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Changes in the forest bird community of an urban sanctuary in response to pest mammal eradications and endemic bird reintroductions

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Abstract Zealandia (Karori Sanctuary) is a forest sanctuary which is surrounded by a predator-exclusion fence, and is situated in the Wellington city town belt, New Zealand. Following eradication of introduced mammals from within the fence in 1999, 10 species of endemic forest birds were reintroduced between 2000 and 2011, and 2 other species recolonised naturally. Five-minute bird counts were used to assess changes in the Zealandia diurnal forest bird community over 2 time periods: 1995-98 to 2002-05, and 2002-05 to 2013-16, as well as changes over the full 21 year period. Tui (*Prosthemadera novaeseelandiae*) was the only bird species present before the fence was completed that showed a significant, year-round positive response to mammal removal. Following the recreation of a diverse and abundant endemic bird community post-2005, detection rates for most of the species that were present before 1999 declined significantly. This included highly significant declines in detection rates for 3 native bird species: silvereye (*Zosterops lateralis*), grey warbler (*Gerygone igata*) and New Zealand fantail (*Rhipidura fuliginosa*). These results suggest that populations of the most common and widespread native and introduced birds are only weakly limited by mammalian predation, but can be rapidly outcompeted by restored endemic bird species if predators are removed. The forest bird community in Zealandia is now more similar to that on nearby Kapiti Island (the source site for many of the bird species translocated to Zealandia) than it is to the bird community that existed at the site before the fence was built.

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Keywords bird; competition; conservation management; fence; Karori Sanctuary; pest eradication; predation; restoration; translocation; Zealandia

INTRODUCTION

New Zealand mainland forest bird communities have changed dramatically and irreparably over the past 150 years. At least 6 endemic forest bird species have become extinct since 1870, 5 further species became restricted to offshore islands, and many of the remaining endemic species that survive on the mainland have become increasingly confined to remote, high altitude forests (Cusa & Lockley 1980; Diamond 1984; Tennyson & Martinson 2007; Ballance 2010; Walker *et al*. 2017). Over the same time period, 17 species of introduced songbirds and parrots have become established in New Zealand, with most of these species utilising indigenous forest or shrubland habitats to some extent, at least around forest margins (Thomson 1922; Turbott 1961; Kikkawa 1966; Diamond & Veitch 1981; McCallum 1982; Robertson *et al.* 2007). As a result, the birds found in forested remnants in and around our main cities are a mix of a few widespread native species (most of which are shared with Australia, or are only recently derived from a common ancestor) along with a wide range of introduced bird species

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(Bull & Underhill 1983; Gill 1989; Day 1995; Brockie 1997; van Heezik *et al*. 2008).

While habitat loss and deterioration, direct hunting, disease, and competition with introduced bird species are likely to have contributed to declines in endemic bird species (Turbott 1961; Craig *et al*. 2000; Wilson 2004), the main cause of recent and ongoing declines of forest birds has been predation by introduced arboreal mammals (principally ship rats *Rattus rattus*, stoats *Mustela erminea* and brushtail possums *Trichosurus vulpecula*) (Atkinson 1996; King & Murphy 2005; Elliott *et al*. 2010; Innes *et al.* 2010; Brown *et al.* 2015; King *et al.* 2015). Protection from these 3 predator species is the first requirement for saving many of New Zealand's endemic birds, and is the primary focus for New Zealand's Predator Free 2050 programme (Brown *et al.* 2015; Russell *et al*. 2015; Parliamentary Commissioner for the Environment 2017; Anonymous 2017).

Predator-exclusion fences are a recent development in the battle to protect and restore populations of vulnerable New Zealand bird species (Clapperton & Day 2001; Burns *et al.* 2012; Butler *et al*. 2014). While the cost-effectiveness of fences compared to traditional predator control methods has been challenged (Clapperton & Day 2001; Pickard 2007; Hayward & Kerley 2009; Scofield *et al.* 2011; Innes *et al.* 2012; Butler *et al*. 2014), there are numerous examples of translocated populations of bird species vulnerable to mammalian predators becoming established within fenced sites throughout New Zealand (Burns *et al.* 2012; Empson & Fastier 2013; Miskelly & Powlesland 2013; Smuts-Kennedy & Parker 2013; Butler *et al*. 2014; Azar & Bell 2016).

Zealandia (Karori Sanctuary) in Wellington city was the first site in New Zealand where predator-exclusion fencing was used to attempt ecosystem restoration (Campbell-Hunt 2002; Burns *et al.* 2012; Empson & Fastier 2013). Following intensive trials of fence design, an 8.6 km long fence was constructed around the Karori Reservoir valley in 1999, enclosing 225 ha of regenerating forest (Campbell-Hunt 2002; Empson & Fastier 2013; Butler *et al*. 2014). All introduced mammals within the fence were removed later in 1999 (although mice *Mus musculus* subsequently reinvaded), and reintroductions of vulnerable endemic bird species began in 2000 (Campbell-Hunt 2002; Miskelly *et al.* 2005; Miskelly & Powlesland 2013; Butler *et al*. 2014).

The length of time that elapsed between project proposal in 1993 (Lynch 1995) and fence completion provided an opportunity for comprehensive baseline monitoring of the 'pre-fence' forest bird community at Zealandia. Birds New Zealand members undertook 3 years of bird counts in the valley in 1995-98, then repeated the same survey effort in 2002-05, starting 3 years after the fence was completed and mammals had been eradicated, but before any of the reintroduced bird species had become well established. Comparison between these first two count blocks provides insights into the extent to which introduced mammals were limiting 'pre-fence' bird populations in the valley. A third block of counts was completed in 2013-16, when four of the reintroduced diurnal bird species were well established. Comparison between the second and third count blocks allowed assessment of the establishment success of translocated and recolonising bird species, and also of the impacts of a more diverse and abundant endemic bird community on the 'pre-fence' bird species. The forest bird community structure at each stage was compared with that of nearby Kapiti Island Nature Reserve, to determine whether the Zealandia forest bird community was on a trajectory towards this potential model bird community.

METHODS

Study sites

Zealandia (Karori Sanctuary, 41°18′S, 174°44′E) is situated in a 3 km-long valley between the suburbs of Karori and Highbury in Wellington city. Much of the valley was cleared for farming in the mid-1800s, with native forest (predominantly kohekohe *Dysoxylum spectabile* and rewarewa *Knightia excelsa*) persisting on steeper western slopes. All farm stock were removed by 1906, after which the valley was managed as a water-supply catchment for Wellington city until 1998 (Campbell-Hunt 2002). The valley is now entirely forested with a mosaic of mature native broadleaf forest, regenerating native forest (dominated by mahoe *Melicytus ramiflorus* and five-finger *Pseudopanax arboreus*), over-mature plantation conifers (predominantly *Pinus radiata*) and invasive woody weeds (including Darwin's barberry *Berberis darwinii*) (further detail in Blick *et al.* 2008). Apart from planted specimens, the valley almost entirely lacks the native podocarps (Podocarpaceae) and northern rata (*Metrosideros robusta*) that dominated forests on the hills around Wellington in the early 1800s (Dieffenbach 1843).

The valley was enclosed in a mammal-exclusion fence in 1999, and all introduced mammals within the fence were eradicated later that year. Species known to have been present (and eradicated) following fence completion included brushtail possum, ship rat, house mouse, feral cat (*Felis catus*), stoat, weasel (*Mustela nivalis*), rabbit (*Oryctolagus cuniculus*), hare (*Lepus europaeus*) and hedgehog (*Erinaceus europaeus*), although house mice reinvaded within a year (Zealandia website; Campbell-Hunt 2002; Blick *et al.* 2008). Endemic forest birds reintroduced to the valley following mammal eradication are listed in Table 1.

Table 1. Endemic forest birds reintroduced to Zealandia. There were also 10 rehabilitated New Zealand pigeons released between 2002 and 2005 (see text). Little spotted kiwi are primarily nocturnal and so were rarely detected during 5-minute bird counts undertaken during daylight.

Date	Species
2000-01	Little spotted kiwi
2000	North Island weka
2001-02	Whitehead
2001-02	North Island robin
2001-04	Tomtit
2001-11	Bellbird
2002-03	North Island saddleback
2002-07	Kaka
2005-10	Stitchbird
2010-11	Red-crowned parakeet

Kapiti Island (40°51′S, 174°55′E) is a 1969 ha forested nature reserve 47 km to the north-northeast of Zealandia. Like Zealandia, much of the island was cleared for farming in the 1800s, and the regenerating forest is dominated by kohekohe, tawa (*Beilschmiedia tawa*) and five-finger (Fuller 2004). All introduced mammals had been eradicated by 1996, including brushtail possums in 1983-87 and Norway rats *Rattus norvegicus* and Pacific rat *R. exulans* in 1996 (Cowan 1992; Empson & Miskelly 1999; Brown 2004). Kapiti Island was the main or sole source for many of the endemic birds reintroduced to Zealandia, including little spotted kiwi (*Apteryx owenii*), whitehead (*Mohoua albicilla*), tomtit (*Petroica macrocephala*), North Island robin (*P. longipes*), bellbird (*Anthornis melanura*) and red-crowned parakeet (*Cyanoramphus novaezelandiae*).

Study design, data collection and analysis

Forty permanent count stations were established inside the former Karori water reservoir catchment (now 'Zealandia') in 1995, 4 years before pest mammals were eradicated. Count stations were spaced c.200 m apart on 4 lines, with observers typically counting two count station lines (i.e. 20 count stations) on each survey day.

The 5-minute count methodology used was based on Dawson & Bull (1975). Observers recorded all birds seen or heard during 5 minutes while stationary at each count station (unbounded counts, *sensu* Dawson & Bull 1975; Hartley & Greene 2012). Any birds that were both seen and heard were recorded as seen only, with totals for seen + heard combined in analyses. Counts along each line of 10 stations were undertaken by a single observer at a time; when trainee observers were paired with experienced observers, only those birds seen or heard by the experienced observer were recorded. Any birds recorded while walking between count stations were excluded from analyses. Each station was counted 4 times by 4 different observers per count session (i.e. the same month in a given year), with no more than 2 counts at any station on the same day. Counts were postponed till later in the month if there was persistent rain or strong winds.

Counts were undertaken in 3 blocks: before the fence was built and pest mammals eradicated (1995-98); 3-6 years after mammal eradication, but before reintroduced bird populations were well established (2002-05); and following the establishment of a restored endemic forest bird community (2013-16). During each count block, counts were completed in the same 4 calendar months (January, April, July and October) for 3 consecutive years. Each 5-minute count was initiated between 0830 and 1430 hours, with an even spread of count start times for each line and station.

The analyses presented are based on 5760 5-minute bird counts split evenly between the three count blocks. The mean count per species was calculated for each of the 40 stations for each count session, to minimise pseudo-replication and to compensate for variance in observer ability. Counts undertaken in the same calendar month were pooled for each 3-year count block, to provide 120 independent estimates per species per 'month' (i.e. 40 count stations x 3 years). Count means for each species-station-month were transformed (square root (x+1)) to reduce skew in order to meet requirements for parametric comparisons. Transformed count means and variances between count blocks for each month were compared with 2-way analyses of variance (ANOVA).

A network of 64 bird count stations on 6 count lines was established on Kapiti Island in the mid-1970s (Miskelly & Robertson 2002). Counts were undertaken by Birds New Zealand members during 1999-2002 (in January, April, July and October), 3-6 years after rat eradication, using the same methodology as in Zealandia.

Bird community structure

Change in the Zealandia bird community structure over time was compared by calculating Bray-Curtis dissimilarity indices between count blocks (Bray & Curtis 1957), based on mean 5-minute bird counts across seasons for each 3-year count block. The Zealandia counts were also compared with similar count data from Kapiti Island, collected in the same calendar months by the same core count team following rat eradication there (Miskelly & Robertson 2002; author, *unpubl. data*). The Zealandia/Kapiti Island comparisons were based on mean counts for 43 species (31 shared species, 6 recorded only at Zealandia, and 6 recorded only on Kapiti Island).

While the Bray-Curtis dissimilarity indices presented here were calculated on encounter rates rather than absolute abundance estimates, the differences over time and between the two locations provide insights into the ecological processes affecting bird species abundance and community structure.

Limitations of study design

The Zealandia bird survey was a Birds New Zealand project undertaken by a large team of volunteers, each with varying levels of ability to detect and recognise bird calls, and it was run over a long time period with changing personnel. This necessitated some compromises in study methods and design. The first was to use the basic 5-minute bird count technique (Dawson & Bull 1975), rather than a more complex distance-sampling methodology that may have allowed calculation of absolute density estimates for a smaller subset of focal species (Greene & Pryde 2013; Broekema & Overdyck 2013). Five-minute bird counts do not provide a measure of absolute or relative abundance, but do provide a readily collected index of abundance and conspicuousness (or 'encounter rate') suited 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 efficient way to survey the diverse and abundant bird community present in the valley (see Johnson 2008).

While a large number of observers were involved over the 21 years, 39% of the counts were completed by 3 observers who each participated in nearly every count session, and 81% of the counts were completed by 11 regular contributors. In order to minimise the effects of varying observer ability (Bibby *et al*. 2000; Hartley 2012), every station was counted 4 times by different observers each count session, and the mean count for each station was used in analyses, rather than single-observer counts.

It was determined at the outset that there was no suitable control site that could be used to generate data on regional changes in bird numbers or encounter rates over time, that would have been independent of management actions, e.g., population responses to severe weather events , unusually wet or dry spells, or large variations in nectar or fruit availability. This was the main reason for undertaking counts in 3-year blocks, and pooling session counts for each count-month, in order to smooth out between-year variations that may have obscured bird population responses to changes in predator and competitor communities. Pooling 3 years of counts plus undertaking counts on 2-4 different days per session also compensated for variation in weather conditions on count days affecting bird behaviour and detectability (Simons *et al.* 2007; Hartley 2012).

Some broader scale bird count data became available from 2011 onwards, when Greater Wellington Regional Council (GWRC) initiated counts at 100 randomly selected sites in forest reserves outside the Zealandia fence, scattered over the wider cityscape (McArthur *et al.* 2016). These 5-minute bird counts were undertaken by 2-3 contractors, in November and early December (cf. our counts undertaken in four months including October). However, the GWRC counts overlapped with our 2013-16 count block, allowing some assessment of whether encounter rates for the most frequently recorded species in Zealandia during October in the final count block reflected their detectability in unfenced reserves throughout the city over the following month or so.

Related temporal problems that are more difficult to control for without comprehensive ecological surveys are successional changes in vegetation over the 21 years of the survey, and other changes in habitat quality related to mammal exclusion. For example, seedling density in the Zealandia forest understorey increased after mammal exclusion, and seedlings of species previously known to be palatable to brushtail possums (e.g., kohekohe, mahoe, pate *Schefflera digitata* and kanono *Coprosma grandifolia*) were detected at higher frequencies following eradication (Blick *et al.* 2008). It is likely that some of this seedling recruitment reflected greater availability of fruits and seeds following eradication of possums and rats (Montague 2000; King 2005; King *et al*. 2015), and would provide even more food for birds over time.

The composition and abundance of invertebrates available as food for birds is also likely to have changed following mammal removal. Within Maungatautari (a fenced forest sanctuary in Waikato), significant increases were found in three weta species (Orthoptera) 2 years after pest mammal eradication, and there was a 300% increase in the abundance of ground-dwelling beetles (Watts 2007; Watts *et al*. 2011). In contrast, within Zealandia beetle abundance declined for 6 years following mammal eradication before stabilising (Watts *et al*. 2014). These potential changes in habitat quality mean that responses to mammal eradication may be more complex than simple release from predation.

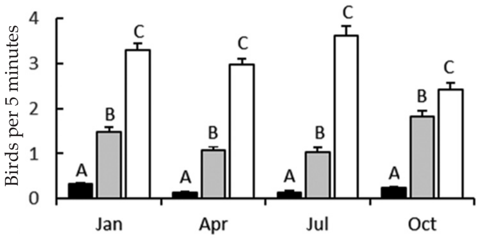

Fig. 1. Changes in tui counts in Zealandia over 3 time periods (birds per 5-minute bird count, mean plus standard error). Black = 1995–98 (pre-fence), grey = 2002–05 (after pest mammal eradication), white = 2013–16 (after several reintroduced endemic bird species had become established). The differing letters above the bars show that all counts differed significantly within each count month (ANOVA, $p < 0.05$).

Terminology

'Introduced' refers to bird species introduced to New Zealand, which were present in Karori Reservoir or nearby before the fence was built. 'Native' refers to species that occur naturally in New Zealand. 'Reintroduced' birds refer to endemic species translocated to the site after the fence was built and pest mammals eradicated. 'Recoloniser' is used to describe endemic species that have recolonised and bred in the sanctuary since 2000 without any (or inconsequential) reintroduction effort. The qualifiers 'pre-fence' and 'resident' are used for both native and introduced species that were present in the valley before the fence was built, and includes migratory species that use the valley seasonally.

'Block 1' refers to bird counts undertaken during 1995-98, before any management actions were undertaken. 'Block 2' refers to counts undertaken during 2002-05, 3-6 years after pest mammals were eradicated, but before any reintroduced bird species were well established. 'Block 3' refers to counts undertaken during 2013-16, when several reintroduced bird species were well established within Zealandia.

Scientific names of bird species recorded during the counts are presented in the Appendix. Scientific names for any additional species mentioned are provided in the main text.

RESULTS

The response of resident bird species to removal of mammals (Block 1 v Block 2)

The only resident bird species to show a significant positive year-round response to pest mammal eradication was tui, with seasonal counts increasing 7-fold between the first two count blocks (Fig. 1). Tui was the 7th-most frequently recorded species during Block 1, and jumped to 2nd (behind silvereye) in Block 2 (Appendix).

The 3 other common native passerines resident in the valley showed little apparent response to removal of mammals, or their response was not evident across all seasons (Fig. 2). Silvereye counts were significantly down in January of Block 2, with an overall decline of 13% across seasons. However, it remained the most numerous species in both of the first two count blocks (Appendix). Grey warbler counts were significantly up in April and October of Block 2, with an overall increase of 7% across seasons. Fantail counts were significantly up in January and October of Block 2, with an overall increase of 24% across seasons. Following the large increase in tui counts by Block 2, grey warbler slipped from the 2nd-ranked species in Block 1 to 3rd in Block 2, and fantail slipped from 4th to 5th (Appendix).

Two native species that use the valley seasonally showed an initial positive response to creation of the sanctuary (Fig. 3). October counts for shining cuckoo increased 67% between the first two count blocks, and those for sacred kingfisher increased 5-fold.

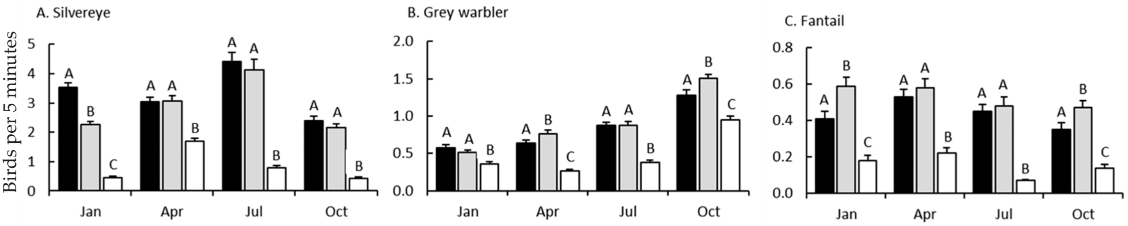

Fig. 2. Changes in counts of 3 resident native passerine species in Zealandia over 3 time periods (birds per 5-minute bird count, mean plus standard error). Black = 1995–98, grey = 2002–05, white = 2013–16. Identical letters above 2 bars within a given month show counts that did not differ significantly between those 2 count blocks, while differing letters show counts that differed significantly over time (ANOVA, $p > 0.05$).

Resident introduced species showed a variable but mainly neutral response to pest mammal eradication. Histograms for the 6 most frequently recorded species, in decreasing order of initial count totals, are presented in Fig. 4. Blackbird counts showed no significant change in any season, with an overall 5% increase in encounter rates between Block 1 and Block 2. Blackbird slipped from the 3rd-ranked species in Block 1 to 4th in Block 2 (Appendix).

Chaffinch counts increased in January and October between the 1st two count blocks, with an overall increase of 23% across seasons (Fig. 4B). Starling counts were the most variable of any resident species, with a significant increase recorded in July only (Fig. 4C). Goldfinch counts showed no significant change in any season between Block 1 and Block 2 (Fig. 4D), while song thrush counts were significantly down in April and up in October (Fig. 4E), and dunnock counts were significantly up in October only (Fig. 4F).

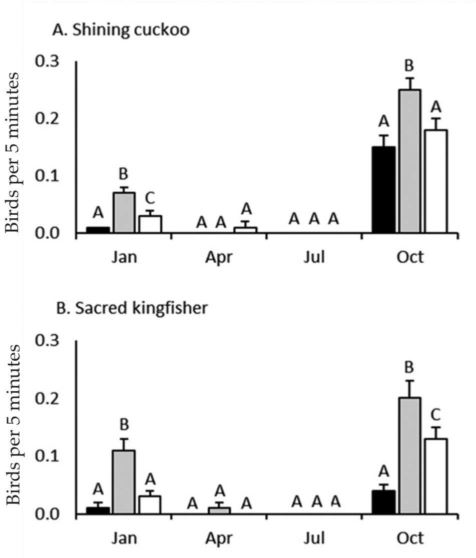

Fig. 3. Changes in shining cuckoo and sacred kingfisher counts in Zealandia over 3 time periods (birds per 5-minute bird count, mean plus standard error). See Fig. 2 caption for explanation of notations used.

Establishment of re-introduced and recolonising endemic forest bird species (Block 2 v Block 3)

Ten endemic forest bird species were translocated to Zealandia between 2000 and 2011 (Table 1), however, weka and tomtit failed to establish

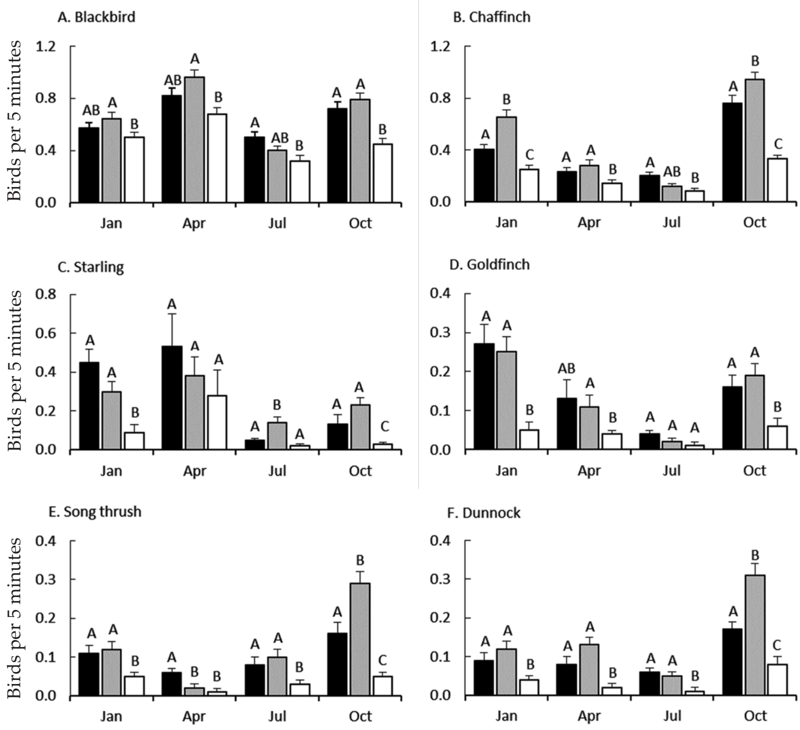

Fig. 4. Changes in counts of the 6 most abundant resident introduced passerine species in Zealandia over 3 time periods (birds per 5-minute bird count, mean plus standard error). Black = 1995–98, grey = 2002–05, white = 2013–16. Identical letters above 2 bars within a given month show counts that did not differ significantly between those 2 count blocks, while differing letters show counts that differed significantly over time (ANOVA, $p > 0.05$).

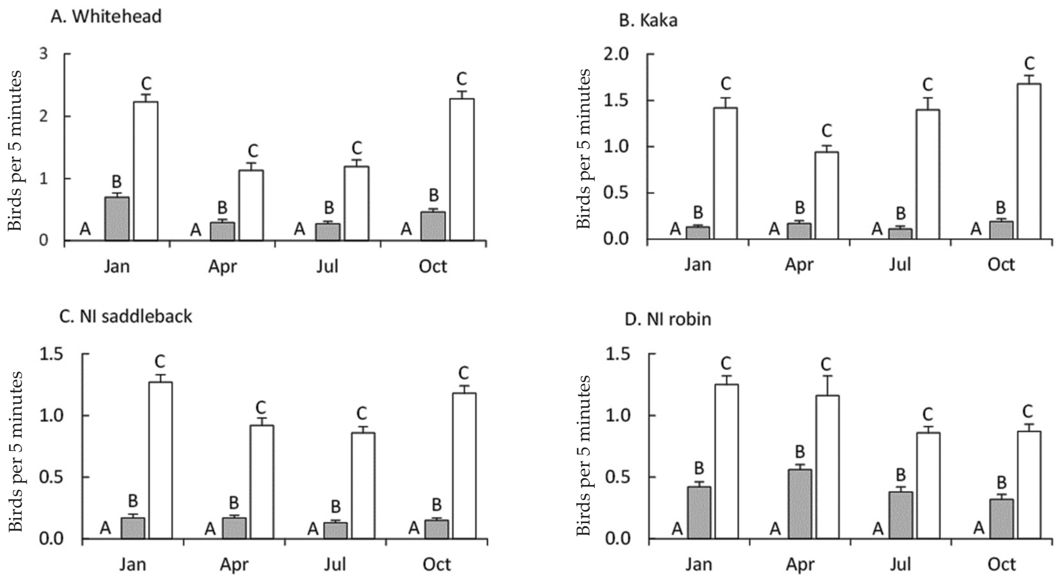

Fig. 5. Changes in counts of 4 reintroduced endemic bird species in Zealandia over 3 time periods (birds per 5-minute bird count, mean plus standard error). All 4 species were absent during the 1995-98 (pre-fence) counts. Grey = 2002–05 (after pest mammal eradication, including or soon after the start of reintroductions), white = 2013–16 (when all 4 species were well established). The differing letters above the bars show that all counts differed significantly within each count month for all species (ANOVA, $p < 0.05$).

(Empson & Fastier 2013; Miskelly & Powlesland 2013). Eight species were released just before or during 2002-05, and the diurnal species were recorded in low numbers during the Block 2 counts (e.g. whitehead ranked 7th, North Island robin 8th and bellbird 10th; Figs 5 & 6, Appendix). Two further species were released mainly or entirely after 2005, and so were barely detected during the Block 2 counts (Fig. 7, Appendix).

Four of the translocated diurnal forest bird species were well established in the valley by 2013-16, and were ranked among the top 5 species recorded during the Block 3 counts (whitehead 2nd, kaka 3rd, North Island saddleback 4th, North Island robin 5th; Fig. 5). Red-crowned parakeet and stitchbird were recorded in lower numbers (ranked 9th and 10th respectively; Fig 7).

Bellbirds were released in large numbers in the valley during Block 2, but subsequently declined in abundance, and were recorded in significantly lower numbers in January, April and July in Block 3 (Fig. 6A).

Two further endemic forest bird species recolonised the valley naturally before 2009, and

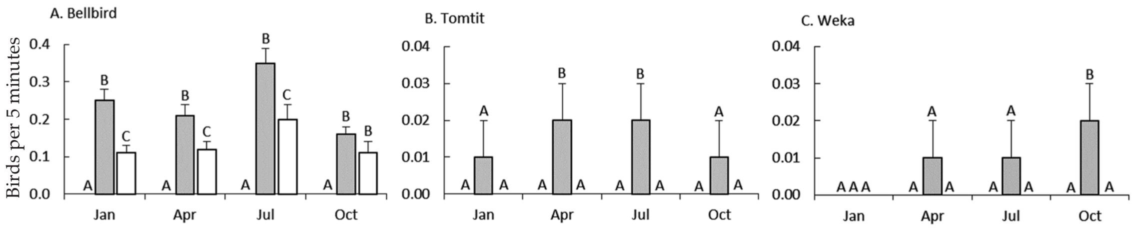

Fig. 6. Changes in counts of 3 reintroduced endemic bird species in Zealandia over 3 time periods (birds per 5-minute bird count, mean plus standard error). All 3 species were absent during the 1995–98 (pre-fence) counts, and died out or declined after 2005. See Fig. 5 caption for explanation of notations used.

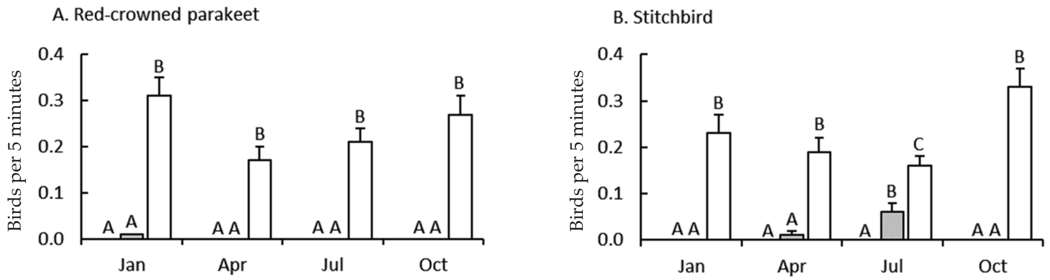

Fig. 7. Changes in counts of 2 reintroduced endemic bird species in Zealandia over 3 time periods (birds per 5-minute bird count, mean plus standard error). Both species were absent during the 1995–98 (pre-fence) counts, and were mainly reintroduced after 2005. Identical letters above 2 bars within a given month show counts that did not differ significantly between those 2 count blocks, while differing letters show counts that differed significantly over time (ANOVA, $p > 0.05$).

were recorded in low numbers during the Block 3 counts. A pair of New Zealand falcons first bred in Zealandia in 2009, and falcons were recorded on 18 occasions during Block 3 (cf. a single sighting in Block 2). Ten rehabilitated New Zealand pigeons were tagged and released in the valley during Block 2. However, the breeding population established since 2005 (Fig. 8) was derived mainly or entirely from unmarked birds presumed to have recolonised naturally from a small population at Otari-Wilton Bush and Ngaio Gorge, 3-4 km away.

The response of resident bird species to the establishment of a more diverse endemic bird community (Block 2 v Block 3)

Tui counts continued to increase markedly after 2005, and it became the most frequently recorded species during the Block 3 counts (Fig. 1, Appendix). Averaged across seasons, tui increased 2.5-fold between Block 2 and Block 3.

In contrast to tui, counts of other resident native passerines declined significantly after 2005 (Fig. 2). Silvereye and fantail counts averaged across seasons both declined by 72% between Block 2 and Block 3, and grey warbler counts declined by 47% (Fig. 2). These 3 species declined from being the species with the highest encounter rate (silvereye), 3rd highest (grey warbler) and 5th (fantail) in Block 2 to 6th, 7th and 12th respectively in Block 3 (Appendix).

Counts of both shining cuckoo and sacred kingfisher declined significantly between Block 2 and Block 3 (Fig. 3). October counts declined 29% for shining cuckoo, and 35% for sacred kingfisher.

Counts for all 6 of the most frequently recorded resident introduced bird species in the valley declined markedly after Block 2 (Fig. 4), with significant declines in all four count months for dunnock (Fig. 4F) and in three out of four count months for blackbird, chaffinch, starling, goldfinch and song thrush (Fig. 4).

Averaged across seasons, blackbird counts declined 29% between Block 2 and Block 3, chaffinch counts declined 53%, starling counts declined 66%, goldfinch counts declined 64%, song thrush counts declined 65%, and dunnock counts declined 74% (Fig. 4).

For most resident species, counts within Zealandia in October 2013-15 (Block 3) were significantly lower than counts in unfenced (and smaller) forested reserves elsewhere in Wellington city undertaken in November and early December in the same years (Fig. 9). During 2013-15, reintroduced endemic forest birds were a rare component of bird communities outside the fence (all species averaged less than 0.15 individuals per

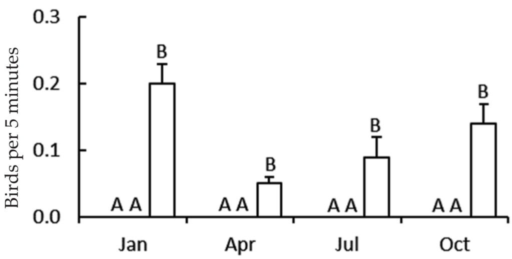

Fig. 8. Changes in counts of New Zealand pigeon in Zealandia over 3 time periods (birds per 5-minute bird count, mean plus standard error). New Zealand pigeons were recorded in 3 counts in each of the 1995–98 (pre-fence) and 2002–05 (after pest mammal eradication) counts, however, they mainly recolonised the valley after 2005. (white = 2013–16). See Fig. 7 caption for explanation of notations used.

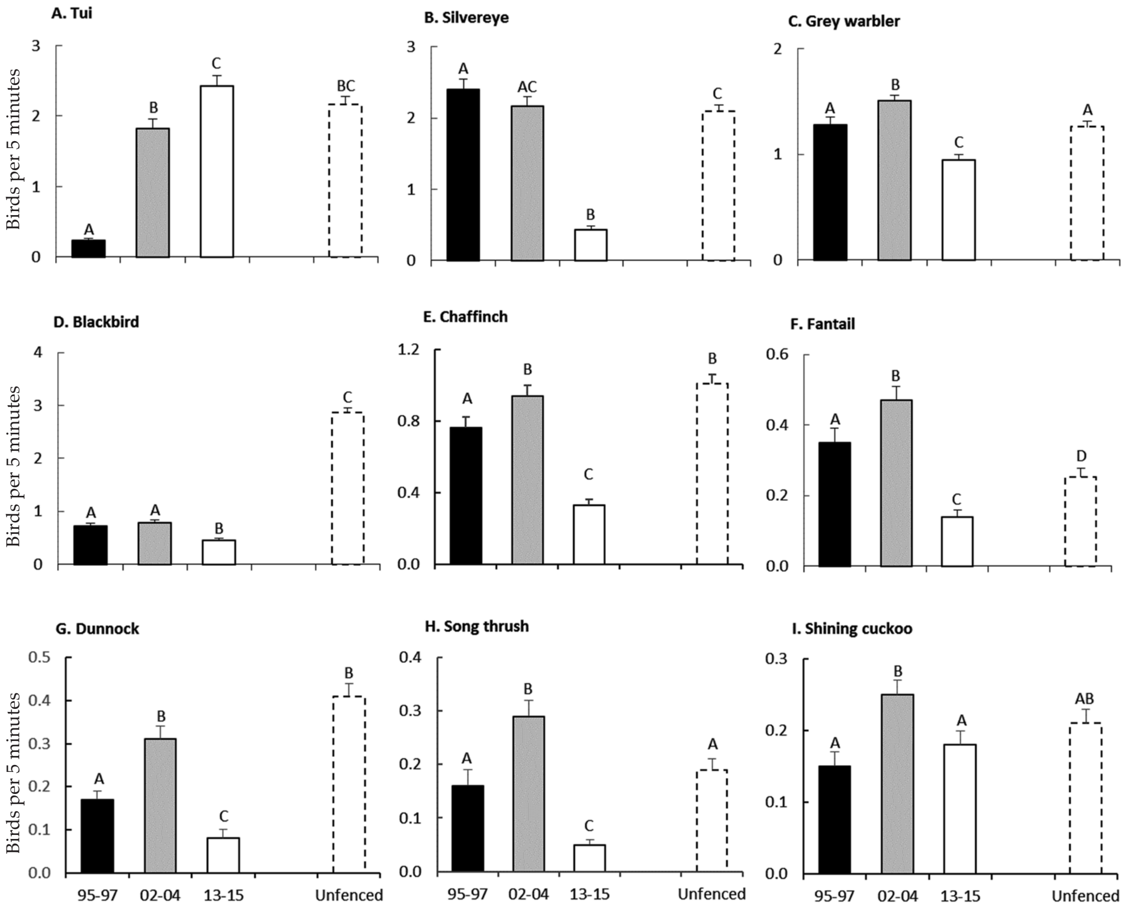

Fig. 9. October counts of 9 resident bird species in Zealandia over 3 time periods compared to counts undertaken in unfenced forest reserves elsewhere in Wellington city almost concurrent with the final Zealandia count session (i.e. October 2013–15 cf. November to early December 2013–15). Zealandia counts with solid borders: black = Block 1 (pre-fence), grey = Block 2 (after pest mammal eradication), white = Block 3 (after reintroduced endemic birds had established). City-wide (unfenced) counts undertaken in 2013–15, white with dashed border. Identical letters above the bars show counts that did not differ significantly for each species, while differing letters show counts that differed significantly over time and/or site (ANOVA, $p > 0.05$). Unfenced bird count data from McArthur *et al.* (2016), with raw count data provided courtesy of N. McArthur (Wildlife Management International Ltd) and P. Crisp (Greater Wellington Regional Council). Translocated endemic forest birds were a minor component of unfenced Wellington forest bird communities during 2013-15 (McArthur *et al.* 2016).

5-minute count when all 100 city-wide sites were combined, with only kaka averaging more than 0.05; McArthur *et al.* 2016). Of the 9 most abundant resident Zealandia species, only tui and shining cuckoo had comparable counts inside and outside the fence in 2013-15 (Figs 9A & 9I). The seven other resident species had all declined in Zealandia compared to earlier counts, and all had significantly lower counts inside the sanctuary than outside in 2013-15 (Figs 9B to 9H). Five species had 'unfenced' 2013-15 counts that did not differ significantly from one of the first 2 Zealandia count blocks: silvereye (Fig. 9B), grey warbler (Fig. 9C), chaffinch (Fig. 9E), dunnock (9G) and song thrush (Fig. 9H). Blackbirds were significantly more abundant outside the fence than had been recorded during any Zealandia count block (Fig. 9D). Fantails were recorded at a lower rate outside the fence than had been recorded

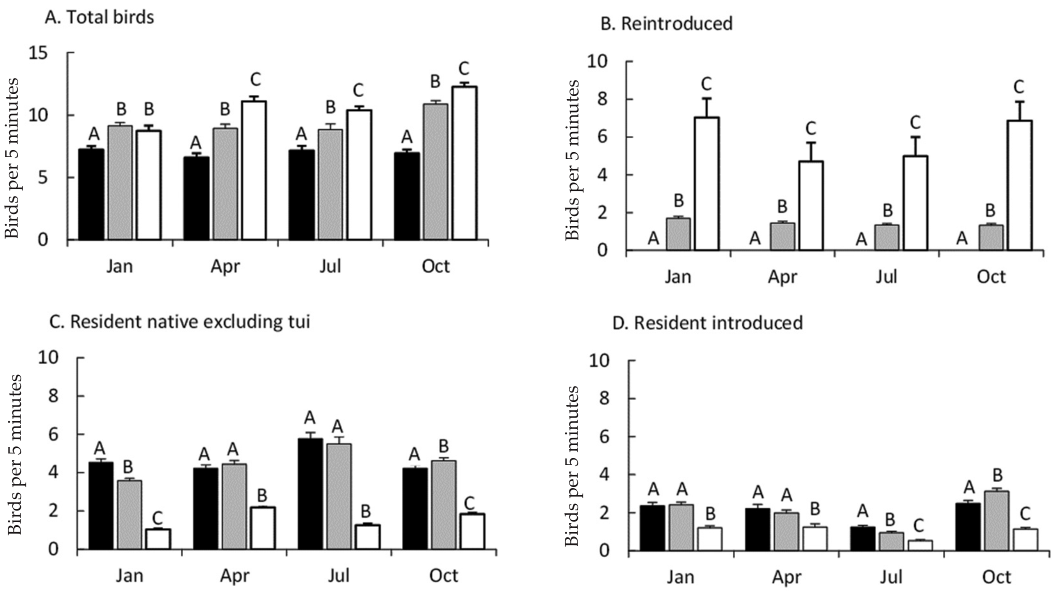

Fig. 10. Changes in aggregated bird counts from Zealandia over 3 time periods (birds per 5-minute bird count, mean plus standard error). A = all 37 species combined; B = 12 reintroduced or naturally recolonising endemic species; C = 9 resident native species excluding tui; D = 14 resident introduced species. Black = 1995–98 (pre-fence), grey = 2002–05 (after pest mammal eradication), white = 2013–16 (after several reintroduced endemic bird species had become established). Identical letters above 2 bars within a given month show counts that did not differ significantly between those 2 count blocks, while differing letters show counts that differed significantly over time (ANOVA, $p > 0.05$).

in Zealandia in Block 1 or Block 2. However, as for most of the resident species, the 'unfenced' 2013-15 (Block 3) fantail counts were still significantly higher than the almost concurrent counts inside the sanctuary (Fig. 9F).

Changes in the Zealandia forest bird community over 21 years (Block 1 v Block 3)

The composition of the Zealandia forest bird community changed dramatically between Block 1 and Block 3. The total number of birds counted increased 52% averaged across seasons (Fig. 10A), with the increase driven almost entirely by increases in tui and reintroduced endemic species (Fig. 1 and 10B). In contrast, counts for most of the resident species decreased significantly between Block 1 and Block 3 (Fig. 10C and 10D). There were a few exceptions to this pattern among the less numerous species, with sacred kingfisher (in October) and California quail recorded in significantly higher numbers in Block 3 compared to Block 1, and eastern rosella recorded in similar low numbers in both count periods (Fig. 3B, Appendix).

Averaged across seasons, tui counts increased 11-fold between Block 1 and Block 3. It was the only resident species to show a significant increase across all seasons between the first and third count blocks (Fig. 1). Seven other resident species had significantly lower counts in all 4 seasons in Block 3 compared to Block 1: silvereye (66% decrease, Fig. 2A), grey warbler (40% decrease, Fig. 2B), fantail (57% decrease, Fig. 2C), chaffinch (41% decrease, Fig. 4B), song thrush (56% decrease, Fig. 4E), dunnock (53% decrease, Fig. 4F) and Australian magpie (100% decrease, Appendix).

Tui was the species counted in the highest numbers during Block 3, followed by 4 reintroduced species (whitehead, kaka, North Island saddleback, North Island robin), then the 3 resident species that had been the top-ranked species in Block 1 (silvereye, grey warbler, blackbird; Fig. 11).

The successful establishment of these four reintroduced species, the large increase in tui, and the declines in other resident species collectively increased the indigenous character of the valley over time. The proportion of the total count comprised of introduced species declined from 30% to 9%

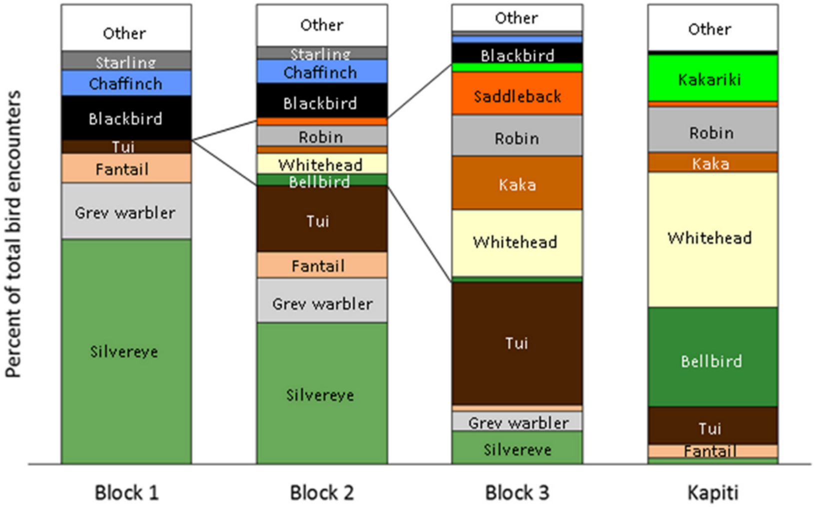

Fig. 11. The composition of the Zealandia bird community over 3 time periods (Blocks 1-3), compared to Kapiti Island (1999-2002), based on the proportional record of each species during 5-minute counts undertaken in January, April, July and August. Equal count effort was made during each month at both sites, with counts averaged across the seasons within each count block. Block 1 = before pest mammal eradication (1995–98); Block 2 = after pest mammal eradication (2002–05); Block 3 = after establishment of a diverse endemic bird community (2013–16). Lines enclose endemic species reintroduced to Zealandia after pest mammals were eradicated. Abbreviated bird names: fantail = New Zealand fantail, kakariki = red-crowned parakeet, robin = North Island robin, saddleback = North Island saddleback.

Table 2. Changing proportions of introduced, native and endemic bird species recorded during 5-minute bird counts in Zealandia over three time periods. Note that endemic birds are a subset of, and included in, the native bird component.

	Block 1 1995-98	Block 2 2002-05	Block 3 2013-16
% introduced	29.8	22.1	8.9
% native	70.2	77.9	91.1
% endemic	21.3	45.0	83.0

between Block 1 and Block 3, while the proportion comprised of endemic species increased from 21% to 83% (Table 2).

The bird community in Zealandia in 2013-16 (Block 3) was more similar to that on predator-free Kapiti Island than it was to the 'pre-fence' (Block 1) Zealandia bird community (Bray-Curtis indices 0.543 v 0.707; Table 3 and Fig. 11). Removal of mammals initially had a relatively small direct impact on the Zealandia bird community structure, but enabled reintroductions of several bird species vulnerable to mammal predation. Despite commencement of reintroductions of all species except for red-crowned parakeet by 2005, there was little change in the Zealandia bird community between 1995-98 and 2002-05 (Bray-Curtis index for Block 1 v Block 2 = 0.233; Table 3 and Fig. 11). In contrast, there was a much greater change in community structure between Block 2 and Block 3 counts (Bray-Curtis index = 0.504) as the reintroduced species already present in Block 2 increased markedly in abundance, and encounter rates for resident species other than tui declined dramatically (Fig. 10 and 11).

DISCUSSION

The benefits of fenced forest sanctuaries to endemic New Zealand birds

The Zealandia project has met the primary restoration objective of restoring indigenous character in the valley (Lynch 2000; Campbell-Hunt 2002), at least with respect to birds. The Zealandia restoration strategy has a multi-faceted 500-year vision, with key conservation outcomes that include *"fauna…representative of a Wellington ecological district lowland…ecosystem restored in [and] the indigenous character of the valley restored to the enclosed area"* (Lynch 2000; Campbell-Hunt 2002). The proportion of native species within each biotic group is identified as an explicit measure of progress

Table 3. Matrix of Bray-Curtis dissimilarity indices comparing the Zealandia bird community over three time periods and with Kapiti Island counts undertaken during 1999–2002. Scores can range between 0 (identical community composition and abundance) and 1 (no shared species). The decreasing values in the 'Kapiti' column show that the Zealandia bird community became more similar to the Kapiti bird community over time.

	Kapiti	Block 1	Block 2
Block 1 (1995-98)	0.894		
Block 2 (2002-05)	0.699	0.233	
Block 3 (2013-16)	0.543	0.707	0.504

towards restoration of indigenous character (Lynch 2000, p.9). With 83% of the birds observed in the valley now endemic (up from 21% before the fence was built), Zealandia has made rapid progress towards the goal that "*in due course the nature and quality of the valley will be overwhelmingly indigenous*" (Campbell-Hunt 2002).

The rapid increase in the proportion of endemic birds recorded in Zealandia within 17 years of mammal eradication was driven by an 11-fold increase in the number of tui counted (a species that was present in low numbers before the fence was built), the establishment of healthy populations of 4 reintroduced diurnal forest bird species, and marked declines in counts of silvereye (a non-endemic native) and most introduced bird species. The proportion of endemic birds in the valley is likely to increase further, as New Zealand pigeon and red-crowned parakeet (at least) have continued to increase in conspicuousness since the counts reported here were completed in January 2016 (author, *pers. obs*.).

The effective predator-resistant fence at Zealandia has facilitated the re-establishment of 3 endemic bird species that became extinct on the mainland after 1880 (little spotted kiwi, North Island saddleback and stitchbird). Viable populations of all 3 species are currently confined to sites with no introduced mammals, or mice only (either islands or fenced sanctuaries; Burns *et al.* 2012; Miskelly & Powlesland 2013; Butler *et al*. 2014). Trials at unfenced sites have indicated that North Island saddleback and stitchbird require near-zero pest levels for population re-establishment, and they are unlikely to survive at unfenced mainland sites using existing predator control methods (Burns *et al.* 2012; Innes *et al*. 2012; Miskelly & Powlesland 2013; McArthur *et al*. 2017a).

A few of the endemic bird species that have benefited from the Zealandia project do not require complete suppression of mammalian predators in order to persist and thrive. Further to their rapid increase in Zealandia since 1999, tui have also increased across the wider city scape in response to effective possum and rat control undertaken in Wellington city parks and reserves (Miskelly *et al.* 2005; Bell 2008; Brockie & Duncan 2012; McArthur *et al*. 2016). Bird counts undertaken for GWRC in unfenced Wellington parks and reserves reveal that tui are now encountered at similar rates inside and outside the Zealandia fence (Fig. 9A; and see McArthur *et al*. 2016). New Zealand pigeons also persisted in unfenced Wellington reserves (McArthur *et al*. 2017a), but are now increasing at a more rapid rate within Zealandia than in other parts of the city (data presented here, and author, *pers. obs*.).

While the extent to which Zealandia has contributed to the recovery of tui across Wellington city is debatable, the sanctuary sustains the sole or predominant source populations for seven other endemic forest bird species that have been recorded beyond the fence since they were translocated to Zealandia (McArthur *et al*. 2016; McArthur *et al*. 2017a). Kaka is the translocated species most widely sighted beyond the fence; it was recorded at 43 of 100 unfenced Wellington count stations, and up to 10 km from Zealandia, between 2011 and 2016 (McArthur *et al*. 2017a). Other translocated species recorded outside the fence included red-crowned parakeet (at 21 count stations), North Island saddleback and whitehead (both at 19 stations), and bellbird (12 stations).

Dispersal of endemic birds beyond sanctuaries is referred to as the halo effect, and has been documented for several fenced sanctuaries in New Zealand (Smuts-Kennedy & Parker 2013; McArthur *et al*. 2017a; Tanentzap & Lloyd 2017). 'Halo Projects' to control predators adjacent to predator-fenced sites have been established in Wellington, Dunedin and Hamilton, with the aim of enhancing the survival rates of endemic birds as they move beyond predator exclusion fences (e.g. Enhancing the halo http://halo.org.nz/, viewed 10 October 2017). All of the bird species successfully translocated to Zealandia currently have much higher survival rates and breeding success inside the fence than out. While at least 5 species (kaka, red-crowned parakeet, North Island saddleback, whitehead and North Island robin) have bred successfully in nearby unfenced reserves (Anonymous 2016; McArthur *et al.* 2016, 2017a; Annette Harvey, pers. comm. 14 Nov 2017), most attempts to date have failed due to cat and rat predation. Within Wellington, the Halo Project complements 'Predator Free Wellington', which aims to increase bird populations through community-led predator trapping. The initial focus is on eradicating rats and stoats from the Miramar Peninsula, where possums were eradicated in 2006 (Wellington City Council 2017). In this way, fenced sanctuaries are contributing to biodiversity gains over a wider landscape, both through dispersal of endemic birds, and the motivation this provides individuals and community groups to undertake pest control beyond the fences (Burns *et al.* 2012; Russell *et al.* 2015).

The impacts of mammals on birds of urban forest remnants

One of the most striking findings of this study was that eradication of introduced mammals had little effect on the 'pre-fence' resident birds of Zealandia. Other than tui, counts of resident native birds showed little response to eradication of introduced mammals, and counts of introduced birds increased by only 2% averaged across seasons (Figs 10C & 10D). This suggests that most of the bird species that had survived in the presence of mammalian predators in Wellington urban reserves were not unduly limited by mammals, whereas (apart from tui and New Zealand pigeon) those species that were limited by predation had long since died out.

Nine species of native forest birds are regularly recorded in New Zealand cities, comprised of 3 species that are common and widespread (silvereye, grey warbler and fantail), and 6 species that are either patchily distributed or occur at much lower densities (tui, New Zealand pigeon, bellbird, morepork *Ninox novaeseelandiae*, shining cuckoo and sacred kingfisher) (Bull & Underhill 1983; Gill 1989; Day 1995; Brockie 1997; van Heezik *et al*. 2008; MacLeod *et al*. 2017). The remaining native forest birds that survived on the mainland are all endemic species (mostly in endemic genera) that are in the process of becoming confined to remote, cold forests with low ship rat abundance and variable stoat abundance (Elliott *et al.* 2010; Brown *et al.* 2015; Walker *et al*. 2017).

Native forest birds can be arranged along a gradient of their susceptibility to predation by introduced mammals (Holdaway 1989, 1999; Innes & Hay 1991; Innes *et al.* 2010). The results presented here suggest that there may be a corresponding gradient representing the extent to which each species will respond to predator control or eradication. Does resilience to predation also mean that a species is not limited by predation? One of the most widely reproduced predator-impact images in New Zealand shows an adult fantail being killed on its nest by a ship rat (Mudge 2002), raising the expectation that removal of rats and other predators will lead to an increase in fantails (Department of Conservation 2010 & undated), yet there is little evidence to support this assertion. While fantails showed some evidence of increased productivity within Zealandia in the absence of mammals (based on a small increase in October and January counts during 2002-05), this did not translate into a year-round increase, and they declined rapidly following the establishment of a diverse endemic bird community. This mirrored results reported following aerial application of 1080 to control pest mammals in Tongariro Forest Kiwi Sanctuary, where fantail nesting success increased following 1080 application, but no increase was detected in 5-minute bird counts undertaken in February, immediately after the breeding season (Sutton *et al*. 2012).

Fantails are susceptible to mass die-offs during severe weather events (Barlow 1989; Nilsson *et al.* 1994; Miskelly & Sagar 2008), complicating attempts to determine the extent to which their populations are limited by predation. Their populations are able to recover rapidly regardless of the presence or absence of introduced predators (Nilsson *et al.* 1994; Aikman & Miskelly 2004; McArthur *et al*. 2017b), and they remain common and widely distributed (Robertson *et al.* 2007; Heather & Robertson 2015).

Numerous studies have indicated that introduced bird species and the silvereye (a recent colonist from Australia) receive little benefit from control of introduced mammals, either on the New Zealand mainland or offshore islands (e.g. Graham & Veitch 2002; Miskelly & Robertson 2002; Innes *et al.* 2004; Elliott *et al.* 2010; Starling-Windhof *et al.* 2011; Johnstone MacLeod *et al*. 2015). However, none of these previous studies documented the effect of eradication of ship rats and stoats, which are widely regarded as the most harmful introduced predators of New Zealand forest birds (Mudge 2002; Elliott *et al*. 2010; Innes *et al.* 2010; Brown *et al.* 2015). The multi-species pest eradications completed in Zealandia in 1999 created a novel and profound change in ecological conditions, and yet tui was the only resident species that responded with a dramatic year-round increase in abundance, followed several years later by a recolonising population of New Zealand pigeons. This same pattern is reflected in the wider Wellington city area, where increasing levels of pest control led to significant increases in tui and New Zealand pigeon, but no measurable increases in other resident species (Miskelly *et al.* 2005; Bell 2008; McArthur *et al*. 2017a). Preliminary results from Maungatautari (a 3300 ha predator-fenced site in the Waikato) also revealed a significant increase in tui within 2 years of pest mammal eradication, but few detectable responses among other resident bird species (Fitzgerald *et al*. 2009).

Several authors have reported failure of grey warblers and fantails to respond to pest control in mainland forests, but it is unclear whether this apparent lack of response was because these species were not limited by predation, or was due to their populations being suppressed through resulting competition from species that responded positively to pest control (see next section). In the Hunua Ranges, New Zealand pigeon, tui and tomtit were significantly more abundant in a managed area compared to unmanaged areas, but grey warbler and fantail were not (Baber *et al.* 2009). Neither grey warbler nor fantail responded to pest control at Boundary Stream, Hawke's Bay (Ward-Smith *et al.* 2004), and the abundance of grey warblers actually declined after pest management in northern Te Urewera, and in Trounson Kauri Park and Motatau, Northland (Jones 2000; Pierce 2001; Innes *et al*. 2004).

Fantail, grey warbler and silvereye all had net increases in range on the New Zealand mainland between 1969 and 2004 (Walker *et al.* 2017), indicating that it is unlikely that any of these 3 native species are limited by predation.

The role of competition in the structure of New Zealand forest bird communities

Establishment of a diverse community of endemic forest birds after 2005 had a much more dramatic effect on 'pre-fence' resident bird species in Zealandia than the eradication of introduced mammals had. Averaged across seasons, counts of resident native birds other than tui declined 65% between the second and third count blocks, while counts of introduced bird species declined 51% (Fig. 10C and 10D). All these species were encountered more often outside the fence during the Block 3 counts (Fig. 9), at a time when translocated endemic forest bird species dispersing from Zealandia were a minor component of unfenced Wellington forest bird communities (McArthur *et al*. 2016).

The large decline in counts of resident native birds between the second and third count sessions was driven by highly significant declines in counts of the 3 (originally) most abundant native species: silvereye, grey warbler and fantail. These same species declined by 66-91% on Tiritiri Matangi Island within 13-17 years of Pacific rat eradication, concurrent with the increase in translocated endemic bird populations that followed rat eradication (Graham *et al.* 2013).

Silvereye, grey warbler, fantail and introduced bird species are all minor components of the bird communities on Kapiti Island and Te Hauturu-o-Toi / Little Barrier Island, which are large, forested islands that lack predatory mammals, and that have diverse endemic bird communities (Diamond & Veitch 1981; Girardet *et al.* 2001; Innes *et al.* 2010; author, *unpubl. data*). Silvereyes are comparatively rare birds on both islands, as are grey warblers on Kapiti, and none of these 3 native species comprise more than 4% of the birds counted on either island (Diamond & Veitch 1981; Girardet *et al.* 2001; author, *unpubl. data*). The blackbird is the most abundant introduced bird on both islands, but is even rarer, comprising less than 0.6% of the birds counted (*ibid*.). The Zealandia bird community is on a trajectory towards the community structure present on Kapiti Island, with competition from endemic species (most likely whitehead, robin, tui/bellbird and saddleback) the most plausible explanation for the large declines in resident native insectivores and introduced birds at Zealandia, and their rarity on Kapiti Island.

Compensatory changes in bird communities in response to management actions have been recorded at several New Zealand sites – i.e. increases in one or more bird species occurring concurrent with a decline in species known or suspected to compete with the more abundant species (Innes *et al.* 2010; Graham *et al.* 2013). Stoat eradication on Adele Island was followed by a significant increase in bellbirds, but significant declines in tomtit, grey warbler, blackbird, chaffinch and dunnock (Wilson 1988). Similarly, possum and ship rat control on Napier Hill was followed by significant increases in the abundance of bellbird and tui, and a significant decline in the relative abundance of silvereyes (Johnstone MacLeod *et al*. 2015). Predator control to protect North Island kokako *Callaeas wilsoni* in northern Te Urewera was followed by a significant increase in silvereyes and whiteheads concurrent with a significant decline in grey warblers (Jones 2000). Four bird species, including bellbird and robin, increased on Kapiti Island following rat eradication, with a concomitant decrease in tui and tomtit (Miskelly & Robertson 2002; author, *unpubl. data*). Competition between congeneric robins and tomtits is considered to have been the main cause of failure of tomtit translocations to two different sites (Empson & Fastier 2013), and tomtits disappeared from at least 9 small islands in Dusky Sound following stoat eradications and the reintroduction of South Island robins *Petroica australis* to nearby islands (Miskelly *et al*. 2017).

Elliott *et al*. (2010) suggested that silvereyes may have benefited from the declines in abundance of competing forest bird species at Nelson Lakes. However, the widely cited decline or disappearance of silvereyes, grey warblers and 4 introduced bird species on Cuvier Island following the eradication of cats and goats (Diamond & Veitch 1981) is contradicted by Bellingham *et al*. (1981) who recorded silvereye and grey warbler as common, and chaffinch and starling as frequently seen in the forest on Cuvier Island.

Some of the most compelling evidence for competitive suppression of introduced birds by endemic forest birds came from the infamous invasion and irruption of ship rats on Taukihepa / Big South Cape Island, south-west of Stewart Island, in 1963-64 (Bell 1978; Bell *et al.* 2016). Introduced passerines were rare in the absence of rats in April 1961, but several species (chaffinch and dunnock, and possibly blackbird) increased markedly after rats had extirpated or decimated numerous endemic bird species including South Island saddleback *Philesturnus carunculatus*, bush wren *Xenicus longipes*, South Island snipe *Coenocorypha iredalei*, fernbird *Bowdleria punctata*, South Island robin, bellbird and 2 species of *Cyanoramphus* parakeets (Bell 1978, although see Blackburn 1965 for conflicting bird counts).

Introduced birds (along with silvereyes, grey warblers and fantails) are more resilient to mammalian predators than are most endemic bird species, however, most of New Zealand's endemic forest bird species are evidently competitively superior in the absence of predators. Less than 2 decades after initiation, the Zealandia ecological restoration project has demonstrated that endemic New Zealand birds can out-compete introduced bird species even within a tiny 225 ha fenced enclave sandwiched between urban and rural landscapes dominated by adventive species.

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Appendix Total counts of 37 land bird species recorded during 5760 5-minute bird counts in Zealandia/Karori Sanctuary between 1995 and 2016 (with equal effort = 1920 counts per count block). Species are listed in decreasing frequency of encounters (all 3 count blocks pooled). Figures in italics are the encounter rate ranking for each species within the count block.

Common name	Scientific name	Block 1 1995–98		Block 2 2002–05		Block 3 2013–16		Total
Silvereye	*Zosterops lateralis*	6264	*1*	5575	*1*	1618	*6*	13,457
Tui	*Prosthemadera novaeseelandiae*	390	*7*	2589	*2*	5954	*1*	8,933
Grey warbler	*Gerygone igata*	1593	*2*	1756	*3*	944	*7*	4,293
Whitehead	*Mohoua albicilla*	0		824	*7*	3275	*2*	4,099
Blackbird	*Turdus merula*	1224	*3*	1341	*4*	930	*8*	3,495
Kaka	*Nestor meridionalis*	0		286	*13*	2614	*3*	2,900
North Island robin	*Petroica longipes*	0		805	*8*	1991	*5*	2,796
North Island saddleback	*Philesturnus rufusater*	0		292	*12*	2056	*4*	2,348
New Zealand fantail	*Rhipidura fuliginosa*	810	*4*	1016	*5*	288	*12*	2,114
Chaffinch	*Fringilla coelebs*	726	*5*	952	*6*	369	*11*	2,047
Starling	*Sturnus vulgaris*	502	*6*	502	*9*	206	*15*	1,210
Bellbird	*Anthornis melanura*	0		468	*10*	263	*13*	731
Goldfinch	*Carduelis carduelis*	266	*8*	275	*14*	81	*18*	622
Dunnock	*Prunella modularis*	185	*9*	295	*11*	77	*20*	557
Song thrush	*Turdus philomelos*	184	*10*	254	*15*	62	*21*	500
Stitchbird (hihi)	*Notiomystis cincta*	0		33	*21*	431	10	464
Red-crowned parakeet (kakariki)	*Cyanoramphus novaezelandiae*	0		3	*30=*	458	*9*	461
Greenfinch	*Carduelis chloris*	130	*13*	163	16	42	*23*	335
Shining cuckoo	*Chrysococcyx lucidus*	75	*14*	154	*18*	94	*17*	323
Sacred kingfisher	*Todiramphus sancta*	23	*17*	160	*17*	78	*19*	261
New Zealand pigeon (kereru)	*Hemiphaga novaeseelandiae*	3	*22*	3	*30=*	231	*14*	237
House sparrow	*Passer domesticus*	145	*12*	37	*20*	26	*24*	208
Australian magpie	*Gymnorhina tibicen*	179	*11*	22	25	0		201
Eastern rosella	*Platycercus eximius*	27	*16*	112	*19*	45	*22*	184
California quail	*Callipepla californica*	0		10	*28*	99	*16*	109
Total (all species)		12,811		18,049		22,260		53,120

Appendix cont.

Common name	Scientific name	Block 1 1995–98		Block 2 2002–05		Block 3 2013–16		Total
Redpoll	*Carduelis flammea*	32	*15*	19	*26*	1	*29*	52
Welcome swallow	*Hirundo neoxena*	17	*19*	27	*22=*	3	*26=*	47
Swamp harrier	*Circus approximans*	19	*18*	9	*29*	3	*26=*	31
Tomtit	*Petroica macrocephala*	0		27	*22=*	0		27
Weka	*Gallirallus australis*	0		24	*24*	0		24
New Zealand falcon	*Falco novaeseelandiae*	0		1	*33=*	18	*25*	19
Yellowhammer	*Emberiza citrinella*	4	*21*	11	*27*	0		15
Spur-winged plover	*Vanellus miles*	12	*20*	2	*32*	0		14
Takahe	*Porphyrio hochstetteri*	0		0		3	*26=*	3
Little spotted kiwi	*Apteryx owenii*	0		1	*33=*	0		1
Rock pigeon	*Columba livea*	0		1	*33=*	0		1
Long-tailed cuckoo	*Eudynamys taitensis*	1	*23*	0		0		1
Total (all species)		12,811		18,049		22,260		53,120