Monitoring forest bird occupancy using acoustic recorders in the Abel Tasman National Park

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Summary

Before being declared a national park, the coastal areas of the Abel Tasman National Park were farmed, and large parts of the forests were milled. Consequently, habitat loss and degradation has taken its toll and many native species were locally lost. A range of native bird species are still present in the park, but due to higher rat densities in the lowlands along the coast, their distribution is mostly limited to higher elevation areas. The goal of Project Janszoon's predator control is to reduce rat abundance to a level that allows native bird species to expand towards the lowlands and successfully establish there.

Initially, human surveyors were deployed to monitor bird occupancy, with mixed success. To overcome observer bias and other problems, acoustic monitoring using automated recorder units (ARUs) in the Abel Tasman National Park was carried out in Spring 2019 and 2020. Recording time was set to 2.5 hours in the morning and late afternoon, respectively, for approximately 14 days. Preliminary subsampling was limited to 90 seconds per day, using the manual batch processing of automatic 15 s intermittent sampling frames every 5 min within a 15 min sound file. In addition to these site-occupancy data, an acoustic detection rate (ADR) was calculated per site for finer resolution. ADRs were higher in the uplands for rat-sensitive bird species and might be used as a surrogate for abundance and as indicators for relative change over time. This makes in an ideal method to measure the outcomes of pest control in the park on a landscape scale and expands the application of acoustic monitoring beyond mere occupancy measures.

Results replicated the findings of previous human surveyor monitoring and suggest first signs of expansion of forest bird distribution towards the coast. Weka showed a sparse occupancy according to human surveyor monitoring in 2016 but now re-colonised the entire monitoring area. Despite an exceptionally strong mast year that resulted in high rat abundance between the survey seasons, most bird species did not show a major decline in occupancy, except for parakeets which declined by 70%. On average, rat-sensitive species are confined to areas above 600 m elevation but show first signs of expansion.

A sampling sensitivity analysis on a dataset comprising full annotations of four locations revealed that birds with high call rates have an acceptable detection probability, but sampling needs to be improved to capture birds with a medium or low call rate. A sampling strategy of ten seconds every five minutes over eight days was identified as an ideal balance between work effort and detectability. Furthermore, the analyses of temporal call activity patterns can be used to optimise sampling strategies for key indicator bird species and improve sampling efficiency. This report is meant to be a first explorative approach towards the potential of acoustic monitoring and to identify promising aspects that should be investigated in more depth in the future.

Introduction

Project Janszoon was launched in 2012. It is a privately funded project to restore the Abel Tasman National Park (www. janszoon.org). The park had a history of early farming and milling (Simpson, 2018) that was mostly concentrated along the coast, resulting in the loss of habitat and many native species. Although the area was declared a National Park in 1942, the lowlands remained an impoverished ecosystem and high abundance of exotic predators impeded the re-establishment of native fauna and flora.

One of the first steps of Project Janszoon's initiative was the introduction of a park wide stoat trapping network and additional aerial rat control using sodium-fluoroacetate (known as 1080) to control exotic mammalian predators like rats (mainly ship rats, *Rattus rattus*) and possums (*Trichosurus vulpecula*), and indirectly mustelids (mainly stoats, *Mustela erminea*), in the heart of the park (Fig. 1). Acoustic bird monitoring has been employed to measure the outcomes for native birds of this landscape-scale predator control.

Predator control within the study area

Stoat trapping has been underway since 2013 on a dense network of stoat trap-lines extending throughout 20,000 ha of Abel Tasman National Park (Deverell, 2013). The stoat trapping network is a joined effort of Project Janszoon, the Department of Conservation, Air New Zealand (who sponsored the network north of Totaranui) and the Abel Tasman Birdsong Trust (who is maintaining the network along the southern coastline).

There are two species of rats in the park: ship rats or black rats (*R. rattus*) and Norway rats (*R. norvegicus*); black rats are likely to be present only in low elevation areas. Rat populations in the park are being monitored quarterly using tracking tunnels (FTT, see Gillies, 2013; Gillies & Williams, 2013), which provide an index of relative rat abundance: the proportion of baited tunnels visited by rats during one fine night (Fig. A1 in appendix). When FTT rates increase above critical levels, rat numbers are reduced to low levels using aerial broadcast 1080 (Sodium Fluoroacetate) operations within the "rat-triggered area" (Figs. 1 & 2), which also reduce numbers of other vertebrate pest species such as brushtail possum and, by secondary poisoning, stoats. A less intense aerial control zone is the "possum-triggered" area in the northern part of the park (Fig. 2).

Aerial broadcast of 1080 in the rat-triggered control area was undertaken during 2014, 2017 2019 and 2020 (Fig. A1). Immediately after each aerial broadcast operation, rat tracking rates in the pest control area were close to zero. Rat populations slowly recovered with time during normal years but irrupted rapidly in response to prolific seed-fall of southern beech trees during mast events. In 2020 an unusually strong mast was observed. During the period 2016 to 2021,

the mean rat tracking rates were 18% (range 0–58%) in the rat-triggered control area (Fig. A1 in the appendix).

Bird monitoring objectives

Some native bird species including robin, brown creeper and rifleman had disappeared along the coast but are still present in high elevation areas of the park like the Upper Wainui Valley and Evans Ridge (Bollongino, 2018). The goal of Project Janszoon's pest control is to reduce predator numbers to a degree that allows native forest birds to expand towards the coast and to re-establish viable populations within the managed area. Based on the results of previous monitoring (see following chapter) a group of indicator species was identified that is currently limited in their distribution to higher elevation but is expected to expand as predator numbers decline: brown creeper/ pīpipi (*Mohoua novaeseelandiae*), South Island robin/ toutouwai (*Petroica australis*), rifleman/ titipounamu (*Acanthisitta chloris*), kākā (*Nestor meridionalis*), and kākāriki (*Cyanoramphus auriceps*). Blue duck/whio (*Hymenolaimus malacorhynchos*) and brown teal/pāteke (*Anas chlorotis*) are also managed by Project Janszoon, but are not suitable to be monitored with acoustic monitoring under its current design. Weka (*Gallirallus australis*) have seen a remarkable comeback and recolonised the park within a decade. They are included in this study due to their potential threat to many invertebrate and vertebrate species which requires monitoring for conservation management purposes.

The goal to achieve an extensive and substantial change on a landscape scale does not require a high resolution and exceedingly sensitive monitoring method. The objective is to detect established populations rather than the presence of individual birds.

Previous monitoring methods

Walk-through surveys were carried out in 2015 and 2018 to map the occupancy of native forest birds within the zone of aerial rat control (Fig. 1). The monitoring took place in September, mostly during fine weather. A surveyor walked along stoat track lines for at least one hour per 1 km grit square on the map. Presence of all birds heard or seen was recorded but not quantified. More intensive line transect monitoring was performed to collect abundance data from selected areas in the high- and lowland, respectively (Fig. 1). Every bird heard or seen was documented within 100 m walking intervals. These transects were repeated three to six times, delivering an abundance index similar to 5-minute bird count (5MBC).

The results of both methods confirmed that the above-mentioned native species were restricted to high elevation areas (Peter Gaze, unpublished), with brown creeper being the most restricted species and not passing beyond the 800 m elevation line, rifleman being limited to approximately 600 m and robin being found as low as 400 m.
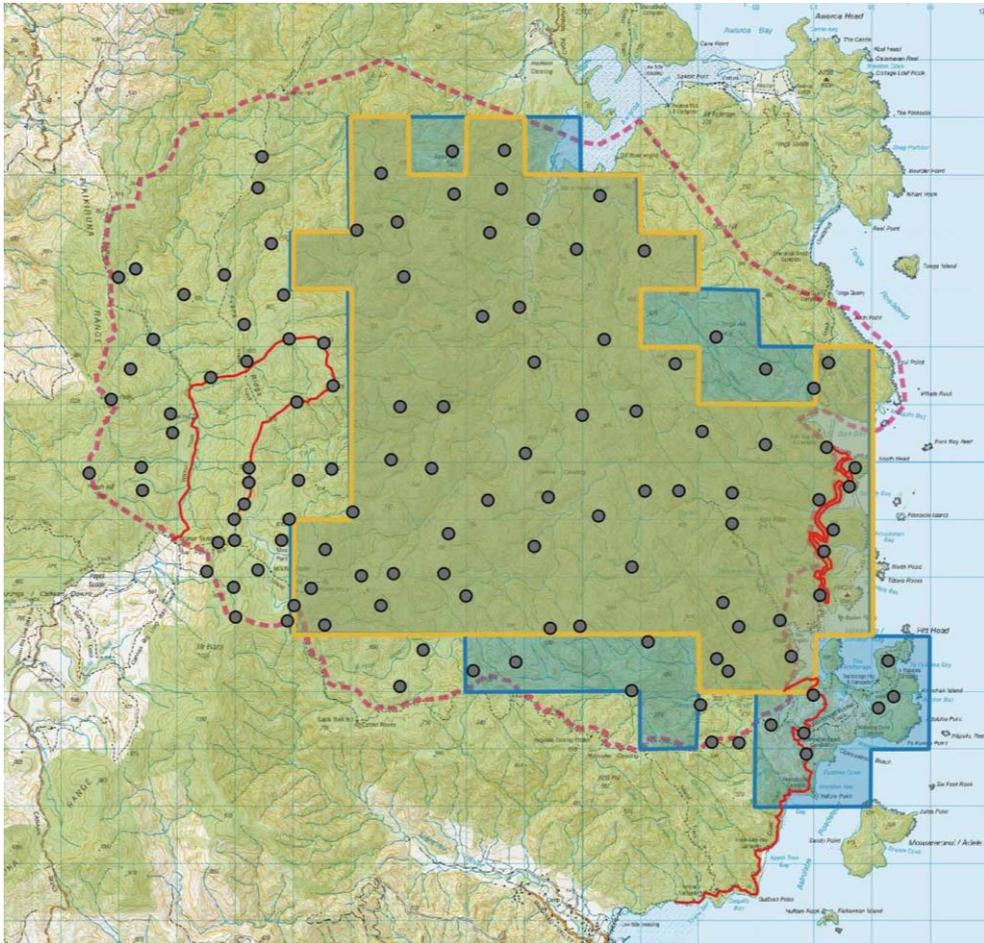
Figure 1: Overview of bird monitoring in the Abel Tasman National Park. Dashed pink line: area of aerial 1080 rat control, red lines: line transects, orange highlight: area of 1 km grit square survey 2015, blue highlight: area of 1 km grit square survey 2018, grey dots: locations of acoustic recorders in 2019 and 2020.

Reasons for Acoustic Monitoring

Although the previous monitoring methods yielded important results, a few detriments raised the need for improvement. Amongst the main problems were observer bias (Lloyd, 2017), lack of verifiability, sensitivity and repetition, inconsistent sampling conditions and times, and inflexible data analyses. Acoustic monitoring has become an increasingly important alternative within avian research (Shonfield & Bayne, 2017), as it offers the following advantages:

 - Establishment of an archive of bird calls that can be revisited

 - Allows for elongated monitoring and is therefore more suitable for cryptic species and reduces bias due to temporal variability

 - Allow for quality controls by random testing of results by a second analyst

 - Reduce observer bias (bias can still be introduced during examination of recordings, but at least it is verifiable)

 - Simultaneous data collection during the preferred time of day

 - No disturbances of bird behaviour caused by human presence

 - Improve data quality and statistical outcomes by repeated data collection at each site

- Flexibility in how the recordings are analysed and interpreted. If indicator species, analytical methods, objectives or research questions change, the acoustic archive can be revisited, which makes it ideal for adaptive management

- Increased accuracy of bird call identifications. Spectrograms facilitate bird identification and overcomes biases introduced by observers with different hearing abilities

- The ability to analyse recordings may increase as acoustic software for identifying birdsong continues to develop (i.e. automatic identifiers)

- Bioacoustics data can be analysed applying occupancy modelling, which can be used as a surrogate for costly abundance measures

Potential critical points are as follows:

- Data loss if device fails in the field

- Monitoring is based on acoustic cues only, no visual information is documented

- Data volumes accumulate rapidly and storage can be a challenge

- Temporal versus spatial trade-off: recorders allow long-term monitoring at one site, whereas human surveyors spend little time at one site but cover a larger area

- Manual analysis of sound files comes with a high work effort

- Initial costs of recorders, batteries, SD-cards and data storage drives

Taking the purpose and objectives of Project Janszoon's monitoring into account, the advantages clearly outweigh the disadvantages, and the establishment of this method has a great potential for other projects of the Next Foundation.

Other areas of acoustic monitoring in the park

Another acoustic monitoring project is run in parallel by the Department of Conservation in Golden Bay (Bollongino, 2021) in the northern part of the Abel Tasman National Park (Fig. 2). Funded by Air New Zealand, the Department has deployed Goodnature A24 traps to protect remnants of original bush from rats and to enhance the recovery and recolonisation of native bird species. Both monitoring projects are run in close collaboration to share progress and new insights in methods, data analyses and results.

This project covered approximate a 12,000 ha area within the aerial rat control zone in the Abel Tasman National Park (Fig. 2). The sampling area ranges from sea level to just over 1000 m elevation and covers are variety of habitats and types of vegetation (Fig. 3). The vegetation along the coast is typically regenerating manuka/kanuka and undifferentiated lowland bush, transitioning into rimu/hard beech forest further up and reaching mixed beech forest and kaikawaka/mountain beech in the uplands.

Acoustic monitoring was carried out in spring 2019/20 and 2020/21 starting in September and continuing until early November. This season was chosen to achieve continuity with previous bird monitoring (see chapter above) and due to higher vocal activity before and during breeding season (Powlesland, 1983). In total, 30 recorders were available (AR4 recorders, purchased from the Department of Conservation). To achieve a larger sampling size, all recorders were deployed four times at different locations, achieving 120 sampling points in total. Sampling points were chosen semi-randomly along stoat trapping lines to ensure accessibility (Fig. 2) and a minimum of 200 m distance between sampling points was applied to increase independence of counts.
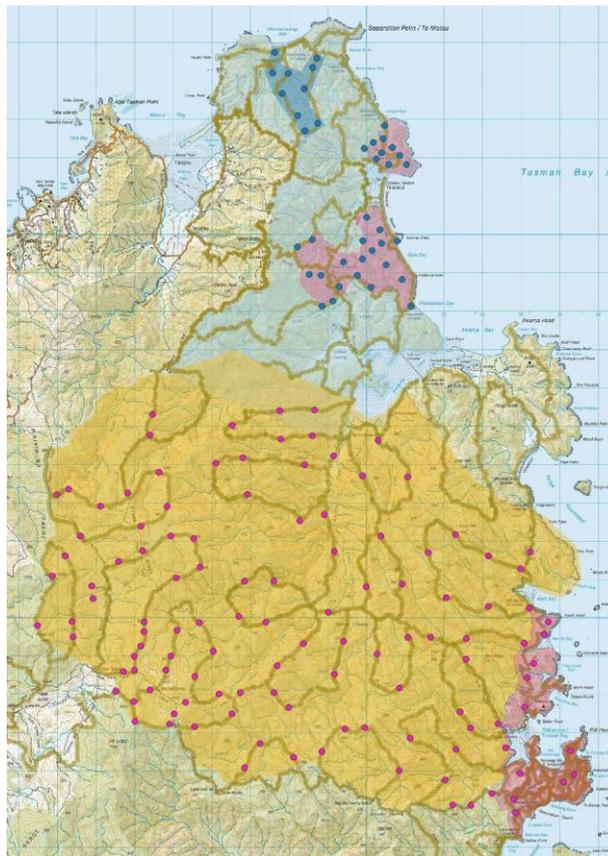
Figure 2: Pest control areas and acoustic recorder locations in the Abel Tasman National Park. Yellow shade: rat-triggered aerial 1080 zone, light blue shade: possum-triggered aerial 1080 zone, pink shade: A24-trap rat control, dark blue shade: non-treatment control block for Air New Zealand project, brown lines: stoat trap lines, pink dots: recorder sites current study, blue dots: recorders sites Air New Zealand project.

The previous inland surveys had shown that forest bird distribution in the park is linked to elevation. Consequently, the sampling design followed a stratified approach, based on six elevation strata from sea level to ≥1000 m ASL using 200 m intervals (Fig. 4). Recorders were distributed in a balanced design of five recorders per stratum and per cycle. The topography of the sampling area determines a narrow highland zone in the south-west, with subsequent elevation strata widening towards the coast. For this reason, recorders are distributed more densely at higher elevation compared to the midland and coastal zone.
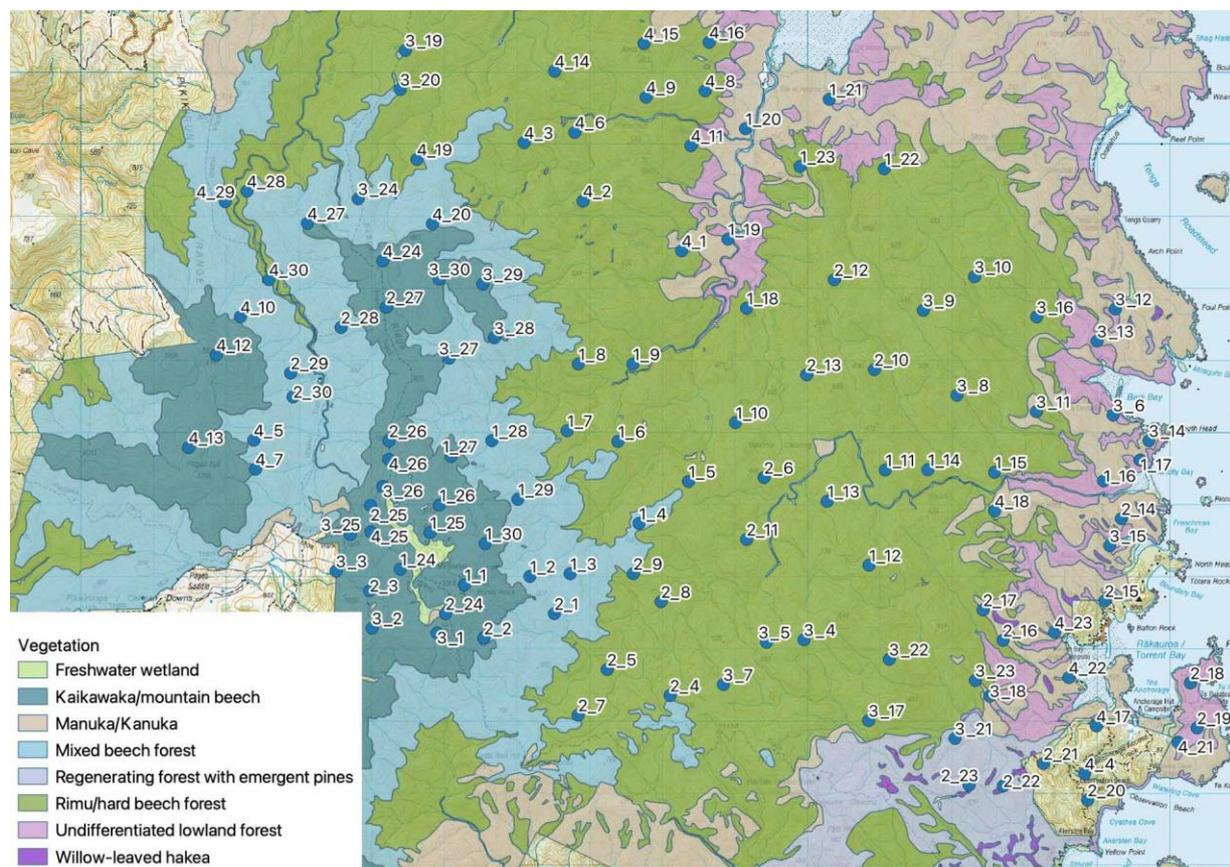
Figure 3: Vegetation zones and recording site identification codes ("cycle"_"recorder ID").
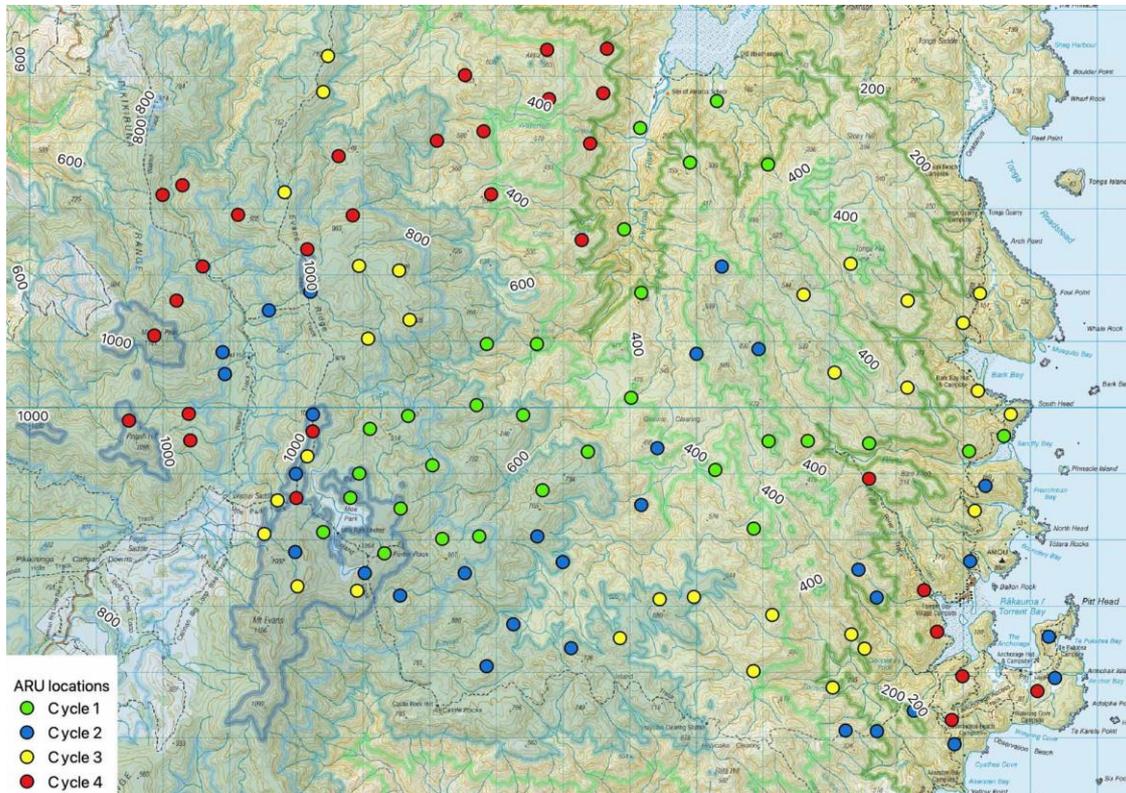
Figure 4: Elevation strata and locations of recorders for each cycle.

The length of deployment per location was around 14 days, after which ARUs were transferred to a different location. Total recording time per day was five hours (Tab. 1) split into two intervals to cover diurnal, crepuscular and to a smaller extend nocturnal birds. Recorders were set on "high" mode as recommended for forest birds. These settings delineate the maximum recording time regarding the capacity of rechargeable batteries and a 16GB SD card.

In the field, locations for recorders were chosen avoiding large objects like rocks, cliffs, large trees, or proximity to streams that would interrupt or cover the soundscape. Recorders were tied to a branch at head height and little twigs that might rub against the microphone during windy conditions were removed (Fig. 5).

Figure 5: Two examples of recorder deployment in the field.

Table 1: Schedule and recording times for all four monitoring cycles. All times are referring to standard time. Cycle 3 and 4: recording times were shifted to one hour earlier in the morning and one hour later in the evening to adjust for changing sunrise and sunset times.

Cycle	Time span	Morning interval	Evening interval
1	1st half of September	07:00-09:30	17:00-20:30
2	2nd half of September	07:00-09:30	17:00-20:30
3	1st half of October	06:00-08:30	18:00-20:30
4	2nd half of October	06:00-08:30	18:00-20:30

Data analyses

Sound files were analysed using the software AviaNZ (versions 2.0 - 3.2, http://www.avianz.net/index.php). DOC recorders automatically divide recording time into 15 min-unit sound files. Sound files were extracted from the main data folders and transferred to a single folder to facilitate batch processing using a python script provided by Geoffrey Irons. For bird call annotations, intermittent subsampling has been shown to be more efficient than one continuous subsample (Cook & Hartley, 2018). One 15 min-unit in the morning and one in the evening were transcribed (starting at 07:30 and 17:30 for cycle 1 and 2, 06:30 and 18:30 for cycle 3 and 4). Files were batch processed to speed up manual processing applying the default intermittent sampling which presents 15 s sampling frames at the beginning of every five-minute block within a 15 min recording unit. This resulted in a total of 90 s per day, for on average of 13 days per site.

Bird calls were annotated manually and summarised in automatic Excel output files. Calls of bellbird and tui were pooled, as both species are known to mimic each other. Output files were merged using a custom python script (also provided by Geoffrey Irons). Summary stats were

also executed in Excel, these included presence of bird species per site, temporal vocal activity patterns and APIs. Batch-processing allows to annotate the presence of a bird species, but neither number of calls nor their duration are documented. These binary data were used to assess an acoustic detection rate (from here on called ADR or call rate), by calculating the proportion of 15 s-subsampling frames in which a species was detected. This approach offers a finer resolution than simple site-occupancy (Jahn et al., 2022; MacKenzie et al., 2002). In this study, ADR was used to distinguish locations with multiple resident birds from those where individuals might be present temporarily or in very small numbers.

Spatial distribution maps were generated in QGIS (version 3.22.0-Białowieża for Macintosh).

Several studies suggest a positive relationship between vocal activity rate and population size (e.g. Borker et al., 2014; Oppel et al., 2014; Pérez-Granados et al., 2019; Pérez-Granados & Traba, 2021; Tingley et al., 2016).

To test for a potential seasonal bias in call rates and thus detectability across the four monitoring cycles, ADRs for four native species were compared for all four cycles. The four species comprised robin, tomtit, warbler, and rifleman. Only sites of the two highest strata were included to avoid sampling bias due to low call rates at lower elevations.

Complete transcriptions of all sound files were generated for four selected locations to test for sensitivity of different sampling regimes (see following chapter). These data were also used to investigate true call rates (percentage of recording time where a bird was singing, hereafter referred to as call percentage) and temporal calling activity patterns for indicator bird species over the entire recording interval.

Sampling sensitivity analysis

The following analysis was carried out and summarised by Dr. Brian Lloyd (Lloyds Ecological Consulting).

To investigate the effectiveness of different sub-sampling transcription regimes for estimating species occurrence from acoustic recordings, we obtained estimates of species occurrence in a complete transcription of an entire sample of recordings and then sub-sampled the complete transcription using different sub-sampling transcription regimes with a range of subsample lengths and sampling intervals. Species occurrence estimates from the various subsamples were then compared with species occurrence estimates from complete transcription.

Analyses were undertaken using a complete transcription of 160 hours of recording from recorders deployed at four sites for eight days during spring 2019. Two 150 min sessions were recorded each day at each site (Tab. 1). Seven bird species were chosen as indicators: robin, rifleman, brown creeper, kākā, kākāriki, kea and weka. Call length and timing was documented, and calls were defined as separate if a break of at least 5 s occurred between syllables. The

selection of locations for complete annotations was based on achieving a gradient in presence of indicator bird species.

Session recording details and details of each of the call sequences identified in the recordings were obtained from the transcription file generated in AviaNZ software. Session recording details were site identity, session date, session start-time and session end time. Details for each call sequence were the species, and the start-time and end-time of each call sequence. Call sequence details were used to calculate call-rate, call-time and call-percentage for each of the identified species for each recorded session. Call-rate is number of call sequences per hour, call-time is the combined length of all call sequences for the species and call-percentage is the proportion of a recording when a species was identified as calling.

Species occurrences for each of the sixteen sessions at each of the four sites were compiled from the transcribed data. Very different species occurrence patterns were apparent in recordings from morning and evening sessions, consequently instead of pooling species occurrence by site species occurrence was pooled by morning and evening sessions separately at each site. Call-rate, call-time and call-percentage were also calculated for each of the species occurring during morning sessions and evening sessions at each site.

The sub-sampling transcription regimes we used had sub-sampling intervals of 2.5, 5 and 10 minutes and sub-sample lengths ranging from 5 s to 120 s with 5 s increments. In all sub-sampling regimes, sub-sampling began at the start of the transcribed recordings for each session. Consequently, for each subsampling interval, shorter sample periods were subsets of longer periods. During subsampling, a species was scored as having been detected during a session whenever one its call sequences overlapped a sampling period during the session. For each session and subsampling interval, the shortest sample lengths with species detections were noted. The procedure was repeated for each site, with recordings from morning and evening sessions separately.

Species occurrences from subsampling of the transcribed recordings and complete transcriptions were compared for each session and for morning and evening sessions at each site pooled separately. For each occurrence in the complete transcriptions, we recorded the minimum subsample length where an occurrence was detected during each of the three subsampling intervals. Because short sub-sample periods are subsets of longer ones, detections in a sub-sample will carry over into all longer subsamples using the same subsampling interval. We constructed tables of the numbers of detections over the ranges of minimum subsample lengths and a cumulative sum of the number detections as the subsample length increased. Using total occurrences from the transcriptions, the cumulative sum of detections by subsample lengths was converted into a cumulative percentage of the number of occurrences.

Results

Costs

Each survey season comprised approximately 55 person days in the field and was carried out by contractors, volunteers, and DOC Rangers. An overview to costs is summed up in Table 2. The initial costs to develop logistics, sound file transcription and data analysis have been higher, the estimates given in Table 2 are an approximation for subsequent surveys that can resort to existing workflow and data analyses pipelines.

Table 2: Estimation of work effort in person days for all four cycles of acoustic monitoring once design, logistics and data pipelines are set up.

Task	Person days (app.)
Planning and organisation (scheduling contractors, H&S, transport, gear)	5
Recorder deployment and retrieval	55
Recorder maintenance (drying, battery exchange & charging, programming) + sound file cataloguing and copying	5
Annotating sound files (180 secs per day/recorder)	20
Data analysis & reporting	20
Sum	**95**

Acoustic analyses

To date, two survey seasons were successfully accomplished in spring 2019 and 2020. The average success rate was 98% (Tab. 3). A majority of 93% of all sites had a recording span of 11-15 days, with an average of 14 days (Tabs. A2 & A3 in the appendix). In seven cases recording time exceeded 20 days during cycle 4, as at the end of the season units were left in the field until an opportunity to pick up devices during trap maintenance occurred. As most of the deployment length was similar across sampling locations and the detection of indicator bird species was the main objective, the entire dataset was used for analyses. The effect of a standardised, truncated dataset is described below.

Table 3: Success rate for deployment of recorders at 120 sampling points per survey season.

	# Successful sampling points	Problems
2019/20	117/120	2 human errors, one recorder did not start
2020/21	117/120	Three incomplete recordings (corrosion issues)

In total, more than 7800 hours of recording time were collected per season, resulting in just under 2 TB of data volume. According to the sampling regime of 90 s per day and per location,

approximately 39 hours (less than 1%) of recordings were transcribed per season. Annotations were made based on spectrogram patterns (see Fig. 6A for examples) and listening to the sound of calls in most cases, except when spectrogram patterns were clearly distinct (Fig. 6B). Annotations were occasionally impeded by high calling activity resulting in overlapping spectrograms (Fig. 6C) and windy conditions which created white noise that often rendered bird call identification impossible.
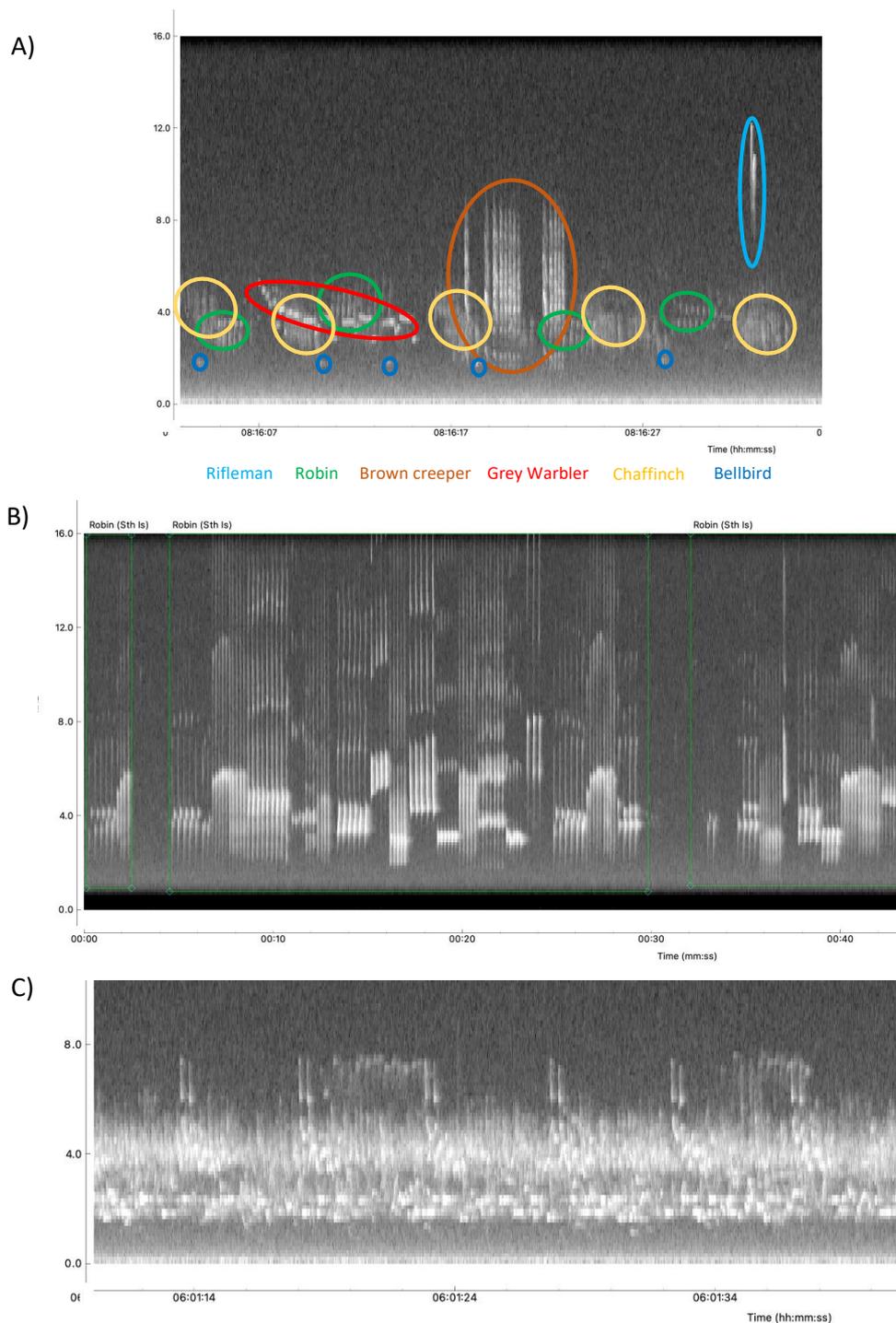

Figure 6: Examples for spectrograms: A) Multiple species singing (see colour code), but identification is still unproblematic B) clear call of a male robin that is close to the microphone C) dawn chorus, some species can be identified (fantail, tomtit silvereye, bellbird), but weaker bird calls would be missed.

Spring 2020 was characterised by long lasting windy and gusty conditions and bird call identification was compromised for many sites. Gentle rain had no large effect on the ability to identify bird calls, except for distant rifleman calls that show similar patterns on the spectrogram. It cannot be excluded that humming sounds of motorboats and aircrafts covered bird calls of lower frequency, such as kākā, kea and weka. Boat and wave noise as well as increased wind along the coast made bird identification difficult in these areas. In rare occasions bird calls could be heard without any appearance on the spectrogram, potentially leading to a false negative result. However, these occasions were rare and bird calls so weak that an unambiguous identification was usually not possible.

The subsequent data are based on the complete dataset, comprising sampling of each day a device recorded. Total recording time varied slightly between devices (Tab. A2 in the appendix). The effect of truncating the dataset to an equal number of sampled days across all sites is outlined in a chapter below. Table 4 comprises a list of bird species that were encountered during sound file analyses. A selection of bird species was excluded from the analyses due to their rare detection rate under the current sampling regime (Tab.4, second column). Fourteen native bird species, including all above mentioned indicator species, were included in the data analyses (Tab. 4, first column).

Table 4: List of bird species that were encountered during sound file analyses. The first column sums up species that were included in the data analysis, the species listed up in the second column were excluded based on the low call rate. Exotic species and marine birds are not managed by Project Janszoon and are therefore not part of this study.

Native bird species documented	Native bird species excluded from analyses	Exotic species present but not documented	Native species excluded from analysis
Bellbird/Tui	Kereru	Goldfinch	All marine species
Robin	NZ Falcon	Chaffinch	Herons
Rifleman	Harrier	Song Thrush	
Brown Creeper	Long-tailed Cuckoo	Blackbird	
Kākā	Morepork/Ruru	Dunnock	
Kākāriki	Fernbird	Redpoll	
Kea		California Quail	
Grey Warbler			
Tomtit			
Fantail			
Weka			
Shining Cuckoo			
NZ Kingfisher			
Silvereye			

The number of locations where each species was detected is given in Table 5. Most species revealed a similar detection rate between survey seasons, with only four species out of fourteen showing a change of more than 20% (creeper, kākāriki, kingfisher and shining cuckoo). Bellbird/Tui, silvereye and warbler are the most prominent birds in the park, followed by weka, fantail and tomtit. Robins occupy just over half of the sampled areas and the remaining species rank well below 50%.

Table 5: Number of sites where each bird species was detected (a maximum of 120 sites was possible).

	Robin	Creeper	Rifleman	Kākā	Kea	Kākāriki	Tomtit	Weka	Fantail	Warbler	Silvereye	Bellbird/Tui	Kingfisher	Shining Cuckoo
2019	65	16	37	30	27	40	106	96	96	110	115	117	15	10
2020	68	11	42	27	27	12	108	108	107	114	117	119	7	18
% Change	+5	-31	+14	-10	0	-70	+2	+13	+11	+4	+2	+2	-47	+80

Average acoustic detection rates (Fig. 7) vary slightly between survey seasons, but overall patterns remain similar. Detailed call rates per species and location are given in Table A2 in the appendix. Testing for a potential seasonal bias in call rates over the four monitoring cycles revealed no significant temporal differences (Fig. 8).
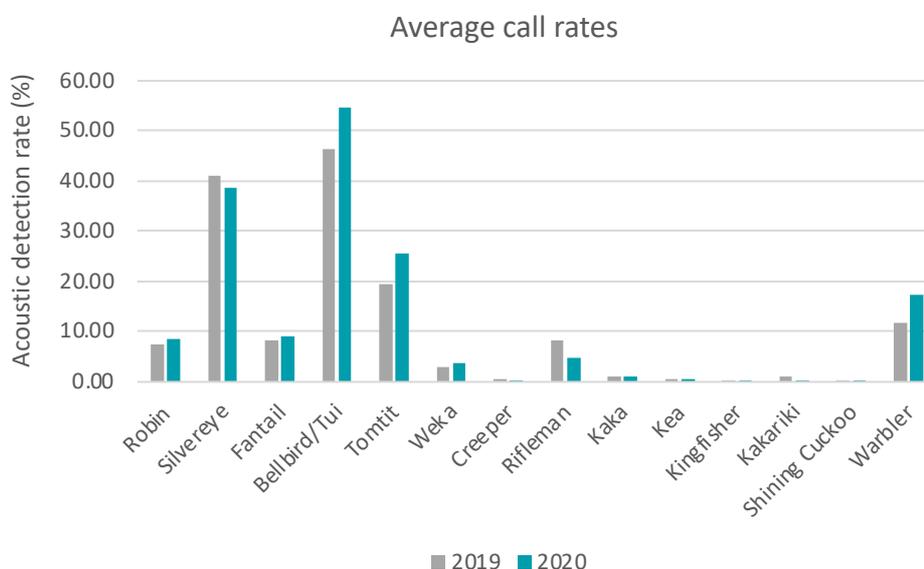
Figure 7: Acoustic detection rates (ADR) in 2019 (grey) and 2020 (blue).
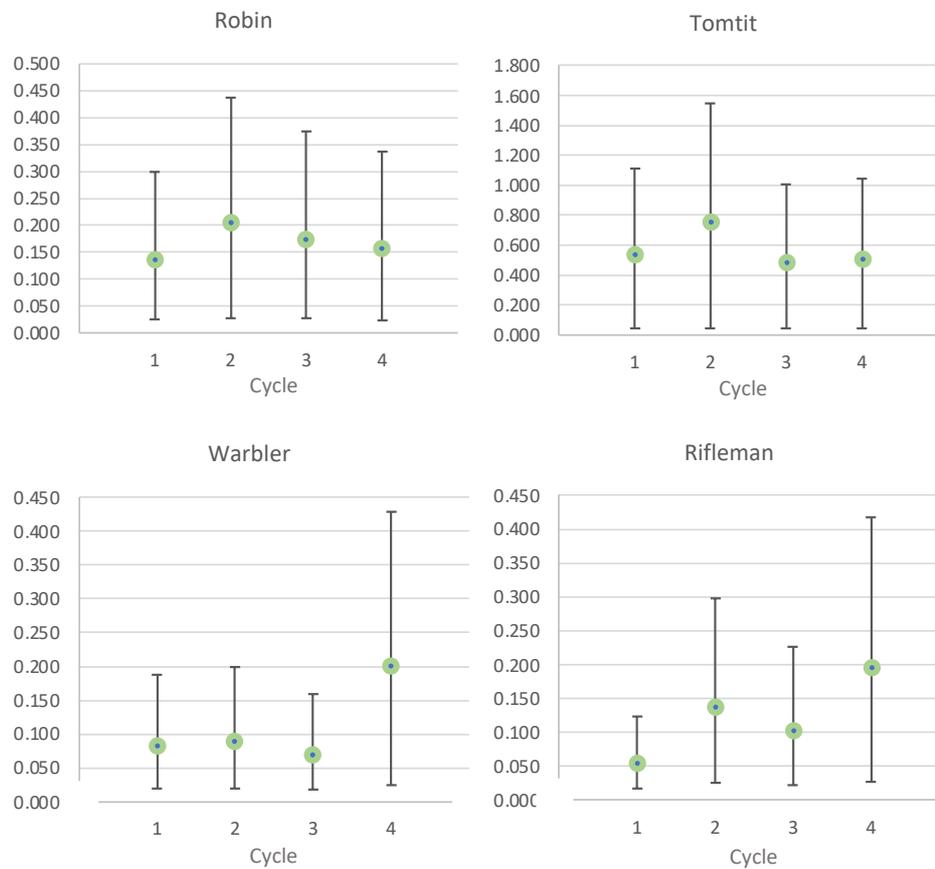
Figure 8: Comparison of acoustic detection rates of all four monitoring cycles for robin, tomtit, warbler, and Rifleman. Binomial proportion confidence intervals show no significant difference.

Spatial distribution of bird species across six different elevation strata supports that the distribution of robin, rifleman, brown creeper, tomtit, and to a lesser extend kākāriki is positively correlating with elevation (Fig. 9). Silvereye, bellbird/tui, and grey warbler are evenly distributed across all elevation strata, whereas fantail tend to be at higher numbers in lower elevation areas. Kākā, kea, and shining cuckoo show no clear preference.

The most common bird species were grouped into rat sensitive (robin, rifleman, creeper, kākāriki and tomtit) and non-rat sensitive species (bellbird/tui, silvereyes, warbler, fantail). Kākā were not included as their distribution and abundance is biased by recent translocations.

Maps comparing the number of species and accumulated ADRs per site (Fig. 10) confirm that rat sensitive species are mainly found above the 600 m elevation mark, whereas non-rat sensitive birds are found across the entire monitoring area. Higher call rates in the lowland indicate an increased abundance of non-rat sensitive species in the lowlands.
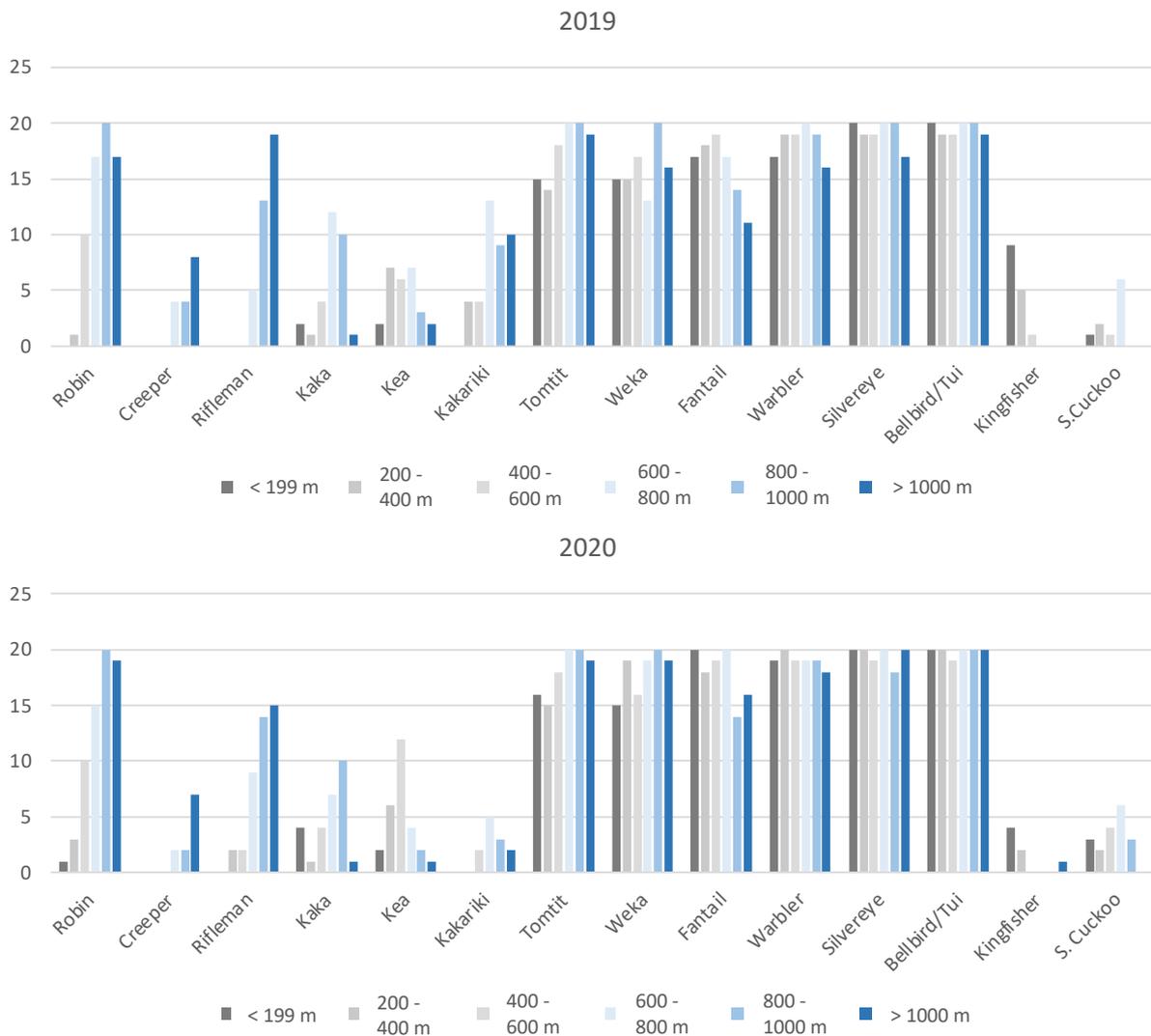
Figure 9: Comparison of number of occupied recorder sites per elevation stratum in 2019 and 2020 (maximum of 20 was possible). For direct comparison, the truncated data set was used (see following chapter).

Acoustic detection rates for rat-sensitive species were 35.2 (2019) and 39.9 (2020) and they averaged 104.4 (2019) and 119.3 (2020) for non-rat sensitive species. These results do not indicate an overall decline of neither rat-sensitive nor non-rat sensitive species, despite the high abundance of rats between survey seasons (Fig. A1 in the appendix).

Pooling all native bird species, the highest diversity is found in the uplands, approximately above the 600 m mark (Fig. A2 in the appendix). The number of sites with high species diversity decreased in 2020, primarily due to the decline of detections of kakariki and kākā missing from the centre of the area. Awaroa River valley and its upper tributaries define an area of low native bird species diversity, and the key five indicator species are seemingly absent (Fig. 11) from this part of the park.
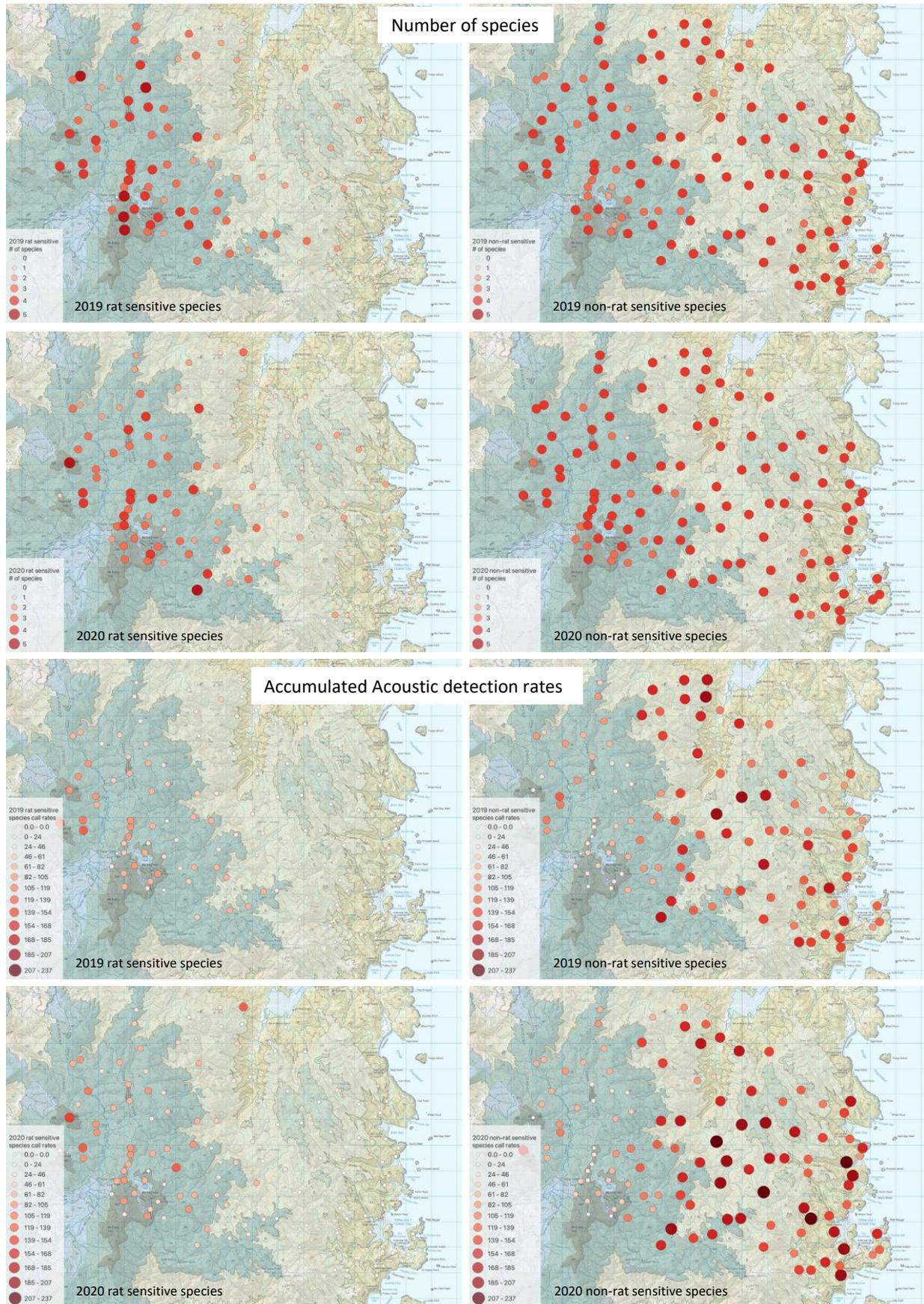
Figure 10: Comparison of rat sensitive (robin, rifleman, creeper, kākāriki and tomtit) and non-rat sensitive species (silvereye, bellbird/tui, warbler, fantail) regarding the accumulated acoustic detection rates (top half) and the number of species (bottom half) per year and monitoring site. 200 m-elevation strata are indicated as blue highlights (higher elevations are shown in a darker blue).
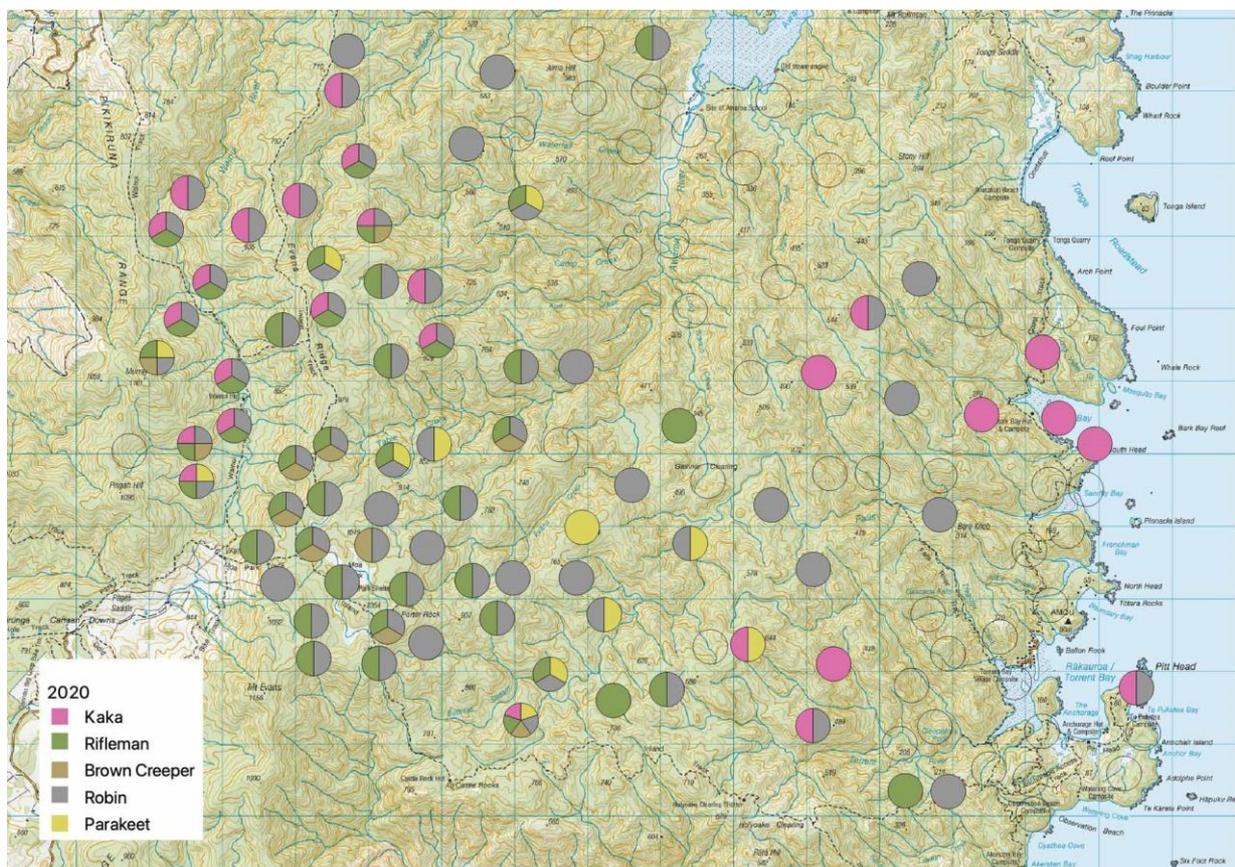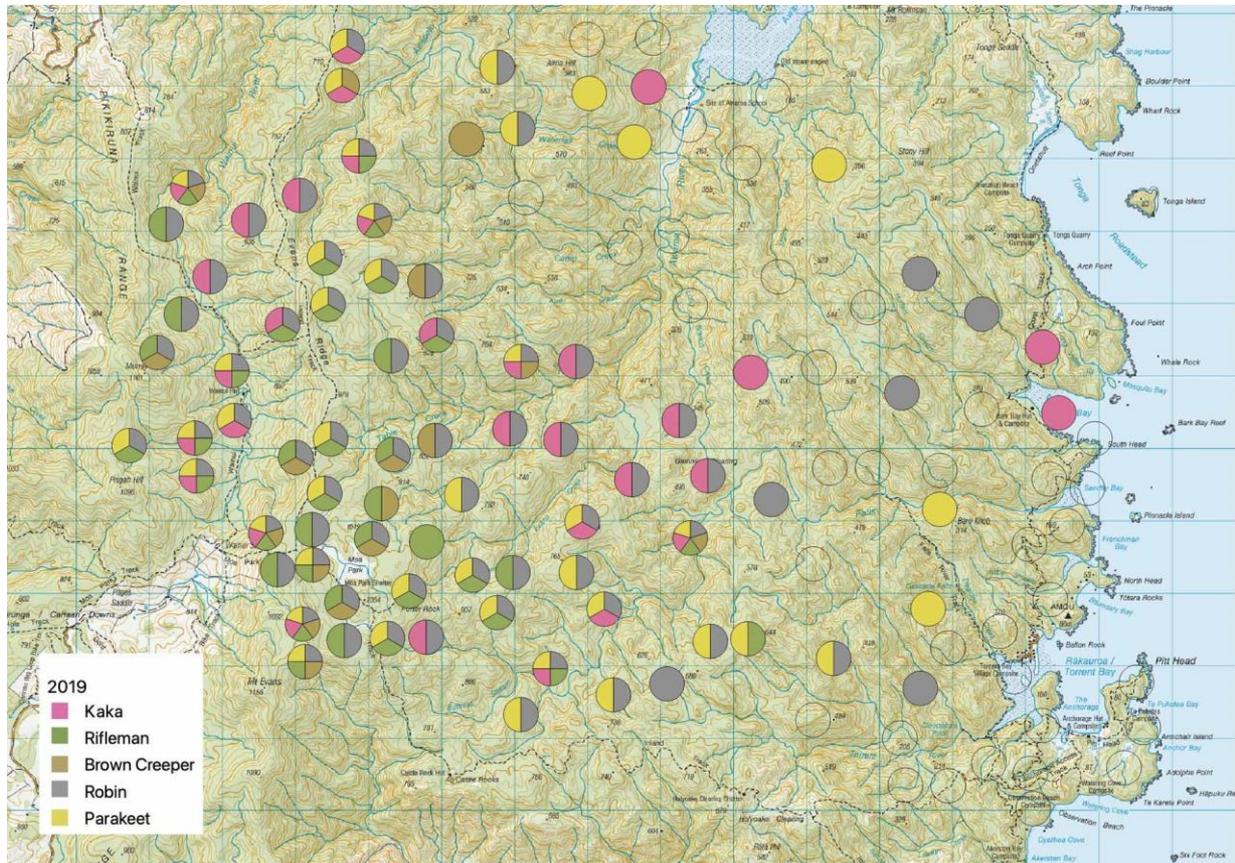
Figure 11: Minimum occupancy of five indicator bird species (see legend). The size of pie chart slices depends on number of species present and does not represent abundance. Open circles mark monitoring locations where none of the five species were detected.

Robins are predominantly found above 400 m elevation, with occasional detections near or at the coast (Fig. 12) and a slightly higher detection rate along the lowland fringes in 2020 compared to 2019. Call rates are highest in the uplands (Fig. 13A & B), and the increase of call rates at Huffam Stream is supported by an observation of 3-5 birds in this area (R. Bollongino, pers. obs.).

Rifleman are mostly present above 800 m elevation, but are expanding along the Alma Hill ridge line, towards the middle of the park around Glennies and along the southern boundaries of the Abel Tasman (Fig. 14), alongside a slight increase of detection sites. The two detections south of Bark Bay are questionable (see discussion). Call rates are highest in the upland and fades towards the fringes, except the location at the foot of Alma Hill (Fig. 15A & B).

Brown creeper are mainly detected around Evans Ridge/Moa Park (Fig. 16). Call rates are amongst the lowest (Fig. 17A & B), and the number of detection sites decreased between seasons.

Kākā are mostly found in the upper Wainui valley and Evans Ridge (Fig. 18). They were also detected in the heart of the park around Evans and Glennies, but failed detection in this area in 2020. Kākā are still present along the southern border of the park, mainly in the Buttress Stream vicinity in 2019 but detectability shifted further down towards Torrent Riven in 2020. The increased distribution along the coast, in particular Bark Bay, coincides with the release of 24 parrots in Spring 2019, just before the onset of acoustic monitoring. Call rates are predominantly low but are increased along the translocation site at Bark Bay (Fig. 19A & B).

Kākāriki displayed the greatest change of all species between monitoring seasons (Fig. 20), showing a sharp decrease in detections. Parakeets were found all along the higher ridge lines within the park in 2019 but locations thinned out by 70% in 2020. Call rates are generally low and do not show any spatial patterns (Fig. 21A & B).

Kea are not limited to high elevation areas, their distribution rather covers the mid- and lowlands (Fig. 22). Detectability was impeded by low call rates (Fig 23A & B). Number of detection sites remained stable over both seasons.

Tomtits are widespread across the park and the number of detection sites stayed stable between seasons (Fig. 24). However, site occupancy rates are higher in the uplands and decrease considerable below the 600 m mark (Fig. 9). Call rates support this trend by showing higher percentages at the top of the park with decreasing call rates towards the coast (Fig. 25A & B).

Weka re-colonised the entire monitoring area since their reintroduction to the park in Totaranui in 2006. (Fig. 26) and numbers of occupied sites are still increasing. Call rates are low (Fig. 27A & B) as calls could not be quantified and weka tend to call simultaneously in response to neighbouring birds.

Bellbird/Tui occupy most sampling sites (Fig. 28) and have the highest call rate (Fig. 29A & B), both values slightly increasing between seasons. In contrast to previously mentioned bird species, Bellbird/Tui call rates tend to be lower in the uplands and are highest in the centre of the park.

Fantails are widespread over the park (Fig. 30), apart from an area of sparse distribution around Moa Park in 2019, but most of these gaps were closed in 2020. Call rates tend to be higher in areas of low native bird diversity (Fig. 31A & B).

Silvereyes like Bellbirds/Tui occupy almost every sampling location (Fig. 32). Silvereyes show a clear gradient of low call rates at higher elevation to higher call rates towards the coast (Fig. 33A & B). Call rates are lowest in areas with high native bird diversity and presence along the upper Wainui Valley and Evans Ridge. Distribution and call rate patterns did not change noticeably between seasons.

Grey Warbler show a slight increase of number of detection sites (Tab. 5, Fig. 34) as well as call rates (Fig. 35A & B). The pattern is similar to that of silvereyes, with call rates being lowest where general forest bird diversity and call rates are highest. Distribution patterns did not change between seasons, but call rates increased in 2020.

Shining cuckoo distribution changed significantly between season, with 80% more detections in 2020 than in 2019 (Fig. 36) which expands the minimum distribution from the fringes to widespread over the park. Call rates are low at any given location (Fig. 37A & B). Grey warblers are the most common host of shining cuckoos, and the detection of cuckoos is concurrent with the presence of warblers at all locations.

Kingfisher could only be detected along the fringes of the park, mainly at the coast between Bark Bay and Pitt Head (Fig. 38). The number of detection sites has almost halved between season (Tab. 5); however, sample numbers and call rates (Fig. 39A & B) were very low.
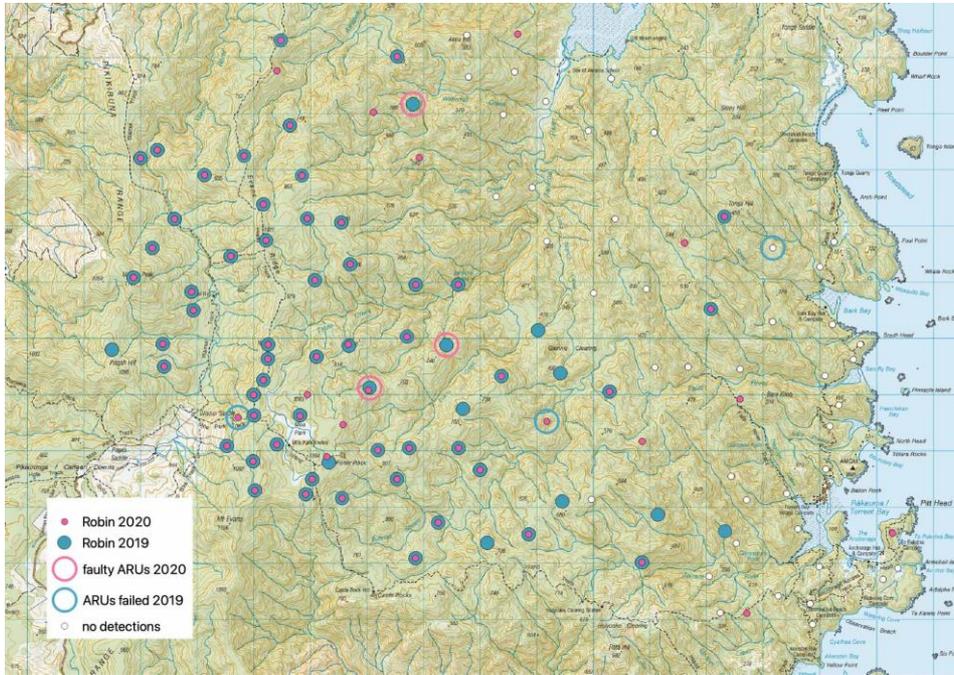
Figure 12: Minimum occupancy of robins.
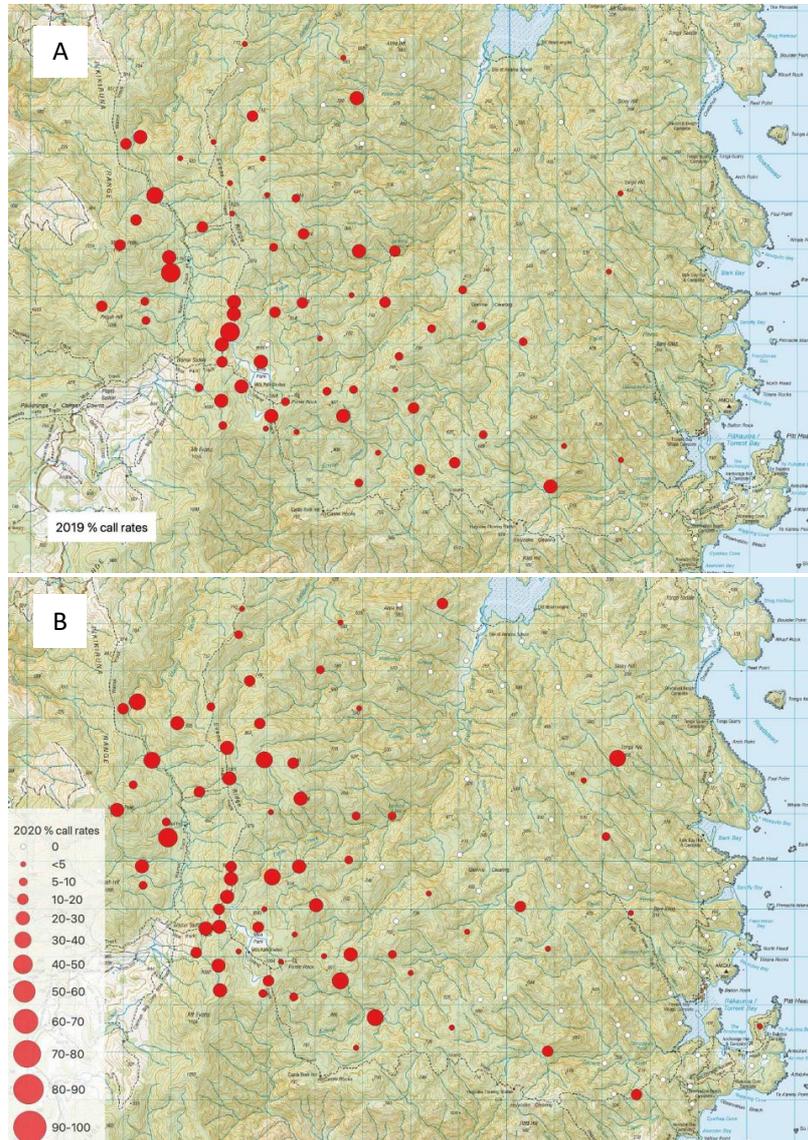
Figure 13: Spatial acoustic detection rates of robins. A) 2019 B) 2020
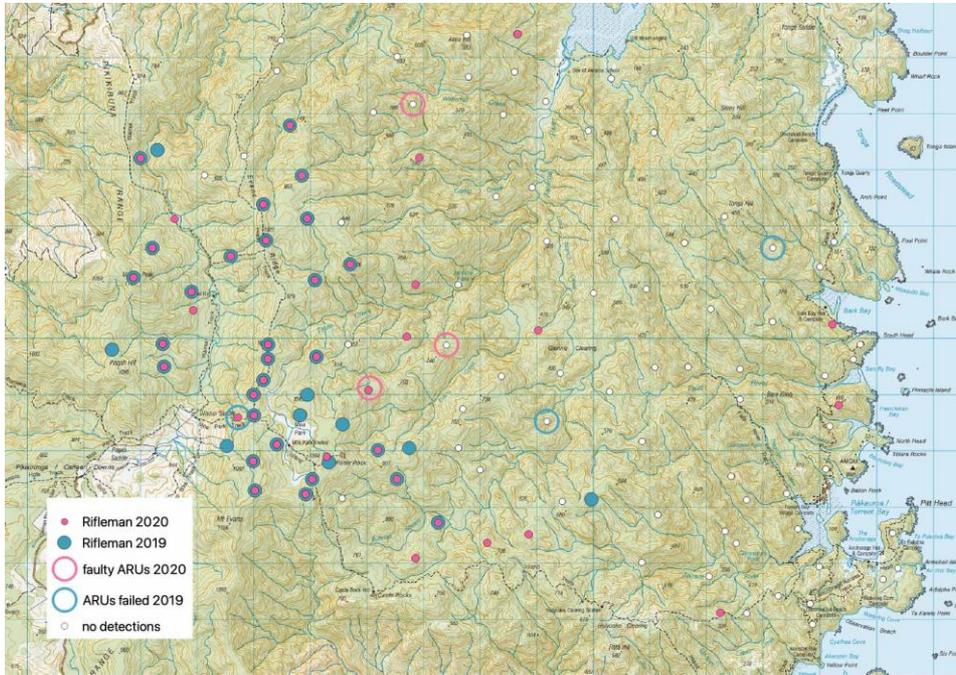
Figure 14: Minimum occupancy of rifleman.
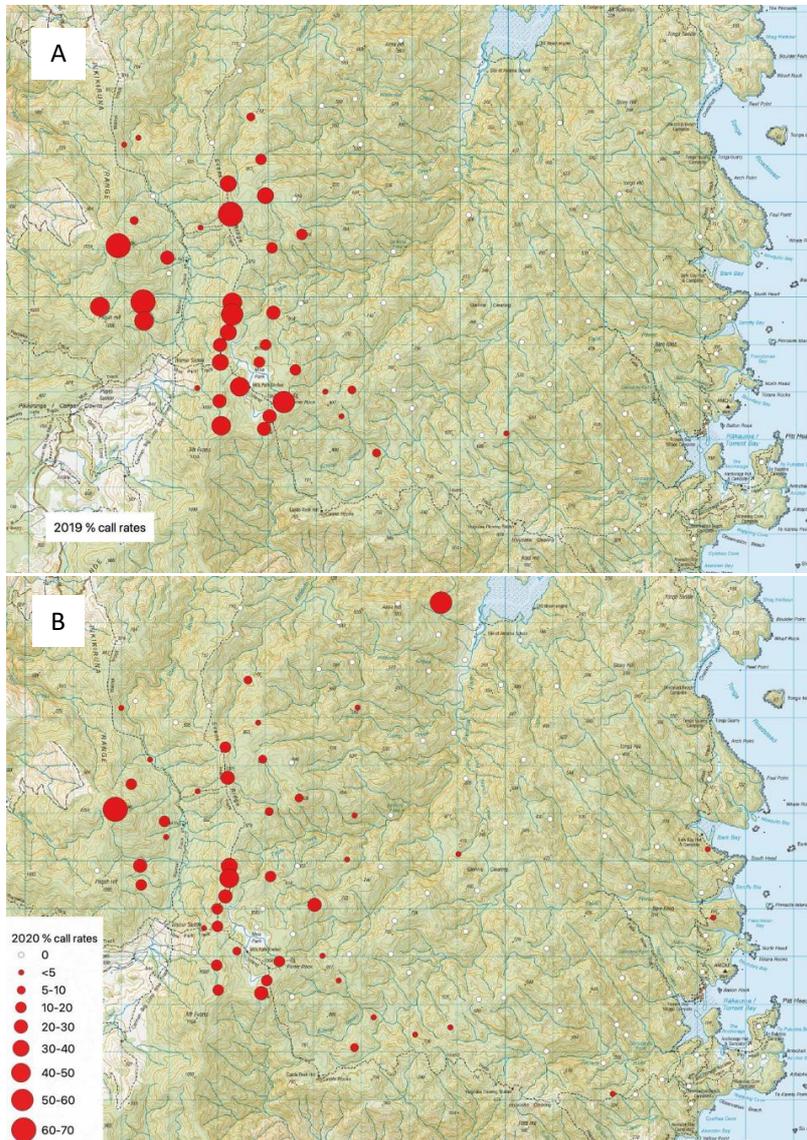
Figure 15: Spatial acoustic detection rates of rifleman. A) 2019 B) 2020
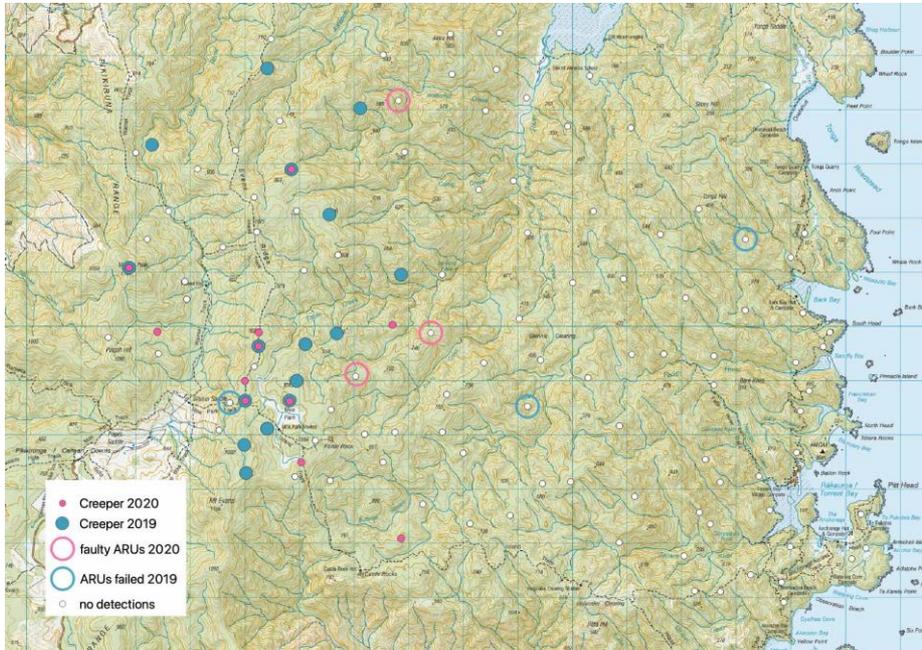
Figure 16: Minimum occupancy of brown creeper.
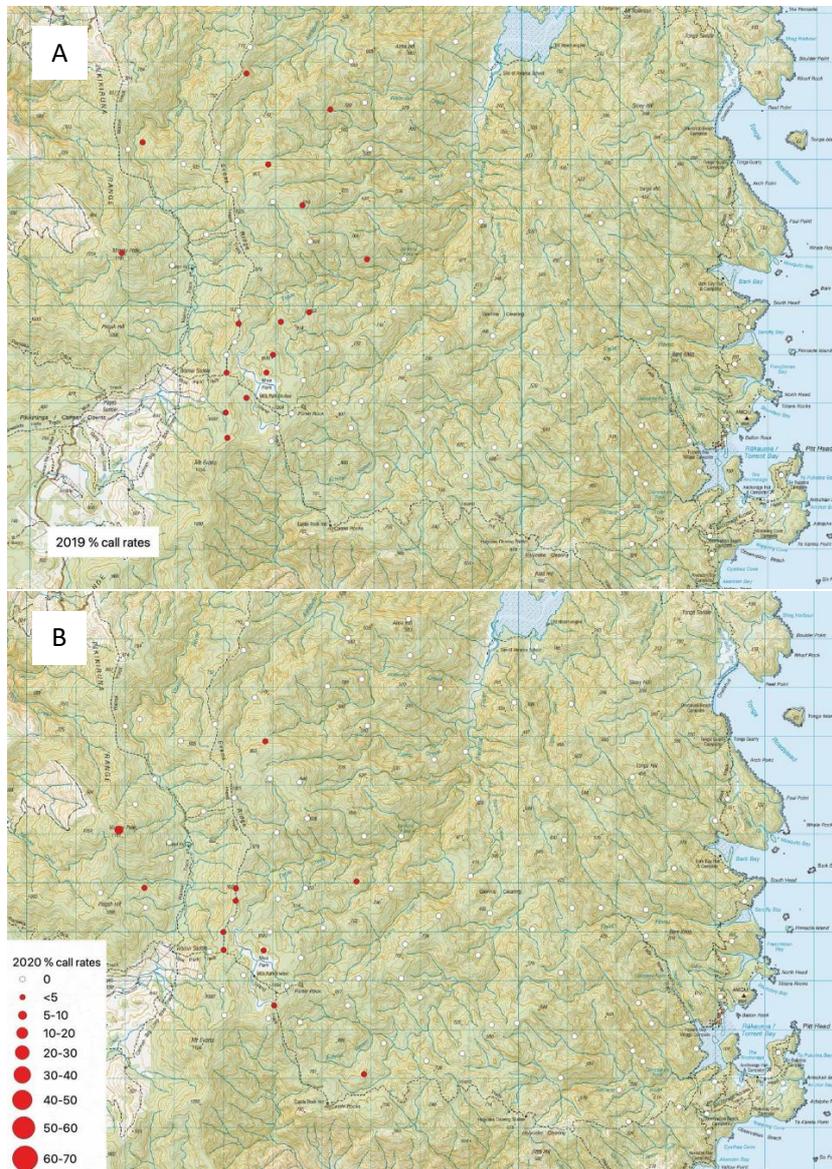
Figure 17: Spatial acoustic detection rates of brown creeper. A) 2019 B) 2020
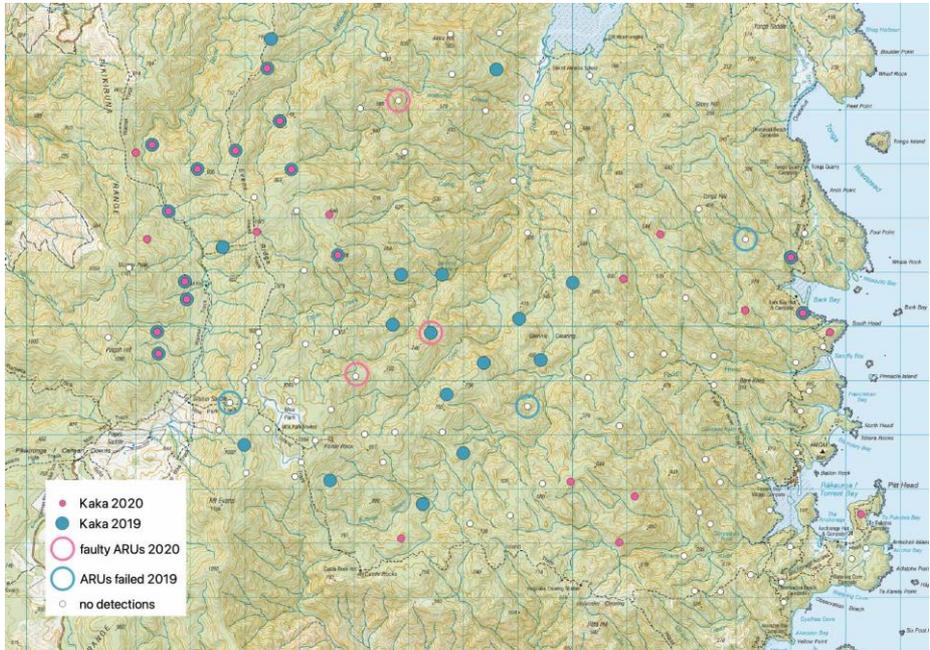
Figure 16: Minimum occupancy of kākā.
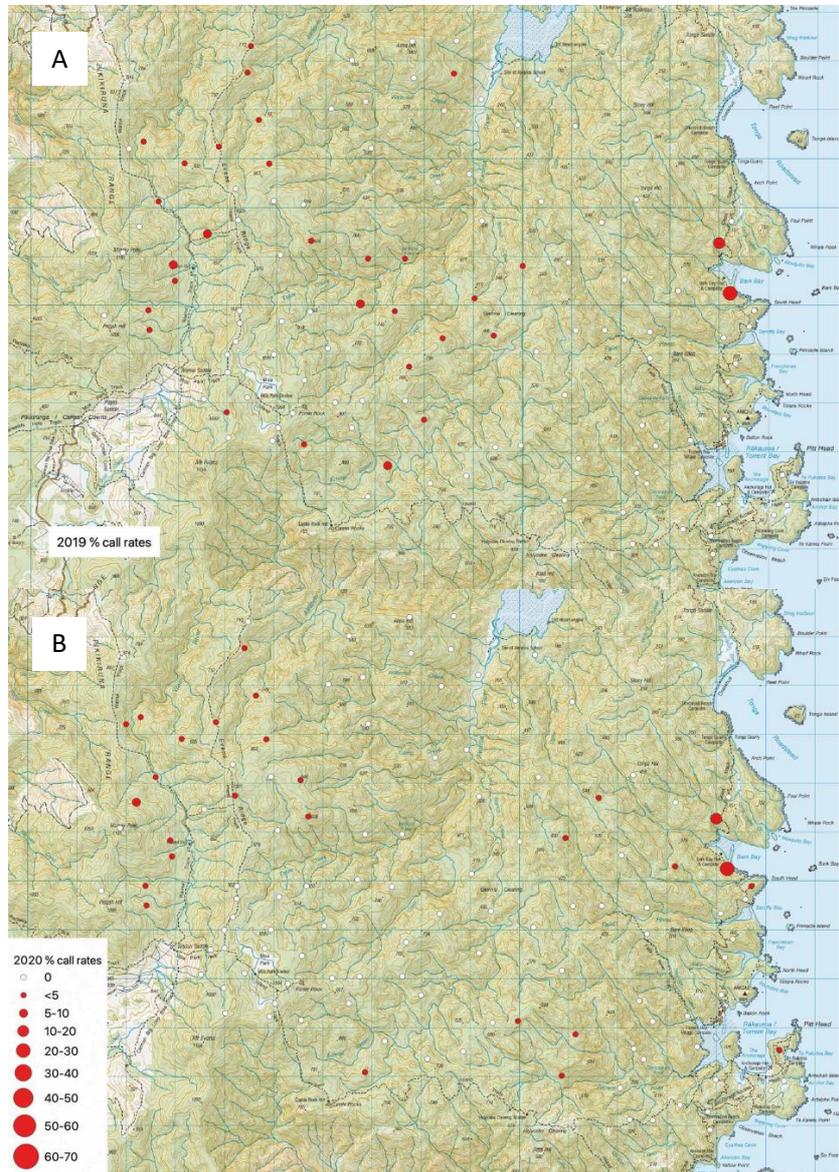
Figure 17: Spatial acoustic detection rates of kākā. A) 2019 B) 2020
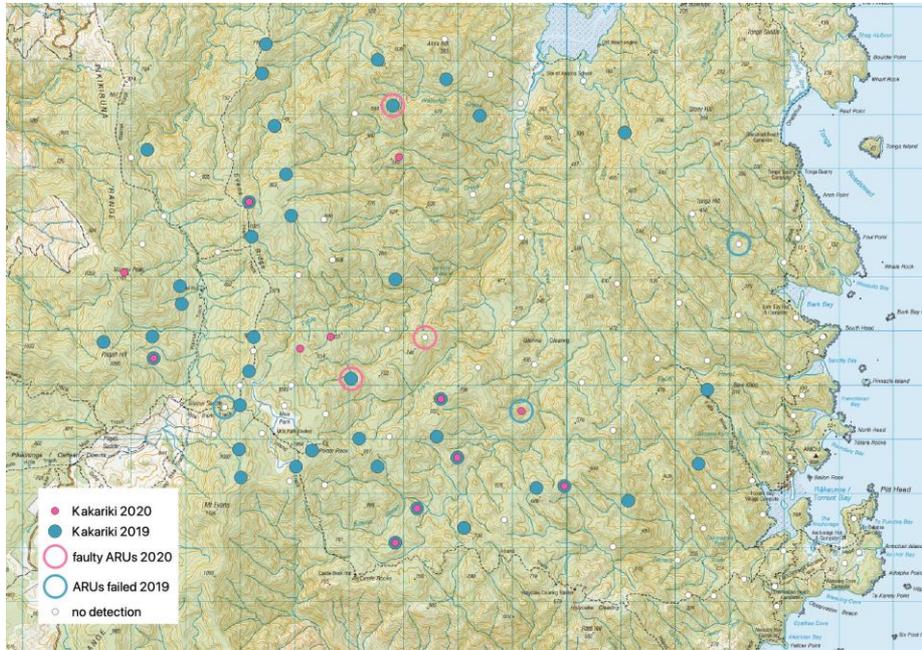
Figure 20: Minimum occupancy of kākāriki.
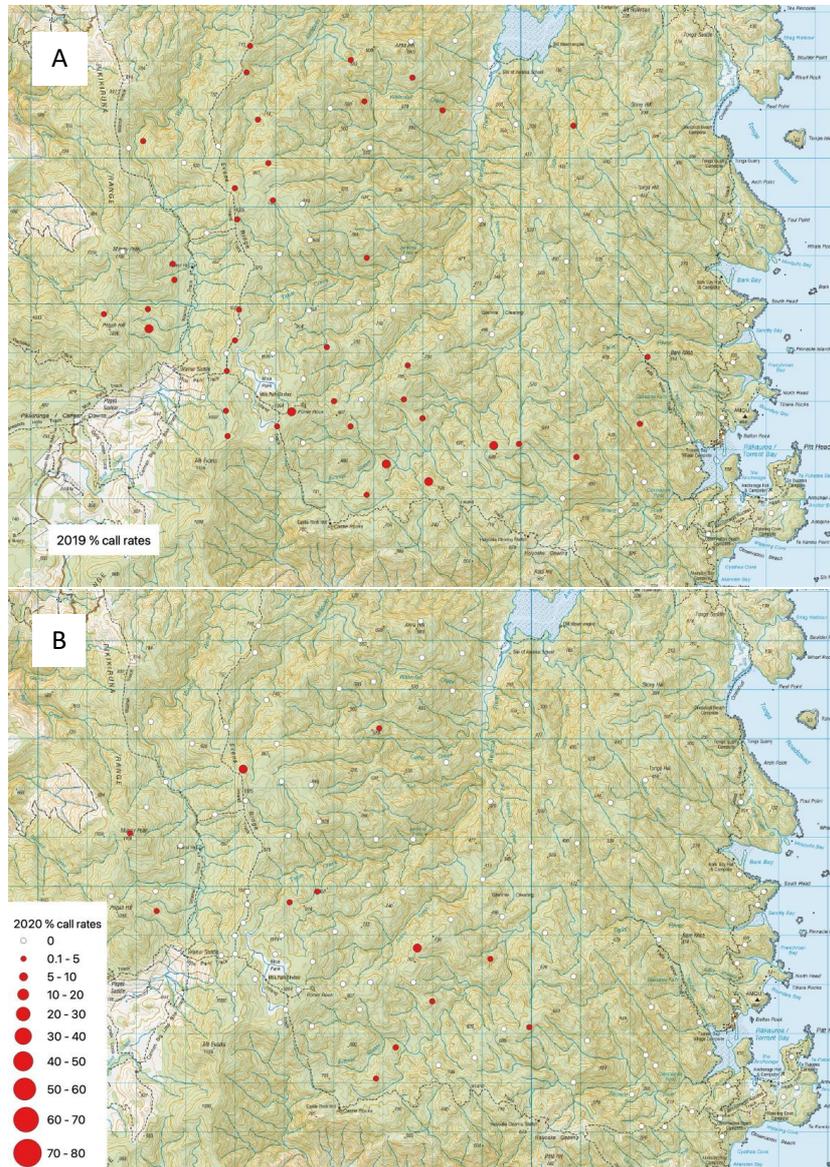
Figure 21: Spatial acoustic detection rates of kākāriki. A) 2019 B) 2020
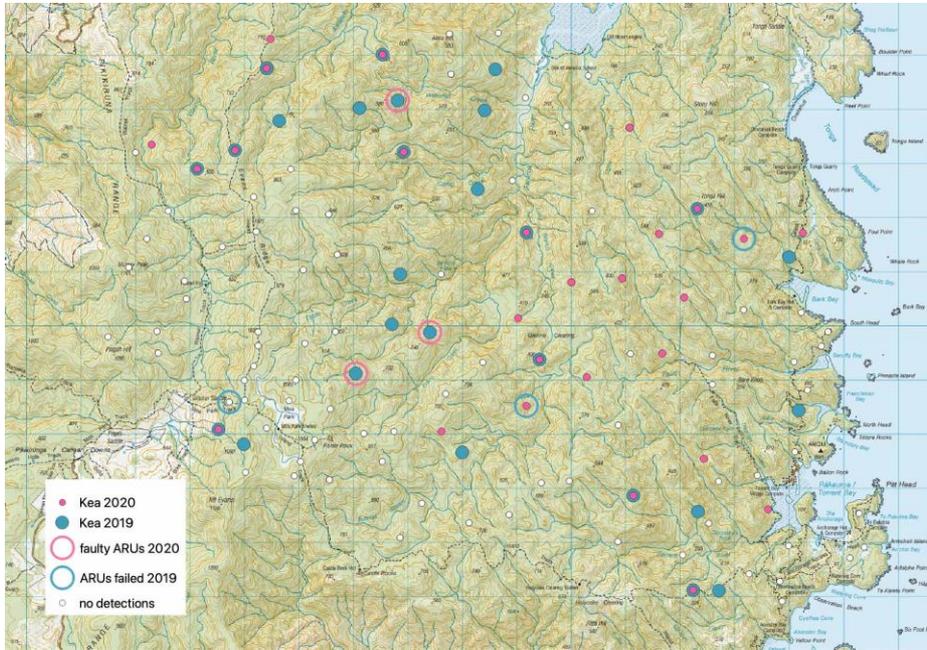
Figure 22: Minimum occupancy of kea.

Figure 23: Spatial acoustic detection rates of kea. A) 2019 B) 2020
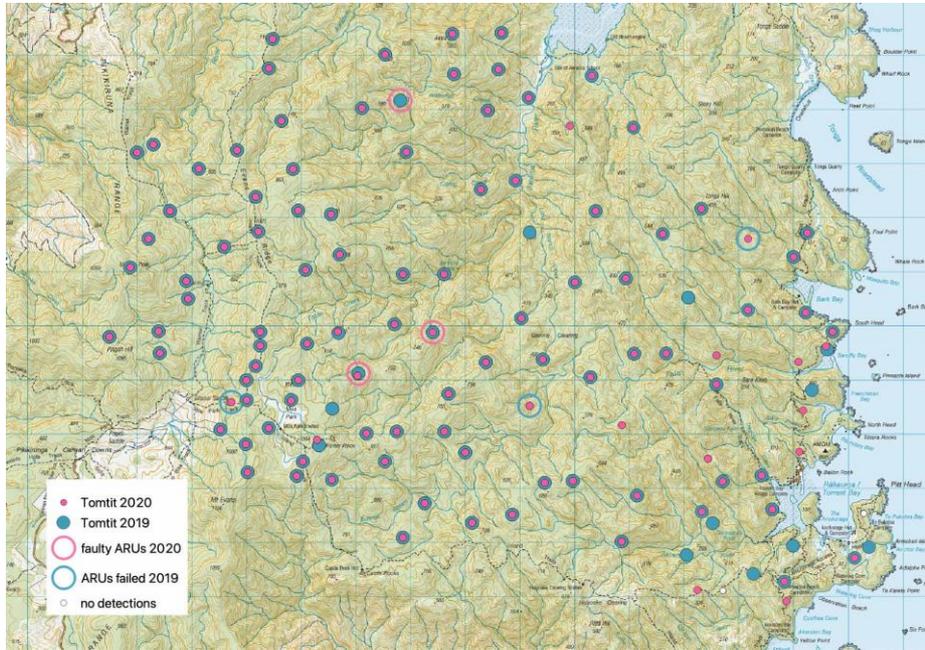
Figure 24: Minimum occupancy of tomtit.
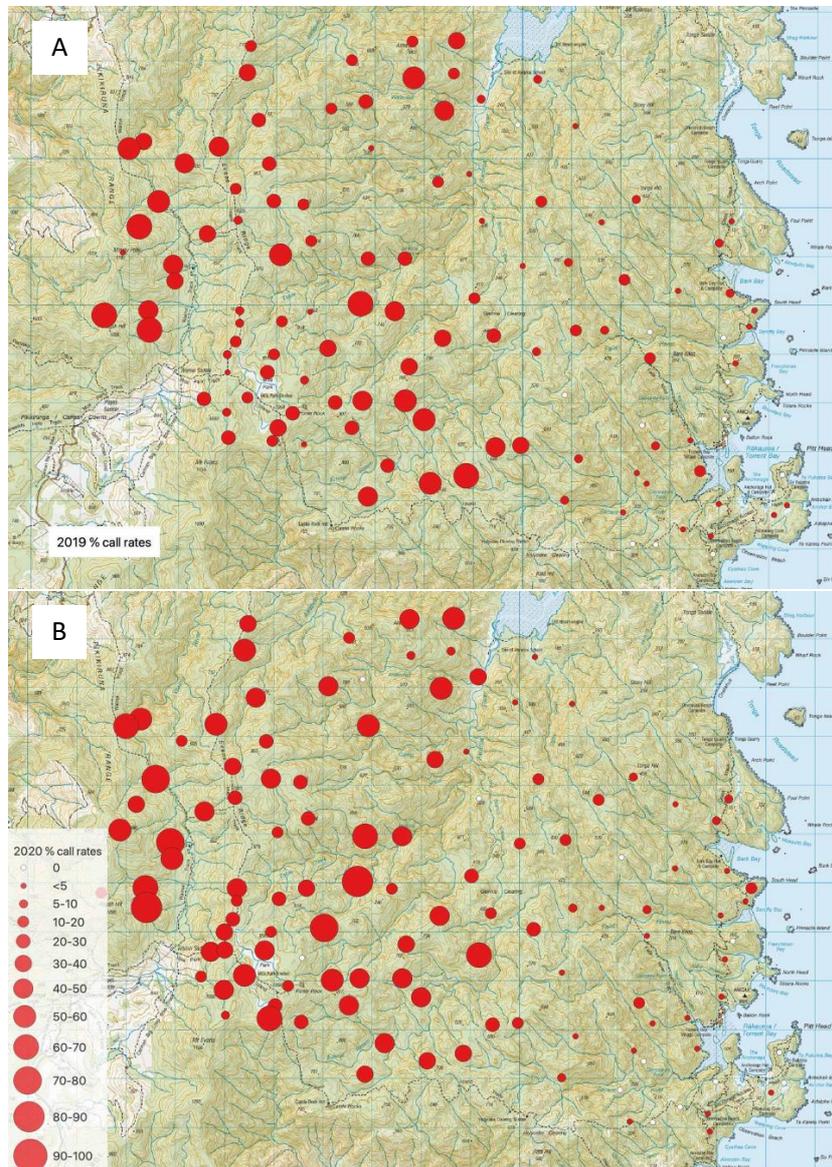
Figure 25: Spatial acoustic detection rates of tomtit. A) 2019 B) 2020
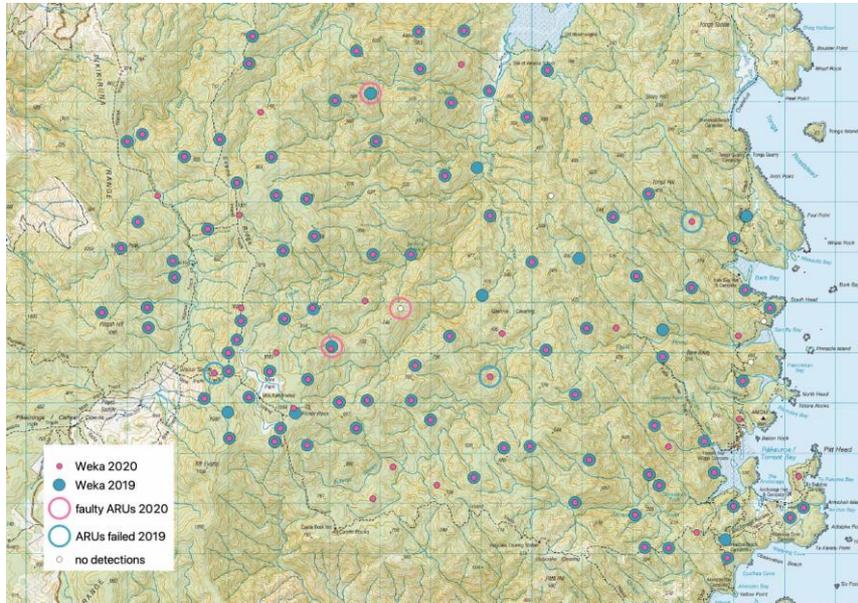
Figure 26: Minimum occupancy of weka.
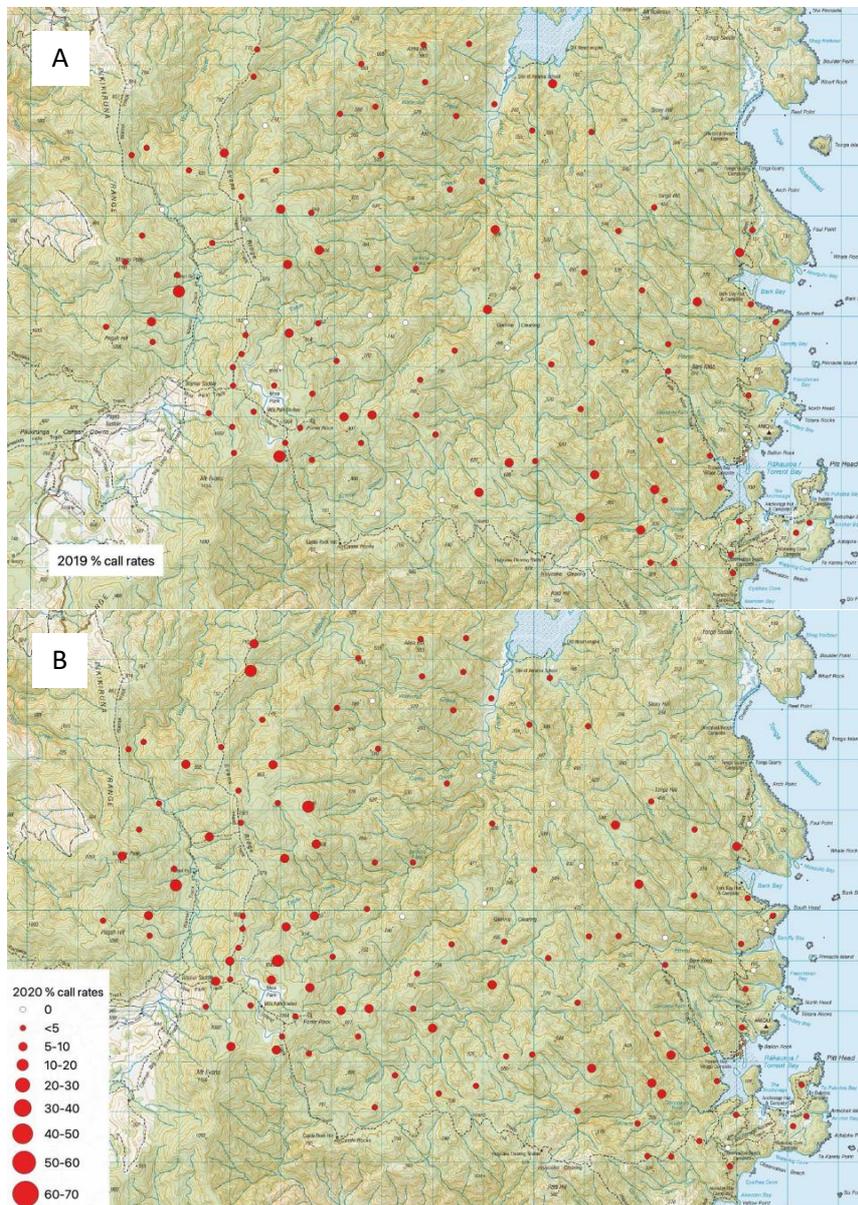
Figure 27: Spatial acoustic detection rates of weka. A) 2019 B) 2020
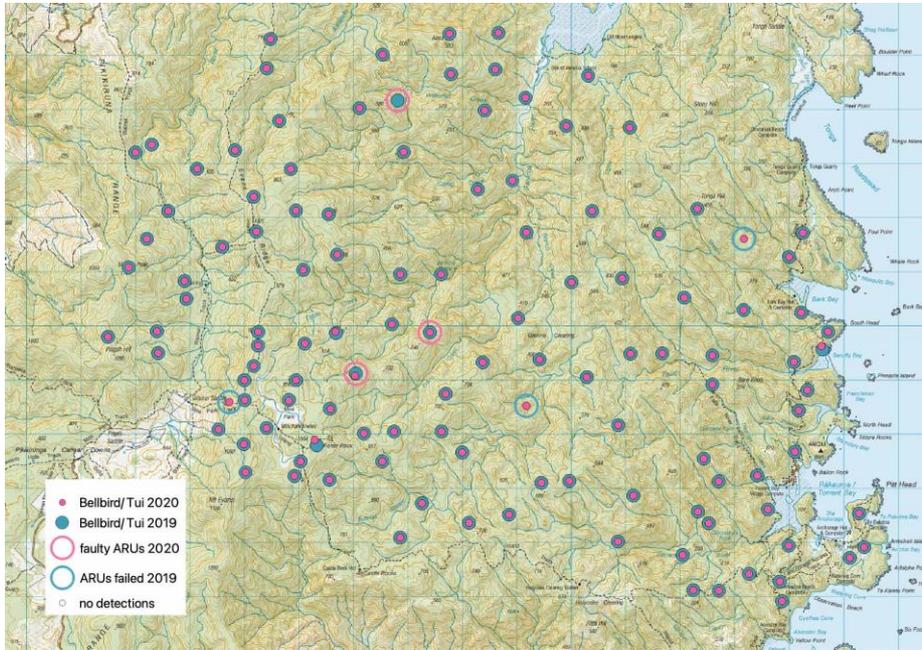
Figure 28: Minimum occupancy of bellbird/tui.
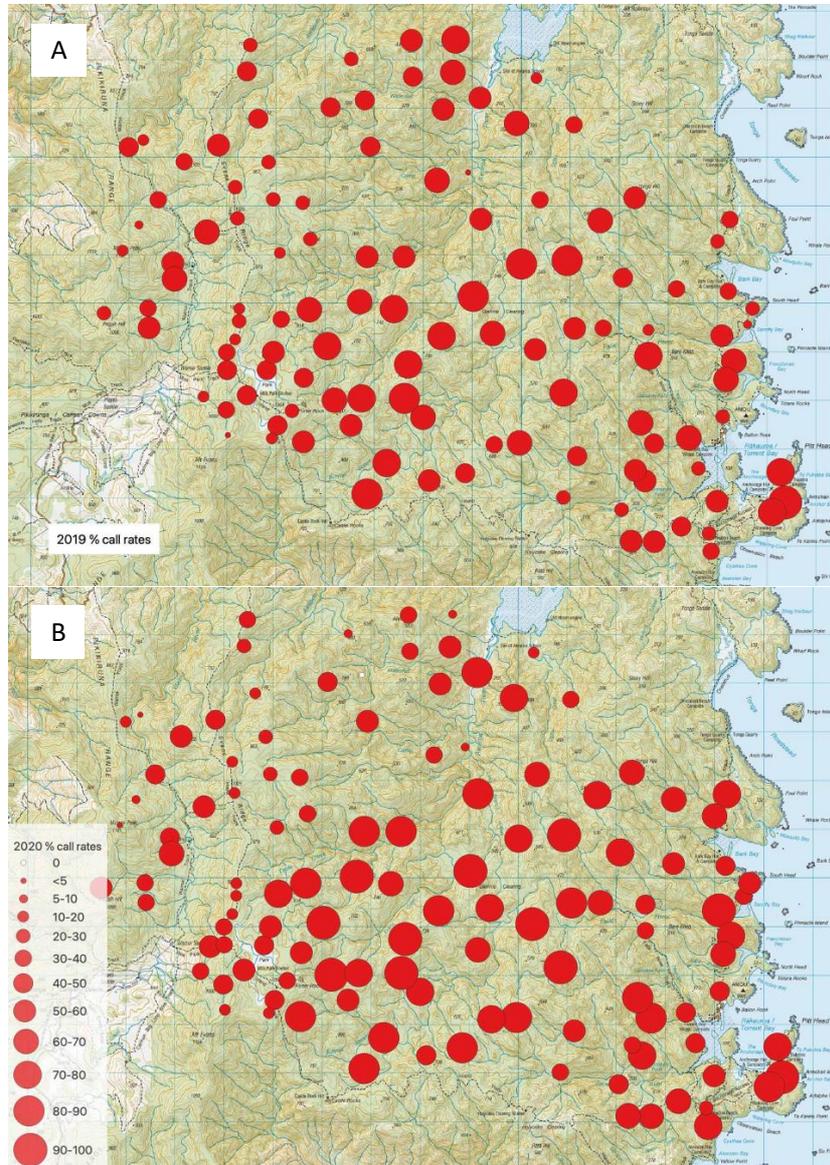
Figure 29: Spatial acoustic detection rates of bellbird/tui. A) 2019 B) 2020
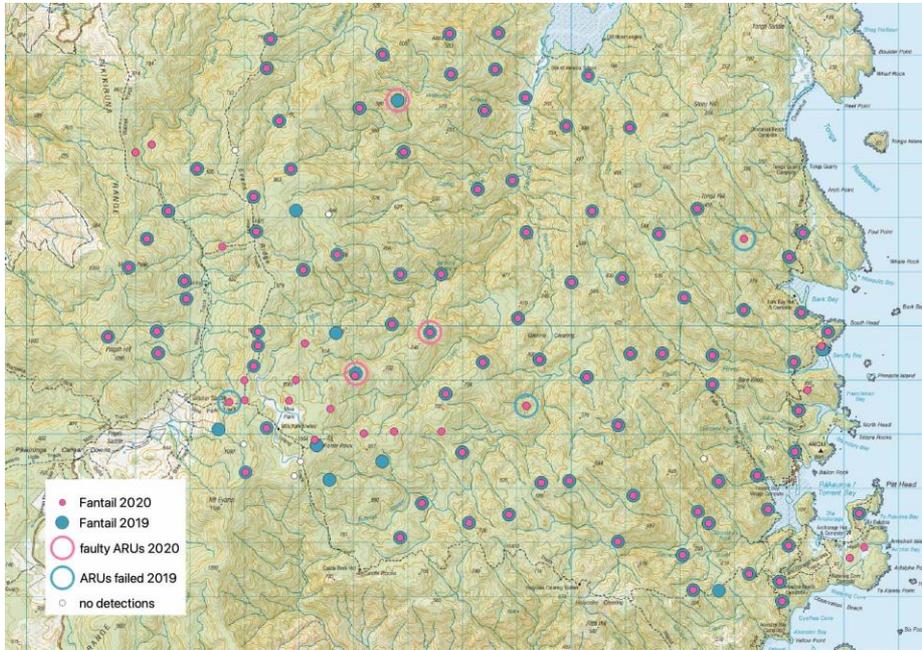
Figure 30: Minimum occupancy of fantial.
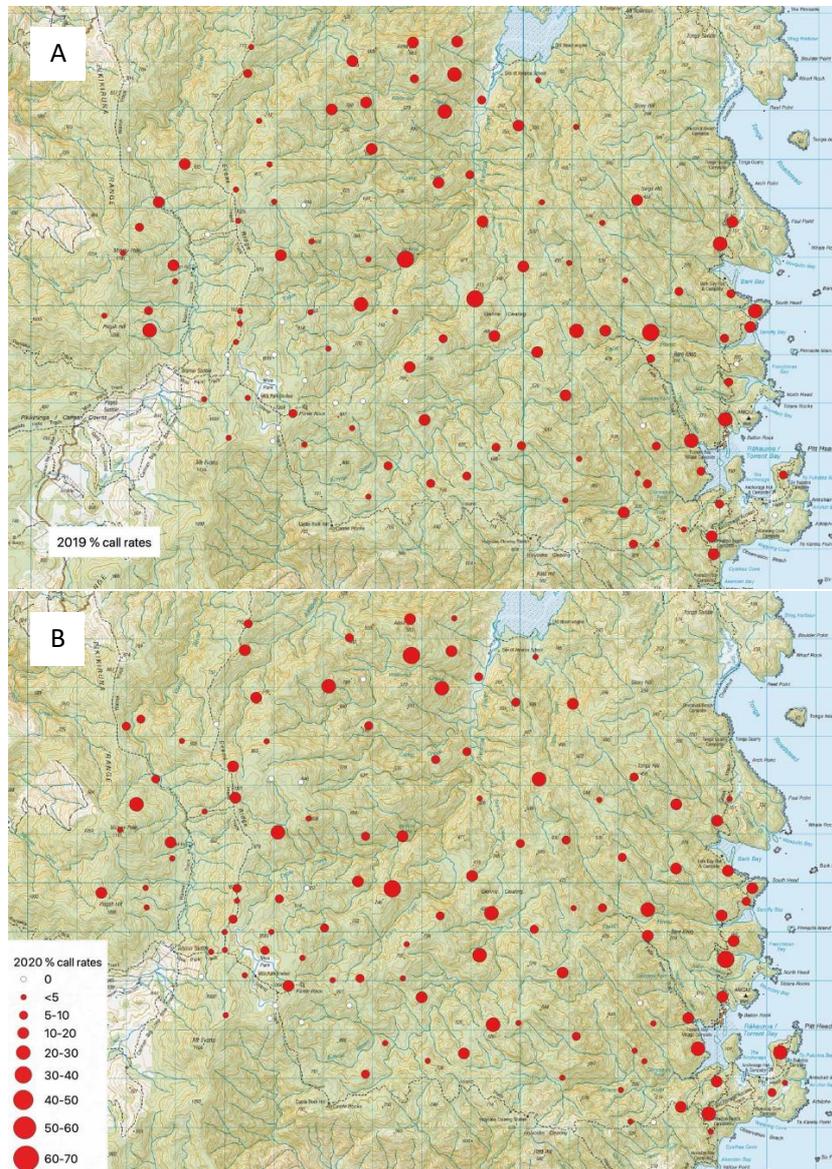
Figure 31: Spatial acoustic detection rates of fantail. A) 2019 B) 2020
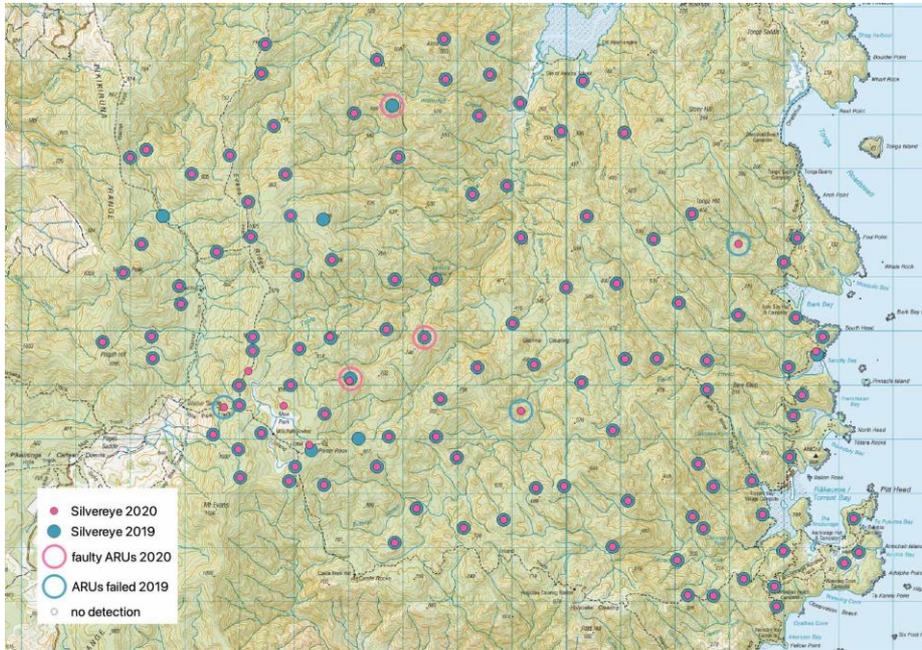
Figure 32: Minimum occupancy of silvereyes.
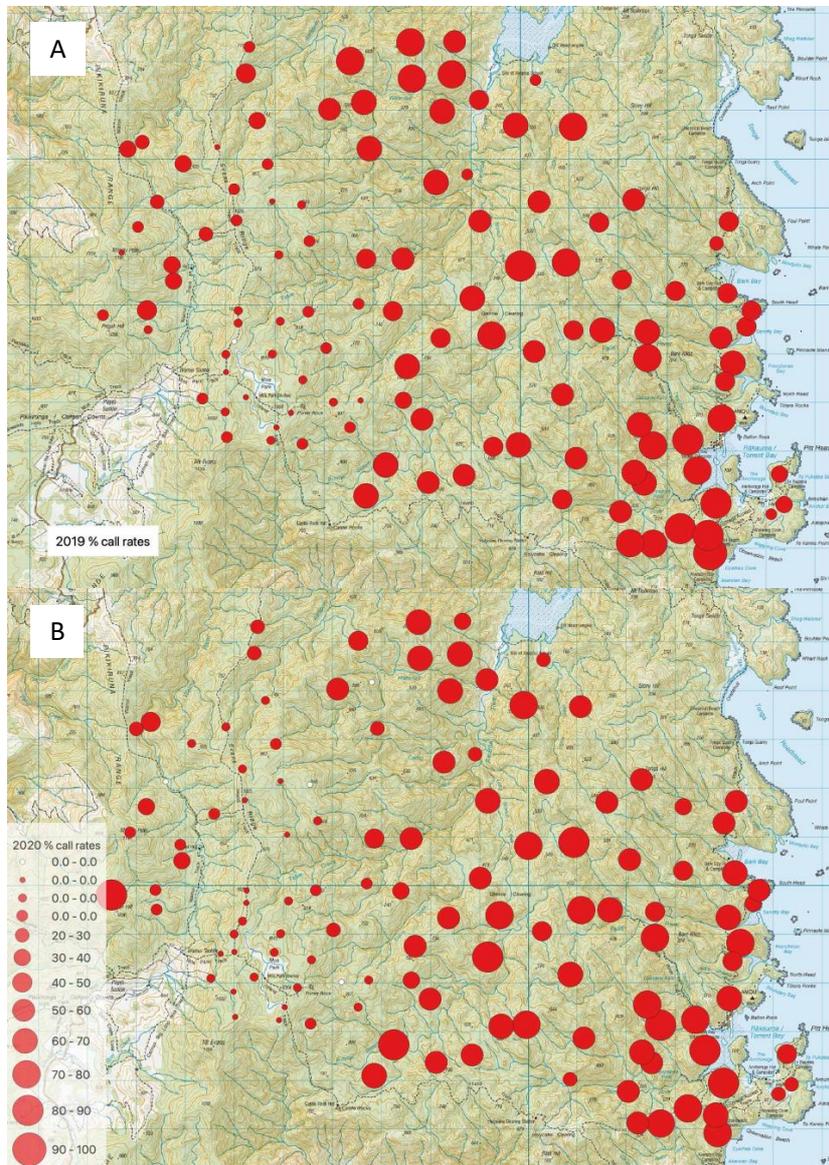
Figure 33: Spatial acoustic detection rates of silvereyes. A) 2019 B) 2020
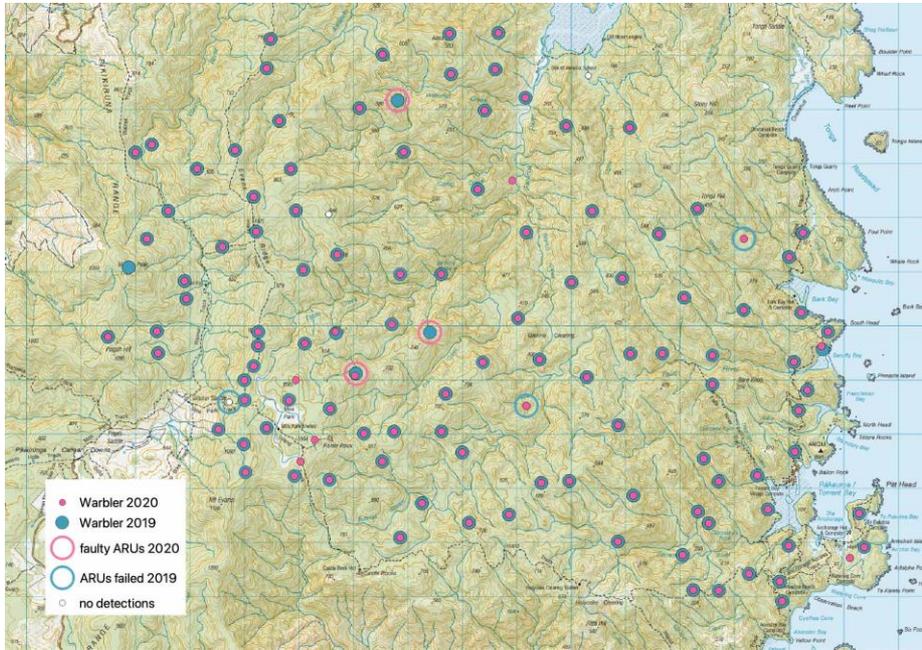
Figure 34: Minimum occupancy of grey warbler.
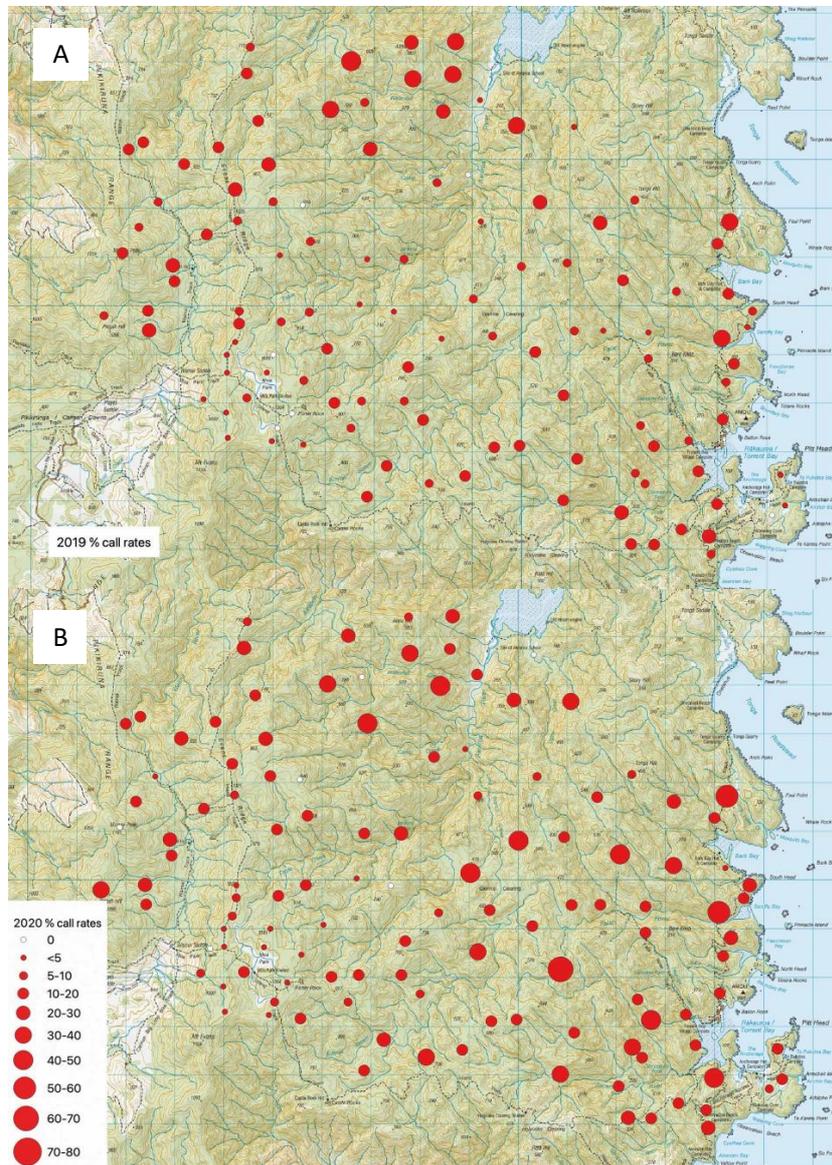
Figure 35: Spatial acoustic detection rates of grey warbler. A) 2019 B) 2020
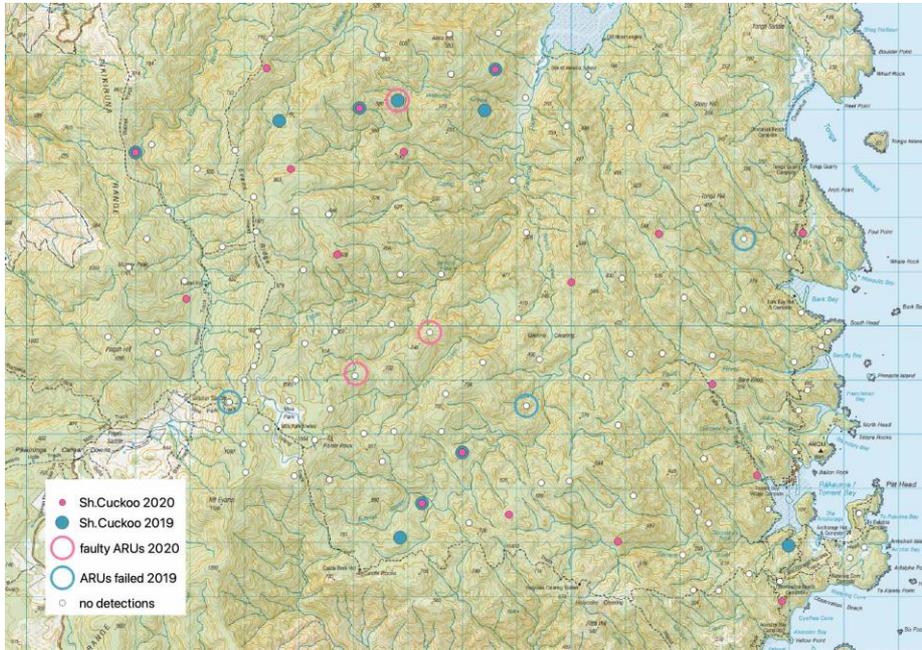
Figure 36: Minimum occupancy of shining cuckoo.

Figure 37: Spatial acoustic detection rates of shining cuckoo. A) 2019 B) 2020
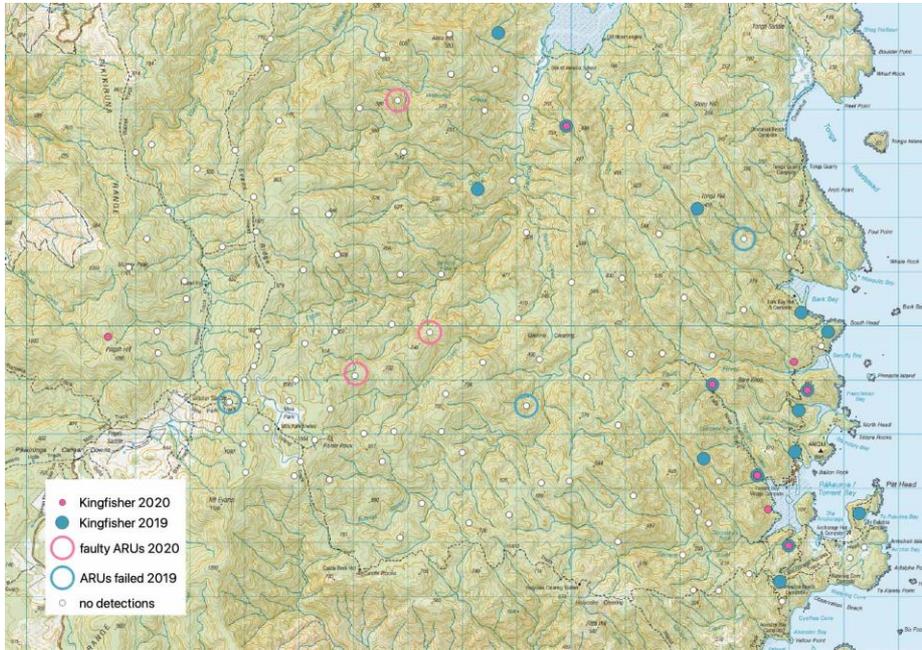
Figure 38: Minimum occupancy of kingfisher.
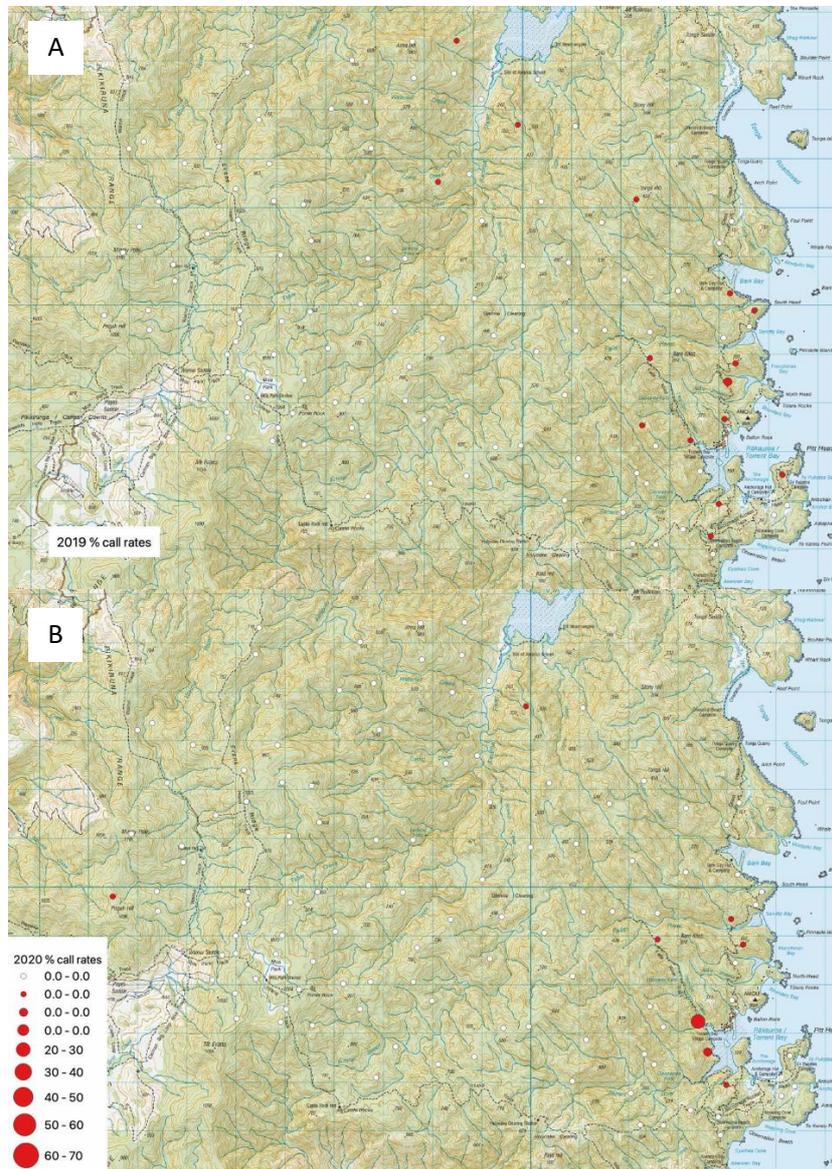
Figure 39: Spatial acoustic detection rates of kingfisher. A) 2019 B) 2020

Truncation of the data set to a maximum of ten recording days resulted in a loss of bird detection for some locations (Tab. 6, Tabs. A2 & A3 in appendix for details). All sites where a loss of detection was observed possessed an ADR of less than three percent, except for Silvereyes, where call rates were up to 81%. A linear regression plot (Fig. 39) shows a negative relationship between average call rates and loss of detection sites using the truncated dataset.

Table 6: Effect on truncation of the dataset to ten days per recorder on results. Shown are the total numbers of sites where a bird was detected, the number of detection sites lost due to truncation ("deviation") and the percentage of lost locations.

	2019			2020		
	Total	**deviation**	**%**	**Total**	**deviation**	**%**
Robin	65	-2	3.08	68	-7	10.29
Rifleman	37	-2	5.41	42	-1	2.38
Brown Creeper	16	-1	6.25	11	-3	27.27
Kaka	30	-3	10.00	27	-7	25.93
Kakariki	40	-9	22.50	12	-2	16.67
Kea	27	-7	25.93	27	-3	11.11
Tomtit	106	-3	2.83	108	-5	4.63
Fantail	96	-5	5.21	107	-5	4.67
Bellbird/Tui	117	0	0.00	119	0	0.00
Silvereye	115	-1	0.87	117	-7	5.98
Grey Warbler	110	-1	0.91	114	-2	1.75
Shining Cuckoo	10	-3	30.00	18	-5	27.78
Weka	96	-9	9.38	108	-7	6.48
Kingfisher	15	-4	26.67	7	-4	57.14
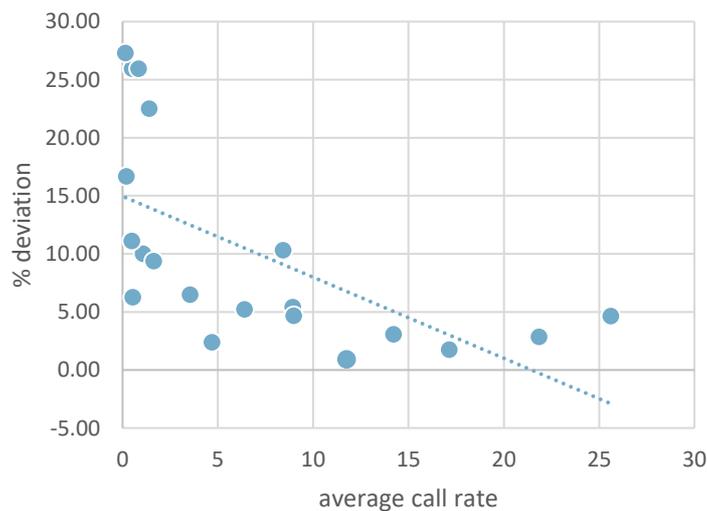
Figure 40: Linear regression of the relationship between average call rates (ADRs) and percentage of deviation of detection sites using the truncated dataset. Species that lost most detection sites due to truncation of dataset had low call rates. Multiple R= 0.62, R Square= 0.38.

A comparison of minimal distribution maps of birds based on results from acoustic monitoring and human observer surveys, respectively, should be considered with great care. Both methods are very different, and detectability can be expected to vary greatly between monitoring techniques. The following maps should be regarded as a comparison of areas where birds are known to be present without making inferences about their absence.

The diachronic map of kākāriki (Fig. 41) shows the minimum occupancy of kakariki for the two survey years in 2015 and 2018, with 1 km grid-squares where a bird was detected. Human observer surveys did not include the upper Wainui Valley or Evans Ridge, where native bird diversity is highest. The results suggests that parakeets are variable in distribution and number, with 2019 being the most prominent year.
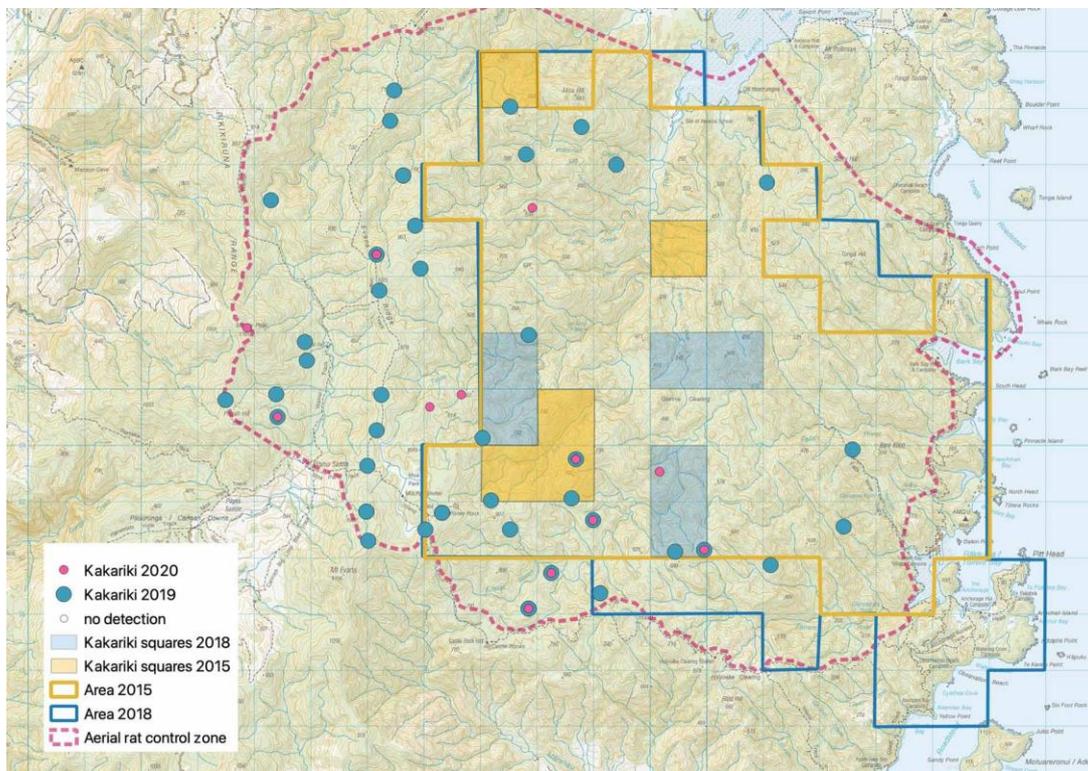
Figure 41: Diachronic minimum occupancy of parakeets (blue dots= 2019, pink dots= 2020). The yellow line depicts the area of the human observer survey in 2015, with yellow highlights marking grid squares where a bird was detected. The blue line depicts the area of the human observer survey in 2018, with blue highlights marking grid squares where a bird was detected. Dashed pink line= boundary of aerial rat control.

Figure 42 shows the minimum occupancy of robins over time. All four monitoring seasons provide evidence for presence of robins in the south-western part of the survey area. However, detections increase along the fringes towards the north and the coast, the latter especially along the southern border of the monitoring area.
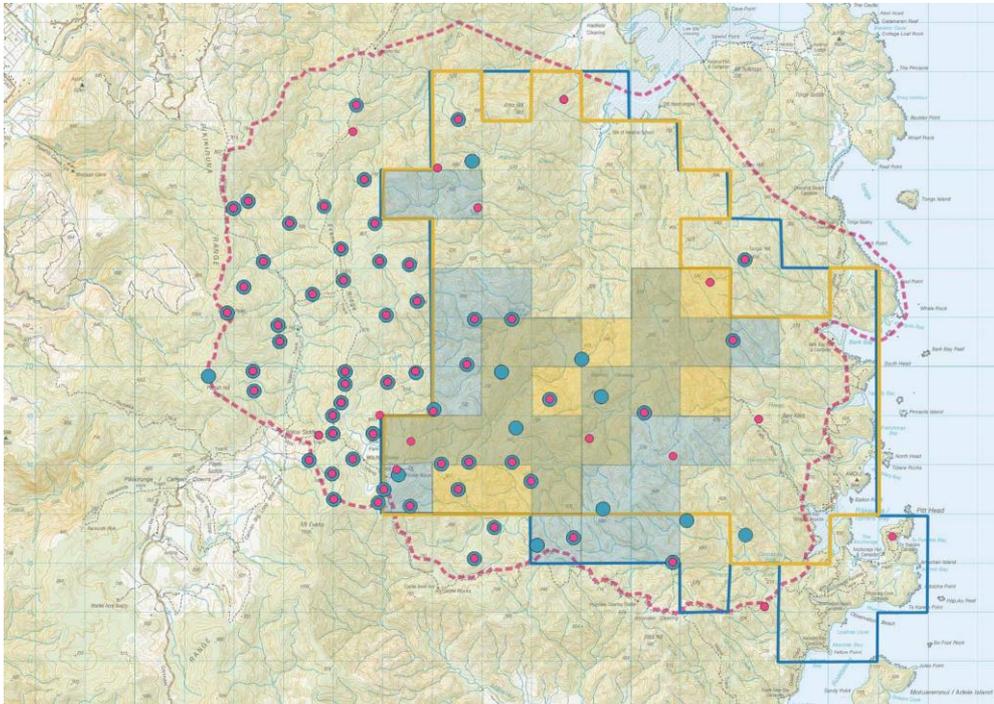
Figure 42: Diachronic minimum occupancy of robins. See description and legend of Fig. 41.

Rifleman are mostly present outside of the 2015 and 2018 survey area (Fig. 43). During these surveys, rifleman were only detected in greater numbers east of Moa Park and rapidly thinning out from there, hardly crossing the 600 m elevation line. Detection rates increased slightly with acoustic monitoring, especially along the southern border near Buttress Stream. Although no major shift in distribution can be observed over time, the appearance of rifleman west of the Awaroa Inlet is noticeable.
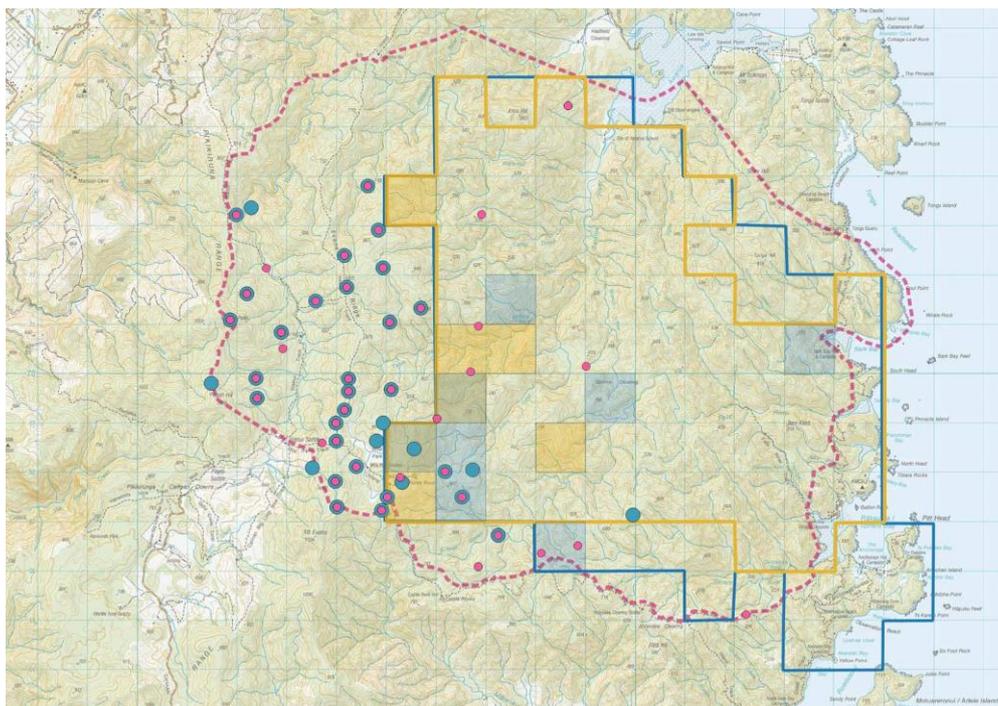
Figure 43: Diachronic minimum occupancy of rifleman. See description and legend of Fig. 41.

Weka revealed the greatest diachronic change of all monitored species. In 2015, weka were not detected in the south-western part of the monitoring area (Fig. 44) and only sparsely distributed across the remaining area. Three years later, they were detected all over the monitoring area, although only within half of the monitoring squares. In 2020, weka were present at all monitoring sites except one, completing the re-colonisation of the Abel Tasman Park in just a bit more than a decade.
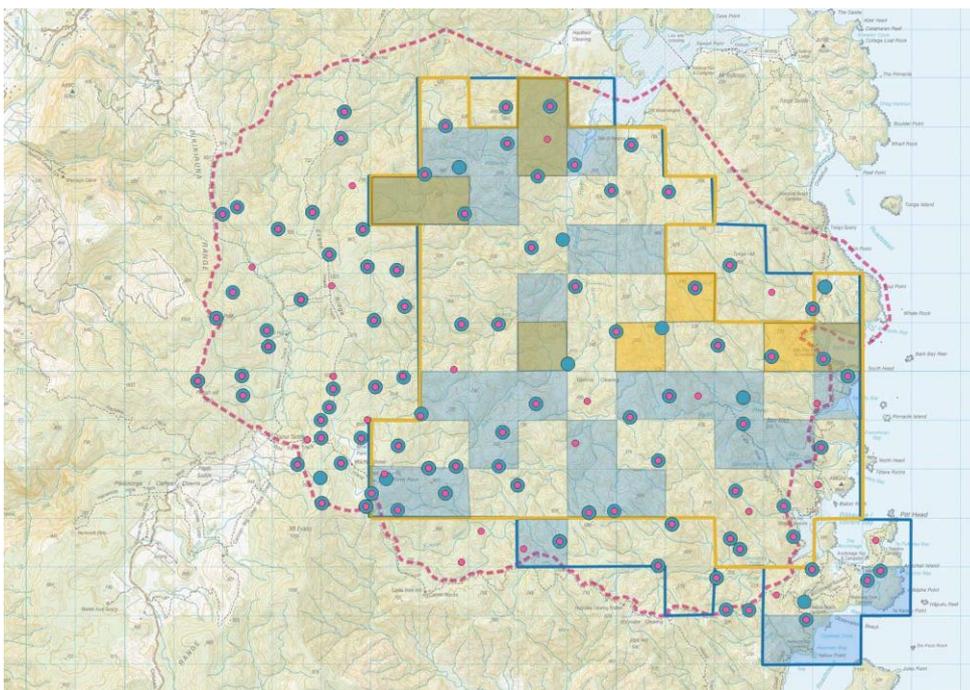
Figure 44: Diachronic minimum occupancy of weka. See description and legend of Fig. 41.
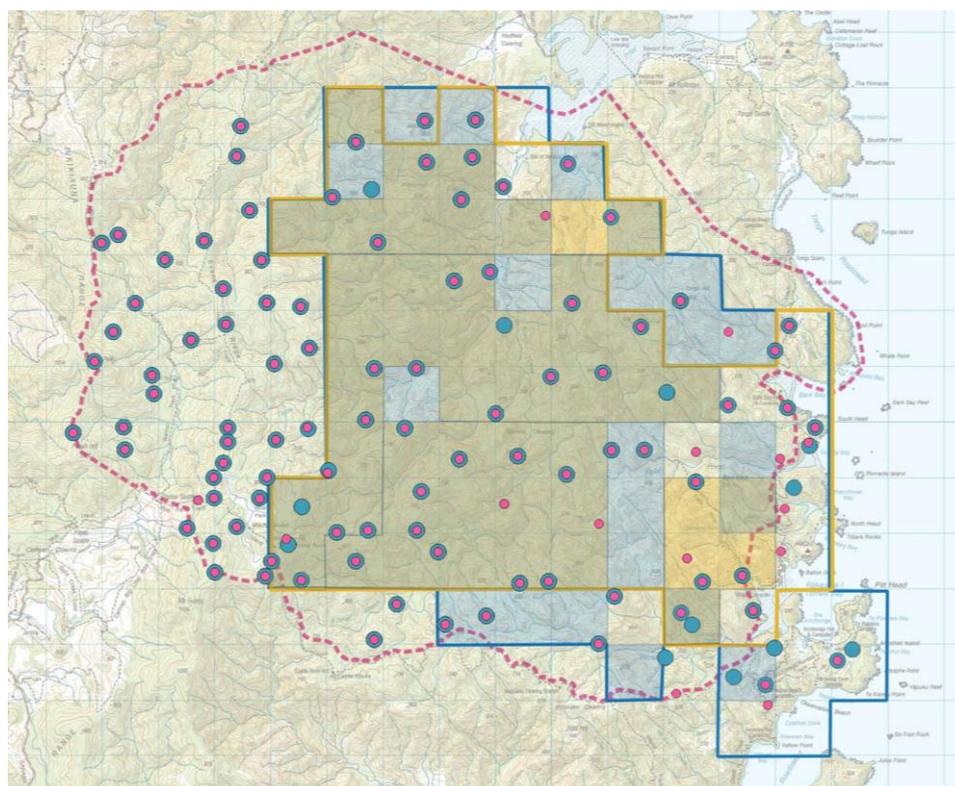
Figure 45: Diachronic minimum occupancy of tomtits. See description and legend of Fig. 41.

Tomtit were initially not detected along the coast (Fig. 45), and the occupancy extends by one kilometre around the fringes by 2018. In 2020, tomtits are recorded at all locations except two in the Pitt Head area.

Data for kākā, brown creeper, kingfisher, kea and cuckoo were too scarce for comparison, whereas bellbird/tui, silvereye, fantail and warbler where already present across the entire study area.

Temporal calling activity patterns

Complete transcripts for four locations showed that amongst all indicator bird species, most calls were of very short duration (here a call is defined by continuous vocalisation with no break longer than 5 s). Figure 46 shows that calls rarely last longer than a few seconds. The longest continuous call was observed for a robin who sang for just over five minutes.

Activity patterns did not differ significantly when they were illustrated as sum of call lengths or accumulated number of calls (Figs. 47-54). Diurnal birds had a higher call rate during the morning session, with a slight peak around 1 h and 2.5 h since sunrise, respectively (Fig. 47). Vocal activity decreased quickly after sunset.
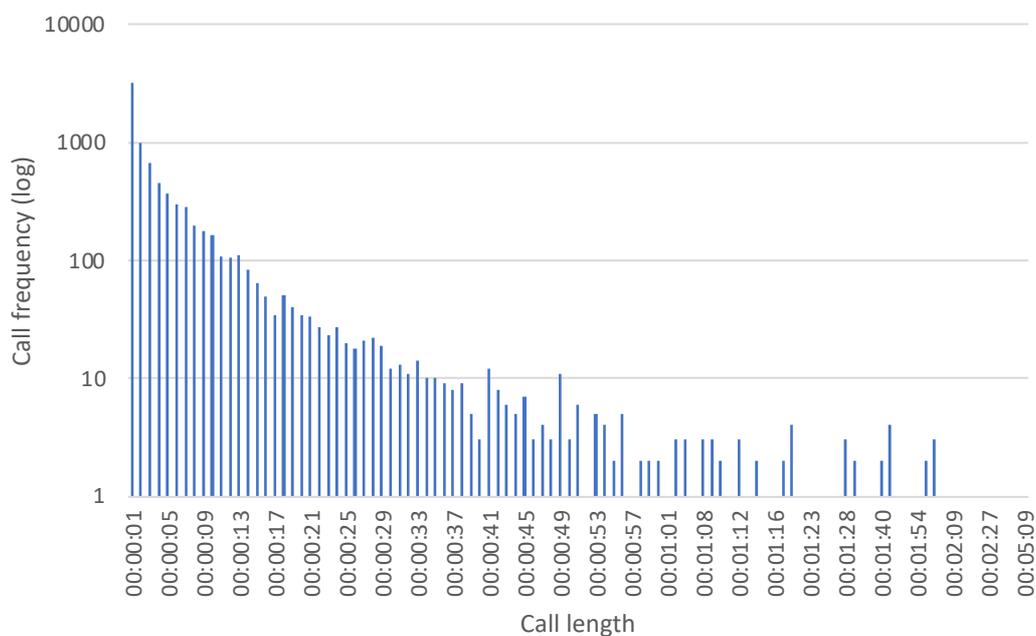
Fig. 46: Call length of all indicator bird species (kākā, kākāriki, rifleman, robin, weka, creeper, kea) based on full transcripts for four sites (call= no longer break than 5 secs).

Most bird species called during both morning and evening sessions, except for robin where most of the activity was restricted to morning sessions (Figs. 48 & 55). Nevertheless, looking at the entire data set of ADRs, robins where only detected during the evening session at three locations (1_30, 3_7, 1_12), albeit calls were at very low numbers.

Rifleman showed a high "two-peak" vocal activity in the morning and around 1 h before sunset (Fig. 49). Weka had a low but steady calling activity in the morning, but clearly peaked around sunset (Fig. 50).

Sampling size for brown creeper was small, the observed birds showed the highest vocal activity in the late morning and during the afternoon, ceasing approximately half an hour before sunset (Fig. 51). Kākā revealed a peak of calls about 45 min after sunrise and a longer period for ca. 2 h around sunset (Fig. 52). Kākāriki were mostly active in the morning hours and ca. 1h before sunset but did not call after nightfall (Fig. 53). Numbers or recorded kea calls were low but peaked an hour either side of sunset, while only occasional calls were detected in the morning (Fig. 54).

Both acoustic detection rates and activity patterns during morning and evening sessions remained similar between survey seasons (Fig. 55).
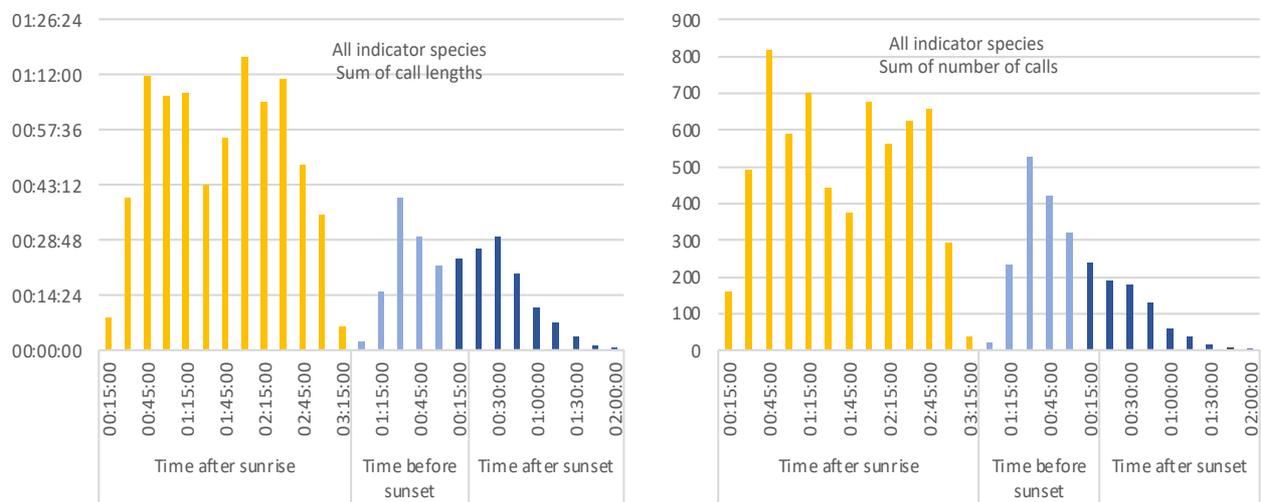
Fig. 47: Sum of call length (left) and sum of number of calls (right) of all seven bird indicator species used for the full transcript of four sites with respect to sunrise and sunset.
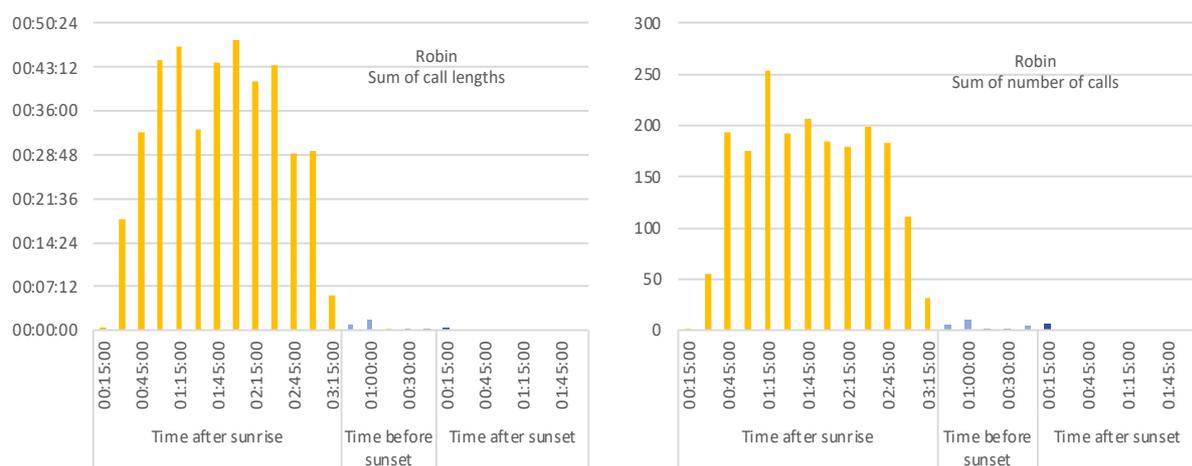
Fig. 48: Sum of call length (left) and sum of number of calls (right) of robins with respect to sunrise and sunset.
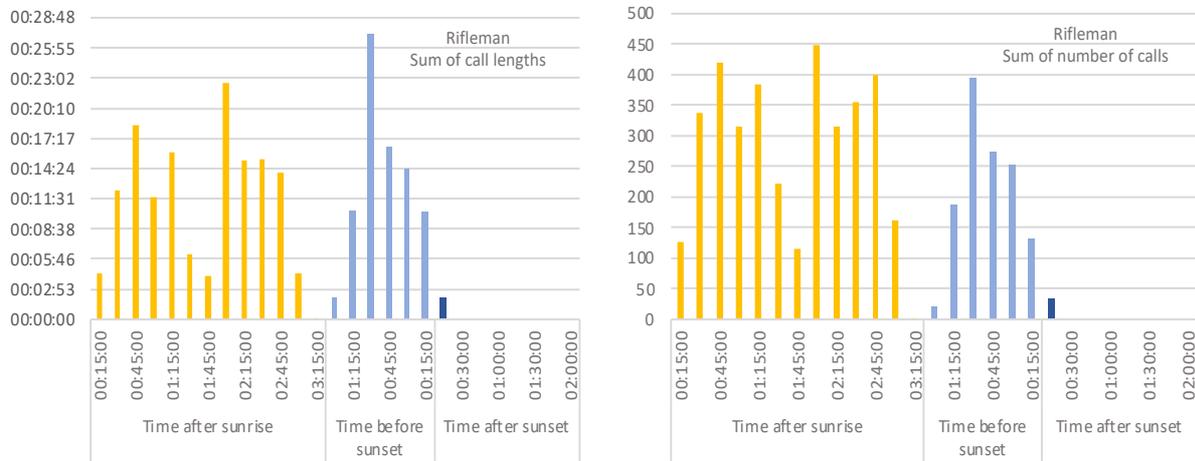
Fig. 49: Sum of call length (left) and sum of number of calls (right) of rifleman with respect to sunrise and sunset.
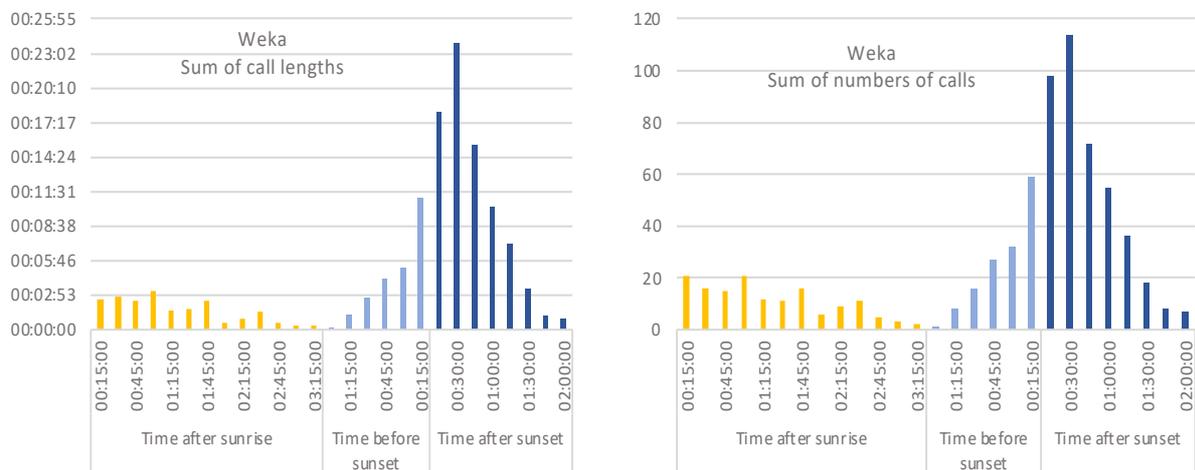
Fig. 50: Sum of call length (left) and sum of number of calls (right) of weka with respect to sunrise and sunset.
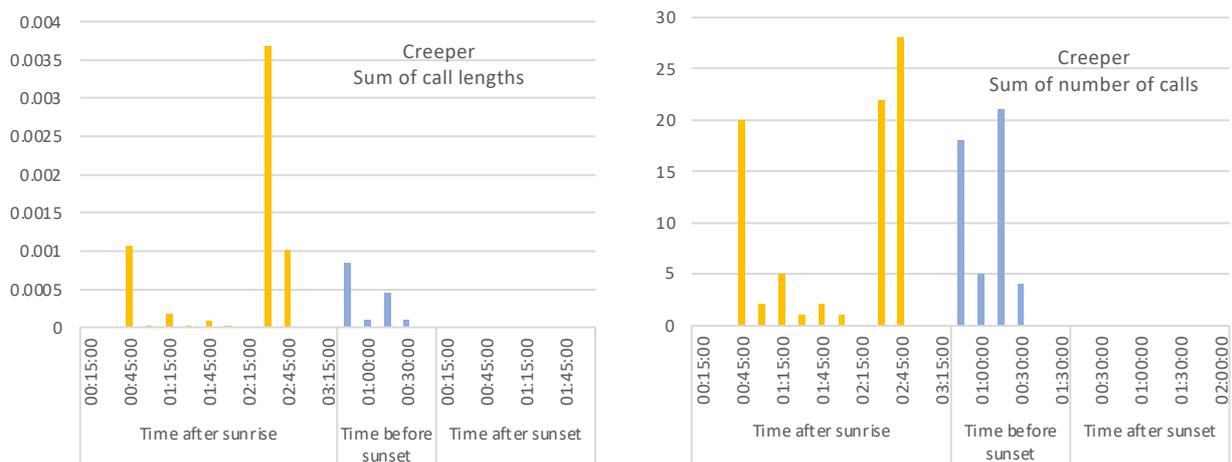
Fig. 51: Sum of call length (left) and sum of number of calls (right) of brown creeper with respect to sunrise and sunset.
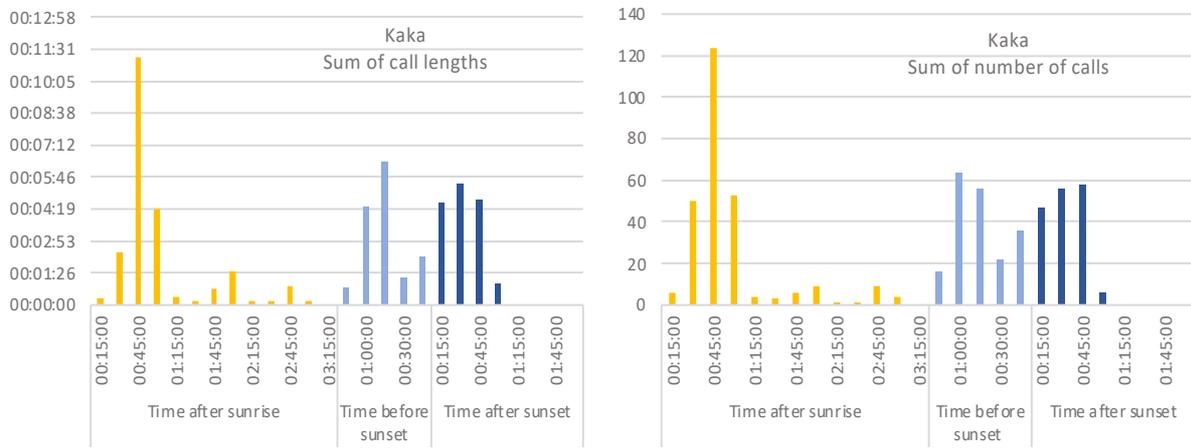
Fig. 52: Sum of call length (left) and sum of number of calls (right) of kākā with respect to sunrise and sunset.
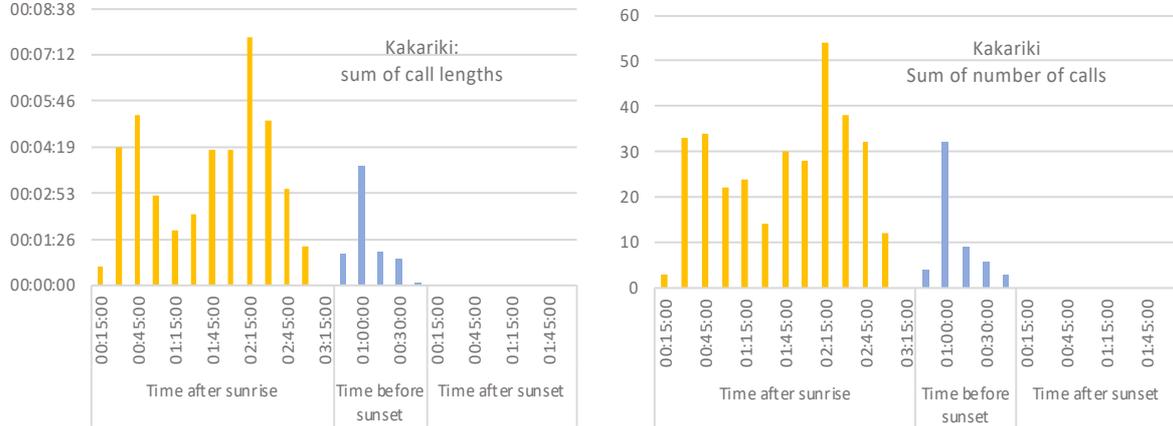
Fig. 53: Sum of call length (left) and sum of number of calls (right) of kākāriki with respect to sunrise and sunset.
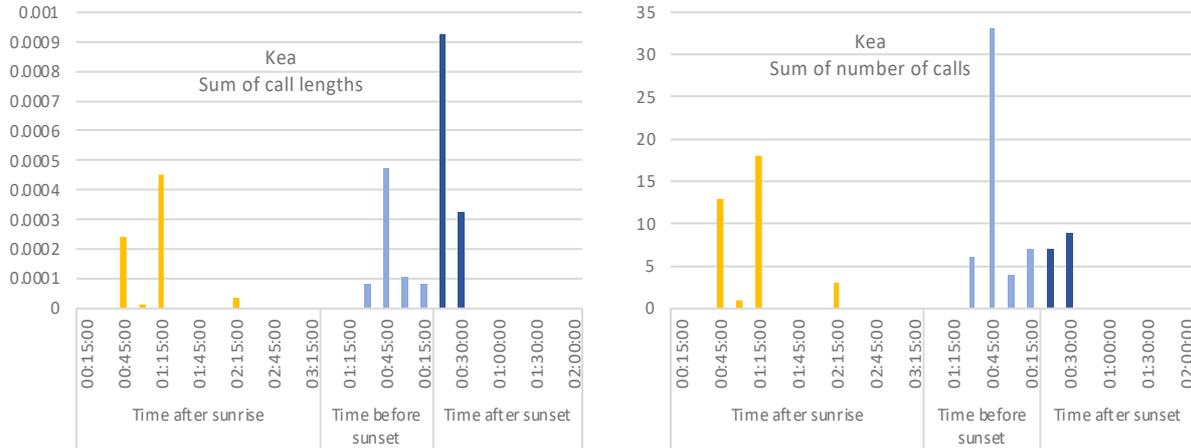
Fig. 54: Sum of call length (left) and sum of number of calls (right) of kea with respect to sunrise and sunset.

45

Call Rate 2019

Call Rate 2020

Fig. 55: Average acoustic detection rates during morning (yellow) and evening (blue) sessions, respectively. Both ADRs and relative activity during the morning and the evening session are similar for both seasons.

Sampling sensitivity analysis

Complete sound file transcription for eight days each was performed for four locations in season 2019 (locations 1_30, 1_7, 2_3, 3_4, Fig. 3). A total of 160 hours of recording time was transcribed. Sampling sensitivity for a range of sampling lengths and sampling intervals were calculated per site and per session, accounting for different call percentages (Tab. 7, Tab. A4 & A5 in the appendix and Fig. 56).

Table 7 presents results for a sampling interval of 2.5 mins using sampling lengths of 5 s increments. The most efficient sampling strategy is to sub-sample 10 s every 2.5 mins, resulting in an 84% detection rate of all indicator bird calls present at a site. Total sampling time per session is 10 mins, resulting in 160 mins total if two sessions are sampled per day over an eight-

day period. For 120 sites, this means a total of 320 hours of 40 person days of pure sampling time if both morning and evening sessions are sampled.

Detections rates can be improved by increasing the sampling length, however, total sampling time per session accumulates rapidly, while the benefit in terms of increased detectability remains modest. Figure 56 A+B shows a graphic representation of the results of the sampling sensitivity analyses per site and per session, respectively. Detection rates per site comprise the accumulated detections of 16 sessions per site, consequently, detection rates per site are higher compared to those per session. Longer sampling intervals lead to increased total sampling times to achieve detection rates above 80% and are therefore inefficient. Figure 57 reveals a positive correlation between call percentage and detection rate, based on the example of 10 s sampling length every 2.5 mins.

Table 7: Sampling sensitivity per site under different sampling regimes, applying a 2.5 min interval, resulting in 60 sub-samples within a 2.5-hour session. Minimum sampling lengths per interval ranges from 5-110 s with 5 s increments. The table shows the cumulative detection of a call of any indicator bird species, e.g., three bird calls were detected when call rates were <0.1% and sampling length was 5 s. Extending sampling length to 10 s leads to the detection of an additional 5 calls, 8 calls in total (whereas a sampling length of 15 s only one additional detection). This regime results in a total sampling time of 10 mins per session. Using a sampling strategy of 10 s every 2.5 mins results in a detection of 37 calls of indicator bird species out of 44 (84%). Results for 5 min and 10 min intervals as well as sampling sensitivity per sessions are shown in Table A4 and A5 in the appendix.

Min. sampling length (sec)	Call %								All call % combined				Σ samp. time (min) p. session
	<0.1	<0.25	<0.5	<1	<5	<10	<25	<50	N	%	Cum. N	Cum. %	
5	3	5	6	4	11	1		1	31	70%	31	70%	5
10	5	1	0	0	0	0		0	6	14%	37	84%	10
15	1	0	0	0	0	0		0	1	2%	38	86%	15
20	0	0	0	0	0	0		0	0	0%	38	86%	25
25	0	0	0	0	0	0		0	0	0%	38	86%	35
35	1	0	0	0	0	0		0	1	2%	39	89%	40
40	1	0	0	0	0	0		0	1	2%	40	91%	45
45	0	0	0	0	0	0		0	0	0%	40	91%	50
50	1	0	0	0	0	0		0	1	2%	41	93%	55
55	1	0	0	0	0	0		0	1	2%	42	95%	60
60	0	0	0	0	0	0		0	0	0%	42	95%	65
65	0	0	0	0	0	0		0	0	0%	42	95%	75
80	0	0	0	0	0	0		0	0	0%	42	95%	80
90	1	0	0	0	0	0		0	1	2%	43	98%	85
95	0	0	0	0	0	0		0	0	0%	43	98%	95
100	0	0	0	0	0	0		0	0	0%	43	98%	100
110	1	0	0	0	0	0		0	1	2%	44	100%	110
Not detect.	0	0	0	0	0	0		0	0	0%	44		
Total	15	6	6	4	11	1		1	44				
% not detect.	0%	0%	0%	0%	0%	0%		0%					

A)

B)
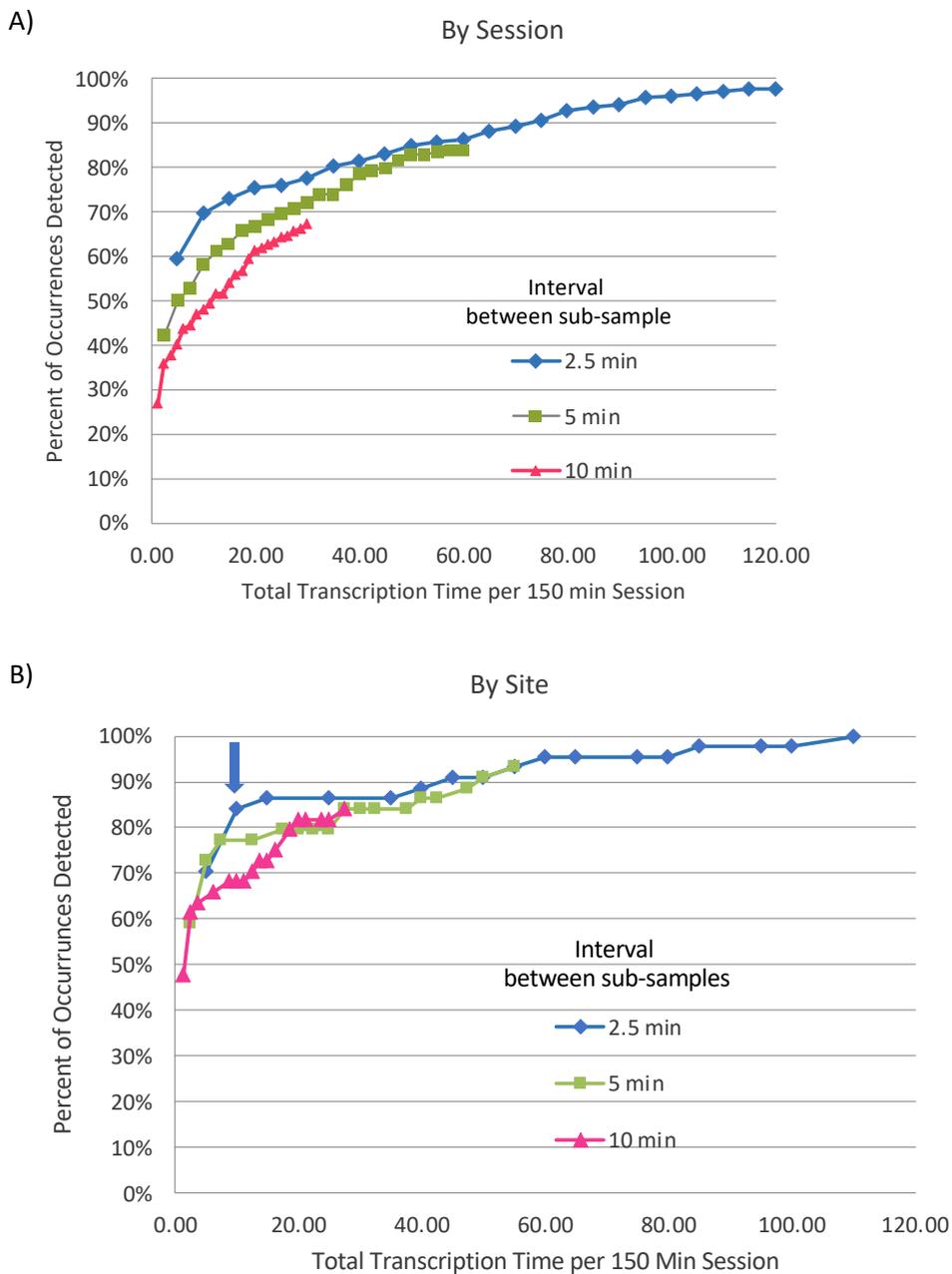
Figure 56: Sub-sampling regimes with intervals of 2.5, 5 and 10 mins, respectively, in 5 s increments ranging from 5-110 s. A) Sub-sampling regimes by session. The most efficient sampling strategy is 10 s sub-sampling every 2.5 min over 8 days (see blue arrow), with a detection rate of 84% and total transcription time of 10 min per site. Although the detection rate can be improved even further, the costs in terms of total transcription time rise rapidly while detectability improves only slightly. B) Sub-sampling regimes by site. Overall trends are similar to fig. A, but detection rates are generally lower by session due to the accumulation of detections from several sessions at a given site.
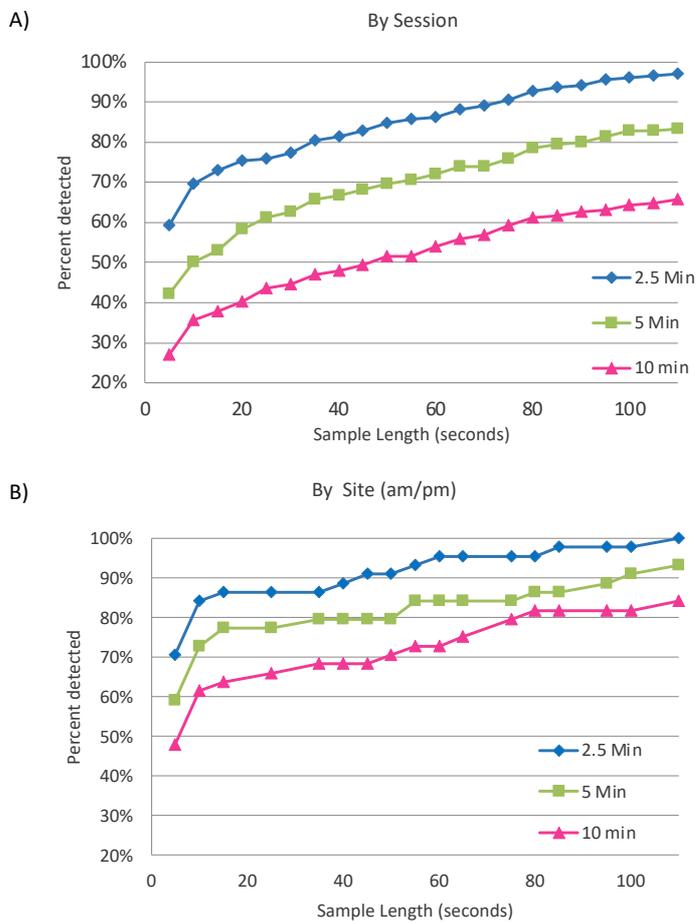
Figure 57: A) Total sampling length detection success under different sampling regimes with intervals of 2.5, 5 and 10 mins, respectively, in 5 s increments ranging from 5-110 s. A) Sampling length by session. B) Sampling length by site (calculating AM and PM sessions separately). Efficiency rises considerable between the first two increments (increasing the sampling frame from 5 to 10 s) but decreases afterwards.
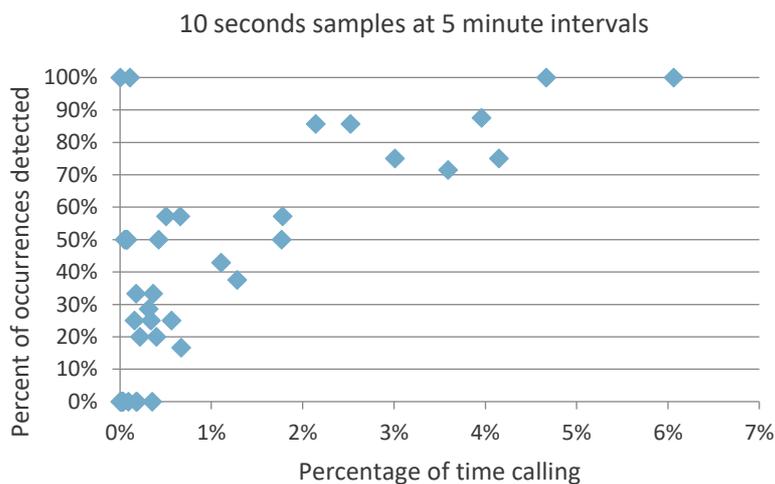
Fig. 58: Call percentage versus detection rate under a sampling regime of 10 s every 2.5 mins. The data suggest that detection rate is positively correlated to call percentage.

At the species level, call percentage per site and time of day varied considerably (Tab. 8). The greatest variation was observed for robins, with call percentages ranging from 0.4 – 30.2%

during the morning session, and only low vocal activity and hence failure to detect during the evening session (0-0.2%).

Tab 8: Call percentage for indicator species at a given site (Call % all), call rate within current 15 s-frame call rate (Call rate sample), occurrence within the session (Occurr.) and detectability under the current 45 s sub-sampling regime (S. occur.).

Sp	Site	Morning Sessions				Evening sessions			
		Call % all	Call rate sample	Occurr.	S. Occurr.	Call % all	Call rate sample	Occurr.	S. Occurr.
Creeper	3_4	0	0	0	0	0	0	0	0
	2_3	0.02	0	1	0	0	0	0	0
	1_30	0.67	0	1	0	0.07	0	1	0
	1_7	0.04	0	1	0	0.11	2.38	1	1
			Totals	3	0		Totals	2	1
Kākā	3_4	0	0.00	0	0	0	0	0	0
	2_3	1.78	15.15	1	1	2.53	0	1	1
	1_30	0	0.00	0	0	0.02	0	1	0
	1_7	0.05	0.00	1	0	0.01	2.38	1	0
			Totals	2	1		Totals	3	1
Kea	3_4	0.01	0	1	0	0.07	0	1	0
	2_3	0.08	0	1	0	0.16	3.03	1	1
	1_30	0	0	0	0	0	0	0	0
	1_7	0	0	0	0	0.01	2.38	1	0
			Totals	2	0		Totals	3	1
Kākāriki	3_4	1.12	7.69	1	1	0.03	0	1	0
	2_3	1.77	0	1	0	0.40	0	1	0
	1_30	0.34	0	1	0	0.03	0	1	0
	1_7	0.314	2.38	1	0	0.09	4.76	1	0
			Totals	4	1		Totals	4	0
Rifleman	3_4	0.178	2.56	1	1	0.19	2.56	1	0
	2_3	0.01	0	1	0	0	0	0	0
	1_30	4.67	22.22	1	1	2.14	16.67	1	1
	1_7	6.07	26.19	1	1	4.15	30.95	1	1
			Totals	4	3		Totals	3	2
Robin	3_4	0.43	0.00	1	0	0	0	0	0
	2_3	3.59	6.06	1	1	0.07	0	1	0
	1_30	0.36	0.00	1	1	0	0	0	0
	1_7	30.20	50.00	1	1	0.22	0	1	0
			Totals	4	3		Totals	2	0
Weka	3_4	0.35	0	1	0	3.01	2.56	1	0
	2_3	0.18	0	1	0	0.50	0	1	0
	1_30	0.66	5.56	1	1	4.00	2.78	1	1
	1_7	0.57	2.38	1	1	1.28	2.38	1	1
			Totals	4	2		Totals	4	2

Bird species with low call percentages like brown creeper and kea are missed at most call occasions (Tabs. 8 & 9), whereas birds with high call rates like robin and rifleman were detected at three out of four sites (Tab. 8). Summarising the overall detection rate under the currently applied sampling regime of 45 s per session (consisting of 15 s sampling length every 5 mins for

15 mins, 45 s in total per 2.5 h session for every day recorded), most indicator bird calls was missed (Tab. 9). The average detection rate was 39% (43% during morning sessions and 33% during evening sessions per site). Pooled bird call percentages and their respective detection success suggests that call percentages > 1% are most likely to be detected by the current sampling regime (Tab. 10), except for one value of 1.771 where detection failed. Actual call occurrence within a session and its detection under the current 45 s sampling regime suggests a positive correlation between call percentage and detectability (Fig. 57, Tab. 8).

Tab 9: Number of occurrences of a species within the total transcript (All) and withing the current 45 s sub-sampling regime (Sample) and percentage of detection (%) using pooled date from all sites and sessions.

Species	Occ. per session			Occ. per site		
	All	Sample	%	All	Sample	%
Brown Creeper	12	1	8.3	5	1	20
Kaka	19	3	15.8	5	2	40
Kea	10	1	10	5	1	20
Parakeet	37	1	2.7	8	1	12.5
Rifleman	38	15	39.5	7	5	71.4
Robin	29	8	27.6	6	3	50
Weka	59	4	6.8	8	4	50
All Species	204	33	**16.2**	44	17	**38.6**

	per session					
	Occurance AM			Occurance PM		
Species	All	Sample	%	All	Sample	%
Brown Creeper	9	0	0	3	1	33.3
Kaka	9	2	22.2	10	1	10
Kea	3	0	0	7	1	14.3
Parakeet	26	1	3.9	11	0	0
Rifleman	20	8	40	18	7	38.9
Robin	22	8	36.7	7	0	0
Weka	28	2	7.1	31	2	6.5
All Species	117	21	**18**	87	12	**13.8**

	per site					
	Occurance AM			Occurance PM		
Species	All	Sample	%	All	Sample	%
Brown Creeper	3	0	0	2	1	50
Kaka	2	1	50	3	1	33.3
Kea	2	0	0	3	1	33.3
Parakeet	4	1	25	4	0	0
Rifleman	4	3	75	3	2	66.7
Robin	4	3	75	2	0	0
Weka	4	2	50	4	2	50
All Species	23	10	**43.5**	21	7	**33.3**

Tab.10: Comparison of pooled call percentages of full transcripts (Tab. 8) that were detected or not detected, respectively, during a session. Birds with call rates above 1% were most likely to be detected under the current 45 s sampling regime.

Call Percentage	
Detected	Not detected
0.108	0.003
0.158	0.004
0.178	0.007
0.363	0.018
0.565	0.019
0.661	0.028
1.108	0.033
1.283	0.036
1.779	0.051
2.143	0.068
2.526	0.072
3.594	0.072
3.961	0.082
4.149	0.093
4.668	0.176
6.065	0.188
30.196	0.219
	0.314
	0.338
	0.353
	0.399
	0.425
	0.504
	0.671
	1.771
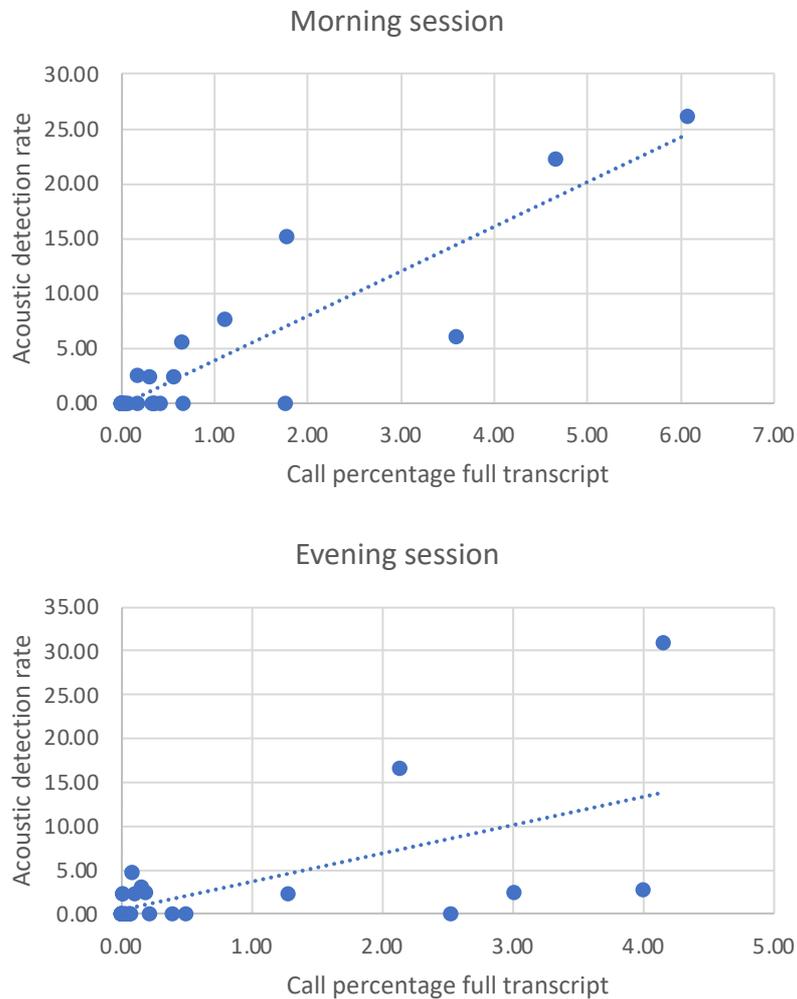
Figure 59: Linear regression of average call percentage of full transcripts per site versus average acoustic detection rate per site for morning and evening sessions, respectively. (Morning session: Multiple R= 0.9, r^2=0.81. Evening session: Multiple R= 0.63, r2=0.40). See Tab. 8 for data.

Discussion

Costs

After the initial cost of recorder purchase the better part of costs is induced by person days needed to deploy and collect recorders. Approximately 55 person days are needed to complete recorder deployment and retrieval.

In the long run, field work costs could be reduced by doubling the number of recorders, which would halve the amount of monitoring cycles. Sampling points that are located deeper in the park require extra walking days or helicopter charters to reach traplines like Evans, Glennies and Long Branch. At least five person days could be saved by consolidating cycle one and two. Also, more recorders could be picked up during trap maintenance, as the final recorder retrieval is not time sensitive and could be postponed until the next trapline cycle.

An additional benefit is the reduction of confounding factors by creating a higher number of simultaneous recording times. Sharing recorders with other projects of the Next Foundation would be the most efficient way to increase recorder numbers and to achieve savings.

Costs for sound file processing depend on the depth of analysis. Under the current scheme of analysing 90 seconds per recorder and day, experienced staff would need about 15 days.

Study design

The stratigraphic design confirmed the impact of elevation, or rather the gradient of rat densities, on rat vulnerable species like robin, rifleman, creeper and to a lesser degree tomtit (Fig. 9). Sampling points were chosen haphazardly within strata as long as a certain distance to creeks was kept in order to avoid high background noise, and at least 200 m between sites were chosen to ensure independence of detections. A random distribution within strata would have been preferable but taking the remote and often impassable conditions in the park into consideration, deployment of recorders along traplines was a practicable necessity. Consequently, around 58% of sampling sites are located on or near ridgelines, the remaining sites are mostly located on hillsides and a few along valley bottoms. Moist gullies often present good habitat but are underrepresented in this study, mainly as a consequence to avoid creek noise.

The non-random nature of the study design can expect to introduce bias; however, the high amount of sampling points delivers a more stable average, and it has to be kept in mind that Project Janszoon's objectives are based on landscape-scale change. The results of both seasons have shown that the method is adequate to detect gradients in bird distribution, and further adjustments according to the results of the sensitivity study will improve results even further.

Recorders were rotated every two weeks across a time frame from early September to early November. A potential alteration in vocal activity due to seasonal change is a likely source of bias. Average call rates of four bird species were compared across monitoring cycles, but did not yield any significant differences, suggesting that seasonal bias is negligible, at least for those four species tested (Fig. 8).

Annotations

Annotations were carried out by three people (Ruth Bollongino, Ruth Cole and Sumudu Priyadarshani) and reviewed by R.B. for quality control and to minimise observer bias. When in doubt, annotators consulted each other for clarification. Special care was taken to confirm the presence of a bird species that was only represented by one or two calls at a given site. These precautions lead to a high confidence in the correctness of species identification, and the assumption that occasional human error has a negligible effect on the results of this study.

Temporal vocal activity patterns

All results are limited by the fact that two 2.5 hour recording sessions per day were implemented, for a comprehensive study of temporal bird calling activity patterns extended recording times covering the entire day and covering multiple locations are recommended.

Vocal activity patterns during morning and evening sessions and acoustic detection rates were very similar for each bird species between seasons (Fig. 55), suggesting that temporal patterns are replicable and stable und the current sampling regime and can be used as a base to optimise the sub-sampling strategy.

Based on the complete transcripts for four locations, both total call length and number of calls showed similar temporal activity patterns across bird species (Figs. 47-54), suggesting that both measures are a good indicator for vocal activity. The results are derived from mainly two sites with high bird call activity that were used for entire transcription for the sampling sensitivity study and thus limited by a low sample size. As many bird species are territorial, the results may reflect the behaviour of just a few individuals.

Comparison with previous human observer surveys

Acoustic monitoring offers a longer survey time per site, whereas human surveyors cover a greater area but only spend minutes within a given location. Additionally, detection probabilities, precision and accuracy vary with technical configurations of recorders and survey abilities of human observers (Figs. 41-45). A direct comparison should therefore be regarded as a minimum known occupancy of a bird species. Theoretically, human surveyors could have a lower detection probability of rare species, as they spend less time at a given location. In this case, robins might have occupied more areas in the lowland than observed (Fig. 42). However, this is not supported by the fact that robins were hardly ever reported during trapline maintenance along the coast until recently.

A more detailed analyses of differences between survey methods can be achieved by applying both methods simultaneously.

Sampling sensitivity study

Effectiveness of different subsampling transcription regimes for detecting species occurrence in acoustic recordings is affected by percentage of time the target species spend calling, which is determined by the species' call rates and call lengths. Regime effectiveness will also be affected by the temporal distribution of calls (i.e. clustered, random or evenly spread).

Simulations could be used to investigate effectiveness of different subsampling transcription regimes with different call rates, call lengths and call distributions, providing estimates of detection rates with confidence intervals for a variety of call patterns. However, this will only

be useful if the call patterns (call rate, lengths and temporal distribution) of the target species are known.

The results of the sampling sensitivity study are probably underestimating the sensitivity of the currently used subsampling regime. The analyses is based on full transcripts of eight days per location, whereas the current sampling strategy was applied to approximately 12-14 days per site. Reasons for the eight day limitation of full transcripts were budget limitations and the fact that some days of the full deployment interval did not reveal sufficient data due to bad weather.

Detection probability

Equal detection probabilities amongst sites are by nature compromised by environmental and topographic conditions. Differences in detectability can be expected between survey years, between sites (topography and soundscape, habitat) and within sites (variation caused e.g. by weather conditions, season and bird abundance: Colbourne & Digby, 2016; Powlesland, 1983; Williams, 2021). Traffic like planes and boats, but also strong wind and wave sound along the coast impeded detectability. Noise was an issue especially along the coast, which decreased the detection probability of bird calls of a lower amplitude. It is also conceivable that noise levels influence the vocal activity of birds (Narango & Rodewald, 2016; Narango & Rodewald, 2018). However, it should be kept in mind that all the above mentioned sources of bias apply to any monitoring method using acoustic cues. Acoustic recorders can introduce a technical bias, if different types of devices are used or if recorders are of different age, as microphones degrade with time (Turgeon et al., 2017). However, this bias is likely to be of less impact compared to the variation in human observer's ability to focus, hear and identify bird calls. The advantage of acoustic recorders over human surveyor methods is that leaving the acoustic recorders over a longer period at one site increases the probability of covering time periods with different and more favourable conditions and thus averaging potential bias (Pérez-Granados & Traba, 2021). The elongated deployment of recorders and the potential to calculate detection rates to account for imperfect detection (see chapter below). High call rates increase the detection probability, but the temporal distribution of calls within a sound file is also of importance, as a bird might call regularly but coincidentally miss times when sub-samples are taken.

Numerous factors have been suggested to influence the vocal activity of birds. Habitat quality has been shown to increase territoriality and call rates in birds (Narango & Rodewald, 2018). Conceivable reasons for this can be 1) a higher population density due to increased resources that leads to denser territories and an increase in (vocal) territory defence or 2) males indicating the accessibility to better resources to females by increasing their call rates (Penteriani, 2003). Disturbances have shown to reduce singing activity in some species (Pillay et al., 2019) or even to impact song structure and complexity (Deoniziak & Osiejuk, 2019). Density dependence of vocal

activity is often discussed, but only few studies investigated this (Cain et al., 2015; Narango & Rodewald, 2016).

South Island robins are territorial, it is therefore unlikely that high call rates reflect a large number of different individuals. But call rates might indirectly reflect population density as males could increase the vocal defence of their territory to neighbouring birds, as has been shown for other bird species (Cain et al., 2015; Penteriani, 2003; Wood et al., 2021).

Correcting for imperfect detection

Acoustic monitoring delivers data on minimum or naïve occupancy. The term presence-absence is avoided here due its misleading assumption of complete detection. False negatives, i.e. failing to detect a species when in fact it is present, are likely, especially in areas where call rates are low. This leads to an inherent underestimation of true occupancy. The solution is to correct for the imperfect detection by estimating the detection probability derived from repeat surveys (MacKenzie et al., 2002; MacKenzie et al., 2005; Pollock et al., 2002). This usually increases the costs considerably, as repeated visits to a site are necessary. This is not the case for acoustic surveys when ARUs are deployed over a long time interval and each day of deployment can be regarded as a replicate. The variation of call rates within this interval can be used to determine the detection probability. The true occupancy, especially for rare birds, can be expected to be higher than reported in this study.

Occupancy and vocal activity as a surrogate for abundance

The positive relationship between occupancy and abundance has been shown by numerous studies (e.g. Hartley, 1998; MacKenzie & Nichols, 2004; Pérez-Granados & Traba, 2021; Royle & Nichols, 2003; Tingley et al., 2016). To achieve this, surveys have to be repeated to infer the detection probability. The underlying assumption is that vocal activity is density dependent, or in other words, the more birds present, the higher the call rate and the higher the detection probability.

A critical point is that various other factors (e.g. weather, season, habitat, mating status, etc.) can impact call rates and result in within-site and in-between site call rate variance. All these factors introduce heterogeneity, and although covariates can be used to accommodate for some of these factors, they also may introduce more noise and bias (Welsh et al., 2013). These effects can be reduced by a large number of sampling sites and sufficient replicates, as has been applied here. Especially the daily variation in vocal activity can be averaged by longer acoustic surveys (Buxton, 2014; Oppel et al., 2014). Additionally, estimating and correcting for imperfect detection as suggested for occupancy studies would increase the precision. However, the level of bias is likely to be different amongst sites, for which reason this method is most suitable for

landscape scale applications where the average trend is of more interest than individual sampling points and where detection of relative change over time is sufficient.

For most conservation managers it is crucial to have an estimate of abundance and, in case numbers decrease, to receive an early warning before a species is prone to local extinction. Vocal activity rates have been used as surrogates for abundance (Pérez-Granados & Traba, 2021 and references therein). Although the above mentioned inherent bias can be expected to impact precision, ADRs deliver a much higher resolution than occupancy data alone and have shown here to be a promising indicator for relative change over time.

The vocal detection rate used in this study is based on binary counts, i.e. a call was either present or absent from a 15 s-annotation frame, and no further information like number of calls or call length was documented. The spatial distribution of ADRs of rat sensitive species intriguingly corresponds with expected abundance patterns (e.g. Figs. 13, 15, 25), with higher call rates in the uplands and a decreasing gradient towards the coast.

Most previous studies using vocal activity rates as a density estimate used traditional point count methods for validation (Digby et al., 2013; Pérez-Granados & Traba, 2021; Stewart & Hasenbank, 2018). As these methods are prone to observer bias and other challenges, a more reliable validation would include comparison to an absolute abundance measure (e.g. banding birds, which could easily be done with robins). Such a task that would be ideal for e.g. a PhD student, thus collaboration with a University should be considered.

Using ADRs as a surrogate for abundance would present an efficient tool for conservation managers and broaden the application of acoustic monitoring considerably.

Results by species

Acoustic monitoring was conducted in two consecutive years, given this short time frame no major changes in bird occupancy are expected. This time frame was chosen to test the replicability of results between monitoring seasons. The strong mast year in 2019 which resulted in high rat numbers previous to the survey season in 2020 (Fig. A1) gave an opportunity to observe the response of native birds to this event. Surprisingly, occupancy for most species (except kākāriki) remained stable and suggests a temporary resilience at least in areas where birds are well established.

 The human surveyor monitoring in 2015 detected **robins** only along a south-western to north-eastern corridor reaching approximately from Moa Park to Huffams Stream (Fig. 42). A subsequent survey in 2018 and both later acoustic monitoring seasons revealed a constant expansion along the fringes (Fig. 42). Figure 12 shows that in some locations robins were detected in 2019 but not in 2020. The sampling sensitivity analyses revealed that robins calls are likely to be missed in areas of low call rates, which are predominant along the expansion front

of robins (Fig. 13). Adjusting the sub-sampling regime of data analyses is necessary to achieve a higher probability in robin detectability in these areas (see recommendations).

The high 15 s-frame call rate at Huffam stream suggests a larger amount of birds and an established population. This is supported by an observation of three to five males in this area (R.B. pers. obs.). The area along Huffam Stream is characterised by lush and diverse native bush, in contrast to regenerating manuka/kanuka shrub vegetation that is common in most other areas along the coast. Tregidga Creek Valley also represents a lush habitat, and robins are reported regularly along the adjacent Falls River Track during trap maintenance, even below 100 m ASL. The nearby recorder location missed the detection of robins, which might either be caused by low call rates or the fact that the ARU is located just outside the lush bush on a dry ridgeline. Although of anecdotal character, these observations suggest that robin occupancy might not be dependent on low rat abundance alone, but also on habitat quality. This would also explain the low diversity in native birds and the absence of robins from the Awaroa River valley (Figs. 12 & A2).

Robin call rates are dependent on sex and mating status. Only male birds give the predominant full territorial song, and males were observed to spend more time singing after they lost their mate (Powlesland, 1983). In the Pelorous River area, robins continuously re-colonised low elevation areas without successfully establishing there (B. Lloyd pers. com.). For these reasons care should be taken to use call rates as a sole indicator for a viable population. Additional monitoring like nest monitoring, banding birds or territory mapping should be implemented at least once to verify inferences from acoustic monitoring. These measures can be combined with a validation of using acoustic detection rates as a proxy for abundance.

The map of **rifleman** occupancy (Fig. 14) reveals a higher amount of occupied sites with time along the eastern fringes towards the lowland. The diachronic map including the human observer survey however (Fig. 45) already showed an expansion towards the heart of the monitoring area The site with high calls rates just east of Awaroa Inlet (Fig. 15) is remarkable, and it coincides with a first detection of robins in this area. Another interesting detection was made on the Holyoake track at the southern border of the park. Both sites are between 250-300 m elevation and are unprecedented, indicating an expansion of rifleman towards the lowland.

The two detections south of Bark Bay in 2020 were spatial outliers and therefore investigated in more detail. Both detections were single "chee-chee" calls that would be typical for rifleman, except for their isolated occurrence. The recordings were compromised by strong winds and call quality was poor, it can therefore not be excluded that the calls were remnants of a distant tui song. Interestingly, rifleman were already reported just east of Bark Bay by a human surveyor in 2018.

Rifleman and parakeets were the only species that showed a significant decrease of average call rates (Fig. 7). This could reflect a decrease in abundance, especially in the light of high rat abundance after the mast year (Fig. A1). However, the 14% increase in occupancy does not support this (Tab. 5). The 2020 survey season was characterised by long periods of consistent wind and rain. As rifleman have rather quiet calls of high frequency, it is more likely that detection rates were impeded by environmental conditions, which suggests that the true number of occupied sites might be higher. Rifleman showed a lower call rate along the fringes of their distribution, an adjustment of the sub-sampling strategy will benefit their detectability.

Brown creeper are probably the most challenging of the indicator bird species. Monitoring by human surveyors has led to unreliable results and acoustic monitoring is impeded by low call rates (Fig. 17). Currently, no creeper were detected below the 600 m elevation line (Fig. 16) Sampling effort would have to be increased significantly in order to achieve an acceptable detection probability. In theory, brown creeper are an ideal indicator species, but there is a high risk that birds are falsely not detected and that their distribution is underestimated. However, even occasional and imperfect detections at lower elevations are of high value as creeper are the most limited species at this stage. This might change in future if creeper numbers rise to an abundance that will considerable increase call rates and thus improve detectability. Thus, monitoring of Brown creeper should be continued under the consideration of imperfect detection.

An interesting note on the side is the observation of a variation of the typical creeper call that has yet been unreported. The local creepers often vocalised a harsh screaking sound previous to the characteristic melodic song. This is an example of an additional application of acoustic recordings in conservation, when local bird dialects play an important role in bird translocations (Lewis et al., 2021).

Human surveyor monitoring in 2015 and 2018 failed to detect **kākā** (Bollongino, 2018). Human surveyors were monitoring around 9:00 AM and 5:00 PM, taking the times of kākā peak vocal activity into consideration (Fig. 52), it is likely that most calls occurred outside of monitoring times.

Although call rates in the centre of the park were low in 2019 (Fig. 19A), it is unlikely that all ten sites were missed due to imperfect detection in 2020 (Fig. 19B). Kākā are mobile birds and can cover larger areas, the occupancy patterns inferred from acoustic recordings therefore rather reflect area usage than local residence.

Kākāriki are known to be a "boom and bust" species, with short term high population densities during mast years and subsequent decline as rat numbers increase (Elliott, 2013). Parakeet occupancy declined by 70% between survey seasons (Tab. 5, Fig. 20), and despite low call rates

(Fig. 21) and associated imperfect detection, the most parsimonious explanation is a decline of parakeets between survey seasons. The 2019 season was characterised by an unusually strong mast, and the aerial operation in June 2019 failed to control rats sustainably (Fig. A1). FTT indices rose to an average of 80% during summer 2019/20, as a consequence, a second aerial operation was deployed in August 2020, just before the second monitoring survey. It is likely that the parakeet population decreased during the period of high rat abundance. In this case kākāriki numbers can be expected to recover over the next years if rat numbers are be kept low.

Tomtits have been present across most of the monitoring area since the beginning of surveys in 2015 (Fig. 45). However, they do display a slight decrease in occupancy towards the coast (Figs. 9,24 and 25), and were not detected directly at the coast during human observer surveys (Fig. 45). In contrast, tomtits were detected all along the coast using acoustic monitoring, which might either reflect a higher sensitivity in detection or an expansion of birds along the coast. Call rates show a strong positive relation to elevation (Fig. 25), which supports that tomtits are at lower abundance in the lowland. Assuming that this pattern is mainly driven by rat abundance (Powlesland, 2013), tomtits are an additional useful indicator for Project Janszoon's objectives.

Kea call rates are low (Fig. 23) and detections were missed in most cases according to the sampling sensitivity study (Tab. 8). The number of occupied sites remained stable over both survey seasons (Tab. 5) but changed in spatial distribution (Figs. 22 & 23). Although kea cover large distances and occasional calls were encountered during fly-overs, detections appear to cluster in the Waterfall Creek area in 2019 and around Glennies Clearing in 2020. A more sensitive sampling approach would be useful to investigate the special clustering of calls to serve as indication of a local breeding pair. A similar observation was made in the Air-New Zealand project area near Totaranui, where kea calls appeared at a higher call rate in a spatially limited area over several weeks (Bollongino, 2021). Kea are vulnerable during aerial 1080 operations and understanding the number and location of breeding pairs in the park is the basis to ensure the welfare of these endangered birds.

Fantail, grey warbler and **silvereye** are not sensitive to rat abundance and thus no useful indicators for this project. All revealed a slight increase in occupancy (Tab. 5) and are distributed over the entire monitoring area. Fantail have a less dense occupancy in the uplands (Fig. 9), and although silvereyes show no clear preference in occupancy, 15 s-frame call rates suggest a lower density in the uplands (Fig. 33). Fantail call rates (Fig. 31) are seemingly higher where native bird diversity is lowest (Fig. A3) and possibly decline as other native species recover due to increased competition (Innes, 2010).

Grey warbler slightly increased in occupancy (Tab.5) and average call rate (Figs. 7 & 35). They are the hosts of **shining cuckoos**, who increased in occupancy, as well (Tab. 5, Fig. 36). Due to their low call rates (Fig. 37) their occupancy is likely to be underestimated.

Kingfisher distribution is primarily along the coast and streams in the lowland (Fig. 38), in congruence with their preferred habitat. They declined almost 50% in occupancy (Tab. 5), for unknown reasons.

The interpretation of **bellbird/tui** occupancy is limited by the fact that detections of both species were pooled, and differentiating trends between tui and bellbirds will be obscured. Figure 9 displays that no stratigraphic pattern is observed, and that occupancy of bellbird/tui is not influenced by elevation. Interestingly, call rates for bellbird/tui tend to be higher in areas of lower native bird diversity (Figs. 29 & A3) and increased between survey seasons (Fig. 7). A possible explanation for this pattern is that bellbird and/or tui are limited by competition with other native birds, that they outcompete other native birds or that lowland habitat is more suitable for these birds.

Weka human observer surveys in 2015 and 2018 were conducted during daytime (app. 9:00 AM- 5:00 PM) and thus outside of peak calling time of weka (Fig. 50). Most weka detections during the day would have been based on visual contacts. Although weka are attracted to the presence of humans, timing of these surveys probably lead to an underestimation of weka distribution. This would also explain the patchy distribution of weka occupancy (Fig. 44). Assuming a similar error intrinsic to this method, weka still displayed an almost trifold increase in occupancy between 2015 and 2018. Due to the differences in temporal design, acoustic recordings can be expected to be more sensitive than human observer surveys. Results from 2019/20 confirm that these birds successfully re-colonised the entire monitoring area (Fig. 26). Weka tend to call mainly during dusk and dawn, call rates are therefore naturally low (Fig. 27). 15 s-frame call rates as well as call percentages underestimate the true call rate, as weka usually call simultaneously and call counts will hardly differ between one bird and a chorus of several individuals. If calls rates are to be used as an abundance measure for weka, the number of birds calling in a chorus should be documented.

Suitability of acoustic monitoring

During the last decade, passive acoustic monitoring has seen a constant increase in usage, according to the number of studies that have been published on this topic (Pérez-Granados & Traba, 2021; Shonfield & Bayne, 2017; Sugai et al., 2019). Acoustic monitoring has the potential to detect even small changes in occupancy on a landscape scale (Franklin et al., 2020; Wood et al., 2019).

In comparison to the challenges of traditional field methods like 5MBC and distance sampling (Greene & Pryde, 2012; Williams et al., 2001), acoustic monitoring offers a non-invasive and standardised alternative. The use of human surveyors has proven to be problematic for previous monitoring surveys in the Abel Tasman National Park (Lloyd, 2017).

However, some potential sources of error and bias is shared amongst all methods using auditory cues (Pérez-Granados & Traba, 2021; Simons et al., 2009), as detectability is influenced by factors like weather, season, habitat, population density and observer bias. Observer bias is minimised by the additional information supplied by spectrograms, the ability to reanalyse calls and to get validation through colleagues. Other sources of bias are weakened by extended monitoring times which increase the number of statistical replicates to an extend that practically cannot be achieved by human surveyors. The high number of sampling sites (N=120) deliver a good resolution for spatial trends and additionally help to flatten local biases.

Using ADRs as a proxy for abundance requires validation through comparison with a census method like mark-resight using banded birds but has already been suggested by several studies (see chapter above). The results presented here show an elevational gradient of ADRs of rat-vulnerable birds, as expected. Furthermore, ADR patterns are replicated between survey years, suggesting that vocal activity is dependent on bird density and sensitive enough to detect relative changes over time (Oppel et al., 2014). A major reservation towards acoustic monitoring is based on the assumption that it only delivers data on occupancy, whereas many conservationists require supplementary estimates on abundance or density. Using vocal activity rates has shown a great potential to circumvent this problem and thus widen the potential application of acoustic monitoring.

The current shallow sub-sampling rate of 90 s per day already delivered important insights into spatio-temporal developments of key indicator bird species. The sampling sensitivity analyses showed that birds with lower call percentages (<1%, Tab. 8, Fig. A3) are often missed under the current sampling regime, thus it can be expected that the results are an underestimate of the true occupancy. Following the results of the sampling-sensitivity study, detectability can be improved by an adjusted sub-sampling regime for future and past monitoring seasons.

The results confirm that acoustic monitoring is a powerful and reliable measure to inform on Project Janszoon's objectives or any conservation project that is seeking to monitor the response of birds on a landscape scale.

Prospect of using automatic identifiers (AI)

A major concern regarding acoustic recordings is the anticipated high work effort to analyse sound files manually. Although this study has shown that subsampling effort can, depending on objectives and desired sensitivity, be reduced to a minimum, an automated process to identify

bird calls is desirable. Several research groups are focussing on this task and first successful applications have been published (Bedoya & Molles, 2021; Priyadarshani et al., 2020; Stowell et al., 2019). So far, deep learning (Salamon & Bello, 2017) has been shown to be a key factor in this process to eliminate an excess of false positives.

Subjects of these pioneer studies are mainly nocturnal bird species with characteristic and less complex calls. Studies on more complex bird calls of diurnal birds that are overlapping with environmental noise and calls of multiple other species has, to my knowledge, yet to be realised. However, the technological principle is available and lends reason for optimism concerning future progress.

Recommendations

Acoustic surveys in two consecutive years did not reveal a major change in occupancy or ADR for most bird species. Response to pest control management is a long-term development, therefor monitoring should be reduced to surveys every second year and can be further adjusted according to future results if needed. However, it should not be left unmentioned that annual monitoring has the advantage of measuring the effects of mast years directly, as has been the case in this study. It is important to understand the resilience of forest birds to different magnitudes of rat irruptions for future management strategies. The results of this study suggest a relative stability of established bird populations, except for parakeets.

The sampling sensitivity analyses revealed that birds with low call percentages (app. below 1%, Tab. 8, Fig. A3) have a low detection probability under the current sampling regime. Increasing the sampling rate to the recommended 10 s every 2.5 mins (Tab. 7) would considerably increase the effort and costs. Taking peak temporal vocal activity patterns (Fig. 47 ff) and spatial distribution of low call rates into consideration, the sampling regime can be optimised in a more efficient way. In the case of robins, for example, birds are hardly calling during the afternoon session and call rates in the morning are lower at both ends of the recording interval. Consequently, the improved sub-sampling rate should be limited to the core 1.5 h in the morning and not be applied to the afternoon session at all. Furthermore, low call rates mostly occur at lower elevation, thus increased sub-sampling could be limited to sites below 600 m. This would reduce the overall sampling length of the improved sampling regime from 320 hours (40 person days) to 72 h (9 person days). If an hour of optimised sub-sampling is added to the afternoon session to increase detectability of brown creeper, kea, kākā, kākāriki and weka over the entire monitoring area, this would add 64 h (8 person days) of sampling length.

Both measures together would mean a total sampling time of 136 hours (17 person days), still more than a 50% reduction from the original 320 h. Note that these numbers reflect recording

times to be analysed, the actual manual analyses require additional time (app. twice as long). These recommendations are based on theoretical models, to verify the true benefits, the improved sub-sampling regime should be applied to the data set of one of the previous seasons only, before it is considered to be applied to all surveys.

Annotation effort could additionally be reduced by stopping the transcription work for a location once the indicator species is detected. Disadvantages of this method would be a loss of data on call rates, and the priority would focus on one indicator species only, which is not desirable for the current objectives.

Robins are a key indicator for the outcomes of Project Janszoon's pest control and are part of the Tomorrow Accord. The results of this report indicate that rat abundance alone might not be the only factor impacting robin distribution in the park: habitat quality and possibly wasp abundance, which is likely to impact food availability for robins, might also be key factors. The investigation of this goes beyond the sensitivity of acoustic monitoring. Given to the importance of robins for the Tomorrow Accord, additional monitoring like mark-resight or nest monitoring is recommend, to allow the objectives for the Tomorrow Accord to be adapted if necessary and to ensure the desired confidence in outcomes prior to the handing over to the Department of Conservation

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Appendix
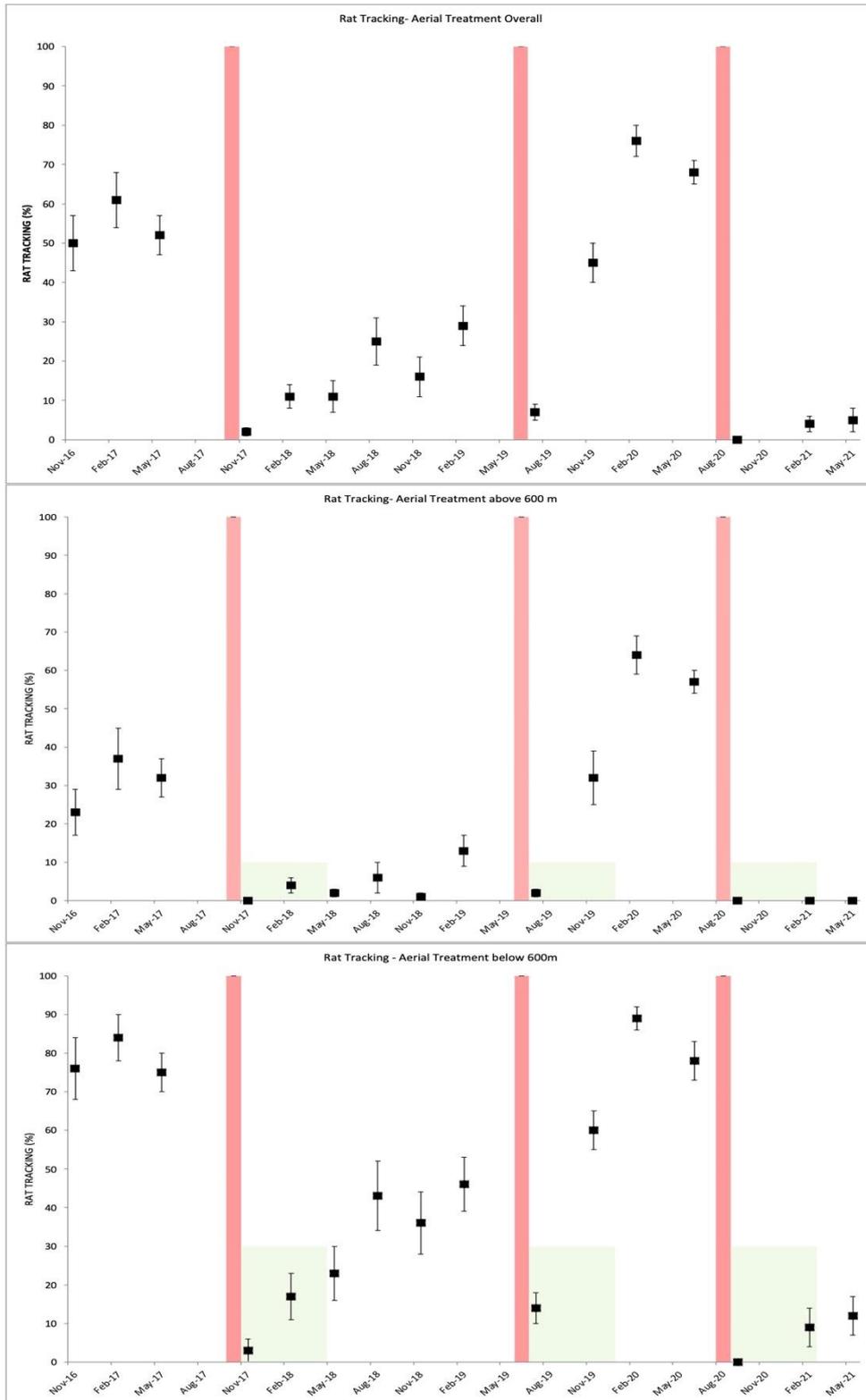
Figure A1: Foot tracking tunnel (FTT) results for the entire aerial treatment area (top), aerial treatment above 600 m (middle) and aerial treatment below 600 m (bottom). Green highlight= rat tracking objective (under 10% for 6 months after treatment above 600 m, under 30% for 6 months after treatment for under 600 m). Red bars= aerial rat control operation. Graphs by Andrew Macalister (R&D Environmental ltd.).
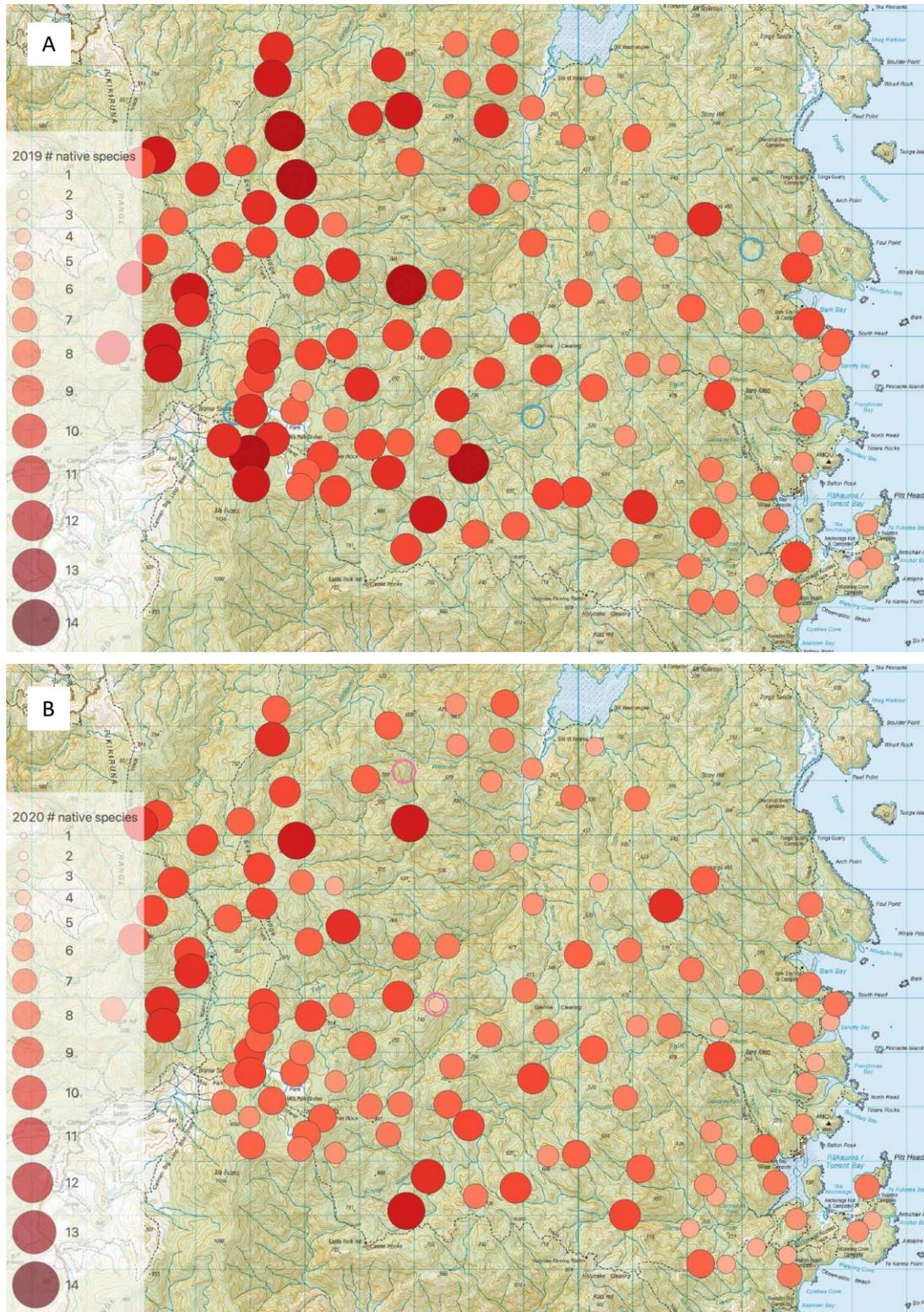
Figure A2: Number of native bird species recorded at a given site. A maximum of 14 species was possible (see Tab. 4 first column). A) 2019 B) 2020. The highest diversity within both survey season can be observed in the uplands, ca. above 600 m ASL.

Table A1: Number of recording days per location and cycle. Top row shows recording length in 2019 and bottom row in 2020, respectively.

Location	Cycle 1	Cycle 2	Cycle 3	Cycle 4
1	13	14	14	14
	14	13	15	14
2	13	14	14	14
	14	13	15	14
3	13	14	14	14
	14	13	15	14
4	13	12	13	14
	14	13	15	14
5	13	12	13	14
	14	13	15	13
6	10	14	14	14
	1	14	14	3
7	11	12	13	14
	14	13	15	14
8	11	14	14	14
	14	14	14	14
9	11	14	14	14
	14	14	14	14
10	11	14	14	14
	13	13	14	14
11	13	0	14	14
	14	14	14	14
12	11	14	14	14
	12	13	12	9
13	11	13	14	27
	14	13	14	35
14	12	12	15	14
	15	15	13	14
15	12	13	14	14
	15	15	13	14
16	12	12	0	23
	15	15	14	14
17	12	12	13	34
	15	15	15	30
18	12	11	14	14
	14	15	15	30
19	12	8	14	22
	12	16	13	14
20	12	11	14	14
	14	14	13	14
21	11	12	14	14
	14	15	14	15
22	11	12	14	14
	14	15	14	15
23	11	12	14	14
	14	15	15	14
24	12	14	14	14
	14	13	13	14
25	11	14	0	14
	14	15	14	14
26	11	14	12	14
	14	15	14	14
27	11	14	13	14
	14	15	12	14
28	12	14	13	14
	14	15	11	13
29	12	14	13	14
	5	15	12	14
30	12	14	13	14
	14	15	12	14
Average per Cycle	**12.48**	**13.33**	**13.27**	**15.45**
Total Average	**13.63**			

Table A2: 15 s-frame call rates per location and species for the 2019 survey. Numbers in red depict sites where detection was lost in the truncated data set of ten recording days only.

Location	Robin	Creeper	Rifleman	Kaka	Kea	Kakariki	Tomtit	Weka	Fantail	Warbler	Silvereye	Bellbird/Tui	Kingfisher	Shining Cuckoo
1_1	7.69	0	58.97	0	0	5.13	25.64	1.28	8.97	0	1.28	25.64	0	0
1_10	9.52	0	0	3.17	0	0	19.05	6.35	30.16	6.35	65.08	88.89	0	0
1_11	0	0	0	0	0	0	17.11	2.63	25	6.58	50	55.26	0	0
1_12	0	0	0	0	0	0	0	3.03	19.7	12.12	57.58	78.79	0	0
1_13	9.09	0	0	0	0	0	9.09	3.03	18.18	13.64	51.52	54.55	0	0
1_14	0	0	0	0	0	0	8	0	18.67	4	68	30.67	0	0
1_15	0	0	0	0	0	0	0	4.05	31.08	1.35	66.22	12.16	0	0
1_16	0	0	0	0	0	0	0	0	6.94	30.56	54.17	55.56	0	0
1_17	0	0	0	0	0	0	2.78	0	11.11	1.39	41.67	8.33	0	0
1_18	0	0	0	0	1.39	0	2.78	5.56	12.5	4.17	55.56	54.17	0	0
1_19	0	0	0	0	0	0	2.78	1.39	8.33	0	11.11	1.39	0	0
1_2	5.13	0	1.28	0	0	1.28	24.36	8.97	0	11.54	8.97	67.95	0	0
1_20	0	0	0	0	0	0	5.56	1.39	5.56	2.78	50	56.94	0	0
1_21	0	0	0	0	0	0	6.06	7.58	1.52	0	10.61	19.7	0	0
1_22	0	0	0	0	0	1.52	1.52	1.52	1.52	4.55	71.21	37.88	0	0
1_23	0	0	0	0	0	0	0	1.52	12.12	30.3	62.12	62.12	1.52	0
1_24	26.39	4.17	48.61	0	0	0	12.5	2.78	1.39	5.56	4.17	48.61	0	0
1_25	23.19	1.45	13.04	0	0	0	23.19	1.45	0	1.45	0	46.38	0	0
1_26	0	4.35	13.04	0	0	0	14.49	0	0	0	8.7	56.52	0	0
1_27	19.05	3.17	26.98	0	0	0	15.87	6.35	0	6.35	7.94	36.51	0	0
1_28	16.67	1.39	0	0	0	0	2.78	1.39	2.78	5.56	11.11	61.11	0	0
1_29	4.17	0	0	0	1.39	1.39	37.5	2.78	1.39	13.89	19.44	73.61	0	0
1_3	7.69	0	7.69	0	0	0	46.15	6.41	0	7.69	3.85	74.36	0	0
1_30	0	0	19.44	0	0	0	8.33	4.17	0	9.72	5.56	45.83	0	0
1_4	6.41	0	0	1.28	0	2.56	32.05	3.85	11.54	17.95	61.54	76.92	0	0
1_5	5.13	0	0	3.85	0	0	34.62	2.56	5.13	1.28	44.87	71.79	0	0
1_6	20	0	0	3.33	1.67	0	50	0	1.67	1.67	43.33	73.33	0	0
1_7	3.03	0	0	7.58	1.52	0	63.64	0	21.21	4.55	19.7	60.61	0	0
1_8	25.76	3.03	0	3.03	1.52	3.03	22.73	3.03	3.03	1.52	40.91	59.09	0	0
1_9	13.64	0	0	1.52	0	0	24.24	3.03	31.82	9.09	53.03	51.52	0	0
2_1	21.43	0	2.38	0	0	1.19	22.62	3.57	3.57	5.95	10.71	59.52	0	0
2_10	0	0	0	0	0	0	5.95	1.19	4.76	8.33	79.76	86.9	0	0
2_12	0	0	0	0	0	0	11.25	0	1.25	21.25	55	33.75	0	0
2_13	0	0	0	1.23	0	0	3.7	2.47	14.81	7.41	81.48	85.19	0	0
2_14	0	0	0	0	0	0	1.45	0	0	11.59	66.67	66.67	1.45	0
2_15	0	0	0	0	0	0	0	0	26.92	17.95	79.49	20.51	1.28	0
2_16	0	0	0	0	0	0	6.94	0	6.94	18.06	75	50	0	0
2_17	0	0	0	0	0	1.39	0	1.39	0	6.94	65.28	65.28	1.39	0
2_18	0	0	0	0	0	0	0	0	9.09	3.03	39.39	78.79	1.52	0
2_19	0	0	0	0	0	0	2.08	2.08	0	2.08	33.33	93.75	0	0
2_2	2.38	0	0	1.19	0	0	2.38	1.19	3.57	2.38	14.29	54.76	0	0
2_20	0	0	0	0	0	0	0	1.52	13.64	7.58	93.94	36.36	0	0
2_21	0	0	0	0	0	0	1.39	0	2.78	12.5	86.11	41.67	0	0
2_22	0	0	0	0	1.39	0	0	1.39	1.39	11.11	73.61	54.17	0	0
2_23	0	0	0	0	1.39	0	0	1.39	5.56	13.89	77.78	58.33	0	0
2_24	21.43	0	22.62	0	0	1.19	30.95	2.38	0	0	3.57	40.48	0	0
2_25	21.43	0	26.19	0	0	0	7.14	1.19	0	3.57	5.95	35.71	0	0
2_26	27.38	0	46.43	0	0	1.19	9.52	0	3.57	8.33	7.14	17.86	0	0
2_27	4.76	0	64.29	0	0	1.19	8.33	0	4.76	8.33	13.1	26.19	0	0
2_28	14.29	0	4.76	5.95	0	0	33.33	3.57	0	13.1	20.24	64.29	0	0
2_29	29.76	0	25	5.95	0	2.38	47.62	1.19	13.1	26.19	38.1	55.95	0	0
2_3	25	1.19	28.57	1.19	1.19	3.57	5.95	2.38	0	4.76	9.52	30.95	0	0
2_30	44.05	0	0	4.76	0	3.57	32.14	10.71	2.38	11.9	30.95	64.29	0	0
2_4	12.5	0	0	0	0	5.56	54.17	0	5.56	9.72	55.56	56.94	0	0
2_5	2.78	0	8.33	6.94	0	6.94	22.22	0	6.94	19.44	65.28	70.83	0	1.39
2_6	6.17	0	0	2.47	1.23	0	23.46	0	16.05	9.88	74.07	64.2	0	0
2_7	8.33	0	0	0	0	2.78	41.67	0	4.17	13.89	69.44	88.89	0	1.39
2_8	16.05	0	0	1.23	1.23	4.94	50.62	2.47	16.05	12.35	51.85	60.49	0	1.23
2_9	4.94	0	0	0	0	3.7	54.32	1.23	0	7.41	38.27	82.72	0	0
3_1	2.38	0	25	0	0	0	15.48	13.1	0	1.19	7.14	17.86	0	0
3_10	2.38	0	0	0	2.38	0	9.52	2.38	10.71	9.52	59.52	57.14	2.38	0
3_11	0	0	0	0	0	0	1.19	5.95	7.14	5.95	41.67	30.95	0	0

Location	Robin	Creeper	Rifleman	Kaka	Kea	Kakariki	Tomtit	Weka	Fantail	Warbler	Silvereye	Bellbird/Tui	Kingfisher	Shining Cuckoo
3_12	0	0	0	0	0	0	2.38	4.76	15.48	35.71	42.86	34.52	0	0
3_13	0	0	0	14.29	2.38	0	5.95	9.52	22.62	19.05	29.76	27.38	0	0
3_14	0	0	0	0	0	0	3.57	4.76	21.43	5.95	42.86	23.81	3.57	0
3_15	0	0	0	0	1.19	0	0	2.38	8.33	9.52	50	69.05	7.14	0
3_17	20.51	0	0	0	0	0	8.97	5.13	2.56	15.38	46.15	23.08	0	0
3_18	0	0	0	0	0	0	2.38	4.76	8.33	8.33	67.86	59.52	0	0
3_19	1.19	0	0	2.38	0	1.19	14.29	3.57	3.57	9.52	17.86	20.24	0	0
3_2	8.33	2.38	42.86	0	0	1.19	23.81	3.57	1.19	1.19	10.71	2.38	0	0
3_20	0	1.19	0	1.19	3.57	1.19	30.95	4.76	5.95	10.71	46.43	41.67	0	0
3_21	0	0	0	0	0	0	2.38	5.95	13.1	21.43	55.95	21.43	0	0
3_22	4.76	0	0	0	1.19	1.19	9.52	9.52	3.57	17.86	57.14	44.05	0	0
3_23	1.19	0	0	0	1.19	0	1.19	9.52	1.19	9.52	65.48	51.19	0	0
3_24	1.19	0	0	2.38	1.19	0	48.81	7.14	0	13.1	2.38	57.14	0	0
3_26	40.28	0	37.5	0	0	4.17	11.11	1.39	1.39	2.78	0	12.5	0	0
3_27	8.97	0	11.54	0	0	0	51.28	5.13	11.54	2.56	8.97	14.1	0	0
3_28	16.67	0	19.23	1.28	0	0	14.1	5.13	1.28	5.13	10.26	28.21	0	0
3_29	7.69	1.28	0	0	0	0	16.67	2.56	0	0	5.13	28.21	0	0
3_3	9.52	0	2.38	0	3.57	0	21.43	3.57	2.38	3.57	10.71	16.67	0	0
3_30	2.56	0	35.9	0	0	2.56	24.36	6.41	1.28	7.69	1.28	25.64	0	0
3_4	0	0	2.56	0	0	3.85	32.05	1.28	7.69	11.54	65.38	67.95	0	0
3_5	7.69	0	0	0	0	5.13	50	8.97	6.41	17.95	47.44	35.9	0	0
3_6	0	0	0	25	0	0	5.95	1.19	9.52	16.67	47.62	32.14	1.19	0
3_7	14.1	0	0	0	0	0	60.26	5.13	8.97	10.26	55.13	43.59	0	0
3_8	4.76	0	0	0	0	0	11.9	3.57	2.38	15.48	45.24	48.81	0	0
3_9	0	0	0	0	0	0	2.38	4.76	3.57	20.24	40.48	60.71	0	0
4_1	0	0	0	0	2.38	0	19.05	2.38	14.29	9.52	64.29	66.67	1.19	0
4_10	16.67	0	7.14	0	0	0	66.67	1.19	9.52	7.14	13.1	9.52	0	0
4_11	0	0	0	0	1.19	1.19	44.05	1.19	27.38	21.43	65.48	51.19	0	1.19
4_12	19.05	2.38	63.1	0	0	0	3.57	3.57	2.38	13.1	2.38	17.86	0	0
4_13	16.67	0	46.91	0	0	3.09	67.28	3.7	1.85	6.17	12.96	21.6	0	0
4_14	3.57	0	0	0	2.38	1.19	19.05	2.38	13.1	48.81	77.38	23.81	0	0
4_15	0	0	0	0	0	0	19.05	1.19	10.71	23.81	71.43	51.19	0	0
4_16	0	0	0	0	0	0	31.88	1.45	16.67	31.88	57.25	71.01	0.72	0
4_17	0	0	0	0	0	0	2.48	1.49	8.91	13.37	89.6	52.48	2.48	0.5
4_18	0	0	0	0	0	1.19	13.1	2.38	8.33	8.33	77.38	70.24	1.19	0
4_19	16.67	0	6.06	3.79	1.52	2.27	21.21	0	2.27	17.42	33.33	41.67	0	0.76
4_2	0	0	0	0	1.19	0	4.76	2.38	10.71	28.57	60.71	41.67	0	0
4_20	1.18	2.35	12.94	1.18	0	1.18	29.41	3.53	2.35	22.35	11.76	25.88	0	0
4_21	0	0	0	0	0	0	1.2	2.41	0	0	18.07	74.7	0	0
4_22	0	0	0	0	0	0	13.1	2.38	8.33	10.71	71.43	28.57	0	0
4_23	0	0	0	0	0	0	4.76	1.19	20.24	5.95	83.33	65.48	3.57	0
4_24	4.76	0	34.52	0	0	1.19	16.67	3.57	2.38	26.19	15.48	20.24	0	0
4_25	17.86	2.38	30.95	0	0	1.19	3.57	2.38	0	2.38	3.57	42.86	0	0
4_26	22.62	4.76	52.38	0	0	0	8.33	2.38	1.19	11.9	9.52	20.24	0	0
4_27	4.76	0	0	2.38	1.19	0	40.48	4.76	10.71	19.05	30.95	39.29	0	0
4_28	29.76	1.19	4.76	4.76	0	1.19	38.1	1.19	0	11.9	22.62	19.05	0	0
4_29	16.67	0	2.38	0	0	0	55.95	3.57	0	13.1	34.52	44.05	0	1.19
4_3	0	1.19	0	0	2.38	0	16.67	2.38	17.86	39.29	57.14	42.86	0	2.38
4_30	33.33	0	0	1.19	0	0	54.76	0	19.05	8.33	20.24	30.95	0	0
4_4	0	0	0	0	0	0	1.19	1.19	17.86	22.62	83.33	23.81	1.19	0
4_5	5.95	0	61.9	2.38	0	1.19	46.43	5.95	8.33	17.86	42.86	39.29	0	0
4_6	21.43	0	0	0	1.19	1.19	21.43	3.57	13.1	9.52	61.9	41.67	0	1.19
4_7	7.14	0	45.24	4.76	0	5.95	61.9	3.57	23.81	20.24	7.14	53.57	0	0
4_8	0	0	0	2.38	1.19	0	10.71	0	21.43	38.1	75	66.67	0	5.95
4_9	0	0	0	0	0	2.38	53.57	1.19	7.14	32.14	72.62	45.24	0	0

Table A3: 15 s-frame call rates per location and species for the 2020 survey. Numbers in red depict sites where detection was lost in the truncated data set of ten recording days only.

Location	Robin	Creeper	Rifleman	Kaka	Kea	Kakariki	Tomtit	Weka	Fantail	Warbler	Silvereye	Bellbird/Tui	Kingfisher	Shining Cuckoo
1_1	3.85	0	19.23	0	0	0	17.95	2.56	14.1	1.28	5.13	35.9	0	0
1_10	0	0	1.39	0	1.39	0	29.17	0	12.5	48.61	59.72	98.61	0	0
1_11	0	0	0	0	0	0	10	5	5	11.25	80	82.5	0	0
1_12	1.32	0	0	0	0	0	2.63	2.63	10.53	63.16	67.11	96.05	0	0
1_13	10.26	0	0	0	1.28	0	25.64	2.56	5.13	17.95	42.31	92.31	0	0
1_14	0	0	0	0	1.19	0	3.57	2.38	8.33	16.67	66.67	65.48	0	0
1_15	0	0	0	0	0	0	5.95	0	20.24	17.86	50	44.05	0	0
1_16	0	0	0	0	0	0	2.38	4.76	15.48	57.14	69.05	90.48	2.38	0
1_17	0	0	0	0	0	0	1.19	0	7.14	10.71	38.1	32.14	0	0
1_18	0	0	0	0	2.56	0	0	2.56	3.85	8.97	61.54	85.9	0	0
1_19	0	0	0	0	0	0	3.03	0	9.09	1.52	28.79	9.09	0	0
1_2	3.85	0	1.28	0	0	0	56.41	6.41	3.85	12.82	0	94.87	0	0
1_20	0	0	0	0	0	0	33.33	1.28	7.69	11.54	52.56	83.33	0	0
1_21	0	0	0	0	0	0	1.28	1.28	2.56	0	25.64	15.38	0	0
1_22	0	0	0	0	2.63	0	3.95	2.63	13.16	34.21	57.89	39.47	0	0
1_23	0	0	0	0	0	0	2.56	2.56	6.41	23.08	71.79	74.36	1.28	0
1_24	2.56	0	6.41	0	0	0	53.85	3.85	1.28	15.38	6.41	56.41	0	0
1_25	17.95	1.28	0	0	0	0	44.87	5.13	5.13	3.85	5.13	44.87	0	0
1_26	1.28	0	0	0	0	0	10.26	10.26	2.56	1.28	5.13	58.97	0	0
1_27	32.05	0	11.54	0	0	1.28	28.21	5.13	8.97	10.26	7.69	74.36	0	0
1_28	29.49	0	0	0	0	1.28	39.74	7.69	0	17.95	12.82	85.9	0	0
1_29	29.63	0	25.93	0	0	0	70.37	3.7	7.41	3.7	29.63	96.3	0	0
1_3	25.64	0	0	0	0	0	48.72	8.97	7.69	11.54	6.41	79.49	0	0
1_30	1.28	0	0	0	0	0	0	7.69	1.28	2.56	7.69	53.85	0	0
1_4	0	0	0	0	0	5.13	39.74	2.56	2.56	12.82	53.85	93.59	0	0
1_5	1.28	0	0	0	0	0	50	1.28	7.69	8.97	58.97	83.33	0	0
1_6	0	0	0	0	0	0	16.67	0	33.33	0	33.33	66.67	0	0
1_7	8.33	1.39	2.78	0	0	0	80.56	2.78	12.5	1.39	15.28	95.83	0	0
1_8	6.41	0	1.28	0	0	0	60.26	2.56	8.97	17.95	46.15	89.74	0	0
1_9	6.41	0	0	0	0	0	46.15	1.28	16.67	23.08	56.41	80.77	0	0
2_1	34.72	0	1.39	0	0	0	50	2.78	0	5.56	5.56	59.72	0	0
2_10	0	0	0	2.78	2.78	0	13.89	0	9.72	16.67	83.33	97.22	0	0
2_11	3.85	0	0	0	1.28	1.28	61.54	5.13	25.64	30.77	85.9	64.1	0	0
2_12	0	0	0	0	0	0	12.5	0	26.39	5.56	66.67	61.11	0	0
2_13	0	0	0	0	5.56	0	16.67	1.39	5.56	40.28	72.22	79.17	0	1.39
2_14	0	0	1.19	0	0	0	0	0	14.29	26.19	79.76	72.62	2.38	0
2_15	0	0	0	0	0	0	1.19	3.57	15.48	16.67	63.1	42.86	0	0
2_16	0	0	0	0	0	0	3.57	7.14	2.38	50	83.33	89.29	0	0
2_17	0	0	0	0	1.19	0	17.86	2.38	0	15.48	71.43	83.33	0	0
2_18	1.19	0	0	1.19	0	0	0	2.38	22.62	15.48	48.81	75	0	0
2_19	0	0	0	0	0	0	0	3.33	1.11	13.33	28.89	94.44	0	0
2_2	6.94	0	0	0	0	0	22.22	1.39	0	15.28	11.11	86.11	0	0
2_20	0	0	0	0	0	0	2.5	2.5	5	25	78.75	77.5	0	1.25
2_21	0	0	0	0	0	0	0	1.15	10.34	10.34	73.56	64.37	0	0
2_22	10.71	0	0	0	0	0	0	1.19	0	13.1	75	63.1	0	0
2_23	0	0	1.19	0	1.19	0	1.19	1.19	4.76	26.19	53.57	69.05	0	0
2_24	11.11	1.39	11.11	0	0	0	25	1.39	0	5.56	1.39	50	0	0
2_25	16.67	1.19	16.67	0	0	0	34.52	7.14	1.19	3.57	5.95	35.71	0	0
2_26	19.05	1.19	32.14	0	0	0	44.05	4.76	8.33	1.19	3.57	10.71	0	0
2_27	28.57	0	23.81	1.19	0	0	26.19	1.19	13.1	5.95	4.76	19.05	0	0
2_28	15.48	0	2.38	0	0	0	45.24	7.14	1.19	13.1	14.29	53.57	0	0
2_29	5.95	0	10.71	3.57	0	0	73.81	1.19	10.71	26.19	17.86	48.81	0	0
2_3	25	0	16.67	0	0	0	48.61	0	0	1.39	4.17	44.44	0	0
2_30	40.48	0	2.38	4.76	0	0	55.95	11.9	4.76	10.71	32.14	66.67	0	1.19
2_4	0	0	1.39	0	0	0	34.72	1.39	2.78	33.33	58.33	50	0	0
2_5	36.11	0	1.39	0	0	1.39	41.67	1.39	4.17	20.83	81.94	87.5	0	1.39
2_6	0	0	0	0	6.41	0	15.38	3.85	25.64	15.38	71.79	79.49	0	0
2_7	4.17	1.39	5.56	1.39	0	2.78	37.5	4.17	8.33	13.89	65.28	80.56	0	0
2_8	2.56	0	0	0	0	1.28	50	5.13	10.26	8.97	56.41	74.36	0	2.56
2_9	6.41	0	0	0	1.28	0	41.03	2.56	2.56	11.54	38.46	98.72	0	0
3_1	8.33	0	21.43	0	0	0	65.48	5.95	0	1.19	2.38	15.48	0	0
3_10	30.77	0	0	0	1.28	0	7.69	2.56	7.69	6.41	53.85	64.1	0	0

Location	Robin	Creeper	Rifleman	Kaka	Kea	Kakariki	Tomtit	Weka	Fantail	Warbler	Silvereye	Bellbird/Tui	Kingfisher	Shining Cuckoo
3_11	0	0	0	3.85	0	0	3.85	2.56	11.54	33.33	50	51.28	0	0
3_12	0	0	0	0	1.52	0	7.58	0	1.52	54.55	53.03	71.21	0	3.03
3_13	0	0	0	14.1	0	0	5.13	6.41	12.82	19.23	51.28	60.26	0	0
3_14	0	0	0	2.78	0	0	13.89	1.39	18.06	26.39	59.72	52.78	0	0
3_15	0	0	0	0	0	0	1.39	1.39	34.72	19.44	44.44	69.44	0	0
3_16	0	0	0	0	1.28	0	1.28	1.28	12.82	24.36	34.62	64.1	0	0
3_17	10.71	0	0	1.19	0	0	7.14	4.76	2.38	38.1	38.1	35.71	0	1.19
3_18	0	0	0	0	0	0	0	7.06	3.53	16.47	52.94	70.59	0	0
3_19	1.39	0	0	0	1.39	0	34.72	6.94	5.56	8.33	27.78	31.94	0	0
3_2	20.24	0	15.48	0	0	0	9.52	5.95	1.19	2.38	3.57	13.1	0	0
3_20	5.56	0	0	1.39	2.78	0	54.17	16.67	11.11	26.39	29.17	27.78	0	1.39
3_21	0	0	0	0	0	0	0	4.76	3.57	13.1	53.57	41.67	0	0
3_22	0	0	0	1.19	1.19	0	2.38	5.95	8.33	11.9	58.33	52.38	0	0
3_23	0	0	0	0	0	0	2.38	7.14	3.57	34.52	61.9	36.9	0	0
3_24	6.94	0	0	1.39	4.17	0	56.94	4.17	0	18.06	5.56	40.28	0	0
3_25	24.36	0	1.28	0	0	0	42.31	7.69	1.28	0	3.85	51.28	0	0
3_26	23.08	0	29.49	0	0	0	20.51	2.56	8.97	7.69	5.13	11.54	0	0
3_27	4.55	0	7.58	0	0	0	18.18	7.58	25.76	10.61	4.55	24.24	0	0
3_28	21.67	0	6.67	3.33	0	0	30	6.67	1.67	11.67	8.33	33.33	0	1.67
3_29	18.18	0	0	1.52	0	0	21.21	10.61	0	0	0	37.88	0	0
3_3	11.9	0	0	0	1.19	0	13.1	3.57	0	9.52	7.14	38.1	0	0
3_30	36.36	0	6.06	0	0	0	48.48	3.03	0	12.12	1.52	28.79	0	0
3_4	0	0	0	1.19	0	1.19	17.86	2.38	2.38	16.67	79.76	84.52	0	0
3_5	0	0	0	0	0	0	28.57	1.19	25	11.9	64.29	76.19	0	0
3_6	0	0	1.28	20.51	0	0	3.85	1.28	11.54	2.56	60.26	50	0	0
3_7	2.38	0	2.38	0	0	0	30.95	2.38	10.71	10.71	55.95	88.1	0	1.19
3_8	6.41	0	0	0	1.28	0	0	6.41	5.13	50	57.69	71.79	0	0
3_9	3.85	0	0	1.28	1.28	0	17.95	5.13	2.56	17.95	46.15	70.51	0	1.28
4_1	0	0	0	0	0	0	37.35	4.82	9.64	10.84	39.76	39.76	0	0
4_10	5.95	0	16.67	5.95	0	0	34.52	1.19	20.24	19.05	21.43	7.14	0	0
4_11	0	0	0	0	0	0	52.38	2.38	25	41.67	50	55.95	0	0
4_12	26.32	5.26	66.67	0	0	1.75	52.63	5.26	3.51	0	8.77	1.75	0	0
4_13	0	0	0	0	0	0	15.07	4.57	19.18	34.7	55.25	53.42	1.37	0
4_14	4.76	0	0	0	4.76	0	19.05	1.19	5.95	21.43	33.33	7.14	0	0
4_15	0	0	0	0	0	0	40.48	4.76	10.71	8.33	45.24	39.29	0	0
4_16	13.1	0	54.76	0	0	0	53.57	3.57	3.57	21.43	26.19	9.52	0	0
4_17	0	0	0	0	0	0	0	1.67	12.22	42.22	80.56	55	0.56	0
4_18	2.78	0	0	0	0	0	2.22	0.56	10.56	17.78	60.56	40	0.56	0.56
4_19	11.9	0	7.14	3.57	0	0	42.86	1.19	17.86	19.05	11.9	19.05	0	0
4_2	4.71	0	1.18	0	2.35	1.18	60	4.71	9.41	47.06	35.29	57.65	0	1.18
4_20	19.05	1.19	1.19	2.38	0	0	22.62	7.14	3.57	23.81	9.52	27.38	0	1.19
4_21	0	0	0	0	0	0	1.19	2.38	7.14	5.95	22.62	83.33	0	0
4_22	0	0	0	0	1.19	0	4.76	2.38	27.38	14.29	80.95	48.81	0	0
4_23	0	0	0	0	0	0	4.76	1.19	17.86	17.86	64.29	42.86	13.1	1.19
4_24	20.24	0	13.1	0	0	4.76	34.52	4.76	11.9	11.9	3.57	19.05	0	0
4_25	28.57	1.19	16.67	0	0	0	38.1	3.57	1.19	1.19	2.38	39.29	0	0
4_26	22.62	1.19	50	0	0	0	11.9	3.57	3.57	9.52	1.19	16.67	0	0
4_27	27.38	0	0	3.57	3.57	0	11.9	5.95	2.38	28.57	9.52	55.95	0	0
4_28	39.74	0	0	3.85	1.28	0	52.56	2.56	8.97	10.26	50	1.28	0	0
4_29	14.29	0	3.57	4.76	0	0	60.71	3.57	7.14	15.48	34.52	11.9	0	2.38
4_3	9.52	0	0	0	0	0	45.24	3.57	20.24	33.33	47.62	45.24	0	2.38
4_30	38.1	0	1.19	1.19	0	0	73.81	1.19	8.33	4.76	4.76	48.81	0	0
4_4	0	0	0	0	0	0	1.19	0	29.76	19.05	61.9	20.24	0	0
4_5	29.63	1.23	25.93	2.47	0	0	67.9	6.17	2.47	24.69	11.11	33.33	0	0
4_6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4_7	5.95	0	15.48	4.76	0	1.19	82.14	2.38	1.19	17.86	7.14	39.29	0	0
4_8	0	0	0	0	0	0	9.52	1.19	11.9	15.48	52.38	59.52	0	1.19
4_9	0	0	0	0	0	0	8.33	3.57	33.33	39.29	54.76	35.71	0	0

Table A4: Analysis by **site** and AM or PM. Call percent is for site by AM or PM over entire transcript. Occurrence is whether a species occurred in the complete transcription: 1 = Occurred, 0 = did not occur. Inf= Infinity, means species not detected in sample which could be because it didn't occur during session or if it occurred during session it was not detected in any of the samples.

A) Interval between samples: **300** s, N samples session: **30**

Min. sampling length (sec)	Call %								All call % combined				Σ samp. time (min) /session
	<0.1	<0.25	<0.5	<1	<5	<10	<25	<50	N	Percent	Cum. N	Cum. %	
5	3	2	4	4	11	1		1	26	59%	26	59%	2.5
10	3	2	1	0	0	0		0	6	14%	32	73%	5
15	0	1	1	0	0	0		0	2	5%	34	77%	7.5
20	0	0	0	0	0	0		0	0	0%	34	77%	12.5
25	1	0	0	0	0	0		0	1	2%	35	80%	17.5
35	0	0	0	0	0	0		0	0	0%	35	80%	20
40	0	0	0	0	0	0		0	0	0%	35	80%	22.5
45	0	0	0	0	0	0		0	0	0%	35	80%	25
50	2	0	0	0	0	0		0	2	5%	37	84%	27.5
55	0	0	0	0	0	0		0	0	0%	37	84%	30
60	0	0	0	0	0	0		0	0	0%	37	84%	32.5
65	0	0	0	0	0	0		0	0	0%	37	84%	37.5
80	1	0	0	0	0	0		0	1	2%	38	86%	40
90	0	0	0	0	0	0		0	0	0%	38	86%	42.5
95	1	0	0	0	0	0		0	1	2%	39	89%	47.5
100	0	1	0	0	0	0		0	1	2%	40	91%	50
110	1	0	0	0	0	0		0	1	2%	41	93%	55
Not detect.	3	0	0	0	0	0		0	3	7%	44	100%	
Total	15	6	6	4	11	1		1	44				
% not detect.	20%	0%	0%	0%	0%	0%		0%					

B) Interval between samples: **600** s, N samples session: **15**

Min. sampling length (sec)	Call %								All call % combined				Σ samp. time (min) /session
	<0.1	<0.25	<0.5	<1	<5	<10	<25	<50	N	Percent	Cum. N	Cum. %	
5	1	1	4	3	10	1		1	21	48%	21	48%	1.25
10	2	2	1	0	1	0		0	6	14%	27	61%	2.5
15	0	1	0	0	0	0		0	1	2%	28	64%	3.75
20	0	0	0	1	0	0		0	1	2%	29	66%	6.25
25	1	0	0	0	0	0		0	1	2%	30	68%	8.75
35	0	0	0	0	0	0		0	0	0%	30	68%	10
40	0	0	0	0	0	0		0	0	0%	30	68%	11.25
45	0	1	0	0	0	0		0	1	2%	31	70%	12.5
50	1	0	0	0	0	0		0	1	2%	32	73%	13.75
55	0	0	0	0	0	0		0	0	0%	32	73%	15
60	1	0	0	0	0	0		0	1	2%	33	75%	16.25
65	1	0	1	0	0	0		0	2	5%	35	80%	18.75
80	1	0	0	0	0	0		0	1	2%	36	82%	20
90	0	0	0	0	0	0		0	0	0%	36	82%	21.25
95	0	0	0	0	0	0		0	0	0%	36	82%	23.75
100	0	0	0	0	0	0		0	0	0%	36	82%	25
110	1	0	0	0	0	0		0	1	2%	37	84%	27
Not detect.	6	1	0	0	0	0		0	7	16%	44	100%	
Total	15	6	6	4	11	1		1	44				
% not detect.	40%	17%	0%	0%	0%	0%		0%					

Table A5: Analysis by **session** and AM or PM. Call percent is for site by AM or PM over entire transcript. Occurrence is whether a species occurred in the complete transcription: 1 = Occurred, 0 = did not occur. Inf= Infinity, means species not detected in sample which could be because it didn't occur during session or if it occurred during session, it was not detected in any of the samples.

A) Interval between samples: **150** s, N samples session: **60**

Min. sampling length (sec)	Call %									All call % combined				Σ samp. time (min) /session
	<0.1	<0.25	<0.5	<1	<5	<10	<25	<50	N	Percent	Cum. N	Cum. %	
5	1	5	9	23	58	16	5	2	121	59%	121	59%	5.00
10	2	3	6	5	5	0	0	0	21	10%	142	70%	10.00
15	0	4	1	0	2	0	0	0	7	3%	149	73%	15.00
20	0	2	1	2	0	0	0	0	5	2%	154	75%	20.00
25	0	0	1	0	0	0	0	0	1	0%	155	76%	25.00
30	1	0	0	0	2	0	0	0	3	1%	158	77%	30.00
35	3	3	0	0	0	0	0	0	6	3%	164	80%	35.00
40	1	0	1	0	0	0	0	0	2	1%	166	81%	40.00
45	1	2	0	0	0	0	0	0	3	1%	169	83%	45.00
50	2	1	1	0	0	0	0	0	4	2%	173	85%	50.00
55	1	1	0	0	0	0	0	0	2	1%	175	86%	55.00
60	1	0	0	0	0	0	0	0	1	0%	176	86%	60.00
65	1	1	2	0	0	0	0	0	4	2%	180	88%	65.00
70	0	1	1	0	0	0	0	0	2	1%	182	89%	70.00
75	2	0	1	0	0	0	0	0	3	1%	185	91%	75.00
80	1	1	1	1	0	0	0	0	4	2%	189	93%	80.00
85	0	1	0	1	0	0	0	0	2	1%	191	94%	85.00
90	0	1	0	0	0	0	0	0	1	0%	192	94%	90.00
95	1	1	1	0	0	0	0	0	3	1%	195	96%	95.00
100	0	0	1	0	0	0	0	0	1	0%	196	96%	100.00
105	0	0	1	0	0	0	0	0	1	0%	197	97%	105.00
110	1	0	0	0	0	0	0	0	1	0%	198	97%	110.00
115	0	1	0	0	0	0	0	0	1	0%	199	98%	115.00
120	0	0	0	0	0	0	0	0	0	0%	199	98%	120.00
Not detect.	4	1	0	0	0	0	0	0	5	2%	204	100%	
Total	23	29	28	32	67	16	5	2	204				
% not detect.	17%	3%	0%	0%	0%	0%	0%	0%	2%				

B)   Interval between samples: **300** s, N samples session: **30**

Min. sampling length (sec)	Call %								All call % combined				Σ samp. time (min) /session
	<0.1	<0.25	<0.5	<1	<5	<10	<25	<50	N	%	Cum. N	Cum. %	
5	0	0	5	15	42	15	5	2	86	42%	86	42%	2.5
10	2	0	3	5	6	0	0	0	16	8%	102	50%	5
15	0	2	2	0	2	0	0	0	6	3%	108	53%	7.5
20	0	0	2	3	5	1	0	0	11	5%	119	58%	10
25	0	1	1	1	3	0	0	0	6	3%	125	61%	12.5
30	1	0	1	0	1	0	0	0	3	1%	128	63%	15
35	2	3	0	0	1	0	0	0	6	3%	134	66%	17.5
40	0	0	1	0	1	0	0	0	2	1%	136	67%	20
45	0	2	0	0	1	0	0	0	3	1%	139	68%	22.5
50	2	0	0	0	1	0	0	0	3	1%	142	70%	25
55	1	0	0	1	0	0	0	0	2	1%	144	71%	27.5
60	1	0	1	1	0	0	0	0	3	1%	147	72%	30
65	0	1	2	1	0	0	0	0	4	2%	151	74%	32.5
70	0	0	0	0	0	0	0	0	0	0%	151	74%	35
75	0	1	1	0	2	0	0	0	4	2%	155	76%	37.5
80	1	0	3	1	0	0	0	0	5	2%	160	78%	40
85	0	0	0	2	0	0	0	0	2	1%	162	79%	42.5
90	0	0	0	1	0	0	0	0	1	0%	163	80%	45
95	0	0	2	0	1	0	0	0	3	1%	166	81%	47.5
100	0	1	1	0	1	0	0	0	3	1%	169	83%	50
105	0	0	0	0	0	0	0	0	0	0%	169	83%	52.5
110	1	0	0	0	0	0	0	0	1	0%	170	83%	55
115	0	1	0	0	0	0	0	0	1	0%	171	84%	57.5
120	0	0	0	0	0	0	0	0	0	0%	171	84%	60
Not detect.	12	17	3	1	0	0	0	0	33	16%	204	100%	
Total	23	29	28	32	67	16	5	2	204				
% not detect.	52%	59%	11%	3%	0%	0%	0%	0%	16%				

C) Interval between samples: **600** s, N samples session: **15**

Min. sampling length (sec)	Call %								All call % combined				Σ samp. time (min) /session
	<0.1	<0.25	<0.5	<1	<5	<10	<25	<50	N	%	Cum. N	Cum. %	
5	0	0	2	9	23	12	5	2	55	27%	55	27%	1.25
10	2	0	1	4	9	2	0	0	18	9%	73	36%	2.5
15	0	2	0	0	2	0	0	0	4	2%	77	38%	3.75
20	0	0	0	2	3	0	0	0	5	2%	82	40%	5
25	0	1	0	1	5	0	0	0	7	3%	89	44%	6.25
30	0	0	0	0	2	0	0	0	2	1%	91	45%	7.5
35	1	2	0	1	1	0	0	0	5	2%	96	47%	8.75
40	0	0	0	0	2	0	0	0	2	1%	98	48%	10
45	0	2	0	0	1	0	0	0	3	1%	101	50%	11.25
50	1	0	0	1	2	0	0	0	4	2%	105	51%	12.5
55	0	0	0	0	0	0	0	0	0	0%	105	51%	13.75
60	0	0	1	2	1	1	0	0	5	2%	110	54%	15
65	0	0	2	1	1	0	0	0	4	2%	114	56%	16.25
70	0	0	0	0	1	1	0	0	2	1%	116	57%	17.5
75	0	2	0	0	3	0	0	0	5	2%	121	59%	18.75
80	0	0	3	1	0	0	0	0	4	2%	125	61%	20
85	0	0	0	1	0	0	0	0	1	0%	126	62%	21.25
90	0	0	0	1	1	0	0	0	2	1%	128	63%	22.5
95	0	0	1	0	0	0	0	0	1	0%	129	63%	23.75
100	0	0	1	0	1	0	0	0	2	1%	131	64%	25
105	0	0	0	0	1	0	0	0	1	0%	132	65%	26.25
110	1	0	0	1	0	0	0	0	2	1%	134	66%	27.5
115	0	1	0	0	0	0	0	0	1	0%	135	66%	28.75
120	0	0	1	1	0	0	0	0	2	1%	137	67%	30
Not detect.	18	19	16	6	8	0	0	0	67	33%	204	100%	
Total	23	29	28	32	67	16	5	2	204				
% not detect.	78%	66%	57%	19%	12%	0%	0%	0%	33%				

Table A6: Minimum sampling length (Min. Sample) per species under different sampling intervals. Inf= infinity, call not detected under this sapling regime. Am/Pm= morning/evening session, N Samples= number of sampling units per session, # Call/H= number of calls per hour, Occurrence= bird call occurred within session yes (1) or no (0), Detected= call detected using 15s-frame sampling regime (yes (1) or no (0)).

Species	Am/Pm	Site	Interval	N Samples	Call %	#Call/H	Occurrence	Min. Sample	Detected
BrownCreeper	AM	3_4	150	60	0.00	0	0	Inf	0
BrownCreeper	AM	3_4	300	30	0.00	0	0	Inf	0
BrownCreeper	AM	3_4	600	15	0.00	0	0	Inf	0
BrownCreeper	AM	2_3	150	60	0.02	0.1	1	55	0
BrownCreeper	AM	2_3	300	30	0.02	0.1	1	Inf	0
BrownCreeper	AM	2_3	600	15	0.02	0.1	1	Inf	0
BrownCreeper	AM	1_30	150	60	0.67	3.3	1	5	0
BrownCreeper	AM	1_30	300	30	0.67	3.3	1	5	0
BrownCreeper	AM	1_30	600	15	0.67	3.3	1	20	0
BrownCreeper	AM	1_7	150	60	0.04	0.65	1	10	0
BrownCreeper	AM	1_7	300	30	0.04	0.65	1	25	0
BrownCreeper	AM	1_7	600	15	0.04	0.65	1	25	0
BrownCreeper	PM	3_4	150	60	0.00	0	0	Inf	0
BrownCreeper	PM	3_4	300	30	0.00	0	0	Inf	0
BrownCreeper	PM	3_4	600	15	0.00	0	0	Inf	0
BrownCreeper	PM	2_3	150	60	0.00	0	0	Inf	0
BrownCreeper	PM	2_3	300	30	0.00	0	0	Inf	0
BrownCreeper	PM	2_3	600	15	0.00	0	0	Inf	0
BrownCreeper	PM	1_30	150	60	0.07	0.4	1	5	0
BrownCreeper	PM	1_30	300	30	0.07	0.4	1	5	0
BrownCreeper	PM	1_30	600	15	0.07	0.4	1	5	0
BrownCreeper	PM	1_7	150	60	0.11	2	1	10	1
BrownCreeper	PM	1_7	300	30	0.11	2	1	10	1
BrownCreeper	PM	1_7	600	15	0.11	2	1	10	1
Kaka	AM	3_4	150	60	0.00	0	0	Inf	0
Kaka	AM	3_4	300	30	0.00	0	0	Inf	0
Kaka	AM	3_4	600	15	0.00	0	0	Inf	0
Kaka	AM	2_3	150	60	1.78	13.35	1	5	1
Kaka	AM	2_3	300	30	1.78	13.35	1	5	1
Kaka	AM	2_3	600	15	1.78	13.35	1	5	1
Kaka	AM	1_30	150	60	0.00	0	0	Inf	0
Kaka	AM	1_30	300	30	0.00	0	0	Inf	0
Kaka	AM	1_30	600	15	0.00	0	0	Inf	0
Kaka	AM	1_7	150	60	0.05	0.15	1	5	0
Kaka	AM	1_7	300	30	0.05	0.15	1	5	0
Kaka	AM	1_7	600	15	0.05	0.15	1	Inf	0
Kaka	PM	3_4	150	60	0.00	0	0	Inf	0
Kaka	PM	3_4	300	30	0.00	0	0	Inf	0
Kaka	PM	3_4	600	15	0.00	0	0	Inf	0
Kaka	PM	2_3	150	60	2.53	17.25	1	5	1
Kaka	PM	2_3	300	30	2.53	17.25	1	5	1
Kaka	PM	2_3	600	15	2.53	17.25	1	5	1
Kaka	PM	1_30	150	60	0.02	0.55	1	90	0
Kaka	PM	1_30	300	30	0.02	0.55	1	Inf	0
Kaka	PM	1_30	600	15	0.02	0.55	1	Inf	0
Kaka	PM	1_7	150	60	0.01	0.25	1	35	0
Kaka	PM	1_7	300	30	0.01	0.25	1	50	0
Kaka	PM	1_7	600	15	0.01	0.25	1	Inf	0
Kea	AM	3_4	150	60	0.00	0.15	1	50	0
Kea	AM	3_4	300	30	0.00	0.15	1	50	0
Kea	AM	3_4	600	15	0.00	0.15	1	50	0
Kea	AM	2_3	150	60	0.08	1.6	1	5	0
Kea	AM	2_3	300	30	0.08	1.6	1	5	0
Kea	AM	2_3	600	15	0.08	1.6	1	60	0

Species	Am/Pm	Site	Interval	N Samples	Call %	#Call/H	Occurrence	Min. Sample	Detected
Kea	AM	1_30	150	60	0.00	0	0	Inf	0
Kea	AM	1_30	300	30	0.00	0	0	Inf	0
Kea	AM	1_30	600	15	0.00	0	0	Inf	0
Kea	AM	1_7	150	60	0.00	0	0	Inf	0
Kea	AM	1_7	300	30	0.00	0	0	Inf	0
Kea	AM	1_7	600	15	0.00	0	0	Inf	0
Kea	PM	3_4	150	60	0.07	0.3	1	10	0
Kea	PM	3_4	300	30	0.07	0.3	1	10	0
Kea	PM	3_4	600	15	0.07	0.3	1	10	0
Kea	PM	2_3	150	60	0.16	2.8	1	5	1
Kea	PM	2_3	300	30	0.16	2.8	1	5	1
Kea	PM	2_3	600	15	0.16	2.8	1	5	1
Kea	PM	1_30	150	60	0.00	0	0	Inf	0
Kea	PM	1_30	300	30	0.00	0	0	Inf	0
Kea	PM	1_30	600	15	0.00	0	0	Inf	0
Kea	PM	1_7	150	60	0.01	0.2	1	110	0
Kea	PM	1_7	300	30	0.01	0.2	1	110	0
Kea	PM	1_7	600	15	0.01	0.2	1	110	0
Parakeet	AM	3_4	150	60	1.11	5.45	1	5	1
Parakeet	AM	3_4	300	30	1.11	5.45	1	5	1
Parakeet	AM	3_4	600	15	1.11	5.45	1	5	1
Parakeet	AM	2_3	150	60	1.77	7.2	1	5	0
Parakeet	AM	2_3	300	30	1.77	7.2	1	5	0
Parakeet	AM	2_3	600	15	1.77	7.2	1	5	0
Parakeet	AM	1_30	150	60	0.34	2.25	1	5	0
Parakeet	AM	1_30	300	30	0.34	2.25	1	5	0
Parakeet	AM	1_30	600	15	0.34	2.25	1	5	0
Parakeet	AM	1_7	150	60	0.31	1.3	1	5	0
Parakeet	AM	1_7	300	30	0.31	1.3	1	5	0
Parakeet	AM	1_7	600	15	0.31	1.3	1	5	0
Parakeet	PM	3_4	150	60	0.03	0.25	1	15	0
Parakeet	PM	3_4	300	30	0.03	0.25	1	Inf	0
Parakeet	PM	3_4	600	15	0.03	0.25	1	Inf	0
Parakeet	PM	2_3	150	60	0.40	1.95	1	5	0
Parakeet	PM	2_3	300	30	0.40	1.95	1	5	0
Parakeet	PM	2_3	600	15	0.40	1.95	1	5	0
Parakeet	PM	1_30	150	60	0.03	0.15	1	10	0
Parakeet	PM	1_30	300	30	0.03	0.15	1	95	0
Parakeet	PM	1_30	600	15	0.03	0.15	1	Inf	0
Parakeet	PM	1_7	150	60	0.09	0.35	1	40	0
Parakeet	PM	1_7	300	30	0.09	0.35	1	80	0
Parakeet	PM	1_7	600	15	0.09	0.35	1	80	0
Rifleman	AM	3_4	150	60	0.18	4.4	1	5	1
Rifleman	AM	3_4	300	30	0.18	4.4	1	10	1
Rifleman	AM	3_4	600	15	0.18	4.4	1	10	1
Rifleman	AM	2_3	150	60	0.00	0.4	1	10	0
Rifleman	AM	2_3	300	30	0.00	0.4	1	10	0
Rifleman	AM	2_3	600	15	0.00	0.4	1	10	0
Rifleman	AM	1_30	150	60	4.67	99	1	5	1
Rifleman	AM	1_30	300	30	4.67	99	1	5	1
Rifleman	AM	1_30	600	15	4.67	99	1	5	1
Rifleman	AM	1_7	150	60	6.07	76.3	1	5	1
Rifleman	AM	1_7	300	30	6.07	76.3	1	5	1
Rifleman	AM	1_7	600	15	6.07	76.3	1	5	1
Rifleman	PM	3_4	150	60	0.19	2.45	1	5	0
Rifleman	PM	3_4	300	30	0.19	2.45	1	100	0
Rifleman	PM	3_4	600	15	0.19	2.45	1	Inf	0
Rifleman	PM	2_3	150	60	0.00	0	0	Inf	0
Rifleman	PM	2_3	300	30	0.00	0	0	Inf	0
Rifleman	PM	2_3	600	15	0.00	0	0	Inf	0

| Species	Am/Pm	Site	Interval	N Samples	Call %	#Call/H	Occurrence	Min. Sample	Detected
Rifleman	PM	1_30	150	60	2.14	31.1	1	5	1
Rifleman	PM	1_30	300	30	2.14	31.1	1	5	1
Rifleman	PM	1_30	600	15	2.14	31.1	1	5	1
Rifleman	PM	1_7	150	60	4.15	30.85	1	5	1
Rifleman	PM	1_7	300	30	4.15	30.85	1	5	1
Rifleman	PM	1_7	600	15	4.15	30.85	1	5	1
Robin	AM	3_4	150	60	0.43	2.6	1	5	0
Robin	AM	3_4	300	30	0.43	2.6	1	5	0
Robin	AM	3_4	600	15	0.43	2.6	1	5	0
Robin	AM	2_3	150	60	3.59	8.8	1	5	1
Robin	AM	2_3	300	30	3.59	8.8	1	5	1
Robin	AM	2_3	600	15	3.59	8.8	1	5	1
Robin	AM	1_30	150	60	0.36	4.15	1	5	1
Robin	AM	1_30	300	30	0.36	4.15	1	10	1
Robin	AM	1_30	600	15	0.36	4.15	1	10	1
Robin	AM	1_7	150	60	30.20	82.75	1	5	1
Robin	AM	1_7	300	30	30.20	82.75	1	5	1
Robin	AM	1_7	600	15	30.20	82.75	1	5	1
Robin	PM	3_4	150	60	0.00	0	0	Inf	0
Robin	PM	3_4	300	30	0.00	0	0	Inf	0
Robin	PM	3_4	600	15	0.00	0	0	Inf	0
Robin	PM	2_3	150	60	0.07	0.55	1	10	0
Robin	PM	2_3	300	30	0.07	0.55	1	10	0
Robin	PM	2_3	600	15	0.07	0.55	1	65	0
Robin	PM	1_30	150	60	0.00	0	0	Inf	0
Robin	PM	1_30	300	30	0.00	0	0	Inf	0
Robin	PM	1_30	600	15	0.00	0	0	Inf	0
Robin	PM	1_7	150	60	0.22	0.85	1	5	0
Robin	PM	1_7	300	30	0.22	0.85	1	5	0
Robin	PM	1_7	600	15	0.22	0.85	1	45	0
Weka	AM	3_4	150	60	0.35	1.8	1	5	0
Weka	AM	3_4	300	30	0.35	1.8	1	15	0
Weka	AM	3_4	600	15	0.35	1.8	1	65	0
Weka	AM	2_3	150	60	0.18	0.75	1	5	0
Weka	AM	2_3	300	30	0.18	0.75	1	15	0
Weka	AM	2_3	600	15	0.18	0.75	1	15	0
Weka	AM	1_30	150	60	0.66	2.55	1	5	1
Weka	AM	1_30	300	30	0.66	2.55	1	5	1
Weka	AM	1_30	600	15	0.66	2.55	1	5	1
Weka	AM	1_7	150	60	0.57	2.3	1	5	1
Weka	AM	1_7	300	30	0.57	2.3	1	5	1
Weka	AM	1_7	600	15	0.57	2.3	1	5	1
Weka	PM	3_4	150	60	3.01	10.05	1	5	0
Weka	PM	3_4	300	30	3.01	10.05	1	5	0
Weka	PM	3_4	600	15	3.01	10.05	1	5	0
Weka	PM	2_3	150	60	0.50	1.85	1	5	0
Weka	PM	2_3	300	30	0.50	1.85	1	5	0
Weka	PM	2_3	600	15	0.50	1.85	1	5	0
Weka	PM	1_30	150	60	3.96	11.6	1	5	1
Weka	PM	1_30	300	30	3.96	11.6	1	5	1
Weka	PM	1_30	600	15	3.96	11.6	1	5	1
Weka	PM	1_7	150	60	1.28	4.05	1	5	1
Weka	PM	1_7	300	30	1.28	4.05	1	5	1
Weka	PM	1_7	600	15	1.28	4.05	1	10	1
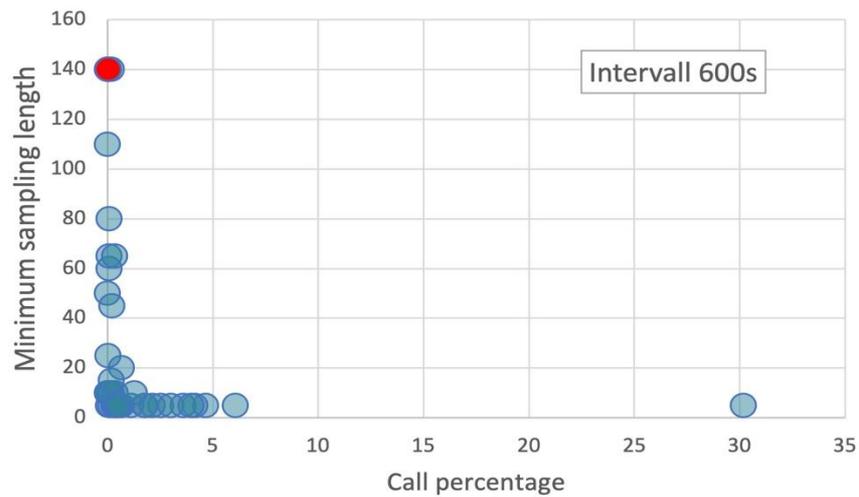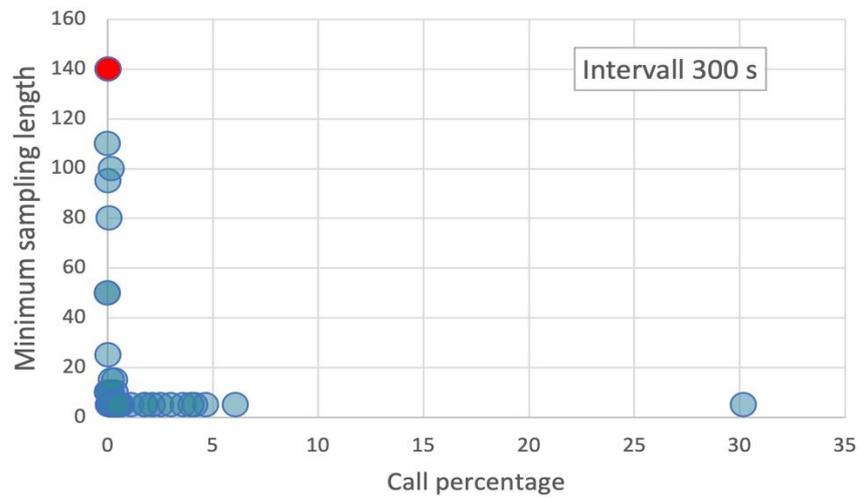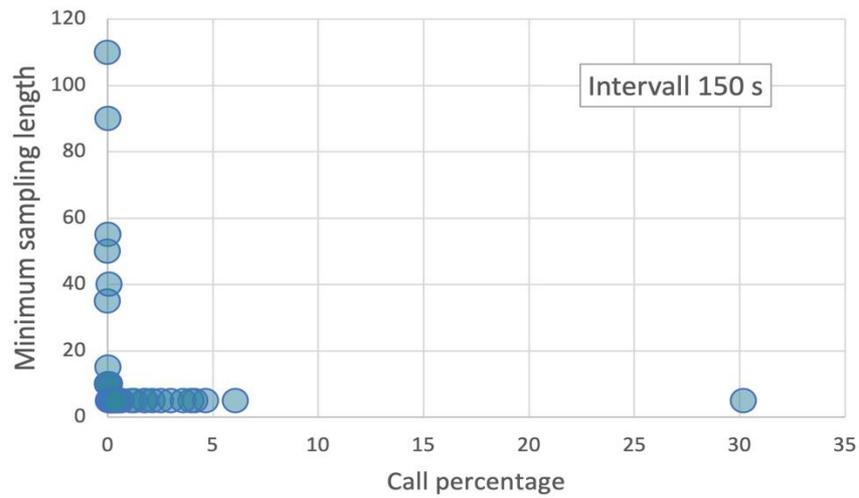
Figure A3: Relationship between call percentage (based on total transcript data) and minimum sampling length (min) until a call was detected using three different sampling intervals. The red circle indicates when sampling length raised to infinity, i.e., a call was not detected. The graphs suggest that sampling effort can be kept low as long as call percentages are above 1%, below this threshold, calls can be missed even when sampling length is high.