Forest Bird Monitoring in the Waitākere Ranges Following Possum Control

Tim Lovegrove and Kevin Parker

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Cover image:

Kererū (*Hemiphaga novaeseelandiae*) in a kauri tree (*Agathis australis*), Birkenhead, Auckland. Credit: Michael Ngatai.

Executive summary

A forest health survey in the Waitākere Ranges in 1995 showed declining forest health and significant damage by possums (*Trichosurus vulpecula*) to palatable tree species. A possum trap-catch survey in 1997 produced a residual trap catch (RTC) index of 24%, indicating a high possum population. In 1997-1998 possums were controlled over the 15,500ha Waitākere Ranges Regional Park and 12,700ha of surrounding mainly privately-owned rural and urban buffer land in a ground-based operation. This reduced the RTC to below 1% by late 1998.

To monitor the impacts of the possum control on bird populations, we carried out five-minute bird counts annually over a 22-year period between 1997-1998 and 2018-2019 at 135 count stations on nine public walking tracks sampling a range of forest types and topographies. To reduce possible effects of observer experience, weather, season and bird conspicuousness on the number of birds counted, we carried out the counts between mid-November and early-January on fine, still days from c.0700-1200 NZST, and all counts were carried out by the same two experienced observers. Total detections of birds increased by 75% from 1997-1998 to 2018-2019 as a result of a significant increase in indigenous birds, while most introduced birds did not increase. In 2018-2019 indigenous birds formed a higher proportion of total birds detected than in 1997-1998. Of the indigenous birds, silvereye (*Zosterops lateralis*), tūī (*Prosthemadera novaeseelandiae*), grey warbler (*Gerygone igata*), and welcome swallow (*Hirundo tahitica*) increased significantly, the increase in kererū (*Hemiphaga novaeseelandiae*) approached significance and positive trends were evident in kingfisher (*Todiramphus sanctus*) and tomtit (*Petroica macrocephala*); although for tomtit there was a positive trend through to 2009, then detections levelled off until 2014, and declined thereafter. Detections of fantails (*Rhipidura fuliginosa*) changed very little. Of the introduced birds, blackbirds (*Turdus merula*) increased significantly and eastern rosellas (*Platycercus eximius*) showed a positive trend.

We believe that the current level of pest control is insufficient to allow further gains in indigenous bird abundance and diversity in the Waitākere Ranges, because ship rats (*Rattus rattus*) and other mammalian predators are still present, and in some cases may have benefited from reduced possum numbers. Pest mammal control across the Waitākere Ranges needs to follow a multispecies approach if significant biodiversity gains are to be achieved.

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1. Introduction

1.1 Effects of introduced mammals on New Zealand ecosystems and birdlife

Australian brushtail possums (*Trichosurus vulpecula*) and other introduced mammals have had enormous impacts on New Zealand forest ecosystems through browsing and seed predation (Clout & Erikson 2000, Payton 2000, Sadleir 2000, Cowan & Glen 2021), while a suite of introduced predatory mammals, including possums (Brown *et al*. 1993, Sadleir 2000), have played a large part in exterminating over 40% of endemic bird species since the arrival of humans (King 1984, Atkinson 1985, Holdaway *et al*. 2001, Worthy & Holdaway 2002, Innes *et al*. 2010). Introduced browsers and predators are also primarily responsible for contemporary ongoing declines of both the health of many forest ecosystems and their extant bird populations (Elliott *et al*. 2010a, Innes *et al*. 2010), along with altering successional pathways and forest regeneration (Clout & Hay 1989, Kelly *et al*. 2010).

1.2 Introduction, spread, effects and early control of possums in the Waitākere Ranges

Between 1837 and 1924 several hundred brushtail possums were introduced into New Zealand from Tasmania and southeast Australia to develop a fur trade (Clout & Erikson 2000). These releases were augmented by many further releases of New Zealand-bred possums throughout the country (Clout & Erikson 2000). By the 1940s possums were recognised nationally as major pests (Brockie 1992). Possums may have been released in the Waitākere Ranges before 1900 (Pracy 1974), and numbers probably peaked there by 1930-1940. Following interviews with local residents, Barton & McClure (1990) reported possums as building up in the 1930s and observations of northern rātā (*Metrosideros robusta*) dying. In the 1950s and 1960s large pōhutukawa (*Metrosideros excelsa*) were described as considerably damaged and dying in the Bethell's/Te Henga area. Possum damage was also noted on Hall's tōtara (*Podocarpus laetus*), kohekohe (*Didymocheton spectabile*), kānuka (*Kunzea robusta*), pigeonwood (*Hedycarya arborea*), *Coprosma* spp., heketara (*Olearia rani*) and nīkau (*Rhopalostylis sapida*). Around 1990, total possum kills by Auckland Regional Parks rangers were 2500-3000 per annum, plus about 1000 killed by locals (Barton & McClure 1990).

Barton and McClure's (1990) survey found that possum densities were highest in places such as the Pararaha, Huia, Ōpanuku and Whatipu catchments, and around Tītīrangi, which had the most palatable forest types including coastal forest, *Beilschmiedia*, *Beilschmiedia/ Didymocheton* and mixed-broadleaf associations. The bulk of possum diet comprised Hall's tōtara, kohekohe, northern rātā, pōhutukawa, kiokio *(Parablechnum novae-zelandiae)* and māhoe (*Melicytus ramiflorus*). Severe damage was also seen on five finger (*Pseudopanax arboreus*) and mamaku (*Cyathea medullaris*) (Barton & McClure 1990).

Denyer *et al.* (1993) noted that possums had had a dramatic impact on particular forest classes, especially coastal pōhutukawa, and that a number of other species such as northern rātā, Hall's tōtara and kohekohe were being damaged and destroyed. They also noted that if left unchecked, possums would irreparably change the forest composition and character of the Waitākere Ecological District. In addition to possums, they also expressed concern about the effects of other pest mammals such as cats (*Felis catus*) and rats (*Rattus rattus* and *R. norvegicus*) on wildlife and habitats, and that it was imperative that future management of the Waitākere Ecological District's ecosystems deal with these problems.

During 1993-1994, two government-subsidised Task Force Green possum control projects were carried out in the Waitākere and Piha Stream catchments. Over 10,000 possums were removed from these two areas alone, and monitoring of bait interference showed that an 80% reduction in numbers had been achieved (Stein 1995). In 1994-1995 two further Task Force Green possum control projects were carried out in the Whatipu/Karekare and North Piha/Anawhata/Pine Road areas. However, these did not achieve the same level of control as the 1993-1994 scheme, due to difficult access and insufficient staffing (Stein 1995).

1.3 Waitākere Forest Health Surveys

As a result of a history of sporadic possum control in the Waitākere Ranges, the Auckland Regional Council allocated funding to carry out a forest health survey (Buddenhagen *et al.* 1995), to determine areas vulnerable to possum browse (see also Warburton & Morgan 1992, Clunie 1993), to measure levels of possum damage, and to set up a system to monitor the health of the forest (Stein 1995). A simultaneous possum trap-catch survey of 35 lines totalling 800 traps, using the methods of Sweetapple & Fitzgerald (1994), (see also Warburton 1997) carried out between June and November 1995, gave an average 20.2% (range 3.8-41.9%) residual trap catch (RTC) across the Waitākere Ranges.

The forest health survey comprising 274 plots in 56 areas and 41 northern rātā photopoints (Buddenhagen *et al.*1995) focussed on the canopy and identified maire tawake (*Syzygium maire*), pōhutukawa, mamaku-broadleaf and pūriri (*Vitex lucens*) composite as the most vulnerable forest types with tawa (*Beilschmiedia tawa*), upland mature kauri (*Agathis australis*), kānuka-mānuka (*Leptospermum scoparium*) scrub and forest and māmāngi (*Coprosma arborea*) as the least vulnerable. Northern rātā, Hall's tōtara, tōtara (*Podocarpus totara*), maire tawake, pōhutukawa and kohekohe consistently showed signs of possum browse or severe damage in the past. The forest health plots and rātā photo points were remeasured in 1997 (Ogden & Carlaw 1997, Carlaw 1997). This survey gave some cause for concern because the health of the canopy and seedling populations had deteriorated since 1995, and although overall browse damage was low (reflecting that much of the Waitākere forest is a mosaic with very scattered possum-palatable species), some sites and species (including maire tawake, Hall's tōtara, tōtara, kohekohe, northern rātā, large-leaved māhoe (*Melicytus macrophyllus*) and five finger were being affected more severely. High levels of mortality were seen in Hall's tōtara, kohekohe and large-leaved māhoe. The Lower Huia swamp forest dominated by the rare and vulnerable maire tawake was of special concern, because it showed the largest increase in possum damage.

1.4 Operation Forestsave possum control programme 1998

In November 1996 the Auckland Regional Council approved funding to carry out an extensive possum control operation across the whole of the Waitākere Ranges. The aim of the control programme, named Operation Forestsave, was to protect and restore the ecological integrity of the forests of the Waitākere Ranges by reducing possum numbers in one coordinated ground-based effort to between a 5-10% residual trap catch (RTC) level (Auckland Regional Council 1998). This target RTC was later reduced to 3% (Steve Hix pers. comm.).

1.5 Monitoring effects of possum control on bird populations in the Waitākere Ranges

Compared with many animal groups, birds are relatively easy to count, so they can be useful indicators of environmental change (Bibby *et al*. 2000). There have been many programmes to control introduced mammalian herbivores and carnivores in New Zealand (e.g. Veitch & Bell 1990), and there is an increasing number of studies where the effects of such control have been measured on bird populations (Innes *et al*. 2004, Bell 2008, Baber *et al*. 2009, O'Donnell & Hoare 2012, Johnstone MacLeod *et al*. 2015, Byrom *et al*. 2016, Miskelly 2018, Fitzgerald *et al*. 2019, Fea *et al*. 2021, Binny *et al*. 2021). However, there have been fewer bird monitoring studies where possums were the only pest species targeted for control (Byrom *et al*. 2016) and fewer still where there was mainly ground-based possum control (Lovegrove 1988, Veltman 2000, Johnstone MacLeod *et al*. 2015).

To monitor the long-term effects of possum control on bird populations in the Waitākere Ranges, we carried out annual five-minute bird counts (5MBC) from December 1997 (Dawson & Bull 1975, Hartley 2012). 5MBCs have been widely used in New Zealand since the early 1970s to determine the presence and relative abundance of forest birds. The 5MBC method provides an index of numbers rather than a census, and aspects such as observer experience, species behaviour, weather and season can all affect the number of birds detected. However, 5MBCs are useful for studying long-term trends, provided that over a number of years, sufficient numbers of counts are undertaken annually, and the effects of variables such as observer experience, weather, season, bird conspicuousness etc. are minimised. Dawson & Bull (1975) recommended a minimum of 125 counts to provide useful results for more abundant species.

We used 5MBCs because this easily repeated method allowed us to gain an index of bird numbers at many sites across the ranges over a relatively short period of time each summer. This report presents the results of five-minute bird counts over a 22-year period in the Waitākere Ranges from 1997-1998 to 2018-2019, with the first counts undertaken during the 1997-1998 summer, shortly before the Operation Forestsave possum control programme began.

2. Methods

2.1 Study Area – the Waitākere Ranges

The Waitākere Ranges support one of the two largest blocks of contiguous indigenous forest in the Auckland region. This area is also a distinct ecological district, supporting a high diversity of vegetation and wildlife (Denyer *et al*. 1993). In pre-human times the forest was dominated by mixed podocarp-broadleaf forest with large areas of kauri. Following the arrival of Māori about 800 years ago, some coastal areas were extensively modified and burned, but the forested interior of the ranges was virtually untouched. During the European era however, kauri and other timber trees were milled, and large areas were burned and cleared for farming (Auckland Regional Council 1992, Denyer *et al*. 1993). Today, relatively few areas of pre-European forest remain, but there has been extensive regeneration of formerly cleared areas. The existing forest is a complex and diverse mosaic of mature forest remnants and successional forest vegetation (Denyer *et al*. 1993).

Part of the forest was protected as water catchment when water supply dams were developed from 1902 by the Auckland City Council (Auckland Regional Council 1992). The scenic values of the catchment land and its reserve potential were recognised in the 1920s. This 8000ha area formed the core of the Auckland Centennial Memorial Park, created in 1941. From 1963 the park was administered by the Auckland Regional Authority (later Auckland Regional Council). Park development work during the 1950s and 1960s included track work, fire and noxious animal control, including the control of possums. There was also considerable volunteer work carried out by tramping clubs, who built tracks and huts. Increasing public use of the park led to the development of the Arataki Information Centre, which opened in 1974 (Auckland Regional Council 1992). As a result of gifts of land and acquisitions over the years, the area of regional parkland has expanded significantly and now comprises 17,500 ha. Since amalgamation of the various councils in the Auckland region in 2010, the Waitākere Ranges Regional Park has been administered by the Auckland Council.

2.2 Possum control

The Operation Forestsave operational area covered 28,200ha comprising 15,500ha of regional parkland, a 10,700ha rural buffer and 2000ha in the urban zone. In the north, the rural buffer included Department of Conservation-administered Goldie Bush Scenic Reserve and the Royal Forest & Bird Protection Society's Matuku Reserve. The control was carried out using performance-based contracts over a 10-month period from May 1998. Since the possum control area included part of the urban zone and rural lifestyle blocks, ground-based methods (i.e. Timms and cage traps, leg hold traps, cyanide baits and brodifacoum and cholecalciferol poison baits in bait stations) were used.

During the study period, ongoing ground-based pest mammal control targeting possums has continued over most of the Waitākere Ranges. For example, since 2017, regular possum control has been implemented to cover the ranges in three sections over a three-yearly rotation cycle, utilizing feratox, brodifacoum, and trapping (Joel Chisholm pers. comm.).

2.3 Possum monitoring

The possum population was monitored annually following national protocols (Warburton 1997). Monitoring lines in most years from 1997-2018 comprised up to 100 trap lines of 20 traps set at 20m intervals placed at randomly selected starting points across the treatment area, with each line run for three nights. The residual trap catch (RTC) was calculated from the total number of possums caught and the total number of corrected trap nights (allowing half a night each for sprung, empty traps), expressed as the number of possums caught per 100 trap nights.

2.4 Five-minute bird counts

We established nine lines, each with 15 5MBC stations (a total of 135 5MBCs annually) on nine separate walking tracks across the Operation Forestsave possum control area (Figure. 1a.). These tracks traversed a range of different forest types and topographies across the Waitākere Ranges. We placed the count lines on tracks because the forest undergrowth is dense in the Waitākere Ranges due to the absence of goats (*Capra hircus*) and deer (Cervidae). This would have made it difficult and very time-consuming to count at randomly placed stations off-track. Moreover, off-track activities have been discouraged in recent years to minimise the spread of kauri dieback disease (*Phytophthora agathidicida*).

Our 5MBCs closely followed the method of Dawson & Bull (1975). Count stations were located at 200m intervals along the nine chosen tracks, and to minimise the challenge of determining the location of distant bird calls and to minimise repeated counting of birds in different counts, we used bounded counts with a radius of 100m instead of the 200m boundary used by Dawson & Bull (Figure 1b). To reduce possible effects of variables such as observer experience, weather, season, bird conspicuousness, ambient noise etc. we carried out the counts between mid-November and early-January on fine, still days from c.0700-1200 NZST, and all counts were carried out by the same two experienced observers. All birds seen or heard within 100 metres of the count station, including those flying over, were recorded, but each individual bird was only recorded once during counts and for analyses, i.e. a bird first heard, but then seen, was recorded as one individual.

One of our chosen 5MBC lines (Upper Kauri) runs through part of the Ark in the Park, a mainland island pest-control area managed as a collaborative project between Forest & Bird and Auckland Council. Since 2002 the Ark in the Park area has received ongoing intensive ground-based pest control targeting all pest mammals. Intensive pest control began at the Ark in the Park over five years after our study started. For the purposes of this analysis, we pooled our data from the Upper Kauri Track (Ark in the Park area) with the other eight 5MBC lines.

2.5 Measuring the level of pest control on birds and limitations of the study

The Operation Forestsave possum control project used various poison baits to target possums. However, in addition to possums, the baits would have also killed rats and possibly also some feral cats and mustelids through secondary poisoning. Although ongoing possum control resulted in greatly reduced possum numbers across the ranges throughout the entire 22-year count period, rats, because of their more rapid recovery rate, along with wider placement of bait stations than is usual for rat control (i.e. 100 metres x 100 metres or greater), were probably suppressed only temporarily around each poison pulse. Since there was some control of rats, and possibly also of cats and mustelids over most of the area sampled, the five-minute counts might not measure the effects of possum control only. In addition, since 2002 the Upper Kauri line in our study received more intensive pest management as part of the Ark in the Park, where the aim was to reduce rats to less than a 5% tracking index (Ark in the Park 2016), but this was not always achieved.

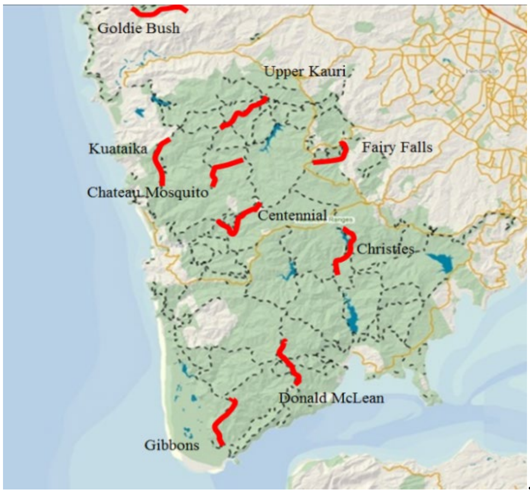


Figure 1a. Locations of the nine 5MBC (five-minute bird count) lines in the Waitākere Ranges. Eight of the lines were located within the Waitākere Ranges Regional Park and one line in Goldie Bush Scenic Reserve (a Department of Conservation reserve), which was also inside the operational area for the Operation Forestsave possum control project, which ran during 1998.

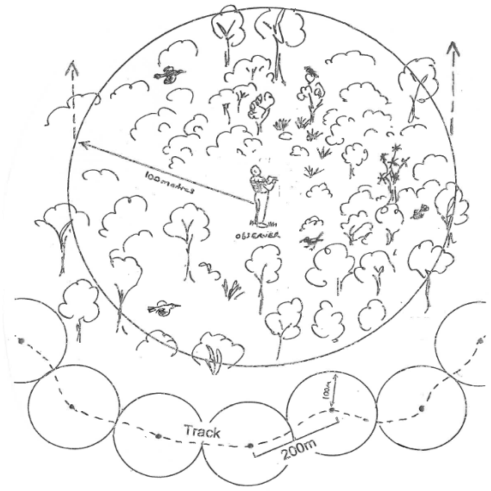


Figure 1b. Diagram of 5MBC (five-minute bird count) method showing bounded 100m radius from observer, column of air above, and typical placement of stations at 200 metre intervals along a walking track.

2.6 Analysis

The analyses presented here are based on a total of 2955 5MBCs carried out annually during summer over a 22-year period from 1997-1998 to 2018-2019. These data were then averaged by count within years, i.e. the mean number of individuals recorded of each species, on each line, each year. The data were square-root transformed and a matrix of Bray-Curtis (Bray & Curtis 1957) similarities in species composition among sites was calculated. The Bray-Curtis coefficient measures similarity in the identity and abundance of species recorded between each pair of counts for each year. Expressed as a percentage, it gives a value of 0% if no species are shared and 100% for sites that share identical species and identical frequencies of occurrence of those species. The initial square-root transformation down-weights the importance of changes in the relative frequencies of common species, so that similarities also appropriately reflect changes in the occurrence of less common species (Clarke & Warwick 2001).

The mean total number of birds recorded, the mean number of indigenous birds, the mean number of exotic birds and the mean number of each individual species where >200 detections were calculated over the count period 1997-1998 to 2018-2019 (Table 1), and were then compared between years using one-way Analysis of Similarities (ANOSIM) (Clarke 1993) with 9999 permutations. The ANOSIM test-statistic, *R*, contrasts the average of the rank between-group versus within-group similarities. *R* takes values from -1 to +1, with values closer to 1 indicating greater distinctiveness of the groups of samples identified by the factor being tested (Clarke 1993). ANOSIM does not require strict assumptions of balanced replication and the equivalent of homogeneity of variance (Clarke & Gorley 2006). However, these data are balanced, and homogeneity of multivariate dispersion was checked for mean total birds, indigenous birds and exotic birds using the PERMDISP routine (Anderson *et al.* 2008) prior to running ANOSIM. All multivariate analyses were done using the PRIMER v6 computer program (Clarke & Gorley 2006) with the PERMANOVA+ add-on (Anderson *et al.* 2008).

3. Results

3.1 Possum monitoring

The ground-based possum control during 1998 reduced the possum population from a 24% RTC in 1997 to 3% in late 1998 (Figure 2). Since 1998, ongoing ground-based possum control did not always achieve the 3% RTC target, however possum numbers have been kept reasonably low. Possum monitoring was carried out annually, except in 2016. The RTC has fluctuated between 0.6% (2005) and 6.58% (2012). In 2018 the RTC was 1.88%.

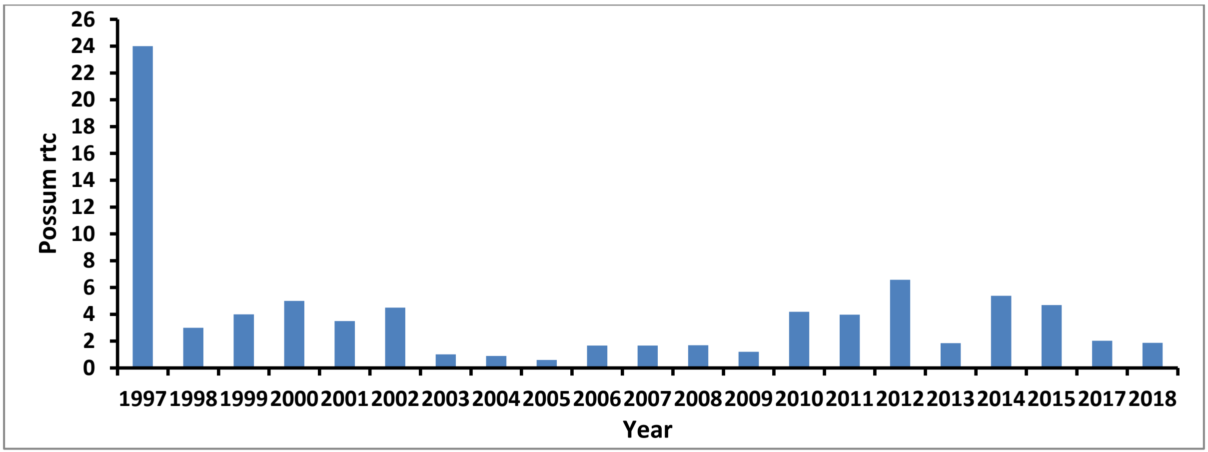


Figure 2. Possum residual trap catch (RTC) figures for the Waitākere Ranges 1997-2018.

3.2 Total birds detected and changes in indigenous and exotic birds

A total of 59,412 individual birds was detected in 2955 bird counts from 1997-1998 to 2018-2019, representing 17 indigenous and 18 exotic species (Table 1). Indigenous birds were detected more frequently than exotic species (33,478 versus 25,934) and birds were more frequently heard than seen (84% of total detections were aural versus 16% visual detections, Table 1). Nine indigenous species and seven exotic species were detected >200 times from 1997-1998 to 2018-2019 (Table 1).

Changes to the overall avian community, and its indigenous and exotic components are shown in Figure 3. There was a statistically significant increase in mean detections of all birds between 1997-1998 and 2018-2019 (Table 1, Figure 3), and over the 22-year period the mean numbers of birds detected per count increased by 58% and the total number of birds increased by 75%. This was driven by statistically significant increases in mean detections of indigenous birds (especially from 1997-2005), whereas there were no significant changes in mean exotic bird detections (Figure 3, Table 1). There was a positive trend in these data from 1997-1998 to 2005 and then a levelling off from 2005 to 2018-2019 (Figure 3). Despite the statistically significant P value, the *R* test statistic is relatively small for both mean total birds and mean indigenous birds, indicating that the changes are quite small (Table 1).

There were statistically significant differences between years for silvereye (*Zosterops lateralis*), tūī (*Prosthemadera novaeseelandiae*), grey warbler (*Gerygone igata*), welcome swallow (*Hirundo tahitica*) and blackbird (*Turdus merula*), although again the R test statistic is small for each species, indicating relatively subtle changes between years (Table 1).

Mean detections per count per year for 16 individual species with >200 detections, are shown in Figures 4a-p. Silvereyes increased significantly (Figure 4a), and they were also the most frequently detected bird from 1997-1998 to 2018-2019, comprising 17.5% of all detections. Silvereyes often occur in mobile flocks, making it difficult to count them accurately by ear when more than a few birds are present, and our data show some large fluctuations (Figure 4a). There was an increase in mean detections of tūī from 1997-1998 to 2018-2019 (Figure 4b), with a more subtle increase in grey warblers (Figure 4c), and a slight increase in swallows (Figure 4d). Mean blackbird detections increased from 1997-1998 to 2018-2019 (Figure 4e), in a similar pattern to the indigenous species above.

Kererū (*Hemiphaga novaeseelandiae*) showed a positive trend in mean detections (especially between 1997 and 2010) that approached significance for the entire count period (P = 0.08, Table 1), however they were detected in lower numbers in 2012 and 2014 (Figure 4f). There was a positive trend in tomtit (*Petroica macrocephala*) detections from 1997-2010, then a decline back to 2003 levels after 2012, so that over the entire count period tomtit detections did not change significantly (Figure 4g). Kingfishers (*Todiramphus sanctus*) (Figure 4h) and eastern rosellas (*Platycercus eximius*) (Figure 4i) also showed positive but non-significant trends in detections from 1997-1998 to 2018-2019. There was no significant change in detections of fantail (*Rhipidura fuliginosa*) (Figure 4j), shining cuckoo (*Chrysococcyx lucidus*) (Figure 4k), chaffinch (*Fringilla coelebs*) (Figure 4l), myna (*Acridotheres tristis*) (Figure 4m), dunnock (*Prunella modularis*) (Figure 4n), goldfinch (*Carduelis carduelis*) (Figure 4o) and redpoll (*Carduelis flammea*) (Figure 4p).

Table 1. Total number of birds, percentage detected aurally, ANOSIM test statistic and p value for Wāitakere Ranges five-minute bird counts, 1997-1998 to 2018-2019.

Species	Total number of detections 1997-1998 to 2018-2019	Total percentage detected aurally	ANOSIM R value[2]	p value[3]
All birds	33478	84	**0.069**	**<0.01**
All indigenous birds	25934	82	**0.136**	**<0.01**
All exotic birds	7544	90	-0.008	0.68
Silvereye	10410	86	**0.153**	**<0.01**
Tūī	4340	72	**0.119**	**<0.01**
Grey warbler	4184	85	**0.068**	**<0.01**
Fantail	2234	83	0.011	0.24
Kererū	2009	70	0.024	0.08
North Island tomtit	1294	90	0.001	0.44
Kingfisher	637	95	0.006	0.34
Welcome swallow	494	59	**0.034**	**0.03**
Shining cuckoo	218	95	-0.015	0.80
Harrier	55	38	-	
North Island fernbird	25	92	-	
North Island robin	10	100	-	
Whitehead	8	25	-	
Morepork	6	100	-	
North Island kākā	5	60	-	
Hihi[1]	4	100	-	
North Island kōkako	1	0	-	
Blackbird	2767	92	**0.068**	**<0.01**
Chaffinch	1374	94	-0.027	0.96
Eastern rosella	1283	84	0.011	0.24
Myna	633	88	-0.007	0.65
Dunnock	318	90	-0.006	0.63
Goldfinch	306	87	-0.015	0.82
Redpoll	268	75	-0.039	1.00
Thrush	125	95	-	
White cockatoo	110	83	-	
Yellowhammer	104	86	-	
Greenfinch	92	93	-	
House sparrow	41	93	-	
Starling	34	56	-	
California quail	28	71	-	
Magpie	26	77	-	
Skylark	20	95	-	
Pheasant	8	100	-	
Spotted dove	7	100	-	

[1]*No longer present in the Waitākere Ranges*

[2]*ANOSIM only conducted on species with greater than 200 detections 1997-1998 to 2018-2019*

[3]*Significant values are in bold*

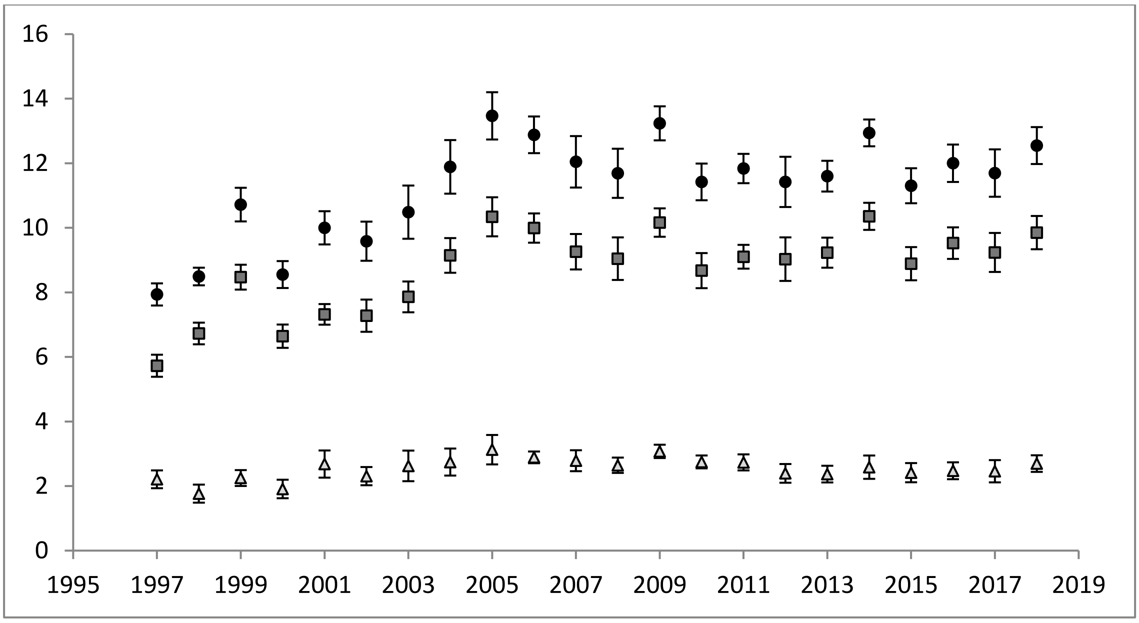


Figure 3. Mean annual detections and 95% confidence intervals of all birds pooled (circles), indigenous birds (squares) and exotic birds (triangles) in the Waitākere Ranges five-minute bird counts 1997-1998 to 2018-2019.

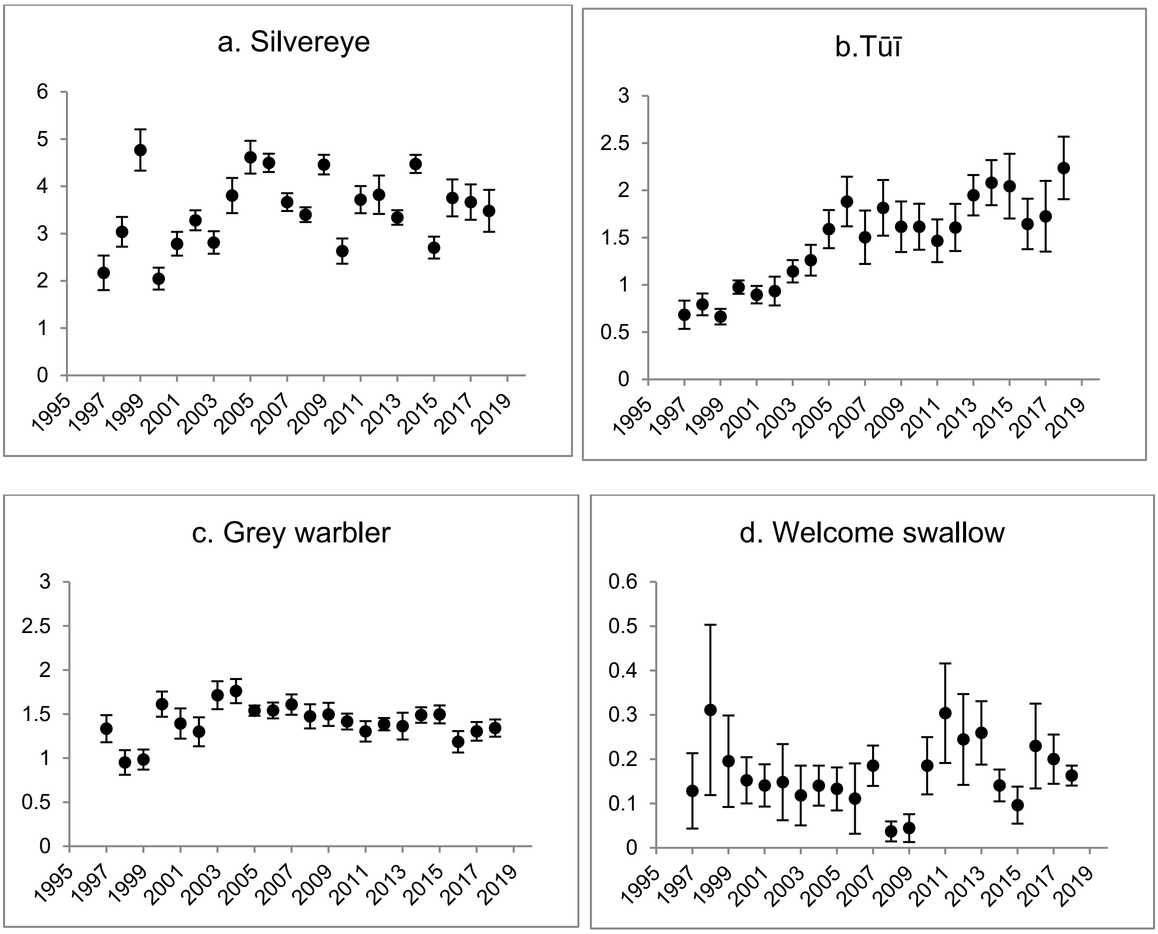
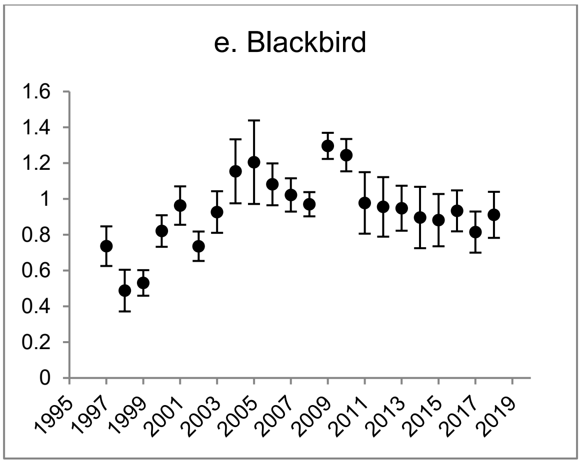


Figure 4a-p. (Continues on pages 12 and 13) Mean annual detections and 95% confidence intervals for species with >200 detections in the Waitākere Ranges 1997-1998 to 2018-2019.


e. Blackbird
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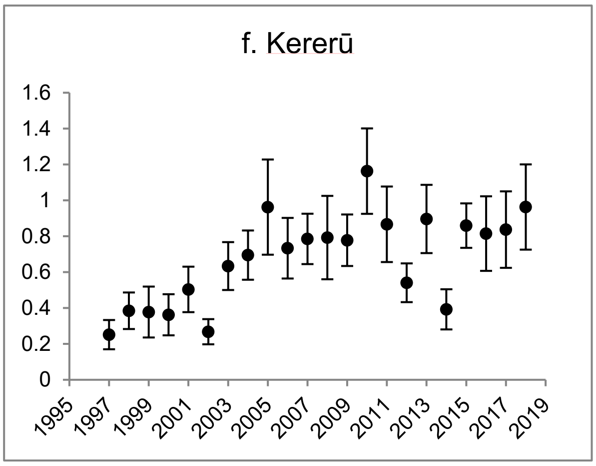
1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019


f. Kererū
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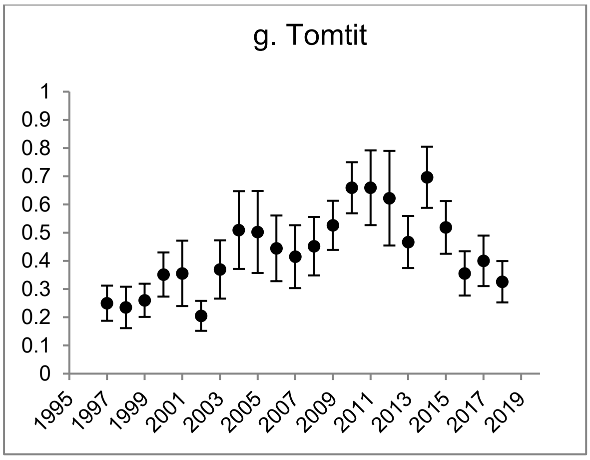
g. Tomtit
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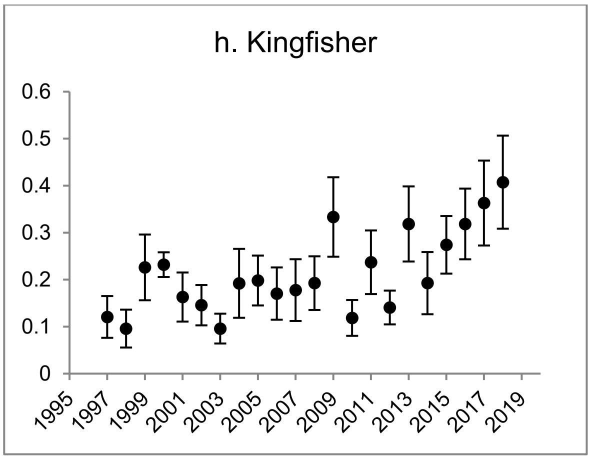
h. Kingfisher
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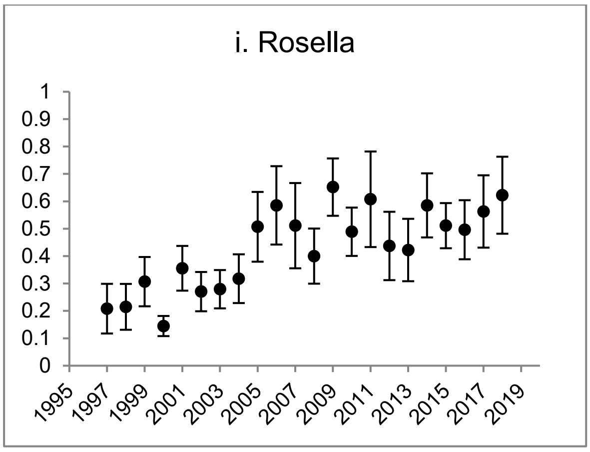
i. Rosella
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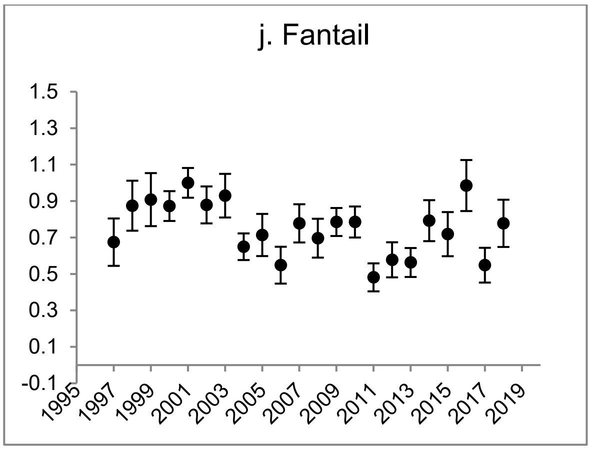
j. Fantail
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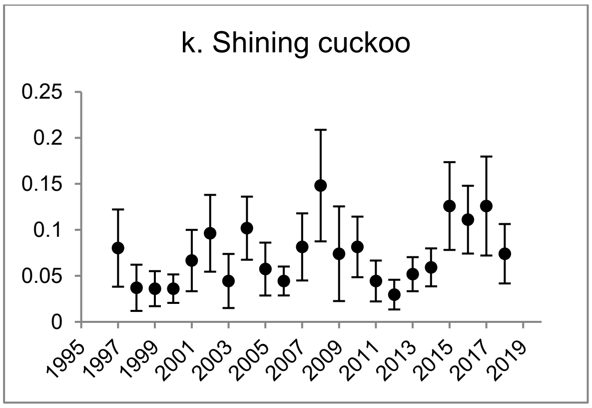
k. Shining cuckoo
0.25
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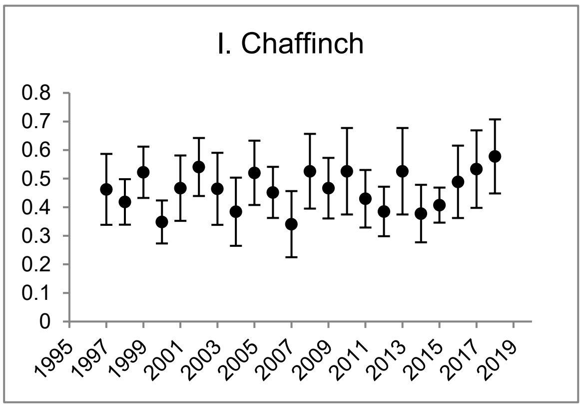
1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019


l. Chaffinch
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1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019

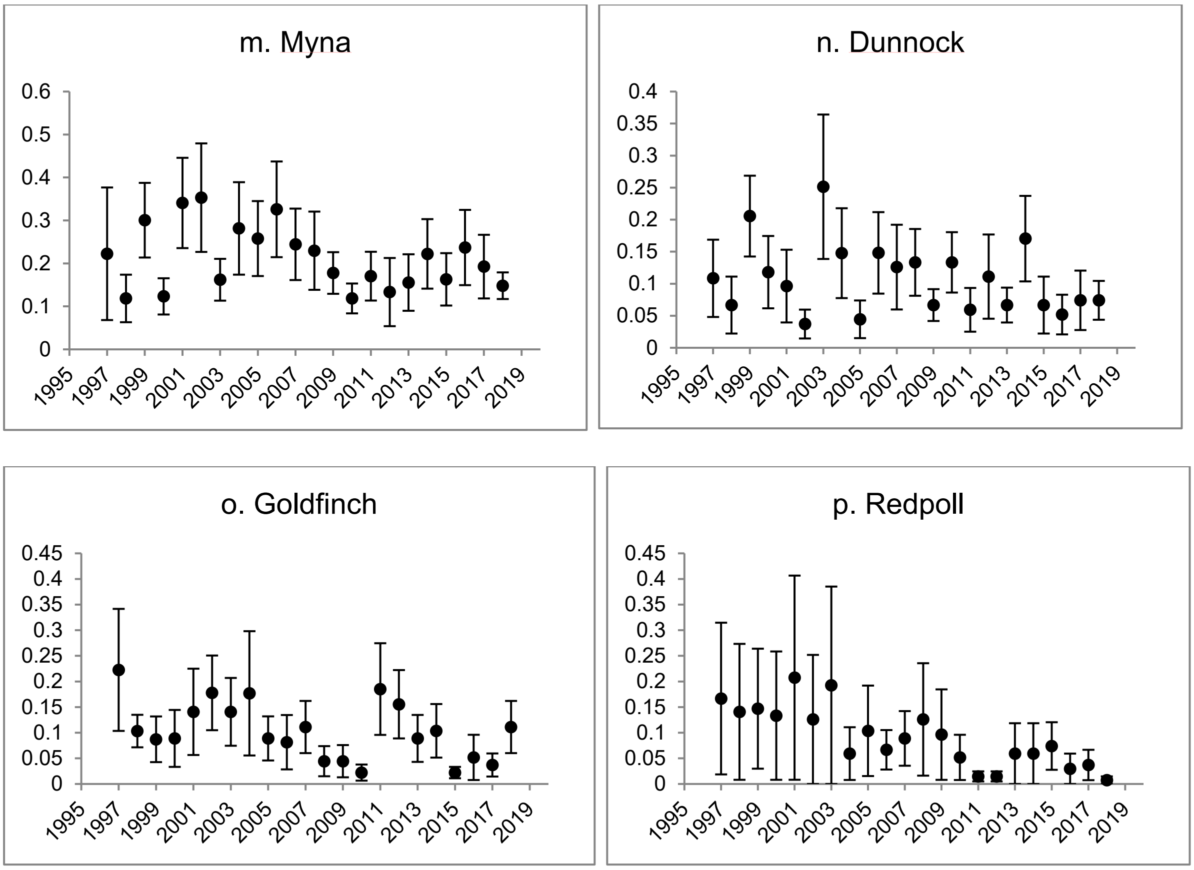

Figure 4a-p. (Continued from page 12) Mean annual detections and 95% confidence intervals for species with >200 detections in the Waitākere Ranges 1997-1998 to 2018-2019.

3.3 Changes in relative abundances of species with greater than 200 detections

Changes in the relative abundances of species with greater than 200 detections (Table 1) between 1997-1998 and 2018-2019 are shown in Figure 5. The relative abundances of some species have changed over the count period, with tūī and kererū now proportionately more abundant than they were previously (Figure 5). Looking at the eight most common species in descending order of abundance, in 1997-1998 the most abundant species were silvereye, grey warbler, blackbird, tūī, fantail, chaffinch, kererū and tomtit. In 2018-2019 they were silvereye, tūī, grey warbler, kererū, blackbird, fantail, rosella and chaffinch. Kingfisher, myna, welcome swallow, goldfinch, redpoll, dunnock and shining cuckoo formed a much smaller proportion of total birds counted (Figure 5).

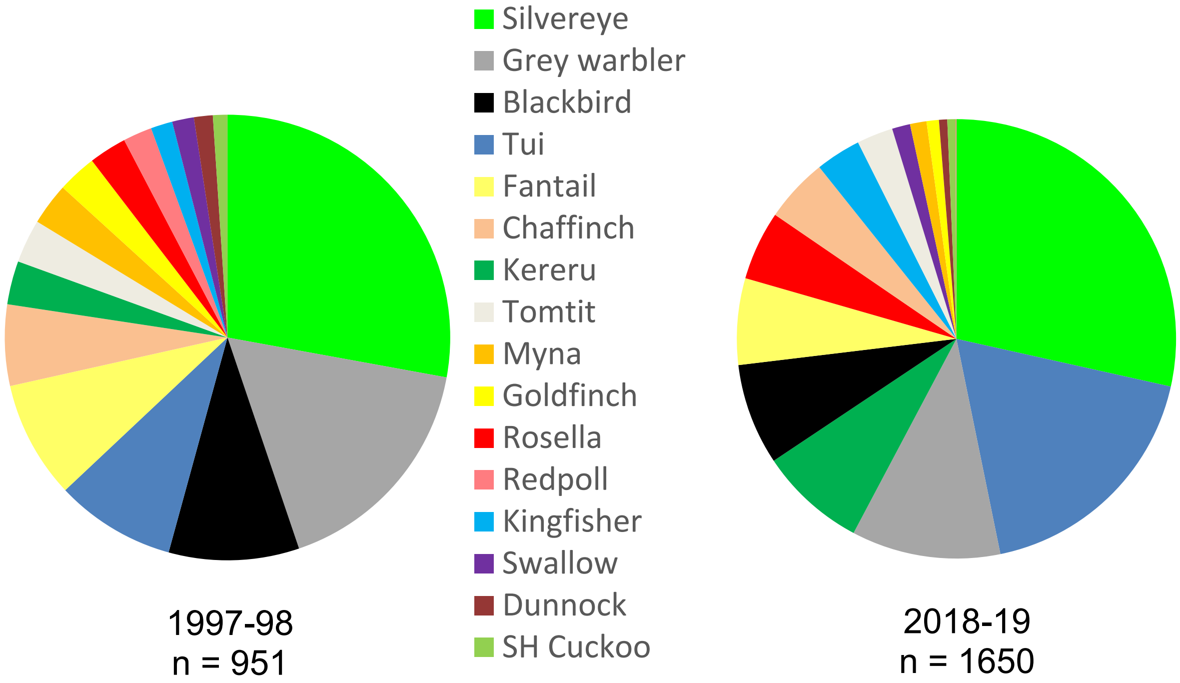

Figure 5. Comparison of relative abundances between 1997-1998 and 2018-2019 of the 16 species with >200 detections in the Waitākere Ranges.

At the start of the count period in 1997-1998, tūī was the 4th most frequently recorded species. In 2018-2019 it was 2nd after silvereye. In 1997-1998 kererū was the 7th most frequently recorded species, but by 2018-2019 it had jumped to 4th behind silvereye, tūī and grey warbler. Of the other native birds comparing 1997-1998 with 2018-2019, grey warbler dropped from 2nd to 3rd, fantail from 5th to 6th, tomtit from 8th to 10th while kingfisher jumped from 13th to 9th. Of the most common exotic birds, blackbird dropped from 3rd most frequently recorded species to 5th, chaffinch from 6th to 8th, myna from 9th to 12th, redpoll from 12th to 16th, while rosella jumped from 11th to 7th.

4. Discussion

4.1 Success of Operation Forestsave possum control

The ongoing decline of forest health in the Waitākere Ranges (Buddenhagen *et al*. 1995, (Ogden & Carlaw 1997, Carlaw 1997), especially of vulnerable species such as northern rātā, Hall's tōtara, tōtara, maire tawake, pōhutukawa and kohekohe due to possum browsing, prompted the Auckland Regional Council to undertake more intensive possum control than had previously been achieved. "Operation Forestsave" aimed … *to restore the character and ecological integrity of the forests of the Waitakere Ranges by reducing possum numbers to "acceptable levels" (5-10% RTC) in one coordinated effort.* The intensive ground-based control during 1998 reduced the RTC from 24% in 1997 to 3% at the end of 1998, and subsequent annual maintenance work has kept RTC levels between 0.6% and 6.8%. In the last monitoring during the bird-count period in 2018 the RTC was 1.88%. Thus, the aim of reducing possum numbers to acceptable levels, and to keep RTC levels low, has been achieved. However, rats and other pest mammals not targeted by possum control are still present, and these are likely to be limiting the indigenous bird community (Innes *et al*. 2010). To achieve further biodiversity gains across the Waitākere Ranges, more intensive control of these other mammalian pests will be essential.

4.2 Five-minute bird counts

We chose the widely-used 5MBC method (Dawson & Bull 1975, Innes *et al*. 2004, Baber *et al*. 2009, Mortimer & Clark 2013, Johnstone MacLeod *et al*. 2015, Miskelly 2018, Fitzgerald *et al*. 2019, see review in Hartley 2012, and see also Landers *et al*. 2021), as this enabled a rapid annual survey across the Waitākere Ranges at multiple count sites each summer. We reduced sources of variation in our counts (Dawson 1981) by using the same two experienced observers repeating the counts at the same count stations and only conducting our surveys on fine, still mornings in the same months each year. Our study aimed to measure the impacts of possum control on bird populations in the Waitākere Ranges. By sampling a range of different forest types and topographies across the Waitākere Ranges on nine widely spaced tracks, we assumed that our count stations were representative of the study area as a whole. However, since these were not located randomly, our counts may not be representative of the wider possum control area. We were unable to replicate our monitoring in a non-treatment site in a similar large forest in the Auckland region, so this weakens the inferences that we can draw from our study. Therefore, without a non-treatment site, this study is a comparison of pre- and post-treatment effects.

The only other large tract of indigenous forest on the mainland in the Auckland region is the c.17,000ha Hunua Ranges Regional Park, but that was also receiving possum control, including aerial 1080 poison drops in 1994, 2015 and 2018, along with intensive mainland-island pest control in a significant part of it to protect kōkako (*Callaeas wilsoni*). The Hunua forest also has different forest ecosystems (Singers *et al*. 2017), has larger areas of higher altitude forest, and the composition of its avifauna differs because it also includes kākā (*Nestor meridionalis*), bellbird (*Anthornis melanura*) and kōkako, which were absent from the Waitākere Ranges (although kōkako were translocated to the Ark in the Park from 2009, but only formed a very minor component of our counts with just one sighting, see Table 1).

It is important to note that 5MBCs do not provide a census, the method merely provides an index of bird numbers (Dawson & Bull 1975, Dawson 1981, Hartley 2012). Our 5MBC sample comprised 135 counts year^{-1} on nine widely spaced lines, and we extrapolated our counts across the study area by pooling the data from each year's counts for the analysis. Dawson & Bull (1975) recommended a minimum of 125 counts to gain useful results for the more abundant species, but that rarer species would require more counts. Thus, with a total of 135 counts year^{-1} we treat our inferences with caution, especially for rarer species, although we believe we detected all resident terrestrial forest species known to be present (Table 1). Further, our analyses show that the large number of counts we carried out annually over a long timeframe were sufficient to detect biologically important changes in bird populations in the Waitākere Ranges as a result of possum control.

4.3 Bird monitoring during possum control programmes

Recent bird monitoring programmes during mammalian pest control projects have used various counting methods to examine changes at sites, where multiple pest species have been removed using various pest control methods (e.g. Innes *et al*. 2004, Smith & Westbrooke 2004, Baber *et al*. 2009, O'Donnell & Hoare 2012, Masuda *et al*. 2014, Johnstone MacLeod *et al*. 2015, Miskelly 2018, Fitzgerald *et al*. 2019). There are rather few studies of the effects on birds of removing possums only (Lovegrove 1988, Veltman 2000, Greene *et al*. 2013, see also Innes *et al*. 2004, and review by Byrom *et al*. 2016). Along with Innes *et al*. (2004) and Johnstone MacLeod *et al*. (2015), ours is one of only a few studies where bird monitoring was carried out at a site where ground-based control only was used, and where possums were the main target of the pest control.

Although possums were targeted by Operation Forestsave, there would have been some by-kill of rats from the poison baits that were used, and there was probably also some secondary poisoning of mustelids and feral cats. This aspect may have confounded our assumption that the changes we found in bird populations resulted from possum control only (James & Clout 1996, Veltman 2000), although rat populations would have recovered quickly. Independent rat monitoring carried out by Ark in the Park workers at a non-treatment area for the Ark project within the Waitākere Ranges (Ark in the Park unpublished data), gave rodent tracking indices of 40-90% between 2002 and 2019. This shows that rat populations were high outside the intensively managed Ark area and is consistent with national rat tracking data showing New Zealand's warmest forests are 'continuously ratty', with tracking rates >35% more than 90% of the time (Walker *et al*. 2019a). It is probably not unreasonable to extrapolate these rodent tracking figures across the wider Waitākere Ranges where there was no intensive (i.e. mainland-island style) pest mammal control. Innes *et al*. (2004) also found that ship rat indices increased quickly, when their baiting regime at Motatau in Northland was changed to target possums more specifically, and rapid recoveries of rat populations following possum control have been reported elsewhere (Ruscoe *et al*. 2011, Byrom *et al*. 2016). We also know from studies elsewhere that stoats (*Mustela erminea*) would probably have recolonised quickly because they are strong dispersers, even capable of swimming to some inshore islands (Elliott *et al*. 2010b, King & Veale 2021).

4.4 Total birds detected

Over the 22-year count period, the mean numbers of birds detected per count increased by 58% (Figure 3) and the total number of birds detected increased by 75%. On Kapiti Island following possum removal (but before removal of Norway and Pacific rats (*R. exulans*), the total number of birds detected on three transects more than doubled, (Lovegrove 1988, Veltman 2000), and at Zealandia (Karori Sanctuary) in Wellington following multispecies pest removal, the total number of birds increased by 52% (Miskelly 2018). In an analysis across multiple sites across northern New Zealand comparing the relative benefits of managing forest loss versus controlling invasive pest mammal species, Ruffell & Didham (2017) also found that total bird abundance increased at sites receiving pest mammal control, although they found that this was largely driven by increases in the numbers of kererū and tūī.

4.5 Proportions of indigenous and exotic birds

Over the count period, the proportion of total birds detected that were indigenous increased significantly. This was driven by significant increases in silvereye, tūī, grey warbler and welcome swallow and a positive trend in kererū, while exotic birds showed little change with the exception of blackbird. Increasing dominance of indigenous birds has been reported at other sites with multi-species pest control or removal (Graham *et al*. 2013, Miskelly 2018, Binny *et al*. 2021, Landers *et al*. 2021). Increased indigenous bird dominance is a useful outcome measure for forest restoration projects. It is also listed as one of three targeted national outcomes in the Department of Conservation's inventory and monitoring framework (Monks *et al*. 2013).

Four of the five most commonly detected species in our counts were indigenous (Table 1). In descending order, the top five indigenous and exotic species were silvereye, tūī, grey warbler, blackbird and fantail. The same five were the species most commonly detected by Landers *et al*. (2021) in the Auckland regional bird monitoring programme, but in a different order. In that study, tūī was the most commonly detected species followed by silvereye, grey warbler, fantail and blackbird. Landers *et al*. (2021) sampled a range of forest sites, which included pest-free island sanctuaries, mainland sanctuaries with intensive pest management and mainland sites with low or little pest management. The wide range of sites sampled by Landers *et al*. (2021) may account for the different order of species.

4.6 Changes in the more common indigenous birds

Of the more commonly detected indigenous birds, silvereye, tūī, grey warbler and welcome swallow increased significantly over the 22-year count period, while kererū showed a positive trend (especially between 1997 and 2010) that approached significance for the entire count period. Tomtits increased from 1997-2010, then declined back to 2003 levels after 2012, so that over the entire count period their numbers did not change significantly. Kingfishers also showed positive but non-significant trends in detections, while there was no significant change in counts of fantails and shining cuckoos.

Elsewhere, kererū and/or tūī have been reported as the two widespread indigenous birds most likely to increase following various levels of mammalian pest control (Innes *et al*. 2004, Spurr & Anderson 2004, Baber *et al*. 2009, O'Donnell & Hoare 2012, Graham *et al*. 2013, Johnstone MacLeod 2015, Ruffell & Didham 2017, Miskelly 2018, Fitzgerald *et al*. 2019, Fea *et al*. 2021). Possums compete with kererū and tūī for flowers and fruit (Clout & Hay 1989) while possums and ship rats prey on the nests of both species (James & Clout 1996, Innes *et al*. 2004, Innes *et al*. 2010, Fitzgerald & Innes 2013). After possums and wallabies were eradicated from Rangitoto Island, silvereye and tūī both increased significantly. Spurr & Anderson (2004) concluded that this was most likely a response to increased flowering of pōhutukawa and rewarewa because of reduced browsing on these food trees by possums. As seen on Rangitoto, silvereyes in the Waitākere Ranges may have benefited through greater supplies of nectar and fruit being available.

In pest control projects elsewhere, kingfishers have increased in some cases (e.g. Tiritiri Matangi, Graham *et al*. 2013; Hunua Ranges, Auckland Council unpubl. data), and declined in others (e.g. Zealandia, Miskelly 2018, Ipipiri Group, Ralph *et al*. 2021). The increase in kingfisher detections in both the Waitākere and Hunua Ranges (Auckland Council unpubl. data) following pest control is interesting because the kingfisher, along with grey warbler, fantail and silvereye has a much shorter evolutionary history in New Zealand. These species are widespread in unmanaged habitats in New Zealand and apparently coexisting with the full suite of introduced predatory mammals. It is these more recent indigenous species which usually either change very little, or even decline, when pest mammals are removed (Baber *et al*. 2009, Ruffell & Didham 2017, Miskelly 2018, Bombaci *et al*. 2018, Binny *et al*. 2021, Ralph *et al*. 2021).

Declines in grey warbler, fantail and silvereye are especially marked at sites where it has been possible to reintroduce missing endemic species, or where some missing endemics have colonised naturally, once the numbers of predatory mammals have been reduced below a certain threshold. The removal of predatory mammals and reintroduction of missing endemic birds has been especially instructive at Tiritiri Mātangi Island and Zealandia (Graham *et al*. 2013, Miskelly 2018). Grey warbler, fantail and silvereye have declined, probably because of competition with increasing numbers of endemics such as bellbird, whitehead (*Mohoua albicilla*), robin (*Petroica longipes*) and saddleback (*Philesturnus rufusater*) (Graham *et al*. 2013, Miskelly 2018, Binny *et al*. 2021). Miskelly (2018) concluded that grey warbler, fantail and silvereye are probably not limited by mammalian predators. We are now seeing a very similar trend at Tāwharanui Regional Park following near eradication of the most significant predatory mammals followed by reintroduction or self-colonisation of a range of endemic forest birds (Auckland Council unpubl. data, Binny *et al*. 2021). On offshore islands (e.g. Hauturu, Kapiti), which now lack predatory mammals, and where there is a near full complement of forest birds including most of the extant endemics, grey warbler, fantail and silvereye are scarce (Diamond & Veitch 1981, Miskelly 2018, Lovegrove *et al.* 2019). Compared with some of these other sites, the different responses of some indigenous birds to possum control in the Waitākere Ranges, such as the increase in silvereyes and grey warblers, possibly reflects the fact that only one key invasive mammal species was controlled, and reintroductions or natural colonisations of missing endemics occurred at low levels or not at all.

For some species, the changes found in our study in the Waitākere Ranges accord with the findings of Ruffell & Didham (2017) where the type and magnitude of the changes in bird populations is context dependent. On the spectrum of pest control, from no pest control to complete eradication, Operation Forestsave and subsequent ongoing possum control across the Waitākere Ranges probably sits at the lower end of the scale, at a level which Ruffell & Didham (2017) categorised as periodic possum control. Based on forest bird counts at multiple sites across mainland northern New Zealand, Ruffell & Didham (2017) found that pest control affected surprisingly few species, with only kererū and tūī being more abundant at pest controlled than uncontrolled sites for any pest control category, while fantail, silvereye and tomtit did not change significantly and grey warblers were significantly less abundant.

Increases in some of the indigenous birds (e.g. kererū, tomtit) were most marked in the first part of the count period, and since the mid-2000s the numbers detected have levelled out or dipped a little. It is possible that the avian community in the Waitākere Ranges reached some sort of equilibrium around the mid-2000s as a result of the possum control. Studies elsewhere show that possum control allows ship rats to increase (i.e. mesopredator release) due to greater availability of, or reduced competition for, seeds and fruit (Innes *et al*. 2004, Sweetapple & Nugent 2007, Innes *et al*. 2010, Ruscoe *et al*. 2011, Masuda *et al*. 2014). For many indigenous forest birds, higher ship rat numbers can result in higher nest losses or even losses of adults from predation (Innes *et al*. 1999). Mesopredator release of ship rats could now be hindering further expansion of indigenous bird populations in the Waitākere Ranges. With the possible exception of the 2200ha Ark in the Park area, without widespread intensive control of the full suite of mammalian predators across the Waitākere Ranges, there may be very little chance that indigenous birds will increase any further. This may also be exacerbated by increased rat abundance caused by a warming climate (Walker *et al*. 2019b).

High ship rat numbers may explain the poor outcome of some recent translocations of endemic birds to the Ark in the Park (Miskelly & Powlesland 2013). Two releases (hihi and whiteheads), where birds dispersed widely outside the protected Ark area, appear to have failed, whereas robins and kōkako, which did not disperse so widely have fared better because sufficient numbers of founders stayed within the Ark, where predators are controlled more intensively.

4.7 Changes in the more common exotic birds

In the Waitākere Ranges blackbird detections increased significantly during the count period, while eastern rosellas showed a positive but non-significant trend. Adult blackbirds are unlikely to be preyed on by possums, but their nests are probably vulnerable, so higher nest success could account for the increase. Increased quantities of fruit might also have provided some benefit. Among the other species with >200 detections, there was no significant change in detections of chaffinch, myna, dunnock, goldfinch or redpoll. Unlike indigenous birds such as kererū, tūī and tomtit, exotic bird populations are usually not limited by introduced predatory mammals (Miskelly 2018). Elsewhere recent studies, especially at sanctuaries or islands where mammalian pests have been removed or occur in very low numbers, the general trend is for exotic species either to change very little or to decline to form a very minor component of the total avifauna (Spurr & Anderson 2004, Graham *et al*. 2013, Miskelly 2018, Binny *et al*. 2021, Ralph *et al*. 2021).

This effect becomes even more marked where pest mammal removal is followed by reintroductions of missing endemic birds. This was first noted on Cuvier Island, where, following the removal of goats and feral cats and the reintroduction of kākāriki (*Cyanoramphus novaezelandiae*) and saddlebacks, introduced birds declined to form a very small part of the total avifauna (Diamond & Veitch 1981). Most exotic birds declined at Tiritiri Matangi, Zealandia and the Ipipiri Islands (in the Bay of Islands) following pest eradication and releases of missing endemics (Graham *et al*. 2013, Miskelly 2018, Ralph *et al*. 2021), and it is assumed that like grey warbler, fantail and silvereye at these sites, exotic species were outcompeted by increasing numbers of some indigenous birds, especially the endemics (Graham *et al*. 2013, Miskelly 2018).

At some sites however, some exotic species have increased following pest control. At Motatau, rosella, chaffinch and myna increased (Innes *et al*. (2004), in the Landsborough Valley song thrushes (*Turdus philomelos*) increased (O'Donnell & Hoare 2012), and on the Ipipiri Islands eastern rosellas and house sparrows (*Passer domesticus*) increased (Ralph *et al*. 2021). Innes *et al*. (2004) were unable to attribute the increases they found at Motatau to pest control with any confidence as their study lacked replication. In the Hunua Ranges, while it may be too early to detect some longer-term trends, in the four-year period following the 1080 poison drop in 2015, mynas increased but rosella, blackbird and chaffinch numbers did not change (Auckland Council unpublished data).

Over the past 20-30 years in the Hunua Ranges, mynas have expanded into dense native forest, e.g. in the Kōkako Management Area where they used to be almost absent (pers. obs.), and recent counts show they are still increasing there. The expansion of mynas at Hunua accords with the findings of Pierce *et al*. (1993), who found that mynas increased across Northland and its offshore islands. However, compared with Hunua, mynas are much less common in the central part of the Waitākere forest. Dead northern rātā are common in the Hunua forest, the result of the decimation of this important emergent species after possums spread and peaked in the Hunua Ranges during the 1940s-50s (Barton 1978). These large, dead trees provide numerous myna song posts and nest holes. Mynas prefer nest holes with good visibility, which large, emergent dead rātā provide. In the Waitākere Ranges however, there was an active programme by ranger staff during the 1960s-70s to fell the dead rātā "to tidy up the bush" (Alastair McArthur pers. comm.). This would have removed numerous tree holes that mynas could potentially use, and a scarcity of preferred tree holes could have limited the spread of mynas in the Waitākere Ranges forest.

Eastern rosellas are expanding their range across the North Island, including into forested habitats (Heather & Robertson 1997, Robertson *et al*. 2007). The increase in rosellas noted on the Ipipiri Islands (Ralph *et al*. 2021) could also be the result of range expansion. The positive trend in rosella numbers in the Waitākere Ranges may reflect an expansion of this species in forest habitat in the ranges during the count period. Like the myna, the rosella is a hole-nesting species. However, rosellas prefer more secluded nest sites, including sites lower in the forest, so the loss of many of the dead, emergent rātā trees may not be a limiting factor.

4.8 Kererū as an indicator species

Mean detections of kererū increased during the first few years of the counts and over the whole count period kererū showed a positive, but not statistically significant trend in mean detections. However, we think this is a biologically significant result because kererū have been a useful indicator species for the success of possum control elsewhere. For example, following the removal of possums from Kapiti Island, kererū numbers increased 6-fold on a transect located in the mid-section of the island (Lovegrove 1988, Veltman 2000). Innes *et al*. (2004) found that possums caused most kererū nest failures at Motatau, and following possum control, kererū numbers increased significantly. There are numerous studies where kererū have benefited from multi-species mammalian pest control e.g. James & Clout (1996), Smith & Westbrooke (2004), Baber *et al*. (2009), Ruffell & Didham (2017), Miskelly (2018), Bombaci *et al*. (2018), Fea *et al*. (2021), Binny *et al*. (2021). The kererū has been chosen as one of a number of key indicator species nationally (Monks *et al*. 2013). Being large and conspicuous, the kererū is also an ideal species for community groups to use in monitoring the outcomes of pest control in established forest habitats.

4.9 Changes in relative abundances of species with greater than 200 detections

The relative abundances of some species changed over the count period (Figure 5) and these changes also show that some indigenous species have become a more dominant component of the forest bird community in the Waitākere Ranges. Of the indigenous species with greater than 200 detections, tūī, kererū and kingfisher became proportionately more abundant than they were previously while grey warbler, fantail and tomtit became proportionately less abundant. Of the exotic species, rosella became proportionately more abundant while blackbird, chaffinch, myna and goldfinch became proportionately less abundant. For some of these species, the changing proportions we found accord with findings elsewhere. At Tiritiri Matangi and Zealandia, silvereye, grey warbler, fantail and introduced species formed a much smaller proportion of the total avifauna following pest mammal removal (Graham *et al*. 2013, Miskelly 2018). These species also form a minor component of the forest avifauna on sanctuary islands such as Kapiti and Hauturu, which lack predatory mammals and where endemic forest birds tend to predominate (Diamond & Veitch 2001, Girardet *et al.* 2001, Innes *et al.* 2010, Miskelly 2018, Lovegrove *et al.* 2019). Unlike Tiritiri Matangi, Zealandia and the island sanctuaries, in our study the proportion silvereyes formed of the forest bird community did not change much and kingfishers and rosellas became proportionately more abundant than they were previously. The reasons for these differences are worthy of further study, but apart from possible range expansion by rosellas (Robertson *et al*. 2007), it may be related to the reduction in just one pest mammal, the possum, while most of the other predatory mammals remained.

4.10 Proportions of birds seen and heard

Eighty-four per cent of the birds detected during the counts were heard only and not seen. In any study of forest birds, it can be difficult to distinguish between the effects of changing density and those of changing conspicuousness (Gibb 1996, Dawson 1981, Hartley 2012). The song periods for many indigenous and exotic passerines vary with the time of day and season. We attempted to minimise possible variability in bird detections due to season and time of day by carrying out the counts in the same months each year, and during the morning after the early dawn chorus period. We also avoided counting from mid-January onwards when many forest birds tend to go quiet during the post-breeding moult, and to minimise possible effects from the noise of cicadas, which not only make calls hard to hear, but also may suppress some bird vocalisations (Hart *et al.* 2015). The high proportion of birds heard in this study emphasises the need for trained observers who are familiar with all songs and calls likely to be heard. In our study, all counts were carried out by two experienced observers.

Kererū and tūī were recorded as first seen or heard in very similar proportions, with a higher proportion of these species recorded as seen (kererū 30%, tūī 28%, Table 1) compared with most of the other smaller forest birds. This aspect is pertinent to the value of kererū and tūī for community-based outcome monitoring where observers may be less experienced. Various studies (Innes *et al*. 2004, Ruffell & Didham 2017, Miskelly 2018, Bombaci *et al*. 2018, Fea *et al*. 2021, Binny *et al*. 2021) show that one or both of these species respond well to pest control, and they've been chosen as indicator species by Monks *et al*. (2013). Both species are conspicuous, therefore if a higher proportion of both species is likely to be seen, then that enhances their suitability for monitoring over less conspicuous forest bird species because of their increased probability of detection.

5. Conclusions

Annual five-minute bird counts over a 22-year period from 1997-1998 to 2018-2019 in the Waitākere Ranges by two experienced observers show changes in some bird populations following possum control. There was a significant increase in mean detections for all birds between 1997-1998 and 2018-2019, with the mean numbers of birds detected per count increasing by 58% and the total number of birds increasing by 75%. This was driven by significant increases in mean detections of indigenous bird species (especially from 1997-2005), whereas there were no significant changes in mean exotic bird detections. Of the indigenous birds, silvereye, tūī, grey warbler and welcome swallow increased, while kererū showed a positive, but not statistically significant trend in mean detections. There was a positive trend in tomtit detections from 1997-2010, then a decline, so that over the entire count period, tomtit detections did not change significantly. Kingfisher showed a positive but non-significant increase while fantail did not change significantly. Of the more common exotic birds, blackbird detections increased significantly while there was little change in chaffinch, rosella, myna, dunnock, goldfinch and redpoll.

Ongoing ground-based pest mammal control over most of the Waitākere Ranges during the study period primarily targeted possums, although there was probably some by-kill of other pest mammals. We have assumed that the changes we found in bird populations mainly resulted from a significant reduction in the numbers of possums competing with indigenous forest birds for foliage, nectar and fruit, and reduced levels of nest predation by possums on species such as kererū and tūī. However, we believe that the current level of pest control, which mainly targets possums, may not allow significant further gains in indigenous bird abundance and diversity, and may risk negative effects on some biodiversity values through elevated ship rat abundance. Pest control across the Waitākere Ranges needs to include all pest mammals if significant biodiversity gains are to be achieved.

Auckland Council's Pest Free Auckland initiative is a restoration initiative which encourages restoration across all land tenures and supports communities, mana whenua and agencies working together to protect and restore the biodiversity of Tāmaki Makaurau. This includes managing predators in corridors and in the wider landscape e.g. on Hauraki Gulf islands, peninsulas and open sanctuaries such as Tāwharanui and Shakespear. However, significant gains for wildlife will not be achieved if they move from safe source populations where there is predator control (such as those on the islands and in open sanctuaries), into a landscape which lacks secure additional forest habitat to expand into. Effective pest mammal control in large forest areas such as the Waitākere and Hunua Ranges would enable support for greater indigenous biodiversity.

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The logo used by the former Auckland Regional Council to publicise Operation Forestsave, the ground-based possum control programme carried out in the Waitākere Ranges in 1997-1998.

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