Biodiversity responses to possum-control in Aorangi and Haurangi Forests

Activity report for 2017-18
(Oct 2018)

Centre for Biodiversity and Restoration Ecology

Victoria University of Wellington

Biodiversity responses to possum-control in Aorangi and Haurangi Forests

Stephen Hartley and Nyree Fea
Centre for Biodiversity and Restoration Ecology
School of Biological Sciences, Victoria University of Wellington

Annual activity report for 2017-18, submitted to TBfree New Zealand.

Executive Summary

Small mammals, invertebrates and birds have been monitored across the Aorangi and the northern Remutaka forests for the past six years (Nov 2012- Oct 2018) using a before-after, control-impact (BACI) study design. During that period the Aorangi Ranges received two aerial 1080 operations, in August 2014 and June 2017. The northern Remutaka Ranges received aerial 1080 in September 2018. A major mast year (i.e. mass seeding of beech trees) affected both sites in 2014 with significant beech seed also falling in 2017. The Department of Conservation are again predicting a major mast year for 2019.

Key results

Possums and rats were knocked down by both 1080 operations in the Aorangis, however, one site out of five in the Aorangis showed persistence or rapid reinvasion of possums. After both the August 2014 and the June 2017 operations, rats were suppressed for 3-5 months post-1080. In 2014, rats had returned to pre-1080 levels after six months whereas rat detections were still comparatively low one year after the 2017 operation.

Short-term, intensive monitoring of birds, six weeks before and after the August 2014 operation, showed no decline in overall bird song. Eight bird species showed no change, whitehead showed an increase in recorded song and tomtit showed a decline in recorded song. Repeat monitoring to check the consistency of these results was undertaken over two more 1080 operations: the Aorangi Ranges in June 2017 and the southern Remutaka Ranges in late-July 2017. Again, there was no evidence of the forest falling silent (or showing a relative drop in bird song) after the two operations in 2017. The introduced chaffinch, a granivore, is the only species that may have suffered a negative effect from the Aorangi 2017 operation, but this was not replicated in the southern Remutaka 2017 operation. The prevalence of tomtit calls did not decline after either of the 2017 operations, in fact in the Southern Remutaka operation it appeared to increase in call rate in the treated zone relative to the untreated area.

Longer-term, inter-annual summer monitoring of bird calls showed that 1.5 to 2.5 years following the August 2014 1080 operation six native bird species showed a significant increase in call rates in the Aorangi Forest relative to the Remutaka Ranges: bellbird, rifleman, tomtit, tui, whitehead and kererū. One introduced species, blackbird, (and no native species) showed a significant decline after the operation.

Analysis of twenty-five different invertebrate taxa, especially weta and beetles, showed no significant effects (positive or negative) of the 2014 aerial 1080 operation on the abundance of any of the invertebrate taxa studied. This results was described in the five-year summary report (2012-2017).

Results have been disseminated via presentations at the Society for Conservation Biology conference, a radio interview, a newsletter and biodiversity report to the Aorangi Restoration Trust and within two doctoral theses published in 2018 and one Master's thesis. One research article (Cook and Hartley 2018) has been published in an international journal, describing and validating the method of analysis used to assess the prevalence of bird song in recordings.

1. **Objective(s) of research**

To determine the incidental population-level effects of 1080 possum control on a range of small mammals (rodents and mustelids) and the concomitant responses of a range of biodiversity indicators, primarily birds and large invertebrates (beetles, weta, spiders) in the Aorangi Forests of southern Wairarapa.

Integrated studies across all these trophic levels and their interactions are scarce in the New Zealand context of modern 1080 possum control, yet a better ecological understanding requires such a "whole of system" analysis. This study contributes to that perspective, and provides results that may be compared and contrasted with the monitoring associated with Project Kaka in the Tararuas.

2. Study design & methods

This study was conceived as a "before-after-control-impact" design. The "impact" or "treatment" area is the Aorangi Forest Park which received an aerial application of 1080 in August 2014 and again in June 2017. Monitoring of the Aorangis has been undertaken regularly at five sites since 2012, two years prior to first application of 1080 within this 10 year TBfree NZ programme. Over the past five years the "non-impact" or "non-treatment" reference site has been the northern Remutaka Ranges. This year there was essentially a "treatment switch", with the northern Remutaka Ranges becoming the "treated" site in Sept 2018, whie the aoranig Ranges remain untreated this year.

As of November 2013, twenty-four monitoring lines (transects) had been established across eight sites; six sites in the Aorangi Forest and two references sites in the Remutaka Ranges (Table 1, Figure 1). Victoria University of Wellington is monitoring five of the Aorangi sites and both of the Remutaka sites on a regular schedule of three visits per year: late spring (Nov/Dec), summer (February) and winter (June/July). One site in the Aoragni Ranges, Tauanui, is surveyed on a less regular schedule, as time allows.

Each line consists of a variety of monitoring devices: 10 tracking tunnels, 10 chewcards, 7 pitfall traps, 3 weta motels, 1-2 DOC bird recorders, designed to provide an index of abundance for various small mammals (possums, rats, mice, hedgehogs, mustelids), invertebrates and birds. Weta motels were introduced between 2013 and 2014. The number of DOC recorders has been increased substantially over the past year. Greater detail of study design can be found in the 2013 report to AHB.

The following report incorporates activity up for the period Sept 2017- Sept 2018, with bird population results until Feb 2017 and small mammal population results until July 2018.

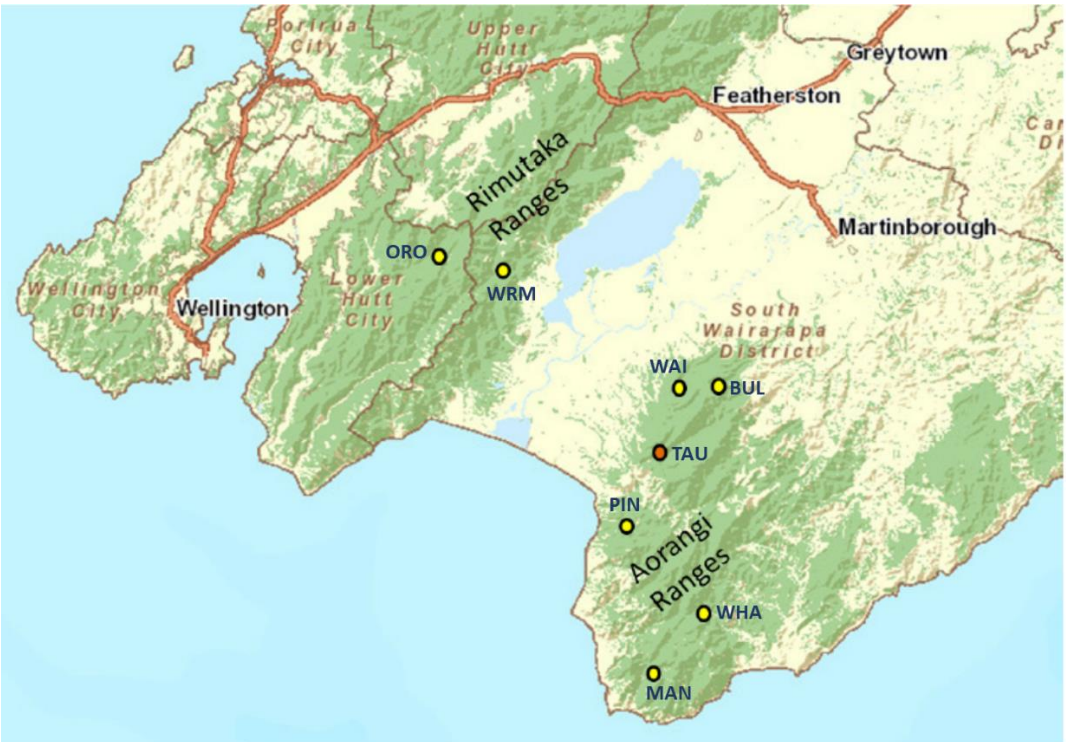


Figure 1. Map of monitoring sites established as of November 2013 (yellow circles). Each site consists of three monitoring lines, 450m long. The orange circle (Tauanui) has only been monitored occasionally. (Background map from GWRC).

Table 1. Summary of the number of lines monitored between Feb 2015 and winter 2018. Three letter site-codes highlighted in bold. (Monitoring began in Nov/Dec 2012.)

Site	Region	2015			2016			2017			2018		
		Feb Mar	Jun Jul	Nov Dec	Feb Mar	Jun Jul	Nov Dec	Feb Mar	Jun Jul	Nov Dec	Feb Mar	Jun Jul	Nov Dec
Waihora	Aorangis	3	3	3	3	3	3	3	3	3	3	3	TBA
Tauanui	Aorangis	-	-	3	@	-	-	@	@	@	3	-	TBA
Bull Hill	Aorangis	3	3	3	3	3	3	3	3	3	3	3	TBA
Pinnacles	Aorangis	3	3	3	3	3	3	3	3	3	3	3	TBA
Mangatoetoe	Aorangis	3	3	3	3	3	3	3	3	3	3	3	TBA
Whawanui	Aorangis	3	3	3	3	3	3	3	3	3	3	3	TBA
Orongorongo	Remutakas	3	3	3*	3	3	3	3	3	3	3	3	TBA
Wai**r**ongo**m**ai	Remutakas	3	3	3	3	3	2#	3	3	3	3	3	TBA

* due to access constraints ORO was surveyed in the first week of January, 2016.
# due to rain & river conditions only two lines at WRM were surveyed in Dec 2016.
@ bird recorders refreshed and weta motels checked, but no mammal monitoring

3. Results

3.1 Small mammals

Possums showed a knockdown after both the August 2014 and June 2017 aerial 1080 operations at four out of the five sites monitored in the Aorangis. The two exceptions were that possums remained at ~30% (one-night chewcard index, CCI) at Whawanui after the August 2014 operation and at ~20% at Mangatoetoe after the 2017 operation (Fig 2a). These two sites showed the highest detection rates during 2013 and were both above 10% in July 2018. Whawanui and Mangatoetoe are both located towards the southern end of the park and are close to areas that did not get treated, suggesting that dispersal from untreated areas may explain these numbers. One of the Mangatoetoe lines was outside of the drop zone of the 2018 treatment. Possums have remained low at the Pinnacles since August 2014.

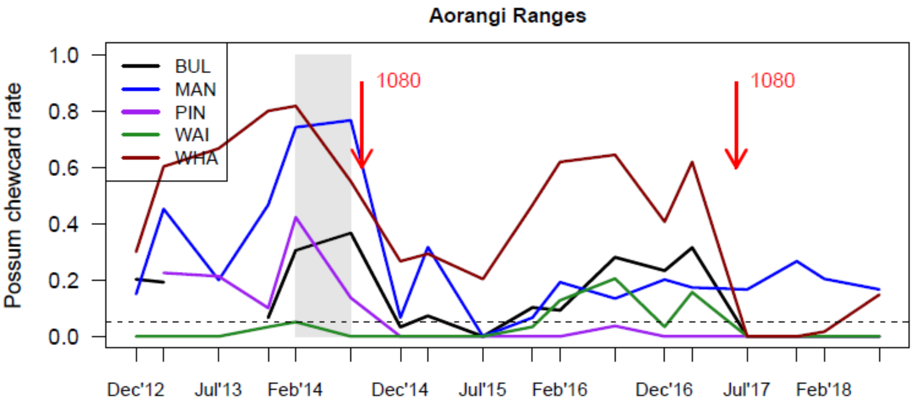
In the Remutaka Ranges, possum numbers have climbed steadily at Wairongomai from 5% in 2013 to 80% CCI in 2017, while remaining consistently low (~5%) at Orongorongo. This disparity may be explained by the different elevations at these two sites: Wairongomai at 100-200m vs Orongorongo at 500-550m and/or a halo effect from the trapping and bait stations distributed through the Wainuiomata Mainland Island. Before the September 2018 aerial 1080 operation, this region of the Remutakas was lasted treated in August 2012. Despite the low level of possum activity recorded at the Orongorongo site from our chewcard monitoring, GWRC have recorded a reasonable number of possums in the same area in the winter of 2018 using camera traps (Roger Uys, personal communication).

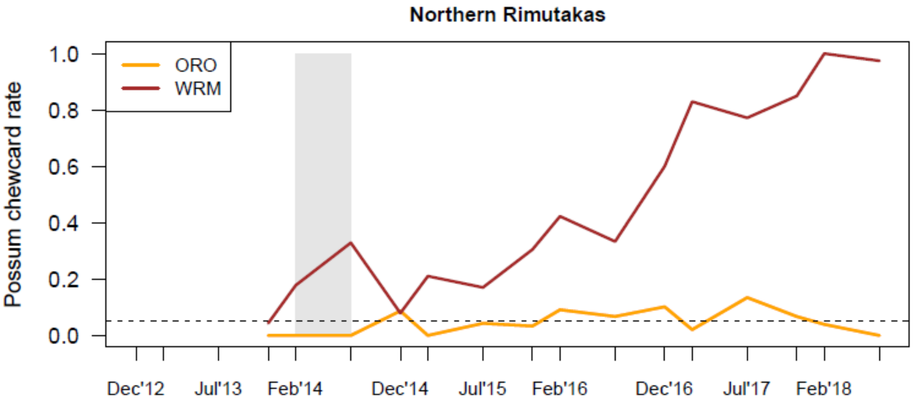
Rats showed a major knockdown after both the August 2014 and June 2017 aerial 1080 operations in the Aorangis. Tracking rates were below 5% across all Aorangi sites in November 2014, three months after the aerial 1080 operation, but by February 2015 had returned to similar levels as July 2014 (Fig 2b). By February 2017 average rat tracking rates were close to 50% but were brought down to 0% detections at all sites in monitoring completed 1-2 months after the June 2017 operation. Twelve months later (July 2018) rat abundance in the Aorangi Ranges remained consistently lower than the pre-1080 levels of Feb 2017. In the Remutaka Ranges, rat numbers showed a sharp increase in the year following the 2014 mast, followed by an even more dramatic crash between July and December 2015 (from 80-100% to 5-10%). Numbers started to recover again at both sites in the summer of 2016/17, perhaps fuelled by a moderate mast year. Rat abundances in July 2018 appear to be similar across the two ranges.

Mouse tracking rates were generally low (less than ~20% tracking) over the past six years, apart from at the Pinnacles and Waihora sites in the Aorangi Ranges. Tracking rates were high at both of these sites in December 2012 before dropping to 0% in the summer of 2013/14. After the mast year, mouse numbers spiked again, temporarily, at the Pinnacles and Waihora (Fig 2c). The 1080 operation in August 2014 did not seem to depress mouse numbers in November 2014, however the most recent 1080 operation in June 2017 appears to have had a noticeable effect, bringing mouse tracking rates down to 0% as of July/August 2017. Mouse populations in the Remutaka Ranges appear to peak around the same time that rat populations do which suggests that both species of rodents experience increases after significant seedfall in these forests (i.e. a heavy mast in 2014 and a moderate mast in 2017).

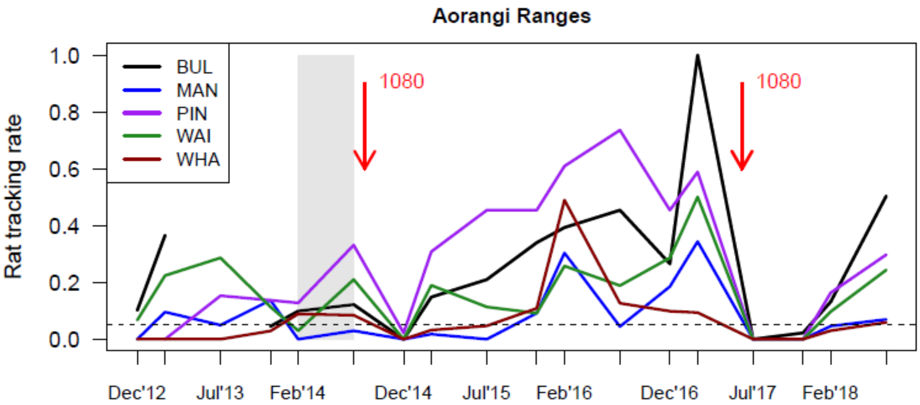
Hedgehog tracking rates showed distinct seasonal fluctuations. They have been recorded only three times in winter (July/August), occasionally they were detected in November/December and most frequently they were recorded in February, usually at 20-40% (Fig 2d). Hedgehog numbers did not seem to be affected by the August 2014 1080 operation, which is not surprising given that they are usually hibernating during winter. Some dead hedgehogs were observed whilst servicing monitoring lines in July 2017, which may be explained by the relatively mild weather and earlier drop in June 2017.

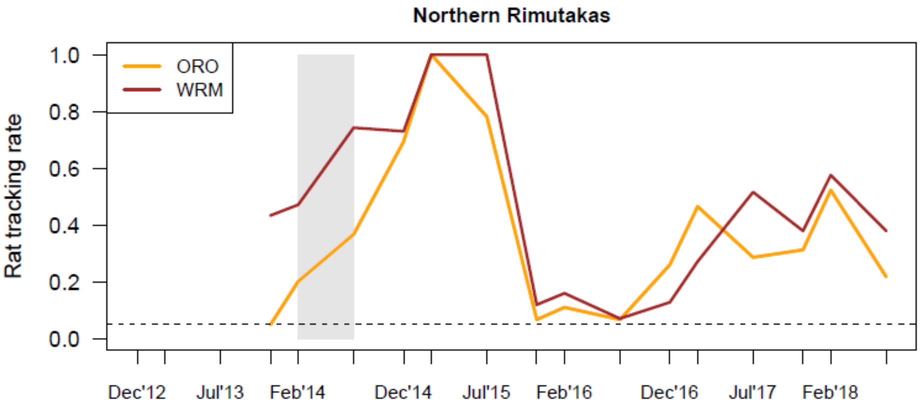
a) Possums



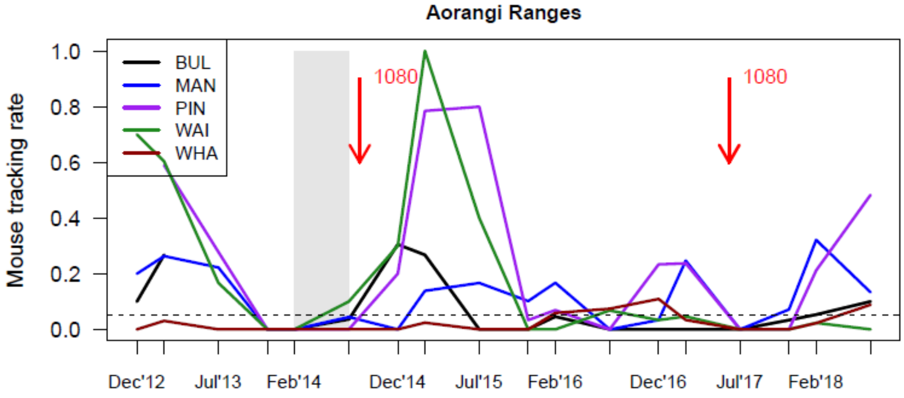


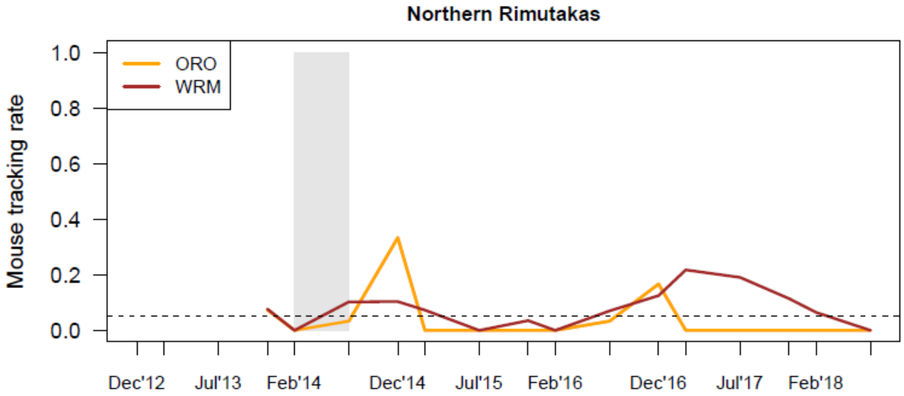
b) Rats



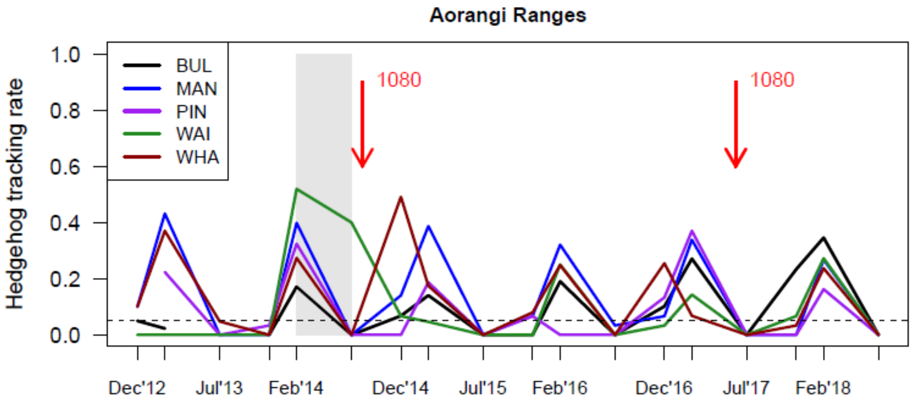


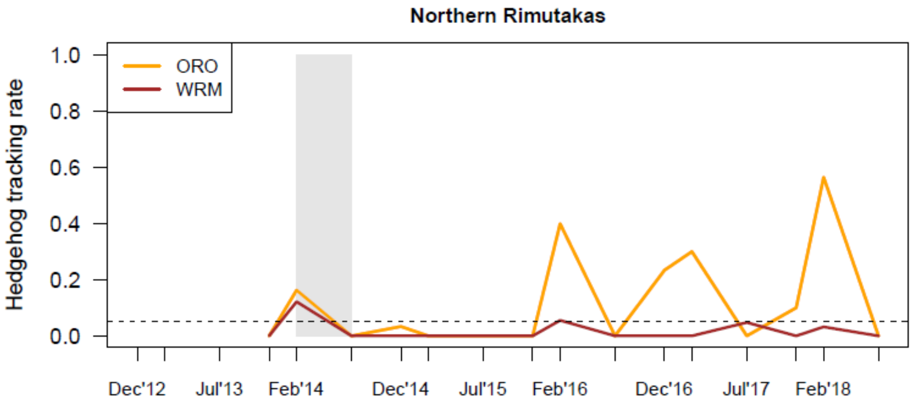
c) Mice





d) Hedgehogs





e) Mustelids

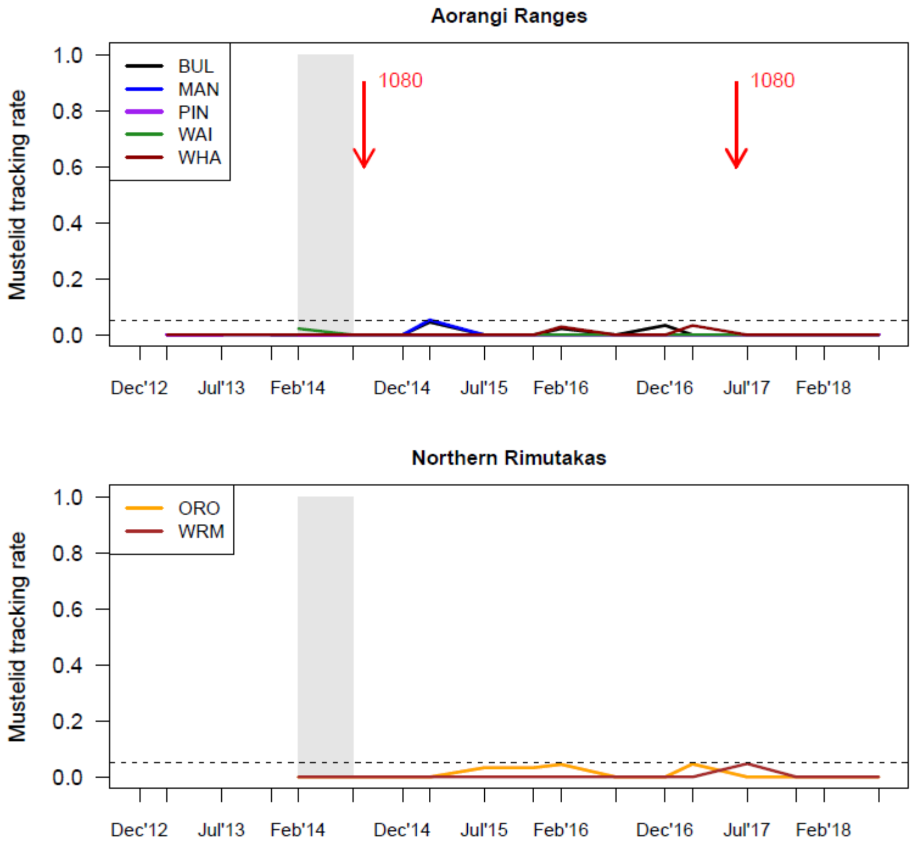


Figure 2. Detection rates of a) possums, b) rats, c) mice, d) hedgehogs and e) mustelids across the Aorangi and Remutaka monitoring sites. Results are shown separately by site (5 sites in the Aorangi and 2 in the Remutaka Ranges). Each site is monitored by 3 lines of 10 tracking tunnels and chewcards.. Possums were indexed using chewcards (with February rates transformed to a one-night equivalent) and adjusted to account for interference by rats following the heuristic in Gilles & Williams (2013) *DOC Tracking Tunnel Guide v2.5.2*. All other mammals were indexed using tracking tunnels. Rat tracking rates have been transformed to equal those expected from DoC standard operating protocols (one-night with peanut butter at both ends) and adjusted to account for possum interference. The horizontal dashed line indicates a 5% tracking rate. The grey band between February and July 2014 represents a heavy mast year with abundant beech seed on the ground. Red arrows indicate the timing of aerial 1080 drops in the Aorangis (August 2014 and June 2017). The most recent 1080 drop in the northern Remutaka Ranges was September 2018 and is not shown on these graphs.

Mustelids (presumably stoats) were very rarely detected at any of the sites. Tracking rates were between 0 and 5% (Fig 2e). Rabbit meat was used as a lure in half of the tracking tunnels during the February monitors. At other times, all tunnels were baited with peanut butter. Trap data may provide more useful data on fluctuations in mustelid numbers, particularly from traps located within the forest habitat.

3.2 Invertebrates

Olivia Vergara completed her PhD successfully in July 2018 and a digital copy of her thesis is now available online (*Macroinvertebrate community responses to mammal control - Evidence for top-down trophic effects* http://hdl.handle.net/10063/6957). Three of her chapters describe research on invertebrates in the Aorangis:

Chapter 3. Neutral responses of ground-dwelling invertebrate communities to aerial 1080 operations in New Zealand.

Chapter 4. Top down effects on ground-dwelling invertebrates in Aorangi and Remutaka Forests, New Zealand.

Chapter 5. The efficiency and biases of squid-baited pitfall traps used for collecting ground weta and other ground-dwelling invertebrates in New Zealand.

The results of chapter 3 were included in the five-year summary report. All three chapters are being worked on for publication in peer reviewed journals. In addition, the taxonomic identity of the beetles collected continues to be refined through comparison with collections at Te Papa and a pictorial guide to their diversity is being developed (Table 2 and Figure 3).

Tiger beetle: *Neocicindela parryi*, (Cicindelidae)

Stag beetle: *Paralissotes reticulatus* Male (Lucanidae)

Ground beetle: *Ctenognathus novaezelandiae* (Carabidae). The most abundant Carabidae in Aorangi and Remutaka forests between 2012-2015

Ground beetle: *Megadromus capito* (Carabidae)

Male crab spider. (Araneae: Thomisidae)

Wellington tree weta: *Hemideina crassidens*

Figure 3. Specimen photos of selected invertebrates found in the Aorangi and Remutaka Ranges. Photos 1-5 by Olivia Vergara.

Table 2. Taxonomic composition and total abundance of invertebrates sampled via pitfall traps in the Aorangi and Remutaka forests from November 2013 to December 2015. 'spp' denotes multiple species (plural) within the genus. (Olivia Vergara, thesis data, updated 24 Sept 2018)

Taxonomic level				Total
Class	Order	Family	Species	
Collembola (springtails)				7768
Insecta	Coleoptera (beetles)	Carabidae (ground beetles)	*Ctenognathus* sp1	134
			Ctenognathus novaezelandiae	189
			Mecodema angustulum	6
			Mecodema sp1	14
			Megadromus capito	29
			Megadromus vigil?	15
			Demetrida nasuta	7
			Holcapsis? sp1	10
			Holcapsis spp	30
			Plocamostethus planiusculus	3
			Morphospecies 4	15
			Morphospecies 9	3
			Morphospecies 13	2
			Morphospecies 16	36
			Carabidae subtotal	493
		Scarabaeidae (dung beetles)	*Saphobius* spp.	1148
		Curculionidae (weevils)	*Nestrius* sp. and others.	48
		Chrysomelidae (leaf beetles)		4
		Staphylinidae (rove beetles)		183
		Pselaphinae		19
		Tenebrionidae (darkling beetles)	*Mimopeus* sp	1
		Lucanidae (stag beetles)	*Paralissotes reticulatus*	1
			Geodorcus sp.	1
		Elateridae (click beetles)		36
		Other beetles		247

	Orthoptera	Raphidophoridae (cave weta)		225
		Anostostomatidae (ground weta)	*Hemiandrus* spp.	590
	Diptera (flies)			5575
	Hemiptera (true bugs)			158
	Hymenoptera (ants & wasps)			736
	Blatteria (cockroaches)			16
Arachnida	Acari (ticks & mites)			1456
	Araneae (spiders)		*Uliodon* sp., *Amphinecta* sp., *Cycloctenus* sp, *Toxopsiella centralis*?, *Aorangia* sp., *Orepukia geophila*, *Maniho vulgaris*, *Cryptachaea blattea,* and others.	771
	Opiliones (harvestmen)			654
	Pseudoscorpions			22
Diplopoda (millipedes)				64
Chilopoda (centipedes)				28
Crustacea	Isopoda			47
	Amphipoda			414
Gastropoda (slugs and snails)				61
TOTAL				20766

3.3 Birds

Bird abundance has been monitored via the use of automated sound recording devices (ARDs). The number of DOC bird recorders in the Aorangi and Remutaka forests has been increased considerably from 13 in the first few years to 48 over the past year. There are currently 16+ DOC recorders in each of three regions (Aorangi Ranges, northern Remutaka Ranges and Southern Remutaka Ranges). Recordings collected between mid-November and March are used to accumulate multi-year trends in summer call rates, starting in Dec 2012. Recordings taken 5-6 weeks either side of a 1080 drop and used to examine for short-term negative effects of a 1080 drop (i.e. testing whether the forest "falls silent").

The recorders in these three forests have been scheduled to record 30 minutes in the morning and 5 minutes at night in order to achieve at least 4 months' worth of recording per service and to maximise the number of weeks in which all recorders are operating simultaneously. The Aorangi Ranges received a 1080 drop in Aug 2014 and June 2017. The southern Remutaka Ranges received its first ever drop in August 2017. All three of these drops have been monitored for short-term ("silent forest") responses. The results of the August 2014 drop have been reported previously. Here we add results from the short-term recording across the two latest drops in 2017.

3.3.1. Prevalence of bird song before-and-after two lower North Island 1080 operations in winter 2017.

This study employed a BACI (Before-After/Control-Impact) experimental design utilising recordings from automated Acoustic Recording Units (ARUs) to compare changes in the prevalence of bird calls from native and introduced day-active bird species in treatment and non-treatment areas from before-and-after two 1080 operations.

Sound recordings were made using Department of Conservation (DOC) ARUs deployed across seven study sites in three study areas within the Wellington region: the Aorangi, Northern Remutaka and Southern Remutaka Ranges. Within a study area, between one and four study sites were utilized. A study site comprised between three and nine recorders that could be serviced in one day (i.e. have their batteries and SD cards replaced) by a pair of field technicians or students. Across all sites, recorders were spaced at least 350 m apart.

Eighteen ARUs were monitored in the Aorangi Range across an operation occurring on 16-17 June 2017. The Aorangi Range previously received aerial 1080 treatment in August 2014. Seven ARUs were monitored across the Southern Remutaka Range's first and most recent aerial 1080 treatment on 30 July 2017. The Northern Remutaka Range area did not receive 1080 treatment throughout the course of this study and served as a control site for both treatments. This area last received aerial 1080 treatment in August 2012 (Uys & Crisp, 2018). Within the Northern Remutaka Range, 18 and 17 ARUs were monitored as control comparisons for the Aorangi and Southern Remutaka Range operations respectively.

Recorders were set to record simultaneously across all locations to minimise the effects of intra-day variability in species' calling prevalences. Recording spanned 30 minutes from 0800-0830 h (NZST) for a period of at least six weeks before and six weeks after each 1080 operation's application of toxic baits. From these recordings, one day (consistent across all sites) was selected and analysed per week based on weather and recording quality criteria for two five-week periods per operation: (1) five weeks before, and (2) weeks two to six after each respective operation (Table 3).

Table 3. Spatial and temporal extent of the sampling. n = number of automated recording devices per area.

1080 Operation	Treatment Area	Reference Area	Period monitored
Aorangi Ranges, 16-17 June 2017	Aorangi Ranges (n = 18)	Northern Remutaka (n=18)	Before = 10 May-15 June After = 24 June – 31 July
Southern Remutaka, 30 July 2017	Southern Remutaka (n=18)	Northern Remutaka (n=17)	Before = 25 June– 29 July After = 6 Aug – 11 Sept

Scoring audio recordings

Audio recordings were scored employing the 'intermittent method' described by Cook and Hartley (2018) for thirty ten-second sub-samples comprising the first ten seconds of every minute in each thirty minute recording. Recordings were scored by simultaneously listening to recordings and visually inspecting their spectrograms. A call was scored as present in a sub-sample if it could be both heard in the recording at maximum volume and seen on the spectrogram. Where possible, calls were identified to one of 17 focal species known to inhabit the areas studied. If a call could not be confidently identified to a species after listening to a sub-sample five times, the call was classed as an 'unknown'. When present in a sub-sample, wingbeats were also classified as a presence for kererū due to the species' infrequent calling.

To account for the potential influence of misidentifications, tūī or bellbird calls were given one of three classifications: calls that could be confidently classified as bellbird or tūī were classified as their respective species, whereas calls that could not be confidently classified were grouped (bellbird/tūī). Blackbird (*Turdus merula*) and song thrush (*Turdus philomelos*) calls can also be similar and difficult to distinguish. As this study was primarily focused on native bird species' responses, calls for these species were grouped (blackbird/thrush, i.e *Turdus* sp.).

Lack of bird song or (kererū wingbeats) was classed as "silence", and the amount of silence was calculated for each acoustic recording analysed to assess if treatment area bird communities 'fell silent' after 1080 operations relative to non-treatment areas.

Statistical analyses

For each 1080 operation, statistical analyses were carried out for the amount of 'silence', and for the calling prevalences of those species found to be both calling in at least 1% of all sub-samples analysed across all counts; and present in at least half of both treatment and non-treatment recording locations for the respective operation. This filter removed very rare and/or highly localised bird species from the analysis.

For each sample, the treatment type (1080 or non-1080), time period (before or after 1080), study site, recorder location, and recording date were recorded. A logistic mixed effects model was fitted in R using the lme4 package and the formula:

$$Species_x\ Calling\ Prevalence \sim Treatment\ Type * Time\ Period \\ + (1|Study\ Site/Recorder\ Location)\ + (1|Date)$$

The dependent variable was entered as a single value proportion (rather than 30 ones and zeroes) weighted by 30. It was of interest whether or not changes in calling prevalences from before to after 1080 operations differed between treatment and non-treatment sites. Hence, a type III ANOVA was carried out on the resulting models to produce a chi-square value for the interaction term (treatment type x time). A non-parametric permutation test (5000 permutations) was applied to test significance for each chi-square value observed. Permutations were made across time periods and within recorder locations. Any observations missing due to recording failure (NAs) were held constant in their location within the dataset.

Results

Silence

Both treatment and non-treatment sites showed a general increase in the prevalence of silent sub-samples for the Aorangi 2017 operation (Figure 4a). There was no significant interactive effect between treatment type and time period on the prevalence of silent sub-samples for this operation ($p = 0.469$, $\chi^2 = 2.699$), hence no evidence fo the 1080-treated forest falling more silent than the untreated forest. In contrast, there was a significant interactive effect between treatment type and time period on the prevalence of silent sub-samples for the Southern Remutaka 2017 operation ($p < 0.001$, $\chi^2 = 139.26$). The 1080-treated forest showed a decrease in silence from before to after the operation, whereas the non-treatment sites showed an increase (Figure 4b). This suggests that, relative to pre-treatment levels, overall bird song became more frequent in the treatment site two to six weeks post-treatment.

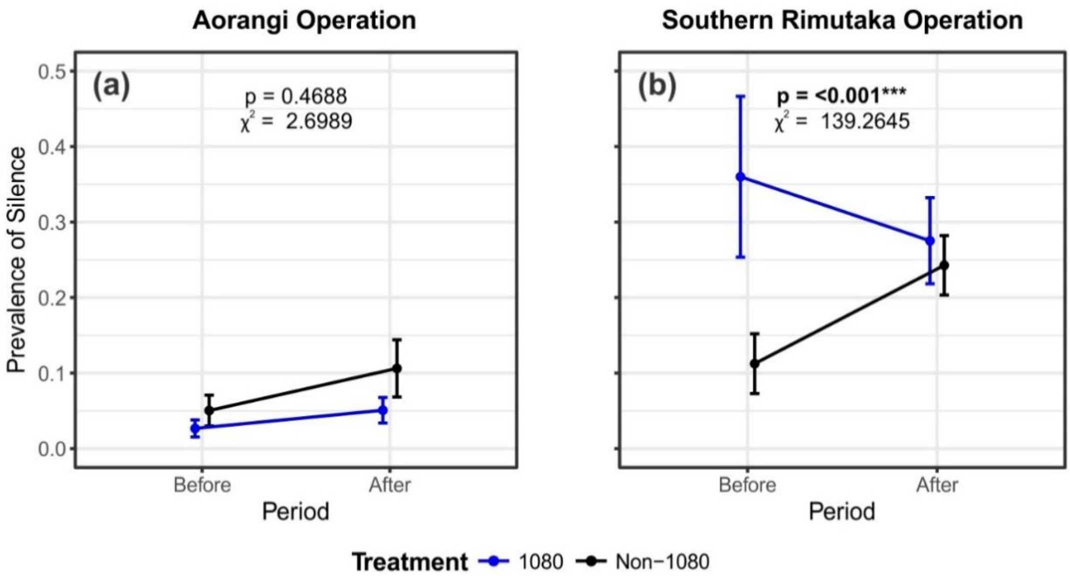


Figure 4 Grand mean prevalences of silent sub-samples ± 1 SE (n = number of recorder locations monitored) in treatment and non-treatment areas before and after (a) the June 2017 Aorangi and (b) July 2017 Southern Rimutaka aerial 1080 operations. Mean and SE estimates are an approximate representation of interactions, whereas associated chi-sqaure and p-values are presented from permutation tests accounting for the spatially-nested and temporally replicated nature of the experimental design. Asterisks (***) indicate p < 0.001, plots share y-axes.

Species-level

Aorangi operation

Eleven taxa satisfied requirements for statistical analyses in the Aorangi operation study. However, only ten are presented here as permutation models for kererū suffered a high rate of convergence failures. Of the results presented, eight species showed no interaction between treatment type and time period (i.e. no response to 1080) at the 5% significance level, with treatment type having no significant effect on changes in calling prevalences from before to after treatment (Figure 5a-e, h-j).

A significant interaction between treatment type and time period was found for the calling prevalence of both bellbird ($p = 0.047$, $\chi^2 = 14.814$) and chaffinch ($p = 0.043$, $\chi^2 = 2.548$). Mean calling prevalences decreased from before to after 1080 treatment in both treatment and non-treatment sites for both of these species (Figure 5f, g). For bellbird, however, this decrease was more substantial in non-treatment sites when compared to treatment sites. The opposite interaction held true for the prevalence of chaffinch calls, which showed a greater decrease in treatment sites than in non-treatment sites. The chaffinch is the only species which may have suffered a direct negative effect of 1080 from the 2017 Aorangi operation. There is no evidence of any negative effects on any native species.

Southern Remutaka operation

Nine taxa satisfied requirements for statistical analyses of the Southern Remutaka operation. However, only eight are presented here as permutation models for tūī suffered high rates of convergence failures. Of these eight taxa, six showed no significant interaction between treatment type and time period at the 5% significance level; there was no significant difference in changes in calling prevalences from before to after the 1080 treatment between treatment and non-treatment sites for these species (Figure 6a, b, d, f-h).

A significant interaction was found for bellbird/tūī (*A. melanura/P. novaeseelandiae*) and tomtit (*P. macrocephala*). Bellbird/tūī showed a decrease in calling prevalence in non-treatment sites relative to treatment sites ($p < 0.001$, $\chi^2 = 31.080$) (Figure 3c). Tomtit showed a significant increase in calling prevalence in treatment sites relative to non-treatment sites ($p < 0.043$, $\chi^2 = 37.438$): mean calling prevalence nearly doubled from 0.232 ± 0.063 to 0.420 ± 0.034 in treatment sites, whereas mean calling prevalence only increased slightly from 0.197 ± 0.035 to 0.216 ± 0.058 in non-treatment sites (Figure 6e). None of these results suggests a direct negative effect of 1080 on birds durign the Southern Remutaka operation.

For further discussion see Roald Bomans' master's thesis: *Bioacoustic monitoring of New Zealand avifauna before and after aerial 1080 operations*

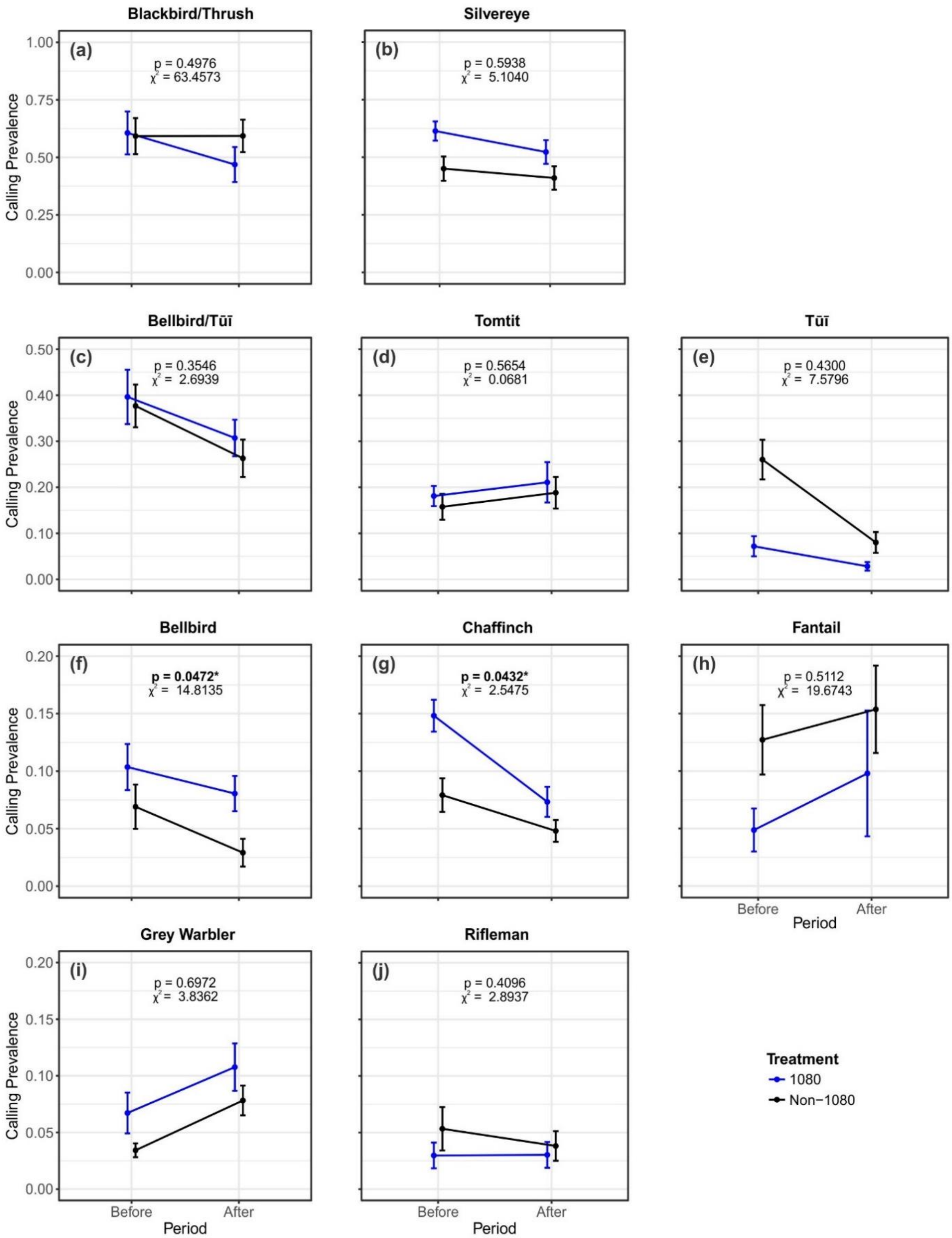


Figure 5 Grand mean calling prevalences ± 1 SE (n = number of recorder locations sampled) from zero to five weeks before to one to six weeks after 1080 treatment for treatment and non-treatment areas monitored across the **June 2017 Aorangi operation**, and associated chi-square and p-values. Mean and SE estimates are shown only for species satisfying statistical analysis requirements, and are an approximate representation of interactions, whereas statistics were calculated via a permutation test accounting for the spatially-nested and temporally replicated nature of the experimental design. Columns and rows of plots share x and y axes respectively.

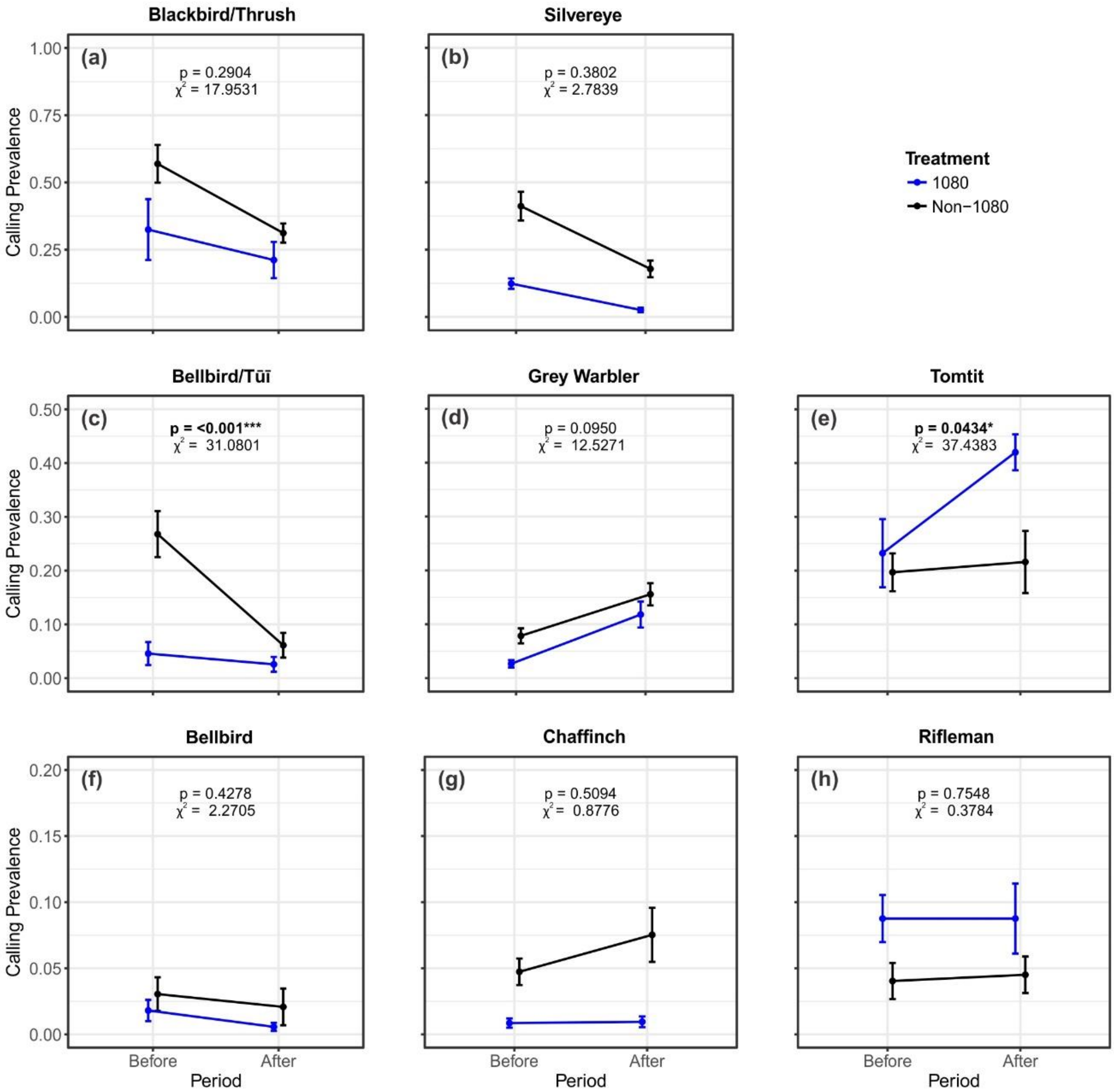


Figure 6 Grand mean calling prevalences ± 1 SE (n = number of recorder locations monitored) zero to five weeks before and one to six weeks after 1080 treatment in treatment and non-treatment areas monitored across the **July 2017 Southern Rimutaka operation**, and associated chi-square and p-values. Mean and SE estimates are shown for species satisfying statistical analysis requirements, and are an approximate representation of interactions, whereas associated statistics were calculated via permutation tests accounting for the spatially-nested and temporally replicated nature of the experimental design. Columns and rows of plots share x and y axes respectively. Asterisks (*, ***) indicate p < 0.05 and 0.001 respectively.

3.3.2. Longer-term (multi-year) bird responses of diurnal birds, 2012-2017.

Nyree Fea completed her PhD successfully in July 2018 and a digital copy of her thesis is now available online (*The responses of New Zealand's arboreal forest birds to invasive mammal control*. http://hdl.handle.net/10063/7640). One of the chapters in this thesis is entirely focused on the responses of birds to mammal control in the Aorangis (Chapter 4: “The effects of aerial 1080 and a heavy seedfall event on forest bird and mammal populations in the Aorangi Forest Park, New Zealand”). Additionally, the bird population data collected in the Aorangi and Remutaka Ranges also contributed to two other research projects in Nyree’s PhD, namely

Chapter 2: “A review of bird population responses to management of invasive mammals in New Zealand forests”, and; Chapter 3: “The responses of native birds to increases in ship rats and changes in climate and seedfall across central New Zealand”.

Results showed that the 1080 operation in the Aorangi Forest Park (August 2014) had an apparent positive effect on populations of six native bird species (bellbird, rifleman, tomtit, tui, whitehead and woodpigeon (kererū), Figures 7 & 8) in the 18-30 months post-1080. For these bird species, the significant differences between treated and non-treated sites post-1080 are a result of declines in the Remutaka Ranges combined with increases in the Aorangi Ranges over the same period. Blackbirds showed the opposite pattern, with a significant decline in the Aorangi Ranges whilst increasing in the Remutaka Ranges. Populations of grey warblers, fantails and silvereyes appear to be unaffected by the 1080 operation, perhaps being more responsive to other factors such as weather.

The results from our bird counts are similar to results from the Project Kaka biodiversity recovery project (DOC: Tararua Forest Park). This team also reported increases in detections for bellbirds, whiteheads, tomtits and riflemen 1.5 years after a 1080 operation. This consistency in reported outcomes across two different projects, treated on different schedules, suggests a level of predictability in the bird responses. It also provides some reassurance that the method of using automated bird recorders (as in project Aorangi) produces similar results as might be expected from manual bird counts (as in the Tararuas). Anecdotal reports from landowners and rangers familiar with the Aorangis also report large increases in the birdsong of bellbirds during the summers of 2014/15, 2015/16 and 2016/17 as well as increased sightings of kererū in 2017/18.

The abundance of several small native bird species, such as the fantail, rifleman and silvereye, generally declined across both forests after the relatively harsh winter of 2015, which recorded the lowest mean temperatures and the highest number of frosts for the past five years. In contrast, 2017 has been a relatively mild (but wet) winter, hence we might expect a population recovery for these species in 2017/18. Tomtit and rifleman appear to have dipped then recovered in the Remutaka Ranges, perhaps associated with the mast-induced irruption of rats followed by their crash in that forest. Simultaneously numbers of tomtit and rifleman have dropped back down in the Aorangis 30 months post-1080, while blackbird and silvereye seemed to have reversed their declines form the previous year (Fig 7).

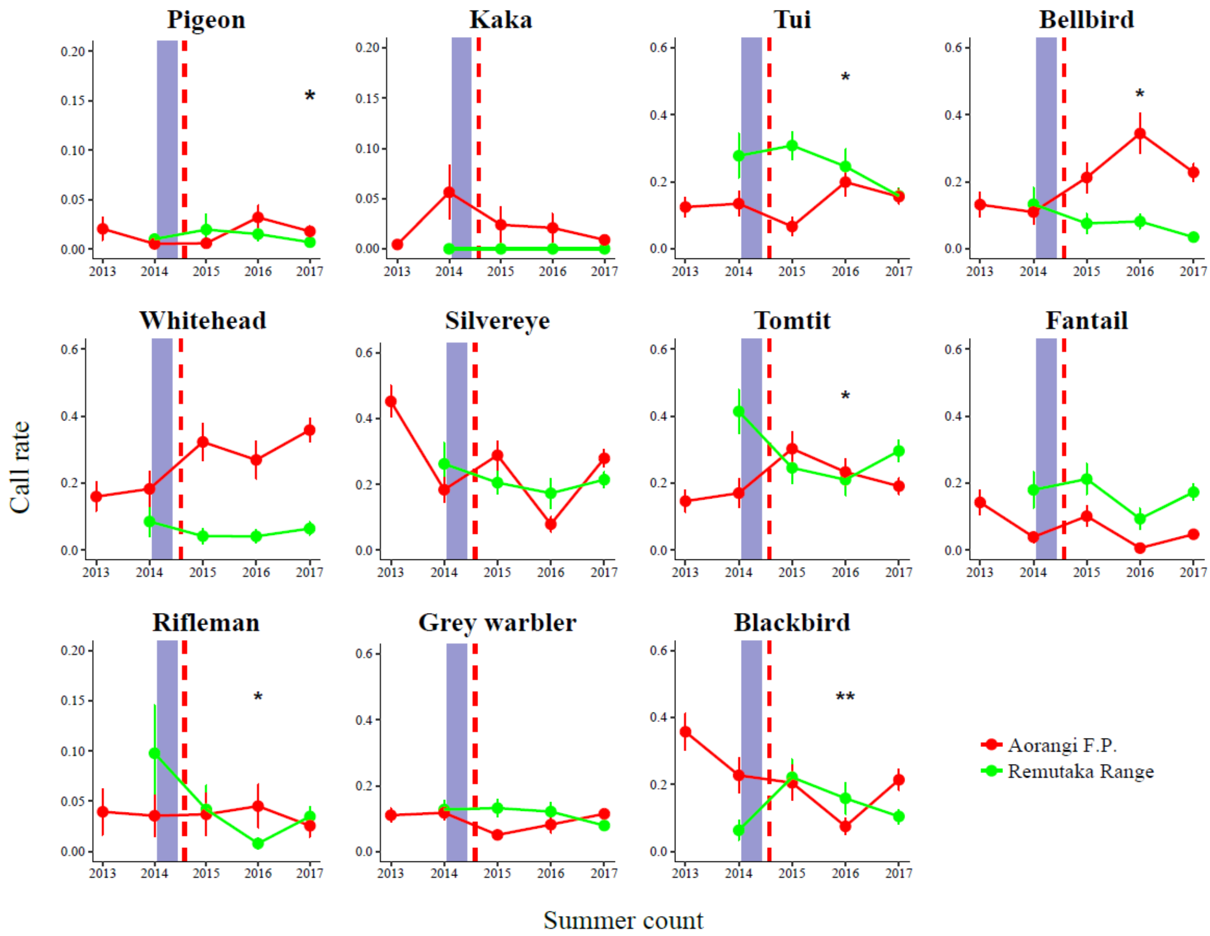


Figure 7. Spring and summer counts (November to March) combined into annual averages for the period 2012 to 2017. Asterisks indicate trends between the post-control year (either 2014/15 or 2016/17) and the pre-control year (2013/14) which differ significantly between the Aorangis and Remutakas (based on a permutation test of the interaction between year and site). Asterisks (above the relevant post-control year) = significant response evident in that year. * P >0.05; ** P > 0.01.

Some species are very rare (e.g. kaka) or entirely absent (e.g. kakariki and robins) in the Aorangi Forest Park. Recovery of populations of these species is likely to require intensive, long-term effective suppression of rats, possums and mustelids and possible reintroductions.

Analytical methods. The significance values (asterisks) of Figure 7 were determined from permutation tests, using the methods described above in section 3.3.1. As an alternative approach we also calculated log ratio response (LRR) values for the summer of 2013/14 compared separately to the summers of 2015/16 and 2016/17 (following methods of Byrom *et al*. 2016).

$$Log\ response\ ratio = \ln\left(\frac{Aorangi\ call\ rate\ post\ 1080}{Aorangi\ call\ rate\ pre\ 1080} \Big/ \frac{Rimutaka\ call\ rate\ post\ 1080}{Rimutaka\ call\ rate\ pre\ 1080} \right)$$

Positive LRR values represent an increase in call rate over time in the Aorangis relative to any temporal trends in the Remutaka Ranges, while negative values represent a decrease. In other words positive values can be interpreted as a positive response to the 1080 operation and negative values as a negative response. The LRR values were then summarised across the nine most common native species using a meta-analysis approach, as presented in Figure

8. The log response ratio results are in close agreement with the permutation tests. Minor differences around the conventional threshold of P>0.05 are that woodpigeon (kererū) show a significant positive response 2.5 years after control according to the permutation test only, tui show a significant positive response 1.5 years after control according to the permutation test only, and the positive response of whitehead 1.5 years after the 1080 operation is only significant according to the LRR test.

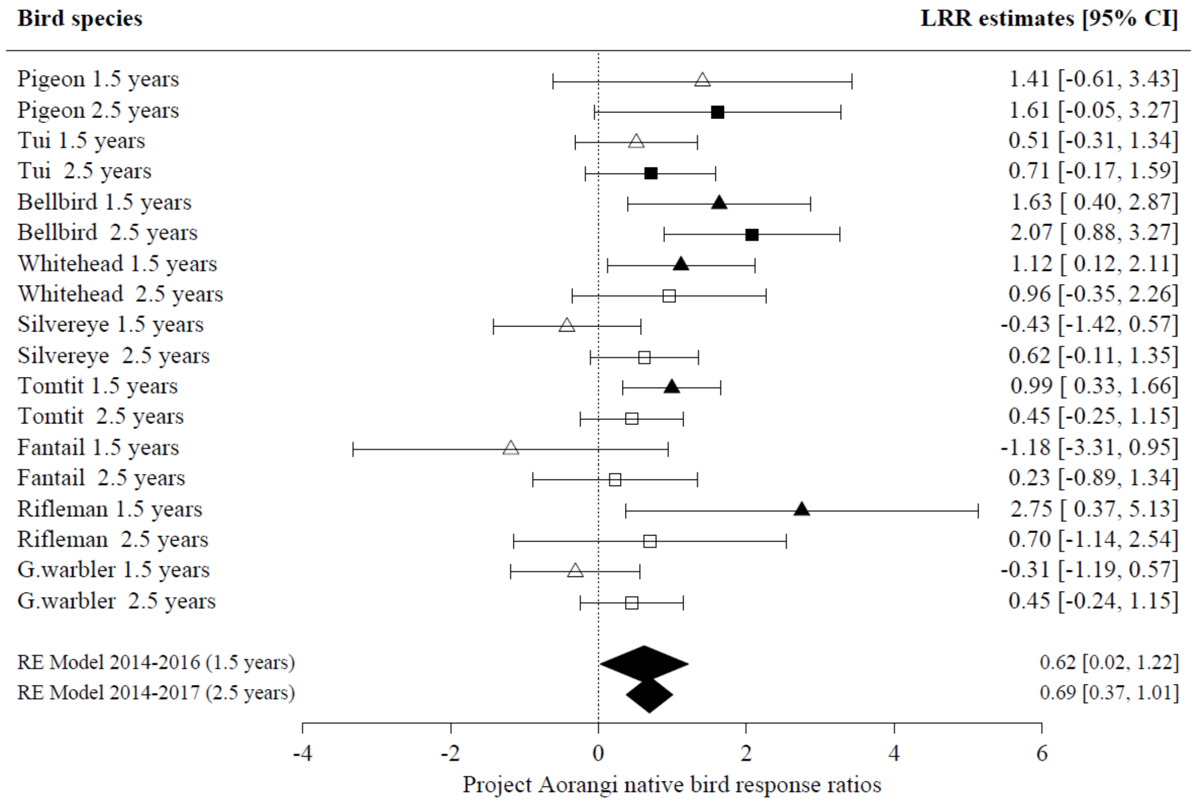


Figure 8. Response ratios for the nine most abundant native bird species in the Aorangis. Log Response Ratios (LRR estimates, and 95% confidence intervals) are the ratio calculated from the natural log of the call rate post-1080 relative to pre-1080 call rate, hence positive values represent an increase in the Aorangis after 1080 relative to any changes in the Remutaka Ranges. Spring and summer counts (November to March) were combined into annual averages. Triangles represent responses 1.5 years after control, squares represent responses 2.5 years after control. Filled shapes represent responses that were significantly positive according to the permutation test (also see previous figure, Figure 7). The diamond at the bottom is an average response for all nine species (RE Model = random effects model of a quantitative meta-analysis, using species as replicates). The most consistent benefit is for bellbirds.

4. Publicity and publications

Publications (peer-reviewed)

Cook, A., and S. Hartley. 2018. Efficient sampling of avian acoustic recordings: intermittent subsamples improve estimates of single species prevalence and total species richness. *Avian Conservation and Ecology* 13(1):21. https://doi.org/10.5751/ACE-01221-130121

Reports

Biodiversity Summary Report, produced by Nyree Fea, September 2018 for the Aorangi Restoration Trust members (see Appendix 1).

Student theses

Bomans, R.E.H. (2018) *Bioacoustic monitoring of New Zealand avifauna before and after aerial 1080 operations*. MSc thesis, Victoria University of Wellington.

Fea, I.N. (2018) *The responses of New Zealand's arboreal forest birds to invasive mammal control*. PhD thesis, Victoria University of Wellington. http://hdl.handle.net/10063/7640.

Vergara Parra, O.E. (2018) *Macroinvertebrate community responses to mammal control - Evidence for top-down trophic effects* PhD thesis, Victoria University of Wellington http://hdl.handle.net/10063/6957.

Presentations at conferences and public seminars

“Responses of New Zealand’s arboreal birds to mammal control: a multi-scale perspective”. Ecology & Evolution seminar by Nyree Fea at Victoria University of Wellington (9 November 2017).

“Macroinvertebrate community responses to mammal control: evidence for top-down trophic effects”. Ecology & Evolution seminar by Olivia Vergara at Victoria University of Wellington (16 November 2018).

“Developing an automatic detector for morepork calls, and using bioacoustics to measure bird responses to 1080 mammal control”. Ecology & Evolution seminar by Roald Bomans at Victoria University of Wellington (29 March 2018).

“Bioacoustic monitoring of native New Zealand avifauna before and after an aerial 1080 operation”, Oral presentation by Roald Bomans at the bi-annual conference of the Society for Conservation Biology Oceania (Wellington, July 2018).

“Macroinvertebrate community responses to mammal control in New Zealand”, Oral presentation by Olivia Vergara at the bi-annual conference of the Society for Conservation Biology Oceania (Wellington, July 2018).

“A review of bird population responses to management of introduced mammals in New Zealand forests”, Oral presentation by Nyree Fea at the bi-annual conference of the Society for Conservation Biology Oceania (Wellington, July 2018).

Media coverage and interviews

"Returning the Birdsong to Aorangi Forest Park", Interview with Roald Bomans (VUW MSc Student) by Lynn Freeman (RNZ), 6 Apr 2018. https://www.radionz.co.nz/national/programmes/ninetonoon/audio/2018639312/birds-call-out-1080-silent-forest-claim

"1080 operation in northern Remutakas continues despite nationwide protests", Piers Fuller, Stuff.co.nz, 10 Sept, 2018. https://www.stuff.co.nz/environment/106951651/1080-operation-in-northern-remutakas-continues-despite-nationwide-protests

"Northern Remutaka aerial operation complete", OSPRI release on their website, 26 Sept 2018, https://ospri.co.nz/news-and-events/news/northern-remutaka-aerial-operation-complete/

5. Acknowledgements

The following people assisted with field work between Sept 2017 and August 2018: Dan Crossett, Nyree Fea (VUW Research Associates), Roald Bomans (MSc student), Chris Steer, Liam Daly (summer scholars), Cora McCauley, Emily McGrath, Shaun Thomason (volunteers), Joe Murphy, Charlie Clark, David Hirst (Research Assistants) and ENSC302 students: Nicole Juan, Sam Redmond, Tom Edwards.

We acknowledge financial support from the Aorangi Restoration Trust and Victoria University of Wellington which made the summer scholarships possible. We also thank the farmers, land owners and councils who have allowed access to their land, especially Paul and Cherry Cutfield for providing accommodation when monitoring near their property.

6. References

Byrom A.E., Innes J. & Binny R.N. (2016) A review of biodiversity outcomes from possum-focused pest control in New Zealand. *Wildlife Research* 43(3), 228-253.

Gillies C.A. & Williams D. (2013) DOC tracking tunnel guide v2.5.2: Using tracking tunnels to monitor rodents and mustelids. Department of Conservation, Science & Capability Group, Hamilton, New Zealand.

Uys R. & Crisp P. (2018) *Key Native Ecosystem Programme – Small Mammal Monitoring Report February 2018*. Wellington, New Zealand. Greater Wellington Regional Council.

Appendix 1 – Summary report for biodiversity in the Aorangi Forest Park produced by VUW for the Aorangi Restoration Trust, Sept 2018

This document is designed for A3 or A4 double-sided printing, flipped on the short edge and folded down the central vertical dotted line.

Invertebrates

Pitfall trapping of ground invertebrates by a PhD student at VUW (Olivia Vergara) has resulted in the identification of a diverse collection of native and introduced species. Olivia found dung beetles to be the most commonly encountered species (for species >5mm body length), followed by hymenoptera (ants and wasps), spiders, harvestmen, ground and cave wētā and ground beetles. Olivia found fewer of the larger ground wētā when rat abundance was higher. Iconic stag beetles were also encountered, including a *Geodorcus novaezealandiae* individual. This genus of insects is vulnerable to rats and considered of equal conservation importance as kiwi. As such they are legally protected under the Wildlife Act.

The VUW team also monitor the abundance of the Wellington tree wētā using wētā motels, as this species is also a favoured prey item of rats.

Clockwise from top: ground beetle, stag beetle (*Paralissotes* sp.), ground wētā, cave wētā, tree wētā in defensive posture on a tree and a gallery of tree wētā in a wētā motel. Except for the last photo, all photos are by Olivia Vergara.

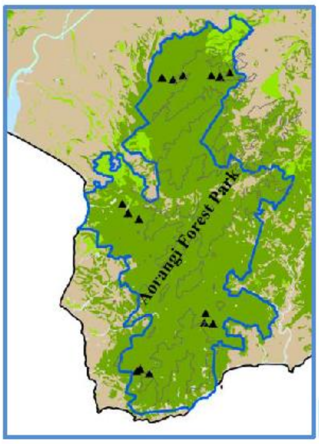
Report produced by Nyree Fea, VUW, September 2018

For information about restoration in the Aorangi Forest Park, please visit: http://www.aorangitrust.org.nz/about

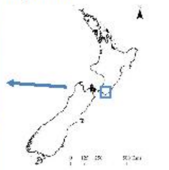
AORANGI RESTORATION TRUST

Biodiversity in the Aorangi Forest Park

Aorangi Forest Park is 20,000 hectares and contains a wide range of native and endemic species. It is located in the southern-most mountain range of New Zealand's North Island. The highest peak in the park is Mount Ross at 983 metres above sea-level. The park was previously known as the Haurangi Forest Park, but this was changed to reflect the Māori name of the range protected by the park. The southern block of native forest was gazetted as a state forest in 1900 and the northern block was added in 1936. The privately farmed land in between was taken over by the New Zealand Forest service in 1974. Since 1978, both the indigenous forest blocks and the farmland has been formally protected as a forest park.



Biodiversity monitoring is undertaken by Victoria University of Wellington (VUW) at five study sites (clusters of black triangles on the map). This ten year programme (2012 – 2021), funded by TbFree NZ, includes monitoring of native and introduced species, namely birds, invertebrates, mammals and vegetation.



CBRE

Vegetation

The forest is a mix of beech forest, lowland broadleaf species, emergent podocarps, and areas of regenerating scrub. The highest elevations (especially in the north-west), are dominated by beech species. The lower slopes are mostly comprised of broadleaf species like māhoe, hīnau, rewarewa, tawa, kāmahi with occasional podocarps (miro, matai, tōtara, rimu and kahikatea). An isolated stand of northern rātā is also found in the north-west edge of the park.

The shrublands of the river terraces and coastal foothills are dominated by tauhinu while elsewhere at low altitudes mānuka and kānuka dominate coastal sites.

Other interesting native species encountered by the VUW team include orchids (e.g. spider orchids, *Corybas* sp. plus green hooded orchids, *Pterostylis* sp., left photo) and a native mistletoe (*Peraxilla* sp.*) that was spotted by the VUW monitoring team in the canopy of a beech tree in the north-west of the park.

Lizards

Very little is currently known about the status of native lizard populations in the Aorangi Forest Park. A VUW student conducted 19 days of pitfall trapping at one site in the north-west of the park and found only two common skinks. Additionally, VUW also detected a forest gecko* in a weta motel along one of their transects (right photo).

The VUW research team also hope to conduct green gecko* (left photo) surveys.

Mammals (native)

The fur seal colony at Cape Palliser is the only one in the North Island where breeding is well-established.

It is unknown if any populations of the native short-tailed* or long-tailed bats¶ (New Zealand's only native land mammals) remain in the Aorangi Forest Park, although a population of short-tailed bats in the nearby Tararua Range was discovered in 1999. VUW will begin searching the AFP for bats in 2019.

Mammals (introduced)

The Department of Conservation (DOC) in collaboration with Greater Wellington Regional Council (GWRC) and TbFree NZ (previously the Animal Health Board) have historically conducted mammal control across the AFP. Four aerial 1080 operations have been carried out in the park since 2006. Brushtail possums, mustelids (stoats, weasels and ferrets), rodents (rats and mice) and hedgehogs are present in the forests. 1080 pellets have been surface-coated with deer repellent since the first operation in 2006 as the forest park is home to red deer, and as such is a popular area for deerstalkers. Goat numbers have been reduced to low levels by hunting and culling. Feral pigs are also present.

Conservation status of species: ¶ Threatened (nationally critical), * At Risk (declining), † At Risk (recovering), ‡ At Risk (relict), # At Risk (naturally uncommon). All other species are considered Not Threatened.

Birds

Bird monitoring in the AFP has been carried out by the VUW team since 2012 and was part of a PhD project (by Nyree Fea) on the responses of birds to mammal control. Nyree found the native species most commonly detected in the VUW bird counts were bellbirds, fantails, grey warblers, kererū, morepork, rifleman*, silvereye, tomtits, tūī and whitehead*. Two migratory species, that over winter in the tropics, were also detected in the spring and summer months (the shining cuckoo and the long-tailed cuckoo#). Falcons† and kingfishers were also present in the forests. Additionally, a remnant population of kākā† was detected at one site in the north-east. Nyree reported increases in populations of bellbirds, rifleman, tomtits, tūī and kererū 1-2 years after 1080 control. Her study also showed that native and endemic birds dominated with only a few introduced species present in the forests, the most common being the blackbird, chaffinch, dunnock and eastern rosella.

The Aorangi Restoration Trust plans to continue intensive mammal control in the AFP after TbFree NZ cease operations (from 2020). The plan is to eventually re-introduce rare species that are missing from the forests. The Trust is especially interested in re-establishing populations of iconic, endemic bird species that are absent, such as the North Island brown kiwi*, the North Island kōkako† and the kākāriki‡.

Mammal control will hopefully boost other native fauna and flora, including resident species whose populations are currently restricted, such as the threatened North Island kākā (left photo) and the little blue penguin†, which breed along the coastline.

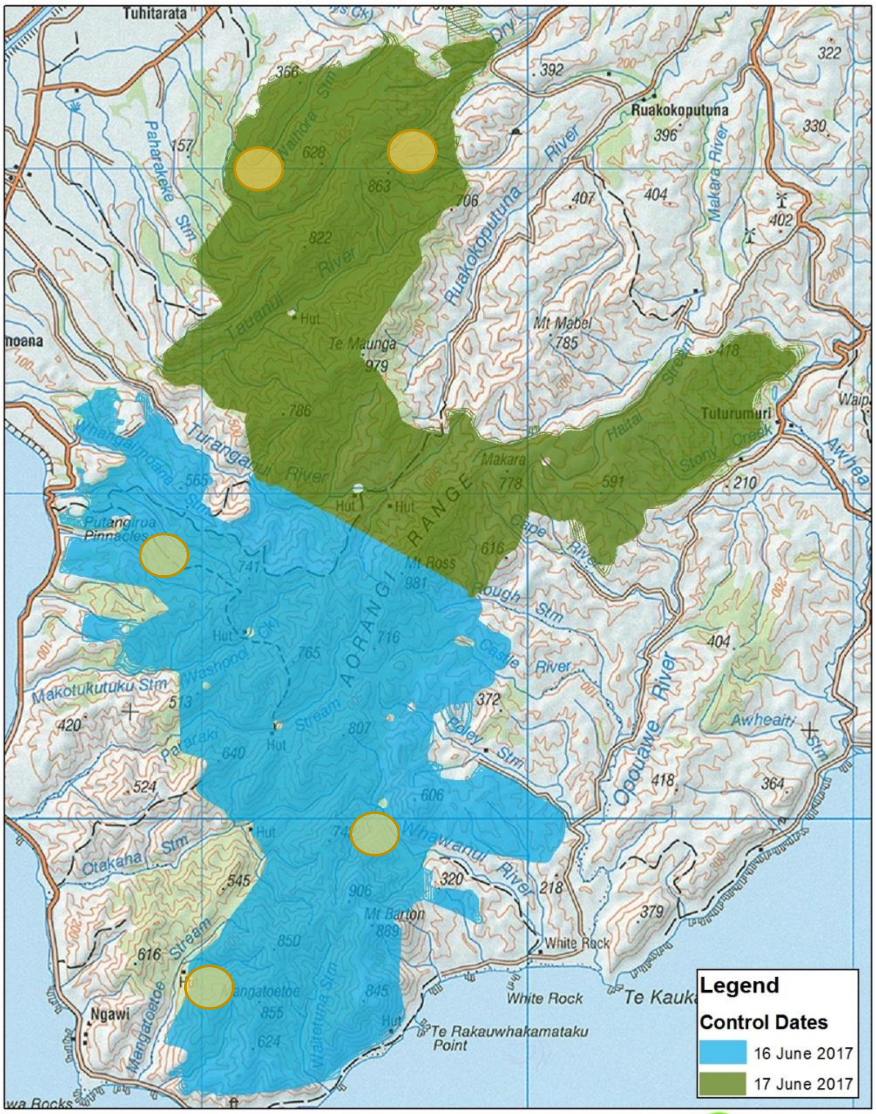
Appendix 2a: Technical specifications for the aerial operation: Aorangi Ranges 2017.

The following information and basemap has been supplied by TBfree New Zealand. Monitoring sites superimposed with pale yellow ovals.

Dates
Pre-feed with non-toxic cereal baits occurred on 30 and 31 May 2017.
Toxic bait application occurred on 16 and 17 June, 2017 (see below).

Bait specifications and sowing rate
Pre-feed: 16mm cereal bait with deer repellent, at 1.5 kg/ha.
Toxic bait: 20mm cereal bait with deer repellent, at 1.5 kg/ha.

Sowing pattern
260m swath for pre-feed, 300m swaths for toxic bait application, with no intervening strips of non-application.



AORANGI AERIAL PROJECT 2017 CONTROL DATES TBfree

Appendix 2b: Technical specifications for the Southern Remutaka Ranges 2017.

The following information and map has been supplied by TBfree New Zealand.

Dates
Pre-feed, non-toxic: 26 April (Western Block) and 16 June, 2017 (Orongorongo).
Toxic bait application: 15 May (Western Block) and 30 July, 2017 (Orongorongo).

Bait specifications and sowing rate
Pre-feed: 6 gram (16mm) cereal bait with deer repellent, sown at 2.0 kg/ha
Toxic bait: 12 gram (20mm) cereal bait with deer repellent, sown at 2.0 kg/ha.

Sowing pattern
180m swaths of toxic bait application, with no intervening strips of non-application.

SOUTHERN RIMUTAKA AERIAL PROJECT
2017 CONTROL DATES

TBfree

Appendix 2c. Technical specifications for the aerial operations: northern Remutaka Range 2018.

The following information and basemaps have been supplied by TBfree NZ. Monitoring sites ORO and WRM indicated by blue ovals.

Dates

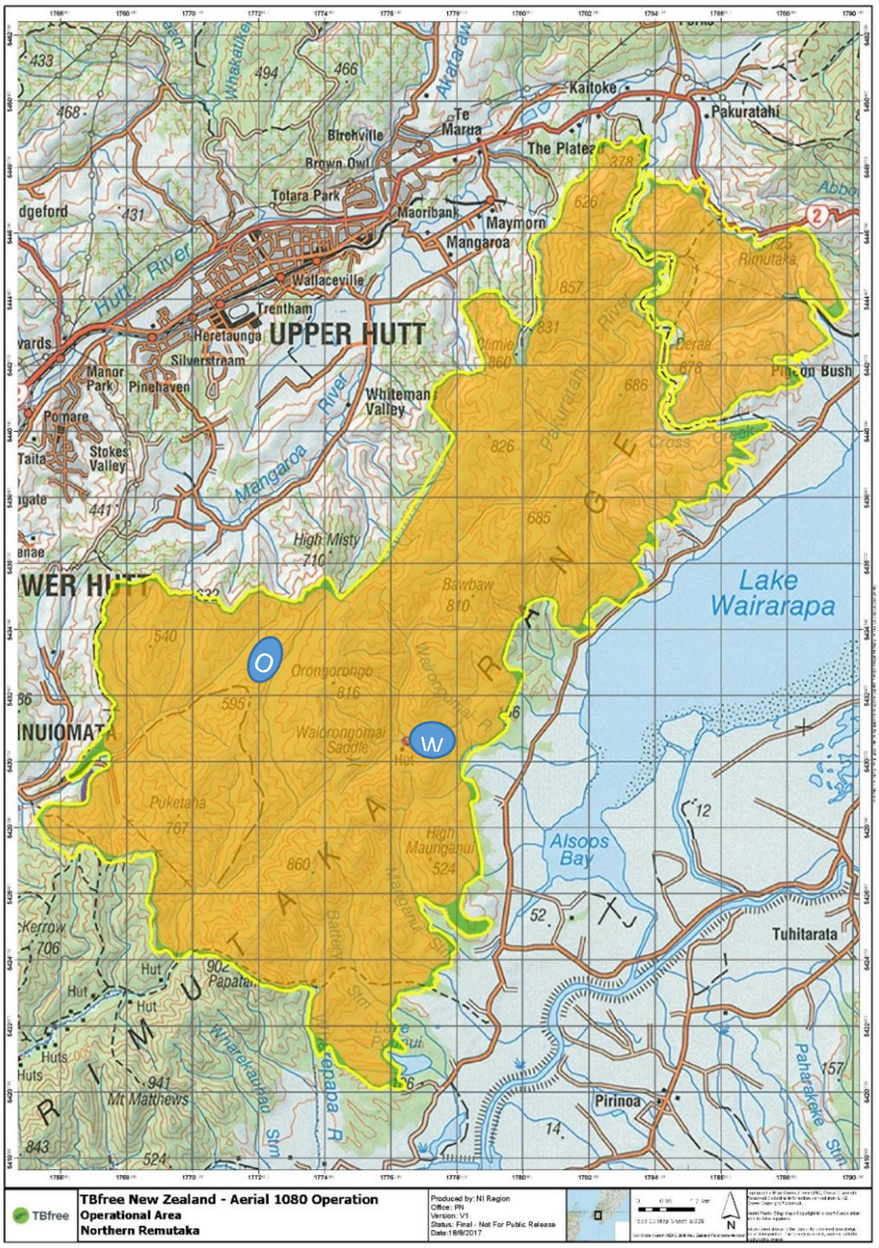
Pre-feed with non-toxic cereal baits occurred on 10 September 2018.
The toxic application occurred on 19 and 20 September 2018.

Bait specifications and sowing rate

Pre-feed: RS5 6 gram (16mm) non-toxic cereal bait with cinnamon lure, no deer repellent, at 1.0 kg/ha.
Toxic bait (0.15% 1080): 12 gram (20mm) cereal bait, no deer repellent, sown at 1.5 kg/ha.

Sowing pattern

Swath width of 180m, no gaps between swaths



Appendix 3: Illustration of monitoring devices

Figure A3.1. Monitoring devices deployed on each 450m monitoring line. In addition, one DoC automatic bird recorder is deployed per site (not shown).