert 2, and islet 661). Prions were attempting to colonise Hawea Island in the presence of rats before 1986 (Taylor & Thomas 1989; G. Taylor, *pers. obs.*), and a substantial colony estimated at 1,200 burrows had established there 33 years after rat eradication. Hāwea Island is (since 1986) the most likely source for a broad-billed prion colony estimated at 50 pairs on the south-eastern headland of Breaksea Island, about 580 m away. This small colony was discovered 31 years after Norway rats were eradicated from Breaksea Island (Taylor & Thomas 1993). In contrast, the small colony on Wairaki Island (where rats and stoats

were never recorded) had declined from *c*. 50 to *c*. 20 burrows, probably due to crushing of burrows, and vegetation changes caused by a large increase in the local New Zealand fur seal (*Arctocephalus forsteri*) population.

Although more than 100 New Zealand islands have been cleared of rats (Towns et al. 2013; Russell & Broome 2016), there are relatively few documented examples of petrels naturally recolonising sites after rat eradication. Examples include: common diving petrels (*Pelecanoides urinatrix*) that recolonised Cuvier Island after Pacific rats/kiore (Rattus exulans) were eradicated in 1993 (Jones et al. 2011); white-chinned petrels (Procellaria aequinoctialis) and grev-backed storm petrels (Garrodia nereis) that recolonised Campbell Island within eight years of Norway rats being eradicated (Jones *et al.* 2011); black-winged petrels (Pterodroma nigripennis), Kermadec petrels (Pt. neglecta), and wedge-tailed shearwaters (Ardenna pacifica) that recolonised Raoul Island (Kermadec Islands) within six years of eradication of Norway and Pacific rats (Gaskin 2011; Jones et al. 2011), and sooty shearwaters, fluttering shearwaters (Puffinus gavia), little shearwaters (*Puffinus assimilis*), common diving petrels, and white-faced storm petrels (Pelagodroma marina) that recolonised Burgess Island, Mokohinau Islands within two decades of Pacific rats being eradicated (Ismar et al. 2014). Natural recolonisation by petrels is largely dependent on the proximity of the nearest potential source population (Jones *et al.* 2011; Buxton *et al.* 2014). In all these cases (including within Breaksea Sound) source populations existed on rat-free islets within 2 km of sites colonised by petrels after rat eradication.

We are unaware of previous examples of petrels recolonising islands cleared of stoats.

Rat eradication is also expected to lead to increased colony size (and reduced clustering) of remnant petrel colonies that survived the presence of rats (Jones 2010; Buxton et al. 2016). This was most apparent on Hāwea Island, where the 40–100 sooty shearwater burrows estimated in April 1986 (G. Taylor pers. obs.) had increased more than 50-fold to an estimated 5,400 burrows in 2019. Population modelling indicates that this large increase over the 33 years since rat eradication could potentially have occurred with minimal immigration, provided productivity and survival rates were close to the maximum recorded for petrel populations in the absence of predation (c. 50% of eggs producing breeding adults recruiting to their natal population, with 90% of pairs persisting between years; *authors' unpubl. data*). However, we suggest that immigration from other sites in Fiordland or nearby (Newman et al. 2009; Miskelly et al. 2017b, 2019a) is likely to have contributed to this rapid population increase.

Habitat use by broad-billed prions in Fiordland

The 2019 survey found broad-billed prions to be breeding on larger islands (Breaksea, Hāwea, and Inner Gilbert 2) and islands further from the sea (Passage islets 1 & 2) than where they were found on during the 2016 and 2017 surveys (Fig. 6). These findings are consistent with previous suggestions that the use of small stacks on the exposed outer coasts of Fiordland as breeding sites by broadbilled prions is an artefact caused by predation by introduced mammals (Norway rats and stoats) at more accessible sites (Miskelly *et al.* 2017b, 2019a). Once this predation pressure is removed, the prions are able to reclaim larger and more inland islands.

At all these sites, broad-billed prions were found breeding under low shrubby coastal vegetation (Veronica, Dracophyllum, Olearia), and have yet to spread into taller podocarp or broadleaved forest (including southern rātā, kāmahi Weinmannia racemosa, silver beech Lophozonia menziesii, pigeonwood Hedycarya arborea, patē Schefflera digitata, and kotukutuku Fuchsia excorticata) away from coastal headlands and slopes. Broad-billed prions breed under forest elsewhere in New Zealand, including on Rangatira Island, Chatham Islands (West & Nilsson 1994), and on at least three islands west of Stewart Island (Kundy Island, Rerewhakaupoko/Solomon Island, Whenua Hou/Codfish Island; C. Miskelly & G. Taylor, pers. obs.). James Cook (in Beaglehole 1961) and Reinhold Forster (in Hoare 1982) did not describe the vegetation where prion burrows were found on Anchor Island in 1773, but this is likely to have been under tall forest: 'When we came to the Creek which was on the NW side of Anchor Isle we found their an immence number of Blue Peterls [sic], some on the Wing, others in the Woods, in holes in the ground, under the roots of trees and in the creveses of rocks where they had desposited their young' (Cook in Beaglehole 1961: 120). Use of the term 'woods' implies that the prions were nesting under forest, and we expect that broad-billed prions will expand back into forest habitat in Breaksea and Dusky Sounds as the population continues to grow in response to ongoing pest mammal control.

CONCLUSIONS

There are numerous breeding colonies of three petrel species (sooty shearwater, broad-billed prion, and mottled petrel) on islands in Breaksea Sound and Dusky Sound, Fiordland. Broad-billed prions have recolonised two islands following eradication of Norway rats, and a further two islands following control of stoats to zero density. Sooty shearwaters have similarly colonised or recolonised five islands where stoats are no longer present or are unlikely to visit. The most dramatic response to predator eradication was on 9 ha Hāwea Island, where sooty shearwaters had increased more than 50-fold within

33 years of Norway rats being eradicated.

Broad-billed prions have started to recolonise larger islands, and islands further from exposed outer coasts following eradications of rats and stoats. However, the prions have yet to re-occupy the tall forest habitats where they were apparently breeding when Captain Cook visited Dusky Sound in 1773.

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LITERATURE CITED

- Beaglehole, J.C. (ed.). 1961. The journals of Captain James Cook on his voyages of discovery. II. The voyage of the Resolution and Adventure 1772– 1775. Hakluyt Society Extra Series No. XXXV. Cambridge, Cambridge University Press. 978 pp.
- Buxton, R.T.; Jones, C.J.; Moller, H.; Towns, D.R. 2014. Drivers of seabird population recovery on New Zealand islands after predator eradication. *Conservation Biology* 28: 333–344.
- Buxton, R.; Taylor, G.; Jones, C.; Lyver, P.O'B.; Moller, H; Cree, A.; Towns, D. 2016. Spatio-temporal changes in density and distribution of burrownesting seabird colonies after rat eradication. *New Zealand Journal of Ecology* 40: 88–99.
- Department of Conservation 2017. Conserving Fiordland's biodiversity 1987-2015; the challenges, the achievements, the knowledge. Ti Tiaki i te Taiao ki Tu Rua o te moko; ngā wero, ngā haumāuiui, ngā mātauranga. Te Anau, Department of Conservation. 128 pp.
- Edge, K.-A.; Crouchley, D.; McMurtrie, P.; Willans, M.J.; Byrom, A. 2011. Eradicating stoats (*Mustela erminea*) and red deer (*Cervus elaphus*) off islands in Fiordland. Pp. 166–171 *In*: Veitch, C.R.;

Clout, M.N.; Towns, D.R. (eds) Island invasives: eradication and management. Gland, Switzerland, IUCN.

- Elliott, G.; Willans, M.; Edmonds, H.; Crouchley, D. 2010. Stoat invasion, eradication and reinvasion of islands in Fiordland. *New Zealand Journal of Zoology* 37: 1–12.
- Ellis, J.C.; Bellingham, P.J.; Cameron, E.K.; Croll, D.A.; Kolb, G.S.; Kueffer, C.; Mittelhauser, G.H.; Schmidt, S.; Vidal, E.; Wait, D.A. 2011. Effects of seabirds on plant communities. Pp. 177–211 *In*: Mulder, C.P.H.; Anderson, W.B.; Towns, D.R.; Bellingham, P.J. (*eds*) Seabird islands: *ecology, invasion, and restoration*. Oxford, Oxford University Press.
- Forster, G. 1777. A voyage round the world: in His Britannic Majesty's sloop, Resolution, commanded by Capt. James Cook, during the years 1772, 3, 4, and 5 (2 vols). London, Benjamin White. 1,200 pp.
- Gaskin, C.P. 2011. Seabirds of the Kermadec region: their natural history and conservation. Science for Conservation 316. Wellington, Department of Conservation. 71 pp.
- Gill, B.J.; Bell, B.D.; Chambers, G.K.; Medway, D.G.; Palma, R.L.; Scofield, R.P.; Tennyson, A.J.D.; Worthy, T.H. 2010. *Checklist of the birds of New Zealand, Norfolk and Macquarie Islands, and the Ross Dependency, Antarctica.* 4th edn. Wellington, Te Papa Press in association with the Ornithological Society of New Zealand. 501 pp.
- Heidrich, P.; Amengual, J.; Wink, M. 1998. Phylogenetic relationships in Mediterranean and North Atlantic shearwaters (Aves: Procellariidae) based on nucleotide sequences of mtDNA. *Biochemical Systematics and Ecology* 26: 145–170.
- Hoare, M.E. (ed.) 1982. The Resolution journal of Johann Reinhold Forster 1772-1775. Vol. 2. London, Hakluyt Society. 370 pp.
- Ismar, S.M.H.; Baird, K.A.; Gaskin, C.P.; Taylor, G.A.; Tennyson, A.J.D.; Rayner, M.J.; Bettesworth, D.; Fitzgerald, N.; Landers, T.J.; Imber, M.J. 2014. A case of natural recovery after the removal of invasive predators – community assemblage changes in the avifauna of Burgess Island. *Notornis* 61: 188–195.
- Jamieson, S.E.; Tennyson, A.J.D.; Wilson, K.-J.; Crotty, E.; Miskelly, C.M.; Taylor, G.A.; Waugh, S.M. 2016. A review of the distribution and size of prion (*Pachyptila* spp.) colonies throughout New Zealand. *Tuhinga* 27: 56–80.
- Jones, H.P. 2010. Seabird islands take mere decades to recover following rat eradication. *Ecological Applications* 20: 2075–2080.
- Jones, H.P.; Towns, D.R.; Bodey, T.; Miskelly, C.; Ellis, J.C.; Rauzon, M.; Kress, S.; McKown, M. 2011. Recovery and restoration on seabird islands.

Pp. 317–357 in: Mulder, C.P.H.; Anderson, W.B.; Towns, D.R.; Bellingham, P.J. (*eds*) *Seabird islands: ecology, invasion, and restoration*. Oxford, Oxford University Press.

- Kolb, G.S.; Young, H.S.; Anderson, W.B. 2011. Effects of seabirds on island consumers. Pp. 212–241 In: Mulder, C.P.H.; Anderson, W.B.; Towns, D.R.; Bellingham, P.J. (eds) Seabird islands: ecology, invasion, and restoration. Oxford, Oxford University Press.
- Lyver, P.O'B. 2000. Sooty shearwater (*Puffinus griseus*) harvest intensity and selectivity on Poutama Island, New Zealand. *New Zealand Journal of Ecology* 24: 169–180.
- Marchant, S.; Higgins, P.J. (eds) 1990. Handbook of Australian, New Zealand and Antarctic birds. Ratites to petrels. Vol. 1, part A. Melbourne, Oxford University Press. 736 pp.
- Mathews, G.M.; Hallstrom, E.J.L. 1943. *Notes on the order Procellariiformes*. Canberra, Verity Hewitt Bookshop. 62 pp.
- Medway, D.G. 2011. The broad-billed prion (*Pachyptila vittata*) nesting colonies recorded during Cook's visit to Dusky Sound in 1773. *Notornis 58*: 165–168.
- Miskelly, C.M.; Bishop, C.R.; Taylor, G.A.; Tennyson, A.J.D. 2019a. Breeding petrels of Chalky and Preservation Inlets, southern Fiordland – a test of the 'refugia from resident stoats' hypothesis. *Notornis* 66: 74–90.
- Miskelly, C.M.; Gilad, D.; Taylor, G.A.; Tennyson, A.J.D.; Waugh, S.M. 2019b. A review of the distribution and size of gadfly petrel (*Pterodroma* spp.) colonies throughout New Zealand. *Tuhinga* 30: 99–177.
- Miskelly, C.M.; Tennyson, A.J.D.; Edmonds, H.K.; McMurtrie, P.G. 2017a. Dispersal of endemic passerines to islands in Dusky Sound, Fiordland, following translocations and predator control. *Notornis* 64: 192–205.
- Miskelly, C.M.; Tennyson, A.J.D.; Stahl, J.-C.; Smart, A.F.; Edmonds, H.K.; McMurtrie, P.G. 2017b. Breeding petrels of Dusky Sound, Fiordland – survivors from a century of stoat invasions. *Notornis* 64: 136–153.
- Morrison K. 1975. Report on visit to Breaksea Sound, December, 1974. Unpublished report, Fiordland National Park. 15 pp.
- Morrison K. 1982. Report on a visit to islands in Breaksea and Dusky Sounds, October 1981. Unpublished report, Fiordland National Park. 12 pp.
- Morrison K. 1983. Report on a visit to Breaksea & Dusky Sounds, February 1983. Unpublished report, Fiordland National Park. 20 pp.
- Morrison K. 1984. Report on a visit to Doubtful, Breaksea & Dusky Sounds, February 1984. Unpublished report, Fiordland National Park. 11 pp.

- Newman, J.; Scott, D.; Bragg, C.; McKechnie, S.; Moller, H.; Fletcher, D. 2009. Estimating regional population size and annual harvest intensity of the sooty shearwater in New Zealand. *New Zealand Journal of Zoology* 36: 307–323.
- Parker, G.C.; Rexer-Huber, K. 2020. Guidelines for designing burrowing petrel surveys to improve population estimate precision. Hobart, Agreement on the Conservation of Albatrosses and Petrels. <u>https://acap.aq/en/resources/ acap-conservation-guidelines/2830-guidelinesfor-designing-burrowing-petrel-surveys/file, 19 pp (viewed 12 May 2020).</u>
- Russell, J.C.; Broome, K.G. 2016. Fifty years of rodent eradications in New Zealand: another decade of advances. New Zealand Journal of Ecology 40: 197–204.
- Scott, D.; Moller, H.; Fletcher, D.; Newman, J.; Aryal, J.; Bragg, C.; Charleton, K. 2009. Predictive habitat modelling to estimate petrel breeding colony sizes: sooty shearwaters (*Puffinus griseus*) and mottled petrels (*Pterodroma inexpectata*) on Whenua Hou Island. *New Zealand Journal of Zoology* 36: 291–306.
- Smith, J.L.; Mulder, C.P.H.; Ellis, J.C. 2011. Seabirds as ecosystem engineers: nutrient inputs and physical disturbance. Pp. 27–55 *In*: Mulder, C.P.H.; Anderson, W.B.; Towns, D.R.; Bellingham, P.J. (*eds*) *Seabird islands: ecology, invasion, and restoration*. Oxford, Oxford University Press.
- Taylor, G.A. 2000. Action plan for seabird conservation in New Zealand. Part B: nonthreatened seabirds. *Threatened Species occasional publication* 17. Wellington, Department of Conservation. 200 pp.
- Taylor, R.H. 1978. Distribution and interactions of rodent species in New Zealand. pp. 135–141 In: Dingwall, P.R.; Atkinson, I.A.E.; Hay, C. (eds.) The ecology and control of rodents in New Zealand nature reserves. Wellington, Department of Lands & Survey.
- Taylor, R.H.; Thomas B.W. 1989. Eradication of Norway rats (*Rattus norvegicus*) from Hawea Island, Fiordland, using brodifacoum. *New Zealand Journal of Ecology* 12: 23–32.
- Taylor, R.H.; Thomas, B.W. 1993. Rats eradicated from rugged Breaksea Island (170 ha), Fiordland, New Zealand. *Biological Conservation* 65: 191–198.
- Taylor, R.H.; Thomas, B.W.; Taylor, G.A. 1986. Preliminary report on a rat eradication project at Breaksea Sound, Fiordland National Park. Unpublished report, Ecology Division, DSIR, Nelson. 15 pp.
- Taylor, R.H.; Tilley, J.A.V. 1984. Stoats (*Mustela erminea*) on Adele and Fisherman Islands, Abel Tasman National Park, and other offshore

islands in New Zealand. New Zealand Journal of Ecology 7: 139–145.

- Thomas, B.W. 1975. Report on visit to Breaksea Island, the 'Seal Islands' and the Gilbert Islands, Fiordland, December, 1974. Unpublished report, Ecology Division, DSIR, Lower Hutt. 24 pp.
- Tennyson, A.J.D.; Miskelly, C.M. 2011. An unprecedented prion wreck. *Southern Bird* 47: 11.
- Towns, D.R.; West, C.J.; Broome, K.G. 2013. Purposes, outcomes and challenges of eradicating invasive mammals from New Zealand islands: an historical perspective. *Wildlife Research* 40: 94–107.
- Warham, J. 1990. *The petrels: their ecology and breeding systems*. London, Academic Press. 440 pp.

- Warham, J.; Keeley, B.R.; Wilson, G.J. 1977. Breeding of the mottled petrel. *Auk* 94: 1–17.
- Waugh, S.M.; Tennyson, A.J.D.; Taylor, G.A.; Wilson, K.-J. 2013. Population sizes of shearwaters (*Puffinus* spp.) breeding in New Zealand, with recommendations for monitoring. *Tuhinga* 24: 159–204.
- West, J.A.; Nilsson, R.J. 1994. Habitat use and burrow densities of burrow-nesting seabirds on South East Island, Chatham Islands, New Zealand. *Notornis* (*supplement*) 41: 27–37.
- Wildland Consultants; Department of Conservation 2016. Tamatea/Dusky Sound conservation and restoration plan. Department of Conservation. 155 pp. <u>http://www.doc.govt.nz/Documents/ our-work/dusky-sound-restoration-plan.pdf</u>

APPENDIX 1. Island locations and search effort. ID ISLAND is the Department of Conservation (DOC) Dusky + Breaksea Sound island database reference no. for each island. Petrels' refers to whether evidence of petrels breeding was found (see Tables 1–3). 'Trap' refers to whether at least 1 stoat trap was maintained on the island by DOC at the time of our visit. Note that many islands receive protection by being adjacent to islands that are trapped. 'Duration' is the approximate length of time (hours:minutes) that observers were ashore.

Island name	Water body	ID ISLAND	Lat (S)	Long (E)	Petrel	Trap	Date O	bservers	Duration
Roof-top stack	Breaksea Sound	669	45.5567°	166.6666°	Yes	No	26 Nov 17 A	r & CM	0:25
Breaksea Island	Breaksea Sound	IJ	45.5775°	166.6380°	Yes	Yes	11 Dec 19 A7	I, CB, CM, GT, JR, PC, PL & TG	5:10
Wairaki Island	Breaksea Sound	12	45.5925°	166.6367°	Yes	No	10 Dec 19 A7	I, CB, CM, PC, PL & TG	1:15
Hāwea Island	Breaksea Sound	13	45.5910°	166.6441°	Yes	Yes	10 Dec 19 A7	I, CB, CM, GT, JR, PC, PL & TG	2:55
North-west Resolution islet	Breaksea Sound	661	45.6035°	166.6089°	Yes	No	25 Nov 17 A7	r & CM	0:15
North-west Resolution islet	Breaksea Sound	661	45.6035°	166.6089°	Yes	No	12 Dec 19 A7	I, CB, CM, GT, PC, PL & TG	0:55
Inner Gilbert 1	Breaksea Sound	666	45.6027°	166.6511°	Yes	No	11 Dec 19 CI	M, GT & PC	2:00
Inner Gilbert 2	Breaksea Sound	110	45.6009°	166.6592°	Yes	Yes	11 Dec 19 A7	I, CB, JR, PL & TG	2:30
Inner Gilbert 3	Breaksea Sound	665	45.6037°	166.6624°	No	No	11 Dec 19 CI	3, JR & TG	0:40
Inner Gilbert 4	Breaksea Sound	663	45.6047°	166.6626°	No	No	11 Dec 19 CI	3, JR & TG	0:35
Inner Gilbert 5	Breaksea Sound	111	45.5994°	166.6718°	Yes	Yes	12 Dec 19 CI	3, GT & TG	1:48
Inner Gilbert 6	Breaksea Sound	113	45.5965°	166.6757°	No	Yes	12 Dec 19 A7	I, CB, CM, GT, JR, PL & TG	2:35
Inner Gilbert 7	Breaksea Sound	112	45.5984°	166.6824°	Yes	No	12 Dec 19 A7	I, CM, JR & PL	1:05
Inner Gilbert 7 (SW islet)	Breaksea Sound	part 112	45.5994°	166.6805°	Yes	Yes	12 Dec 19 CI	M & PL	0:15
Inner Gilbert 8	Breaksea Sound	668	45.6004°	166.6807°	No	No	12 Dec 19 A	ſ & JR	0:20
Entry Island	Breaksea Sound	27	45.5959°	166.7025°	Yes	Yes	9 Dec 19 A	I, CB, CM, GT, JR, PC, PL & TG	2:40
Harbour Islands (large)	Breaksea Sound	102	45.5857°	166.7687°	Yes	No	9 Dec 19 A.	I, CB, CM, GT, JR, PC, PL & TG	1:20
Harbour Islands (small)	Breaksea Sound	103	45.5794°	166.7715°	Yes	No	9 Dec 19 A.	r & PL	0:19
John Islands (large)	Breaksea Sound	100	45.5711°	166.7904°	Yes	No	10 Dec 19 A	I, CB, CM, GT, JR, PC, PL & TG	1:10
John Islands (small)	Breaksea Sound	101	45.5665°	166.8073°	Yes	No	10 Dec 19 A	I, CB, CM, PC, PL & TG	1:42
John Islet (west)	Breaksea Sound	701	45.5629°	166.8162°	Yes	No	10 Dec 19 CI	ví & JR	0:50
John Islet (north)	Breaksea Sound	702	45.5622°	166.8172°	Yes	No	10 Dec 19 G	r & PC	0:44
John Islet (south)	Breaksea Sound	700	45.5633°	166.8174°	Yes	No	10 Dec 19 A	r & PL	0:40
islet in Second Cove	Breaksea Sound	704	45.5558°	166.8057°	No	No	10 Dec 19 CI	3 & TG	0:07
islet west of Third Cove	Breaksea Sound	710	45.5429°	166.8718°	No	No	10 Dec 19 G	I, JR & PC	0:15
large islet opposite Third Cove	Breaksea Sound	209	45.5390°	166.8848°	No	No	10 Dec 19 A	r & CM	0:45

Appendix 1. continued								
Island name	Water body	ID ISLAND	Lat (S)	Long (E) P	etrel Tra	p Date	e Observers	Duration
small islet opposite Third Cove	Breaksea Sound	708	45.5397°	166.8843° N	o No	10 Dec 19) CB & TG	0:10
Woodhen Cove islet	Outer coast	594	45.6346°	166.5588° N	o No	12 Dec 19) AT, CB & CM	0:10
Five Finger Peninsula stack	Outer coast	619	45.6233°	166.5438° Y	es No	25 Nov 15	7 AT, CB, CM, LR & RP	0:50
Inner Finger (Five Fingers)	Dusky Sound	361	45.7435°	166.4481° N	o No	25 Nov 15	7 CB & LM	0:25
Outer Finger (Five Fingers)	Dusky Sound	353	45.7447°	166.4991° N	lo No	25 Nov 15	7 AT & CM	0:35
South Dusky stack	Dusky Sound	253	45.8011°	166.4952° Y	es No	25 Nov 15	7 AT, CB & CM	0:35
Luncheon Cove pen., Anchor I	Dusky Sound	21	45.7657°	166.5231° Y	es Yes	14 Dec 19) AT, CB, CM, GT, PL & TG	0:35
Many Islands (largest)	Dusky Sound	93	45.7720°	166.5210° N	lo No	14 Dec 19) CB, CM, PC & TG	1:10
Many Islands (north-east)	Dusky Sound	98	45.7682°	166.5259° N	lo No	14 Dec 19) CB, JR & TG	0:07
Many Islands (west)	Dusky Sound	85	45.7726°	166.5125° N	lo No	14 Dec 19) AT & PL	0:30
Many Islands (south-west)	Dusky Sound	78	45.7742°	166.5118° N	lo No	14 Dec 19) GT & JR	0:42
Many Islands (south)	Dusky Sound	77	45.7750°	166.5199° N	lo No	14 Dec 19) AT & PL	0:45
Prove Island	Dusky Sound	11	45.7646°	166.5588° Y	es Yes	13 Dec 19) GT, PC & PL	1:10
Passage Island	Dusky Sound	71	45.7657°	166.5684° Y	es Yes	13 Dec 19) AT, CB, CM, JR & TG	2:37
Passage Islet 1	Dusky Sound	323	45.7683°	166.5539° Y	es No	13 Dec 19) CM, GT, PC & PL	0:50
Passage Islet 2	Dusky Sound	70	45.7676°	166.5628° Y	es No	13 Dec 19) AT, CB, JR & TG	0:35
Passage Islet 3	Dusky Sound	69	45.7687°	166.5655° Y	es No	13 Dec 19) AT, CB, JR & TG	0:45
Passage Islet 4	Dusky Sound	68	45.7699°	166.5642° Y	es No	13 Dec 19) CM, GT, PC & PL	0:27
Passage Islet 5	Dusky Sound	no no.	45.7684°	166.5671° N	lo No	13 Dec 19) AT, CB, JR & TG	0:07
Passage Islet 6	Dusky Sound	no no.	45.7655°	166.5743° N	lo No	13 Dec 19) GT, PC & PL	0:40
Passage Islet 7	Dusky Sound	72	45.7639°	166.5751° N	lo No	13 Dec 19) AT & CM	0:25
Passage Islet 7a	Dusky Sound	no no.	45.7645°	166.5753° N	lo No	13 Dec 19) AT & CM	0:05
Passage Islet 8	Dusky Sound	no no.	45.7636°	166.5756° N	lo No	13 Dec 19) AT & CM	0:20
Paget Passage islet	Dusky Sound	420	45.7455°	166.7882° N	lo Yes	12 Dec 19) AT, CB, CM & TG	0:50

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SHORT NOTE

Marine debris in the nests of tākapu (Australasian gannets, *Morus serrator*) in the inner Hauraki Gulf, New Zealand

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Marine debris, principally plastics, are a persistent pollutant in marine systems (Law 2017). The recovery of plastics from the digestive tracts of both coastal and pelagic seabirds or from around their nests has demonstrated that plastics are ubiquitous across all oceans (Wilcox *et al.* 2015; Jagielle *et al.* 2019) and has led to the use of these birds as indicators for the distribution and relative amount of marine plastic debris (Hartwig *et al.* 2007; Ryan *et al.* 2009; van Franeker *et al.* 2011; van Franeker & Law 2015; Acampora *et al.* 2016).

Seabirds are impacted by plastics through the consequences of ingestion and entanglement (e.g. Votier *et al.* 2011; Lavers *et al.* 2014; Ryan 2018). The likelihood of different types of impacts on species are related to their feeding behaviour (e.g. Provencher *et al.* 2014a). Gannets feed by a combination of plunge diving and underwater pursuit (Machovsky-Capuska *et al.* 2011). Although diving seabirds, including gannets, have been recorded with ingested plastics (Pierce *et al.* 2004; Provencher *et al.*

2010; Tavares *et al.* 2016) direct ingestion of mostly floating plastic debris is generally less likely than for surface feeding birds (Provencher *et al.* 2010, but see Tavares *et al.* 2016). However, several studies have noted that the incorporation of marine debris, particularly fibres, cord, or rope manufactured from plastics, occurs in the nests of both northern (*Morus bassanus*) and Australasian (tākapu, *Morus serrator*) gannets (Montevecchi 1991; Norman *et al.* 1995; Bond *et al.* 2012). Entanglement may occur around the mandible of gannets, when feeding or manipulating nesting material, or around the legs and feet on plastic that has been used in nest construction (Schrey & Vauk 1987; Votier *et al.* 2011; Rodriguez *et al.* 2013).

Our objective was to determine the extent and nature of plastic debris in the nests of Australasian gannets at Horuhoru Island in the inner Hauraki Gulf, New Zealand. This may provide an indication of the likely risk of entanglement and the prevalence of plastic, particularly fishing debris in the surrounding gulf (Montevecchi 1991; Bond *et al.* 2012; Provencher *et al.* 2014b). Gannets are coastal feeding seabirds that occur

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in warm or cool temperate waters characterised by seasonally productive waters that frequently support important fish populations, and hence may encounter debris arising from commercial or recreational fishing as well as terrestrial sources. Commercial fishing is focussed in the outer gulf, but does occur within the inner Hauraki Gulf and includes bottom longlining, set netting, and trawling (Whitehead *et al.* 2019). In addition, due to its proximity to the largest urban area in New Zealand, recreational boating and fishing effort in the gulf is high (Whitehead et al. 2019). This coupled with the semi-enclosed nature of the water body may result in plastic debris persisting in the area (Barnes et al. 2009; Whitehead et al. 2019). Gregory (1991) noted that beaches around the inner Hauraki Gulf had substantial amounts of plastic debris from land-based sources although only small amounts of debris from fishing activities. A review of the environmental state of the Hauraki Gulf did not specifically consider the issue of plastic debris in the system (Aguirre et al. 2016).

This study was conducted at Horuhoru (Gannet Rock) (36°43'S, 175°10'E), 1.5 km off the north east corner of Waiheke Island in the inner Hauraki Gulf, New Zealand. The gannet colony is located along the top of the main ridge of the islet and on the east-facing slopes of Horuhoru. The west-facing side of the rock falls off as a cliff and is not suitable for nesting. We conducted our nest checks on 12 January 2019 when the colony contained a total of 134 chicks. A count of occupied nests in November 2017 in the previous breeding season indicated a breeding population of approximately 1,000 pairs (Gaskin et al. 2019). This suggests that gannets had a poor breeding season, or that by the January count date a substantial number of chicks had fledged and departed from the island. While not necessarily mutually exclusive explanations, that most chicks on the rock were large and replacing the down with feathers or had completed this process is suggestive of departures of fledglings prior to counting. To minimise disturbance to remaining birds we examined nests at the lowest section of the colony on the east facing slope. In this part of the colony chicks had moved away from their nest sites to form small crèches. We examined all 57 nest pedestals in the area.

For each nest we recorded the number of plastic items that formed part of the nest. We did not distinguish between polypropylene, nylon, and polyester ropes or cords. These items were classified into braided plastic cord, plastic threads, knot clumps of plastic cord, and packaging straps. Tangles consisted of individual threads of plastic that had become twisted together into an inseparable bundle. Knots were short pieces of plastic cord that had been deliberately knotted. We measured the length of the plastic items and recorded their colour. In contrast to some other studies in which nests were probed for plastic waste (e.g. Montevecchi 1991; Norman *et al.* 1995; Bond *et al.* 2012), we only recorded details from plastic that was visible.

A total of 49 (86%) of the 57 nests examined contained plastic. Most of the items of plastic recovered (N = 125) consisted of braided cord or individual threads most likely derived from the cord (Fig. 1 & 2). Many of the plastic items were black (56%) with other darker colour items (black combination and blue) comprising another 29.6% (Fig. 3). The average length of plastic cord or threads was 21.6 ± 1.2 cm (\pm 1S.E.) (Fig. 4).



Figure 1. Plastic debris in Australasian gannet nest at Horuhoru, Hauraki Gulf. The nest bowl is about 25 cm.

The prevalence of plastic debris in nests at Horuhoru was substantially higher than the 28.4% of nests of the same species at three colonies in Victoria, Australia (Norman *et al.* 1995). It was also higher than the 46% averaged across 29 northern gannet colonies that contained marine debris, including plastics (O'Hanlon *et al.* 2019) although values at some colonies was substantially higher. For example, 97% of all nests examined across two Northern gannet colonies in Newfoundland,



Figure 2. Proportion (%) of different categories of marine debris recovered from 57 Australasian gannet nests at Horuhrou, Hauraki Gulf, New Zealand.



Figure 3. Proportion (%) of colours from marine debris (N = 125) recovered from Australasian gannets at Horuhoru, Hauraki Gulf, New Zealand.



Figure 4. Size frequency distribution of long axis of marine debris (N = 125) recovered from gannet nests at Horuhoru, Hauraki Gulf, New Zealand.

Canada in 1988 and 1989 (Montevecchi 1991) and 80% of nests in a Welsh colony in the western Atlantic (Votier *et al.* 2011) contained plastic debris. Our nests represented a group of neighbouring nests on the periphery of the colony, and so may not be representative of the whole colony. By not probing nests for debris, we may have underestimated plastic prevalence. In the Australian study, Norman *et al.* (1995) noted that in one of three colonies the central nests, presumed to be older established nests, contained more plastic items than more peripheral nests.

Australasian gannets build nests from a combination of guano deposited by birds over time and material, such as strands of seaweed, collected at sea by male birds (Matthews *et al.* 2008). Although individuals will pilfer seaweed from nearby nests or birds, most seaweed is likely collected from the surface of surrounding waters. The elongated nature of plastics items recovered from the nests of other Australasian gannets and other sulids is consistent with the described collection of nesting material, as suggested by other studies (e.g. Bond *et al.* 2012).

While some recycling of plastic by birds is likely to occur through pilfering within the colony, our data suggest that plastic marine debris is frequently encountered by gannets in the inner Gulf and more often than that of Australasian gannets in Victoria in the early 1990s. In the absence of historical data from Horuhoru it is unclear whether this reflects an increase in plastic debris over time across the species range and/or differences in the local conditions between the two sites. Partly consistent with the largely black and red marine debris collected by the tropical sulid Sula leucogastea (brown booby), recovered debris from Australasian gannets was dominated by dark colours. This may result from selection by gannets for elongated nesting materials similar in colour to the seaweeds although without data on relative abundance of different plastic debris in the surrounding water this conclusion is tentative. Despite its high prevalence in nests we noted no entanglement of gannets by plastic in January 2019. During three visits over three consecutive breeding seasons to the colonies at Horuhoru and Mahuki Island (in the outer gulf) we noted only a single case of entanglement involving a bundle of plastic threads wound around the lower bill of an adult gannet. Higher entanglement rates have been recorded for some populations of northern gannets. Votier *et al.* (2011) noted that nestlings were most at risk and that once entangled, mortality rate was high. However, the total numbers of birds affected remained relatively small and was considered to have little population level effect (Votier *et al.* 2011). At-sea surveys conducted in the non-breeding season have shown similarly, that immature

northern gannets are disproportionally impacted (Roderiguez *et al.* 2013) and that, exceptionally at one sampling location entanglement rate reached 20.2 % of the observed birds.

Much of the plastic encountered by Australasian gannets in the Hauraki Gulf is likely derived from discharged fishing gear, boat gear, or possibly mariculture operations that are located nearby (Kemper et al. 2003). In contrast to some studies on northern gannets (e.g. Bond et al. 2012) we did not recover pieces of plastic fishing nets from gannet nests at Horuhoru. The link between fishing intensity or activity and prevalence of fishing related debris in gannet nests has been demonstrated in several studies on northern gannets (Bond et al. 2012; O'Halon et al. 2019). O'Halon et al. (2019) noted colonies located in areas of high fishing effort had a greater proportion of nests with incorporated debris. Similarly, Bond et al. (2012) showed that the proportion of northern gannet nests with marine debris decreased following the closure of a gill net based fishery and the occurrence of debris in gannet nests was substantially higher at colonies closer to fishing areas compared to those located further away. A similar relationship between the occurrence of marine debris in bird nests and availability in the environment has been demonstrated for brown boobies (Sula leucogaster) in the tropical Atlantic Ocean off Brazil (Tavares et al. 2016). Consequently, we conclude the high prevalence of plastic at gannet nests at Horuhoru indicates these plastics are common in the surrounding waters although incorporation of plastic into nests may also be affected by the availability of seaweed as nesting material. While plastic debris was common in gannet nests at Horuhoru the number of discrete items per nest was low (125 items from 57 nests). Internet sourced images of gannets; identified using search terms that included gannet, nest, plastic, and marine debris; as well as estimates of the average amount of plastics (470 g) at some northern gannet colonies (Votier et al. 2011) suggest accumulation amounts were substantially greater at some of these northern gannet colonies with an increased risk of entanglement than at Horuhoru.

In summary, plastic marine debris commonly occurs in gannet nests at a colony in the inner Hauraki Gulf consistent with its collection as nesting material and its likely commonly availability in the surrounding water. At present levels the risk of plastic entanglement of gannets breeding at Horuhoru seems low compared to other northern gannet colonies. Future surveys should indicate whether prevalence and abundance of plastic marine debris in nests increases, along with the associated risks of entanglement, and by expanding to other colonies whether the inner Gulf waters are particularly polluted with plastic marine debris.

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LITERATURE CITED

- Acampora, H.; Lyashevska, O.; Van Franeker, J.A.; O'Connor, I. 2016. The use of beached bird surveys for marine plastic litter monitoring in Ireland. *Marine Environmental Research* 120: 122– 129.
- Aguirre, J.D.; Bollard-Breen, B.; Cameron, M.; Constantine, R.; Duffy, C.A.; Dunphy, B.; Hart, K.; Hewitt, J.E.; Jarvis, R.M.; Jeffs, A.; Kahui-McConnell, R.; Kawharu, M.; Liggins, L.; M. Lohrer, A.M.; Middleton, I.; Oldman, J.; Sewell, M.A.; Smith, A.N.H.; Thomas, D.B.; Tuckey, B.; Vaughan, M.; Wilson, R. 2016. Loved to pieces: Toward the sustainable management of the Waitematā Harbour and Hauraki Gulf. *Regional Studies in Marine Science* 8: 220–233.
- Barnes, D. K. A.; Galgani, F.; Thompson, R. C.; Barlaz, M. 2009. Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 364: 1985–1998.
- Bond, A.L.; Montevecchi, W.A.; Guse, N.; Regular, P.M.; Garthe, S.; Rail, J.F. 2012. Prevalence and composition of fishing gear debris in the nests of northern gannets (*Morus bassanus*) are related to fishing effort. *Marine Pollution Bulletin* 64: 907–911.
- Gaskin, C.; Frost, P.; Friesen, M. 2019. *Indirect effects* on seabirds in the northern North Island region. Final report on seabird colony and population assessments prepared by NNZST for the Conservation Services Programme, Department of Conservation. POP2017-06. 23pp.
- Gregory, M.R. 1991. The hazards of persistent marine pollution: drift plastics and conservation islands. *Journal of the Royal Society of New Zealand* 21: 83–100.
- Hartwig, E.; Clemens, T.; Heckroth, M. 2007. Plastic debris as nesting material in a kittiwake (*Rissa tridactyla*) colony at the Jammerbugt, Northwest Denmark. *Marine Pollution Bulletin* 54: 595–597.
- Jagiello, Z.; Dylewski, Ł.; Tobolka, M.; Aguirre, J.I. 2019. Life in a polluted world: a global review of anthropogenic materials in bird nests. *Environmental Pollution* 251: 717–722.
- Kemper, C. M.; Pemberton, D.; Cawthorn, M.; Heinrich, S.; Mann, J.; Würsig, B.; Shaughnessy, P.; Gales, R. 2003. Aquaculture and marine

mammals: co-existence or conflict? pp. 208– 228. *In*: Gales, N.; Hindell, M.; Kirkwood, R. (*eds*) *Marine Mammals: Fisheries, Tourism and Management Issues*. Victoria, CSIRO Publishing.

- Lavers, J.L.; Bond, A.L.; Hutton, I. 2014. Plastic ingestion by flesh-footed shearwaters (*Puffinus carneipes*): implications for fledgling body condition and the accumulation of plasticderived chemicals. *Environmental Pollution 187*: 124–129.
- Law, K.L. 2017. Plastics in the marine environment. Annual Review of Marine Science 9: 205–229.
- Matthews, J.L.; Ismar, S.M.; Hauber, M.E. 2008. Seaweed provisioning behaviour confers thermal benefit for nesting Australasian gannets (*Morus serrator*). *Behaviour 145*: 1823–1837.
- Machovsky-Capuska, G.E.; Vaughn, R.L.; Würsig, B.; Katzir, G.; Raubenheimer, D. 2011. Dive strategies and foraging effort in the Australasian gannet *Morus serrator* revealed by underwater videography. *Marine Ecology Progress Series* 442: 255–261.
- Montevecchi, W.A. 1991. Incidence and types of plastic in gannets' nests in the northwest Atlantic. *Canadian Journal of Zoology* 69: 295–297.
- Norman, F.I.; Menkhorst, P.W.; Hurley, V.G. 1995. Plastics in nests of Australasian gannets *Morus serrator* in Victoria, Australia. *Emu* 95: 129–133.
- O'Hanlon, N.J.; Bond, A.L.; Lavers, J.L.; Masden, E.A.; James, N.A. 2019. Monitoring nest incorporation of anthropogenic debris by northern gannets across their range. *Environmental Pollution* 255: 113152.
- Pierce, K.E.; Harris, R.J.; Larned, L.S.; Pokras, M.A. 2004. Obstruction and starvation associated with plastic ingestion in a northern gannet *Morus bassanus* and a greater shearwater *Puffinus* gravis. Marine Ornithology 32: 187–189.
- Provencher, J.F.; Gaston, A.J.; Mallory, M.L.; O'hara, P.D.; Gilchrist, H.G. 2010. Ingested plastic in a diving seabird, the thick-billed murre (*Uria lomvia*), in the eastern Canadian Arctic. *Marine Pollution Bulletin* 60: 1406–1411.
- Provencher, J.F.; Bond, A.L.; Hedd, A.; Montevecchi, W.A.; Muzaffar, S.B.; Courchesne, S.J.; Gilcrest, H.G.; Jamieson, S.E.; Merkel, F.R.; Falk, K; Durinck, J. 2014a. Prevalence of marine debris in marine birds from the North Atlantic. *Marine Pollution Bulletin 84*: 411–417.
- Provencher, J.F.; Bond, A.L.; Mallory, M.L. 2014b. Marine birds and plastic debris in Canada: a national synthesis and a way forward. *Environmental Reviews* 23: 1–13.
- Rodríguez, B.; Bécares, J.; Rodríguez, A.; Arcos, J.M. 2013. Incidence of entanglements with marine debris by northern gannets (*Morus bassanus*) in the non-breeding grounds. *Marine Pollution Bulletin* 75: 259–263.

- Ryan, P.G. 2018. Entanglement of birds in plastics and other synthetic materials. *Marine Pollution Bulletin* 135: 159–164.
- Ryan, P.G.; Moore, C.J.; van Franeker, J.A.; Moloney, C.L. 2009. Monitoring the abundance of plastic debris in the marine environment. *Philosophical Transactions of the Royal Society B: Biological Sciences* 364: 1999–2012.
- Schrey, E.; Vauk, G.J. 1987. Records of entangled gannets (*Sula bassana*) at Helgoland, German Bight. *Marine Pollution Bulletin*, 18: 350–352.
- Tavares, D.C.; da Costa, L.L.; Rangel, D.F.; de Moura, J.F.; Zalmon, I.R.; Siciliano, S. 2016. Nests of the brown booby (*Sula leucogaster*) as a potential indicator of tropical ocean pollution by marine debris. *Ecological Indicators* 70: 10–14.
- van Franeker, J.A.; Blaize, C.; Danielsen, J.; Fairclough, K.; Gollan, J.; Guse, N.; Hansen, P-L.; Heubeck, M.; Jensen, J-K.; Guillou, G.L., Olsen B.; Olsen, K-O.; Pedersen, J.; Stienen, E.W.M.; Turner, D.M. 2011. Monitoring plastic ingestion by the northern fulmar *Fulmarus glacialis* in the North Sea. *Environmental Pollution* 159: 2609–2615.

- van Franeker, J.A.; Law, K.L. 2015. Seabirds, gyres and global trends in plastic pollution. *Environmental Pollution* 203: 89–96.
- Votier, S.C.; Archibald, K.; Morgan, G.; Morgan, L. 2011. The use of plastic debris as nesting material by a colonial seabird and associated entanglement mortality. *Marine Pollution Bulletin* 62: 168–172.
- Wilcox, C.; Van Sebille, E.; Hardesty; B.D. 2015. Threat of plastic pollution to seabirds is global, pervasive, and increasing. *Proceedings of the National Academy of Sciences* 112: 11899–11904.
- Whitehead, E.A.; Adams, N.; Baird, K.A.; Bell, E.A.; Borrelle, S.B.; Dunphy, B.J.; Gaskin, C.P.; Landers, T.J.; Rayner, M.J.; Russell, J.C. 2019. *Threats to seabirds of northern Aotearoa New Zealand*. Auckland, New Zealand, Northern New Zealand Seabird Charitable Trust. 76pp.
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SHORT NOTE

First record of rose-crowned fruit-dove (*Ptilinopus regina*) from New Zealand

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A juvenile rose-crowned fruit-dove (*Ptilinopus regina*) was captured alive on the deck of FPSO *Raroa* in the South Taranaki Bight at about 2100 h on 22 August 2019. This is the first record of rose-crowned fruit-dove from New Zealand.

The *Raroa* is a petroleum processing and storage vessel that remains at anchor about 1.5 km from the Maari oilfield wellhead, at 39.972°S 173.300°E (*c.* 73 km south-west of Opunake and *c.* 69 km northeast of Farewell Spit). Conditions were cold when the lethargic bird was found, with strong westerly winds for the preceding 2 days (Gary Ingram *pers. comm.*, 22 Jan 2020). Oil-tankers periodically come alongside FPSO *Raroa* to take on processed fuel, but there were no off-takes in the 2 weeks before 22 August 2019 (Gary Ingram *pers. comm.*, 24 Jan 2020).

The bird was placed in a carton, and perked up once warm (Fig. 1). It was taken by helicopter to New Plymouth the following morning, where it was brought to the attention of Biosecurity New Zealand staff. After seeking advice on the identity of the bird, Biosecurity New Zealand decided that the bird presented an undue biosecurity risk to native wildlife, as it may have carried pests and/or diseases not present in New Zealand. The bird was put down, and subsequently forwarded to Te Papa, where it was preserved as specimen OR.030538 (Fig. 2).





Figure 1 (A & B). Juvenile rose-crowned fruit-dove on 23 August 2019, the day after it was found and caught on FPSO *Raroa* (Photographs: Biosecurity New Zealand).



Figure 2. Study skin OR.030538 (dorsal, lateral and ventral views) and spread right wing OR.030538/1 (dorsal and ventral views) of the juvenile rose-crowned fruit-dove caught in the South Taranaki Bight on 22 August 2019 (Photographs: Te Papa).

The following description is based on images of the bird in life, and from the specimen. Measurements of the New Zealand bird are compared with measurements of juvenile and immature rose-crowned fruit-doves from eastern Australia in Table 1. The bird is predominantly mid-green on the head and back, with thin yellow fringes to the scapulars and greater wing coverts. The primaries and secondaries are dark grey on the inner webs, merging into mid-green on the outer webs, with contrasting thin pale outer edges, and with whitish tips to the primaries. The rectrices are dark grey. A small pale-yellow vertical stripe just in front of the eye (well separated from the beak) and a very narrow pale yellow eye-ring (single row of tiny feathers) are the only markings on the otherwise uniformly grey-green head. The green extends onto the upper breast (with very narrow pale feather tips giving a slightly barred appearance) apart from a small, narrow grey chin patch. The lower breast and belly are mottled pale yellow and green (rather scruffy, with some paler feathers), with a mottled orange patch each side of the mid-line in front of the legs. The undertail coverts are lemon yellow, with the underside of the rectrices pale grey. The underwing is entirely pale grey, with little contrast between remiges and coverts. The eye was dark brown with a large black pupil. The beak was midgrey, darker at the tip, with paler grey cere (poorly developed). The legs and toes were mid-grey, with prominent grey scales accentuated by pale offwhite skin separating them. The claws were darker grey than the toes. The specimen has no evidence of missing feathers or the waxy sheaths of growing feathers. Nor are there signs of feather wear or fault bars, which could be indicators of captive-rearing or previous cage confinement (Petrak 1982; Wolf *et al.* 2003; Vriends & Erskine 2005).

Table 1. Measurements of the juvenile rose-crowned fruitdove captured in the South Taranaki Bight (OR.030538) compared with measurements of juvenile and first-year rose-crowned fruit-doves of the subspecies *regina* from eastern Australia (sourced from Higgins & Davies 1996). All measurements in millimetres.

	OR.030538		Eastern	Australia	
		Mean	SD	Range	Ν
Bill	13	13.0	1.2	10.6–14.9	13
Tarsus	19	21.9	1.1	20.2–23.7	15
Mid toe & claw	26	24.1	0.8	23.0–25.3	8
Wing	122	127.3	4.6	119–134	16
Tail	65	71.4	3.0	66–77	15

The orange feathering on the belly and the pale patch in front of the eye are diagnostic of rose-crowned fruit-dove when compared to other *Ptilinopus* fruit-dove species found in Australia and the south-west Pacific (Higgins & Davies 1996; del Hoyo *et al.* 1997; Watling 2001). The predominantly green plumage (combined with these diagnostic characters), without evidence of initiation of moult into first basic plumage, is typical of a juvenile rose-crowned fruit-dove less than 10 weeks old (Higgins & Davies 1996; moult from juvenile to adult plumage commences 43–70 days after hatching). The relatively short wing and tail (Table 1), together with fresh (unworn) fine pale margins to the remiges point to the bird being a recent fledgling that was still growing its main flight feathers.

Rose-crowned fruit-doves are found in rainforests of coastal eastern and northern Australia, and north-west into Indonesia as far north as Morotai in the North Maluku (Moluccas) Islands (Higgins & Davies 1996). The nominate subspecies occurs from islands in Torres Strait south to northern New South Wales, and is vagrant to Victoria and Tasmania (Higgins & Davies 1996). It is a seasonal migrant in southern parts of its range (from southern Queensland south), being more abundant in summer (Higgins & Davies 1996; Menkhorst et al. 2017). Breeding has been recorded from mid-August to February (Higgins & Davies 1996). As loss of juvenile plumage commences within 2-3 months of fledging, this again points to the Taranaki bird being a recent fledgling (and from an unusually early breeding event, as the bird presumable hatched from an egg laid in June or July).

Fruit-doves of the genus *Ptilinopus* are well known for their ability to colonise remote islands (Mayr & Diamond 2001). The genus contains about 55 species, spread from south-east Asia east as far as Henderson Island in the Pitcairn group, eastern tropical Pacific (Pratt *et al.* 1987; del Hoyo *et al.* 1997).

This is the first reported occasion where a new vagrant bird species to New Zealand has been intercepted at the border and killed due to biosecurity concerns. This situation arose partly due to misalignment of two different pieces of legislation. Since 1996, the Wildlife Act 1953 has covered waters out to the edge of the New Zealand exclusive economic zone (200 nautical miles = 370.4km from the coast; Miskelly 2016). In contrast, the Biosecurity Act covers only territorial seas (12 nautical miles = 22.2 km from the coast). As the bird was flown to shore by helicopter from a vessel anchored c. 73 km offshore, Biosecurity New Zealand staff treated it as an importation of a live bird, which is not covered by an existing Import Health Standard (Biosecurity New Zealand, pers. comm., 27 Aug 2019).

The case has close parallels with the first Nicobar pigeon (*Caloenas nicobarica*) to reach the Australian mainland. Soon after its discovery near the coast on the remote Dampier Peninsula (northern Western Australia), the bird was captured by indigenous Bardi Jawi rangers and held in guarantine "as part of biosecurity protocol" by the Western Australia Department of Agriculture (Australian Geographic 2017). Once it had been deemed clear of any pathogens, parasites, and potential weed seeds by the Australian Quarantine and Inspection Services, it was transferred to permanent captivity at the Adelaide Zoo (Davis & Watson 2018). Davis & Watson argued that extra-limital dispersal is an intrinsic aspect of the ecology and life history of many species, and that vagrancy (and establishment of new populations) may provide a buffer to the impacts of climate change. Ironically, they cite New Zealand's Wildlife Act 1953 as one of the few pieces of legislation globally that provides automatic protection to vagrant birds.

Although this is the first accepted record of rosecrowned fruit-dove from New Zealand, there is at least one previous record that may have been of this genus (UBR 2008/07; Scofield 2008). Bill Malpress and Paula Barrett reported a small "greenishfawn" dove at their property in Manchester Street, Christchurch, during 3-17 Feb 2008. When first seen, the bird was perched in a damson plum tree (*Prunus domestica* subsp. *insititia*) that was heavily laden with fruit. Although it was seen occasionally in flight, and more often heard, several times over the following fortnight, the information recorded was insufficient to determine the identity of the bird (Scofield 2008). Bill Malpress and Paula Barrett consider that their bird more closely resembled a female whistling fruit-dove (*Ptilinopus layardi*) from Kadavu, Fiji (Bill Malpress pers. comm., 29 Mar 2020).

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LITERATURE CITED

- Australian Geographic, 2017. Endangered dodo relative found in WA. 9 May 2017. http://www. australiangeographic.com.au/news/2017/05/ endangered-dodorelative-found-in-wa.
- Davis, R.A.; Watson, D.M. 2018. Vagrants as vanguards of range shifts in a dynamic world. *Biological Conservation* 224: 238–241.

- del Hoyo, J.; Elliott, A.; Sargatal, J. (*eds*) 1997. *Handbook of the birds of the world*. Vol. 4, sandgrouse to cuckoos. Barcelona, Lynx Edicions.
- Higgins, P.J.; Davies, S.J.J.F. (eds) 1996. Handbook of Australian, New Zealand and Antarctic birds. Vol. 3, snipe to pigeons. Melbourne, Oxford University Press.
- Mayr, E.; Diamond, J. 2001. *The birds of northern Melanesia: speciation, ecology & biogeography.* Oxford, Oxford University Press.
- Menkhorst, P.; Rogers, D.; Clarke, R.; Davies, J.; Marsack, P.; Franklin, K. 2017. *The Australian bird* guide. London, Bloomsbury, Christopher Helm.
- Miskelly, C.M. 2016. Legal protection of New Zealand's indigenous aquatic fauna – an historical review. *Tuhinga* 27: 81–115.
- Petrak, M.L. (ed.). *Diseases of cage and aviary birds*. Philadelphia, Lea and Febiger.
- Pratt, H.D.; Bruner, P.L.; Berrett, D.G. 1987. A field guide to the birds of Hawaii and the tropical Pacific.

Princeton, New Jersey, Princeton University Press.

- Scofield, R.P. 2008. Rare Birds Committee report for the two years to 31st July 2008. *Southern Bird* 36: 5.
- Vriends, M.M.; Erskine, T.E. 2005. *Pigeons; a complete pet owner's manual*. Hauppauge, Barron's Educational Series.
- Watling, D. 2001. A guide to the birds of Fiji and western Polynesia including American Samoa, Niue, Samoa, Tokelau, Tonga, Tuvalu and Wallis & Futuna. Suva, Fiji, Environmental Consultants.
- Wolf, P.; N. Rabehl, N.; Kamphues, J. 2003. Investigations on feathering, feather growth and potential influences of nutrient supply on feathers' regrowth in small pet birds (canaries, budgerigars and lovebirds). *Journal of Animal Physiology and Animal Nutrition 87*: 134–141.
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SHORT NOTE

Acoustic attraction system draws in competing seabird species

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Seabirds are among the most threatened taxa on the planet (Croxall et al. 2012,) and are affected by a wide variety of threats, including invasive predators, interspecific competition, accidental bycatch, light pollution, and climate change (Dias et al. 2019). Seabirds are of high conservation interest, not only because of the large number of threats they face, but also because seabirds are considered ecosystem engineers (i.e. they have a disproportionate impact on their surrounding environment; Orwin et al. 2016; Otero *et al.* 2018). As such, seabirds are prime targets for intensive conservation management translocations and including reintroductions (Armstrong & Seddon 2008; Seddon et al. 2014). Translocations of seabirds, however, are both labour and cost intensive, especially when highly philopatric species, such as Procellariiformes, are targeted (Miskelly & Taylor 2004; Miskelly et al. 2009). Acoustic attraction systems take advantage of the colonial and social nature of many seabirds by broadcasting acoustic cues to attract individuals

Received 21 April 2020; accepted 3 June 2020 *Corresponding author: *johannesfischer@live.nl* to localities of conservation interest (Podolsky & Kress 1992; Miskelly & Taylor 2004; Buxton & Jones 2012). The passive nature of these systems renders them cost-efficient and thus acoustic attraction systems have become a common tool to restore and conserve seabird populations (Jones & Kress 2012; Buxton *et al.* 2016; Friesen *et al.* 2017).

The Whenua Hou diving petrel (*Pelecanoides* whenuahouensis; WHDP) is a 'Critically Endangered' seabird species (BirdLife International 2020). The WHDP has recently been split from the South Georgian diving petrel (P. georgicus) and here we follow Fischer et al. (2018a) in treating the WHDP as a full species. The historic WHDP distribution included numerous colonies throughout southern Aotearoa (New Zealand) and the subantarctic islands (Worthy 1998; Taylor 2000; Wood & Briden 2008; Tennyson 2020). Today, the species is confined to a single remaining breeding colony in a narrow strip of foredunes <20 m from the springtide line on Whenua Hou (Codfish Island; Fig. 1; Fischer et al. 2018a, b). The current WHDP population size is estimated at 194-208 adults (Fischer et al. 2020). Due to its breeding habits (burrowing in fragile foredunes), the WHDP is highly vulnerable to stochastic events, such as storms and storm surges (Cole 2004), and the impending effects of climate change (e.g. increased coastal erosion; Vousdoukas *et al.* 2020). In addition, the WHDP suffers from competition for burrow sites with a congeneric species, the common diving petrel (*P. urinatrix*; CDP; Fischer *et al.* 2017). CDPs breed in low numbers (10–20 pairs) in the same dune system as the WHDP, and probably in higher numbers in other coastal areas throughout Whenua Hou (Taylor 2000; Fischer *et al.* 2017).

To attract WHDPs to burrow sites that are less at risk from storms and storm surges, a custommade acoustic attraction system in a back dune within the WHDP colony (18 m from the springtide line; Fig. 1) was installed in September 2018. The selected area contained few WHDPs burrows, but still appeared suitable (i.e. limited vegetation cover, low soil penetrability, and steep slopes; Fischer et al. 2018b). For the acoustic attraction, calls recorded in previous breeding seasons at six different WHDP burrows, including both solo and duet calls, were used (i.e. calls produced by both sexes were included). WHDP calls were edited together into a "mixtape" which was played on a loop with natural pauses (1 minute between calls, 15 minutes between repetitions of the "mixtape"). CDP and WHDP calls differ markedly and no CDP calls were used in the "mixtape" (Payne & Prince 1979; Fischer et al. 2018a). Based on WHDP activity at the breeding colony (Fischer et al. 2017), the acoustic attraction system was set to play WHDP calls from 2100 h to 0100 h. To further tempt WHDPs to settle in the vicinity of the acoustic attraction system, ten artificial "starter" burrows (30 cm deep) were installed. To assess the responses of both WHDPs and CDPs, the acoustic attraction system was played for four consecutive nights in each of three time periods during the WHDP courtship phase: 09–12 September 2018, 18–21 September 2018, and 03–06 October 2018. When the acoustic attraction system was operating, the surrounding area was surveyed twice per night, and all WHDPs and CDPs prospecting in its vicinity were caught and banded. Four contour feathers were sampled from flanks of all captured birds (Taylor et al. 2010) and used for genetic sex determination (using PCR primers specific to CHD-W gene; Norris-Caneda & Elliott 1998). In addition, two remote cameras and stick palisades at the entrances of the "starter" burrows were used to further monitor WHDP and CDP activity around the acoustic attraction system (Fischer *et al.* 2017). When the acoustic attraction system was not operating, the surrounding area was monitored, both actively and passively (i.e. with remote cameras), for 25 nights during the WHDP courtship period.



Figure 1. Location of acoustic attraction system (star) in relation to all known Whenua Hou diving petrel (black circles) and common diving petrel burrows (white circles) within the Sealers Bay dunes on Whenua Hou (Codfish Island).

The acoustic attraction system drew in considerably more CDPs than WHDPs. Two WHDPs and 19 CDPs were caught around the acoustic attraction system (Fig. 2). No WHDPs, but multiple CDPs, were recorded on the remote cameras. Of the captured individuals, female CDPs outnumbered male CDPs 9:1 (Table 1). No male WHDPs were caught around the acoustic attraction system. No WHDPs showed any interest in the "starter" burrows. At least two CDPs started digging in these "starter" burrows, but abandoned their efforts after the acoustic attraction system was turned off. When the acoustic attraction system was not broadcasting, no CDPs or WHDPs were detected in the surrounding area.



Figure 2. Number of Whenua Hou diving petrels (black bars) and common diving petrels (white bars) caught at the acoustic attraction system, in relation to, 1) the time periods during which the acoustic attraction system was operational (grey), 2) number of active burrows in the colony (based on stick palisades; dashed line = no data) and, 3) Whenua Hou diving petrel phenology (dotted lines; mean arrival date = 13 September, mean lay date = 10 October).

Table 1. Number and sex of diving petrels (WHDP = Whenua Hou diving petrel, CDP = common diving petrel) captured while an acoustic attraction system was operating on Whenua Hou.

Time period	Species	Female	Male
09–12 September	WHDP	2	-
	CDP	7	2
18–21 September	WHDP	-	-
	CDP	2	-
03–06 October	WHDP	2	-
	CDP	9	-
Total	WHDP	2	-
	CDP	17	2

Despite the short operating time of the acoustic attraction system and the absence of CDP calls in the "WHDP mixtape", a comparatively large number of CDPs was attracted. The number of attracted CDPs may suggest that the CDP population on Whenua Hou, in contrast to the WHDP population, is recovering after the eradications of invasive predators (McClelland 2002; Fischer *et al.* 2020). The CDP population may now be expanding from past refugia (i.e. offshore stacks and inaccessible cliffs; Taylor 2000) resulting in a high number of prospecting birds. The disproportionate number of female CDPs attracted to WHDP calls is remarkable. Potentially, prospecting male CDPs dig the burrows and call from these, like other petrels (e.g. grey-faced petrels Pterodroma gouldi; Imber 1976). Prospecting female CDPs may search for calling males in flight and then mistake broadcasted WHDP calls for a potential partner. Alternatively, prospecting CDPs may simply be attracted to areas of higher petrel activity, potentially to reduce predation risk (Warham 1996). Some records of non-target species being attracted to social attraction system exist (e.g. fork-tailed storm petrels Oceanodroma furcata being attracted to Leach's storm petrel O. leucorhoa calls, and vice versa; Buxton & Jones 2012). However, to our knowledge, this constitutes the first record of a non-target species outnumbering a target species at an acoustic attraction site (Podolsky & Kress 1992; Miskelly & Taylor 2004; Sawyer & Fogle 2010; Jones & Kress 2012; Buxton et al. 2016; Friesen et al. 2017).

A wide range of seabird species have benefited from acoustic attraction systems (Podolsky & Kress 1992; Miskelly & Taylor 2004; Sawyer & Fogle 2010; Jones & Kress 2012; Friesen et al. 2017), but this tool may be less useful for the conservation of the WHDP. Any additional CDPs in the WHDP colony are undesirable because this species already competes with the WHDP for burrow sites (Fischer et al. 2017). Subsequently, no further attempts were made to attract WHDPs into the less erosion prone back dune. The attraction of CDPs to WHDP calls will create further challenges for future WHDP conservation. As the WHDP is under ongoing pressure from severe weather events (Cole 2004; Fischer et al. 2018b), translocation(s) may be a suitable conservation strategy. However, translocation efforts often also utilise acoustic attraction systems to maximise success (Miskelly & Taylor 2004; Miskelly et al. 2009). Given the abundance and wide distribution of CDPs in southern Aotearoa (Taylor 2000) and their comparatively high ability to disperse (Miskelly et al. 2004), prospecting CDPs may also be drawn to WHDP translocation sites if an acoustic attraction system is operating. Consequently, it may be of high conservation interest to identify the vocal cues in the WHDP repertoire that are less attractive to CDPs,
but still attractive to WHDPs (Friesen *et al.* 2017). Otherwise, future WHDP translocations may need to proceed without the aid of acoustic attraction systems, potentially lowering translocation success.

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LITERATURE CITED

- Armstrong, D.P.; Seddon, P.J. 2008. Directions in reintroduction biology. *Trends in Ecology and Evolution* 23: 20–25.
- BirdLife International. 2020. *IUCN Red List for Birds.* Species Factsheets. <u>www.birdlife.org</u> (accessed 10 April 2020).
- Buxton, R.T.; Jones, C.J.; Lyver, P.O.; Towns, D.R.; Borelle, S.B. 2016. Deciding when to lend a helping hand: a decision-making framework for seabird island restoration. *Biodiversity and Conservation* 25: 467–484.
- Buxton, R.T.; Jones, I.L. 2012. An experimental study of social attraction in two species of storm-petrel by acoustic and olfactory cues. *Condor* 114: 733– 743.
- Cole, R. 2004. Summary of South Georgian diving petrel field observations for 2003/04, Codfish Island/ Whenua Hou. Invercargill, Department of Conservation.
- Croxall, J.P.; Butchart, S.H.M.; Lascelles, B.; Stattersfield, A.J.; Sullivan, B.; Symes, A.; Taylor, P. 2012. Seabird conservation status, threats and priority actions: a global assessment. *Bird Conservation International* 22: 1–34.
- Dias, M.P.; Martin, R.; Pearmain, E.J.; Burfield, I.J.; Small, C.; Phillips, R.A.; Yates, O.; Lascelles, B.; Borboroglu, P.G.; Croxall, J.P. 2019. Threats to seabirds: a global assessment. *Biological Conservation*. doi: 10.1016/j.biocon.2019.06.033
- Fischer, J.H.; Debski, I.; Miskelly, C.M.; Tennyson, A.J.D.; Fromant, A.; Tessler, J.; Hiscock, J.A.; Cole, R.; Bost, C.-A.; Taylor, G.A.; Wittmer, H.U.

2018a. Analyses of phenotypic differentiations between South Georgian Diving Petrel (*Pelecanoides georgicus*) populations reveal an undescribed and highly-endangered species from New Zealand. *PLoS ONE 13(6)*: e0197766

- Fischer, J.H.; Debski, I.; Taylor, G.A.; Wittmer, H.U. 2017. Assessing the suitability of non-invasive methods to monitor interspecific interactions and breeding biology of the South Georgian diving petrel (*Pelecanoides georgicus*). *Notornis* 64: 13–20.
- Fischer, J.H.; Debski, I.; Taylor, G.A.; Wittmer, H.U. 2018b. Nest-site selection of South Georgia diving-petrels on Codfish Island (Whenua Hou), New Zealand: implications for conservation management. *Bird Conservation International 28*: 216–227.
- Fischer, J.H.; Taylor, G.A.; Cole, R.; Debski, I.; Armstrong, D.P.; Wittmer, H.U. 2020. Population growth estimates of a threatened seabird indicate necessity for additional management following invasive predator eradications. *Animal Conservation* 23: 94–103.
- Friesen, M.R.; Beggs, J.R.; Gaskett, A.C. 2017. Sensory-based conservation of seabirds: a review of management strategies and animal behaviours that facilitate success. *Biological Reviews* 92: 1769–1784.
- Imber, M.J. 1976. Breeding biology of the grey-faced petrel *Pterodroma macroptera gouldi*. *Ibis* 118: 51–64.
- Jones, H.P.; Kress, S.W. 2012. A review of the world's active seabird restoration projects. *Journal of Wildlife Management* 76: 2–9.
- McClelland, P.J. 2002. Eradication of Pacific rats (*Rattus exulans*) from Whenua Hou Nature Reserve (Codfish Island), Putauhinu and Rarotoka Islands, New Zealand. pp. 173–181 *In*: Veitch, C.R.; Clout, M.N. *Turning the tide: the eradication of invasive species*. Proceedings of the International Conference on Eradication of Island Invasives. Occasional Paper of the IUCN Species Survival Commission No. 27. Auckland, New Zealand, Hollands Printing Ltd.
- Miskelly, C.; Timlin, G.; Cotter, R. 2004. Common diving petrels (*Pelecanoides urinatrix*) recolonise Mana Island. *Notornis* 51: 245–246.
- Miskelly, C.M.; Taylor, G.A. 2004. Establishment of a colony of common diving petrels (*Pelecanoides urinatrix*) by chick transfers and acoustic attraction. *Emu* 104: 205–211.
- Miskelly, C.M.; Taylor, G.A.; Gummer, H.; Williams, R. 2009. Translocations of eight species of burrow-nesting seabirds (genera *Pterodroma*, *Pelecanoides*, *Pachyptila* and *Puffinus*: Family Procellariidae). *Biological Conservation* 142: 1965– 1980.
- Norris-Caneda, K.H.; Elliott, J.D. 1998. Sex identification in raptors using PCR. *Journal of Raptor Research* 32: 278–280.

- Orwin, K.H.; Wardle, D.A.; Towns, D.R.; John, M.G.; Bellingham, P.J.; Jones, C.; Fitzgerald, B.M.; Parrish, R.G.; Lyver, P.O. 2016. Burrowing seabird effects on invertebrate communities in soil and litter are dominated by ecosystem engineering rather than nutrient addition. *Oecologia 180*: 217–230.
- Otero, X.L.; de la Peña-Lastra, S.; Pérez-Alberti, A.; Ferreira, T.O.; Huerta-Diaz, M.A. 2018. Seabird colonies as important drivers in the nitrogen and phosphorus cycles. *Nature Communications* 9: 246.
- Payne, M.R.; Prince, P.A. 1979. Identification and breeding biology of the diving petrels *Pelecanoides georgicus* and *P. urinatrix* at South Georgia. *New Zealand Journal of Zoology* 6: 299– 318.
- Podolsky, R.; Kress, S.W. 1992. Attraction of the endangered dark-rumped petrel to recorded vocalizations in the Galápagos Islands. *Condor* 94: 448–453.
- Sawyer, S.L.; Fogle, S.R. 2010. Acoustic attraction of grey-faced petrels (*Pterodroma macroptera gouldi*) and fluttering shearwaters (*Puffinus gavia*) to Young Nick's Head, New Zealand. *Notornis* 57: 166–168.
- Seddon, P.J.; Griffiths, C.J.; Soorae, P.S.; Armstrong, D.P. 2014. Reversing defaunation: restoring species in a changing world. *Science* 345: 406–412.

- Taylor, G.A. 2000. *Action plan for seabird conservation in New Zealand*. Part B: Non-threatened seabirds. Wellington, Department of Conservation.
- Taylor, G.; Jakob-Hoff, R.; Hitchmough, R.; Gummer, H. 2010. Sampling avian blood and feathers, and reptilian tissue (Standard Operating Protocol). Wellington, Department of Conservation.
- Tennyson, A.J.D. 2020. Holocene bird bones found at the subantarctic Auckland Islands. *Notornis* 67: 269–294.
- Vousdoukas, M.I.; Ranasinghe, R.; Mentaschi, L.; Plomaritis, T.A.; Athanasiou, P.; Luijendijk, A.; Feyen, L. 2020. Sandy coastlines under threat of erosion. *Nature Climate Change* 10: 260–263.
- Warham, J. 1996. *The behaviour, population biology and physiology of the petrels*. London, Academic Press.
- Wood, J.R.; Briden, S. 2008. South Georgian diving petrel (*Pelecanoides georgicus*) bones from a Maori midden in Otago Peninsula, New Zealand. *Notornis* 55: 46–47.
- Worthy, T.H. 1998. Fossils indicate *Pelecanoides* georgicus had large colonies at Mason Bay, Stewart Island, New Zealand. *Notornis* 45: 229– 246.
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SHORT NOTE

Black petrel (*Procellaria parkinsoni*) congregations at sea off Perú during the Austral summer

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The black or Parkinson's petrel (Procellaria varkinsoni) is an endemic medium-sized procellariform breeding only on two islands in sub-tropical areas of northern New Zealand: Great Barrier Island (Aotea; 36°12'S, 175°25'E) with ~2,750 breeding pairs (Richard & Abrahams 2015) and Little Barrier Island (Te Hauturu-o-Toi; 36°12'S, $175^{\circ}05'E$) with ~600 breeding pairs (Bell *et al.* 2016). Their breeding cycle ends in June (ACAP 2009) and then the birds migrate to the Eastern Tropical Pacific (Pitman & Balance 1992; Bell et al. 2007). Black petrels have been recorded from California (USA) (Jehl 1974) to northern Chile (Cabezas *et al.* 2012). The areas of highest concentration of black petrels are distributed from southern Mexico (~15°N) to northern Perú (~5°S) and around the Galápagos Islands (~0°20'S) (Pitman & Balance 1992; Gaskin et al. 2016). Despite reports of black petrels off Perú, data on the specific geographical

positions are sparse (Pitman & Balance 1992; Spear et al. 2005; Spear & Ainley 2008). Individuals have been reported off Perú. In February 1983, during a strong El Niño event one was found dead on a beach near Lurin (12°16'S), ~15 km south of Lima (Pitman & Balance 1992). In December 1991 a bycatch individual was reported ~40 km offshore from Paita (05°00'S, 81°05'W) (Imber et al. 2003). More recently, in October 2018, two individuals were photographed off northern Perú, one 26 km offshore from Tumbes (03°33'S, 80°56'W) and one 20 km offshore from northern Piura (04°05'S, 81°18'W) (eBird 2020). There are 22 other sightings in eBird between 1998 and 2019 without photographs, between 03°30'S and 08°30'S, with the highest concentration of sightings between 03°S and 06°S. The majority (>86%) of the sightings were reported between 2016 and 2019. The distribution of black petrels in these areas reflects the quality of food availability in the Northern Humboldt Current System, one of the most productive habitats in the world.

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The Peruvian Marine Research Institute ran a pelagic research cruise from 2 February to 24 March 2020 completing 50 uniformly parallel survey tracks, each separated by 15 nautical miles (nm). The geographic sampling coverage was between the Ecuador (03°23'S) and Chile (18°20'S) boundaries, and from the coastline to 80 nm offshore. The sampling intensity allowed us to assess black petrel habitat use during a short time period, i.e. a snapshot of their distribution in the middle of the austral summer. The seabird sightings were carried out by two observers working simultaneously on the bridge, one on the port and one on the starboard sides of the vessel. Continuous strip-transects were conducted from dawn to dusk while underway with sightings stopped at oceanographic stations or during pelagic trawl operations systematically performed during the whole survey. Transects over the whole cruise were partitioned into sevenminute intervals (equivalent to one nautical mile) at a cruising speed of 10 knots. All bird species were recorded within a 90° quadrant. During these surveys, we counted black petrels in Peruvian waters and categorized the habitat birds where encountered. For each sighting we observed behaviour as follows: flying, resting on the water, feeding or scavenging, and associated species. Ship position and course, water depth (m), sea-surface temperature (°C), salinity (ppt), and wind speed (m/s) were also recorded. Zooplankton trawl tows using Hensen (n = 200) and Bongo nets (n = 20)were also carried out. Zooplankton and fishing operations were used to quantify biodiversity and to determine potential prey for top predators.

A total of 47 black petrels were recorded during our surveys (Fig. 1). Of these records, 96% occurred between 03°40'S and 06°40'S (Fig. 2). Two records were located further south at 10°44'S and 13°46'S. Most birds (94.7%) were recorded on the continental slope, with a mean depth of 2,073 m (Table 1). In contrast, few black petrels were recorded over the continental shelf, the Perú trench and the pelagic seabed (Table 1). Areas with the most black petrel records were characterized by two oceanographic processes: a southward intrusion of low salinity (<34.5 PSU, Practical Salinity Unit) Equatorial Superficial Waters (ESW) from Ecuador, reaching up to Paita (05°S) and a mix of ESW with Subtropical Superficial Waters (SSW) to 08°S. This area was also characterized by shelf-break fronts and upwelling fronts formed by the convergence of waters masses of different densities, providing mechanical energy that contributes to the trophic energy, concentrating zooplankton and promoting secondary production (Acha *et al.* 2015). These areas are frequently used by albatrosses and petrels that may travel thousands of kilometres to feed on zooplankton, fishes or squids which concentrate at these fronts (Nevitt 1999).



Figure 1. Distribution of black petrels (*Procellaria parkinsoni*) off northern Perú in February–March 2020. Two other sightings at 10°44'S and 13°45'S were excluded. Black lines represent the sighting transects. Continuous blue line represents the shelf break (200 m isobath).



Figure 2. Parkinson's petrels photographed at sea off Northern Perú during February 2020.

 Table 1. Habitat use of black petrels (Procellaria parkinsoni)

 recorded off Perú.

Habitat	Depth mean (m)	Depth ranges (m)	Number of birds (%)
Continental Shelf	72 (n = 3)	21–129	3 (2.7)
Continental Slope	2,073 (n = 41)	498–4,347	107 (94.7)
Perú Trench	4,889 (n = 2)	4,617–5,160	2 (1.8)
Pelagic Sea Bed	3,431 (n = 1)	-	1 (0.9)

The surveyed area was characterized by high concentrations of zooplankton bio-volumes (>10 ml/sample) and up to 100 ml/sample, mainly represented by copepods Centropages furcatus (a bio-indicator of ESW) and Acartia danae and Oncaea conifer (both bio-indicators of SSW). Possible prey sources were recorded in areas with high numbers of black petrel records. Specifically, several species of small cephalopods, including small bioluminescent squids (*Abraliopsis* sp.) and paper nautiluses (Argonauta nouryi) were caught in the trawls. Both species were recorded at higher abundances over the continental slope and the Perú trench from 04°S to 07°S. Another possible prey species that was recorded regularly (70% of the 220 trawls) was the Panama lightfish larvae (Vincinguerria *lucetia*). The area along the continental shelf break and continental slope (06–14°S) in northern Perú, where black petrels were also recorded during these surveys (Fig. 2), was characterized by concentrations of paralarvae of Argonauta and Abraliopsis (Orosco 2016). Squid larval distribution is presumed to be a proxy for the adult distribution in the same area, since paralarvae and adults were captured in shelf-break areas. Analyses of black petrel diet during the breeding season showed it was dominated by squid (particularly Ommastrephidae, Histioteuthidae, and Cranchidae) and supplemented by fish, tunicates, crustaceans, and cyclostomes (Imber 1976). These squid species are characterized by their bioluminescence and Imber (1976) inferred that black petrels obtain most of their food at night. Dive depth analysis over the 2013 and 2014 breeding seasons showed that over 90% of black petrel foraging occurred during the day (Bell 2016), which suggests that black petrels have multiple foraging strategies including in the day targeting fish or other prey species, in association with cetaceans or following fishing vessels, and at night targeting bioluminescent squid (Imber 1976; Pitman & Balance 1992; Bell 2016).

Seabird/cetacean assemblages where seabirds take live prey forced to the surface by dolphins were reported from the Eastern Pacific (Au & Pitman 1986;

Pitman & Balance 1992). Four such black petrel/ cetacean associations were recorded during our research surveys. All records were on the continental slope. Black petrels were recorded associating with 250-300 short-beaked common dolphin (Delphinus delphis; 04°50'S; ~40 km offshore Paita), two sperm whales (Physeter catodon; 04°56'S; 35 km offshore), and 75 short-beaked common dolphins (06°37'S; ~30 km southwest of Lobos de Tierra Island). The associations recorded in this study differed from those previously reported (Pitman & Balance 1992) where associations occurred with other species: the melon-headed whale (Peponocephalu electra) and the false killer whale (Pseudorca crassidens). Given the data suggesting multiple foraging strategies during the breeding season within New Zealand waters (Imber 1976; Bell 2016), it appears that black petrels may also utilize different feeding strategies in the eastern Pacific: diving at the surface to feed on live prey, composed mostly by small cephalopods and fish, and associating with cetaceans targeting prev forced to the surface and scavenging food remains.

We present new information showing that black petrels were recorded regularly on the continental slope, north of Perú during the peak of the austral summer (February/March). As most adult black petrel are nesting in New Zealand during this period, it is evident that part of the population at different age classes is spending their summers in northern Perú. These birds are likely to be affected by different levels of risk associated with human-induced factors including fisheries bycatch, pollution events and climate change compared to those birds that migrate to breed in New Zealand. Management measures such as the creation of a Marine Important Bird Area in the highly productive waters of Northern Perú and introducing mitigation measures to fisheries vessels could help protect this vulnerable New Zealand species whenever they are present in the region.

LITERATURE CITED

- ACAP. 2009. Species assessments: Black Petrel Procellaria parkinsoni. <u>http://www.acap.aq</u>. Accessed: 14 April 2020.
- Acha, E.M.; Piola, A.; Iribarne, O.; Mianzan, H. 2015. Ecological Processes at Marine Fronts: Oases in the Ocean. Heidelberg, New York, Dordrecht, London, Springer Cham. 66 pp.
- Au, D.W.K.; Pitman, R.L. 1986. Seabird interactions with dolphins and tuna in the eastern tropical Pacific. *Condor* 88: 304–317.
- Bell, E.A.; Mischler, C.P.; MacArthur, N.; Sim, J.L. 2016. Black petrel (*Procellaria parkinsoni*) population study on Hauturu-o-Toi/ Little Barrier Island, 2015/16. Report to the Conservation Services Programme, Department

of Conservation. Wellington, New Zealand. 22 pp. <u>https://www.doc.govt.nz/Documents/</u> <u>conservation/marine-and-coastal/marine-</u> <u>conservation-services/reports/pop2015-01-</u> <u>black-petrel-lbi-final.pdf</u> Accessed: 14 April 2020.

- Bell, E.A. 2016. Diving behaviour of black petrels (*Procellaria parkinsoni*) in New Zealand waters and its relevance to fisheries interaction. *Notornis* 63: 57–65.
- Bell, E.A.; Sim, J.L.; Scofield, R.P. 2007. Demographic parameters of the black petrels (*Procellaria parkinsoni*). DOC Research and Development Series 273. Wellington, Department of Conservation.
- Cabezas, L.A.; Ruiz, J.; Yates, O.; Bernal, M. 2012. The black petrel (*Procellaria parkinsoni*) in pelagic waters off northern Chile: a southern extension to the known distribution and interactions with the pelagic longline fishery. *New Zealand Journal of Marine and Freshwater Research* 46: 537–544.
- eBird. 2020. eBird: An online database of bird distribution and abundance [web application]. eBird, Cornell Lab of Ornithology, Ithaca, New York. Available: <u>https://ebird.org/peru/species/parpet1/PE</u> Accessed: 15 April 2020.
- Gaskin, C.P.; Harrison, P.; Baird, K.A.; Cunninghame, F.; Ismar, S.M.; Bell, E.A. 2016. An opportunistic sighting of a flock of Black Petrels (*Procellaria parkinsoni*) at the Galapagos Islands, Ecuador. *Notornis* 63: 54–56.
- Imber, M.J.; McFadden, I.; Bell, E.A.; Scofield, R.P. 2003. Post-fledging migration, age of first return and recruitment, and results of intercolony translocation of black petrels (*Procellaria parkinsoni*). Notornis 50: 183–190.
- Imber, M.J. 1976. Comparison of prey of the black Procellaria petrels of New Zealand. New Zealand

Journal of Marine and Freshwater Research 10: 119–130.

- Jehl, J.R. 1974. The nearshore avifauna of the Middle American west coast. *Auk* 91: 681–699.
- Nevitt, G. 1999. Olfactory foraging in Antarctic seabirds: a species-specific attraction to krill odours. *Marine Ecology Progress Series* 177: 235– 241.
- Orosco, X. 2016. Variabilidad espacio-temporal de paralarvas de cefalópodos en el mar peruano entre los años 2013 y 2014, Tesis Facultad de Ciencias Biológicas, Universidad Ricardo palma, 89 pp. http://biblioimarpe.imarpe.gob.pe/ handle/123456789/3029 Accessed: 15 April 2020.
- Pitman, R.L.; Ballance, L.T. 1992. Parkinson Petrel distribution and foraging ecology in the Eastern Pacific – aspects of an exclusive feeding relationship with dolphins. *Condor* 94: 825–835.
- Richard, Y.; Abraham, E.R. 2015. Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2012–13. New Zealand Aquatic Environment and Biodiversity Report 162. Wellington, New Zealand, Ministry for Primary Industries. 85 pp.
- Spear, L.B.; Ainley, D.G.; Webb, S.W. 2005. Distribution, abundance, habitat use and behaviour of three *Procellaria* petrels off South America. *Notornis* 52: 88–105.
- Spear, L.B.; Ainley, D.G. 2008. The seabird community of the Perú Current, 1980–1995, with comparisons to other eastern boundary currents. *Marine Ornithology* 36: 125–144.
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SHORT NOTE

Observation of a predation event on a black-bellied storm petrel (*Fregetta tropica*) by brown skuas (*Stercorarius antarcticus*) on Enderby Island

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The brown skua (*Stercorarius antarcticus*) is a versatile predator of marine ecosystems that feeds on a diversity of prey including seabirds, fish, small mammals, and marine invertebrates (Reinhardt *et al.* 2000). As adaptable hunters they employ a variety of feeding methods including aerial pursuit, terrestrial and cooperative hunting, fishing, scavenging, and kleptoparasitism (Schulz 2004; Carneiro *et al.* 2014).

The black-bellied storm petrel (*Fregetta tropica*) is a small pelagic seabird that forages widely at sea during daylight hours and only attends breeding sites on islands at night (Beck & Brown 1971; Higgins & Davies 1996). Black-bellied storm petrels are a recognised prey item of brown skuas and are susceptible to predation whilst flying near shore during the day and upon returning to breeding sites at night (Osborne 1985; Hahn & Quillfeldt 1998; Reinhardt 2000). Whilst not highly abundant, they are the most commonly observed storm petrel species in the Auckland Islands group of the New Zealand subantarctic but are rarely found breeding (French *et al.* 2020; Miskelly *et al.* 2020).

Remains of black-bellied storm petrels have been found in skua middens across the Auckland Islands group and brown skuas have been observed pursuing or capturing storm petrels close to shore on several occasions (French *et al.* 2020; Miskelly *et al.* 2020). Herein I report on a direct observation of a predation event of a black-bellied storm petrel by brown skuas.

On 10 January 2020 at 0930 h during small boat

operations off the New Zealand sea lion (Phocarctos hookeri) colony at Sandy Bay, Enderby Island (approximately 50°30'S, 166°17'E) in the Auckland Islands group, a black-bellied storm petrel was observed flying in an easterly direction. When it was approximately 150 m offshore a brown skua immediately began to pursue it from the beach. The skua quickly gained on the storm petrel with two more skuas flying close behind. After approximately another 30 seconds many more skuas arrived from the shore and began mobbing the storm petrel, forcing it repeatedly into the water. It was then seized by several skuas in the mob which now numbered twenty individuals. It was killed through repeated pecking whilst being driven into the water. When it was finally seized in the bill of one skua, it was instantly torn apart by several individuals who each swallowed their portions whole. The entire sequence of events took less than one minute.

The brown skua's mode of hunting small seabirds by pursuit and grounding has been described elsewhere for other prey species such as prions, diving petrels and other storm petrels (Sinclair 1980; Osborne 1985; Flood *et al.* 2015) including within the Auckland Islands (Miskelly & Symes 2020). Prey is normally plucked of their feathers before consumption by solitary skuas (Osborne 1985). However, in this instance of intense intraspecific competition between skua, it was not the case.

Prior to 1950, black-bellied storm petrels were thought to be absent from Enderby Island. During 1976–2018, they have occasionally been observed

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offshore or in skua middens (French *et al.* 2020). Only one burrow has been found (in 2018), with a bird incubating an egg under a Ross lily (*Bulbinella rossii*) (Miskelly *et al.* 2020). Black-bellied storm petrels are more common elsewhere in the Auckland Islands group including on Ewing, Rose, Adams, and Disappointment Islands. Breeding records remain sparse with only seven eggs found and no chicks, but this is also reflective of the difficulty of finding active nests and the lack of personnel on island during the hatching period (March to May) (Miskelly *et al.* 2020).

Predation by skuas and other birds of prey can have a substantial impact on established or establishing populations of colonial seabirds. Population declines of Leach's storm petrel (Oceanodroma leucorhoa) at St Kilda in the Outer Hebrides have been attributed to significant predation by great skua (Stercorarius skua), estimated at over 14,000 individuals annually in some years (Phillips et al. 1999). In Hawaii predation by barn owls (Tyto alba) is considered a key threatening process to seabird conservation (Raine et al. 2019). On Big Island off the New South Wales south coast re-colonisation of white-faced storm petrels (Pelagodroma marina) was significantly hampered by an individual barn owl which consumed more than sixty individuals from an establishing colony of less than five breeding pairs. It was assumed that the depredated birds were likely prospecting for burrows, and this highlights that excessive predation by even a single predator can impede colony establishment and subsequent population growth (N. Carlile *pers. comm.*).

It is possible that black-bellied storm petrel breeding could be impeded by the high density of brown skuas at the Enderby Island New Zealand sea lion colony. Skuas feed on carrion and dead sea lion pups and the presence of the colony could be subsidising large numbers of skuas in the area (Miskelly *et al.* 2020). Elsewhere in the Auckland Islands group skuas are not reported to occur at densities as found on Enderby Island (Miskelly *et al.* 2020). On Macquarie Island a similar pattern was observed historically with the increased availability of rabbit prey shown to be correlated with higher skua nesting density (Jones & Skira 1979; Skira 1984).

New Zealand sea lions have experienced a drastic population decline with pup production having decreased by 40% since 1998 (Robertson & Chilvers 2011; Childerhouse *et al.* 2018). Accordingly, the availability of food in the form of carrion has been reduced for skuas with a potential consequent need for skuas to find alternative food sources. A similar scenario has been highlighted for the ashy storm petrel (*Oceanodroma homochroao*), a species of conservation concern on South Farallon Island, California, where burrowing owls (*Athene*

cunicularia) stopover during migration to feed predominately on introduced house mice before moving on (Nur *et al.* 2019). Population numbers of mice drop with the onset of winter which coincides with the arrival of ashy storm petrels (Nur *et al.* 2019). Late arriving and lingering owls subsequently switch their diet to ashy storm petrels (Nur *et al.* 2019). Management concerns have been raised on the potential impact of increased predation of ashy storm petrels due to prey switching following planned mouse eradication (Nur *et al.* 2019).

The presence of skuas in the summer (which depart from mid-May) overlaps with the known breeding period of black-bellied storm petrels (late January to June) (Miskelly et al. 2020). However, other historic and current threatening processes such as habitat degradation by extirpated herbivores such as pigs, sheep, and cattle (Enderby Island) and the continued predation pressure of feral cats, pigs, and mice (Auckland Island) cannot be excluded as causal effects for low numbers of black-bellied storm petrels or lack of established breeding colonies (Torr 2002; Miskelly et al. 2020; Russell et al. 2020). Cat predation specifically has been implicated as the chief contributing factor to the extinction of the only known breeding colony of white-faced storm petrels on Auckland Island, not seen since the mid-1940s (Miskelly et al. 2020).

Given that storm petrels typically forage in open seas, coupled with the considerable threat of skua predation at this location, it remains unclear why the storm petrel would have been flying so close to shore. European storm petrel (*Hydrobates* sp.) have been observed feeding in highly productive waters close to shore along the Lisbon coast in Portugal (Poot 2008). Yet, the absence of other feeding seabird species in any significant numbers at the time of this observation do not support the notion that the black-bellied storm petrel was drawn in by a high concentration of food.

Hahn & Quillfeldt (1998) presented a case of differential predation between two storm petrel species by brown skua. They showed that skuas preved about 1.7 times more often on blackbellied storm petrel than on Wilson's storm petrel (Oceanites oceanicus) despite the latter being 4.4 times more abundant. This indicated a 7.4 times higher predation pressure upon black-bellied storm petrels. They postulated that their observations of predation success bias were due to differing flight styles. The unsteady and more manoeuvrable flight style of Wilson's storm petrel contrasts strongly to the straight-line flight of black-bellied storm petrels making Wilson's storm petrel more difficult to catch. Evidently, as witnessed in this observation, blackbellied storm petrels can be particularly vulnerable to predation by brown skuas during the day.

Many small seabirds are nocturnal to avoid predation; however, skuas are still able to target

them by hunting at night, particularly on moonlit evenings, by homing in on mating calls, and through directly excavating nesting burrows (Osborne 1985; Mougeot & Bretagnolle 2000; Votier *et al.* 2005). Whether the high density of brown skuas significantly impedes colonisation or breeding success by storm petrels on Enderby island post feral animal eradication remains the subject of further investigation.

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LITERATURE CITED

- Beck, J.R.; Brown, D.W. 1971. The breeding biology of the Black-bellied Storm Petrel *Fregetta tropica*. *Ibis* 113: 73–90.
- Carneiro, A.P.B.; Manica, A.; Phillips, R. 2014 Foraging behaviour and habitat use by brown skuas *Stercorarius lonnbergi* breeding at South Georgia. *Marine Biology* 161: 1755–1764.
- Childerhouse, S.; Burns, T.; Michael, S.; Godoy, D.; McNutt, L.; McCormack, C. 2018. Final report for CSP Project— New Zealand sea lion Auckland Island monitoring 2017–18. Wellington, New Zealand: Department of Conservation. 19 pp.
- Flood, R.L.; Danzenbaker, M.; Wilson, A.C.; Zufelt, K. 2015. Long-tailed Skua predation of Wilson's Storm-petrel. *British Birds* 108: 547.
- French, R.K., Miskelly, C.M., Muller, C.G., Russ, R.B., Taylor, G.A.; Tennyson, A.J. 2020. Birds of Enderby Island, Auckland Islands, New Zealand subantarctic. *Notornis* 67(1): 189–212.
- Hahn, S.; Quillfeldt, P. 1998. Different predational pressures on two Antarctic storm petrel species. *Reports on Polar Research 299*: 285–289.
- Higgins, P.J.; Davies, S.J.J.F. (eds) 1996. Handbook of Australian, New Zealand and Antarctic birds. Volume 3: Snipe to Pigeons. Melbourne, Oxford University Press. 1028 pp.
- Jones, J., Skira, I.J. 1979. Breeding distribution of the Great Skua at Macquarie Island in relation to numbers of rabbits. *Emu* 79: 19–23.
- Miskelly, C.M.; Elliott, G.P.; Parker, G.C.; Rexer-Huber, K.; Russ, R.B.; Taylor, R.H.; Tennyson, A.J.D.; Walker, K.J. 2020. Birds of the Auckland Islands, New Zealand subantarctic. *Notornis* 67: 59–151.
- Miskelly, C.M.; Symes, C. (eds) 2020. Lost Gold: Ornithology of the subantarctic Auckland Islands. Notornis 67(1): 1–436.
- Mougeot, F.; Bretagnolle, V. 2000. Predation as a cost of sexual communication in nocturnal seabirds:

an experimental approach using acoustic signals. *Animal Behaviour 60*: 647–656.

- Nur, N.; Bradley, R.W.; Salas, L.; Warzybok, P.; Jahncke, J. 2019. Evaluating population impacts of predation by owls on storm petrels in relation to proposed island mouse eradication. *Ecosphere 10*: e02878
- Osborne, B.C. 1985. Aspects of the breeding biology and feeding behaviour of the Brown Skua *Catharacta lonnbergi* on Bird Island, South Georgia. *British Antarctic Survey Bulletin* 66: 57–71.
- Phillips, R.A.; Thompson, D.R.; Hamer, K.C. 1999. The impact of great skua predation on seabird populations at St Kilda: a bioenergetics model. *Journal of Applied Ecology* 36: 218–232.
- Poot, M. 1998. Nocturnal and diurnal nearshore foraging of European Storm Petrels *Hydrobates sp.* along the Lisbon coast, Portugal. *Airo* 18: 13–21.
- Raine, A.F.; Vynne, M.; Driskill, S. 2019. The impact of an introduced avian predator, the Barn Owl *Tyto alba*, on Hawaiian seabirds. *Marine Ornithology* 47: 33–38.
- Reinardt, K.; Hahn, S.; Peter, H.-U.; Wemhoff, H. 2000. A review of the diets of southern hemisphere skuas. *Marine ornithology* 28: 7–19.
- Robertson, B.C.; Chilvers, B.C. 2011. The population decline of the New Zealand sea lion *Phocarctos hookeri*: A review of possible causes. *Mammal Review* 41: 253–275.
- Russell, J.C.; Horn, S.R.; Miskelly, C.M.; Sagar, R.L.; Taylor, R.H. 2020. Introduced land mammals and their impacts on the birds of the subantarctic Auckland Islands. *Notornis* 67: 247–268.
- Schulz, M. 2004. Co-operative hunting by subantarctic skuas (*Catharacta skua lönnbergi*) at Macquarie Island. *Notornis* 51: 167.
- Sinclair, J.C. 1980. Subantarctic skua *Catharacta antarctica* predation techniques on land and at sea. *Cormorant* 8: 3–6.
- Skira, J. 1984 Breeding distribution of the Brown Skua on Macquarie Island. *Emu* 84: 248–249.
- Torr, N. 2002. Eradication of rabbits and mice from subantarctic Enderby Island and Rose Islands. pp. 319–328 In: Veitch C.R.; Clout, M.N. (eds) Turning the tide: the eradication of invasive species. IUCN SSC Invasive Species Specialist Group. Gland, Switzerland and Cambridge, UK, IUCN.
- Votier, S.C.; Crane, J.E.; Bearhop, S.; de Leon, A.; McSorley, C.; Minguez, E.; Mitchell, I.P.; Parsons, M.; Phillips, R.A.; Furness, R.W. 2005. Nocturnal foraging by great skuas *Stercorarius skua*: implications for conservation of storm-petrel populations. *Journal of Ornithology* 147: 405–413.
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SHORT NOTE

Buller's mollymawk (*Thalassarche bulleri platei*) count at Rosemary Rock, Manawatāwhi (Three Kings Islands)

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On 21 February 2020 we landed on Rosemary Rock, Manawatāwhi (Three Kings Island's), to collect blood samples and measurements from breeding Buller's mollymawk Thalassarche bulleri. Buller's mollymawk, one of New Zealand's more numerous small albatrosses, has been described as two distinct subspecies (northern Buller's mollymawk, Thalassarche bulleri platei breeding on the Chatham Islands; and southern Buller's mollymawk, Thalassarche bulleri bulleri breeding on the Snares and Solander Islands (Gill et al. 2010). In 1983 a small population of Buller's mollymawk was discovered breeding on Rosemary Rock and has been assigned to T. b. platei (Wright 1984; McCallum et al. 1985). The purpose of our visit was to obtain genetic and morphological data to help clarify the taxonomic

Received 15 May 2020; accepted 30 May 2020 *Correspondence: mrayner@aucklandmuseum.com relationships between this colony and the species' larger populations approximately 1,500 km to the south east and south of Manawatāwhi.

During approximately four hours (1100 h – 1500 h) we made a thorough ground survey of Rosemary Rock for mollymawk nests, aided by the aerial survey results of Frost et al. (2018). We found four nests containing live mollymawk chicks which were estimated at between four and six weeks old (P. Sagar pers. comm.) (Fig. 1 A, B). Two other nests contained dead chicks, which we estimate had perished between three and six weeks previously. We found only one other intact pedestal nest that looked like it had been used in the same season and there was no other nesting sign (e.g. broken eggshell). We were able to capture three adult mollymawks and observed 13 adults either loafing on the rock or flying past. No adults were in attendance of any chick.



Figure 1. A. Positions of nesting Buller's mollymawk on the southern face of Rosemary Rock adapted from Frost *et al.* (2018). Yellow arrows show locations of apparent nesting birds on 23 November 2017: A is the location where Wright (1985) discovered the species nesting; B-D were single sites occupied by pairs of birds in 2017. Green and red arrows show nesting locations identified by Frost *et al.* (2018) that contained living and dead chicks respectively on 21 February 2020. (Photograph: Richard Robinson). B. Two Buller's mollymawk chicks on Rosemary rock estimated between four to six weeks old. Their position on the rock is shown by two green arrows closest to C in previous figure. (Photograph: Kevin Parker).

Our count of only four mollymawk chicks on Rosemary Rock was surprisingly low given that historic surveys suggest a greater chick output. The first complete count of the colony in January 1985 documented 18 adults and 13 occupied nests, eight with an egg or young chick (McCallum *et al.* 1985). From aerial photographs taken on 23 November 2017, Frost *et al.* (2018) counted 34 apparently active nests with incubating birds (although some birds may have been birds sitting on empty nests). They also reported a count of 11–14 chicks and six adults made from boat-based photographs taken by Ian Southey and Igor Debski in March 2014.

Compared with previous observations our count suggests a poor breeding season for Buller's mollymawk on Rosemary Rock in 2019/20. This

is supported by the presence of dead chicks. Atsea mortality, foraging conditions, and colony breeding habitat and weather are contributors to reduced breeding success in the shy mollymawk Thalassarche cauta (Alderman et al. 2010; Alderman 2012; Alderman et al. 2012; Thomson et al. 2015). There are no survivorship or foraging and chick provisioning data for adult mollymawks from Rosemary Rock. However, our observations at the colony suggest that a poor breeding outcome in 2020 could be related to the quality of breeding habitat and/or local weather. There is a limited amount of level nesting sites in the preferred areas on the steep southern side of the rock. These areas likely protect birds from extreme gales arising from summer-time subtropical weather systems and provide shade from the sun.

Our visit coincided with one of the worst droughts in Northland's history, with record low rainfall and temperature extremes. The rock was a near "lunar landscape" baked dry with little or no vegetation or low leafless shrubs in comparison with historic photographs (Wright 1984), albeit these were taken at an earlier stage of the season. In surface nesting seabirds, high colony temperatures can kill chicks, which have a poor ability to reduce rising body temperatures (Alderman et al. 2012). For example, in the shy mollymawk daily maximum temperatures over 23°C are strongly associated with reduced breeding success through increased chick death (Thomson et al. 2015). A review of meteorological data from the Cape Reinga weather station (approximately 60 km from Rosemary Rock) across January and February 2020 (up to the day of our visit) showed 26 days of maximum temperatures exceeding 23°C (CliFlo 2020). These temperature extremes may explain the observed low chick numbers and/or mortality in the 2019/2020 season. However, with few or no available data on interannual population size, adult survival and breeding success variability, further work is clearly required to ascertain the trajectory and threats to New Zealand's most northern albatross colony.

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LITERATURE CITED

- Alderman, R.; Gales, R.; Hobday, A.J.; Candy, S.G. 2010. Post-fledging survival and dispersal of shy albatross from three breeding colonies in Tasmania. *Marine Ecology Progress Series* 405: 271–285. doi: 10.3354/meps08590
- Alderman, R.L. 2012. The shy albatross (*Thalassarche cauta*): population trends, environmental and anthropogenic drivers, and the future for management and conservation. PhD dissertation. University of Tasmania.
- Alderman, R.L.; Gales, R.; Tuck, G.N.; Lebreton, J.D. 2012 Global population status of shy albatross and an assessment of colony-specific trends and drivers. *Wildlife Research* 38: 672–686.
- CliFlo 2020. NIWA's National Climate Database on the Web, http://cliflo.niwa.co.nz/ Accessed: 26 April 2020.
- Frost, P.G.H.; Fitzgerald, N.; Robinson, R.; Hamilton, O. 2018. Buller's mollymawk (*Thalassarche bulleri*) on Rosemary Rock, Three Kings Islands, New Zealand. *Notornis* 65: 164–167.

- Gill, B.J.; Bell, B.D.; Chambers, G.K.; Medway, D.G.; Palma, R.L.; Scofield, R.P.; Tennyson, A.J.D.; Worthy, T.H. 2010. Checklist of the Birds of New Zealand, Norfolk and Macquarie Islands, and the Ross Dependency, Antarctica. 4th edn. Wellington, Te Papa Press & Ornithological Society of New Zealand Inc.
- McCallum, J.; Brook, F.; Francis, M. 1985. Buller's mollymawks on Rosemary Rock, Three Kings Islands, in 1985. *Notornis* 32: 257–259.
- Thomson, R.B.; Alderman, R.L.; Tuck, G.N.; Hobday, A.J. 2015. Effects of Climate Change and Fisheries Bycatch on Shy Albatross (*Thalassarche cauta*) in Southern Australia. *PLOS ONE 10(6)*: e0127006. doi: 10.1371/journal.pone.0127006
- Wright, A.E. 1984. Buller's mollymawk breeding at the Three Kings Islands. *Notornis* 31: 203–207.
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SHORT NOTE

Eggs salvaged from an abandoned black-billed gull (*Larus bulleri*) colony on the Ashley/Rakahuri River, North Canterbury

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The black-billed gull (*Larus bulleri*) is an endemic species that is declining rapidly in numbers (McClellan 2008). It is currently classified as Endangered by BirdLife International (2018), and Nationally Critical by the New Zealand ranking scheme (Robertson *et al.* 2017). A large majority of the population breeds in dense colonies on braided gravel riverbeds, east of the main divide in the South Island (Robertson *et al.* 2007).

The braided river environment is highly dynamic, and colonies may show low site-fidelity between years (Beer 1966). They are also prone to desertion, particularly early in the nesting cycle, and it has been suggested that this is often because of an unstable food supply (Evans 1982). However, the species is susceptible to disturbance and vandalism, which can also result in desertion (McClellan 2008).

A colony of black-billed gulls was present in the Ashley/Rakahuri River about 250–500 m upstream of the Ashley road bridge for the three consecutive seasons 2011/12, 2012/13, 2013/14. In Sep–Oct 2014, the colony established 100 m downstream of the road bridge (43°16′53.6″S, 172°35′08.6″E), and about 400 m from its location the previous season. A count from photographs taken on 20 October 2014 showed that the colony contained at least 375 individuals. The colony was abandoned on or about 24 October, but the reasons for the desertion are not known.

I inspected the abandoned colony site on 05 November 2014. No gulls were present. There were about 140 nests in various stages of construction, and laying had begun before desertion. Whether eggs had been lost after the gulls deserted and before my inspection was unknown, but water had not been over the site. At the time of my inspection, three nests contained two eggs each (the usual clutch), and 23 nests contained one egg. The number of partly built nests, the high proportion of one-egg clutches, and the low proportion of nests with eggs all suggested that laying was at a very early stage when the colony was abandoned.

Of the 29 eggs, 21 were intact and were collected for the Canterbury Museum collection (Accession Number 2017.42.1). Measurements of the intact eggs (n = 21) were 50.5 mm ($sd \pm 2.35$, range 46.3– 55.3) x 36.9 mm (\pm 0.77, 35.5–38.7). Volumes were calculated using the method of Hoyt (1979), with K = 0.497 (the mean volume coefficient for three gull species given by Hoyt [1979]), and averaged 34.2 ml (\pm 2.68, range 30.2–40.4). Elongation (length/ width) averaged 1.37 (\pm 0.05, 1.28–1.50). Values for length and breadth are mostly within those given in Higgins & Davies (1996), but the Ashley sample contained three eggs that were longer than the maximum length of 52.8 mm quoted there.

Avian eggs can show considerable intraspecific variation in size. There may be environmental reasons for this (such as changes in food availability or temperature), but differences between individual females (in age, mass, size, or other characteristics) are also important (for a review, see Christians 2002).

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Visual inspection of the Ashley eggs suggested they were highly variable in size, shape, colouration, and patterning for a relatively small sample (Figure 1). As is usual (Preston 1969), there was greater variability in length (Coefficient of Variation = 4.7%) than in width (CV = 2.1%). The largest egg (by calculated volume) was 34% larger than the smallest. Shape (as measured by elongation) was particularly variable; although the average elongation (1.37) was typical, the range (1.28–1.50) was wider than that given by Preston (1969) for low and high values among 33 species or subspecies of gulls and terns (1.33–1.46).



Figure 1. Variability in size, shape, background colour and patterning of black-billed gull (*Larus bulleri*) eggs from an abandoned colony on the Ashley/Rakahuri River, October 2014. The scale bar represents 100 mm.

The fact that all the Ashley eggs were laid within a limited time in the same colony suggests that in this case the high level of variation in size and shape was probably due more to inherent differences between females than to environmental factors.

The black-fronted tern (*Chlidonias albostriatus*) is another endemic species that breeds in braided rivers; it is classified as Endangered (BirdLife International 2018) and Nationally Endangered (Robertson *et al.* 2017). The species often nests in association with black-billed gulls (Higgins & Davies 1996). At least four tern nests were located around the Ashley gull colony and were abandoned at the same time. On 05 November, three of these still contained their full clutches of two eggs, but no terns were present. All six eggs were intact

and were collected for Canterbury Museum (also Accession Number 2017.42.1); they measured 40.5 mm ($sd \pm 1.51$, range 38.0–42.1) x 28.3 mm (\pm 0.43, range 27.9–29.0). Calculated volumes averaged 16.4 ml (\pm 0.98, range 15.0–18.0), and elongation averaged 1.43 (\pm 0.05, range 1.36–1.47). The linear dimensions are similar to those given by Keedwell (2005), but the widths of all six Ashley eggs were below Keedwell's (2005) mean of 29.2 mm. The average calculated volume of the Ashley eggs (using the same K_v of 0.507 as Keedwell) was also lower than Keedwell's mean of 17.7 ml. As for the gull eggs, there was greater variability in length (CV = 3.7%) than in width (CV = 1.5%)

Abandoned colonies provide the opportunity to collect eggs of highly threatened species, when either the collection of live eggs or the disturbance associated with measuring them in an active colony would be illegal or unethical. In addition to increasing sample sizes in museum collections (and potentially increasing the geographic spread of samples), periodic collection of such samples may be useful to monitor long-term intraspecific changes in laying date or egg size, particularly in response to environmental change (e.g. Scharlemann 2001; Blight 2011).

LITERATURE CITED

- Beer, C.G. 1966. Adaptations to nesting habitat in the reproductive behaviour of the black-billed gull *Larus bulleri*. *Ibis* 108: 394–410.
- BirdLife International 2018. http://datazone. birdlife.org/species/search Accessed: 27 March 2018.
- Blight, L.K. 2011. Egg production in a coastal seabird, the Glaucous-Winged Gull (*Larus glaucescens*), declines during the last century. *PLoS ONE 6(7)*: e22027. doi: 10.1371/journal.pone.0022027
- Christians, J.K. 2002. Avian egg size: variation within species and inflexibility within individuals. *Biological Reviews* 77: 1–26.
- Evans, R.M. 1982. Colony desertion and reproductive synchrony of black-billed gulls *Larus bulleri. Ibis* 124: 491–501.
- Higgins, P.J.; Davies, S.J.J.F. (eds.) 1996. Handbook of Australian, New Zealand and Antarctic Birds. Vol. 3. Snipe to pigeons. Melbourne, Oxford University Press.
- Hoyt, D.F. 1979. Practical methods of estimating volume and fresh weight of bird eggs. *The Auk* 96: 73–77.
- Keedwell, R.J. 2005. Breeding biology of Blackfronted Terns (*Sterna albostriata*) and the effects of predation. *Emu* 105: 39–47.
- McClellan, R.K. 2008. The ecology and management of Southland's black-billed gulls. Unpubl. PhD thesis, University of Otago, Dunedin, New Zealand.

- Preston, F.W. 1969. Shapes of birds' eggs: extant North American families. *The Auk* 86: 246–264.
- Robertson, C.J.R.; Hyvönen, P.; Fraser, M.J.; Pickard, C.R. 2007. *Atlas of bird distribution in New Zealand* 1999–2004. Wellington, Ornithological Society of New Zealand.
- Robertson, H.A.; Baird, K.; Dowding, J.E.; Elliott, G.P.; Hitchmough, R.A.; Miskelly, C.M.; McArthur, N.; O'Donnell, C.F.J.; Sagar, P.M.; Scofield, R.P.; Taylor, G.A. 2017: Conservation

status of New Zealand birds, 2016. *New Zealand Threat Classification Series* 19. Wellington, Department of Conservation.

Scharlemann, J.P.W. 2001. Museum egg collections as stores of long-term phenological data. *International Journal of Biometeorology* 45: 208–211.

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