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NOTORNIS

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Editor: CRAIG T. SYMES

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- To encourage, organise and promote the study of birds and their habitat use particularly within the New Zealand region.
- To foster and support the wider knowledge and enjoyment of birds generally.
- To promote the recording and wide circulation of the results of bird studies and observations.
- To produce a journal and any other publication containing matters of ornithological interest.
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Towards the reestablishment of community equilibrium of native and non-native landbird species in response to pest control on islands in the Eastern Bay of Islands, New Zealand

C. JOHN RALPH* Moturoa Island, Private Bag, Paihia, New Zealand U.S. Forest Service, Redwood Sciences Laboratory, Arcata, California 95521, USA

CAROL P. RALPH 7000 Lanphere Road, Arcata, California 95521, USA

LINDA L. LONG U.S. Forest Service, Redwood Sciences Laboratory, Arcata, California 95521, USA

Abstract: Disequilibrium of bird communities, due to introduced pests and human-caused habitat changes, is a fundamental property to be understood in restoration of island biota. In this paper, we suggest that the reestablishment of native forests and food webs favour long-established and native species, and is less favourable to more recently introduced species. To test this hypothesis, we compared population trends of native and non-native birds on five islands in the Ipipiri Group in the north of New Zealand. We used over 900 station counts starting in 2008 when habitat recovery and pest (rat [*Rattus*], mouse [*Mus musculus*], and stoat [*Mustela erminea*]) removal began, as well as comparing to a set of earlier counts. In general, we found that detection rates of most long-established endemic native species significantly increased, while non-native species mostly decreased, suggesting population increases and decreases, respectively. Of the native species, six are relatively recent natural immigrants to New Zealand, and most of these declined or remained unchanged. We suggest that the increase in long-established natives is likely due to increased size and quality of native bush areas making habitat more favourable to these natives, as well as reduced predation and competition from the pest mammals.

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Keywords: bird, island, New Zealand, community equilibrium, introduced species, pest eradication, restoration, Bay of Islands

INTRODUCTION

Efforts to reestablish native bird populations in New Zealand attempt to shift the present community structure by removing predators, improving vegetation, and reintroducing bird species. This process would, at least partially, return community composition to more stable, earlier, stages. This

form of equilibrium is perhaps analogous to the "ecological integrity" of Lee *et al.* (2004) which they define as "the full potential of indigenous biotic and abiotic factors, and natural processes, functioning in sustainable communities, habitats, and landscapes."

The reestablishment of bird species that have become locally extinct is a central theme of conservation ecology in New Zealand, especially on islands (Parker 2013). These islands have been

Received 12 October 2019; accepted 28 November 2019 *Correspondence: *cjralph@xtra.co.nz*

actual islands, or areas of habitat surrounded by a predator-proof fence. When pests are removed from an island, and native trees and shrubs are planted and regeneration occurs, it is envisaged that native ecosystems will be restored and previous niches for birds recreated. In this event, we would predict that: (1) most native birds (especially forest species) would increase; (2) translocated species, reintroduced onto the islands, would also increase: and (3) exotic, non-native (introduced in the last 150 vears) species would decrease. These predictions are basic tenets of restoration ecology, with tests of these recorded on few occasions in New Zealand, by following pest control actions with monitoring, in order to assay the efficacy of the actions and to guide management (Towns 1991; Girardet et al. 2001; Innes et al. 2010; Green et al. 2011; Graham et al. 2013; Miskelly 2018).

Background

The seven islands and many smaller islets that make up the Ipipiri Group (Fig. 1) in the eastern Bay of Islands, northeast of Russell, have importance historically and now increasingly, biologically. After settlement and grazing for more than 100 years, the past 50 years have seen a gradual change with decreased grazing and increased planting of native trees and shrubs. Grazing ended and planting began on most of the islands about 2000 (for details see Project Island Song 2014). Grazing continues today only in a fenced area of about one-third of Urupukapuka Island. Birds are an important part of the biota, for which counts were conducted on several of these islands for 18 months in 1995–96 by David Tindall (Tindall 1996). The islands experienced a major ecological shift in June 2009 with a concentrated pest control programme (Towns et al. 2013), under the aegis of "Project Island Song," a collaboration between organizations and individuals to restore the native birds and habitats (Project Island Song 2014). Thus, began one of the more ambitious conservation experiments in the country. To monitor its effects, we report here on bird counts started in November and December 2008 before the eradication, and continued on for nine years through January 2017.

Between 2012 and 2016, five species have been reintroduced to various islands of Ipipiri: brown teal (*Anas chlorotis*) to Urupukapuka in September 2012; North Island robin (*Petroica longipes*) to Moturua in 2014 (to augment 16 released in 1986, from the Mamaku Plateau) and to Urupukapuka in July 2016; whitehead (*Mohoua albicilla*) to Motuarohia in May 2015 and to Urupukapuka and Moturua in April 2016; North Island saddleback (*Philesturnus rufusater*) to Moturua and Urupukapuka in March 2015 (from Lady Alice Island) and May 2015 (from Tiritiri Matangi Island); and since our study, redcrowned parakeet (*Cyanoramphus novaezelandiae*) to Moturua in June 2017. North Island brown kiwi (*Apteryx mantelli*) are not sampled by diurnal counts, and have been introduced on Moturua and Motuarohia.

We refer to three groups of birds as: (1) the "non-native" species, introduced from outside of New Zealand in the past 150 years; (2) the endemic "native" species that have evolved in New Zealand; and (3) the "recent immigrants," species that have relatively recently colonized New Zealand, and have diverged only slightly from their Australian relatives.

Objectives

It is a basic requirement of introduction science that the species will be monitored after introduction, to make adaptive management possible. Bird monitoring is also a primary objective of Project Island Song to determine long-term responses of fauna and flora to pest eradication in the Bay of Islands. From this monitoring, we expected to find an increase in both bird numbers and species as predation and competition from rats, mice, and stoats are suddenly absent. This study contributes to the testing of this hypothesis.

MATERIALS AND METHODS

Common and scientific names of birds follow the Ornithological Society of New Zealand (Te Papa; Birds New Zealand; New Zealand Department of Conservation 2013) *Checklist of New Zealand birds* – <u>http://www.nzbirdsonline.org.nz</u>.

Study area and pest control treatment

We counted birds in eight routes on five of the islands in the Ipipiri group (Fig. 1). They have differing land uses, conservation status, and vegetation.

Urupukapuka Island (229 ha) is in predominately public conservation status. The main vegetation type is regenerating manuka (*Leptospermum*) kanuka scoparium) and (Kunzea ericoides) shrubland, extensive grasslands of the introduced kikuyu (Pennisetum clandestinum), and a forest of pohutukawa (Metrosideros excelsa) that occupies the coastal fringe. Extensive planting of native shrubs and trees has occurred. Livestock grazing occurs on approximately a third of the island to maintain open space. There is some wetland habitat created in the 1980s.

Moturua Island (166 ha) is largely a scenic reserve. The vegetation is dominated by manuka/ kanuka shrubland with pohutukawa along the coast. It is more advanced in succession than the other islands and is developing a more diverse understory of coastal broadleaf forest augmented by planting of native shrubs and trees. Motuarohia/Roberton Island (63 ha) is mostly private with about 30% public conservation land. Vegetation consists of kikuyu grass flats, kanuka native shrub hardwood forest, and extensive stands of maritime pine (*Pinus pinaster*) with a regenerating understorey of native shrub hardwoods that are mainly hangehange (*Geniostoma ligustrifolium*) and *Coprosma* spp.

Waewaetorea Island (55 ha) is uninhabited and managed as a Scenic Reserve. Grasslands are the dominant feature with kikuyu as well as native grasses. The remaining habitat is composed of stands of regenerating manuka/kanuka forest situated mainly on the south western face and coastal pohutukawa.

Okahu Island (27 ha) is uninhabited and has grassland, some regenerating manuka/kanuka, and coastal pohutukawa.

In June 2009, the New Zealand Department of Conservation performed an aerial drop of the poison bait Brodifacoum by helicopter with the goal of removing pests, namely stoats (*Mustela erminea*), mice (*Mus musculus*), and three species of rats (*Rattus* spp.) from the islands. They targeted seven islands and numerous islets, including the five islands which we subsequently monitored for changes in bird populations. In the subsequent eight years, through 2017, they conducted continuous monitoring for reinvasions, followed immediately by focused eradication programmes if a pest was detected. During the first three years after treatment, they detected and removed a total of 16 incursions of rats, mice, stoats, and cats (Towns *et al.* 2013).

Point Counts

More than 900 station counts (Table 1) were conducted on five islands. We followed the protocols in Vestena (2009) and the specifics in Spurr & Ralph

(2006). This protocol covers most landbird species and involved a ten-minute count, consisting of two consecutive 5-minute standardised morning counts at each station, usually about 100 m apart on eight established routes, during fine weather. Birds flying overhead were counted if they were judged to be using the habitat of the count circle of 100 m. Additional species of waterbirds were tallied but not included in most analyses unless their principal habitat was on land. Most routes consisted of 15 stations (Table 1): Motuarohia (Roberton) (2 routes, one added in 2015); Moturua (2 routes); Okahu (1 route of 6-9 stations - infrequently counted and not included in the "all islands" totals below); Urupukapuka (2 routes); and Waewaetorea (1 route). In some years, a few stations were repeated, missed, or added, such as on Waewaetorea and Okahu to better sample bush and wetter areas. Many of the stations were those originally surveyed by David Tindall in 1995-1996 (Tindall 1996; Tindall et al. 2007), and those data (referred to as the 1996 data) are included for the three islands counted in both periods (Table 1). Over the nine years (2009-2017) of continuous pest monitoring and control, the bird counts were done mostly by volunteers from the Ornithological Society of New Zealand (Birds New Zealand), Guardians of the Bay, staff from the Department of Conservation (DOC), and others, working together to inform Project Island Song and DOC.

Data limitations

As was the case with Miskelly's (2018) work, in our study a team of volunteers conducted the counts, each with varying levels of ability to detect and recognise bird calls. This necessitated adjustments in study methods and design. The first was to use the basic fixed-radius (of 100 m)



Figure 1. The islands of the Ipipiri group with count transects routes shown in lines on the aerial photograph from Google Earth.

Island-route	1996	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Motuarohia East	0	15	15	0	15	0	15	11	16	0	87
Motuarohia West	15	0	0	0	0	0	0	15	13	30	73
Moturua East	15	15	15	15	15	15	15	15	21	29	170
Moturua West	15	15	15	4	15	14	15	13	18	30	154
Okahu	0	6	0	6	10	0	0	11	11	0	44
Urupukapuka East	15	15	14	15	15	15	16	13	15	33	166
Urupukapuka West	15	15	19	0	15	15	15	15	15	28	152
Waewaetorea	0	11	15	15	11	12	15	14	15	30	138
TOTAL	75	92	93	55	96	71	91	107	124	180	984

 Table 1. Number of station-mornings of the monitoring stations by island-route and austral year. In some years some routes had stations that were counted more than once.

bird count technique (Dawson & Bull 1975) where all detections are used, rather than a more complex distance-sampling methodology that may have allowed calculation of absolute density estimates for a smaller subset of focal species (e.g. Greene & Pryde 2013). Such bird counts as ours do not provide a measure of absolute or relative abundance, but do provide a readily collected index of abundance and conspicuousness (or 'encounter rate') suitable for comparisons within the same species over time or between habitats (Dawson & Bull 1975; Verner 1985; Koskimies & Väisänen 1991; Ralph *et al.* 1995). This survey methodology was chosen as the most practical way to survey the diverse bird community present on the islands (see also Johnson 2008).

Most often, to ensure good coverage two people counted each station together with one primarily recording and the other listening and looking. Of the two people, one was usually highly experienced. If this was not possible, two moderately experienced observers were paired together. We found that, as they interacted, the strengths of each observer complemented the other. Further, as we examined the data, we found a high degree of similarity between experienced observers and less experienced counters when comparing numbers of individuals and species on an island between years.

Statistical analysis

For this analysis, we used data collected in the austral summer months of December and January. Data were divided into "Austral Years" in order to define the summer breeding season more conveniently for analyses; for example, counts in December 2008 and January 2009 would be considered to be in Austral Year 2009. Thus, the counts in austral year 2009 were conducted prior to pest control treatment in June 2009.

The mean values for species were calculated by summing the number of birds recorded each station-morning (the number of individuals at one station on one morning) and dividing by the number of stations counted to calculate the mean number (± standard error) of birds per stationmorning per austral year. This mean was calculated for all islands combined as well as by individual island, combining routes if two routes were surveyed on an island. For the analysis below, we primarily used this latter metric which we termed an "island-species combination." If a species was present on all islands with an analysis involving five islands, it would have five such combinations. All calculations were done on log-transformed values. We calculated r² values, regression slope estimates, and regression significance levels for each island-species combination using Proc Reg in SAS (SAS Institute 2012).

RESULTS

Of the more than 20,000 birds counted (Table 2), tui (*Prosthemadera novaeseelandiae*) was the most common, with more than 4,800 individuals recorded. Three native species (i.e. silvereye [*Zosterops lateralis*], grey warbler [*Gerygone igata*], and welcome swallow [*Hirundo neoxena*]), and the introduced common myna (*Acridotheres tristis*) and house sparrow (*Passer domesticus*), all tallied more than 1,000 individuals each. The native New Zealand fantail (*Rhipidura fuliginosa*) and two introduced species each had more than 500 individuals. Overall, 47 species were tallied (including 35 landbirds), many of them with multiple individuals seen, and many species observed in most years.

During the nine years of pest control, of 122 possible island-species combinations for the most abundant 27 landbird species (those with 50 or more total birds observed, Table 2), 51 (42%) significantly increased or decreased ("Individual Islands" columns in Table 3) as community equilibrium was being established. By chance alone, one would have expected fewer than seven to have significantly changed (5% of 122 = 6.1).

)			Austra	lvear									Manu/	LotoL
Common name	Scientific name	Status	1996	2009	2010	2011	2012	2013	2014	2015	2016	2017	station	indiv.
Tui	Prosthemadera novaeseelandiae	ш	1.07	2.29	3.41	3.65	4.03	4.35	5.92	7.21	6.98	6.32	4.90	4,818
Silvereye	Zosterops lateralis	R	7.48	2.15	3.86	1.65	2.14	1.73	2.15	1.71	3.60	1.64	2.70	2,657
Grey warbler	Gerygone igata	R	2.19	2.37	1.77	2.29	2.23	2.34	1.64	1.49	1.74	2.07	1.81	1,785
Common myna	Acridotheres tristis	Z	4.87	1.52	2.98	3.27	1.79	0.92	1.99	1.08	1.73	0.98	1.92	1,888
Welcome swallow	Hirundo neoxena	R	0.93	1.13	0.83	1.05	0.79	0.93	1.41	1.17	1.89	1.68	1.19	1,171
House sparrow	Passer domesticus	Z	1.32	0.92	1.56	0.25	0.55	0.14	1.73	1.36	1.19	1.06	1.06	1,045
New Zealand fantail	Rhipidura fuliginosa	R	1.33	0.79	1.05	0.33	0.69	0.96	0.81	0.87	0.87	1.36	0.96	942
Eurasian blackbird	Turdus merula	Z	2.49	1.74	0.54	0.47	1.04	1.07	0.62	0.89	0.70	0.41	0.92	910
Chaffinch	Fringilla coelebs	Z	1.04	1.09	0.27	0.93	1.26	1.10	0.51	0.91	0.35	0.32	0.71	697
Sacred kingfisher	Todiramphus sanctus	R	0.35	0.60	0.46	0.55	0.56	0.30	0.57	0.41	0.22	0.25	0.38	371
Yellowhammer	Emberiza citrinella	Z	0.28	0.58	0.42	1.07	0.61	0.52	0.27	0.23	0.20	0.07	0.36	355
Tomtit	Petroica macrocephala	Ы	0.00	0.04	0.03	0.49	0.31	0.70	0.78	0.56	0.31	0.37	0.36	350
European goldfinch	Carduelis carduelis	Z	0.63	0.28	1.02	0.33	0.30	0.17	0.58	0.16	0.06	0.15	0.34	331
Pukeko	Porphyrio melanotus	R	0.61	0.45	0.24	0.09	0.23	0.28	0.52	0.26	0.15	0.45	0.34	330
Red-billed gull	Chroicocephalus scopulinus	н	0.00	0.16	1.98	0.02	0.08	0.04	0.22	0.10	0.11	0.22	0.30	296
Eastern rosella	Platycercus eximius	Z	0.07	0.08	0.38	0.05	0.15	0.21	0.16	0.37	0.58	0.35	0.27	269
Song thrush	Turdus philomelos	Z	0.79	0.34	0.34	0.18	0.43	0.11	0.14	0.28	0.06	0.11	0.25	250
Eurasian skylark	Alauda arvensis	Z	0.65	0.30	0.12	0.15	0.21	0.14	0.22	0.19	0.03	0.19	0.21	205
Southern black-backed gull	Larus dominicanus	R	0.00	0.16	0.41	0.18	0.17	0.24	0.21	0.10	0.23	0.26	0.20	200
Dunnock	Prunella modularis	Z	0.84	0.28	0.13	0.16	0.17	0.35	0.09	0.09	0.15	0.02	0.19	191
Pied shag	Phalacorcroax varius	R	0.00	0.08	0.02	0.02	0.42	0.31	0.44	0.21	0.26	0.12	0.19	189
North Island saddleback	Philesturnus rufusater	Ы	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.69	0.17	164
Variable oystercatcher	Haematopus unicolor	Е	0.00	0.16	0.40	0.04	0.22	0.04	0.20	0.23	0.12	0.09	0.16	153
European greenfinch	Carduelis chloris	Z	0.24	0.05	0.45	0.00	0.23	0.08	0.15	0.03	0.06	0.12	0.14	139
European starling	Sturnus vulgaris	Z	0.13	0.24	0.12	0.29	0.11	0.21	0.12	0.07	0.03	0.06	0.12	117
Whitehead	Mohona albicilla	Ы	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.50	0.11	111
Shining cuckoo	Chrysococcyx lucidus	R	0.01	0.10	0.00	0.40	0.19	0.37	0.03	0.10	0.01	0.07	0.10	103
Brown quail	Coturnix ypsilophora	Z	0.36	0.11	0.00	0.00	0.19	0.00	0.10	0.10	0.03	0.07	0.09	91
North Island robin	Petroica longipes	Е	0.05	0.03	0.02	0.07	0.00	0.04	0.00	0.21	0.06	0.15	0.07	73

			Austra	l year									Mean/	Total
Common name	Scientific name	Status	1996	2009	2010	2011	2012	2013	2014	2015	2016	2017	station	indiv.
New Zealand pipit	Anthus novaeseelandiae	ш	0.01	0.03	0.00	0.02	0.02	0.10	0.03	0.06	0.15	0.13	0.07	64
New Zealand dotterel	Charadrius obscurus	ц	0.00	0.03	0.04	0.02	0.13	0.03	0.14	0.11	0.07	0.03	0.06	62
Swamp harrier	Circus approximans	R	0.03	0.05	0.00	0.04	0.05	0.03	0.08	0.16	0.06	0.06	0.06	57
Ring-necked pheasant	Phasianus colchicus	Z	0.00	0.10	0.04	0.11	0.04	0.06	0.05	0.04	0.01	0.01	0.04	38
Australasian gannet	Morus serrator	R	0.00	0.01	0.03	0.00	0.00	0.01	0.01	0.02	0.01	0.10	0.03	27
Spur-winged plover	Vanellus miles	R	0.00	0.00	0.01	0.00	0.00	0.01	0.08	0.07	0.05	0.00	0.02	23
Little shag	Phalacrocorax melanoleucos	R	0.00	0.02	0.08	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.02	15
Brown teal	Anas chlorotis	ц	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.01	11
Australian magpie	Gymnorhina tibicen	Z	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.01	0.01	0.01	10
White-fronted tern	Sterna striata	ц	0.00	0.01	0.04	0.02	0.00	0.03	0.00	0.01	0.00	0.01	0.01	10
New Zealand pigeon	Hemiphaga novaeseelandiae	ц	0.00	0.02	0.06	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	10
California quail	Callipepla californica	Z	0.04	0.03	0.00	0.04	0.01	0.00	0.00	0.00	0.00	0.01	0.01	10
Banded rail	Gallirallus phillipensis	R	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.02	0.01	8
Common redpoll	Acanthis flammea	Z	0.00	0.00	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	~
Paradise shelduck	Tadorna variegata	ц	0.00	0.02	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00	0.01	9
Caspian tern	Hydroprogne caspia	R	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	С
Morepork	Ninox novaeseelandiae	R	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.00	С
Black-billed gull	Larus bulleri	н	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	1
TOTAL INDIVIDUALS			2.088	1.693	2.262	1.049	1,880	1.282	2,006	2.238	2.815	3.721		21.034

Table 2. cont.

Table 3. Population trends of native and non-native landbird species, for all islands combined and for individual islands. Trends are shown by two time periods: 2000s (2009–2017) for 5 islands, and 1996 & 2000s (1996, 2009–2017) for three islands. If two routes occurred on an island, the data were combined. Codes after native species names: E = endemic, R = recent immigrant.

	2000s			1996 & 2000s		
	All islands ¹	Individual isl	ands ²	All islands	Individual isla	ands
Common name	(n=5)	Decreasing	Increasing	(n=3)	Decreasing	Increasing
Native Snecies						
Shining cuckoo R	:	X		116	~	× ×
Pukeko R	us	XX	XXX		×××	<
Swamp harrier R	+		XXxxx	su	×	xx
Sacred kingfisher R	1	XXXXX		ns	×	хх
Tui E	++++		XXXXX	+ + +		XXX
Grey warbler R		XXXXX			XXx	
North Island saddleback E	++++		XX	++++		XX
Whitehead E	++++		XX	+ + +		X×
New Zealand fantail R	su	x x x	XX		X x x	
Tomtit E	++++	×	XXx	+ + +		XXX
North Island robin E	+++		XXx	ns		X X X
New Zealand pipit E	+++++		XXxxX	+++	×	X×
Welcome swallow R	+++		Хххх	ns		Ххх
Silvereye R		X x x	ХХ		XXX	
Non-native Species						
Brown quail	su	X X X			ХХ×	
Eastern rosella	+++++		XXXxx	++++++		XXx
Dunnock	:	X x x	xx		XXx	
House sparrow	+++	Xx	XXX	ns	Xx	×
Chaffinch		XXXX	×		ХX	×
European greenfinch	:	Ххх	ХХ	1	×	X X
European goldfinch		XXXXX			XXX	
Yellowhammer		XXXXX		,	Xx	×
Eurasian skylark	:	Ххх	x	1	ХX	
European starling	1	$X \times \times \times \times$		ns	ХХ	x
Common myna	1	X x x x	x		XXX	
Song thrush	1	X x x x		1	XXX	
Eurasian blackbird		XXXX	Х		XXX	
Simificance of increasing (+) or docreasing	i lei lle nor de four el liel.	ai ore boaidanoo shac	$d_1 = \frac{1}{2} + \frac{1}{2} $	$0.01 + \pm 0.02 =02 - 0.002$	10	ionificant twords as

Native species

Of the 14 native landbird species, eight increased significantly during the pest control period in the all islands combined analysis (Table 3). Four native species (i.e. grey warbler, shining cuckoo [*Chrysococcyx lucidus*], sacred kingfisher [*Todiramphus sanctus*]), and silvereye, decreased significantly. Fantail and pukeko (*Porphyrio melanotus*) showed no trends. The latter six species were classified as recent immigrants. Comparing the 1996 counts with the pest control period on all islands produced a mixed result as five species increased, four decreased, and five showed no change on the three islands monitored in all years (Table 3).

Species that Increased.

Of the eight increasing species, saddleback and whitehead were introduced after the pest control period, and, as expected, had significant increases (Table 3). The other six increasing natives – tui, tomtit (*Petroica macrocephala*), North Island robin, swamp harrier (*Circus approximans*), New Zealand pipit (*Anthus novaeseelandiae*), and welcome swallow – are detailed below.

Tui was the most-frequently observed species and it increased considerably for all islands and routes combined (Fig. 2A). This increase was highly significant (P < 0.001; Table 3). During the period since pest control began, this conspicuous and aggressive bird has nearly tripled in numbers; over the 20-year period, it has increased even more.

Tomtit (Fig. 2B) has had remarkable and significant (P < 0.001; Table 3) increases as it self-introduced into the islands. This native species had not been detected in the 1996 counts, before pest control. It was confirmed to be breeding on Moturua in December 2008 (Ralph *et al.* 2008). Since then, it has rapidly increased on Moturua, spreading on its own to Urupukapuka, and most recently to Motuarohia (Fig. 2B). It was even detected occasionally on small Okahu Island (in 2011 and 2012). The species initially had a population increase on Moturua and, as is typical of species recently introduced, they have since apparently stabilized at a lower level.

North Island robin on Moturua Island had maintained a very small population (Fig. 2C), since an introduction of this native in February 1986 (Project Island Song 2014). It was missed by counts in two years during the last nine years of pest control. However, the introduction of new birds in the winter of 2014 on Moturua resulted in an immediate increase in the 2015 count, followed by fewer the next year, and increases in 2017. An introduction in 2016 on Urupukapuka resulted in birds detected in 2017. Birds are now thinly scattered in good bush habitat throughout the two islands. The robin might be expected to spread on



Figure 2. The mean number $(\pm se)$ of birds seen or heard on the 10-minute station counts on four islands of the Ipipiri group and the overall mean (All Islands). "X" = island was not counted in that year; A) tui, B) tomtit, C) North Island robin.

its own as has the tomtit, but it seems relatively sedentary, as its many decades solely on Moturua Island show.

Swamp harrier and welcome swallow both increased during the pest control project (Table 3; Appendix 1). When including the earlier 1996 counts, however, they showed no significant increase. New Zealand pipit increased markedly (Table 3; Appendix 1), in both comparisons.

Species that were Unchanged or Declined.

New Zealand fantail was a common bird (Fig. 3A), and, with its confiding nature, we probably have excellent detection rates with few birds missed by observers. Overall, with all islands combined, abundance was unchanged through the 2000s after pest removal (P > 0.05; Table 3), counts usually, on average, between 0.5 and 1.0 birds per station (Fig. 3A). Looking at each of four of the islands during this time period (Fig. 3A), the population had no consistent pattern between islands or years. Only in 2011 was there a consistently lower count on the three islands. The fantail's abundance significantly decreased from 1996 on all islands combined (P < 0.001; Table 3) and decreased on all three of the islands sampled in 1996; significantly so on one of the islands.

The recent immigrant silvereye was the second most common bird detected. It declined (Fig. 3B) significantly during the 9-year period (P < 0.001),



Figure 3. The mean number $(\pm se)$ of birds seen or heard on the 10-minute station counts on four islands of the Ipipiri group and the overall mean (All Islands). "X" = island was not counted in that year; A) New Zealand fantail, B) silvereye.

and also when including the 1996 counts over the 20-year study period for all islands combined (P < 0.001; Table 3), and at all three individual islands.

Pukeko showed mixed results, with a significant decrease from 1996 through the 2000s (P < 0.01; Table 3; Appendix 1), but no significant change during the 2000s.

The other decreasing native species (Table 3; Appendix 1) were sacred kingfisher, shining cuckoo, and grey warbler, all declined during the pest control period, depending upon the analysis.

Non-native species

In a very different pattern from most of the native species, of the 13 common, non-native landbird species, ten species declined (Table 3) on all islands combined during the pest control period, including Eurasian blackbird (*Turdus merula*), chaffinch (Fringilla coelebs), European starling (Sturnus vulgaris), European goldfinch (Carduelis carduelis), European greenfinch (Carduelis chloris), dunnock (Prunella modularis), common myna, Eurasian skylark, song thrush (Turdus philomelos), and yellowhammer (*Emberiza citrinella*). Just two species increased – eastern rosella (*Platycercus eximius*) and house sparrow. Only brown quail (Coturnix ypsilophora) remained unchanged. Comparing the 1996 counts with the pest control period, ten species declined significantly, only eastern rosella increased and two species (house sparrow and European starling) were unchanged. We detail two nonnative species below, common myna and Eurasian blackbird. The other species of non-native birds are shown in Appendix 2.

Common myna showed a great deal of variation between years on the different islands, with especially low numbers in 2012, 2013, and 2015 on all islands (Fig. 4A). This could well be due in part to flocks of non-breeding individuals being detected irregularly. Overall, it declined significantly on all islands combined, most notably when 1996 data are included in the regression (P < 0.001; Table 3).

Eurasian blackbird had low numbers during 2010 and 2011, just after the pest control that began in June 2009 (Fig. 4B). The species declined overall during both the entire 20-year period as well as the last nine years of pest control. It appeared to rebound in 2012, with a continued steady decline thereafter.

DISCUSSION

We had expected the total eradication of mammalian predators to result in an increasing trend broadly across bird species, both native and non-native, with the presumption that reduction in predation and competition would be widely felt as community equilibrium was established.



Figure 4. The mean number $(\pm se)$ of birds seen or heard on the 10-minute station counts on three islands of the Ipipiri group and the overall mean (All Islands). "X" = island was not counted in that year; A) common myna, B) Eurasian blackbird.

Rats in particular are a significant competitor with native avian species for fruits and flowers, and both rats and mice also have an important impact in preventing forest regeneration by eating seeds and seedlings (e.g. Shiels *et al.* 2014; Rankin *et al.* 2018). We suggest that rat removal had the major role in the trends we report. Other limiting factors besides predation and competition from mammals could, of course, be involved in these trends, including disease, variable environmental conditions, and weather patterns. The changing habitat from the planting of native trees and shrubs, and naturally occurring succession and maturing of the forest, may both interact in an unpredictable fashion to increase or decrease certain species.

Our central finding was a striking difference in the response between native and non-native birds. Of the 27 landbird species with reasonable sample sizes, many more native species increased (eight) than non-native species (two; Table 3). In addition, within the native species, there was also a marked difference between long-established endemic natives and the relatively recent natural immigrants. That is, of the native species, the exceptions to the general rule of increases after pest control were the six species that are more recent arrivals in New Zealand which declined –pukeko, sacred kingfisher, shining cuckoo, grey warbler, New Zealand fantail, and silvereye. These recent immigrants might be considered analogues to the non-native species.

In New Zealand, some other studies have looked at the prediction that native birds would outperform non-native species when mammalian pests are eliminated. Providing indirect evidence, Diamond and Veitch (1981) observed, in a largely intact avifauna and native forest on 2,800 ha Little Barrier, far more individuals of native species than non-natives. A direct test was provided on the smaller (220 ha) and nearby Tiritiri Matangi Island where, in a detailed 24-year study, Graham et al. (2013) found that of the native species, 5 significantly increased, 3 decreased, and 8 had no significant change. Of native species that were reintroduced onto the island, 4 significantly increased, 2 decreased, and 3 had no change. By contrast, of the non-native species, none increased, 3 decreased, and 11 had no change. Similarly, at Zealandia in Wellington, Miskelly (2018) found that the proportion of non-native species declined during a 25-year period from 30% (in 1995–1998) to 22[%] (2002–2005), and 9[%] (2013–2016). Overall, the number of birds over that period increased 52%, mostly of reintroduced native species. They reintroduced 10 species, eight successfully. Counts for all six of the most frequently recorded resident non-native species declined markedly after the 2002–2005 period.

Two meta-analyses have examined this question. In one, Bombaci et al. (2018) found that "densities of nine endemic species were higher in sanctuaries compared to unprotected sites (0.27-9.00 more birds/ha)", but "...found no significant difference in mean population densities for introduced and biogeographically-recent native species". In the other, Fea (2018) found that the "larger endemic species" (i.e. kaka [Nestor meridionalis], North Island kokako [Callaeas wilsoni], New Zealand pigeon [*Hemiphaga novaeseelandiae*], red-crowned parakeet [*Cyanoramphus novaezelandiae*], and tui), consistently showed positive population-level responses to both high and low-intensity mammal control whereas populations of smaller, "deep endemic species" (i.e. stitchbird [Notiomystis cincta], rifleman [*Acanthisitta chloris*], and whitehead) "responded positively only within sites receiving high intensity management." She also "identified three small, native bird species of shallow or zero endemism" (i.e. "recent immigrants", New Zealand

fantail, grey warbler, and silvereye) and three nonnative species (Eurasian blackbird, chaffinch, and dunnock) "that routinely decline in detections after mammal control."

The apparent effects of the increases or decreases of bird populations over the pest control period in our study is perhaps predictable. However, with some species, the effects apparently began much before the pest control period, and in a few species was a continuation of the increase or decline since 1996, when the first count was undertaken. For instance, silvereye and tui showed a decrease and increase respectively between 1996 and the period of pest control. A possible explanation is that before pest control a modest amount of planting was taking place, grazing had been largely removed, and some form of succession was underway, heading the islands towards a more natural state of the forests.

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Appendix 1. The mean number of 7 native bird species ($\pm se$) seen or heard on the 10-minute station counts on all islands combined, summed by four time periods. Means within each graph with different letters are statistically significantly different (P < 0.05, ANOVA), while means with the same letters are not different (P > 0.05, ANOVA).



Appendix 2. The mean number of 11 non-native bird species (\pm *se*) seen or heard on the 10-minute station counts on all islands combined, summed by four time periods. Means within each graph with different letters are statistically significantly different (P > 0.05, ANOVA), while means with the same letters are not different (P > 0.05, ANOVA).



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Breeding of little penguins (*Eudyptula minor*), including multiple brooding, at South Bay, Kaikōura, New Zealand, 2006–2017

LINDSAY K. ROWE* T198 24 Charles Upham Drive, Rangiora 7400, New Zealand

JODY S. WEIR ALASTAIR G. JUDKINS Kaikōura Ocean Research Institute Inc. (KORI), c/o Takahanga Marae, PO Box 39, Kaikōura 7340, New Zealand

Abstract: For 11 breeding seasons, a colony of little penguins (Eudyptula minor) was monitored at South Bay, Kaikoura. The 106 breeding attempts from 86 pairings consisted of 68 single clutches, eight attempts made up four replacement clutches (an unsuccessful original clutch followed by a second clutch by a pair in one season), 26 attempts consisting of 13 double broods (a successful original clutch followed by a second clutch by a pair in one season), and one complex triple brood (three successful attempts by a penguin in one season, the triple brood, plus another successful attempt by its first mate after separation). The earliest laying date was 18 April for multiple brooders and 12 August for single clutch pairs. Single clutch pairs raised a mean of 1.42 fledglings/clutch. Four pairs with first clutch failures laid replacement clutches; one was successful. Seven of the 13 pairs of double brooders successfully raised the second clutch; the productivity of the 13 pairs was 2.69 fledglings/pair. The first record of a successful triple brood by little penguins was complex in that the female separated from her mate after the first brood chicks fledged, and then completed her second and third broods with a different male. Her original mate also produced a further brood with another female to complete his double brood. These four clutches laid eight eggs of which seven hatched and six chicks fledged. This may also be the first reported multiple brood with a change of mate after a successful first brood. On a colony-wide basis productivity per season was 2.36 eggs/pair, 1.80 chicks/pair, and 1.66 fledglings/pair. Previous research indicated Kaikoura birds belonged to the New Zealand Only (NZO) clade of little penguins. As double brooding and rafting are traits of the Australia and south east New Zealand (ASENZ) clade only, this classification is now questionable suggesting a mix of both clades and/or hybrids.

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Keywords: Eudyptula minor, little penguin, breeding success, double brooding, triple brooding

INTRODUCTION

The little penguin (*Eudyptula minor*) is considered to be a species of "least concern" (BirdLife International 2018) but under the New Zealand Threat Classification it has recently been

Received 25 July 2018; accepted 7 February 2020 *Correspondence: lindsay.jan.rowe@xtra.co.nz downgraded within the "At Risk - Declining" category (Robertson *et al.* 2017). A recent review (Wilson & Mattern 2018) summarises current knowledge of little penguins and sets priorities for research and conservation in New Zealand.

Five subspecies of little penguins were recognised by Kinsky & Falla (1976) for New Zealand including the Cook Strait blue penguin (Eudyptula minor variabilis) found as far south as Kaikoura (42.43°S, 173.68°E) and Motunau Island (42.43°S, 173.68°E), and the white-flippered penguin (E. m. albosignata) from Banks Peninsula (42.43°S, 173.68°E) north to Motunau Island. There is continuing uncertainty about the taxonomy of little penguins, and hence, all little penguins including the white-flippered morph have been placed into a single species, Eudyptula minor, awaiting clarification (Gill et al. 2010). Recent research using mitochondrial DNA variation has determined that little penguins can be separated into two clades, the first being birds from Australia and south east New Zealand (ASENZ) and the second being mainly New Zealand Only birds from Banks Peninsula north (NZO) (Banks et al. 2002; Peucker et al. 2009; Clark et al. 2013; Grosser *et al.* 2015). Double brooding and rafting are considered traits of the Australia-Southeast NZ clade only (Grosser et al. 2015).

The main concentration of little penguins on the Kaikoura Peninsula is at South Bay on the southern side of the peninsula (42.43°S, 173.68°E) although in later years there have been isolated instances of penguins breeding on the north side of the Kaikoura Peninsula under roadside protection boulders and under a house (LKR pers. obs.). Until the mid-1990s, penguins at South Bay nested under boat sheds and houses, in gardens and hedges. The boat sheds were gradually removed and the Kaikoura District Council built a new seawall and jetties (I. Bradshaw *pers. comm.*). Birds that once nested and moulted under the old boat sheds began seeking shelter under houses and were prone to disturbance by household pets. As a consequence of local residents voicing concerns about a perceived decline in penguin numbers, the Department of Conservation (DOC) built a shelter in 2002 in which were placed multiple nestboxes created from inverted fish crates with a hole cut in one end (M. Morrissey, DOC, pers. comm.). Penguins began to breed there, as well as under the local Coastguard building, in the new marina boulder bank and in the boat park shrubbery (Fig. 1).

There are multiple threats to the survival of this colony. The boat park is used extensively each day by commercial and recreational fishers, tourism operators, charter fishing boats, and the Kaikōura Coastguard is headquartered there. The area is also used by people for recreation, mainly walking around the Kaikōura Peninsula. Predators, mainly dogs (*Canis familiaris*), have killed penguins in the area including three banded study birds in one night (Coastguard *pers. comm.*) and cats (*Felis catus*) have been seen near nests (AGJ *pers. obs.*).

A better understanding of penguin breeding within known colonies is important for establishing baselines for future comparisons. In 2006, LKR began to study the little penguins at South Bay, Kaikōura, to determine the subspecies present, how many birds were present, and how successful they were at breeding in an area where there was much activity and many threats to their wellbeing. While little penguins are known to have multiple broods in a season (Marchant & Higgins 1990; Flemming 2013), in New Zealand it has been reported that outside Otago little penguins do not double brood (Gales 1985; Heber 2008; Agnew *et al.* 2014). Here, we report on breeding by little penguins at the South Bay colony, Kaikōura, including replacement clutches and multiple brooding and how the Kaikōura birds might fit into the two-clade scenario.



Figure 1. Extent of South Bay little penguin colony on 20 August 2012. During summer 2012–13, the marina boulder bank was replaced with new rock protection from the Coastguard building to the slipway outside the bottom-right of the photo. (Photo: Andrew Spencer).

METHODS

Monitoring and penguin handling from 2006–2017, including flipper banding and microchipping was led by LKR, a Level 3 Department of Conservation (DOC) certified bander, and later by AGJ, also a Level 3 DOC certified bander. The colony is located on grounds that are owned by Kaikoura District Council and by Kaikoura Coastguard. Both organizations support the penguin monitoring work described here.

Penguins nested in a variety of habitats: deep amongst boulders at the Marina where they were subject to splash during high storm tides and near the DOC shelter; under vegetation including flax (*Phormium* spp.) at the Boat Park and DOC shelter, and under the Coastguard building (Fig. 1). From winter 2008, purpose-built nestboxes (after Houston 1999) were placed over nests found in vegetation, at the top of the Marina boulders and under the Coastguard building. These gave the penguins some protection from predators; no nest desertion happened as a result and penguins have renested in some nestboxes every year for 12 seasons until 2019-20. A season is defined as the period from 1 April (after completion of moult) to 31 March next year. Many nests could not be monitored. Nestboxes under the DOC shelter occupied by six or more pairs each year, were inaccessible, and it was not always possible to find or reach eggs or birds in the boulders nor to attribute nests or chicks to adults seen.

Visits to the colony were made approximately weekly from summer 2006 but there were occasional periods up to six weeks long in late winter when no-one was available to check on the colony. Most visits were made at dusk to record birds already present at the colony, which birds came in, and the numbers of eggs and/or chicks present at each nest. Unique numbered stainless-steel flipperbands obtained from DOC were applied to all adult birds found and to chicks about to fledge. Passive integrated transponder (PIT) tags were implanted in the necks of adults from December 2008. PIT tag readers at tunnels into the Coastguard building and the DOC shelter allowed movements of birds to be recorded at those sites between the weekly visits. All observations reported here were of pairs of banded birds on nests or in nestboxes, and the bands were read every visit to confirm which birds were on which accessible nest.

Because visits to the colony were weekly with some large gaps, recorded dates for the first sighting of eggs were often approximations. The incubation period of little penguins average about 35 days (e.g. Chiaradia & Kerry 1999; Kemp & Dann 2001; Heber *et al.* 2008; Flemming 2013) and laying of the two egg clutch usually occurs 2–4 days apart (Marchant & Higgins 1990; Kemp & Dann 2001; Heber *et al.* 2008). Therefore, laying dates for pairs of eggs have been determined as follows:

- if an egg was seen on day x and a second egg was seen the next visit, laying date = x+1;
- if laying occurred in an interval <8 days, the laying date is the middle of the two dates;
- if laying occurred in an interval >8 days, laying date is 35 days before hatching if known or estimated.

Brood definitions (these apply to one season):

- a successful clutch is one where at least one chick fledged;
- a single clutch is one set of eggs produced by a breeding pair in a season (which starts after moulting has finished – 1 April);

- a replacement clutch refers to a failed first clutch followed by a second clutch by the same pair which may or may not have been successful;
- a successful double brood is two successive clutches by the same pair with one or two chicks fledged from each;
- a failed double brood is two successive clutches by a given pair with one or two chicks fledged from the first and no chicks from the second laying;
- a triple brood has three successive successful clutches in the same season.

Statistical tests were carried out using routines in Microsoft Excel and at the 95% significance level.

RESULTS

Records of banded birds at the colonies indicated the adult population of little penguins seen at South Bay, Kaikoura, was approximately 30-40 individuals including non-breeders and those only seen sporadically. Most of the penguins at South Bay are the "normal" blue penguins with little, if any, white on the anterior edge of their flippers. During the study there were at least 19 birds recorded with significant white on the anterior edge to be considered white-flippered morphs. Apart from three of these birds that were seen breeding with blue-morph birds, the rest were present for a short time either moulting or as itinerants. The mixed pairs fledged one, two and seven chicks, most of which were never seen after fledging; one fledgling was seen one year later and one successfully raised four fledglings.

Not all birds were on accessible nests so we could only monitor up to 14 pairs each season. Prior to 2009–10, we had not found all nest sites hence the low numbers of pairs monitored then (Table 1); the low numbers in 2016-17 reflected some losses from a small tsunami and limited observations possible after the magnitude 7.8 Kaikoura earthquake on 14 November 2016. From 2009-10 to 2015-16, we are confident we monitored most of the accessible nests, an average of ten nesting pairs that laid 12 clutches each season. There were 106 known clutches from 86 pairings monitored over the 11 seasons (Table 1); 68 pairings were single clutches, four pairings had replacement clutches, 13 had double broods, and there was one complex triple brood (two pairings, four clutches) in 2016–2017. Most seasons over 80%of pairs successfully fledged one or more chick. The 2014–15 season was exceptional for the number of double broods with four of five attempts being successful.

Season	Nesting	Clutches	Singl	e clutches	Rep cl	lacement utches	Dout	ole broods	Triple complex	Successfu	l pairs
	pairs	attempted	Failed	Successful	Failed	Successful	Failed	Successful	Successful	Number	%
2006–07	1	1	0	1	0	0	0	0	0	1	100
2007–08	5	6	0	4	0	0	0	1	0	5	83
2008–09	5	5	0	5	0	0	0	0	0	5	100
2009–10	8	8	0	8	0	0	0	0	0	8	100
2010-11	7	8	0	6	0	0	1	0	0	6	86
2011–12	14	17	5	6	1	0	1	1	0	7	50
2012-13	11	15	2	5	1	1	2	0	0	6	11
2013–14	11	11	2	9	0	0	0	0	0	9	82
2014–15	11	17	2	3	1	0	1	4	0	7	63
2015–16	9	9	1	8	0	0	0	0	0	8	89
2016–17	4	9	0	1	0	0	1	1	1	3	75
Total	86	106	12	56	3	1	6	7	1	65	76

Table 1. Summary of breeding attempts of little penguins, South Bay colony, Kaikōura, 2006–2017. The triple complex has been treated as if it was one pair.

Single clutches

Of the 68 single clutches laid, 52 with known lay dates and four with unknown lay dates were successful; 12 failed. Laying dates for the successful clutches were between 12 August and 17 November with a mean of 26 September (n = 46; 95% CL = \pm 7 days). All 50 successful clutches of known size comprised two eggs; hatching averaged 1.87 chicks/pair and 1.75 chicks/pair fledged. Including failed single clutches, there was 1.91 eggs/pair, 1.55

chicks/pair (hatching rate 81%) and 1.42 fledglings/ pair (fledging rate 92%); the breeding success rate (chicks/egg) was 75%.

Replacement clutches

In addition to the single clutches, there were four first clutches that failed and the same pairs laid replacements. Only one of these was successful with one chick fledging (Table 1; Table 2).

Table 2. Little penguin pairs at South Bay, Kaikōura, that laid two clutches in a season.

	Male	Female	Laying date	Eggs	Fledged	Laying date	Eggs	Fledged	Outcome
2007–08	P38217	P38219	2 September	2	2	15 December	2	2	Successful double
2010–11	P38223	P38222	3 September	2	1	12 December	2	0	Failed double
2011–12	P38223	P38222	14 August	2	2	30 November	2	2	Successful double
2011-12	P38214	P44315	-	2	1	14 November	1	0	Failed double
2011-12	P38314	P38299	-	1	0	-	1	0	Failed replacement
2012-13	P38217	P38216	12 September	2	1	27 November	2	0	Failed double
2012-13	P38258	P38269	5 October	2	0	21 November	2	1	Successful replacement
2012-13	P38273	P38222	17 September	2	2	1 December	1	0	Failed double
2012-13	P38325	P38215	3 October	2	0	-	2	0	Failed replacement
2014–15	P38217	P38216	28 July	2	2	15 November	2	2	Successful double
2014–15	P38280	P38278	23 July	2	2	5 November	2	2	Successful double
2014–15	P44317	P38299	16 July	2	2	30 October	2	0	Failed double
2014–15	P38325	P38215	-	1	0	20 October	2	0	Failed replacement
2014–15	P44345	P44358	13 August	2	2	28 November	2	2	Successful double
2014–15	P44369	P44354	27 August	2	1	6 December	2	2	Successful double
2015–16	P38217	P44315	23 May	2	2	1 October	2	0	Failed double
2015–16	P44317	P44358	6 July	2	2	28 October	2	1	Successful double

Double broods

Excluding two that were part of the triple brood, there have been 13 known double broods by same pairs at the South Bay colony; six failed and seven were successful (Table 1, Table 2). In all cases the second clutches were in the same nestbox as the first clutch, and the same adults were identified from bands when sitting on the eggs and attending to the chicks throughout the season. Double brooding pairs laid eggs as early as 23 May, 12 weeks earlier than the earliest single brood birds; the mean lay date, 7 August (n = 13; 95% CL = \pm 21 days), was seven weeks earlier that for single broods. Mean laying dates were similar for the first clutches of failed (8 August) and successful double brooders (7 August) suggesting laying date was not a contributing factor to failure (t = 0.005 c.f. t = 2.28, P = 0.05, df = 10.

The successful and failed double brooders all laid two eggs in their first clutches. Hatching rates for first clutches of these groups were similar at 1.86 (n = 7) and 1.83 (n = 6) chicks/clutch, respectively, but the successful pairs fledged more chicks, 1.86 (n = 7) and 1.50 (n = 6) fledglings/first clutch, respectively. With respect to the second clutch, there were obvious differences with the successful brooders having the same success rate as the first clutch, 1.86 chicks/clutch, whereas, by definition, unsuccessful brooders did not fledge any chicks from the second clutch. Overall, the 13 double brood pairs produced 3.84 eggs/pair, 2.92 chicks/ pair and fledged 2.69 chicks/pair, a success rate of 70% chicks/egg. The last chicks fledged in mid-March.

Two pairs had new eggs laid before the first clutch fledglings had left the nest. When visited on 27 November 2012, nestbox CG1 held both parents, P38216 and P38217, and their chick P44367 (aged 42 days) together with a new egg; 4 December P38216 and P44367 were present with the two eggs. P38216 and P38217 were still visiting the nextbox through to mid-February but there was only one egg present on 18 December and none on 8 January. The second pair, P38222 and P38273, were not present in nestbox CG5 on 4 December 2012 but it held their two large chicks (aged 44 days) and one new egg; one dirty egg was present until 27 December.

Five of the 15 birds that double brooded are known to have hatched at South Bay and first bred as 3–5 year-olds. Three double brooders were the progeny of a pair that failed once but later succeeded as a double brooder. Another successful double brooder was a product of a pair that had a failed replacement clutch in 2011–12 before one went on to have a failed double brood in 2014–15 and then completed a triple brood in 2016–17 with two different partners.

Triple brood

One complex triple brood was successfully completed in the 2016–17 season by female P38299. The earliest egg laying recorded at South Bay, 18 April, was the start of the triple brood (Table 3). After the first brood chicks fledged, P38299 separated from P44345, the partner for her first clutch, and paired with P48417 with whom she produced two further successful clutches that season each with one fledgling. Meanwhile, P44345 paired with P48466 with whom he produced a further successful twofledgling clutch that same season. This triple brood complex laid four clutches in total, producing eight eggs of which seven hatched and six chicks fledged, the last being about 20 February, earlier than most double broods.

Table 3. A triple brood by little penguins at the South Bay colony, Kaikōura, 2016–2017. At the end of the first clutch, P38299 and P44345 separated and proceeded to have additional broods with their respective new partners, P48417 and P48466.

Female Male	P38299 P44345	P38299 P48417	P48466 P44345
Laying date	18 April		
Number of eggs	2		
Hatching date	23 May		
Number of chicks	2		
Fledging date	13 July		
Number fledged	2		
Laying date		7 August	31 October
Number of eggs		2	2
Hatching date		14 September	5 December
Number of chicks		1	2
Fledging date		9 November	2 February
Number fledged		1	2
Laying date		26 November	
Number of eggs		2	
Hatching date		31 December	
Number of chicks		2	
Fledging date		20 February	
Number fledged		1	

Colony summary

As a colony over the 11 seasons (2006–2017) 82 pairings with known outcomes produced 2.36 eggs/pair, 1.80 chicks/pair and fledged 1.66 chicks/pair; hatching success 76%, fledging success 92% and breeding success 70%.

DISCUSSION

The population of little penguins at Kaikōura is about 30–40 seen during a season. Over the seven seasons from 2009–10 we monitored an average of ten pairs (range 7–14) that laid an average of 12 clutches/season. The annual variation and limits on detection in the early and later years means it was not possible to determine any trend in numbers during the study. That there was more clutches than pairs shows there was a significant number of replacement clutches laid, or there is double brooding at this colony which is contrary to the view that, in New Zealand, little penguins do not double brood outside Otago (Gales 1985; Perriman & Steen 2000; Agnew *et al.* 2014).

At Kaikōura, the majority of the annual pairings pairs, 68 of the 86 (79%), laid single clutches over the 11 seasons; 81% of clutches were successful and this is higher than for single clutches in many other New Zealand studies: Taiaroa Head 55% (Gales 1985); Matiu-Somes Island 58% (Bull 2000), 51% (Kinsky 1960); Tiritiri Matangi Island 40% (Jansen van Rensburg 2010). The success of clutches at Kaikōura was very high with 1.91 eggs laid/clutch, 1.55 chicks hatched from each clutch, and 1.42 chicks fledged/clutch. The breeding success rate of 75% is amongst the highest reported for single clutches in New Zealand which range between 3.5% at Tiritiri-Matangi (Boyer 2010) and 79% at South Westland (Braidwood 2009; Braidwood et al. 2011; Wilson & Mattern 2018). Productivity of these single clutches is also very high at 1.42 fledglings/ pair; South Westland has the only reported higher productivity at 1.55 fledglings/pair (Braidwood 2009; Braidwood et al. 2011).

There were four replacement clutches (25%) of failed first clutches) at Kaikoura with only one successfully fledging one chick. Replacement clutches after first clutch failures are laid at many New Zealand colonies but very rarely on the West Coast (Heber et al. 2008; Braidwood, 2009; Braidwood et al. 2011, K-J. Wilson pers. comm.) and rarely at Banks Peninsula (Allen et al. 2011). With only one fledgling from four replacement nests at Kaikōura, the success rate was lower than two North Island colonies; Matiu-Somes Island: five fledglings for seven replacements (Kinsky 1960), four fledglings from four replacements (Bull 2000); Tiritiri Matangi Island: three fledglings from seven replacements (Jansen van Rensburg 2010), but was better than at Taiaroa Head where all nine replacements failed (Gales 1985).

At South Bay between 2006 and 2017, 13 (15%) pairs had double broods of which seven second broods were successful. Double brooding has been reported in New Zealand for little penguins attributed to the ASENZ clade at Oamaru (45.11°S, 170.97°E; 370 km south west of Kaikōura) (Perriman

et al. 2000; Johannesen *et al.* 2003; Agnew *et al.* 2014) and Taiaroa Head (45.82°S, 170.75°E; 440 km south west of Kaikōura) (Gales 1985; Perriman & Steen 2000; Perriman *et al.* 2000)-but not at any other colony. The number of pairs double brooding was low compared to Oamaru (27%, Agnew *et al.* 2014) and Taiaroa Head (30%, Gales 1985; 0–48%, Perriman & Steen 2000). Seasonal productivity at Kaikōura for all double brooders was 2.69 fledglings/pair, a rate slightly higher than the 2.5 chicks/pair that Johannesen *et al.* (2003) measured at Oamaru but their analysis included replacement clutches.

Overall productivity at Kaikōura was 1.66 fledglings/pair which is lower than 1.89 fledglings/ pair reported for Oamaru where there was about twice as many double brooders (Agnew *et al.* 2014). The fledging success rate was similar to some Australian colonies: Bowen Island, 1.6 fledglings/ pair with 14% double brooders (Fortescue 1999), and North Harbour, Sydney, 1.71 fledglings/pair with 24% double brooders (Priddel *et al.* 2008).

The triple brood by P38299 in 2016–17 appears to be very unusual as there are no published records of a penguin successfully rearing three broods in one season. The very early laying dates of the first clutch, 17 April, meant there was plenty of time to fledge the three consecutive broods. Three clutches, likely to have been replacements after unsuccessful attempts, have been reported for 12 of 1,050 breeding attempts by Australian little penguins but the final outcome was not given (Nisbet & Dann 2009). Johannesen et al. (2003) reported seven pairs laying three clutches at Oamaru but none managed to raise all three broods. Similarly, Perriman *et al.* (2000) report pairs laying three clutches but does not specify the site(s) or outcomes. Thus, this is the first report of a successful triple brood known to us. This triple brood is also unique in that birds that have separated after a successful brood have not been reported to have produced further broods that season. After their separation P38299 and P44345 had two and one additional broods with new partners, respectively.

Gill *et âl.* (2010) placed all little penguins including the white-flippered morph into a single species, *Eudyptula minor*, awaiting clarification. If the simplistic definition of a species "is a group of organisms that share a genetic heritage, are able to interbreed, and to create offspring that are also fertile" (Biologydictionary.net 2019) is applicable, then a pair of blue- and white-flippered morphs at Kaikōura that have fledged chicks that successfully raised a further generation helps support the inclusion of the white flippered morph in the New Zealand taxon.

A study of mitochondrial DNA variation (Banks *et al.* 2002) determined that little penguins could

be separated into two clades, the first being birds from Australia and Otago (now called the ASENZ clade), and the second the rest of New Zealand (NZO clade); there were no Kaikoura birds in that analysis. A subsequent study using more specimens but, again, without Kaikōura birds, confirmed the 2-clade scenario but noted that both clades were present at Oamaru (Banks et al. 2008). Later studies confirmed that ASENZ birds only were present at the Catlins and Otago Peninsula and that both clades were present at Oamaru (Banks et al. 2008; Peucker et al. 2009; Clark et al. 2013). Birds sampled north of Oamaru have been almost entirely NZO with the exceptions of one ASENZ bird found at Banks Peninsula (Clark et al. 2013) and one at Motunau Island (Peucker et al. 2009); a sample of six Kaikoura birds were all placed in the NZO clade (Peucker et al. 2009). Later work (Grosser et al. 2015) found a beach-wrecked specimen from Kaikoura had Australian lineage but it was not known whether that was vagrant or a Kaikoura colony penguin.

We now have evidence of double brooding of little penguins at Kaikõura, a trait believed to only belong to the ASENZ clade of little penguins (e.g. Agnew *et al.* 2014; Grosser *et al.* 2015). That clade is also known to have penguins congregate near shore in rafts after dusk, to swim ashore as groups and walk to their nesting sites whereas NZO birds do not (Grosser *et al.* 2015). At Kaikõura, penguins are heard calling offshore after dusk and then come ashore along set paths in small groups, up to ten at the DOC shelter and six at the Coastguard. Therefore, based on these two factors, the Kaikõura penguin colony appears to have a substantial component from the ASENZ clade.

There has been one ASENZ bird found at Motunau Island, 87 km south-west of South Bay (Peucker et al. 2009), another at Banks Peninsula 150 km to the south west (Clark et al. 2013), and P37188 banded in Oamaru, an ASENZ stronghold, in 2007 arrived at South Bay where it paired with a local penguin for three seasons producing at least two chicks (LKR unpubl. data). Together, these suggest there could be northward expansion of ASENZ birds and that the Kaikoura Peninsula might be a transition zone of hydridisation between the two clades. Peucker et al. (2009) suggested a focus for future work could be sampling from coexisting sites to see if one clade is displacing the other and/ or hybridising. It would seem that the South Bay colony could be a good candidate for this work as the total population sample is about 30–40 adult birds with up to 20 chicks hatched in a season.

A second, but perhaps more difficult, focus might be to find a simple physical method to characterise the clades. While there is a clear separation of the clades and the possibility of relating that to subspecies, at sites where they coexist there does not seem to be a practical way for the casual observer to visually determine the clades from close up, or at a distance. This lack of easy separation might therefore provide a case for maintaining the status quo of lumping all New Zealand little penguins into one *Eudyptula minor* taxon.

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Aberrant and deformed Antarctic penguins and unusual eggs

SERGEY V. GOLUBEV Russian Antarctic Expedition, 38 Bering Street, 199397 St Petersburg, Russia

Abstract: Nineteen cases of physical deformities, colour aberrations, and unusual eggs were recorded in emperor penguins (*Aptenodytes forsteri*) and Adélie penguins (*Pygoscelis adeliae*) from the Haswell archipelago in the Davis Sea, East Antarctica, during 1956–2016. Two very small eggs and one very large egg were recorded from emperor penguins, and two very small eggs from Adélie penguins. Physical deformities included beak deformities in two emperor penguin adults and two chicks, and two chicks had deformed spines. Colour aberrations included the ino mutation in a juvenile emperor penguin. Adélie penguins. Feather-loss disorders were recorded in two downy emperor penguin chicks. Data on the occurrence of identified abnormalities and disorders are given. These cases provide a baseline for assessing changes in the frequency of physical abnormalities in these Antarctic penguin species.

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Key words: colour aberrations, abnormalities, aberrant eggs, physical deformities, penguins

INTRODUCTION

Penguins are an important component of Antarctic ecosystems that make up *c*. 90% of the avian biomass (Bargagli 2005). Multifaceted studies of penguin populations allow us to understand the current status, assess threats, and take adequate protective measures for their long-term survival (Trathan *et al.* 2015; Ropert-Coudert *et al.* 2019).

To date, a wide range of colour aberrations, physical deformations, and egg anomalies in various species of penguins have been described (e.g. Splettstoesser & Todd 1998; Voisin *et al.* 2002; Morandini *et al.* 2019). However, a better understanding of the factors affecting the occurrence of such anomalies in penguins, and the

frequency of occurrence and survival of abnormal individuals is needed.

This paper presents information on physical abnormalities in emperor penguins (*Aptenodytes forsteri*) and Adélie penguins (*Pygoscelis adeliae*) at the Haswell archipelago, East Antarctica, over a period of almost 60 years of non-annual monitoring. This extends the study of bird health in the Haswell archipelago (Golubev 2018) and develops knowledge about diseases and abnormalities of Antarctic birds. Careful recording of physical abnormalities in Antarctic penguins over long-term historical time series could be of value in monitoring the health of populations, and the extent to which they might be affected by human activities (Vanstreels *et al.* 2018a).

Received 2 December 2019; accepted 2 March 2020 Correspondence: *gol_arctic@mail.ru*

METHODS

Long-term monitoring of penguin populations was undertaken at the Haswell archipelago (Davis Sea basin, southern Indian Ocean) adjacent to the Russian Mirny Antarctic research station (12 km²; 66°33'11"S, 93°00'35"E) from 1956 to 2016. This report is based on a compilation of historical records from published literature, expedition reports, personal records by expedition members, and collections of penguin skins and eggs held solely by museums in St Petersburg, Moscow, and Yaroslavl.

The historical records are supplemented by my own observations made from 8 January 2012 to 7 January 2013, and from 9 January 2015 to 14 January 2016. Observations were made on a regular basis (almost daily) from the tops of the Radio and the Komsomol nunataks, using 8-20x binoculars. Penguin colonies on islands of the Haswell archipelago were visited on foot when fast ice was present. All images presented were taken by the author using a hand-held Canon 60D digital camera fitted with Sigma 50–500 mm zoom lens, or by other expedition researchers using other digital equipment.

On the Internet there are important and rare reports (digital images and video material) of adult melanistic individuals (at least two cases) and leucistic chick (at least one case) of emperor penguins, as well as aberrant Adélie penguins. These data have not yet been published in the scientific literature and are not included in this review.

Colonies of emperor penguins and Adélie penguins at the Haswell archipelago were discovered by the Douglas Mawson expedition in 1911/12 (Mawson 1915). The emperor penguin colony was one of the largest in Eastern Antarctica. Its size ($18,000 \pm 500$ adult individual) was estimated in the 1960s (Pryor 1968), but in the following decades it declined (Barbraud *et al.* 2011). The colony was visited and counted regularly in 2012, and on nine occasions from 28 April to 16 October 2015. Adélie penguins are the most numerous seabirds breeding at the Haswell archipelago, with six sub-colonies (Pryor 1968). These were visited less frequently than the emperor penguin colony.

Aberrant penguins and eggs were not purposefully searched for, but were found incidentally during other research programs. The ages of penguins with physical or colour abnormalities was determined by their plumage (Marchant & Higgins 1990); however, birds were not sexed. Terminology for aberrant colouration is based on Van Grouw (2006, 2013). Three unusual emperor penguin eggs were found – two very small eggs and one very large – and two very small Adélie penguin eggs were found. I presented data on 104 emperor penguin eggs size from the Haswell archipelago, average \pm SD (min–max): 119.9 \pm 6.7 (103.1–146.9) × 82.1 \pm 4.0 (72.8–92.0) mm, I.A. Mizin (2010) presented data on 15 Adélie penguin eggs size: 70.1 \pm 3.2 (64.1–77.5) × 55.8 \pm 2.2 (50.7–59.9) mm. The shape, surface structure, and pigmentation of any unusual eggs were described (Romanov & Romanova 1959), and their length and width measured to \pm 0.1 mm using Vernier calipers. Only eggs lost by emperor penguins were examined. Emperor penguin eggs were considered unusually small when <100 mm, and unusually large when >140 mm long. Adélie penguin eggs were considered unusually small when <45 mm long.

RESULTS

Aberrant emperor and Adélie penguins and unusual penguin eggs found at the Haswell archipelago from 1956 to 2016 are summarised in Table 1, and described more fully below in the same sequence.

Unusually sized eggs

Descriptions of unusual eggs

№ 1: A very small emperor penguin egg in the collection of the Department of Ornithology and Herpetology of the Zoological Institute of the Russian Academy of Sciences (ZIRAS), № 202-967 (Kamenev 1967; Fig. 1B). The egg is ellipsoidal (68.5 x 55.0 mm) and of normal colouration. The surface of the shell is covered with a thin layer of lime with thickening at the ends. The egg was frozen when found, weighed 114 g and contained no yolk (Kamenev 1967). The length and width of this egg was less than the arithmetic average size of an emperor penguin egg by 42.8% and 33.1%, respectively.



Figure 1. Normal egg (A) and very small egg (B) of the emperor penguin, found on 19 May 1966 by V.M. Kamenev in vicinity of Mirny station. Collection of the Department of Ornithology and Herpetology of ZIRAS. 14 May 2019. Photo: S.V. Golubev.

Table 1. Physical deformities, colour aberrations and feather-loss disorder of emperor penguins *Aptenodytes forsteri* and Adèlie penguins *Pygoscelis adeliae*, Haswell archipelago, Antarctica.

N⁰	Species	Type of abnormality	Name of abnormality	Age stage	Breeding status	Date	Location	Observer/ publication
1	Aptenodytes forsteri	Physical abnormalities	Very small egg	Embryo	-	19 May 1966	Surroundings of Mirny station	Kamenev 1967
2	Aptenodytes forsteri	Physical abnormalities	Very small egg	Embryo	-	10 September 2012	Near Haswell Island	SVG unpubl. data
3	Aptenodytes forsteri	Physical abnormalities	Very large egg	Embryo	-	06 June 2012	Near Haswell Island	SVG unpubl. data
4	Pygoscelis adeliae	Physical abnormalities	Very small egg	Embryo	-	08 December 1956	Haswell Island	Data of E.S. Korotkevich
5	Pygoscelis adeliae	Physical abnormalities	Very small egg	Embryo	-	18 December 1966	Haswell Island	Kamenev 1971
6	Aptenodytes forsteri	Physical abnormalities	Spinal deformity	Medium chick	-	20 November 2012	Surroundings of Haswell Island	SVG unpubl. data
7	Aptenodytes forsteri	Physical abnormalities	Spinal deformity	Medium chick	-	20 November 2012	Surroundings of Haswell Island	SVG unpubl. data
8	Aptenodytes forsteri	Physical abnormalities	Beak deformity	Chicks	-	1962	Haswell archipelago	Pryor 1968
9	Aptenodytes forsteri	Physical abnormalities	Beak deformity	Chicks	-	1962	Haswell archipelago	Pryor 1968
10	Aptenodytes forsteri	Physical abnormalities	Beak deformity	Adult	Breeder?	2012, austral spring	Haswell archipelago	SVG unpubl. data
11	Aptenodytes forsteri	Physical abnormalities	Beak deformity	Adult	Breeder?	10 October 2015	Haswell archipelago	SVG unpubl. data
12	Aptenodytes forsteri	Colour aberrations	Mutation Ino	Small chick	Non breeding	18 November 1958	Haswell archipelago	Makushok 1959
13	Pygoscelis adeliae	Colour aberrations	Dilution	Adult	Breeder?	03 February 1957	Haswell Island	Data of E.E. Syroechkovsky
14	Pygoscelis adeliae	Colour aberrations	Isabelline	Adult	Unknown	1962–1963, season	Haswell Island	Pryor 1968
15	Pygoscelis adeliae	Colour aberrations	Progressive greying	Adult	Unknown	1962–1963, season	Haswell archipelago	Pryor 1968
16	Pygoscelis adeliae	Colour aberrations	Progressive greying	Adult	Breeder	1962–1963, season	Haswell archipelago	Pryor 1968
17	Pygoscelis adeliae	Colour aberrations	Dilution	Adult	Unknown	21 December 2014	Haswell Island	Data of A. Shevelev
18	Aptenodytes forsteri	Disorder	Feather-loss disorder	Large chick?	-	1962	Haswell archipelago	Pryor 1968
19	Aptenodytes forsteri	Disorder	Feather-loss disorder	Large chick	-	1962	Haswell archipelago	Pryor 1968

 \mathbb{N} 2: A very small emperor penguin egg. The egg was ellipsoidal of normal colour. Measurements are not available as the egg broke during handling.

№ 3: Very large emperor penguin egg (146.9 × 92.0 mm). The egg was pear-shaped and of normal colour. The surface of the shell was smooth, apart from bumps near the blunt end, and abnormal calcareous formations at both poles of the shell.

The length and width of this egg exceeded the arithmetic average size of an emperor penguin egg by 18.3% and 17.8%, respectively.

№ 4: Very small Adélie penguin egg in the collection of the Department of Ornithology and Herpetology of ZIRAS (N^o 83/202-967; Fig. 2B). The egg is nearly spherical (38.4 x 36.5 mm) and smooth apart from a few calcareous formations; colouration is normal. The length and width of this egg was less than the arithmetic average size of an Adélie penguin egg by 45.3% and 34.6%, respectively.

№ 5: Very small Adélie penguin egg in the collection of the Department of Ornithology and Herpetology of ZIRAS (№ 78/105-958). This egg was found by V.M. Kamenev on 18 December 1966 in an Adélie penguin nest containing three eggs and one chick. The egg is ellipsoidal, 29.0 x 23.8 mm, and is brownish with rough texture (Kamenev 1971, Fig. 2C). The length and width of this egg was less than the arithmetic average size of an Adélie penguin egg by 58.7% and 57.4%, respectively.



Figure 2. A normal (A) and two very small; eggs of Adélie penguins, one of which was discovered on 8 December 1956 by E.S. Korotkevich on Haswell Island (B), another on 18 December 1966 in the same place by V.M. Kamenev (C). Collection of the Department of Ornithology and Herpetology of ZIRAS. 14 May 2019. Photo: S.V. Golubev.

Physical abnormalities (chicks and adults)

Physical abnormalities were recorded in four downy emperor penguin chicks (deformed spine and recurved maxilla) and two adult emperor penguins (crossing and pronounced curvature of beak). No visible physical abnormalities were found in Adélie penguins.

Descriptions of abnormalities

№ 6–7: Two downy chicks of emperor penguins were found in one of the subcolonies of this species. Their spines were deformed — twisted at 90° in the dorso-ventral plane. The chicks were at least four months old – down was absent on parts of the back, legs, and flippers. Both chicks moved with difficulty on fast ice and appeared delayed in development (in size) from other chicks (Fig. 3 & 4). They were found among about 5,000 chicks that hatched at the colony in 2012.

№s 8–9: In 1962, two emperor penguin chicks moulting into juvenile plumage had a curved maxilla that moved in horizontal apposition to



Figure 3. Moulting emperor penguin chick with a deformed spine. Surroundings of Haswell Island, 20 November 2012. Photo: S.V. Golubev.

Figure 4. Moulting emperor penguin chick with a deformed spine. Surroundings of Haswell Island, 20 November 2012. Photo: S.V. Golubev.

the mandible (Pryor 1968). The total number of chicks that hatched in that year was not reported (Pryor 1968). Therefore, to calculate the occurrence of chicks with deformed beaks, the resulting ratio is the maximum, since the number of unfertilised (empty) eggs produced annually in the colony of emperor penguins of the Haswell archipelago was not taken into account. The number of hatchlings in 1962 was 6,812.

№ 10: One adult had an abnormally downward bent beak. Aside from the anomaly of the beak, the penguin was no different from other adults. In the austral winter of 2012, 4,920 ± 250 incubating males were in the colony on 26 June. The frequency of occurrence of this anomaly was < 0.01%.

Figure 5. Adult emperor penguin (A) with a deformed beak (B, C). Surroundings of the Fulmar Island, 10 October 2015. Photo: S.V. Golubev.

№ 11: In 2015, an adult emperor penguin with an abnormally downward curved beak appeared in a colony where $11,777 \pm 300$ adults were present on 28 May. Beak deformation consisted of lateral deviation of the top of the upper jaw to the right (Fig. 5). The individual was in good condition and at the pre-moulting stage. Since the maxillae were only somewhat bent but not significantly altered, the deformation did not adversely affect its survival since the individual lived to puberty and was obviously capable of hunting and preening.

Colour aberrations (chicks, juveniles, and adults)

Colour aberrations were recorded in both penguin species and affected the expression of the melanin pigments.

Description of plumage colour abnormalities

№ 12. V.M. Makushok (1959) reported of the presence of a downy albino emperor penguin chick, which was "taken into care" on 18 December 1958. The chick had a white beak, claws, and palate, and its skin, feet, and eyes were pink; its plumage was not described (Makushok 1959). The specimen could not be located in the collections of the largest zoological museums of Russia. However, it may have been the source of a feathered juvenile emperor penguin with unusual pale plumage, which is on exhibit in the Zoological Museum of ZIRAS (Fig. 6). This specimen (male) came from Mirny and was prepared for exhibition by taxidermist M.A. Zaslavsky in 1960. However, the penguin in Fig. 6 is not an albino. The overall plumage colour is

very light, the beak and claws are pale cream. The skin on the legs is painted pink, and the (artificial) eyes are pink-red. Cream and pale brown colours remain on the feathers at the base of the beak, in places near the eyes, feet and tail, as well as in areas that normally should be dark. Thus, a small amount of melanin pigmentation was preserved in some feathers. The plumage of the penguin was possibly exposed to sunlight and faded. The plumage markings correspond to ino mutations.¹

Figure 6. A young male emperor penguin. Colour aberration: ino. Haswell archipelago. Exposition of the Zoological Museum of the ZIRAS. 15 May 2019. Photo: S.V. Golubev.

¹ Ino is defined as a strong qualitative reduction of eumelanin and phaeomelanin. Any adult bird in the wild with "white" plumage and reddish eyes is ino, not an albino. There is no pigment in the eyes of ino, but their eyesight is much better than that of albinos. Inheritance ino is recessive and gender related (Van Grouw 2006).

№ 13: A single adult "semi-albino" Adélie penguin of this species was observed among 15,000 Adélie penguins at the Haswell archipelago in 1956 (Korotkevich 1959). The feathers of the head, back, tail, and upper surfaces of the flippers were light grey, almost smoky. The beak was orange-brown, the skin on the legs was light, flesh-coloured, and the claws were bright orange. Similar birds were frequently observed paired with normal Adélie penguins at Haswell Island, but there is no evidence that they bred successfully. The "smoky" penguin was collected (Korotkevich 1959), and may be specimen № oφ-7043 in the Darwin State Museum.

Figure 7. Adult Adélie penguin. Colour aberration: dilution. Haswell Island. The collection of the State Darwin Museum. 17 May 2019. Photo: I.V. Fadeev.

This bird was collected by E.E. Syroechkovsky in the eastern part of Haswell Island on 3 February 1957 (Fig. 7). Description: dilution (quantitative reduction of melanins).

№ 14: A single abnormal "isabelline" adult Adélie penguin guarded a nest site on the north side of Haswell Island 1962 (Pryor 1968). The plumage was not described, so correct identification of the type of colour aberration is not possible. There were $35,600 \pm 500$ breeding adult Adélie penguins in late-November 1962 (Pryor 1968).

№ 15: An adult Adélie penguin with coloured glossy blue-black feathers on the head, neck, and undersides of the flippers was seen at several sites during the 1962/63 breeding season. A horizontal band of mottled feathers about 6 cm wide separated black and white areas on the breast (Pryor 1968). The bird was not associated with a nest. Description: progressive greying (partial or total loss of eumelanin and phaeomelanin in feathers caused by gradual loss of pigment cells with age).

№ 16: Also, during 1962/63, an adult male Adélie penguin was observed with a horizontal band of white feathers above each eye (illustrated by Pryor 1968). The white feathers were approximately 3 cm long and stood erect on the otherwise normally coloured head. The bird produced chicks of normal plumage. Description: progressive greying (the same reason as that for the individual №15).

Figure 8. Adult Adélie penguin. Colour aberration: dilution. Haswell Island, 21 December 2014. Photo: A. Shevelev.

№ 17: On 21 December 2014, an abnormally coloured adult Adélie penguin was observed. It moved among the incubating adults. The feathers of the head, upper body, and flippers had a delicate grey-beige colour. The tail was yellow-beige, legs were pale pink, the eyes black, the beak orangebrown, and the claws orange to reddish-black (Fig. 8). Description: dilution (quantitative reduction of melanins).

Feather loss by emperor penguin chicks

Disorders related to the loss of feathers were found in two emperor penguin chicks during 1962/63.

Description of feather loss

N 18–19: One moulting chick had a completely bare head. Another chick approximately four months old had neither down nor feathers on the lower part of the abdomen. Both chicks were smaller

than normal, and they did not survive (Pryor 1968).

DISCUSSION

An analysis of the deviations in the breeding populations of both penguin species shows us they are relative rare. From the point of view of survival, in some cases, individuals with deviations are doomed to death, in others they lead a full life. The role of abnormal individuals in reproduction is not always clear.

Unusual eggs

Abnormal eggs are rare in penguins (Peklo 2007; Morandini *et al.* 2019). At the Haswell archipelago, very few eggs of emperor and Adélie penguins were of abnormal size. Very small eggs were more

Table 2. Registration of beak deformities in the colonies of the emperor penguins *Aptenodytes forsteri* in Antarctica; size for all colonies are from Klages & Gerdes (1988), Woehler (1993), and SVG *unpubl. data*.

N⁰	Colony name	Coordinates	Date	Number of individuals with deformed beak	Colony size	Age	Source
1	Drescher Inlet	72°52′S, 19°25′W	16 January 1990	2	About 15,000 individuals	Chick	Pütz & Plötz 1991
2	Drescher Inlet	72°52′S, 19°25′W	After 1990	Several chicks	About 15,000 individuals	Chick	Pütz & Plötz 1991
3	Dawson- Lambton Glacier	76°30′S, 29°W	November 1993	2	11,700 breeding pairs	Chick	Splettstoesser & Todd 1998
4	Riiser-Larsen	72°S, 17°W	09 December 1994	1	5,900 breeding pairs	Chick	Splettstoesser & Todd 1998
5	Haswell Island	66°31′S, 93°00′E	1962	2	18,000 individuals	Chick	Pryor 1968
6	Haswell Island	66°31′S, 93°00′E	2012	1	More than 12,000 individuals	Adult	SVG unpubl. data
7	Haswell Island	66°31′S, 93°00′E	10 October 2015	1	More than 12,000 individuals	Adult	SVG unpubl. data

common than very large ones. The causes of such anomalies are not clear. Very small eggs can be the result of, for example, narrowed oviducts. In general, in birds, very small eggs have a small yolk or the yolk is absent (Romanov & Romanova 1959). In general, very small eggs are infertile and often lack a yolk. The large emperor penguin egg (N^Q 3) was fertilized and contained a yolk. This egg could have produced a chick. Since more "normal" eggs are lost during a breeding season accidentally or due to fights, the occurrence of abnormal eggs (0.1%) does not pose a problem to either penguin species.

Physical abnormalities (chicks and adults)

Penguins suffer from various physical abnormalities, such as pronounced scoliosis and cyst above eye (Voisin et al. 2002), craniofacial and beak deformations (Pütz & Plötz 1991; Splettstoesser & Todd 1998; Voisin et al. 2002; Buckle et al. 2014; Jones et al. 2015; Corbeau & Bost 2017), and threelegs (Voisin et al. 2002; Vanstreels et al. 2018a). At the Haswell archipelago, the only physical abnormalities were noted solely among emperor penguins. These comprised beak deformations (one adult, four chicks) and spinal deformities (two chicks). Physical abnormalities are generally rare and have been reported only in four emperor penguin colonies (Pryor 1968; Pütz & Plötz 1991; Splettstoesser & Todd 1998; SVG *unpubl. data*).

Permanently crossed mandibles are a relatively common anomaly among a wide spectrum of bird species. However, the frequency of beak deformities in wild birds was <1% (Pomerov 1962). In the Antarctic and Sub-Antarctic, beak deformities have been recorded in nine penguin species from all six genera (Jones et al. 2015), but have rarely been reported in the scientific literature for the Antarctic shag (Phalacrocorax [atriceps] bransfieldensis) (Casaux 2004) and the southern giant petrel (Macronectes giganteus) (Marti et al. 2008). Among Aptenodytes, cases of beak deformation were recorded in both the species (Pütz & Plötz 1991; Splettstoesser & Todd 1998; Voisin et al. 2002; Jones et al. 2015; Corbeau & Bost 2017). The causes of beak anomalies in penguins have not been established. They may be due to natural factors, mechanical influences, disorders, or diseases (including viral). For instance, the strong association between poecivirus and avian keratin disorder (AKD) in black-capped chickadees (Poecile atricapillus) in Alaska suggests a possible cause for AKD in penguins (Zylberberg et al. 2016). Survival of penguins with such anomalies is possible and depends on the nature of the beak deformation. Emperor penguin chicks with asymmetrical deformities (i.e. crossed mandibles; №s 8–9) probably do not survive, as they are likely to have difficulty in obtaining and consuming food, or caring for their plumage. Emperor penguins №s 10 and 11 survived and reached the adult stage because the deformation of their beaks was slight and did not impair beak function.

Colour aberrations

Colour aberrations are diverse and widespread among many species of birds, but remain rare. Among scientists, there is a confusion about colour mutations in wild birds and the correct classification of these anomalies (Van Grouw 2006). Some colour aberrations are difficult to identify, and it would require careful analyses of tissue samples to identify the nature of a mutation. Not all plumage anomalies have a genetic basis, but can result from feather wear due to a combination of factors encountered by birds (Vanstreels *et al.* 2018b). In this review, I based identification of the colour aberrations on Van Grouw (2006) but this is open to further interpretation and criticism.

Abnormal colouration is rarely recorded in the genus *Aptenodytes*. Colour aberrations, such as melanism, are more commonly reported in king penguins (*Aptenodytes patagonicus*) (Van Wyk 1995; Blight & Stevens 2000; Oosthuizen & de Bruyn 2009) than in emperor penguins. In the reports of colour abnormalities in penguins, emperor penguins are absent (Everitt & Miskelly 2003; Juáres *et al.* 2011). Albinism, leucism, brown, dilution, ino, and melanism are among the most common mutations in birds (Van Grouw 2006, 2013). At the Haswell archipelago, among Adélie penguins, dilution and progressive greying appears to be most common. According to the ino mutation survey performed by M.A. Juáres and colleagues (2011), cases of albinism among penguins are not clearly documented and there is no certainty that such aberrations were well established. It is well known that albinos have difficulties with acuity and become easy prey for predators and suffer from other dangers (Van Grouw 2006, 2013).

Feather-loss disorder

The feather loss disease was recorded in African (*Spheniscus demersus*), Magellan (Kane *et al.* 2010), Adélie (Barbosa *et al.* 2015; Grimaldi *et al.* 2015; Varsani *et al.* 2015), and emperor penguins (Ropert-Coudert *et al.* 2019). The cause of this phenomenon remains unknown.

Feather-loss in emperor penguin (Nºs 18 and 19) chicks was recorded only once at the Haswell archipelago (Pryor 1968). The survival of individuals affected by this type of disorder is likely to be limited.

CONCLUSIONS

- 1. For almost 60 years of observation, 19 cases of abnormalities and disorders were recorded in emperor and Adélie penguins, including eleven cases of physical abnormalities and six cases of colour aberrations.
- 2. The origin of abnormalities, the survival of abnormal individuals and their reproductive contribution are not well understood.
- 3. Data analysis (Table 2) suggests that the detection of abnormalities is most feasible in relatively large colonies (~ 6,000 breeding pairs). Abnormalities are more frequently encountered in Adélie penguin colonies, since their colonies are often larger than those of emperor penguins, and many Adélie penguin colonies are logistically more accessible or in close proximity to polar stations and temporary field research bases.
- 4. Recording the types and the frequency of occurrence of physical anomalies in the colonies of Antarctic penguins should continue to improve our understanding of the occurrence of aberrations in these populations.

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SHORT NOTE

Recoveries of Hutton's shearwaters (*Puffinus huttoni*) from Kaikōura, New Zealand

LINDSAY K. ROWE* T198 24 Charles Upham Drive, Rangiora 7400, New Zealand

GRAEME A. TAYLOR Department of Conservation, PO Box 10420, Wellington 6143, New Zealand

The Hutton's shearwater (Puffinus huttoni), first described by Mathews (1912), is currently classified by BirdLife International (2018) as "Endangered" and as "Threatened - Nationally Vulnerable" under the New Zealand Threat Classification system (Robertson et al. 2017). It is a small black-andwhite shearwater (length 36–38 cm; weight 365 g; Marchant & Higgins 1990) whose breeding grounds were unknown to the scientific community until 1965, when, following up on anecdotal reports from Māori, musterers, hunters, and Kaikoura locals of "muttonbirds" nesting in burrows high in the Seaward Kaikōura Ranges, Harrow (1965) found breeding colonies in the headwaters of the Kowhai River (42.26°S, 173.60°E) at altitudes between 1,200 and 1,800 m a.s.l. The New Zealand Department of Conservation (DOC) identified the Hutton's shearwater as a threatened species requiring medium term action for its recovery (Molloy & Davis 1992).

From DOC banding archives, the first Hutton's shearwaters were banded in March 1961 in Blenheim and Wellington. These were probably juvenile birds that were disorientated and landed on shore ("fallout" birds) while undertaking their first migration to Australia. It was not until 1966 that adult birds were first banded at the Kōwhai River colony. Since the late 1990s, a number of research projects have been conducted in the Kōwhai River colonies and the respective teams undertook a large amount of banding and recorded the band numbers of birds recovered (includes dead and recaptured birds unless specified otherwise) at colonies near Shearwater Hut. To date, over 6,500 birds have been banded including fallout birds near the Kaikōura township and over 2,300 recoveries have been recorded, mostly at the Kōwhai River colony.

The mean laying date for Hutton's shearwaters is 8 November and the incubation period is about 50 days (Cuthbert 2001). Therefore, the mean hatching date is about 28 December. Fledgling Hutton's shearwaters leave the breeding grounds from mid-March to early-April to undertake their first migration to Australian waters (Harrow 1976; Rowe 2018). Generally, young birds do not usually return to the breeding colonies until they are in at least their third year but they can return as near 2-yearolds, an uncommon occurrence but observed at Te Rae o Atiu (LKR *unpubl. data*), the colony established on the Kaikoura Peninsula by translocating chicks from the Kowhai River (Miskelly et al. 2009; Rowe 2014). Thus, when determining the ages of birds banded as adult birds here, we have considered the average hatching date to be 1 January and have added 3 years to the time between banding of adult

Received 15 October 2019; accepted 8 November 2019 *Correspondence: *lindsay.jan.rowe@xtra.co.nz*

Table 1. Minimum ages of Hutton's shearwaters recovered alive at the Kōwhai River, Seaward Kaikōura Range. The age for adults includes a conservative allowance of 3 years for time spent in Australian waters as young birds. * no banding record held by DOC - see text.

Ban num	d 1ber	Banding date	Recovery date (s)	Age at last recovery (years)
Band	ded as ac	lults		
>	(8716	06 December 1983*	13 December 2011, 21 November 2012	31.9
>	(8714	06 December 1983*	11 September 2001, 22 September 2003	22.7
>	K11026	10 January 1996*	16 November 2012, 11 November 2014	21.9
>	(8878	07 October 1983	13 September 2001	20.7
>	(9861	06 March 1996	13 December 2010, 13 December 2011, 15 December 2011, 13 December 2012	19.9
>	(9898	06 March 1996	13 December 2010, 13 December 2012	19.9
>	(10529	05 March 1996	13 December 2010, 11 December 2011, 13 December 2012	19.9
>	X11100	05 March 1996	08 December 2010, 13 December 2010, 26 November 2012, 13 December 2012	19.9
>	(5037	30 November 1994	13 December 2011	19.9
>	(4755	28 February 1994	13 January 2010	19.0
Band	ded as pu	ulli		
>	(9896	06 March 1996	13 November 2011, 19 January 2015	19.0
>	(8360	10 March 1987	17 September 2001, 21 October 2004	17.8

birds and recovery. This will give conservative estimates of ages for birds when recovered, as adult birds could have been up to 20+ years old at the date of banding. It is likely that the oldest birds recovered will have been young birds when banded so the estimated age for these birds will be closest to the real age. Table 1 lists the birds with the longest recovery periods; only two of these birds were banded as pulli and were, therefore, of known age when recovered.

Recoveries from the Kōwhai River

X8716 This bird was sighted on 13 December 2011 and again on 21 November 2012 (Table 1). The DOC database does not have a record of the banding date, but the band was issued by the New Zealand Wildlife Service on 8 July 1983 (S. Taylor, DOC, *pers. comm.* 15 June 2018) to researchers who only banded Hutton's shearwaters at the Kōwhai River on 7 October 1983 (38 birds, data filed with DOC) and 6 December 1983. Therefore, using 6 December 1983 as the banding date we would get a realistic minimum age. The two recoveries in different seasons by different observers give credence to the sightings and the minimum age of 31.9 years for a bird still alive in 2012. **X8714** This was another bird probably banded the same day as X8716 and found 22.7 years later. **X11026** was recovered in 2012 and 2014 but there is no banding record in the DOC database. Bands X11001–X11100 were issued to DOC Nelson and X11092–X11100 were used on 5 March 1996. A field notebook reference to a trip 3 months earlier, 8–13 January 1996, has "caught *c*. 90 birds on surface – no retraps" (GAT *unpubl. data*). It seems logical for these to be the 91 unrecorded bands used on that trip so we used 10 January 1996 as the banding date for birds in the missing sequence. Thus, the last recovery date for X11026 implies a minimum age of 21.9 years.

The next longest living birds banded as adults were all a minimum of about 19–20 years old. The two oldest known-age birds, i.e. banded as chicks, were 19.0 and 17.8 years old (Table 1).

Manx shearwaters (*Puffinus puffinus*) can live over 50 years (BTO 2019; Welsh Wildlife Centre 2019), much longer than the maximum Hutton's shearwater recovery here, 32 years, which is longer than other small shearwaters in New Zealand. For example, a fluttering shearwater (*P. gavia*) banded as an adult was found dead 27.1 years later while the **Table 2.** Recoveries of banded Hutton's shearwaters on New Zealand coasts at >100 km point distance from Kaikōura. All birds were found dead except X12407 which was found alive but died in captivity. See Fig. 1.

Band	Date banded	Age at banding	Banding locality	Date recovered	Locality	Point distance from Kaikōura (km)	Duration (years)
X12384	24 October 1997	Adult	Kōwhai River	28 November 2010	90 Mile Beach	807	13.1
X12791	07 March 1998	Pullus	Kōwhai River	05 February 2005	90 Mile Beach	804	6.9
X12407	24 October 1997	Adult	Kōwhai River	27 October 2002	W of Auckland	598	5.0
X14266	21 October 2004	Adult	Kōwhai River	02 December 2011	Raglan Harbour	484	7.1
X9867	06 March 1996	Adult	Kōwhai River	22 December 2010	Whareakeke Beach, Dunedin	470	14.8
X12355	24 October 1997	Adult	Kōwhai River	10 January 2003	10 km S of Oamaru	395	5.2
E3801	20 March 1961	Juvenile	Wellington	27 March 1961	35 km S of Gisborne	364	0.02
X10933	09 January 1997	Adult	Kōwhai River	10 October 2101	Timaru	302	4.8
X3382	01 November 1985	Adult	Kōwhai River	05 December 1987	Foxton Beach	214	2.1
X12530	31 October 1997	Adult	Kōwhai River	13 September 2008	Otaki Beach	209	10.9
X13145	12 November 1998	Adult	Kōwhai River	27 January 2008	Taumutu Beach	209	9.2
X12567	15 November 1997	Adult	Kōwhai River	14 January 1999	Pines Beach, Kaiapoi	146	11.2
X5676	18 January 1995	Adult	Kōwhai River	05 January 2004	North Brighton Beach	138	9.0



Figure 1. Locations where banded Hutton's shearwaters were recovered in New Zealand. See Table 2. (Picture: Google Earth 7 November 2019)

oldest New Zealand little shearwater was seen only 19.3 years after banding as an adult (M Bradshaw, DOC, *pers. comm.*).

Recoveries from New Zealand

Only 13 banded Hutton's shearwaters have been found on New Zealand beaches over 100 km from the banding site (Table 2; Fig. 1). Six birds were found south of Kaikoura between 10 October and 27 January. These would have been birds from the Kowhai River colony on expeditions to the feeding grounds as recently shown by Bennet et al. (2019). Another six were found on the west of the North Island and these fit the pattern of beach patrol recoveries that has shown birds are mainly found there from September through February (e.g. Imber & Crockett 1970; Powlesland & Pickard 1992). E3801 was the sole bird found on the North Island east coast and was a juvenile banded in Wellington in March, a fallout bird, and suggests that some young birds migrating to Australia might travel up the east coast and pass around North Cape.

Recoveries from Australia

To date, seven banded Hutton's shearwaters have been recovered on Australian shores (Table 3; Fig. **Table 3.** Recoveries of banded Hutton's shearwaters in Australia. All birds were found dead except X19085 which was found alive, rehabilitated and released. See Fig. 2.

Band	Date banded	Banding locality	Date recovered	Locality	Point distance from Kaikōura (km)	Duration (years)	Age at banding
X11645	13 September 2001	Kōwhai River	11 April 2003	50 km W of Albany	4,880	1.9	Adult
E76201	31 March 1969	Kaikōura, released at a Christchurch Beach	30 November 1970	230 km ENE of Albany	4,700	1.7	Juvenile – fallout
X12681	07 December 1997	Kōwhai River	15 February 2011	Kangaroo Island, South Australia	3,330	13.3	Adult
X15707	21 October 2004	Kōwhai River	08 April 2006	Toogoom, 270 km N of Brisbane	2,680	1.5	Adult
X2463	19 February 1972	Kōwhai River	09 April 1978	Bass Strait, 150 km SW of Melbourne	2,550	6.1	Adult
X1926	27 March 1976	Kaikōura	05 April 1976	220 km S of Brisbane	2,330	9 days	Juvenile – fallout
X19085	25 March 2014	Kaikōura	01 April 2014	Nambucca Heads, 350 km S of Brisbane	2,260	7 days	Juvenile – fallout





2). Apart from E76201, all recovery dates fit with birds leaving New Zealand in late summer/early autumn heading to winter feeding grounds in northern Australia. Three birds were found on the south coast possibly heading towards the feeding grounds in the Indian Ocean off NW Australia, and three more were found on the east coast heading to Torres Strait and then, perhaps, on to the Indian Ocean grounds. This indicates that birds, if they do circumnavigate Australia as hypothesised by Warham (1981), may travel along either route. That Hutton's shearwaters have been found off all coasts of Australia (Warham 1981; Marchant & Higgins 1990) supports this notion. The recovery of E76201 on 30 November 1970 banded as a juvenile on 31 March 1969 suggests it could be returning to New Zealand as a near 2-year-old. Alternatively, Halse (1981) suggested some non-breeders might spend part of the breeding season in southern Australian waters.

Two juveniles, both fallout shearwaters, X1926 and X19805, were found on the New South Wales/ Queensland coast. On their maiden flights from the Kōwhai River colony, these birds made landfall in the Kaikoura township instead of reaching the sea. These birds were collected at night, held until banding the next morning and released at sea shortly thereafter. There, they had to become used to diving and feeding themselves, and then depart for Australian waters, where in the case of X19805, it was found alive on a beach at Nambucca Heads (30.65°S, 153.02°E, Fig. 2), all in less than seven days. Assuming it took five days (a day to get used to being a shearwater at sea, and it crashed ashore the day/night before recovery) to fly a minimum of 2,440 km if it went through Cook Strait rather than around North Cape (3,300 km), it travelled at a rate of about 500-600 km/day. X1926 was found dead 150 km north of Nambucca Heads nine days after banding.

This note has shown that, from banding and recovery records, Hutton's shearwater longevity is >30 years, migration to and from Australia is likely to be through Cook Strait and along the west coast of the North Island, and departing fledglings likely spend little time in New Zealand waters before heading to Australian waters.

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Keywords: *Puffinus huttoni*, Hutton's shearwater, longevity, recoveries, migration

SHORT NOTE

Observations of New Zealand kingfisher (*Todiramphus sanctus*) foraging on insects associated with artificial sugar-water feeders

DARIA A. ERASTOVA* MARGARET C. STANLEY The University of Auckland, School of Biological Sciences, Private Bag 92019, Auckland, New Zealand

Feeding birds in residential backyards is becoming more popular worldwide, and allows residents to connect with nature (Cox & Gaston 2016). The popularity of urban bird feeding is probably driven by birds, unlike other life forms, being conspicuous and associated with aesthetic pleasure (Jones 2018). However, while often aimed at supporting specific birds, these feeders can attract other animals that take advantage of opportunities associated with supplementary food. For example, seed feeders set out for granivorous birds are often visited by other granivores, such as squirrels (Sciuridae), rats (*Rattus* sp.), and raccoon (*Procyon lotor*), as well as predatory birds that take advantage of the aggregation of prey species (Hoff 2005).

In New Zealand, feeding birds in residential backyards is a popular practice (Spurr 2012), with a recent study identifying about half of New Zealand households feeding birds in their gardens (Galbraith *et al.* 2014). Furthermore, almost 20% of households provided sugar-water, a food source aimed at attracting native nectarivorous birds (Galbraith *et al.* 2015). Our research focusses on the effect of residential garden sugar-water provisioning on the behaviour and health of native New Zealand nectarivorous bird species, such as tūī (*Prosthemadera novaeseelandiae*, hereinafter

binominal nomenclature follows Gill *et al.* 2010), bellbird (*Anthornis melanura*), and silvereye (*Zosterops lateralis*).

Sugar-water feeders are becoming an increasingly prevalent means of encouraging native birds to New Zealand gardens, but they also have potential to attract insects, such as Hymenoptera (particularly bees, wasps, and ants) or Diptera (flies), to a concentrated food source, which in turn may act as a food source for insectivores. Here we report on a previously unpublished observation that occurred during behavioural data collection associated with our sugar-water feeder project. One of the authors (DAE) observed a New Zealand kingfisher (Todiramphus sanctus vagans) foraging for flies attracted to a sugar-water feeder.

Kingfishers (Halcyonidae) are а group of conspicuously coloured birds distributed throughout the world (Woodall 2001). Some of these birds are associated with water and aquatic prey, caught via aerial attack from a perch (Schockert 1998; Laudelout & Libois 2003; Libois & Laudelout 2004; Čech & Čech 2015). However, some species, particularly those inhabiting inland habitats, prey on a wide range of small animals (Ali 1996; Soud et al. 2010). The New Zealand kingfisher has a diverse range of prey, including lizards (Mead 1947; O'Donnell 1981; van Winkel & Ji 2012), crabs, tadpoles, crayfish, small fish, insects, spiders, mice,

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and small birds (McKinlay 2013).

In November 2018, the volunteer householder at one of our study gardens alerted us that he had observed a kingfisher visiting his garden occasionally ("sometimes every day, but then gaps of several weeks"; not specific to a season) throughout the preceding two years. The householder, whose garden is located in the Grey Lynn suburb of Auckland (coordinates 36.860°S, 174.737°E), and who has been providing birds with sugar-water for the last five years, witnessed a kingfisher foraging on the insects visiting one of his two feeders in early afternoons. The householder was unable to give us more details on the nature of these insects; however, he observed "some big flies" around the feeder. One of the authors (DAE) also observed bees visiting the feeder on the 30 November 2018 and 14 August 2019. The feeder in question was a handmade feeder, a wooden trough design, permanently installed on a tree. This open-style construction does not exclude insects and should not prevent larger birds, such as kingfishers, from catching insects feeding on the sugar-water. Later, on the 12 December 2018, 9 June, and 14 August 2019, DAE saw or heard a kingfisher in this garden (a total of 4 times) during behavioural observation periods, but never witnessed it foraging there.

One of the other study gardens is located within the same suburb, only 1.5 km away from the aforementioned garden. Although the householder reported observing a kingfisher in his garden from time to time, we had never observed any individuals of this species in the garden. However, on the 14 August 2019, DAE was collecting behavioural data in this garden and saw a kingfisher visit the backyard three times despite a resident tuī pair vigorously attempting to chase it away. This unusual behaviour was conspicuous to the observer. When the pair of tuī moved out of the garden, the kingfisher entered the garden again and perched within the large gingko tree (Ginkgo biloba) to which the feeder was attached (Fig. 1). This feeder is a commercial aviary feeder type, which consists of a 3 L inverted white plastic bottle on an open dish, within a wooden frame. A few moments later the kingfisher slightly turned to face the feeder, then plunged swiftly downward. As the bird reached the feeder, it hovered for less than a second at the feeder and caught a large black fly crawling on the outside of the feeder bottle. Immediately after catching its prey, the kingfisher beat its wings vigorously to gain height and flew away from the garden. The feeder bottle was white, so provided an easy visual contrast for the kingfisher to detect insects.

Other studies have found that kingfishers, such as white-breasted kingfisher (*Halcyon smyrnensis*), include Diptera (flies) and Hymenoptera (bees, wasps, ants) in their diet (e.g. Asokan *et al.* 2009).



Figure 1. The feeder at which the New Zealand kingfisher behaviour was recorded. The white feeder colour made visiting insects conspicuous.

However, to the best of our knowledge there are no previous published observations of kingfishers in either New Zealand or elsewhere hunting for insects at sugar-water feeders. Thus, this is a single documented observation of a kingfisher taking advantage of sugar-water feeder confirmed by anecdotal observation (as reported by a householder).

Given we never marked individual kingfishers (e.g. via colour banding), we can only speculate if the observed behaviour could be a learned behaviour, potentially of a single bird visiting the two gardens in Grey Lynn. However, this assumption might be supported by the fact that such a feeding behaviour is expected to be quite rare due to the low expected population density of kingfishers in the highly urbanised inner city suburbs of Auckland (Gill 1989; Heggie-Gracie 2016) and given sugar-water feeders serve as a very unnatural and inconsistent supplementary food source. It would be interesting to investigate the potential for sugar-water feeders to support other garden insectivorous species, such as New Zealand fantail (Rhipidura fuliginosa) and grey warbler (*Gerygone igata*), through attracting and concentrating insects to a source point. Tuī, bellbird, and silvereye also include invertebrates such as Diptera species (Roper 2012) in their diet, especially during the breeding season (Kikkawa 1968, 1961; Gravatt 1971, 1970; Craig et al. 1981; Kikkawa et al. 1986; Murphy & Kelly 2003; Spurr et al. 2011; Roper 2012). Thus, this would be an additional "opportunistic" food source for these native species contributing to more available resources. The latter may support increased reproduction, hence higher densities in urban areas if it translates into increased reproduction. However, there are also a number of

potentially negative effects. First, the discovery of a new insect source by introduced insectivorous birds, might lead to physical exclusion of smaller native nectarivores, such as silvereyes, that cannot compete for feeder access with larger birds (DAE *pers. obs.*). Second, kingfisher diet includes small birds (McKinlay 2013), so there is a risk of predation of smaller birds, such as silvereyes. Such predation may then have a negative influence on householders' attitudes to sugar-water feeding.

We encourage other researchers and/or observers to report any events of invertebrate consumption by insectivorous birds at sugar-water feeders in New Zealand gardens, so that we might better understand the prevalence of this behaviour and the potential importance it may have for native urban bird communities.

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Keywords: sugar-water feeder, sacred kingfisher, *Todiramphus sanctus*, feeding behaviour, New Zealand

SHORT NOTE

First record of a New Zealand banded red-billed gull (*Larus novaehollandiae scopulinus*) recovered from mainland Australia

JAMES A. MILLS* 3 Miromiro Drive, Kaikoura 7300, New Zealand 10527A Skyline Drive, Corning New York 14830, USA

JOHN W. YARRALL 14 Ashgrove Court, Lincoln, Christchurch 7608, New Zealand

DEBORAH A. MILLS 3 Miromiro Drive, Kaikoura 7300, New Zealand 10527A Skyline Drive, Corning New York 14830, USA

On 8 September 2017, an individually colour-banded red-billed gull (*Larus novaehollandiae scopulinus*) (L.L. blue/metal, R.L. red/yellow/white) that was banded at the Kaikoura Peninsula colony (42°26'S, 173°42'E) was found washed up freshly dead on a beach near Woolgoolga, New South Wales (30°07'S, 153°12'E), 459 kilometres north-east of Sydney, Australia, by Graham Jupp. Ten days later Gay Bell reported seeing the same dead bird on the beach. The gull, E203088, was found on the high tide mark and was estimated to have been there less than two weeks.

The red-billed gull breeding colony at Kaikoura is the largest in New Zealand (Frost & Taylor 2018; Mills *et al.* 2018). The species is highly philopatric; during the breeding season adults and their adult offspring return annually to Kaikoura to breed or as non-breeders (Mills 1989; Mills *et al* 2008) They are attracted to the Kaikoura region because of the abundance of the euphausiid, Nyctiphanes australis, which inhabit the continental shelf area off the Kaikoura Coast (Mills et al. 2008). Outside of the breeding season, some gulls remain in the environs of Kaikoura but others disperse, with the majority spending the autumn and winter within 300 kilometres of Kaikoura. The population at Kaikoura has been banded annually for 59 years and studied for 54 years. Between 1958 and 2017, 76,878 chicks and 5,972 adults have been banded. Of these, 5,077 have been individually colour-banded, and a further 7,914 have had a single colour band. The bird recovered in Australia is the first known banded individual to be sighted, or recovered, outside of the mainland of New Zealand.

Red-billed gulls have been reported as rare stragglers to Lord Howe Island and the Kermadec Islands (Gill *et al.* 2010). In the past, red-billed gulls from mainland New Zealand have reached and established small breeding colonies on the outlying

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Chatham and Snares Islands and the Subantarctic Campbell and Auckland Islands. A genetic study of individuals from the small Subantarctic Campbell population, located 600 kilometres south of New Zealand, demonstrated that the population has become differentiated from the New Zealand mainland population (Given 2004), indicating that there has been limited or no recent gene inflow. The Campbell population have slightly shorter but stouter bills (Falla *et al.* 1966). Over the past several decades researchers visiting the Chatham, Snares, Auckland, and Campbell Islands have been asked to look for banded or colour-banded red-billed gulls, but none has been found.

LIFE HISTORY OF E203088

The gull found dead in Australia was 9 years and 10 months old. It was banded as an 8-day old nestling at the Kaikoura Peninsula on 19 November 2007, when a single white band was added. It was the second chick hatched from a clutch of two eggs laid by E202173, a five-year-old female, and a male of unknown age.

The bird was subsequently captured as a 2-year-old, non-breeder in 2009, sexed as a female by standard measurements (Mills 1971) and individually colour-banded. The bird remained as a non-breeder for the next two breeding seasons, and first bred in 2012 as a 5-year-old. Its partner was another female. Female-female pairings make up approximately 6% of the breeding pairs at Kaikoura (Mills *et al.* 1996). This arises because there is an excess of females in the population and many females have difficulty in obtaining male partners (Mills *et al.* 1996). The pair did not breed in 2013, but resumed breeding together in the 2014, 2015, and 2016 breeding seasons.

Outside of the breeding season, the gull was seen at the Waitangi Park Beach near Oriental Bay, Wellington on 18 August 2014 by Dr Hugh Robertson. It is possible that the gull returned annually to Wellington Harbour during the autumn and winter, as it is common for individuals to spend the non-breeding period in the same locality in subsequent years (JAM *unpubl. data*).

It is likely that the bird was blown off the New Zealand coast during a storm. It would be surprising that a bird that has regularly returned to Kaikoura and had an established breeding pattern would voluntarily travel to Australia.

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Keywords: red-billed gull, *Larus novaehollandiae scopulinus*, Kaikoura population, Australian recovery

SHORT NOTE

Large-scale hail-induced mortality in white-fronted tern (*Sterna striata*) and black-billed gull (*Larus bulleri*) breeding colonies on the Rangitata River, New Zealand

KERRY A. WESTON* Biodiversity Group, Department of Conservation, Christchurch, New Zealand

IAN FRASER Operations Unit, Department of Conservation, Geraldine, New Zealand

Extreme weather events can pose a serious threat to bird populations due to the potential for direct impacts on vital rates such as survival and breeding success. There is increasing concern that extreme weather events may have even stronger effects on the population dynamics of some species than mean, long-term changes in climate (Moreno & Møller 2011; Jenouvrier 2013; Maxwell *et al.* 2019). For example, birds which flock or form large colonies for breeding are more vulnerable to localised stochastic events than more dispersed species.

Hail storms pose a potential threat to birds that breed or flock in open habitats, such as river beds. Large-scale avian mortality events resulting from severe hail storms have been recorded overseas across a range of avian groups, including shorebirds (Higgins & Johnson 1978; Narwade *et al.* 2014) and grassland species (Sarasola *et al.* 2005; Carver *et al.* 2017). Reports of hail storms affecting birds during the nesting cycle are less common. Carver *et al.* (2017) reported a 50% nest loss rate among *c.* 200 nests and widespread adult mortality among mostly Lark Buntings (*Calamospiza melanocorys*) following a hailstorm in northern Colorado, USA. Hightower *et al.* (2018) reported a similar nest loss rate in sagebrush songbirds at 47 hail damaged nests in central Wyoming, USA. Nest losses among several species were also reported among the damage during a series of severe hailstorms in Western India from February to May 2014 (Narwade *et al.* 2014). Over 62,000 dead birds from 35 species were recovered, in what appears to be the largest hail-induced mass mortality ever recorded.

The formation of large hail stones (larger than 2.5 cm in diameter), is often related to severe thunderstorms with strong convection and updrafts (Prein & Holland 2018). In many regions of the world, including New Zealand, the frequency of such storm events is increasing, or is predicted to increase, as a consequence of anthropogenic climate change (Trapp *et al.* 2007; Seneviratne *et al.* 2012; Brimelow *et al.* 2017; Sanchez *et al.* 2017; MFE 2018; Prein & Holland 2018).

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Given the potential for large-scale impacts of severe storms on local bird populations, it is important to document and build an understanding of species responses to these extreme weather events. Here, we describe the impacts of a severe hailstorm on two bird species which breed in braided river ecosystems. The white-fronted tern (Sterna striata) is a predominantly coastal native species currently classified as At Risk (Declining) by Robertson et al. (2017). The black-billed gull (Larus bulleri) is endemic, breeds mainly in braided river beds, and is currently classified as Threatened (Nationally Critical) by Robertson et al. (2017). We are unaware of any previous records of a severe hailstorm causing large-scale mortality or nest failure among bird populations in New Zealand.

On 14 November 2019, a large breeding colony of 3,000–4,000 white-fronted terns, with nests containing 1–2 eggs, was located by Department of Conservation (DOC) staff at the Rangitata River mouth, South Canterbury (44.19°S, 171.51°E). Approximately 100 black-billed gulls were also nesting in two areas, one at either end of the tern colony. A total of 42 gull nests were counted, each containing 1–3 eggs (n=50 eggs). No chicks of either species were observed. On 20 November 2019 between 12:48 pm and 1:20 pm, an extreme weather event producing large hail stones *c*. 2–4 cm in diameter (Fig. 1a) passed over the Rangitata River Mouth.

Following a report from a member of the public on 21 November 2019 of numerous dead and injured birds at the site, the colonies were revisited by DOC staff. On arrival at the colony on 21 November 2019, hundreds of dead and injured birds were observed (Fig. 1b, c). From 21-22 November, 267 white-fronted terns and 21 black-billed gulls were found to have sustained serious injuries and were euthanised. The carcasses of c. 300 white-fronted terns and 70 black-billed gulls (including many of the euthanised specimens) were recovered on 22 November, with a further *c*. 360 dead birds recovered on 27 November yielding a total of c. 650 dead white-fronted terns and c. 80 dead black-billed gulls. This equates to over 95% of the black-billed gull colony destroyed, and 16-22% of the whitefronted tern colony.

The great majority of injured birds had suffered significant and conspicuous injuries to their wings, including compound fractures, and were incapable of flight. Some birds had no obvious external injuries but made no attempt to move away when approached. All birds that were euthanised were essentially incapable of flight and were caught either by hand or using a short hand net. Some injured birds, especially black-billed gulls, entered the water (braids of the Rangitata River) when approached and were carried away downstream, unable to be recovered.



Figure 1. (a) photo taken during the hail storm showing the large size of the hailstones compared with a golf ball (scale; short side of NZD5 = 69 mm), (b) critically injured white-fronted tern following hail storm, and (c) section of the white-fronted tern and black-billed colony after the hail storm. Photo credits: Steve Cowie, Anna Aichele, and Clare Halpine.

In addition to the dead and injured birds, a large number of broken eggs of both species were noted. While it is possible that some of these eggs had been preyed on or scavenged in the 36 hours between the hail storm and the first visit to the site, or by adult birds stepping on eggs during the storm, it seems more likely that the majority of damage was caused directly by hail stones.

Impacts of the hail storm on breeding colonies appeared to have been very localised. Another large colony of white-fronted terns (thousands of birds) was recorded on the northern side of the Rangitata River mouth, only *c*. 600 m from the affected colony. This colony was also visited on 22 November, but fewer than 10 injured birds were observed, and all of these were still capable of flight when approached.

Damage to infrastructure, including broken skylights and spouting, was also reported by residents within the small settlement of Rangitata Huts (44.19°S, 171.50°E), immediately south of the colonies.

The damage observed at the Rangitata breeding colonies demonstrates the substantial impact that an extreme weather event producing large hail stones can have on local populations of threatened and at-risk bird species in New Zealand. While numerous studies have demonstrated large-scale avian mortality associated with extreme weather events, the longer-term population consequences are difficult to quantify given the rarity and randomness of these events, and the lack of longterm data over an appropriate time scale (Jenouvrier 2013). However, using 26 years of reproductive data, van de Pol et al. (2010) showed a decrease in local population viability of Eurasian Oystercatchers (Haematopus ostralegus) in response to an increased frequency of catastrophic nest flooding events.

In combination with other threats to braided river birds such as ongoing habitat loss and predation (Sanders & Maloney 2002; Cruz et al. 2013), the increased frequency of damaging extreme weather events is likely to negatively affect the population trajectories of already threatened and at-risk species. Braided river birds are often considered well-adapted to breeding within an unstable and flood-prone ecosystem and many species are able to renest in response to losses (Beer 1966; Hughey 1985). However, events that cause adult mortality in addition to reproductive failure are likely to have a disproportionate influence on population dynamics, as is usually the case for longlived species (Sæther & Bakke 2000). It is therefore increasingly important that stochastic weather events are built into population models to inform future management.

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Keywords: extreme events, hail storms, severe weather, climate change, braided river birds

SHORT NOTE

Eurasian tree sparrow (*Passer montanus*) recently established on Guadalcanal, Solomon Islands

SCOTT C. BUTCHER Pacific Planning and Community Development Solutions, 62a Rockinghorse Road, Southshore, Christchurch 8062, New Zealand

ANDREW C. CROSSLAND* Limnodromus International, 42 Lignite Drive, Rolleston 7614, New Zealand

PHILIP CRUTCHLEY Regional Parks Team, Parks Unit, Citizens & Community Group, Christchurch City Council, PO Box 73014, Christchurch 8154, New Zealand

NIALL D. MUGAN. Keystone Ecology, 326 Halswell Road, Halswell, Christchurch 8025, New Zealand

KELLINGTON SIMEON Pacific Horizons Consulting Ltd, 17 NPF Plaza, Point Cruz, Honiara, Guadalcanal Solomon Islands

The Eurasian tree sparrow (*Passer montanus*) is a widespread species, naturally occurring across most of Europe and Asia, including South-East Asia (Summers-Smith 1988; del Hoyo *et al.* 2016). It has been naturalised in many parts of the World including the south-western Pacific region where it has been introduced into parts of Micronesia, New Guinea, New Britain, New Ireland, and Australia (Pratt *et al.* 1987; van Perlo 2011; Pratt & Beehler 2015; BirdLife International 2017). Introductions have been both deliberate and accidental, the latter

usually attributed to birds carried to new locations aboard ships (Summers-Smith 1988; Clement *et al.* 1993).

Eurasian tree sparrows were not known from the Solomon Islands until one bird was reported from Henderson Airport near Honiara, Guadalcanal, on 18 September 2004 (Dutson 2011; Tarburton 2017). Another was reported (date unknown) at Auki on Malaita (Dutson 2011), but all subsequent records were from Guadalcanal (Van Beirs 2013, 2015; Lagerqvist 2013; Hottola 2014; Gregory 2015; Van Beirs & Bergmark 2017) until very recent records of 15 birds around the docks at Buala, Santa Isabel, on 27 June 2018 (DeCicco 2018) and one bird on

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the edge of a residential area on Tulagi, Central Province, on 15 October 2019 (SCB *pers. obs.*).

From October 2014 to March 2015, November to December 2017, and October 2019 we recorded sightings of Eurasian tree sparrows on Guadalcanal in order to ascertain the distribution of this species on the island. We found birds in low numbers (single birds or small groups) in various parts of Honiara city, including the harbour and the surrounding central business district, in the hotel and business zone along Mendana Avenue, industrial areas along the Kukum Highway, the Rove Police Headquarters, and the airport terminal carpark and surrounding service areas. The species has also been reported by several ebird observers in suburban parts of Honiara. These sites are encompassed within an urban and peri-urban area measuring approximately 17 x 3 km.

On 18 October 2014, SCB located an outlying population at the Guadalcanal Plains Palm Oil 2 Ltd (GPPOL2) processing plant near Tetere Village. This is located 19 km east of Henderson airport in the middle of the oil palm plantation belt. On this first visit he found seven birds close to the main gate. We returned on 1 March 2015 and counted a minimum 67 birds (Fig. 1) feeding around the entrance gate and roosting along the security fence on the western side of the 4.6 ha facility. More tree sparrows may have been present elsewhere within the GPPOL2 site, but we did not see any along roadsides in the surrounding extensive oil palm plantations or in nearby settlements. Between 13 and 20 October 2019 SCB searched the plains east of Honiara for Eurasian tree sparrows. He confirmed their continued presence (15+ birds observed) around buildings and shipping containers at the GPPOL2 plant and also observed a single bird 500 m away at the intersection of the Tetere Beach road with the main east-west road. Despite several days searching, he did not find the species at any other location east of Honiara.

These observations confirm that, since the first



Figure 1. Sixteen of 67 Eurasian tree sparrows roosting on the eastern security fence at GPPOL2 palm oil processing plant, Guadalcanal, 1 March 2015. Inset: Eurasian tree sparrows, Guadalcanal, Solomon Islands.

sighting in 2004, the Eurasian tree sparrow has successfully established a feral population within Honiara city environs and has crossed almost 20 km of intervening agricultural and plantation areas to establish at least one outlier population at a large industrial site (Fig. 1). We estimate that the population is currently in the low hundreds with a slow incremental spread. The potential for substantial further range expansion, however, may be limited once the species fully occupies the agricultural areas on the plains east of Honiara. This is because much of Guadalcanal beyond these lowlands comprise unsuitable habitat for Eurasian tree sparrows, being mountainous and densely forested. The preferred habitat of this species in the Asia-Pacific region is around human habitation, particularly buildings, road-sides and gardens (Summers-Smith 1988). Further spread would therefore likely be confined to inland road corridors and to scattered villages around the coastline.

As has been the case in other parts of the Pacific and New Guinea where this species has colonised, dispersal between islands seems most often to be ship-assisted (Summers-Smith 1988; Pratt & Beehler 2015; del Hoyo *et al.* 2016). They could therefore reach any of the many islands in the Solomons Archipelago, particularly in areas where ships arrive directly from Honiara or from overseas ports where the species is common. We encourage other ornithologists visiting the Solomons to continue to document the spread of Eurasian tree sparrows on Guadalcanal, and to report sightings on other islands.

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Key words: Eurasian tree sparrow, Solomon Islands, Guadalcanal

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SHORT NOTE

A little penguin (*Eudyptula minor*) from South Bay, Kaikōura, New Zealand with a unique breeding history

LINDSAY ROWE* T198 24 Charles Upham Drive, Rangiora 7400, New Zealand

JODY WEIR

Kaikōura Ocean Research Institute Inc. (KORI), c/o Takahanga Marae, PO Box 39, Kaikōura 7340, New Zealand

The little penguin is considered a species of "least concern" (BirdLife International 2018) but recently under the New Zealand Threat Classification it has been downgraded within the "At Risk: Declining" category (Robertson *et al.* 2017). There is also continuing uncertainty about the taxonomy of little penguins, and hence, all little penguins including the white-flippered morph have been placed into one species, *Eudyptula minor*, awaiting further clarification (Gill *et al.* 2010). Wilson & Mattern (2018) have recently undertaken a review of the state of knowledge and priorities for research on little penguins.

In 2006, LR began a study at South Bay, Kaikōura, (42.43°S, 173.68°E) where the main concentration of little penguins on the Kaikōura Peninsula is located (Fig. 1). Rowe *et al.* (2020) reported the background to the study and breeding by little penguins over 11 seasons. Approximately weekly visits were made to the colony throughout the year to band and record penguins present, and to determine the numbers of eggs, chicks, and fledglings. While little penguins are known to have multiple broods in a season (e.g. Marchant & Higgins 1990; Flemming 2013), in New Zealand it has been reported that outside Otago penguins do not double brood (Gales 1985; Agnew *et al.* 2014; Heber *et al.* 2008). There are few, if any, studies which publicly report the detailed breeding histories of individual penguins. Here, we report on the first 11 years in the life of a little penguin, P38299, at the South Bay colony, Kaikōura. This is one of 12 little penguins known to have multiple brooded at this site (Rowe *et al.* 2020).

2010-11

P38299, a female blue-morph little penguin, was first seen on the beach outside the DOC shelter (Fig. 1) on 9 November 2010 when it was banded and a passive integrated transponder (PIT) tag inserted; this was the only sighting for that summer (Table

Received 16 October 2018; accepted 31 March 2020 *Correspondence: *lindsay.jan.rowe@xtra.co.nz*



Figure 1. South Bay (Kaikōura, New Zealand) little penguin colony showing sites where P38299 and partners nested. (Photo: Andrew Spencer).

1). All unbanded penguins that were seen ashore at South Bay were captured and banded. Those penguins that were only seen a few times or were ashore to moult and never seen again are thought to have been birds from other South Island sites. Young birds disperse widely after fledging and return to their natal colony after two or three years (Marchant & Higgins 1990). At Kaikōura, returning chicks banded between 2006 and 2015 were first seen back on average at 15.9 months old (41 birds; range 7.1-26.9 months, 95% CL ± 1.4 months). Therefore, birds first caught without bands and that have stayed at the colony after banding were probably chicks that were not able to be caught and banded before they left the colony in the previous 1–2 seasons (a season is defined as 1 April to 31 March the following year, this starting after moulting is completed). As most Kaikoura chicks hatch in late October/early November, when first seen in November 2010, P38299 may have been about 12 months-old having been assumed to have been raised at the colony during the 2009–10 breeding season.

2011-12

This season P38299 paired with P44314. The one egg found on 17 October 2011 failed, as did a single replacement egg found on 14 November 2011 (Table 1). Many little penguins first breed at about two years old (Dann 2013) but Perriman & Steen (2000) noted some bred as early as 16 months. One known age bird at South Bay was seen on an egg first at 12 months old and nine more were first seen on eggs or chicks between 23 and 27 months. Therefore, the age for P38299, now estimated at about 24 months old, is in the expected range.

2012-13

For this season P38299 paired with P44314; two eggs were laid and two chicks fledged.

2013-14

It appears that this pair, P38299 & P44314, separated about 1 May 2013 because P38299 was nesting with P44332 under the walking ramp up to the

Date	Site	Mate seen	Comment
09 November 2010	Outside DOC shelter		First sighted. Banded and PIT tagged
26 May 2011	Marina		
17 October 2011		P44314	1 cold egg
03 November 2011	Cg11	P44314	0 eggs = failed
14 November 2011	Cg11	P44314	1 egg = clutch 2
28 December 2011	Cg11	P44314	0 eggs = failed replacement
02 October 2012	Cg11	P44314	1 egg
09 October 2012	Cg11		2 eggs
30 October 2012	Cg11	P44314	1 egg + 1 egg pipping
20 November 2012	Cg11	P44314	2 chicks
01 January 2013	Cg11		2 chicks fledged = successful double brood
23 April 2013	Cg11	P44314	Last time seen together – divorce
08 May 2013	Cg ramp	P44332	New pairing – first time seen together
12 September 2013	Cg ramp	P44332	2 eggs
15 October 2013	Cg ramp	P44332	2 chicks
22 October 2013	Cg ramp		P44332 last seen – dead?
>03 December 2013	Cg ramp		2 chicks fledged
13 May 2014	Cg5	P44317	First seen with new mate
12 August 2014	Bp1	P44317	Change of nestbox; 2 eggs
20 August 2014	Bp1	P44317	2 chicks
<23 October 2014	Bp1	P44317	2 chicks fledged
29 October 2014	Bp1	P44317	1 egg = clutch 2
05 November 2014	Bp1	P44317	2 eggs
24 December 2014	Bp1		Abandoned = failed double brood
02 July 2015	Cg5	P44317	Change of nestbox; last time seen with P44317
28 July 2015	Cg5	P44345	New mate; P44317 divorced
06 October 2015	Mb5	P44345	Change of nestbox; 2 eggs
04 November 2015	Mb5	P44345	1 chick
>14 December 2015	Mb5		1 chick fledged

Table 1. The breeding history of little penguin P38299 and partners, 2010–2020, at South Bay, Kaikōura, New Zealand.

Table	1.	continued

Date	Site	Mate seen	Comment
18 April 2016	Cg9	P44345	2 eggs
23 May 2016	Cg9	P44345	2 chicks
25 May 2016	Cg9	P44345	2 chicks; last sighting of P44345 with P38299
08 June 2016	Cg5	P48417	Change of nestbox; new partner
20 July 2016	Cg9		Chicks in nestbox Cg9 now fledged
03 August 2016	Cg5	P48417	
10 August 2016	Cg5	P48417	2 eggs = clutch 2
14 September 2016	Cg5		2 chicks
>09 November 2016	Cg5		2 fledged chicks
04 December 2016	Cg4	P48417	2 eggs = clutch 3
31 December 2016	Cg4		1 egg, 1 chick
09 January 2017	Cg4	P48417	1 chick
27 February 2017	Cg4		Chick fledged = successful triple brood
31 March 2017	Cg5	P48417	Birds together
02 July 2017	Ca5		2 orge soon
02 July 2017	Cg5	D49417	
20 July 2017	Cg5	D49417	2 eggs
<01 October 2017	Cg5	140417	2 chicks flodged
<01 October 2017	Cg5	P48417	2 chicks hedged
15 October 2017	CgJ	140417	
17 December 2017	Cg5 Cg4		P38299 on 1 old egg from clutch 2 P48417 on 1 new egg = clutch 3
24 December 2017	Cg5		P38299 on 1 old & 1 new egg = clutch 3
>24 December 2017			Eggs failed, thus a failed triple brood. P48417 & P38299 not seen again this season
12 August 2018	Cg5	P48498	P38299 & P48498 on 2 eggs = clutch 1
??	Cg5		2 chicks fledged
29 November 2018	Cg11	P48498	2 eggs which did not hatch = clutch 2 Thus, a failed double brood
1 December 2019	Cg5	Unknown	Two eggs that did not hatch

Coastguard building on 8 May. P38299 laid two eggs and the resulting chicks fledged despite P44332 not being seen after 22 October 2013. When carrying out our observations it was common for both adults of a pair to be present in the nest. Only P38299 was seen in or near that nest for the rest of the season, so we suspect the two chicks were raised by her from about two weeks-old through to fledging.

2014–15

By May 2014, P38299 had a new mate, P44317. Eggs were laid in July and two chicks fledged in October. Two more eggs were laid about the end of October but they did not hatch. The season's activity constituted a failed attempt at a double brood (a successful double brood is two consecutive clutches in one season with a least 1 fledgling per clutch).

2015-16

P44317 was divorced in July 2015 and the new pairing of P38299 with P44345 had a successful single clutch raising one chick from the two eggs laid in this season.

2016-17

The pairing of P38299 and P44345 had two eggs in nestbox Cg9 on 18 April 2016, the earliest published date for little penguins to lay in New Zealand (Rowe et al. 2020), and possibly Australia. Two eggs hatched and the chicks fledged by 20 July. It appears that P44345 was divorced between 25 May and 8 June as P38299 was sharing nestbox Cg5 with P48417 on that date. The second clutch for P38299 for this season, two eggs, was laid in Cg5 before 10 August, they hatched by 14 September, and the resulting two chicks fledged about 9 November. On 4 December, two eggs found in Cg5 made up clutch 3 for P38299 and clutch 2 for P48417. One of the two eggs hatched before 31 December and that chick fledged by 27 February 2017. This Kaikoura pairing has, with others, extended the range reported previously for successful double brooding, for Otago and Australia only (Gales 1985; Agnew et al. 2014). To our knowledge, this is the first record of successful triple brooding in a season by a little penguin (Rowe et al. 2020). In total, P38299 laid six eggs in the 2016–17 season, five of which hatched and fledged.

2017-18

P38299 attempted another triple brood with P48417 this season. Again, she laid the first known eggs at the colony for the season. Both chicks from the first clutch fledged about 1 October 2017 from eggs laid before 30 June. The second clutch in October was also two eggs; one egg was found outside the nestbox on 10 December but the other was incubated until at least 24 December when the clutch was considered to have failed. On 17 December, P48417 was seen on a new egg in box Cg4 but it is not known whether P38299 had laid that egg; this was the last time P48417 was seen so was considered lost. On December 24, P38299 was in Cg5 sitting on a new egg and the remaining one egg from clutch 2. These eggs were abandoned in the next week and the Cg5 egg at least can be considered the third clutch for the season. Thus, for this season P38299 had a failed triple brood.

2018-19

With a new partner, P48498, P38299 had laid two eggs in Cg5 before 12 August 2018. Again, she laid the earliest eggs in the colony that season. Both chicks fledged. This pair laid another two eggs, this time in Cg11 before 29 November, but neither egg hatched, therefore constituting a failed double brood.

2019–20

P38299 had laid two eggs in Cg5, partner unknown, by 1 December 2019 and neither hatched.

Table 2	2.	The	produ	ctivity	of	little	peng	guin	P38299	at
Kaikōu	ra	Peni	nsula,	2010-2	020	, at S	South	Bay,	Kaikōu	ra,
New Ze	eal	and.								

Season	Clutch	Eggs	Chicks	Fledglings
2011–12	1	1	0	0
	Z	1	0	0
2012–13	1	2	2	2
2013–14	1	2	2	2
2014–15	1	2	2	2
	2	2	0	0
2015–16	1	2	1	1
2016–17	1	2	2	2
	2	2	2	2
	3	2	1	1
2017–18	1	2	2	2
	2	2	0	0
	3	2	0	0
2018–19	1	2	2	2
	2	2	0	0
2019–20	1	2	0	0
Total	16	30	16	16

Over nine breeding seasons, P38299 laid a total of 30 eggs, 3.3 per season over her breeding lifetime to date (Table 2). From the 16 clutches, 16 eggs hatched at a hatching success rate of 53%. All chicks survived to fledging and, hence, P38299 has produced 1.8 chicks/season.

Divorce is not uncommon in little penguins ranging from 0-42% in a year at some Australian colonies (Chiaradia 2001; Rogers & Knight 2006). At the Kaikoura colony there have been many instances where mates have been replaced after winter storms and the occasional divorce, but no other little penguin there has had six mates in nine seasons: the original mate, two replacement mates after losses, and three more after divorces one of which took place mid-season. This is considerably more than an average of 1.8 mates/lifetime in Victoria (Reilly & Cullen 1981) but less than the eight pair bonds for an individual at Phillip Island where some birds were 22 years old (Nisbet & Dann 2009). Having successfully fledged 16 chicks since 2011, including a successful triple brood, P38299 is a remarkable little penguin.

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SHORT NOTE

Palaeoecological reconstructions depend on accurate species identification: examples from South Island, New Zealand, *Pachyornis* (Aves: Dinornithiformes)

RICHARD N. HOLDAWAY* Palaecol Research Ltd, PO Box 16 569, Hornby, Christchurch 8042, New Zealand

RICHARD J. ROWE

Visiting Fellow, Research School of Biology, Evolution, Ecology and Genetics, Australian National University, Canberra 0200, Australia

Accurate identification of fossil remains is fundamental to analysis of the composition of New Zealand extinct bird assemblages and their habitats (e.g. wet forest, dry forest, shrubland, seral vegetation, and low and high altitudes) through space and time. Until the advent of ancient genetic analyses in the early 1990s, identification of fossil bird remains was based perforce solely on morphology (Archey 1941; Oliver 1949; Worthy 1988) and morphometrics (Cracraft 1976a, b, c; Worthy 1987, 1989, 1992, 1994). Most research has been focused on moa (Aves: Dinornithiformes), a group of large (20-200 kg) flightless palaeognathous birds (Worthy & Holdaway 2002) presently assigned to nine species in three families (Megalapterygidae; Dinornithidae; Emeidae) (Bunce et al. 2009). From the late 1990s (e.g. Cooper *et al.* 2001), the development of moa ancient DNA (aDNA) was rapid and greater reliance is now placed on use of aDNA analyses over morphology

and morphometrics (Huynen *et al.* 2003; Bunce *et al.* 2005; Huynen *et al.* 2008; Allentoft *et al.* 2009; Bunce *et al.* 2009; Seabrook-Davison *et al.* 2009; Oskam *et al.* 2010; Allentoft *et al.* 2012; Rawlence *et al.* 2012; Holdaway *et al.* 2014; Huynen *et al.* 2014).

In the moa genus *Pachyornis* (Aves: Dinornithiformes), the validity of the species P. australis Oliver, 1949 was accepted on morphological characters in 1989 (Worthy 1989) and then by ancient genetic analysis 20 years later (Bunce et al. 2009). It is known mainly from subalpine sites, with outliers in coastal dunes in Southland during the Holocene. Lowland records from Honeycomb Hill in northwest Nelson and the Punakaiki area on the West Coast of the South Island (Worthy & Holdaway 1993) date from the most recent (Weichselian-Otiran) glaciation. The species is important in palaeoecological and palaeoclimatic analyses because it is the only moa thought to be associated solely with high altitudes and cooler temperatures (Worthy & Holdaway 2002; Rawlence et al. 2012). As with other species apparently associated with

Received 20 January 2020; accepted 6 April 2020 *Correspondence: *turnagra@gmail.com*

a single habitat, such as *Anomalopteryx didiformis* in lowland rain forest (Worthy & Holdaway 2002), the presence of *P. australis* is evidence for its contemporary vegetation.

The post-cranial skeleton of *P. australis* (44–90 kg) has in the past been confused not only with that of its South Island sister species *P. elephantopus*, but also with *Euryapteryx curtus*, a similar-sized (80–90 kg) moa (Worthy 1989); see Worthy & Holdaway (2002) and Brassey *et al.* (2013) for body mass estimates for moa. Before the advent of aDNA, re-identification of individuals on morphological grounds of *E. curtus* from the late Pleistocene at Honeycomb Hill as *P. australis* altered understanding of the regional fauna and relative ecological requirements of both *Pachyornis australis* and *Euryapteryx curtus* (Worthy & Holdaway 1993, 1994, 1995, 1996, 2002).

A survey of the relationships and historical biogeography of South Island Pachyornis moa (Rawlence et al. 2012) relied almost exclusively on aDNA. They found several instances where individuals had apparently been misidentified on morphology (Table 1). Incorrect identification based on morphology has been reported for other moa taxa at Bell Hill Vineyard, North Canterbury when re-assessed using aDNA (Allentoft et al. 2014; Holdaway et al. 2014). Although examples of misidentification by genetics are reported rarely, laboratory error and contamination are always possible. Full and accurate documentation of data and methodologies are fundamental to traceability of error. Independent methodologies provide additional means of verification and validation leading to better practice.

The early years of aDNA were plagued by many issues of contamination (Cooper & Poinar 2000; Willerslev & Cooper 2004; Malmström et al. 2005; Pruvost et al. 2005; Leonard et al. 2007). Gilbert et al. (2005) cautioned against a "checklist" system of verification of aDNA results [i.e. running through a set of criteria that could be checked off on a list that was becoming accepted: "these criteria are not foolproof, and we believe that they have, in practice, replaced the use of thought and prudence when designing and executing ancient DNA studies... researchers must take a more cognitive and self-critical approach...[and] must explain, in sufficient enough detail to dispel doubt, how the data were obtained [i.e. the aDNA methodologies and laboratory conditions], and why they should be believed to be authentic [i.e. that the genetic data were actually from the samples, without contamination]" (Gilbert et al. 2005: 541).

Research on fossil birds now includes stable isotopic analysis of bone proteins, as well as the morphology, morphometrics of skeletal elements, and ancient mitochondrial and nuclear genetics

(Worthy & Holdaway 2002; Holdaway et al. 2011; Rawlence et al. 2012; Williams et al. 2012; Holdaway et al. 2013). The stable isotopes of carbon, nitrogen, oxygen, hydrogen, and sulphur are now used routinely in ecological studies of both living and extinct species and ecosystems, providing information on food webs, habitat, and trophic levels that is otherwise difficult – or for extinct systems, impossible - to obtain (Peterson & Fry 1987; Hobson 1999). Stable isotope ratios of bone proteins are more stable than, for example, aDNA and provide information relating to most of the organism's life span and comparable to that available from living organisms. The concept of isotopic niche (Bearhop *et al.* 2004) allows guantitative analysis of ecology for living and extinct species (Williams et al. 2012; Holdaway et al. 2013), although integration with ecological niches per se is an ongoing process of interpretation (Flaherty & Ben-David 2010).

Stable isotopic analysis can, as well as identifying aspects of the bird's biology and environment, be useful in testing identification of individual moa now that considerable archives of comparative data are available (e.g. Bunce *et al.* 2009; Rawlence *et al.* 2012; Allentoft *et al.* 2014; Holdaway *et al.* 2014). A survey of isotopic data for moa taxa in northwest Nelson revealed nitrogen stable isotopic ratios of three *Pachyornis* individuals that were anomalous, in relation to both their species identification by Rawlence *et al.* (2012), and to isotopic values for both taxa from the rest of the South Island.

Radiocarbon dated individuals of P. australis and P. elephantopus from deposits in northwest Nelson, the South Island West Coast, western Southland, and Stewart Island identified by morphology or genetically are listed in Table 1. The three *Pachyornis* individuals, from sites on Takaka Hill (Table 1) had been identified as *P. elephantopus* on both morphology (Worthy & Holdaway 1994) and their aDNA (Rawlence et al. 2012). The carbon and nitrogen stable isotopic ratios and altitudes of deposition of the three individuals identified by Rawlence et al. (2012) as P. elephantopus were compared with those of all other dated individuals of both taxa (of all geologic ages) for which both isotopic ratios were known, using R version 3.5.3 (R-Core-Team 2017) (script in Appendix 1) and PAST® Version 3.26 (Hammer et al. 2001) statistical software.

In 3-dimensional multivariate kernel distributions, the three individuals lay between two (altitudinal) clusters of *P. australis*, separate by their δ^{15} N values from the series of *P. elephantopus* (Fig. 1A upper, arrowed circle). When the three individuals were reclassified as *P. australis* they were accommodated in a continuous 95.4% confidence envelope for that species (Fig. 1A, lower).

Table 1. Radiocarbon dated specimens of *Pachyornis australis* and *P. elephantopus* used in analysis of species representation in northwest Nelson and Westland: ? shaded, identified genetically as *P. elephantopus* (north), identification questioned here; *, identified by morphology as *P. elephantopus* but as *P. australis* genetically; **, identified by morphology as *P. elephantopus* but potentially *P. australis*; ***, identified genetically as *P. elephantopus* (south) but potentially *P. australis*. Individual from Te Ana Titi (bold) was originally identified as *P. australis* by morphology (Worthy & Holdaway 1993) and not as *P. elephantopus* as listed by Rawlence *et al.* (2012). The Tarakohe Cave individual for which Rawlence *et al.* (2012) list no repository or registration number is one of six individuals from that site in Museum of New Zealand Te Papa Tongarewa (NMNZ), catalogued collectively as S401-410, S454 (Worthy & Holdaway 1994). Other collections are: WCM, Waitomo Museum of Caves; CM, Canterbury Museum; SMAG, Southland Museum and Gallery; OM, Otago Museum.

Original taxon	Sample	Site	Museum/ register	¹⁴ C lab no.	¹⁴ C age	$\delta^{13}C$	$\delta^{\scriptscriptstyle 15}N$
		Takaka Hill					
Pachyornis elephantopus?	A3749	Predator Cave	MNZ S32425	OxA20336	$32,\!230\pm380$	-20.53	1.42
Pachyornis elephantopus?	A3755	Takaka Hill	MNZ DM417E	OxA20293	$20,\!330\pm90$	-21.86	0.9
Pachyornis elephantopus?	A3756	Takaka Hill	MNZ DM417E	OxA20292	$14,\!145\pm60$	-21.67	2.3
Pachyornis elephantopus**	-	Hawkes Cave	MNZ S28424	NZA3240	$13{,}470\pm94$	-22.2	-
Pachyornis elephantopus**	-	Kairuru Cave	MNZ S27797	NZA1568	$18,\!950\pm230$	-20.6	-
Pachyornis elephantopus**	-	Tarakohe Cave	[MNZ S401-410,454]	NZA3047	$19,\!520\pm130$	-22.6	-
Pachyornis australis*	A3713	Takaka Hill	WCM WO90.47	OxA20291	$10,\!120\pm45$	-24.69	-1.5
Pachyornis australis	A2597	Takaka Hill	NMNZ Unreg.	OxA20290	$18,\!235\pm80$	-23.09	2.00
Pachyornis australis	-	Hawkes Cave	NMNZ S28422	NZA3237	29,011 ± 312	-22.1	-
Pachyornis australis	GU139065	Bone Cave	CM Av21331	OxA12430	$10,\!165\pm50$	-23.17	1.00
		Takaka Valley					
Pachyornis australis	A3739	Irvine's Tomo	MNZ S27881	NZA3049	$28,\!520\pm\!20$	-23.5	-
Pachyornis australis	A3740	Commentary C	MNZ S35298.1	OxA20294	$28,050 \pm 300$	-25.19	3.40
		Other areas					
Pachyornis australis	GU139066	Charleston	CM Av29445	OxA12431	$14,\!045\pm65$	-22.42	1.99
Pachyornis australis	-	Te Ana Titi	MNZ S28192	NZA2320	$25,\!070\pm\!260$	-23	-
Pachyornis australis	GU139064	Honeycomb Hill	In situ	OxA12435	$18,\!925\pm80$	-21.47	1.86
Pachyornis australis*	A3781	Honeycomb Hill	NRS348 in situ	OxA20284	$19,575\pm80$	-20.92	1.50
Pachyornis australis*	A3783	Honeycomb Hill	NRS350 in situ	OxA20285	$20,\!760\pm90$	-21.44	0.88
Pachyornis australis*	A3726	Honeycomb Hill	MNZ S25863.2	OxA20366	$17\!,\!645\pm60$	-21.03	1.65
Pachyornis australis*	A3727	Honeycomb Hill	MNZ S25867	OxA20367	$19,335\pm70$	-21.73	2.20
Pachyornis australis*	A3742	Honeycomb Hill	MNZ S25655	OxA20286	$16,\!860\pm75$	-22.66	0.60
Pachyornis australis*	A2556	Honeycomb Hill	MNZ 25868	ANU-1611	$14{,}730\pm170$	-21.8	-
Pachyornis australis*	A2557	Honeycomb Hill	MNZ S25867	ANU-1612	$14{,}950\pm150$	21.2	-
Pachyornis australis*	A2555	Honeycomb Hill	MNZ S25864	NZA7646	$15,\!000\pm200$	-	-
Pachyornis australis*	A2594	Magnesite Q	NP 5305.1-2	OxA20289	$1{,}021\pm26$	-24.69	-1.5
Pachyornis australis*	GU139067	Moa Trap Cave	MNZ S33754	OxA12669	$10,\!450\pm\!45$	-22.5	-0.8
Pachyornis australis*	A3766	Moa Arch	NRS324 in situ	OxA20297	$10,\!235\pm45$	-22.32	1.28
Pachyornis australis*	A3761	Moa Arch	NRS324 in situ	OxA20296	$10,\!265\pm45$	-21.97	0.30
Pachyornis australis*	A3757	Moa Arch	NRS324 in situ	OxA20595	$10,\!280\pm\!45$	-25.75	0.60
Pachyornis australis*	AC923	Cheops Cave	MNZ S41344	OxA20288	$1{,}928\pm27$	-22.24	1.07
Pachyornis elephantopus**	AC3736	Bulmer Cave	MNZ S23569	OxA20287	564 ± 26	-21.73	3.62
Pachyornis elephantopus**	-	Honeycomb Hill	-	NZ6586	$14{,}029\pm138$	-21.47	-
Pachyornis elephantopus**	-	Honeycomb Hill	-	NZ6453	$15,\!677\pm163$	-21.67	-
Pachyornis elephantopus**	-	Honeycomb Hill	-	NZ7323	$18,\!600\pm\!230$	-	-
Pachyornis elephantopus**	-	Honeycomb Hill	-	NZ7292	$20,\!600\pm\!450$	-21.44	0.88

Table 1. continued							
Pachyornis elephantopus**	-	Honeycomb Hill	-	NZ7642	$13,\!850\pm140$	-	-
Pachyornis elephantopus**	-	Honeycomb Hill	-	NZ6480	$14,\!194\pm140$	-23.35	-
Pachyornis elephantopus**	-	Honeycomb Hill	-	NZA574	$18,\!300\pm170$	-22.77	-
Pachyornis elephantopus**	-	Honeycomb Hill	-	NZ7647	$18,\!650\pm250$	-	-
Pachyornis elephantopus**	-	Honeycomb Hill	-	NZ6589	$14,\!062\pm138$	-21.54	-
Pachyornis elephantopus**	-	Honeycomb Hill	-	NZ7675	$12{,}950\pm450$	-21.51	-
Pachyornis elephantopus**	-	Madonna Cave	MNZ S28064	NZA2505	$14,\!740\pm110$	-22.6	-
Pachyornis elephantopus**	-	Madonna Cave	-	NZA2446	$20{,}680\pm160$	-22.4	-
Pachyornis elephantopus***	A2757	Avondale	SMAG 88.95	OxA20326	$2,\!885\pm28$	-22.42	2.28
Pachyornis elephantopus***	A2759	Riverton	SMAG E80.13	OxA20333	$1,336\pm24$	-24.54	3.49
Pachyornis elephantopus***	GU139071	Stewart Island	OM Av4661	NZA9069	654 ± 56	-22.3	3.18

The $\delta^{15}N$ values of the three individuals were significantly different from those of a sample of 11 other P. elephantopus from northwest Nelson (Single factor ANOVA: mean 1.54 v 5.973, df = 1,12, F = 51.521, $P = 1.12 \times 10^{-5}$, $F_{crit} = 4.747$) but not from those of 13 P. australis from the same area (Single factor ANOVA: mean 1.54 v 1.354, df = 1,14, F =0.0531, P = 0.8211, $F_{crit} = 4.600$). A bi-isotopic plot (Fig. 1B) placed the three individuals clearly within the range for *P. australis*. On this basis, the three birds are most likely to be P. australis rather than P. elephantopus.







Figure 1. Carbon and nitrogen stable isotopic evidence for mis-identification of three Pachyornis moa from sites on Takaka Hill. A. 3-dimensional (95.4% confidence interval envelopes) kernel distributions of carbon and nitrogen stable isotopic values of P. australis (green) and P. elephantopus (blue) in relation to altitude above ambient sea level at time of deposition: upper, three Takaka Hill individuals identified as P. elephantopus in Rawlence et al. (2012) circled, arrowed; lower, three individuals reclassified as P. australis. B. bi-isotopic plot for P. australis (black) and P. elephantopus (blue) with three Takaka Hill individuals identified as P. elephantopus in Rawlence et al. (2012) high-lighted (yellow). Large symbols for P. elephantopus are for data included in Rawlence et al. (2012); small symbols are data for P. elephantopus in North Canterbury from Allentoft et al. (2014) and Holdaway et al. (2014).

We do not suggest that stable isotopic ratios are a stand-alone method for taxon identification, but they are certainly an additional, independent criterion that can highlight potential issues in morphological and genetic taxonomy. No method can be taken as inherently error-free, but at present it seems that aDNA might be seen in that light. Hence, it is not a case of stable isotopes versus aDNA and morphology. Rawlence et al. (2012) highlight a significant number of individuals whose identifications by one or other of these methods are in conflict. Stable isotope data can provide measures of the ecology of the different taxa, which, as competitors rarely co-exist, can provide independent evidence that suggests revisiting identifications by one or both standard methods.

Potential issues with stable isotopic ratios in bone protein could include abnormal reliance on a different diet forced on the birds by local circumstances. However, bone proteins are longlived in an individual and integrate dietary and ecological conditions over many years (Holdaway *et al.* 2011). The ratios are largely independent of plant taxon, especially given that there are few C4 plants in New Zealand and none in the habitats generally used by moa. Similarly, aberrant stable isotopic values are extremely unlikely to result from introgression between the two *Pachyornis* taxa. Hybridisation has never been mooted/recorded for moa, either on the basis of morphology or genetics.

Finally, the distribution of the taxa in space and time supports the new species identification better than the present attributions. In addition, the authors of most of the genetic identifications for *Pachyornis* moa in the deposits at Honeycomb Hill (Rawlence *et al.* 2012) themselves suggest significant levels of mis-identification in the sample. The statistically significant differences – see above – between the δ^{15} N values of unquestioned *P. elephantopus* and *P. australis* show that the individuals with "anomalous" values can be clearly allocated to the other taxon.

We believe that by using all the available data we have made a strong case for revisiting the genetic and morphological identifications of the individuals concerned, and in general for use of stable isotopic data in future studies. The relationships within *Pachyornis* require further work as the phylogenetic tree provided by Rawlence *et al.* (2012) nests two species within the *P. elephantopus* clade, between separate branches still attributed to *P. elephantopus*. Clearly, if independent data such as from stable isotopes can focus attention on particular issues of identification, this will benefit all moa research. As Gilbert *et al.* (2005), point out there is no basis for an assumption of error-free analysis in aDNA, any more than in any other field.

The potential re-identification of the three *Pachyornis* individuals as *P. australis* on stable isotopic data arising from the present analysis suggested that a wider inspection of the identification was warranted. A starting point was the observation that *P. australis* individuals of all geologic ages exhibited δ^{15} N values <4‰ (Fig. 2). Morphologically and genetically identified *P. elephantopus* individuals other than the three from

Takaka Hill, in contrast, all had δ^{15} N values >4‰ (Fig. 2). A classification tree analysis (Breiman *et al.* 1984) implemented in the *rpart* package in R, yielded a partition value of δ^{15} N = 2.24‰ (Fig. 2), with three (of 19) *P. australis* and two (of 64) *P. elephantopus* mis-categorised. Two of the three *P. elephantopus* from Takaka Hill fell beneath the 2.24‰ separator and the third, at 2.3‰, within measurement error (Table 1; Fig. 2). Two accepted aDNA-identified *P. australis* and two of the southern individuals here suggested to be *P. australis* fell in the "grey area" between the observational interspecies boundary and the third was, again, within measurement error of the partition value (Table 1; Fig. 2).



Figure 2. Bone protein nitrogen stable isotopic ratios for Pachyornis australis (black circles) and P. elephantopus (northern South Island, black stars; southern clade, blue stars) and contested identifications of P. elephantopus (Takaka area, orange circles; Southland and Stewart Island, orange triangles) through time. $\delta^{15}N$ values and conventional radiocarbon ages for P. australis and contested identifications from Table 1; "northern" and "southern clade" data for *P. elephantopus* from Rawlence *et al.* (2012) and their sources. Abbreviations: PAAU, P. australis; PAEL, P. elephantopus; SC, southern clade. Interspecies boundary (dotted line) set at the $\delta^{15}N$ value separating the values for presently accepted genetically identified P. australis and P. elephantopus individuals. All three north-western South Island individuals here assigned to *P. australis* have δ¹⁵N values within the range of accepted identifications of that taxon, as do those for the three southern South Island individuals.



Figure 3. Geographic distribution of *Pachyornis* individuals with the bases for identification, conventional radiocarbon ages (without SD), and bone protein δ^{15} N values (where available). **A**, for individuals identified as *Pachyornis elephantopus* from fossil deposits west of the South Island Main Divide, in western Southland, and on Stewart Island. M, identified on morphology; G, identified genetically; ******, identification on morphology questioned by Rawlence *et al.* (2012); *******, identified both on morphology and by genetic analysis, questioned here on species differences in δ^{15} N values. **B**, for individuals identified as *Pachyornis australis* from fossil deposits west of the South Island Main Divide, in western Southland, and on Stewart Island. M, identified on morphology and by genetic analysis, questioned here on species differences in δ^{15} N values. **B**, for individuals identified as *Pachyornis australis* from fossil deposits west of the South Island Main Divide, in western Southland, and on Stewart Island. M, identified on morphology; G, identified genetically; *****, identified genetically; *****, identified genetically; *****, identification on morphology by Worthy (1989), changed from genetic analysis by Rawlence *et al.* (2012) M25070 (MNZ S28192, Table 1) was identified originally (Worthy & Holdaway 1993) as *P. australis*, not as *P. elephantopus* as listed by Rawlence *et al.* (2012). Digital Elevation Model courtesy School of Earth and Environmental Sciences, University of Canterbury.

There was no relationship between δ^{15} N values and time for the 18 individuals of unchallenged identification as *P. australis* (Table 1): a generalised linear model of δ^{15} N against conventional radiocarbon age yielded a *P* value for zero slope of 0.092; reduced major axis regression, $r^2 = 0.1505$, t =1.6834, permutation P = 0.1097; robust regression, r^2 and *t* as for reduced major axis, permutation P =0.117.

Of the ten *P. elephantopus* from Honeycomb Hill caves, a $\delta^{15}N$ measurement is presently available for only the individual dated by NZ7292. The $\delta^{15}N$ value of 0.88‰ (Table 1) supports the contention that it is *P. australis* (Rawlence *et al.* 2012). Three other individuals identified as *P. elephantopus* had $\delta^{15}N$ values <4‰ (Fig. 2), two from western Southland and a third from Mason Bay, Stewart Island (Table 1; Fig. 3). If the $\delta^{15}N$ value is indeed species-specific, as present data suggest, then SMAG 88.95 (Avondale) and SMAG E 80.13 (Riverton) as well as OM Av 4661 (Mason Bay, Stewart Island) should be identified as *P. australis*. As noted above, Worthy (1989) included Southland dunes in the range of *P. australis*, and Worthy (1998c) recorded one *P. australis* from dunes there. Worthy (1998a) makes a case for the Mason Bay individual having been brought to the island by early Polynesians, there being no other evidence that moa taxa other than *Dinornis robustus* were present there (Worthy 1998b; Holdaway *et al.* 2001). The Mason Bay individual would be the first *P. australis* to be found in an archaeological context (Worthy 1999).

It appears from these analyses that all the *Pachyornis* individuals west of the Divide presently identified as *P. elephantopus* are, instead, *P. australis*. If the remainder are also *P. australis*, too, it would mean that the glacial and interglacial moa faunas would need major re-assessment. The distributions of *P. elephantopus* and *P. australis* (Fig. 3) will need to be combined under *P. australis*. It would also

mean that the systematics of the genus *Pachyornis* will need to be revisited. That in turn would raise the possibility that the canonical association of *P. elephantopus* with *Euryapteryx curtus* as part of a fauna associated with forest-shrubland mosaics (Worthy 1997; Holdaway & Worthy 1997; Worthy & Holdaway 1993, 1994, 1995, 1996; Worthy 1998d; Worthy & Holdaway 2002) during the Holocene in the eastern South Island, occupying similar habitats west of the Divide during the Weichselian-Otiran glaciation, will have to be abandoned. *P. elephantopus* may have been confined always to the eastern South Island, as was *Emeus crassus* (Worthy & Holdaway 2002).

If these changes in identification are confirmed, it will have significant implications for the *Pachyornis* phylogenetic tree presented by Rawlence *et al.* (2012). That tree has issues such as the nesting of *P. geranoides* (North Island) and *P. australis* within a 'fragmented' *P. elephantopus*. Removing the western and southwestern *P. elephantopus* individuals to *P. australis*, as already suggested in part by Rawlence *et al.* (2012), may assist in resolving relationships within the genus. That, in turn, may involve the recognition of other taxa for, for example, the isolated western Southland population.

The re-identifications supported by stable isotopic evidence also caution against automatic acceptance of genetic identifications. State of preservation of bone and its biochemical contents, particularly in older material, and laboratory errors such as mislabelling or inter-sample contamination can and do introduce errors, just as misidentified voucher material can affect identification on morphology (Holdaway & Worthy 1993).

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- **Keywords:** palaeoecology, moa, Dinornithiformes, identification, *Pachyornis*, morphology, morphometrics, aDNA, South Island, New Zealand

Appendix 1. Basic R script for generation of 3-dimensional kernel distributions.

require (ks) require (misc3d) require (rgl) d<-read.table(file.choose()) Altitude<-d\$V1 d13C<-d\$V2 d15N<-d\$V3 plot3d(x=Altitude,y=d13C,z=d15N,type="s",size=0.9,col="green") d.dens3d<-kde(x=d,gridsize=c(64,64,64),compute.cont=TRUE) x.latt<-d.dens3d\$eval.points[[1]] y.latt<-d.dens3d\$eval.points[[2]] z.latt<-d.dens3d\$eval.points[[3]] contour3d(x=x.latt,y=y.latt,z=z.latt,f=d.dens3d\$estimate,color="green",level=d.dens3d\$cont[95.4],add=TRUE,alpha=0.5) decorate3d(box = TRUE,axes = FALSE, main = NULL, sub = NULL,top = TRUE, aspect = FALSE, expand = 1.03) d<-read.table(file.choose()) Altitude1<-d\$V1 d13C1<-d\$V2 d15N1<-d\$V3 plot3d(x=Altitude1,y=d13C1,z=d15N1,type = "s", col="blue",size=1.0,add=TRUE) d.dens3d<-kde(x=d,gridsize=c(64,64,64),compute.cont=TRUE) x.latt<-d.dens3d\$eval.points[[1]] y.latt<-d.dens3d\$eval.points[[2]] z.latt<-d.dens3d\$eval.points[[3]] contour3d(x=x.latt,y=y.latt,z=z.latt,f=d.dens3d\$estimate,color="blue",level=d.dens3d\$cont[95.4],add=TRUE,alpha=0.5) decorate3d(box = FALSE,axes = FALSE, main = NULL, sub = NULL,top = TRUE, aspect = FALSE, expand = 1.03)

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