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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

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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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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

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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 years) 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, red-crowned 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* – http://www.nzbirdsonline.org.nz.

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 scoparium*) and kanuka (*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)

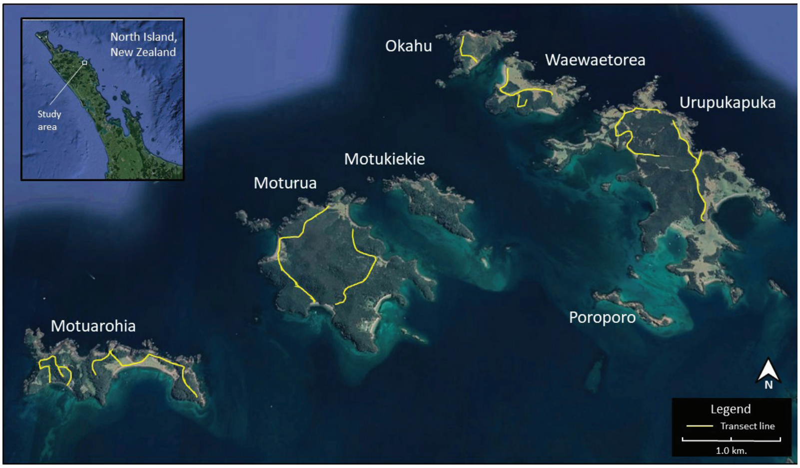

Figure 1. The islands of the Ipipiri group with count transects routes shown in lines on the aerial photograph from Google Earth.

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.

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**

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 station-morning 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 r^2 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).

Table 2. Mean number of individuals recorded per 10-minute count per station in each Austral Year from 1996, and 2009–2017 in order of total abundance. Landbird species with more than a grand total of 50 individuals observed during the study were included in our analysis. Status of landbirds in study: E = endemic, R = recent immigrant, N = non-native.

Common name	Scientific name	Status	Austral year										Mean/ station	Total indiv.
			1996	2009	2010	2011	2012	2013	2014	2015	2016	2017		
Tui	*Prosthemadera novaeseelandiae*	E	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*	N	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*	N	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*	N	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*	N	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*	N	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*	E	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*	N	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*	E	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*	N	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*	N	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*	N	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*	N	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*	E	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*	E	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*	N	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*	N	0.13	0.24	0.12	0.29	0.11	0.21	0.12	0.07	0.03	0.06	0.12	117
Whitehead	*Mohoua albicilla*	E	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*	N	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*	E	0.05	0.03	0.02	0.07	0.00	0.04	0.00	0.21	0.06	0.15	0.07	73

Table 2. cont.

Common name	Scientific name	Status	Austral year 1996	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean/ station	Total indiv.
New Zealand pipit	*Anthus novaeseelandiae*	E	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*	E	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*	N	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*	E	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*	N	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*	E	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*	E	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*	N	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*	N	0.00	0.00	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	7
Paradise shelduck	*Tadorna variegata*	E	0.00	0.02	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00	0.01	6
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	3
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	3
Black-billed gull	*Larus bulleri*	E	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 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 islands[2]		All islands	Individual islands	
Common name	(n=5)	Decreasing	Increasing	(n=3)	Decreasing	Increasing
Native Species						
Shining cuckoo R	- -	X x x x		**ns**	x	x x
Pukeko R	**ns**	X x	x x x	- -	X x x	
Swamp harrier R	+		X X x x x	**ns**	x	x x
Sacred kingfisher R	- - -	X X x x x		**ns**	x	x x
Tui E	+ + +		X X X X X	+ + +		X X X
Grey warbler R	- - -	X X x x x		- - -	X X x	
North Island saddleback E	+ + +		X X	+ + +		X X
Whitehead E	+ + +		X X	+ + +		X x
New Zealand fantail R	**ns**	x x x	x x	- - -	X x x	
Tomtit E	+ + +	x	X X x	+ + +		X X X
North Island robin E	+ +		X X x	**ns**		x x x
New Zealand pipit E	+ + +		X X x x x	+ +	x	X x
Welcome swallow R	+ +		X x x x x	**ns**		X x x
Silvereye R	- - -	X x x	x x	- - -	X X X	
Non-native Species						
Brown quail	**ns**	x x x		- - -	X X x	
Eastern rosella	+ + +		X X X x x	+ + +		X X x
Dunnock	- -	X x x	x x	- - -	X X x	
House sparrow	+ +	X x	X X X	**ns**	X x	X
Chaffinch	- - -	X X X x	x	- - -	X X	x
European greenfinch	- -	X x x	x x	- -	X	x x
European goldfinch	- - -	X X X x x		- - -	X X x	
Yellowhammer	- - -	X X X x x		-	X x	x
Eurasian skylark	- -	X x x	x	- - -	X X	
European starling	- - -	X X x x x		**ns**	x x	x
Common myna	- - -	X x x x	x	- - -	X X X	
Song thrush	- - -	X x x x		- - -	X X X	
Eurasian blackbird	- - -	X X X x	x	- - -	X X X	

[1] Significance of increasing (+) or decreasing (-) trends for all islands combined are indicated by: $P < 0.05$: + or - ; $P < 0.01$: + + or - - ; $P < 0.001$: + + + or - - -; non-significant trend: **ns**.
[2] Each island where the species was found is represented with an "x" under either Decreasing or Increasing trend. Significant trends ($P < 0.05$) were indicated by a capital "X".

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

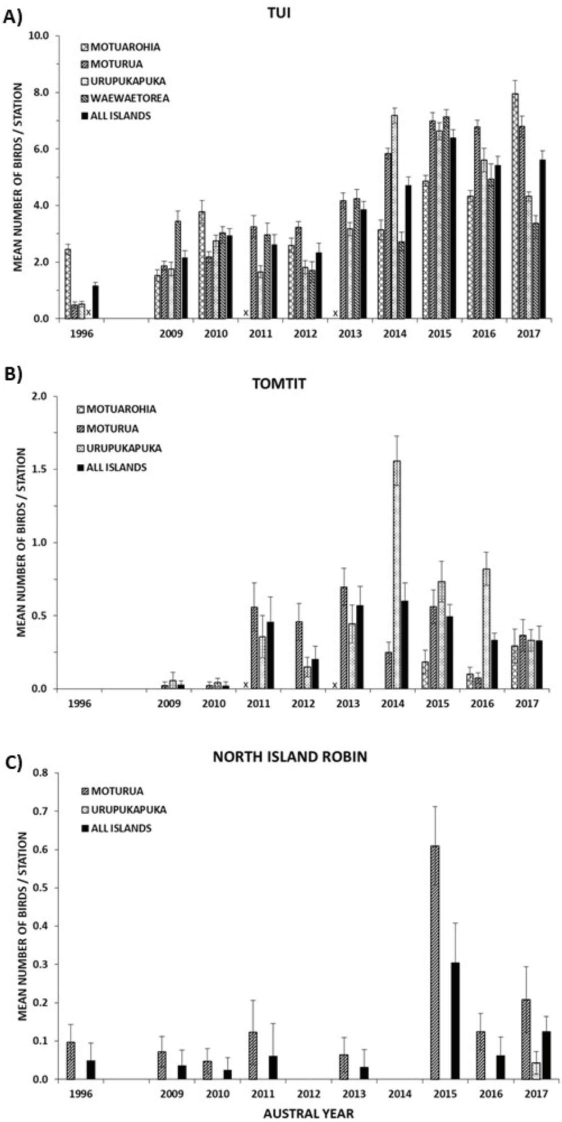

Figure 2. The mean number (± *se*) of birds seen or heard on the 10-minute station counts on four islands of the Ipipiri group and the overall mean (All Islands). "X" = island was not counted in that year; A) tui, B) tomtit, C) North Island robin.

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 ($P < 0.001$),

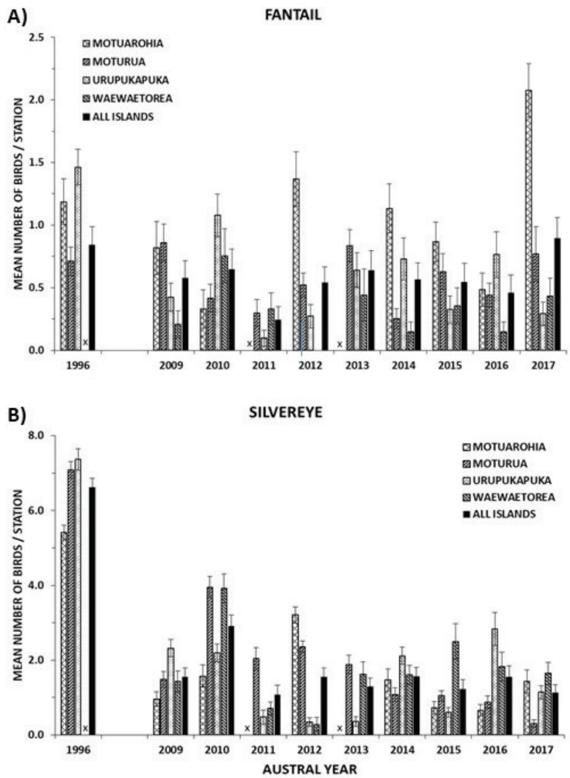

Figure 3. The mean number (± *se*) of birds seen or heard on the 10-minute station counts on four islands of the Ipipiri group and the overall mean (All Islands). "X" = island was not counted in that year; A) New Zealand fantail, B) silvereye.

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 non-native 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.

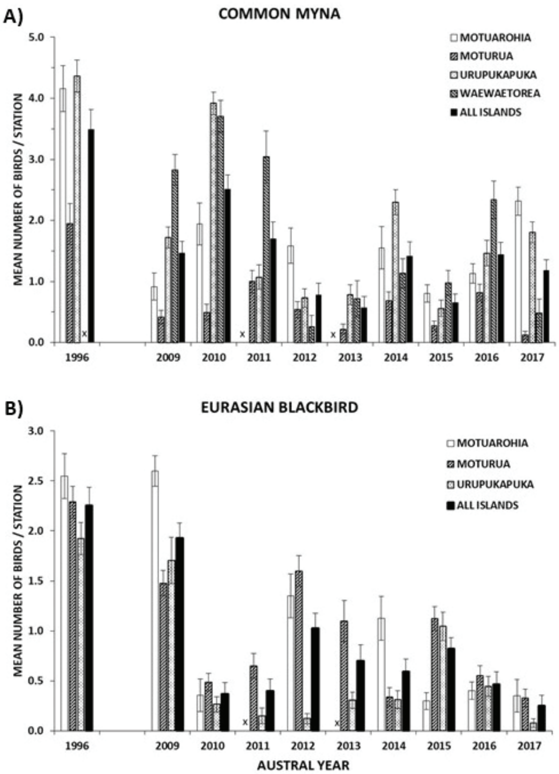

Figure 4. The mean number (± *se*) of birds seen or heard on the 10-minute station counts on three islands of the Ipipiri group and the overall mean (All Islands). "X" = island was not counted in that year; A) common myna, B) Eurasian blackbird.

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 non-native 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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LITERATURE CITED

Bombaci, S.; Pejchar, L.; Innes, J. 2018. Fenced sanctuaries deliver conservation benefits for most common and threatened native island birds in New Zealand. *Ecosphere 9(11)*: e02497. doi: 10.1002/ecs2.2497

Dawson, D.G.; Bull, P.C. 1975. Counting birds in New Zealand forests. *Notornis 22*: 101–109.

Diamond, J.M.; Veitch, C.R. 1981. Extinctions and introductions in the New Zealand avifauna: cause and effect? *Science 211*: 499–501.

Fea, N. 2018. The responses of New Zealand's arboreal forest birds to invasive mammal control. Unpubl. Ph.D. thesis, Victoria University of Wellington.

Girardet, S.A.B.; Veitch, C.R.; Craig, J.L. 2001. Bird and rat numbers on Little Barrier Island, New Zealand, over the period of cat eradication 1976–80. *New Zealand Journal of Zoology 28*: 13–29.

Graham, M.F.; Veitch, C.R.; Aguilar, G.; Galbraith, M. 2013. Monitoring terrestrial bird populations on Tiritiri Matangi Island, Hauraki Gulf, New Zealand, 1987–2010. *New Zealand Journal of Ecology 37*: 359–369.

Green, C.J., Gibbs, G.W. and Barnett, P.A. 2011. Wetapunga (*Deinacrida heteracantha*) population changes following Pacific rat (*Rattus exulans*) eradication on Little Barrier Island. pp. 305–308 *In*: Veitch, C.R.; Clout, M.N.; Towns, D. (*eds*) *Island Invasives: Eradication and Management*. Auckland, CBB and Gland, IUCN.

Greene, T.C.; Pryde, M.A. 2013. Three population estimation methods compared for a known South Island robin population in Fiordland, New Zealand. *New Zealand Journal of Ecology 36*: 340–352.

Innes, J.; Kelly, D.; Overton, J.McC.; Gilles, C. 2010. Predation and other factors currently limiting New Zealand forest birds. *New Zealand Journal of Ecology 34*: 86–114.

Johnson, D.H. 2008. In defense of indices: the case of bird surveys. *Journal of Wildlife Management 72*: 857–868.

Koskimies, P.; Väisänen, R.A. 1991 (*eds*). *Monitoring bird populations: a manual of methods applied in Finland*. Zoological Museum, Finnish Museum of Natural History, University of Helsinki.

Lee, W.; McGlone, M; Wright, E. 2004. *Biodiversity Inventory and Monitoring: A review of national and international systems and a proposed framework for future biodiversity monitoring by the Department of Conservation*. Report number: LC0405/014. Wellington, Department of Conservation.

Miskelly, C.M. 2018. Changes in the forest bird community of an urban sanctuary in response to pest mammal eradications and endemic bird reintroductions. *Notornis 65*: 132–151.

Parker, K.A. 2013. Restoring Richard Henry's dream: the evolution of translocation in New Zealand. *Notornis 60*: 1–2.

Project Island Song. 2014. *Project Island Song Translocation Feasibility and Action Plan. Guardians of the Bay of Islands*. November. Available at: https://www.projectislandsong.co.nz/index.php/the-project/species-reintroductions.html

Ralph, C.J.; Droege, S.; Sauer, J.R. 1995. Managing and monitoring birds using point count: standards and applications. pp. 161–169 *In*: Ralph, C.J.; Sauer, J.R.; Droege, S. (*technical eds*). *Monitoring bird populations by point counts*. USDA Forest Service, Pacific Southwest Research Station General Technical Report. Albany, California.

Ralph, C.J.; Ralph, C.; Szabo, J. 2008. Tomtits confirmed breeding on Moturua Island, Bay of Islands. *Apteryx 22*: 11. Available online at http://osnz.org.nz/newsletters/far-north-apteryx-december-2008.

Rankin, E.E.W.; Knowlton, J.L., Gruner, D.S.; Flaspohler, D.J., Giardina, C.P.; Leopold, D.R.; Buckardt, A.; Pitt, W.C.; Fukami, T. 2018. Vertical foraging shifts in Hawaiian forest birds in response to invasive rat removal. *Plos ONE 13*(9). doi: 10.1371/journal.pone.0202869

SAS Institute. 2012. *SAS/STAT Release 9.4*. Cary, North Carolina, SAS Institute, Inc.

Shiels, A.B.; Pitt, W.B.; Sugihara, R.T.; Witmer, G.W. 2014. Biology and Impacts of Pacific Island Invasive Species. 11. *Rattus rattus*, the Black Rat (Rodentia: Muridae). *Pacific Science 68(2)*: 145–184. doi: 10.2984/68.2.1

Spurr, E.B.; Ralph, C.J. (*compilers*). 2006. *Development of bird population monitoring in New Zealand: Proceedings of a workshop*. Landcare Research Science Series No. 32. Lincoln, Canterbury, New Zealand, Manaaki Whenua Press. 25 pp.

Te Papa; Birds New Zealand; New Zealand Department of Conservation. 2013. *New Zealand Birds Online – the Digital Encyclopaedia of New Zealand Birds*. www.nzbirdsonline.org.nz. Last accessed 26 March 2018.

Tindall, S.D. 1996. Ecological Impacts and Management of the common myna *Acridotheres tristis*. Unpubl. M.Sc. Thesis, Biological Sciences, University of Auckland, New Zealand.

Tindall, S.D.; Ralph, C.J.; Clout, M.N. 2007. Changes in bird abundance following common myna control on a New Zealand island. *Pacific Conservation Biology 13(3)*: 202–212.

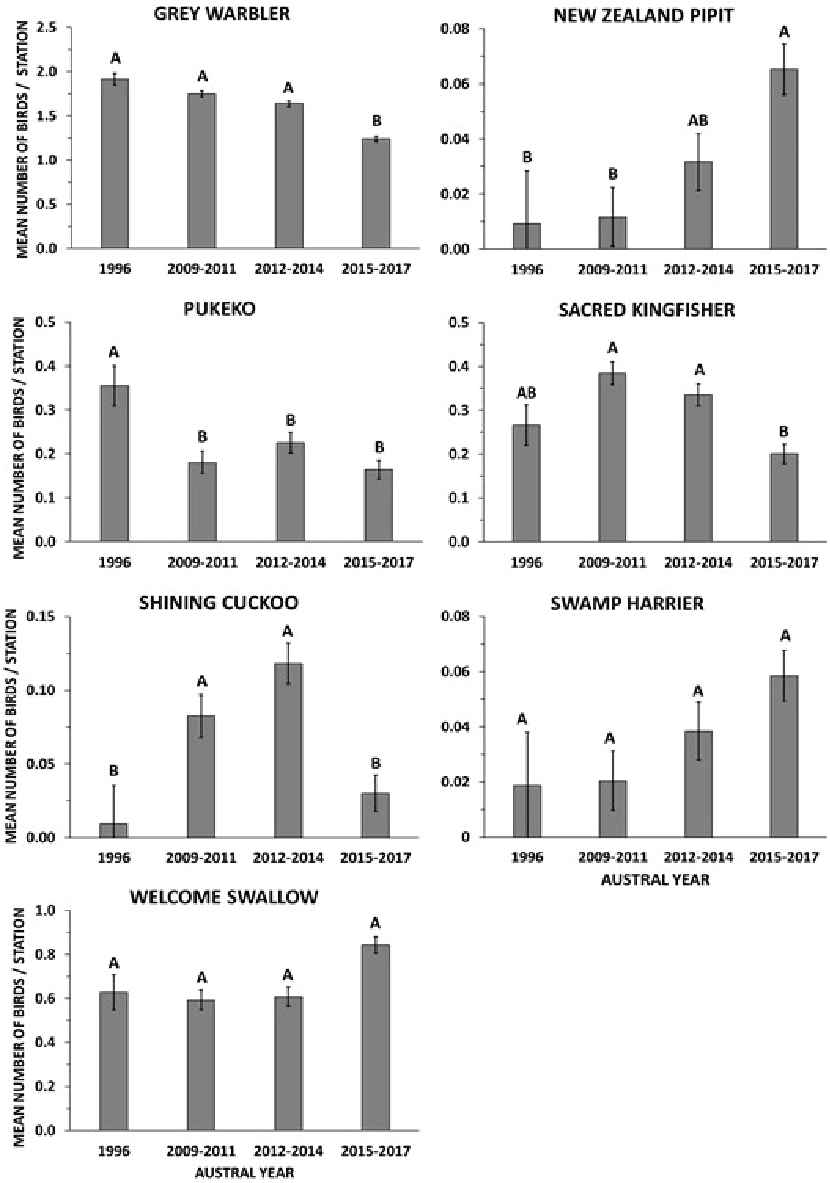
Towns, D.R. 1991. Response of lizard assemblages in the Mercury Islands, New Zealand, to removal of an introduced rodent: the kiore (*Rattus exulans*). *Journal of the Royal Society of New Zealand 21*: 119–136.

Towns, D.R.; West, C.J.; Broome, K.G. 2013. Purposes, outcomes and challenges of eradicating invasive mammals from New Zealand islands: an historical perspective. *Wildlife Research 40*(2): 94–107. doi: 10.1071/wr12064

Verner, J. 1985. Assessment of counting techniques. *Current Ornithology 2*: 247–302.

Vestena, C. 2009. *Project Island Song Monitoring Plan – Draft*. Kerikeri, New Zealand. New Zealand Department of Conservation.

Appendix 1. The mean number of 7 native bird species (± *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 (± *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).