Manaaki Whenua
Landcare Research

Tier One monitoring framework: design evaluation

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Tier One monitoring framework: design evaluation

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Summary

Project and client

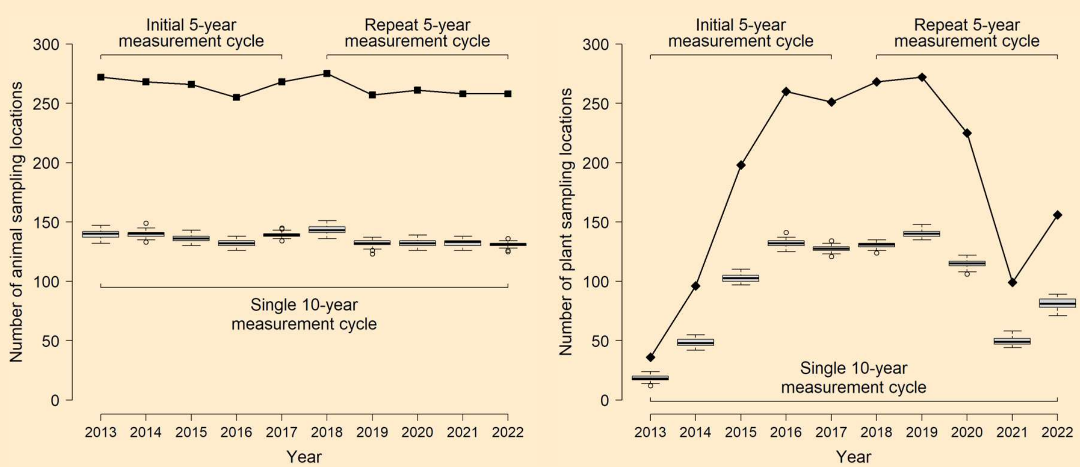
- The Department of Conservation (DOC) contracted Manaaki Whenua – Landcare Research to evaluate two designs for DOC's Tier One biodiversity monitoring framework (contract DOC 3033855 Variation 2).

Objectives

- To evaluate two designs for DOC's Tier One biodiversity monitoring framework: the current design versus the proposed modified design (Box 1).
- To analyse the occupancy and abundance trends of 15 guilds or species aligned with two indicators and five measures within DOC's Biodiversity Monitoring and Reporting System (BMRS, Box 1).

Box 1. DOC's Tier One monitoring framework – designs and biodiversity metrics

- *Current design:* encompasses roughly 1,300 sampling locations (all on the same 8 × 8 km grid overlapping public conservation land) that are surveyed once every 5 years. During a 5-year measurement cycle a fifth of the sampling locations is measured each year. The figures below show the number of sampling locations surveyed each year over a 10-year period (2013–2022) for ungulates and birds (squares, left), and plants (diamonds, right).
- *Modified design:* proposes to survey each sampling location only once every 10 years, with only a 10th of the 1,300 sampling locations measured each year. The box plots in the lower part of each graph show 50 simulated replicates for the proposed modified design.



At each sampling location the occupancy and abundance of 15 focal guilds or species are measured, as follows:

- *ungulates*: the probability of faecal pellets being recorded on a transect
- *plants:* the probability or total count of a sapling group (exotic saplings, or those that were either palatable or unpalatable to ungulates) being recorded in a subplot
- *birds:* the probability or total count of a bird guild or species being recorded at a count station – focal species represent four guilds (cavity nesters, less-mobile birds, mobile birds, and open-habitat birds) as well as spanning low to high occupancy across woody and non-woody habitats.

Methods

The analyses evaluated:

- observed 10-year trends based on the current design (2013–2022), using an alert system to draw attention to trends of conservation concern (Box 2), for up to four sets of sampling locations, which represent all public conservation land, woody vs non-woody habitats, inside and outside national parks, and two focal sites (Rakiura National Park and Ruahine Forest Park)
- the power to detect rapid to moderate changes in the future after 10 years of monitoring, using simulated trends applied to the current design and the proposed modified design, across all public conservation land, a given habitat, or a focal site
- the expected time taken to raise early warnings for rapid to moderate changes in the future, using simulated 10-year trends applied to the current design and the proposed modified design, across all public conservation land, a given habitat, or a focal site.

Box 2. Classifying trend alerts

An international alert framework (used by the British Trust for Ornithology and the New Zealand Garden Bird Survey) was adapted to categorise the observed trends according to the trend direction and size of change (alert raised), and the strength of evidence for the change (alert signal strength), as follows.

- Rapid decreases (≤50%) in indigenous guilds or species raise a red alert, while moderate decreases (25% to 50%) raise an amber alert.
- Signal strength relates to the precision of the change estimates (higher signal strength indicates lower error and higher certainty of change estimates).
- Rapid increases (>100%) in exotic animals and weeds also raise a red alert, while moderate increases (50% to 100%) raise an amber alert.

The trend direction is signalled by an arrow (see key below), while the alert strength (size of change) is indicated by the colour of the symbols, and signal strength (evidence for change) is indicated by the density of shading (darker shading indicates greater signal strength).

Observed occupancy trends (2013–2022) based on the current design

EXOTIC PEST & WEED DOMINANCE

- Pests
  - *All public conservation land:* Ungulate occupancy is increasing moderately. Increases are most rapid in non-woody habitats, particularly within national parks.
  - *Focal sites:* Ungulate occupancy is increasing rapidly in Rakiura National Park but decreasing moderately in Ruahine Forest Park.
- Weeds
  - *All public conservation land:* Exotic sapling occupancy shows little change, with declines in woody habitats (outside national parks) but potential shallow increases in non-woody areas.
  - *Focal site:* No exotic saplings were detected.

ECOSYSTEM COMPOSITION

- Plant functional types
  - *Woody habitats:* Shallow declines in palatable sapling occupancy outside national parks.
  - *Focal sites:* Rapid declines in palatable sapling occupancy within Ruahine Forest Park, but little change in Rakiura National Park.
- Common and widespread birds
  - *Woody habitats:* Cavity-nesting birds are declining moderately within woody habitats, but rapidly outside national parks. Riflemen are declining rapidly in all woody habitats. Although both mobile and less-mobile birds show little change overall, some species show shallow to moderate declines nationally (the less-mobile grey warbler) and outside national parks (the grey warbler and the relatively mobile tūī). Others are showing improvements, with shallow to moderate increases nationally (kererū and fantail).
  - *Non-woody habitats*: Shallow declines were flagged for the open-habitat bird guild nationally, with rapid declines for swamp harriers.
  - *Focal sites:* In Rakiura National Park there was moderate evidence for a rapid decline in cavity nesters, with very weak evidence for moderate declines for grey warblers and tūī, and rapid improvement in riflemen, fantails, and kererū. In Ruahine Forest Park, tūī and fantails show weak signals for rapid improvements.

Power to detect simulated rapid to moderate changes in occupancy after 10 years

Note: Power analyses apply the standard 95% confidence level as the criterion for detecting trends (i.e. the probability that if a survey were repeated, the results obtained would be the same).

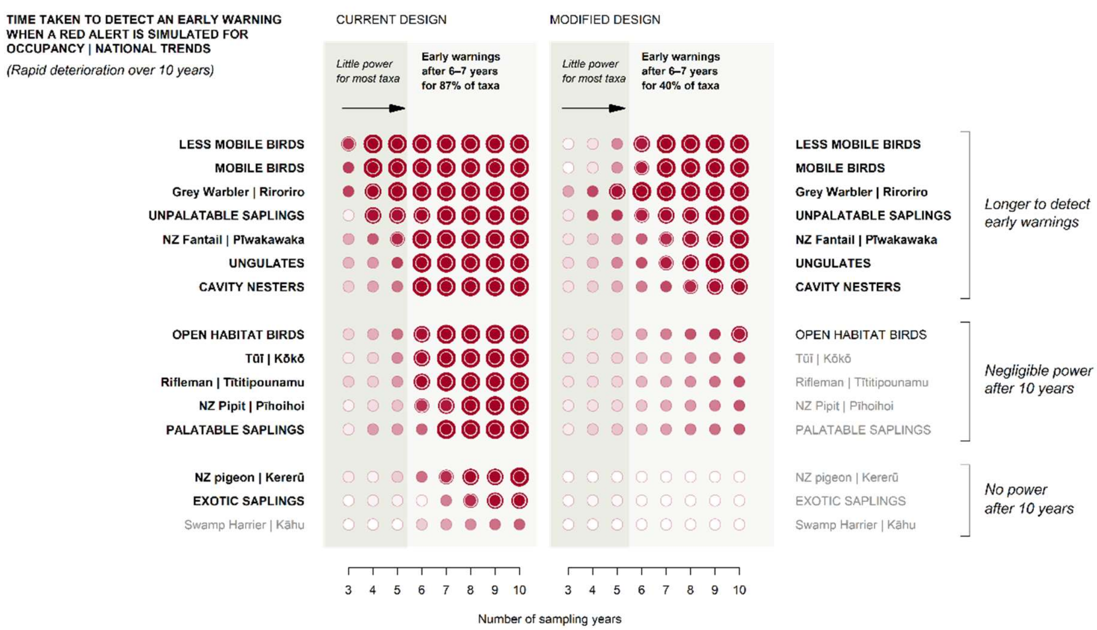
NATIONAL TRENDS

- The current design (5-year measurement cycle) has very high power to detect rapid to moderate changes in occupancy within 10 years for ≥80% of the 15 guilds or species analysed (see figure on previous page).
- Under the proposed modified design (10-year measurement cycle) there will be very high power to detect rapid changes within 10 years for half of the 15 guilds or species considered, but only about a third of the guilds or species for moderate changes. Power will be most reduced for species or guilds that are highly mobile (e.g. kererū) or sparsely distributed (e.g. swamp harriers, exotic saplings).

FOCAL SITE TRENDS

- At focal sites the current design only has power to detect rapid to moderate changes in occupancy within 10 years for half or less of the 11 guilds and species analysed, and generally only those that are common and widespread.
- The proposed modified design will not have sufficient power to detect rapid to moderate changes in occupancy within 10 years for any of the guilds and species analysed at focal sites.

Time taken to detect an early warning for simulated rapid to moderate changes in occupancy over 10 years



Note: Power analyses apply the standard 95% confidence level as the criterion for detecting trends (i.e. the probability that if a survey were repeated, the results obtained would be the same). Black bold font indicates guilds or species with sufficient power to detect an early warning, plain black font indicates those with sufficient power only after 10 years, and plain grey font indicates those with no power after 10 years.

- Alerts will be raised earlier under the current design than under the proposed modified one (e.g. DOC will know sooner that management actions for exotic ungulates are effective, or if more intensive management is required; see accompanying figures).
- The current design generally provides very high power to raise early warnings for rapid and moderate changes, with:
  - *red alerts:* detectable within 6–7 years for 87% of guilds or species
  - *amber alerts:* detectable within 6–7 years for 53% of guilds or species.
- By contrast, the modified design will take longer to raise alerts and only do so for roughly half the number of guilds and species:
  - *red alerts:* up to 7 years for 40% of guilds or species
  - *amber alerts:* up to 7 years for 20% of guilds or species (with another 40% losing power to detect amber alerts flagged by the current design).

Conclusions

- Tier One has provided us with the ability to detect trends across a wide range of plant and animal guilds and species nationally, in different habitat types, in areas of different protection status, and for individual protected natural areas.
- Transitioning from a 5-year to a 10-year measurement cycle will reduce our power to detect trends for many guilds and species and lessen our ability to detect declines early enough to implement timely management interventions. This may limit our ability to prevent declines in vulnerable species or groups of species.
- Notable results include the finding that transitioning to the modified design would remove the power to detect rapid changes for the following guilds and species:
  - *riflemen:* one of only two species in a New Zealand endemic family of ancient wren species
  - *tūī and kererū:* iconic bird species with massive cultural significance

- *palatable saplings:* vulnerable to exotic herbivores
- *exotic saplings:* early warning of invasions in woody ecosystems.

Recommendations

- Apply a hierarchical assessment of trend alerts to support the goals of the BMRS by helping users quickly identify trends of conservation concern (and uncertainty about their estimates), as well as early warning signals.
- Maintain national monitoring at a 5-year cycle so that we can track trends in biodiversity and threats to it. This gives better options to intervene to enhance positive trends or mitigate declines in indigenous biodiversity. Shifting to a 10-year cycle reduces the power to detect trends and, at worst, would result in management to prevent declines being far too late.
- Develop a standardised framework for data analyses, interpretation, and visualisation that evaluates both biodiversity state and biodiversity trend. This framework should include a transparent set of rules for when it is appropriate to report alerts for different locations, as well as for species, guilds aligned to the BMRS measures, and indicators.
- Use Tier One sampling locations to estimate state and trend at scales other than the national one only when sample sizes are large. The original design of the BMRS relied on three inter-related tiers of measurement, with an emphasis on local Tier Two networks of sampling locations to inform managers of state and trend (including in response to management). Significant departure from national trends in response to particular pressures or management interventions could be judged by comparing Tier Two networks against the national (Tier One) network. In the case of management units with as few samples as Ruahine Forest Park, Tier One sampling locations might be used to supplement Tier Two networks of sampling locations, but would not give the statistical confidence needed to inform management.

1 Introduction

This report evaluates the efficacy of DOC's Tier One monitoring framework to provide robust and timely information to support the goals of the Biodiversity Monitoring and Reporting System (BMRS), which are to:

- provide national and regional reporting of status and trend in ecological integrity
- evaluate the effectiveness of conservation management and policy
- provide an early-warning system
- inform prioritisation for resource allocation on public conservation land.

The report consists of eight sections.

Following this introduction, **Indicators and measures** introduces the 15 guilds or species this report focuses on and how they align with the indicators and measures within DOC's BMRS. Indicators in the BMRS are aspects of ecological integrity linked to outcome objectives, while measures are metrics with explicitly defined data collection and analytical methodologies.

Information sources describes DOC's Tier One monitoring framework, which provides an unbiased sample of locations on public conservation land, and the two designs this report sets out to evaluate: the current design (which DOC has implemented over the last 10 years, 2013–2022), and a modified design (which proposes to reduce the sampling intensity and frequency in the future).

Analytical approach outlines the protocols used to calculate, interpret, and visualise the observed trends based on the current design; the power to detect simulated trends for the current versus modified designs; and the time taken to raise alerts for simulated trends for the current versus modified designs.

Observed trend directions and alerts detected by the current design summarises the 10-year trends (2013–2022) derived from the current design for up to four sets of sampling locations (drawn from the Tier One framework), representing: all public conservation land; woody vs non-woody habitats; inside and outside national parks within a given habitat; and two focal sites (Rakiura National Park and Ruahine Forest Park).

Power to detect simulated trends after 10 years for the current versus modified designs evaluates the power to detect rapid to moderate changes after 10 years of monitoring in the future, using simulated trends applied to the current design and proposed modified design, across all public conservation land, a given habitat or a focal site.

Time taken to an early warning for the current versus modified designs gauges the expected time taken to raise early warnings for rapid to moderate changes in the future, using simulated 10-year trends applied to the current design and proposed modified design, across all public conservation land, a given habitat or a focal site.

Finally, the **Discussion** addresses the proposal to measure vegetation on a 10-year cycle, and animals on a 5-year cycle: what would be the benefits and risks associated with the implementation of this change and the decoupling of the data for these measures (e.g. interpretation of changes in measures in relation to each other and over relevant timescales), in addition to the costs.

2 Indicators and measures

The BMRS assesses whether the ecological integrity of public conservation land is being maintained. This system defines ecological integrity as "the full potential of indigenous biotic and abiotic features, and natural processes, functioning in sustainable communities, habitats and landscapes" (McGlone et al. 2020). Ecological integrity encompasses all levels and components of biodiversity, and can be assessed at multiple scales, up to and including the whole of New Zealand.

More specifically, the BMRS was designed to assess whether the following three components of ecological integrity are being maintained on public conservation land:

- **indigenous dominance** – the level of indigenous influence on the composition, structure, biomass, trophic and competitive interactions, mutualisms and nutrient cycling in a community
- **species occupancy** – the extent to which any species capable of living in a particular ecosystem is actually present at a relevant spatial scale
- **ecosystem representation** – the abiotic aspects of ecosystems, which measures the distribution of indigenous biota across environmental gradients derived from data layers based on climate, soils, and geology.

Each component of ecological integrity is assessed using outcome objectives, which have aligned indicators and measures (McGlone et al. 2020):

- **outcome objectives** – key factors contributing to an intermediate outcome (i.e. an essential biodiversity element needed to ensure ecological integrity is maintained)
- **indicators** – quantitative or qualitative aspects that should be assessed in relation to an objective
- **measures** – concrete factors with an explicitly defined methodology and source of information for assessing indicator performance.

Our analyses focus on two indicators and five measures that are aligned to two outcome objectives (see Table 1).

Table 1. Outcome objectives, indicators, and measures from the DOC Biodiversity Monitoring and Reporting System used to assess two components of ecological integrity in this report, as well as the aligned focal guilds or species (in CAPITALS and *italics*, respectively) included in the analyses

Component	Outcome objective	Indicator	Measure	Focal guilds or species	Metric		Habitat associations	
					Occupancy	Abundance	Woody	Non-woody
Indigenous dominance	Outcome objective 2: Reducing the spread and impact of exotic species	Indicator 2.2: Exotic weed and pest dominance	Measure 2.2.1: Distribution and abundance of exotic weeds and animal pests considered a threat – Pests	UNGULATES	●		●	●
			Measure 2.2.1: Distribution and abundance of exotic weeds and animal pests considered a threat – Weeds	EXOTIC SAPLINGS	●		●	●
Species occupancy	Outcome objective 5: Improving ecosystem composition	Indicator 5.1: Ecosystem composition	Measure 5.1.3: Representation of plant functional types	PALATABLE SAPLINGS	●	●	●	
				UNPALATABLE SAPLINGS	●	●	●	
			Measure 5.1.2: Demography of widespread animal species – Birds	CAVITY NESTERS[a]	●	●	●	
				Rifleman / tītitipounamu	●	●	●	
				LESS-MOBILE BIRDS[b]	●	●	●	
				Grey warbler / riroriro	●	●	●	
				MOBILE BIRDS[c]	●	●	●	
				Tūī / kōkō	●	●	●	
				NZ pigeon / kererū	●	●	●	
				NZ fantail / pīwakawaka	●	●	●	
				OPEN-HABITAT BIRDS[d]	●			●
				Swamp harrier / kāhu	●			●
				NZ pipit / pīhoihoi	●			●

[a] Cavity nesters: rifleman/tītitipounamu, mohua, kiwi spp., kākā, kea, parakeet/kākāriki spp., morepork/ruru; [b] less-mobile birds: kōkako, brown creeper/pīpipi, whitehead/pōpokotea, grey warbler/riroriro, tomtit/hōmiromiro, weka, blue duck/whio; [c] mobile birds: kererū, long-tailed cuckoo/koekoeā, shining cuckoo/pīpīwharauroa, NZ falcon/kārearea, robin/tōtōwai spp., tūī, bellbird/kōmako, fantail/pīwakawaka, silvereye/tauhou; [d] open-habitat birds: NZ pipit/pīhoihoi, welcome swallow, paradise shelduck/pūtangitangi, swamp harrier/kāhu.

2.1 Focal guilds and species

This report focused on a subset of guilds and species aligned with the 'Exotic weed and pest dominance' and 'Ecosystem composition' indicators (Table 1). The following focal guilds and species were selected:

- **Ungulates:** Exotic, herbivorous mammals, which in this report include all species of deer, goats, sheep, chamois, and tahr. Ungulates can have potentially significant impacts on vegetation communities, in particular through the browsing of palatable tree seedlings and saplings in forest understories. Ungulate occupancy increased across public conservation land over the period 2012–2018, and abundance increased across the North Island over the same period (Moloney et al. 2021). However, management interventions aimed at reducing the abundance of ungulates are socially divisive because many species are prized as game animals. Timely data on ungulate occupancy and abundance are vital to support evidence-based decision-making on ungulate management in New Zealand.
- **Exotic saplings:** The New Zealand flora includes almost 1,800 species of naturalised, exotic plants (Brandt et al. 2021). Some of these species can substantially alter ecosystem structure, function, and dynamics, particularly those that are woody (Dickie et al. 2011). Reporting on exotic sapling occupancy can directly guide weed control activities.
- **Palatable and unpalatable saplings:** Successful recruitment of tree saplings is vital for maintaining forest canopies (Allen et al. 2002). Browsing by exotic ungulates can reduce the abundance of species that are palatable to ungulates (e.g. *Schefflera digitata* [pāte] or *Pterophylla racemosa* [kamahi]) and favour those that are unpalatable (e.g. *Pseudowintera colorata* [horopito] or *Phyllocladus trichomanoides* [tanekaha]). Counts of saplings in these two groups enable an assessment of ungulate impacts in forest ecosystems and whether canopy-replacing processes are in place (Peltzer et al. 2014).
- **Bird guilds and species:** Four bird guilds (cavity nesters, and mobile, less-mobile, and open-habitat birds) were selected to reflect a range of nesting and dispersal traits and habitat associations; these guilds were largely defined by an existing trait classification (Walker et al. 2019) but were modified to keep the guild composition mutually exclusive and to reflect advice from one of DOC's bird monitoring experts (T. Greene, pers. comm.). At least one focal bird species was selected to align with each of the four guilds. These species were chosen to reflect a range of occupancy metrics (i.e. encompass high to low occupancy estimates across woody or non-woody habitats; this information was derived from the relevant Tier One 2021/22 factsheet[1]).

[1] https://www.doc.govt.nz/our-work/monitoring-reporting/national-status-and-trend-reports-2021-2022/bird-species-2021-2022/

2.2 Field survey protocols

Field data on each of the focal guilds and species were collected using a grid-based, systematic sampling approach centred on a permanently marked 20 m × 20 m vegetation plot (Figure 1; Table 2; Bellingham et al. 2020). Exotic and indigenous sapling counts were gathered from 16 subplots in the vegetation plot (for methods, see Hurst & Allen 2007a,b). Ungulate faecal pellet counts were quantified in circular subplots of 3.14 m^2 (i.e. 1 m radius) spaced at 5 m intervals along randomly located 150 m-long transects (Forsyth et al. 2011). Five-minute bird counts were gathered from up to five count stations (with one station centred on the vegetation plot and the other four 200 m from each other and the central one; MacLeod et al. 2012).

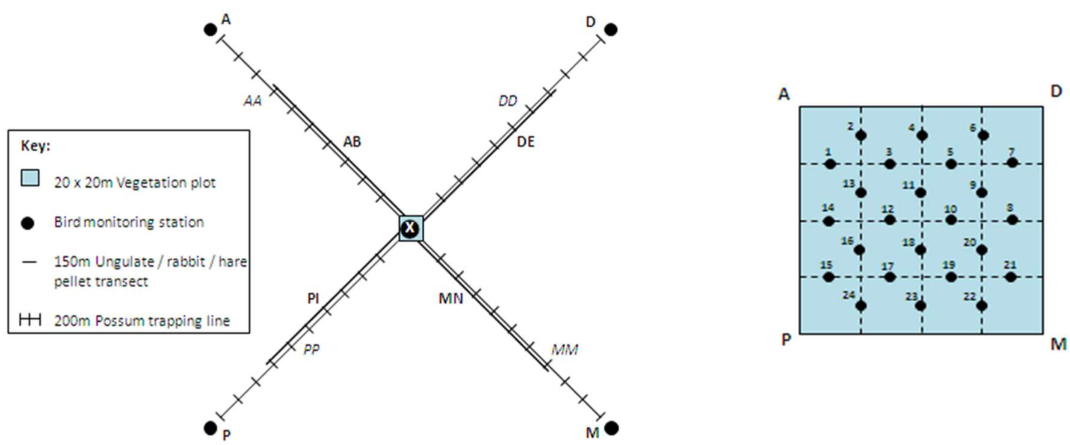


Figure 1. Layout of the animal survey sampling units in relation to the vegetation plot at each sampling location, along with an outline of the 20 × 20 m vegetation plot, subdivided into 16 subplots for saplings, with 24 (0.75 m^2) subplots for seedlings dispersed throughout the vegetation plot.

Table 2. Biodiversity measures, sampling units, and response variables in models

Taxa	Measure	Sampling unit		Response variable in models		Reference
		Type	Number per sampling location	Occupancy	Abundance	
Ungulates	Faecal pellet count	Transect line	Up to four x 150 m transects	Number of up to 30 circular subplots per transect where pellets were recorded as present or absent	-	Forsyth et al. 2011
Plants	Sapling count	Subplot	16 subplots within a 20 x 20 m plot	Observed presence or absence of saplings within subplot	Total number of saplings per subplot	Hurst & Allen 2007a,b
Birds	Five-minute bird count	Count station	Up to 5 stations	Observed presence or absence of birds	Total number of birds recorded	MacLeod et al. 2012

3 Information sources

National environmental reporting requires robust and consistent sampling of the New Zealand landscape (Allen et al. 2003). Part of our national environmental reporting is achieved using an 8 km grid-based plot network that includes all public conservation land, and all remaining natural (indigenous) forests and shrublands (Bellingham et al. 2020).

The 8 km grid-based plot network was originally designed to provide an unbiased estimate of carbon stocks and carbon sequestration rates across New Zealand's natural forests and shrublands, irrespective of land tenure (Coomes et al. 2002; Payton et al. 2004; MfE 2010, 2013). The grid size (8 km) was determined based on the sample size required to estimate national carbon stocks, with a 95% probability that estimates would be within 5% of the mean (+/- 10 Mg/ha) (Payton et al. 2004).

A subset of plots was measured each year based on a 5-year measurement cycle with no stratification (Payton et al. 2004). Plots are randomly allocated to a sampling year. Sampling started in 2002, but since then the grid has been modified because the area mapped as natural forest and shrubland has changed; for example, with the creation of the Land Use Map (LUM; Paul et al. 2021). To accommodate these changes, new plots have been added and others have been removed. All new plots were randomly allocated to a sampling year.

In 2011/12 DOC adopted the 8 km grid for its Tier One biodiversity monitoring programme (MacLeod et al. 2012). DOC extended the 8 km grid-based plot network to include any sample point located on public conservation land, irrespective of the vegetation type present. Whereas carbon monitoring focused solely on woody ecosystems, this extension of the grid included diverse non-woody ecosystems. DOC followed the 5-year measurement cycle that had been in place for carbon monitoring since 2002, and new plots were randomly allocated a sampling year without stratification. In addition, DOC widened the scope of monitoring to include new methods to estimate animal abundance (ungulates, possums, birds).

The Tier One biodiversity monitoring programme is a 'ground-breaking, systematic sampling programme for all public conservation land, and potentially over the whole of New Zealand' (PCE 2020). Tier One was designed to integrate both vegetation and animal measures, and such coupling of essential biodiversity variables is world-leading (Pereira et al. 2013; Bellingham et al. 2020). Coupled measurements using consistent methods are central to the integrity of the monitoring programme.

DOC have now completed the second 5-yearly cycle of plot-based measurements across public conservation land, so repeated-measures data are now available to evaluate precision and the capacity to detect change across the plot network. DOC must weigh up the costs of monitoring many plots frequently (compared to fewer plots less frequently) against the risks and costs of not knowing about change in ecosystems sooner and with greater precision (confidence).

3.1 Current design

To evaluate the current design, our analyses focused on field data gathered from over 1,300 sampling locations on the DOC Tier One framework between 2013 and 2022 (Table 3). These field data included 300,000 faecal pellet counts over 10,000 transects for ungulates, sapling counts from almost 30,000 vegetation subplots, and almost 12,000 bird counts.

During this period up to 275 sampling locations were surveyed each year (Figure 2), but with lower sampling effort for the plant surveys in the initial and final 3 years. Within each year these sampling locations overlapped at least nine of DOC's ten operating regions (as sampling only occurred in some years in the Auckland region; see Appendix 1), with roughly two-thirds situated in woody habitats (Figure 3) and a similar proportion outside national parks (Figure 4). Within the two focal parks at least one sampling location was visited each year for the animal surveys, but not always for the plant surveys (Figure 5).

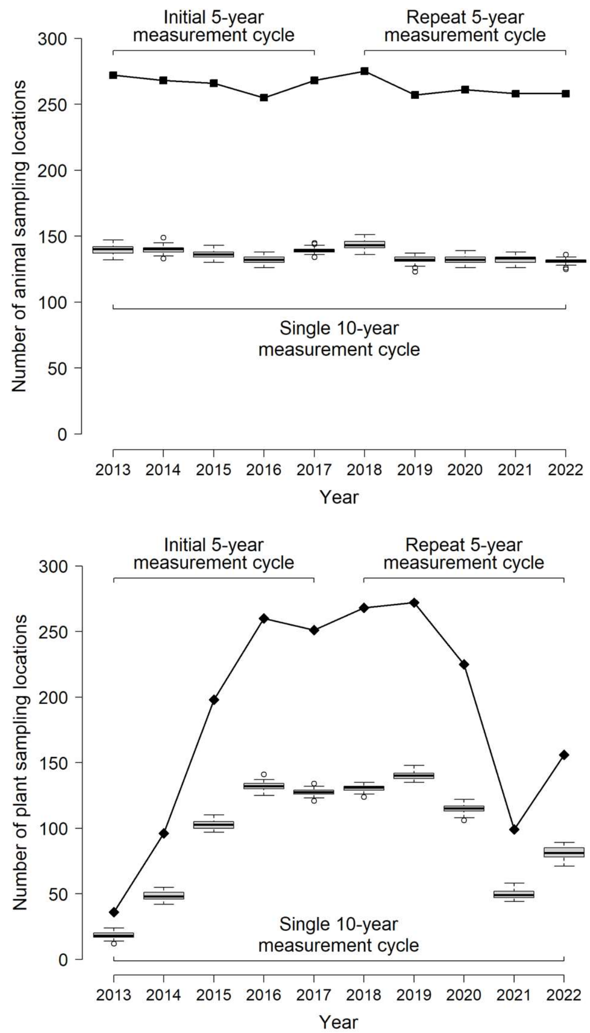


Figure 2. Total number of sampling locations per year for the animal (squares, top) and plant (diamonds, bottom) surveys completed on all public conservation land using the Tier One monitoring framework's current design and a proposed modified design. The box plots show how the total number of sampling locations per year varied across the 50 simulated replicates of the modified design.

Table 3. Number of sampling locations within DOC's Tier One monitoring framework (the current and proposed modified designs), where ungulate, plant, and bird field surveys were completed during the period 2013–2022, and the total sampling effort for each taxon (i.e. the number of ungulate transects, plant subplots, and bird counts) across all public conservation land, within woody and non-woody habitats, inside and outside national parks, and at two focal sites (Rakiura National Park and Ruahine Forest Park)

Set of sampling locations representing	Land cover	Current design						Proposed modified design (n = 50 replicates)					
		Number of sampling locations			Total sampling effort			Number of sampling locations			Total sampling effort		
		Ungulates	Plants	Birds	Ungulates	Plants	Birds	Ungulates	Plants	Birds	Ungulates	Plants	Birds
Public conservation land	All	1,354	1,317	1,355	10,414	29,776	11,909	1,349–1,354	911–947		5,317–5,351	14,864–15,456	
	Non-woody	388	361	388	2,940	7,424	3,392			386–388			1,760–1,782
	Woody	966	956	967	7,474	22,352	8,517		675–706	963–967		11,024–11,536	4,306–4,355
National parks	All	437	425	438	3,351	9,504	3,738						
	Non-woody	108	98	108	818	1,920	896						
	Woody	329	327	330	2,533	7,584	2,842						
Rakiura National Park	All	23	23	23	175	594	218	22–23			87–91		
	Non-woody	1	1	1	8	16	10						
	Woody	22	22	22	167	576	208		15–19	21–22		240–304	103–109
Outside national parks	All	917	892	917	7,063	20,272	8,171						
	Non-woody	280	263	280	2,122	5,504	2,496						
	Woody	637	629	637	4,941	14,768	5,675						
Ruahine Forest Park	All	17	17	17	132	336	145	17			68		
	Non-woody	2	2	2	16	48	15						
	Woody	15	15	15	116	288	130		7–11	15		112–176	67–68

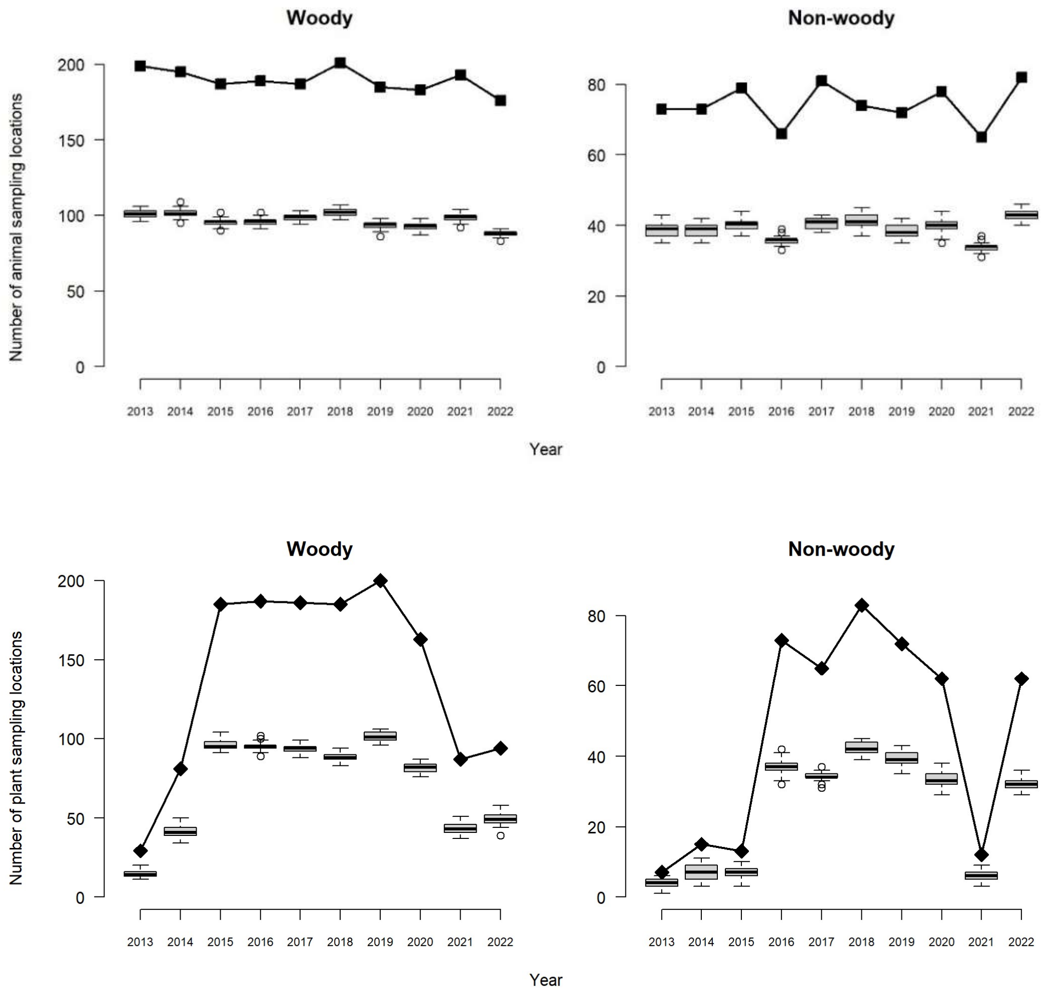


Figure 3. Number of sampling locations per year within woody and non-woody habitats on public conservation land for the current design (squares and diamonds for animal and plant surveys, respectively) and the proposed modified design (box plots showing variation in effort across 50 replicates).

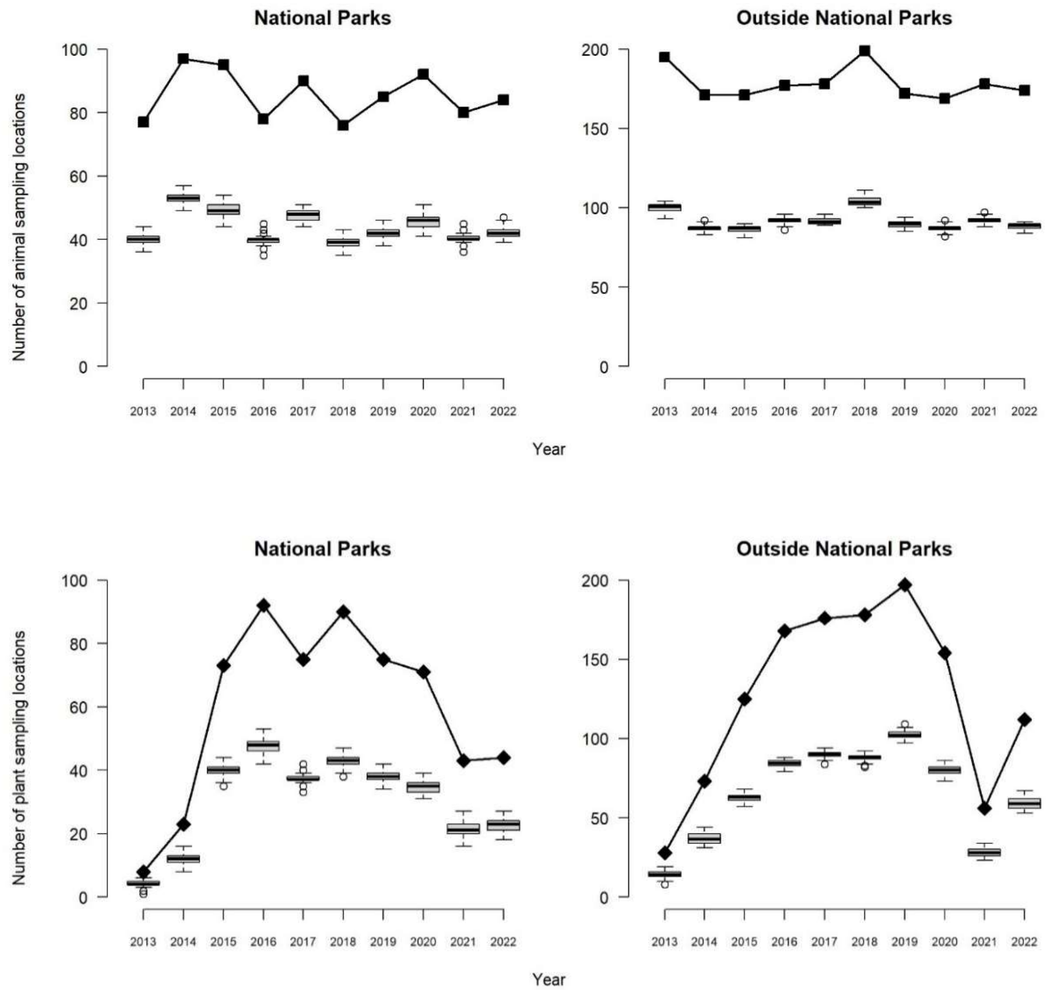


Figure 4. Number of sampling locations per year within national parks and outside national parks on public conservation land for the current design (squares and diamonds for animal and plant surveys, respectively) and the proposed modified design (box plots showing variation in effort across the 50 replicates) for each year.

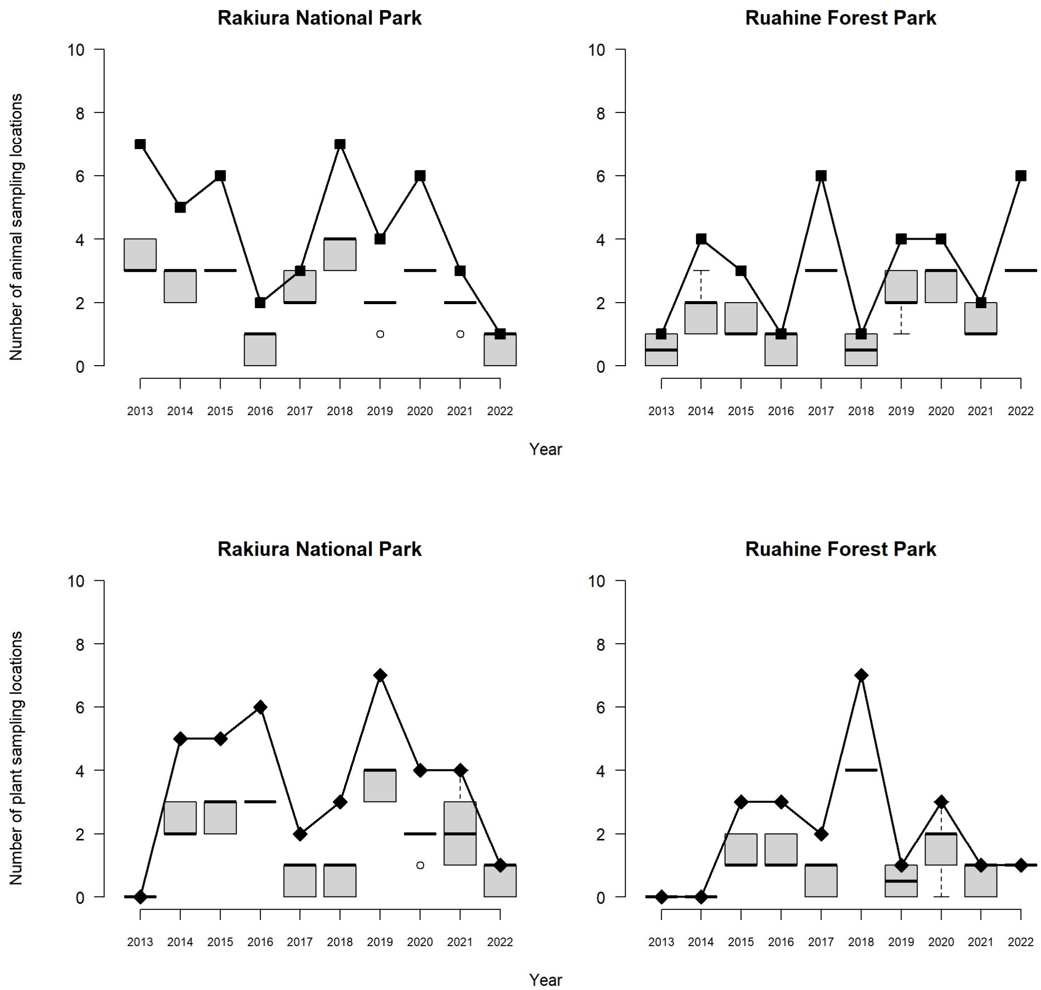


Figure 5. Number of sampling locations per year within the focal parks (Rakiura National Park and Ruahine Forest Park) for the current design (squares and diamonds for animal and plant surveys, respectively) and the proposed modified design (box plots showing variation in effort across the 50 replicates).

3.2 Proposed modified design

The proposed modified design extends the measurement cycle to a 10-year cycle, halving the number of sampling locations sampled each year, which allows no repeat measures within a decade. For the purposes of our analyses we created 50 replicates for the proposed modified design (i.e. a single 10-year cycle).

For each year the total number of sampling locations was halved (cf. current design; Figure 2). Sampling locations that were only sampled once (under the current design) were always selected, with the remainder selected through restricted randomisation, whereby the random draws of sampling locations were weighted according to the number available (under the current design) in each region, habitat type and management area (but with no replacement; see Appendix 1).

The order in which years were assigned sampling locations was randomised to avoid bias in sampling intensity through time. This provided a spatially representative sample, whereby a unique set of sampling locations were surveyed each year. The code used to generate data sets under the proposed modified design is provided in Appendix 2 (R source file BalancedSampling_v2.0.r).

4 Analytical approach

4.1 Observed trend directions and alerts detected by current design

Here we outline our protocols for calculating, interpreting, and visualising the 10-year trend estimates (2013–2022) for ungulates, plants, and birds on public conservation land. These analyses are based on field data gathered using the current design for the DOC Tier One monitoring framework (i.e. the 5-year measurement cycle, where most sampling locations were measured twice during the 10-year period; Table 3; Figure 2 to Figure 5). All analyses were undertaken using R (R Core Team 2023).

4.1.1 Specifying models to calculate observed trends

Separate models were fitted for each focal guild or species and metric (occupancy or abundance) to estimate the observed trends for up to four sets of sampling locations (from the Tier One monitoring framework; Table 4), representing:

- all public conservation land
- woody vs non-woody habitats
- inside and outside national parks within a given habitat
- two focal sites (Rakiura National Park and Ruahine Forest Park).

For occupancy models the response variable was specified as the observed presence or absence of the focal guild or species. For abundance models the response variable was specified as the number of individuals observed. For the purposes of these analyses, species detection probabilities were assumed to be equivalent to 1 (i.e. observers accurately recorded all the species and individuals present at each sampling location).

Note that abundance models were generally not fitted for guilds or species with very low total counts (exotic saplings, open-habitat birds, swamp harriers, and New Zealand pipits). Abundance models were also not fitted for ungulates (which had highly skewed counts), and occupancy models had previously performed well as surrogate measures of abundance (A Gormley, pers. comm.).

Table 4. Metrics and sets of sampling locations that were included in models fitted for each focal guild or species (in CAPITALS and *italics*, respectively; see Table 1 for more information on guild composition)

Focal guilds or species	Metric		Sets of sampling locations representing						
			All public conservation land	Habitat		National parks		Focal sites	
	Occupancy	Abundance		Woody	Non-woody	Inside	Outside	Rakiura	Ruahine
UNGULATES	●		●	●	●	●	●	●	●
EXOTIC SAPLINGS	●		●	●	●	●	●		
PALATABLE SAPLINGS	●	●		●		●	●	●	●
UNPALATABLE SAPLINGS	●	●		●		●	●	●	●
CAVITY NESTERS	●	●		●		●	●	●	●
Rifleman | tītitipounamu	●	●		●		●	●	●	●
LESS-MOBILE BIRDS	●	●		●		●	●	●	●
Grey warbler | riroriro	●	●		●		●	●	●	●
MOBILE BIRDS	●	●		●		●	●	●	●
Tūī | kōkō	●	●		●		●	●	●	●
NZ pigeon | kererū	●	●		●		●	●	●	●
NZ fantail | pīwakawaka	●	●		●		●	●	●	●
OPEN-HABITAT BIRDS	●				●	●	●		
Swamp harrier | kāhu	●				●	●	●		
NZ pipit | pīhoihoi	●				●	●	●		

All models were fitted using the glmer function from the R package lme4 (Bates et al. 2015), with binomial and Poisson error distributions specified for occupancy and abundance, respectively. Year was standardised ('Ys') for the 10-year period (on a scale of –4.5 to 4.5) to aid model fitting. For a small subset of guilds or species (typically those with consistently low occupancy or abundance, or consistently high occupancy, at sampling locations across the focal sites), model convergence was aided by specifying the 'bobyqa' optimiser and in some cases with 100,000 iterations.

In line with DOC's existing analytical protocols, the fitted models assumed all sampling locations follow the same trend. These models allowed each sampling location ('Place') to have its own intercept (accounting for differences in mean values across survey periods between sites), but all locations had a common trend. At the most basic level, a national monitoring network should be able to reliably detect national trends.

However, to interpret trends it may also be useful to detect the effects of covariates relating to habitat types or conservation management intensity on trends. To this end we fitted the following base models (Table 5) for the relevant subset of sampling locations:

- *all public conservation land:* only survey year was used as a continuous fixed effect to estimate the trend across all public conservation land
- *woody vs non-woody habitats:* survey year, woody classification, and their interaction were included as fixed effects to estimate the trends within woody and non-woody habitats
- *within vs outside parks:* survey year, national park or not, and their interaction were included as fixed effects to estimate trends inside and outside national parks (these models were fitted for woody and non-woody habitats independently).

Table 5. Base model specifications

Model	Model specifications	Distribution	
		Occupancy	Abundance
All public conservation land[a]	~ Ys + (1|Place)	Binomial	Poisson
Habitat	~ Ys*Woody + (1|Place)	Binomial	Poisson
Parks[b]	~ Ys*park + (1|Place)	Binomial	Poisson

Notes: Ys = standardised year centred around zero. Place = sampling location identity. Woody and park were both specified as two-level factors.

[a] Only fitted for ungulates and exotic saplings (as these models for other taxa were generally unstable).

[b] For ungulates and exotic saplings, these models were fitted to woody and non-woody habitats separately. For all other taxa these models were limited to the taxon's main habitat association.

4.1.2 Measuring uncertainty

Parametric bootstrapping was used to measure uncertainty in the fitted coefficients, referred to here as 'point estimates' (Canty & Riple 2020; Davison & Hinkley 1997). For the current design, 1,001 bootstrap replicates were generated by repeating the following steps.

1 Simulate new data from the fitted base model (using the doSim function from the R-package simr; Green & MacLeod 2016), keeping all the fixed and random effects the same as in the observed data.

2 Refit the base model using the new data.

3 Predict estimates for the key variable of interest.

For a very small subset of guilds or species within focal sites the number of bootstrap replicates was reduced, because the simulated data predicted consistent absence or presence across all sampling locations at a focal site.[2]

4.1.3 Calculating percentage changes in occupancy and abundance

The point estimates derived from base models were used to calculate the percentage change in occupancy or abundance for the 10-year measurement period (2013–2022) for each set of sampling locations. The respective set of 1,001 bootstrap replicates was then used to estimate uncertainties (or 80% confidence intervals), after calculating the percentage change in occupancy or abundance for each of the bootstrap runs (e.g. Figure 6A).[3]

4.1.4 Classifying trend direction and signals

The trend direction was classified based on the point estimate (Figure 6). The signal strength for the trend direction (confidence in the direction of change; McBride et al. 2014) was then determined by the proportion of bootstrap estimates in the same direction as the point estimate (Figure 6). This classification was applied based on an existing protocol (MacLeod et al. 2019). The derived information was then visualised using arrows to depict the trend direction, with signal strength proportional to the number of shaded dots as well as the shading intensity for the arrow and dots.

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[2] Rakiura: occupancy of mobile birds (993 bootstraps), riflemen (984 bootstraps), kererū (1,000 bootstraps); abundance of riflemen (985 bootstraps). Ruahine: occupancy of less-mobile birds (998 bootstraps), kererū (963 bootstraps). Note: a small proportion (up to 2%) of bootstrap replicates was derived from models with convergence issues that were not resolved.

[3] Note: these estimates were also recentred on the point estimate and bias corrected.

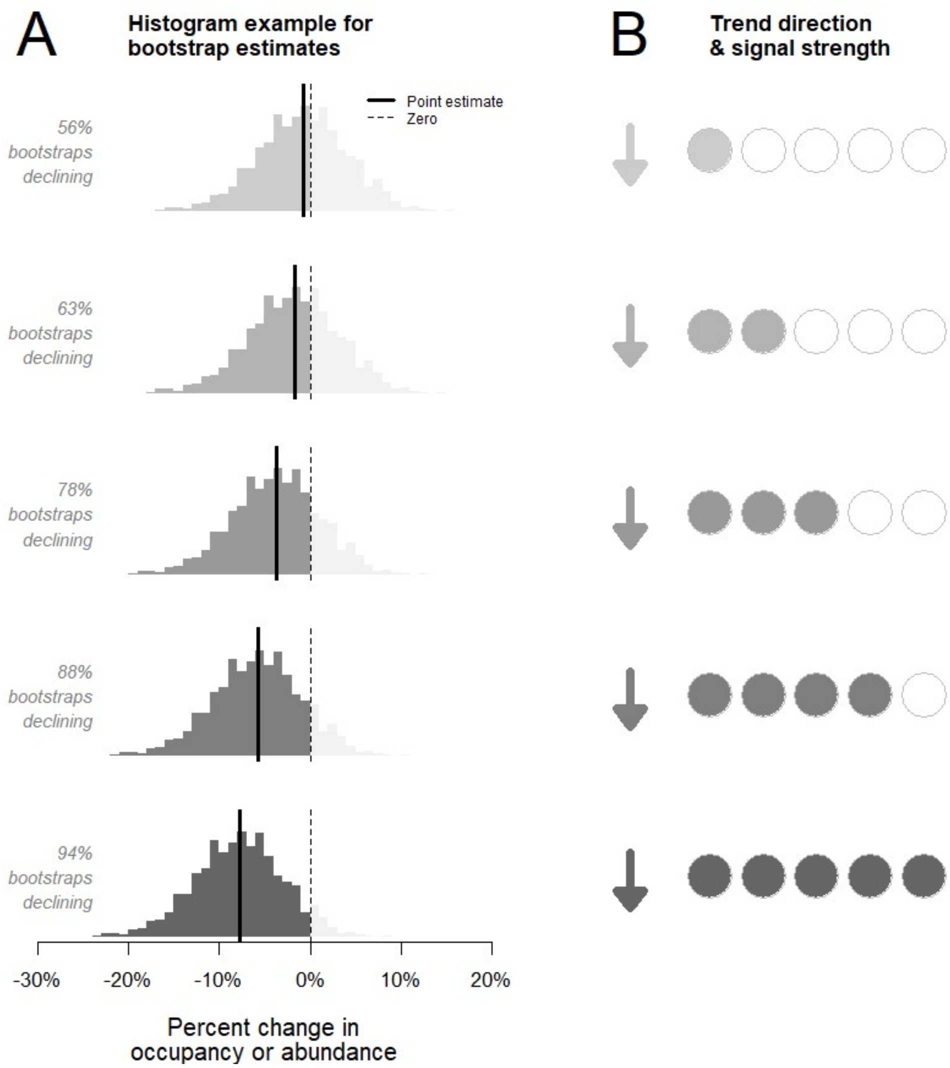


Figure 6. Trend direction and signal strength classification process for five hypothetical trends, where the derived point estimate determines the trend direction: solid lines (A); these examples are all declining and so depicted as downward-pointing arrows (B).

Notes: The proportion of bootstrap estimates that match the trend direction (i.e. the darker shaded areas of the histograms in (A) determine the signal strength, which is depicted by the number and intensity of shaded dots (B); a single light-shaded dot indicates a very weak signal (when just over 50% of bootstraps match), and five dark-shaded dots indicate a very strong signal (when at least 90% of bootstraps match). Arrows are colour coded to match the signal strength. (The arrow direction is reversed for increasing trends, and a double-headed horizontal arrow is used when there are an equal number of declining and increasing bootstrap estimates.)

4.1.5 Classifying trend alert and signals

A standardised protocol (adapted from MacLeod et al. 2022) was then used to classify the trend sizes as equivalent to rapid, moderate, and shallow declines (colour coded red, amber, and light amber, respectively), as well as shallow, moderate, and rapid increases (coded using light to dark blue), and little or no change (indicated by a pale blue shade) over 10 years (Figure 7B). The signal strength of each colour-coded alert was ranked from insufficient or very weak to very strong; these ranks were based on the distribution of the bootstrap estimates in relation to specified trend threshold criteria and/or whether they overlapped zero (Figure 7C). Species with smaller variance will have stronger signals. The resulting alert category classifications (Figure 7D) were undertaken using purpose-built R functions (Appendix 2).

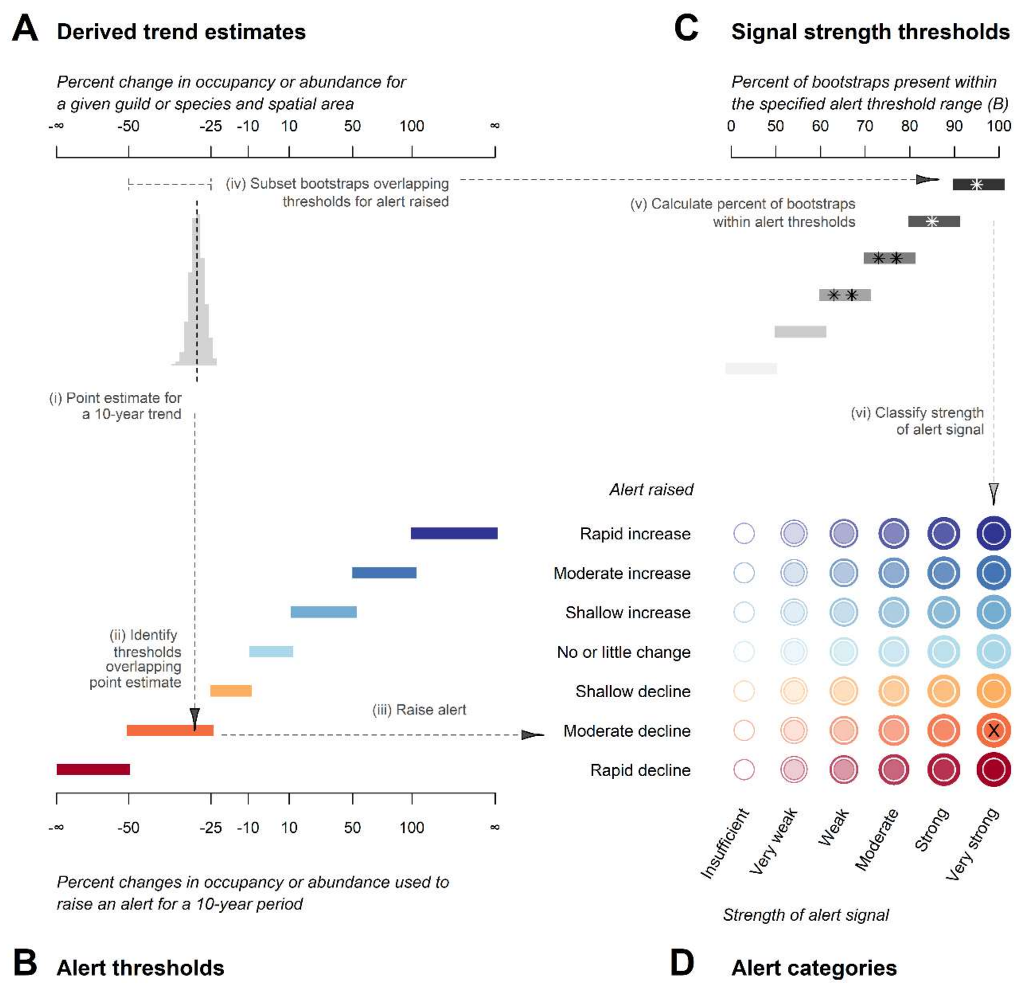


Figure 7. Alert classification process for 10-year trends (2013–2022), where the derived point and bootstrap estimates (black dotted line and grey histogram, respectively, in (A) for each guild or species, location, and time period are independently overlaid on standardised alert and signal strength thresholds (B and C, respectively) to identify their relevant alert category and colour code (D).

Notes: If the 10%–90% quantile range for the bootstrap estimates included zero, the strength of alert signal was downgraded for very strong or strong classes to a weak one (as denoted by * in C) and for moderate or weak classes to a very weak one (** in C). For exotic species, the colour coding is reversed (e.g. a red alert is raised when the taxon is increasing rapidly). (Figure adapted from MacLeod et al. 2022.)

4.2 Power to detect simulated trends after 10 years for the current versus modified designs

In this section we outline our analytical protocols for addressing the following question: How does increased uncertainty of trend estimates resulting from halving sampling effort affect our ability to detect trends? The analyses consider scenarios where the 15 focal guilds or species (Table 6) are monitored either under the current design (locations measured on a 5-year cycle, or twice in a 10-year period) or the proposed modified design (each location measured once every 10 years). More specifically, the analyses evaluate the power to detect simulated rapid to moderate changes after 10 years of monitoring. For each guild and species and metric, the simulated trends were applied, as appropriate, across all public conservation land, a given habitat or a focal site independently (Table 6).

Table 6. Focal guilds and species (in CAPITALS and *italics*, respectively), their metrics and sets of sampling locations to which the power analyses were applied

Focal guilds or species	Metric		Sets of sampling locations representing				
			All public conservation land	Habitat associations		Focal sites	
	Occupancy	Abundance		Woody	Non-woody	Rakiura	Ruahine
UNGULATES	●		●			●	●
EXOTIC SAPLINGS	●		●				
PALATABLE SAPLINGS	●	●		●		●	●
UNPALATABLE SAPLINGS	●	●		•		●	●
CAVITY NESTERS	●	●		●		•	•
Rifleman | tītitipounamu	●	●		●		○	•
LESS-MOBILE BIRDS	●	●		•		●	●
Grey warbler | riroriro	●	●		•		●	●
MOBILE BIRDS	●	●		•		●	●
Tūī | kōkō	●	●		●		•	●
NZ pigeon | kererū	●	●		●		●	●
NZ fantail | pīwakawaka	●	●		●		●	●
OPEN-HABITAT BIRDS	●	●			●		
Swamp harrier | kāhu	●	●			●		
NZ pipit | pīhoihoi	●	●			●		

Notes: See Table 1 for more information on guild composition. Open circles indicate scenarios where power analyses could not be run for the modified design. Grey dots indicate where power analyses were only run for a subset of trends (typically when the starting occupancy estimates were too high to apply an increasing trend).

4.2.1 Calculating power to detect simulated 10-year trends

Power analyses for the simulated 10-year trends were carried out using the powerSim function in the simr package in R (Green & MacLeod 2016). For each focal guild or species, metric, and set of sampling locations (Table 6), power analyses were implemented as follows.

- The appropriate base model (~ Ys + (1|Place)) was fitted using the glmer function in the lme4 package in R,[4] simulating a 10-year trend equivalent to a rapid decline (60% over 10 years), moderate decline (36% over 10 years), moderate increase (64% over 10 years) or a rapid increase (115% over 10 years).[5] (These trends were specified using the 'fixef' function in simr; Green & MacLeod 2016.) Note that when modelling occupancy scenarios, the simulated trends and intercepts were tailored relative to the occupancy estimate for the initial year of monitoring (as predicted by the respective base model). For the abundance models, Ys was standardised so that initial year of monitoring equalled zero, and values for simulated trends, but not model intercepts, were specified.
- The power to detect simulated trends was calculated based on 50 simulations per scenario (using the powerSim function in R), while varying the confidence level for the statistical test (i.e. the probability that if a survey were repeated, the results obtained would be the same) to standard (95%), liberal (90%) or very liberal (80%). (These confidence levels were specified using their respective 'alpha' levels (0.05, 0.10, 0.20) in the powerSim function; Green & MacLeod 2016.)

For the modified design these steps were repeated for each of the 50 replicates independently, before calculating the median of power estimates for the 50 replicates.

4.2.2 Visualising power to detect simulated 10-year trends

Dot plots were then used to help the reader quickly identify those scenarios where there was sufficient power to detect the simulated trends (Figure 8), by:

- colour-coding the power estimates (%) to reflect the simulated trend (using the same scheme as applied in Figure 7D), with the dot shading proportional to its respective power estimate (i.e. light and dark shading used to signal low and high power, respectively)
- identifying those scenarios where there was moderate to very high power to detect the simulated trends by adding outer rings to those dots where the power was ≥80% (fine ring), ≥90% (intermediate ring), or 100% (thick ring).

[4] Note that the random effects (1|Place) for the current design encompasses both spatial and temporal repeat measures, but for the modified design encompasses only spatial repeated measures. For the purposes of our power analyses we have assumed this will not affect the power estimate.

[5] For each trend category the simulated trend was selected to be at least 10 units away from its respective trend alert band (see Figure 7).

POWER TO DETECT SIMULATED TRENDS AFTER 10 YEARS

A

GUILD OR SPECIES	RED ALERT (Rapid deterioration)						AMBER ALERT (Moderate deterioration)						BLUE ALERT (Moderate improvement)						INDIGO ALERT (Rapid improvement)					
	CURRENT DESIGN			MODIFIED DESIGN			CURRENT DESIGN			MODIFIED DESIGN			CURRENT DESIGN			MODIFIED DESIGN			CURRENT DESIGN			MODIFIED DESIGN		
Confidence level	*Standard*	*Liberal*	*V liberal*	*Standard*	*Liberal*	*V liberal*	*Standard*	*Liberal*	*V liberal*	*Standard*	*Liberal*	*V liberal*	*Standard*	*Liberal*	*V liberal*	*Standard*	*Liberal*	*V liberal*	*Standard*	*Liberal*	*V liberal*	*Standard*	*Liberal*	*V liberal*
Tūī | Kōkō	100	100	100	69	77	83	98	100	100	27	39	50	100	100	100	46	56	68	100	100	100	72	82	88
NZ pigeon | Kererū	100	100	100	2	6	25	68	88	92	0	0	6	88	94	100	0	4	13	100	100	100	7	16	33

B

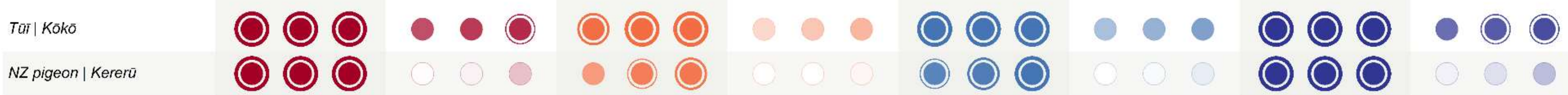


Figure 8. Power estimates (A) for hypothetical scenarios for tūī and kererū (using artificially generated percentages) are colour-coded (B) to highlight where there is sufficient power to detect rapid or moderate changes in occupancy or abundance after 10 years under the current and proposed modified designs for DOC's Tier One framework when the confidence level was specified as standard (95%), liberal (90%) or very liberal (80%).

Notes: Shading of dots (B) is proportional to the power estimate (%), with the outer rings highlighting those scenarios where the power was ≥80% (fine ring), ≥90% (intermediate ring), or 100% (thick ring).

4.3 Time taken to detect early warnings for the current versus modified designs

In this section we outline our analytical protocols for addressing the following question: How does increased uncertainty of trend estimates resulting from halving sampling effort affect the time taken to raise alerts? The analyses consider scenarios where the 15 focal guilds or species (Table 6) are monitored either under the current design (locations measured on a 5-year cycle, or twice in a 10-year period) or the proposed modified design (each location measured once every 10 years). The analyses evaluate the earliest point in time that an early warning could be raised for simulated rapid to moderate trends. For each guild and species, the simulated trends were applied, as appropriate, at the national scale (across all public conservation land, a given habitat; Table 6), or a focal site independently (Table 6).

Calculating time taken to detect an early warning

To calculate the time taken to detect an early warning for a given trend alert, power analyses were carried out using the powerCurve function in the simr package in R (Green & MacLeod 2016). The following steps were implemented for each focal guild or species, metric, and set of sampling locations (Table 6).

1. The base model (~ Ys + (1|Place)) was fitted with the focal guild's or species' occupancy or abundance as the response variable using the glmer function in the lme4 package in R.[4]
2. The 10-year trend equivalent to a rapid decline (60% over 10 years), moderate decline (36% over 10 years), moderate increase (64% over 10 years) or a rapid increase (115% over 10 years) was simulated.[5] (These trends were specified using the 'fixef' function in simr; Green & MacLeod 2016.) Note that when modelling occupancy scenarios, the simulated trends and intercepts were tailored relative to the occupancy estimate for the initial year of monitoring (as predicted by the respective base model). For the abundance models, Ys was standardised so that initial year of monitoring equalled zero, and values for simulated trends, but not model intercepts, were specified.
3. The power to detect simulated trends was calculated based on 50 simulations per scenario and the standard confidence level of 95% (using the powerCurve function in R; Green & MacLeod 2016), while varying the number of years of sampling from 3 to 10, with 1-year increments.

For the modified design these steps were repeated for each of the 50 replicates independently, before calculating the median of power estimate for the 50 replicates.

Visualising time taken to detect an early warning

Dot plots were then used to help the reader quickly identify the time taken to detect an early warning (i.e. when there was sufficient power to detect the simulated trends; Figure 9), by:

- colour-coding the power estimates (%) for each year to reflect the simulated trend (using the same scheme as applied in Figure 7), with the dot shading proportional to its respective power estimate (i.e. light and dark shading used to signal low and high power, respectively) and the power estimate overlaid as text
- identifying those scenarios where there was moderate to very high power to detect the simulated trends by adding outer rings to those dots where the power was ≥80% (fine ring), ≥90% (intermediate ring), or 100% (thick ring).

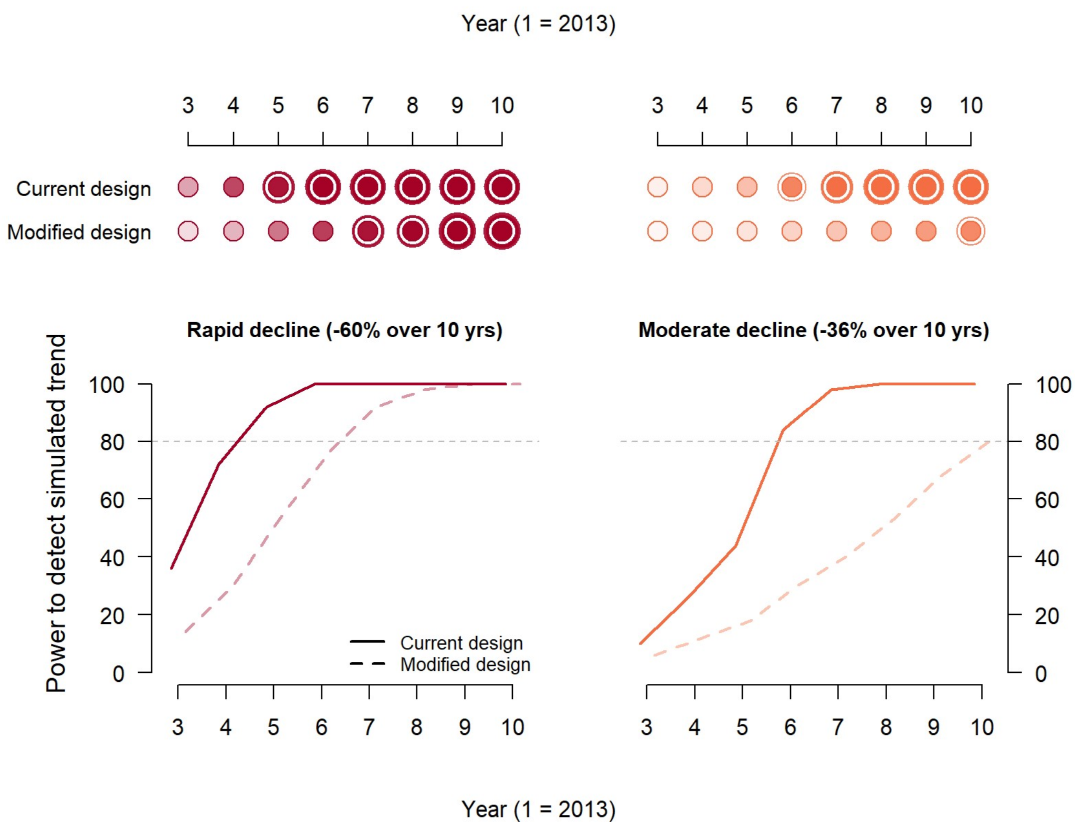


Figure 9. Conversion of power curves into summary dot plots (using the power curves for fantail occupancy in woody habitats on public conservation land as an example).

Notes: shading of dots is proportional to the power estimate (%), with the outer rings signalling when the power estimate is ≥80% (fine ring), ≥90% (intermediate ring) or 100% (thick ring).

5 Observed trend directions and alerts detected by the current design

5.1 National trends

All public conservation land

An amber alert was raised for ungulate occupancy across all public conservation land, with an early warning for a potential emerging red alert (the alert signal straddles both amber and red alerts; Figure 10). At the same time, exotic saplings showed little to no change in occupancy across all public conservation land.

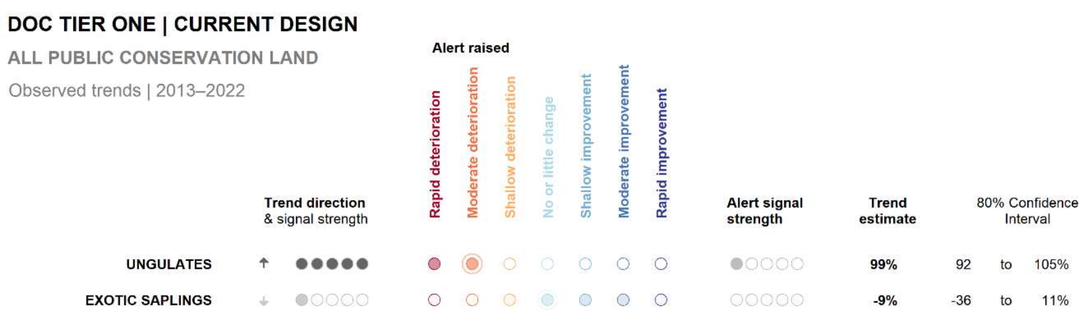


Figure 10. Trend summary (2013–2022) for two guilds across all public conservation land.

Notes: Trend estimates for occupancy were derived from the respective model for the guild or species (~ Ys + (1|Place)). These estimates were based on field data gathered on the DOC Tier One framework using the current design (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system, see Figure 7, and for sampling sizes see Table 3).

Woody habitats

Trend signals for woody habitats indicate a deterioration in some components of ecological integrity, but improvements in others.

An amber alert was raised for ungulate occupancy. In parallel with this moderate increase in ungulates, palatable sapling abundance has declined (shallowly), while unpalatable saplings have become more abundant. At the same time, the occupancy of palatable and unpalatable saplings showed little change, but exotic sapling occupancy decreased moderately.

Amber alerts were raised for cavity nester occupancy and abundance, with an early warning for an emerging red alert for this guild's occupancy. At the species level, red alerts were raised for the occupancy and abundance of the rifleman (a cavity-nesting bird).

Occupancy of mobile and less-mobile bird guilds showed little or no change over the 10 years of monitoring. However, in both cases, shallow declines in abundance were flagged in woody habitats. Grey warblers, an example of a less-mobile species, not only experienced shallow declines in abundance, but also signalled (albeit weakly) potential declines in occupancy. Of the three mobile bird species considered, tūī and kererū showed little change in occupancy and abundance. By contrast, fantails experienced a moderate increase in occupancy and a shallow increase in abundance across all woody habitats

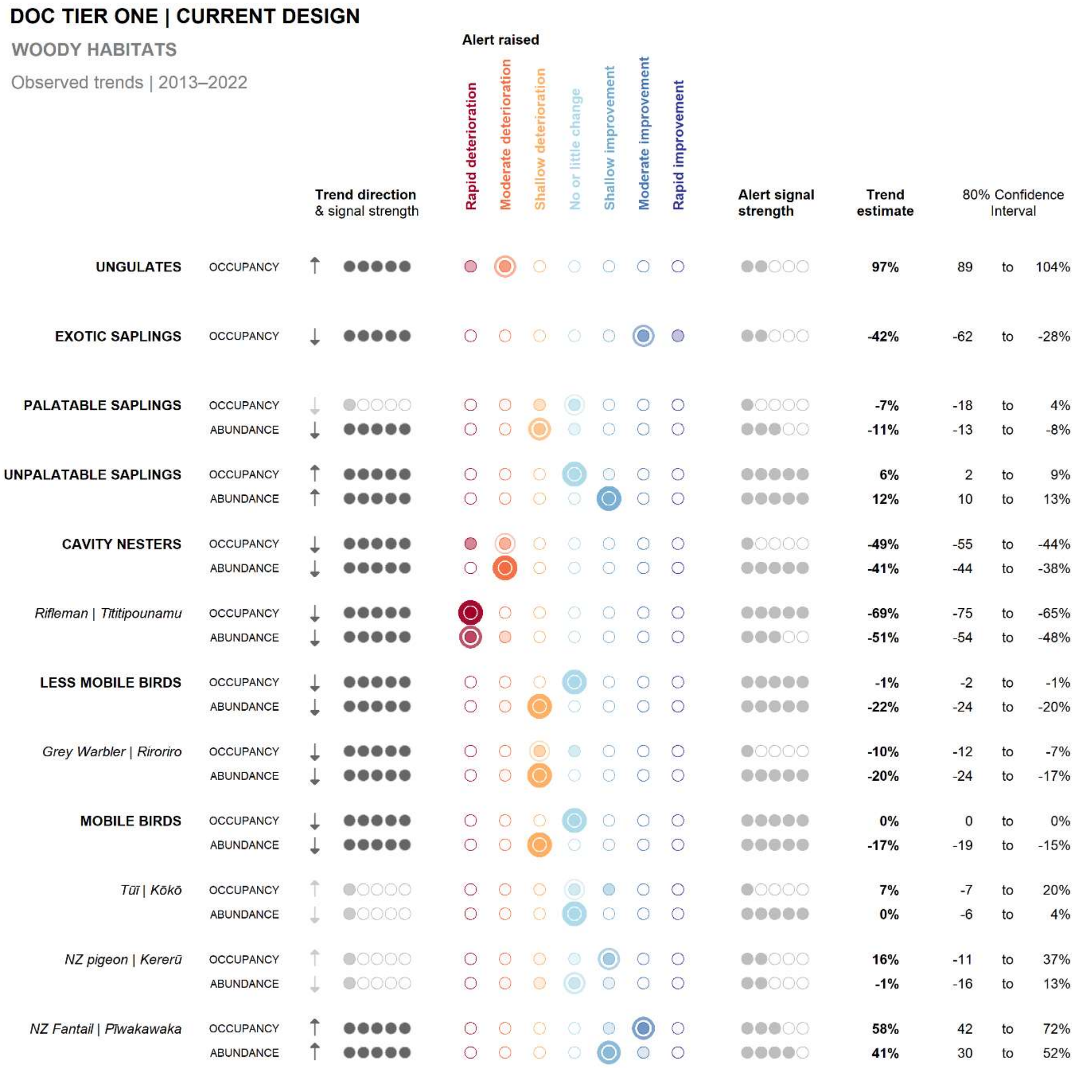


Figure 11. Trend summary (2013–2022) for seven guilds and five species within woody habitats on public conservation land.

Notes: Trend estimates for occupancy were derived from the respective model for the guild or species (~ Ys*Woody + (1|Place)). These estimates were based on field data gathered on the DOC Tier One framework using the current design (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system see Figure 7, and for sampling sizes see Table 3).

Non-woody habitats

Within non-woody habitats, the overall trend was for a deterioration in ecological integrity. Red alerts were raised for ungulates (which increased rapidly) and swamp harriers (which decreased rapidly). Trend alerts were also flagged for a shallow deterioration in exotic saplings and open-habitat birds (including the New Zealand pipit), albeit supported by weak signals.

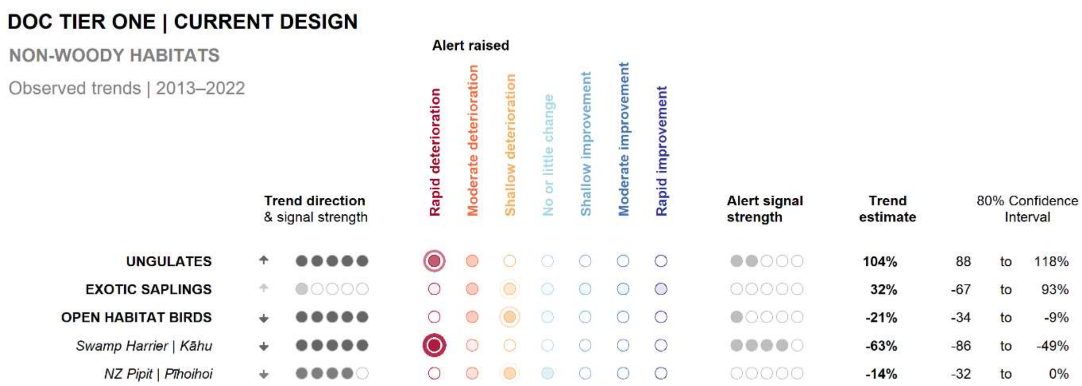


Figure 12. Trend summary (2013–2022) for three guilds and two species within non-woody habitats on public conservation land.

Notes: Trend estimates for occupancy were derived from the respective model for the guild or species (~ Ys*Woody + (1|Place)). These estimates were based on field data gathered on DOC Tier One framework using the current design (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system see Figure 7, and for sampling sizes see Table 3).

5.2 Inside and outside national parks

Woody habitats

An amber alert was raised for ungulate occupancy both inside and outside national parks in woody habitats, but with an early warning signal for an emerging red alert outside national parks (Figure 13). Exotic sapling occupancy improved (moderately) outside national parks, but showed little change within national parks.

Occupancy and abundance of palatable saplings exhibited little change inside national parks but declined (shallowly) outside them (Figure 13). Conversely, unpalatable sapling occupancy and abundance increased (shallowly) within national parks, but changed little outside them.

Amber alerts were raised for cavity-nesting birds inside national parks (occupancy and abundance) and outside national parks (abundance), with red alerts for occupancy and abundance of this guild outside national parks, flagged by a strong signal and an early warning, respectively (Figure 13). Red alerts were also raised for rifleman occupancy inside national parks and occupancy and abundance outside national parks, but with an amber alert for this cavity-nesting species' abundance in national parks; this species' alerts were all supported by moderate to very strong signals.

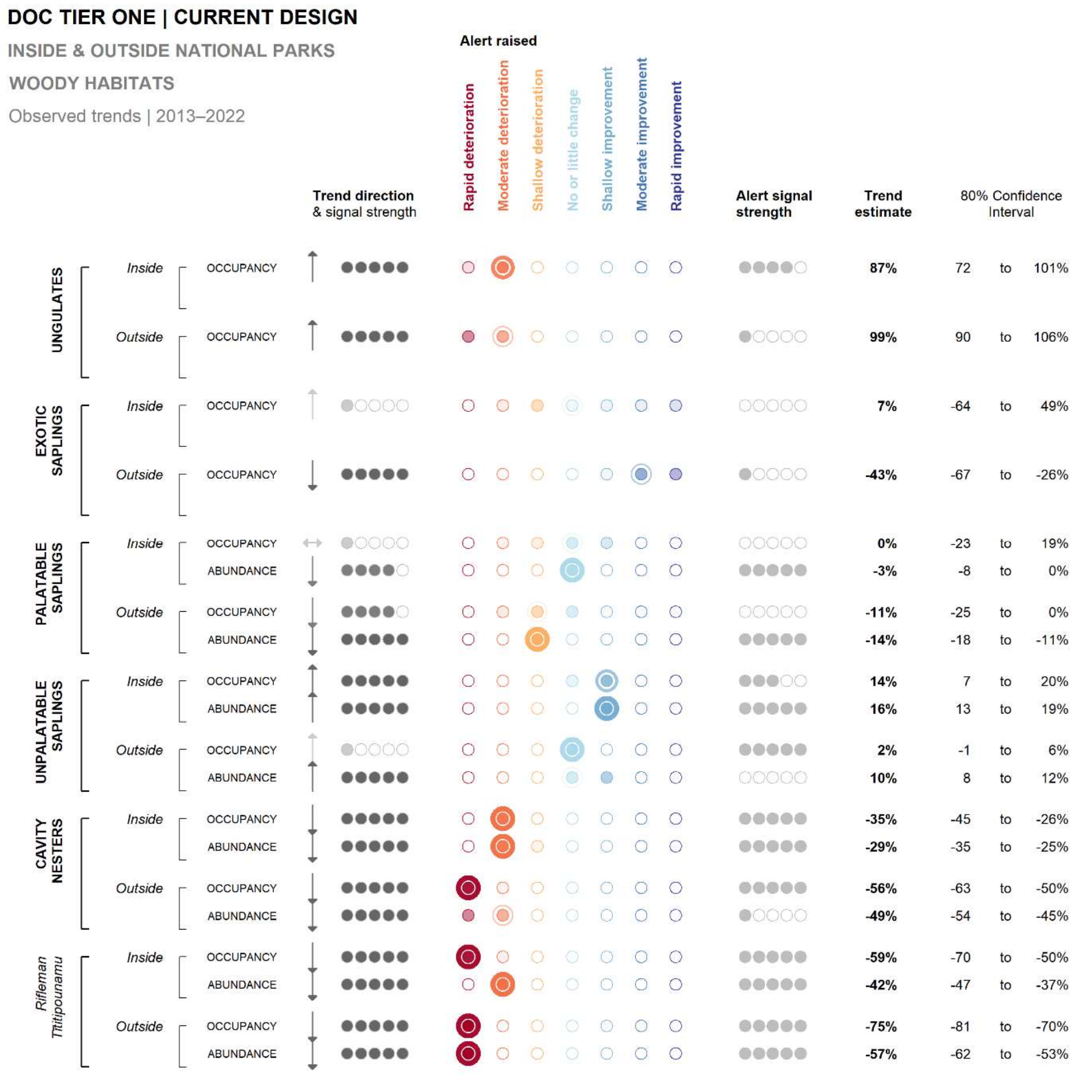


Figure 13. Trend summary (2013–2022) for five guilds and one species inside and outside national parks within woody habitats on public conservation land.

Notes: Trend estimates for occupancy or abundance were derived from the respective model for the guild or species (~ Ys*park + (1|Place)). These estimates were based on field data gathered on the DOC Tier One framework using the current design (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system see Figure 7, and for sampling sizes see Table 3).

Occupancy of mobile and less-mobile bird guilds showed little or no change inside and outside national parks (Figure 14). However, in both cases, shallow declines in abundance were flagged inside and outside national parks (with these alert classifications all supported by moderate to very strong signals). Grey warblers, an example of a less-mobile species, not only experienced shallow declines in abundance inside and outside national parks, but also signalled (albeit weakly) potential declines in occupancy outside national parks (Figure 14).

Of the three mobile bird species considered, tūī and kererū increased moderately to rapidly in both occupancy and abundance within national parks while undergoing declines outside national parks (at least a shallow decline for kererū abundance, but a potentially moderate decline for tūī occupancy and abundance; Figure 14). By contrast, fantails increased (at least shallowly) in occupancy and abundance inside and outside national parks, while also signalling a potential transition to a faster rate of increase for both occupancy and abundance within national parks (where the alert signals straddled two alert classes; Figure 14).

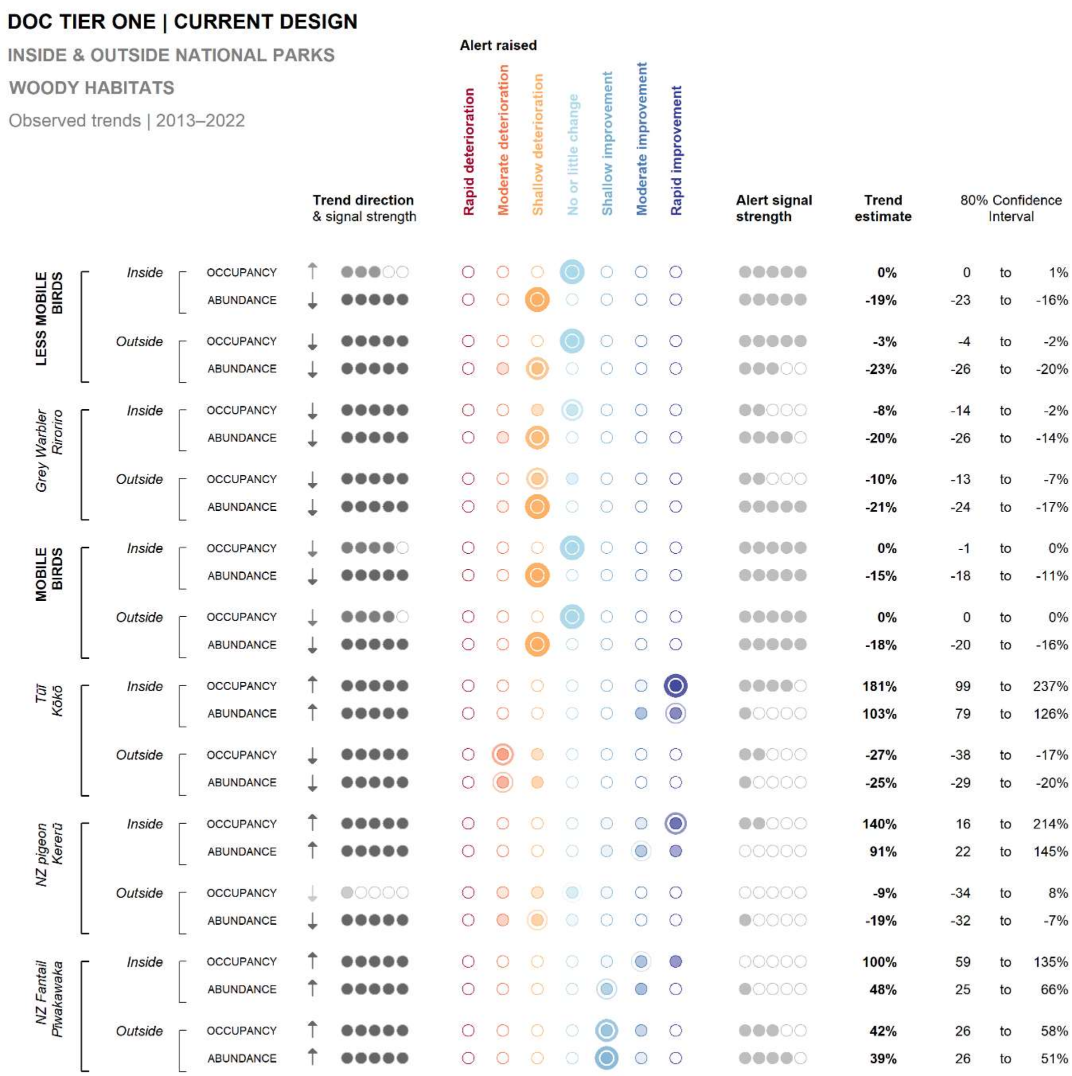


Figure 14. Trend summary (2013–2022) for mobile and less-mobile birds inside and outside national parks within woody habitats on public conservation land.

Notes: Trend estimates for occupancy or abundance were derived from the respective model for the guild or species (~ Ys*park + (1|Place)). These estimates were based on field data gathered on the DOC Tier One framework using the current design (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system see Figure 7, and for sampling sizes see Table 3).

Non-woody habitats

Red and amber alerts were raised for ungulate occupancy inside and outside national parks, respectively, but with an early warning for an emerging red alert flagged outside national parks. Exotic sapling occupancy decreased within national parks (at least moderately, but possibly rapidly). However, outside national parks this guild increased at least shallowly, but possibly moderately.

Red alerts were also flagged for swamp harriers inside and outside national parks (with both alerts supported by strong signals). Open-habitat birds, including New Zealand pipits, declined (at least shallowly but potentially moderately) inside and outside of national parks.

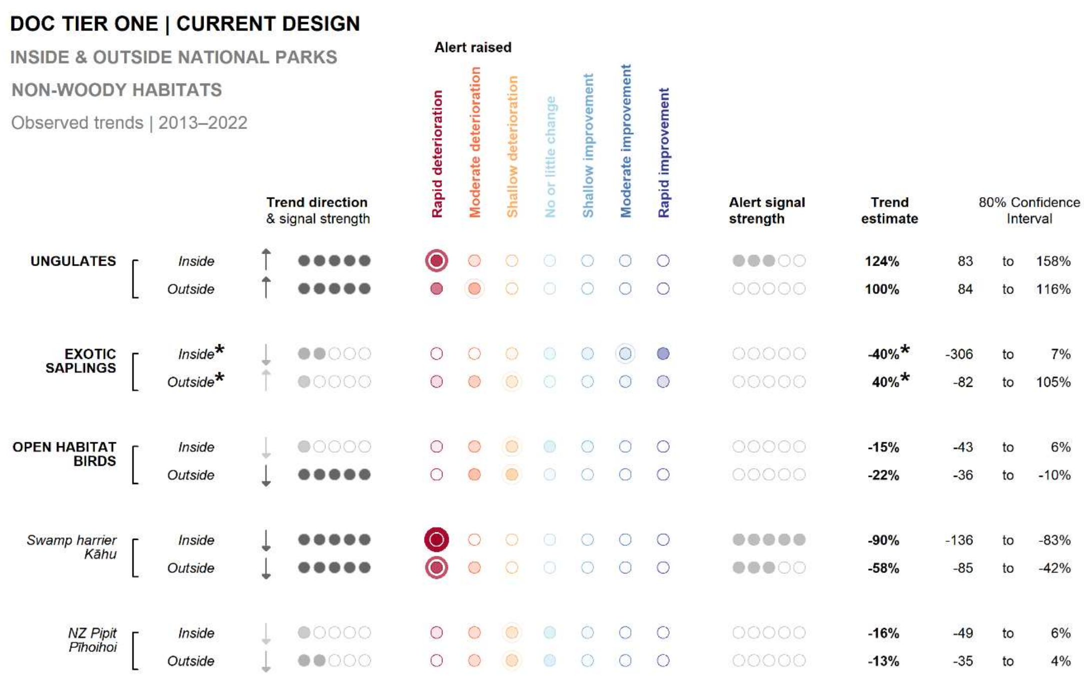


Figure 15. Trend summary (2013–2022) for inside and outside national parks within non-woody habitats on public conservation land.

Notes: Trend estimates were derived (from the respective models (~ Ys*park + (1|Place)) for occupancy for five guilds or species. These estimates were based on field data gathered on the DOC Tier One framework using the current design (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system see Figure 7, and for sampling sizes see Table 3). Asterisks indicate poorly fitting models (based on a visual inspection of bootstrap diagnostic plots).

5.3 Focal sites

In general, when Tier One data were used to estimate trends in focal sites, poorly fitting models were most likely to result. This was particularly so for guilds and species that were sparse or highly mobile, as indicated by high uncertainty in the derived trend estimates, which were also exceptionally large (due to relatively large changes for very low occupancy estimates). (Note that exotic saplings were not recorded at either focal site.)

Rakiura National Park

A red alert was raised for ungulate occupancy in Rakiura National Park (supported by a very strong signal; Figure 16).

There was little change in unpalatable sapling occupancy and (possibly) abundance, with very weak signals for a shallow increase in occupancy and abundance of palatable saplings.

A red alert was flagged for cavity-nester occupancy, and an amber alert flagged for their abundance. By contrast, rifleman occupancy and abundance increased rapidly over the same period at this focal site.

For mobile and less-mobile birds, abundance declined moderately, but with little change in occupancy. Grey warbler occupancy and abundance declined moderately, with each metric also signalling an early warning for an emerging rapid decline. The alert signals for the mobile bird species for both occupancy and abundance were generally very weak, making it difficult to determine their status.

Ruahine Forest Park

A moderate decline in ungulate occupancy was detected in Ruahine Forest Park (supported by a moderate strength signal; Figure 17).

Rapid declines in the occupancy and abundance of palatable saplings were detected (but were informed by poorly fitting models), with moderate (but possibly rapid) declines in unpalatable sapling abundance also flagged.

There was little change in the occupancy of mobile and less-mobile birds, with moderate declines in abundance for less-mobile birds (but no clear alert signal for mobile birds). Grey warblers declined in occupancy and abundance. However, no clear alert signals were detected for cavity nesters, riflemen, grey warblers, and mobile bird species at Ruahine Forest Park.

Figure 16. Trend summary (2013–2022) for Rakiura National Park.

Notes: Trend estimates for occupancy and abundance of each focal guild or species were derived from the respective model (~ Ys + (1|Place)). These estimates were based on field data gathered on the DOC Tier One framework using the current design (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system see Figure 7, and for sampling sizes see Table 3). Asterisks indicate poorly fitting models (based on a visual inspection of bootstrap diagnostic plots).

Figure 17. Trend summary (2013–2022) for Ruahine Forest Park.

Notes: Trend estimates for occupancy and abundance of each focal guild or species were derived from the respective model (~ Ys + (1|Place)). These estimates were based on field data gathered on the DOC Tier One framework using the current design (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system see Figure 7, and for sampling sizes see Table 3). Asterisks indicate poorly fitting models (based on a visual inspection of bootstrap diagnostic plots).

6 Power to detect simulated trends: current vs proposed modified designs

6.1 National trends

After 10 years of monitoring, the current design will generally have very high power to detect rapid to moderate changes in occupancy (Figure 18) and abundance (Figure 19) of the 15 focal guilds or species across public conservation land. However, this design will struggle to detect rapid changes in swamp harrier occupancy, and moderate changes in exotic sapling and kererū occupancy unless the confidence level is relaxed. Moderate changes in swamp harrier occupancy will not be detectable even when relaxing the confidence level.

The proposed modified design will have reasonable power to detect rapid changes in abundance for all but two species (kererū and swamp harrier; Figure 19) and occupancy at the guild level (except palatable saplings; Figure 18). However, it will have low or no power to detect rapid changes in occupancy of species that are highly mobile (e.g. tūī and kererū) or sparsely distributed (e.g. exotic saplings, swamp harrier, New Zealand pipit; Figure 18). At the guild level there will only be sufficient power to detect moderate changes in ungulate occupancy, as well as occupancy and abundance for unpalatable saplings, mobile birds, and less-mobile birds. At the species level moderate changes will be detectable for fantail abundance, and for grey warbler occupancy and abundance. If the confidence level is relaxed, there will also be sufficient power to detect moderate changes in fantail occupancy and in cavity-nester occupancy and abundance.

(Note that power analyses were not run for increases in unpalatable saplings because occupancy estimates for this guild were high [66%] at the outset.)

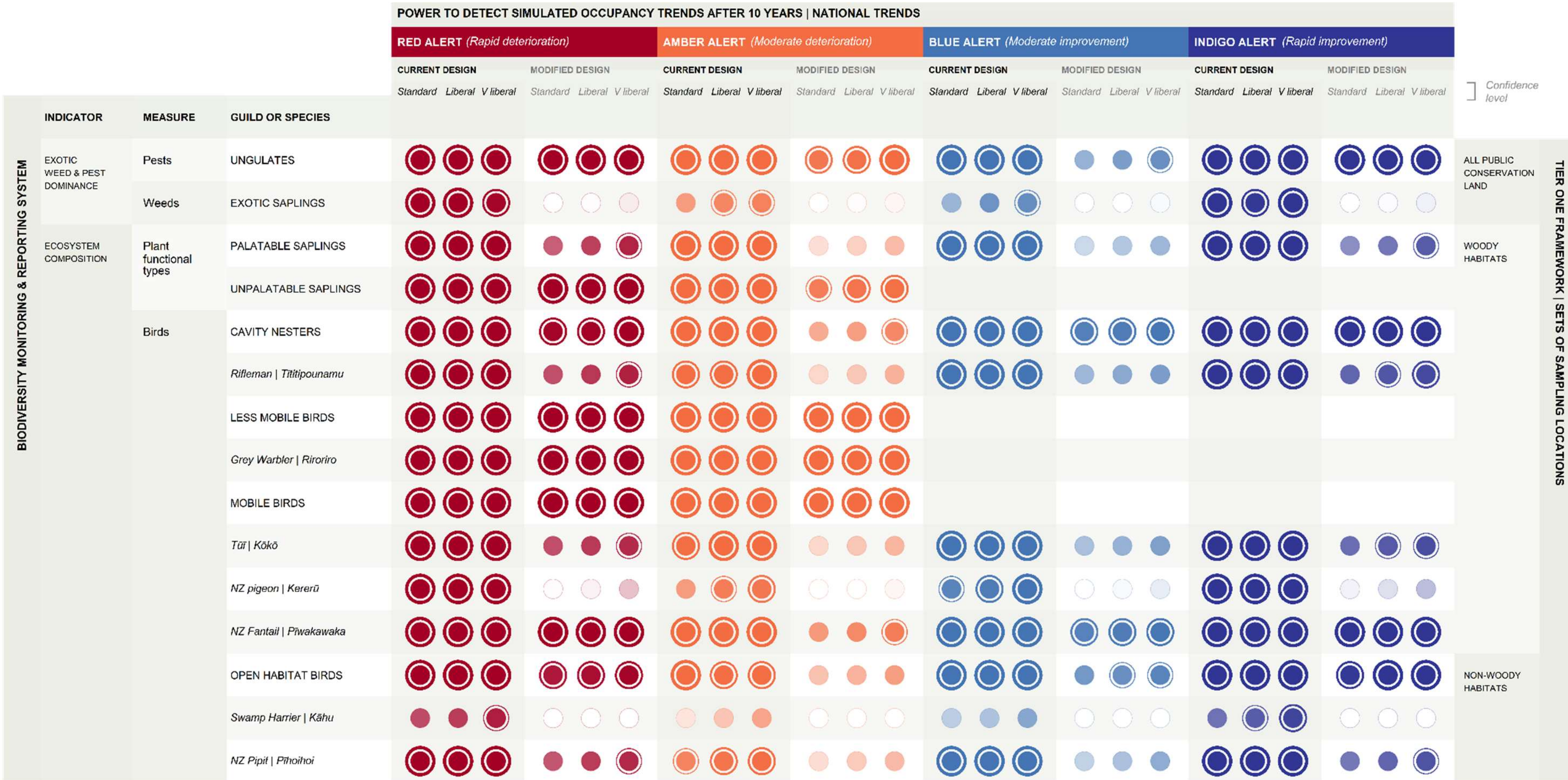


Figure 18. Power (%) to detect rapid or moderate changes in occupancy across all public conservation land or within woody or non-woody habitats after 10 years.

Notes: Power estimates are presented for 15 focal guilds or species monitored under the current design of DOC's Tier One framework versus the proposed modified design when the confidence level was specified as standard (95%), liberal (90%) or very liberal (80%). Shading of dots is proportional to the power estimate, with the outer rings highlighting those scenarios where the power was ≥80% (fine ring), ≥90% (intermediate ring), or 100% (thick ring). The power estimate for each scenario was derived using their respective base model ~ Ys + (1|Place), with 50 simulations per scenario. For the modified design, the power estimate is the median value across the 50 replicates. Note that power analyses were not run for increases when occupancy estimates were high at the outset. (See Table 3 for sample sizes.)

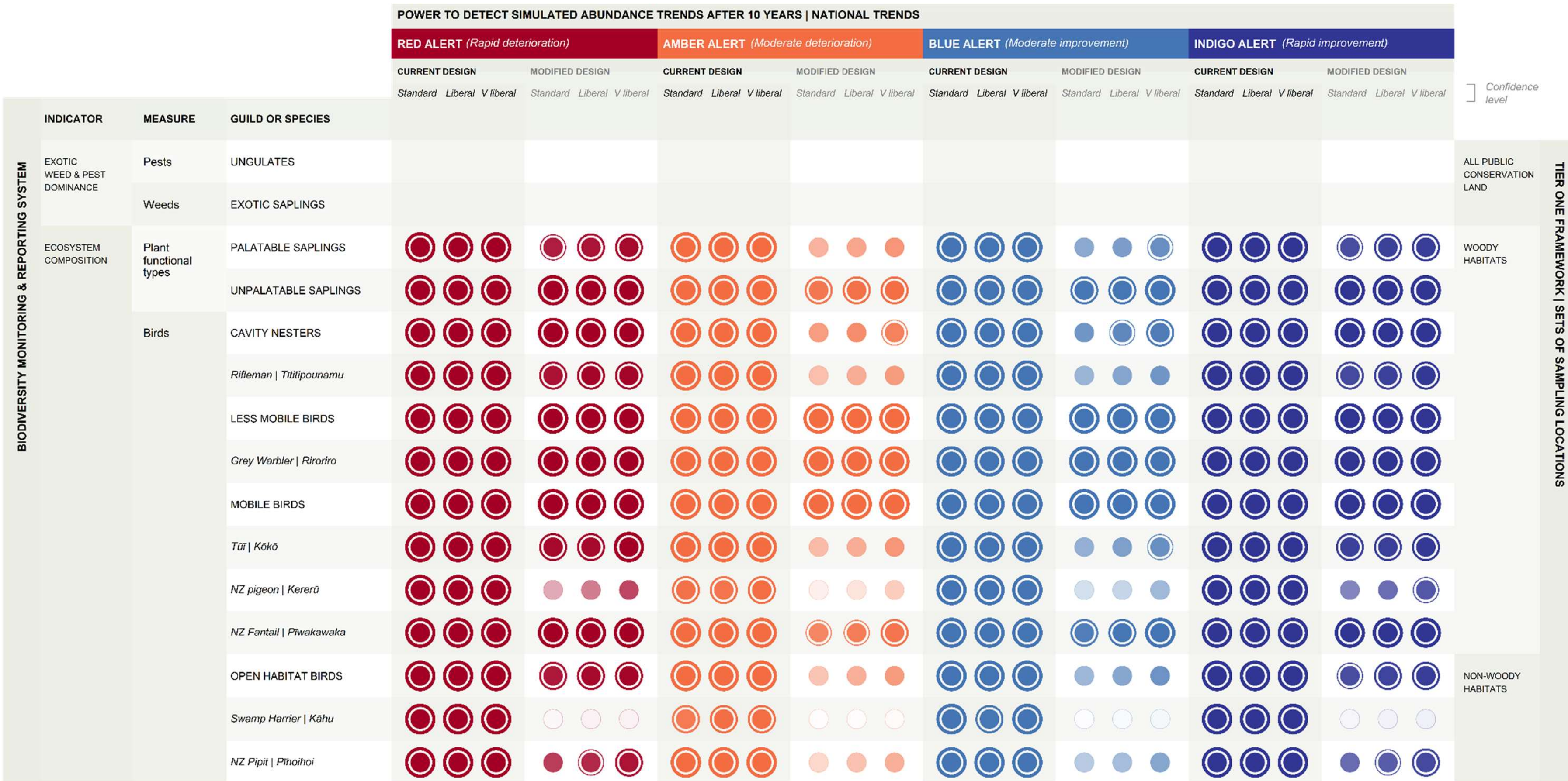


Figure 19. Power (%) to detect rapid or moderate changes in abundance across all public conservation land or within woody or non-woody habitats after 10 years.

Notes: Power estimates are presented for 13 focal guilds or species monitored under the current design of DOC's Tier One framework versus the proposed modified design when the confidence level was specified as standard (95%), liberal (90%) or very liberal (80%). Shading of dots is proportional to the power estimate, with the outer rings highlighting those scenarios where the power was ≥80% (fine ring), ≥90% (intermediate ring) or 100% (thick ring). The power estimate for each scenario was derived using their respective base model ~ Ys + (1|Place), with 50 simulations per scenario. For the modified design, the power estimate is the median value across the 50 replicates. (See Table 3 for sample sizes.)

6.2 Focal sites

Power analyses were run for only 11 guilds or species at each focal site, where sampling locations were predominantly associated with woody habitats. Exotic saplings were not recorded at either focal site. Because there were only one or two sampling locations associated with non-woody habitats at each site, there were insufficient observations for open-habitat birds, New Zealand pipits, and swamp harriers.

Rakiura National Park

After 10 years of monitoring in Rakiura National Park the current design will have the power to detect trends in six guilds and two species, but the power available will vary depending on the trend direction and size, as well as the confidence level required (Figure 20 and Figure 21).

Rapid and moderate changes in occupancy will be detectable under the current design for unpalatable saplings, less-mobile birds, and mobile birds (Figure 20). Only rapid changes in occupancy will be detectable for ungulates, palatable saplings, and grey warblers, but only increasing trends for cavity nesters and tūī. If the required confidence level is reduced to 80%, rapid declines in occupancy of cavity nesters, moderate declines in ungulate and grey warbler occupancy, and moderate increases in palatable sapling occupancy will also be measurable.

The power to detect rapid and moderate changes in abundance will be high under the current design for palatable and unpalatable saplings, and for less-mobile birds and mobile birds, but only rapid changes in cavity nesters, grey warblers, and tūī (Figure 21). However, moderate changes for the latter three will only be detectable if the confidence level is relaxed and, in the case of the grey warbler and tūī, the trend is increasing.

When implementing the proposed modified design in Rakiura National Park there will be insufficient power to detect even relatively large changes in occupancy and abundance of all the focal guilds or species after 10 years. However, if the required confidence level is reduced to 80%, rapid declines will be measurable for the abundance of less-mobile and mobile birds, as well as occupancy and abundance for the grey warbler.

Ruahine Forest Park

After 10 years of monitoring in Ruahine Forest Park the current design will have the power to detect trends in just four guilds and one species (Figure 22 and Figure 23).

Rapid changes will be detectable under the current design for ungulate occupancy, as well as occupancy and abundance for less-mobile birds (including the grey warbler) and mobile birds. Moderate changes in occupancy will also be detectable for most of these guilds, but only when the confidence level is relaxed for occupancy. Rapid to moderate changes in the abundance of unpalatable saplings will only be detectable if the confidence level is reduced.

The power to detect these trends in Ruahine Forest Park will be lost if the proposed modified design is implemented.

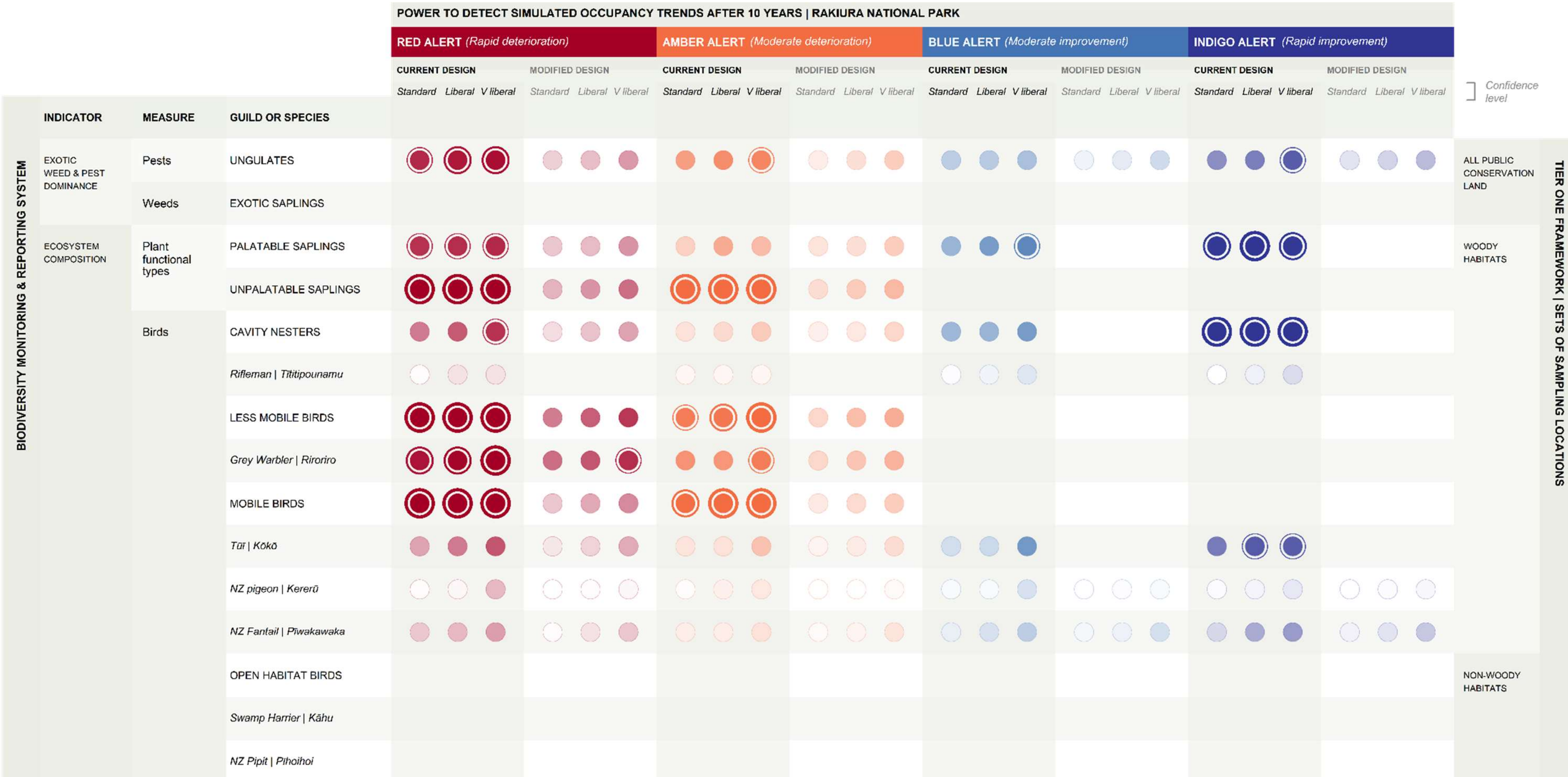


Figure 20. Power (%) to detect rapid or moderate changes in occupancy for 11 focal guilds or species after 10 years for sampling locations in Rakiura National Park.

Notes: Power estimates are presented for the current design of DOC's Tier One framework versus the proposed modified design when the confidence level was specified as standard (95%), liberal (90%) or very liberal (80%). Shading of dots is proportional to the power estimate, with the outer rings highlighting those scenarios where the power was ≥80% (fine ring), ≥90% (intermediate ring), or 100% (thick ring). The power estimate for each scenario was derived using their respective base model ~ Ys + (1|Place), with 50 simulations per scenario. For the modified design the power estimate is the median value across the 50 replicates. (See Table 3 for sample sizes.)

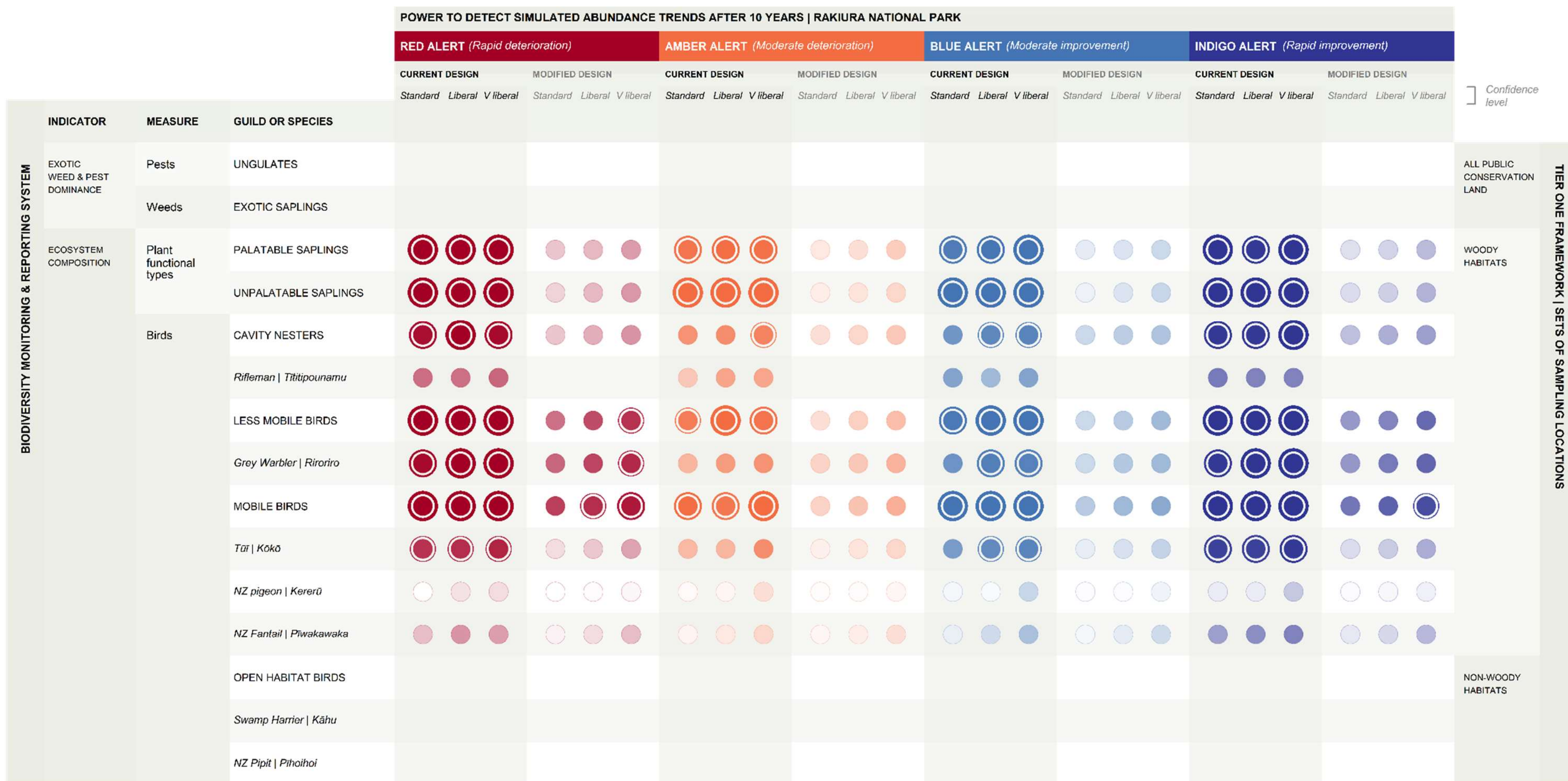


Figure 21. Power (%) to detect rapid or moderate changes in abundance for 10 focal guilds or species after 10 years for sampling locations in Rakiura National Park.

Notes: Power estimates are presented for the current design of DOC's Tier One framework versus the proposed modified design when the confidence level was specified as standard (95%), liberal (90%) or very liberal (80%). Shading of dots is proportional to the power estimate, with the outer rings highlighting those scenarios where the power was ≥80% (fine ring), ≥90% (intermediate ring) or 100% (thick ring). The power estimate for each scenario was derived using their respective base model ~ Ys + (1|Place), with 50 simulations per scenario. For the modified design, the power estimate is the median value across the 50 replicates. (See Table 3 for sample sizes.)

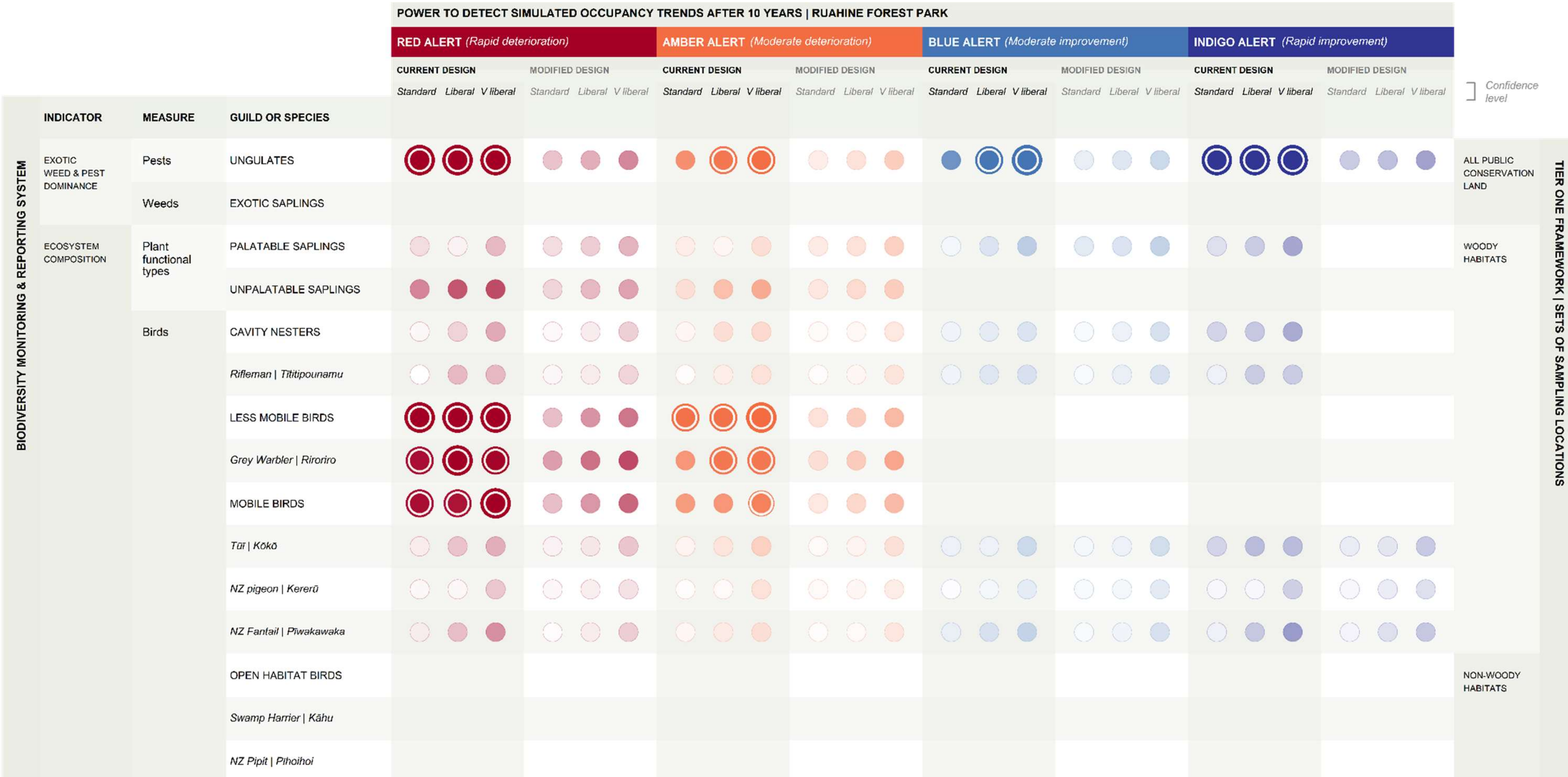


Figure 22. Power (%) to detect rapid or moderate changes in occupancy for 11 focal guilds or species after 10 years for sampling locations in Ruahine Forest Park.

Notes: Power estimates are presented for the current design of DOC's Tier One framework versus the proposed modified design when the confidence level was specified as standard (95%), liberal (90%) or very liberal (80%). Shading of dots is proportional to the power estimate, with the outer rings highlighting those scenarios where the power was ≥80% (fine ring), ≥90% (intermediate ring), or 100% (thick ring). The power estimate for each scenario was derived using their respective base model ~ Ys + (1|Place), with 50 simulations per scenario. For the modified design, the power estimate is the median value across the 50 replicates. (See Table 3 for sample sizes.)

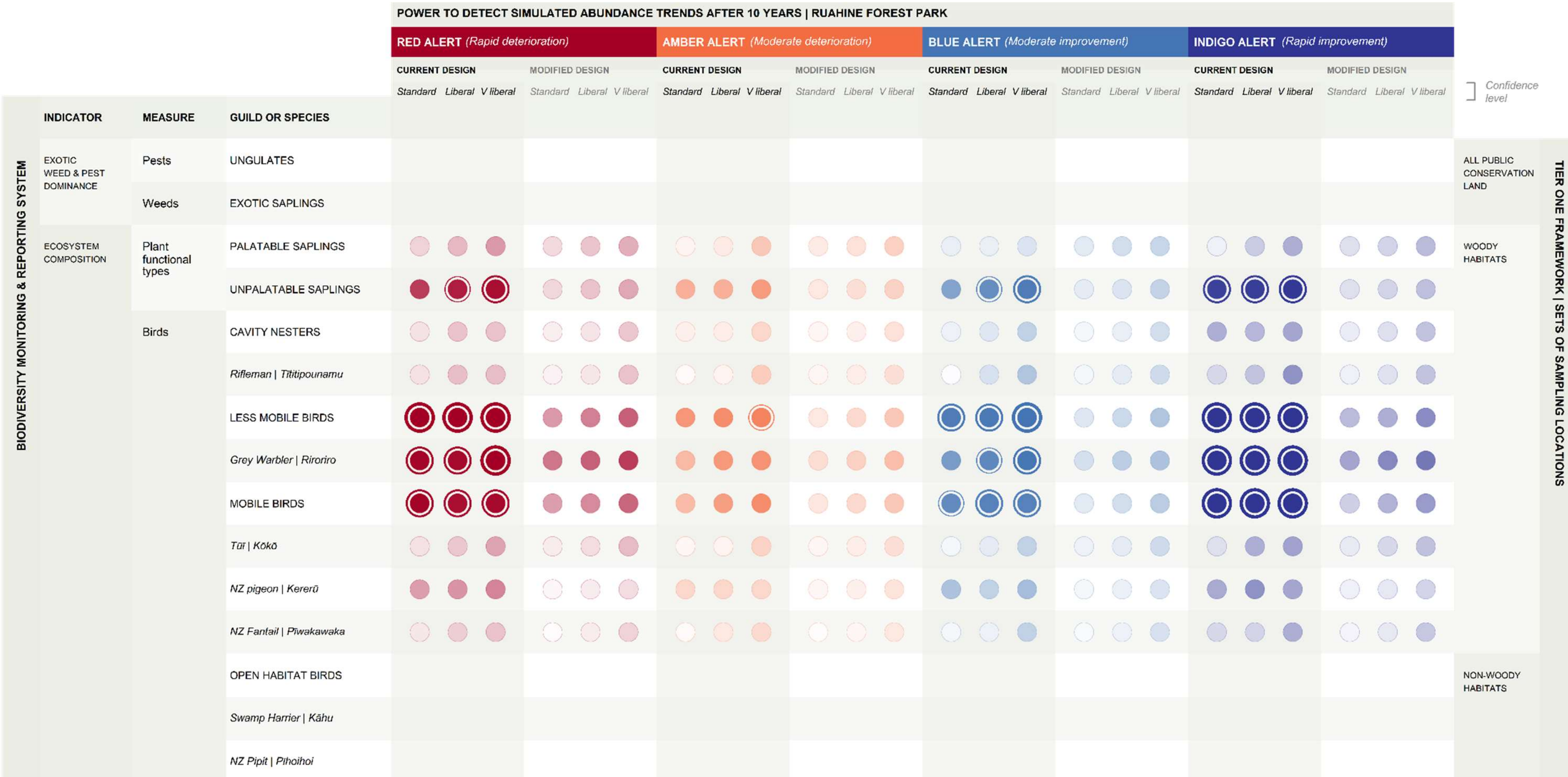


Figure 23. Power (%) to detect rapid or moderate changes in abundance for 10 focal guilds or species after 10 years for sampling locations in Ruahine Forest Park.

Notes: Power estimates are presented for the current design of DOC's Tier One framework versus the proposed modified design when the confidence level was specified as standard (95%), liberal (90%) or very liberal (80%). Shading of dots is proportional to the power estimate, with the outer rings highlighting those scenarios where the power was ≥80% (fine ring), ≥90% (intermediate ring) or 100% (thick ring). The power estimate for each scenario was derived using their respective base model ~ Ys + (1|Place), with 50 simulations per scenario. For the modified design, the power estimate is the median value across the 50 replicates. (See Table 3 for sample sizes.)

7 Time taken to an early warning for the current versus modified designs

7.1 National trends

The current design generally provides very high power to raise early warnings for red and amber alerts at the national scale (i.e. either across all public conservation land or in a given habitat). Early warnings for red and amber alerts in occupancy will be flagged within 6–7 years for 87% and 53% of the 15 guilds or species considered, respectively (Figure 24A & B). Similarly, early warnings for red and amber alerts in abundance will be raised within 5–6 years for 93% and 69% of the 13 guilds or species considered, respectively (Figure 24C & D).

By contrast the modified design will take longer to detect early warnings for national trends, and only for roughly half the number of guilds or species. For occupancy, it will typically take an extra 2 years to raise warnings for red alerts for each guild and species, with just 40% being flagged within 6–7 years (Figure 24A). Amber alerts for occupancy will only be flagged for 20% of the focal guilds or species within 7 years (Figure 24B). For abundance, red and amber alerts will only be raised within 7 years for 53% and 31% of guilds and species (Figure 24C & D)

7.2 Focal sites

Only the current design will have sufficient power to detect early warnings within Rakiura National Park (Figure 25) and Ruahine Forest Park (Figure 26). Those early warning will generally be raised for fewer guilds and species in Ruahine Forest Park, where warnings will also take longer to flag.

In Rakiura National Park the current design will have power to detect early warnings for a red alert within 8 years for half of the 10 guilds and species considered when monitoring occupancy (Figure 25A), but two-thirds of those guilds and species when monitoring abundance (Figure 25C). Early warnings for amber alerts will be raised within 8 years for just 20% and 44% of cases when monitoring trends in occupancy (Figure 25B) and abundance (Figure 25D), respectively.

In Ruahine Forest Park early warnings for red alerts will be flagged within 8 years for just three guilds (occupancy of ungulates, abundance of unpalatable saplings, and occupancy and abundance of less-mobile birds) and one species (occupancy of grey warbler; Figure 26A & C). Amber alerts will only be raised after 9 years for ungulate occupancy (Figure 26C & D).

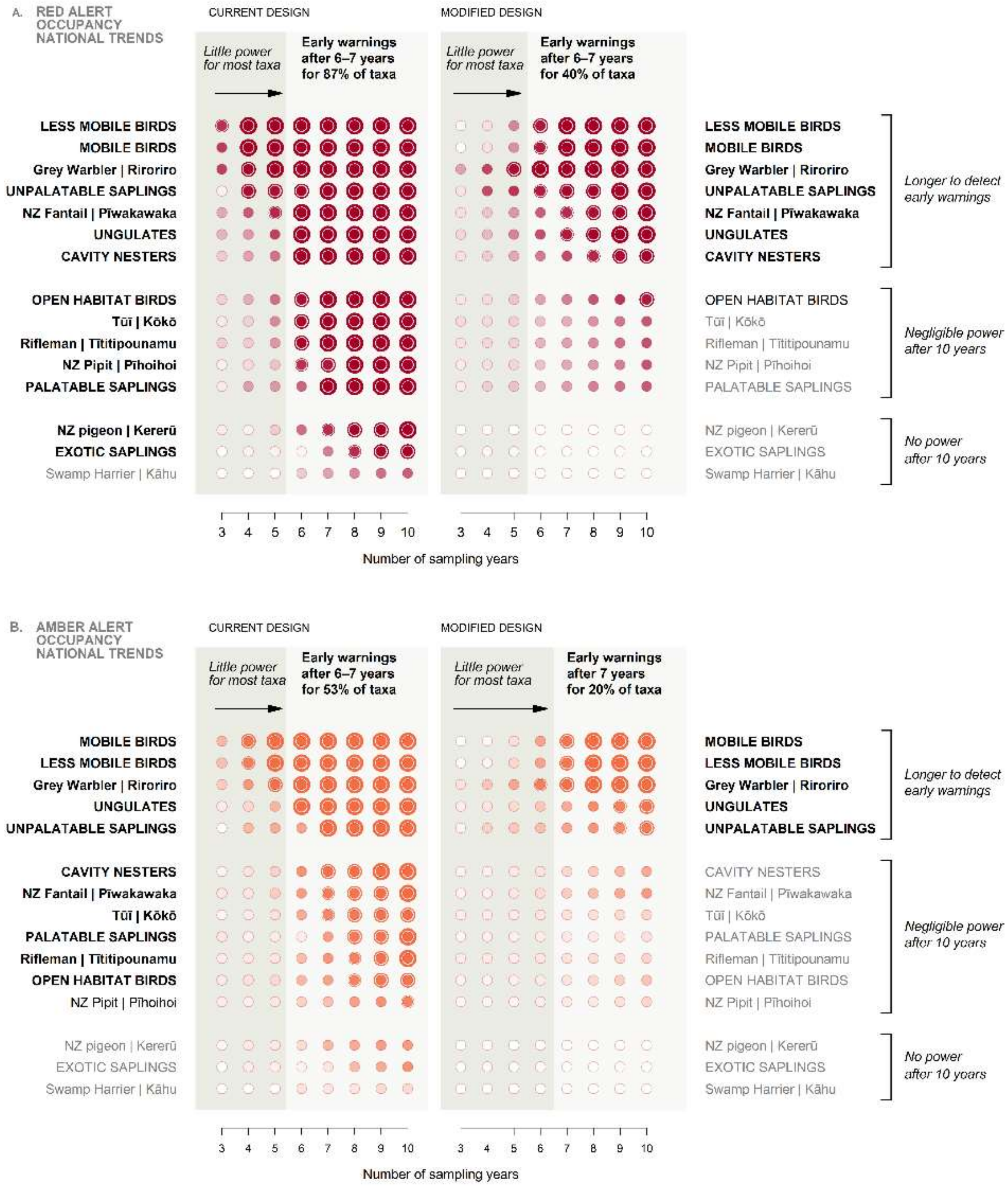
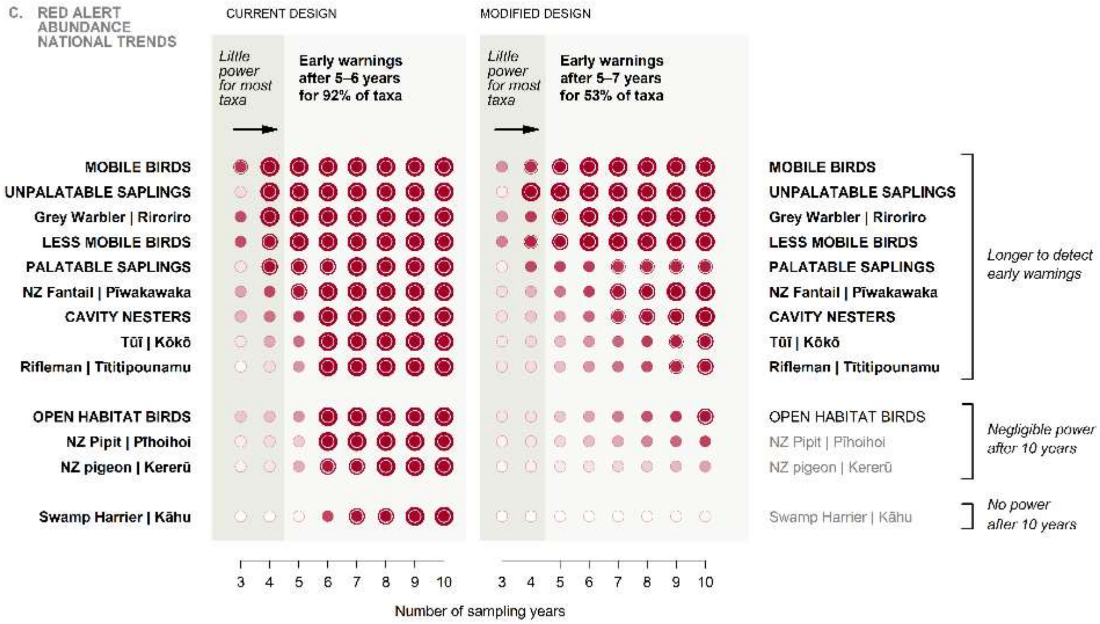


Figure 24. Time taken to detect an early warning for a red or amber alert across public conservation land or a habitat (simulated as a rapid or moderate deterioration over 10 years).

Notes: Power estimates are presented for occupancy (A & B) and abundance (C & D) of 15 focal guilds or species for different sampling periods (3–10 years, with 1-year increments) under Tier One's current design versus the proposed modified design. Shading of dots is proportional to the power estimate, with the outer rings signalling when the estimate is ≥80% (fine ring), ≥90% (intermediate ring) or 100% (thick ring). The power estimate for each scenario was derived using the respective base model ~ Ys + (1|Place), with 50 simulations and a standard confidence level of 95%. For the modified design the power estimate is the median value across the 50 replicates. (See Table 3 for sample sizes and Table 6 for spatial scale of models.)



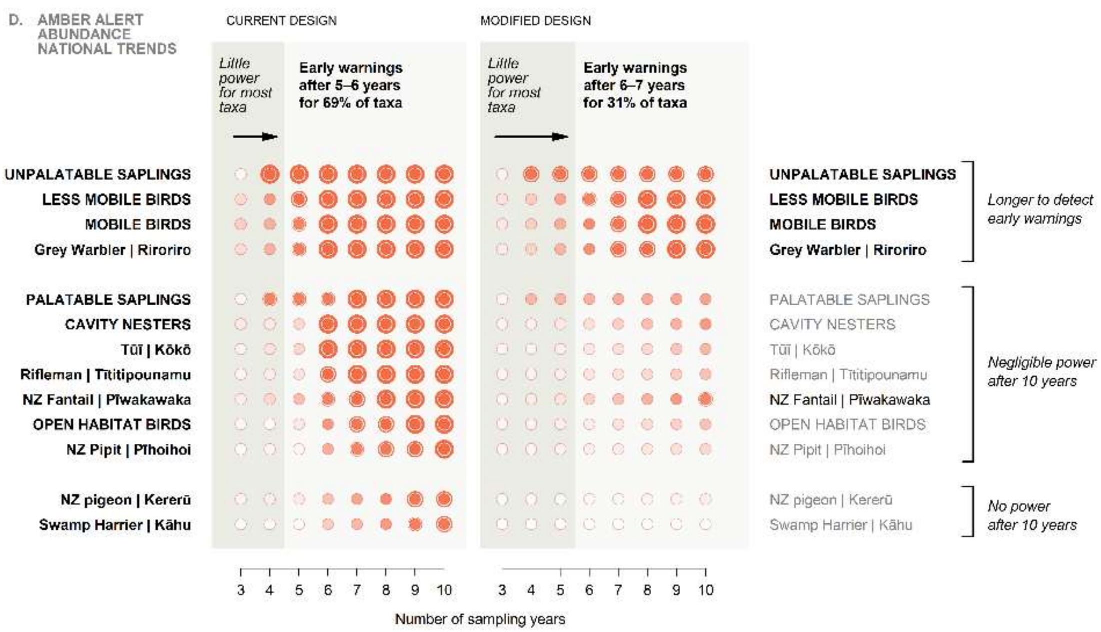


Figure 24 (continued)

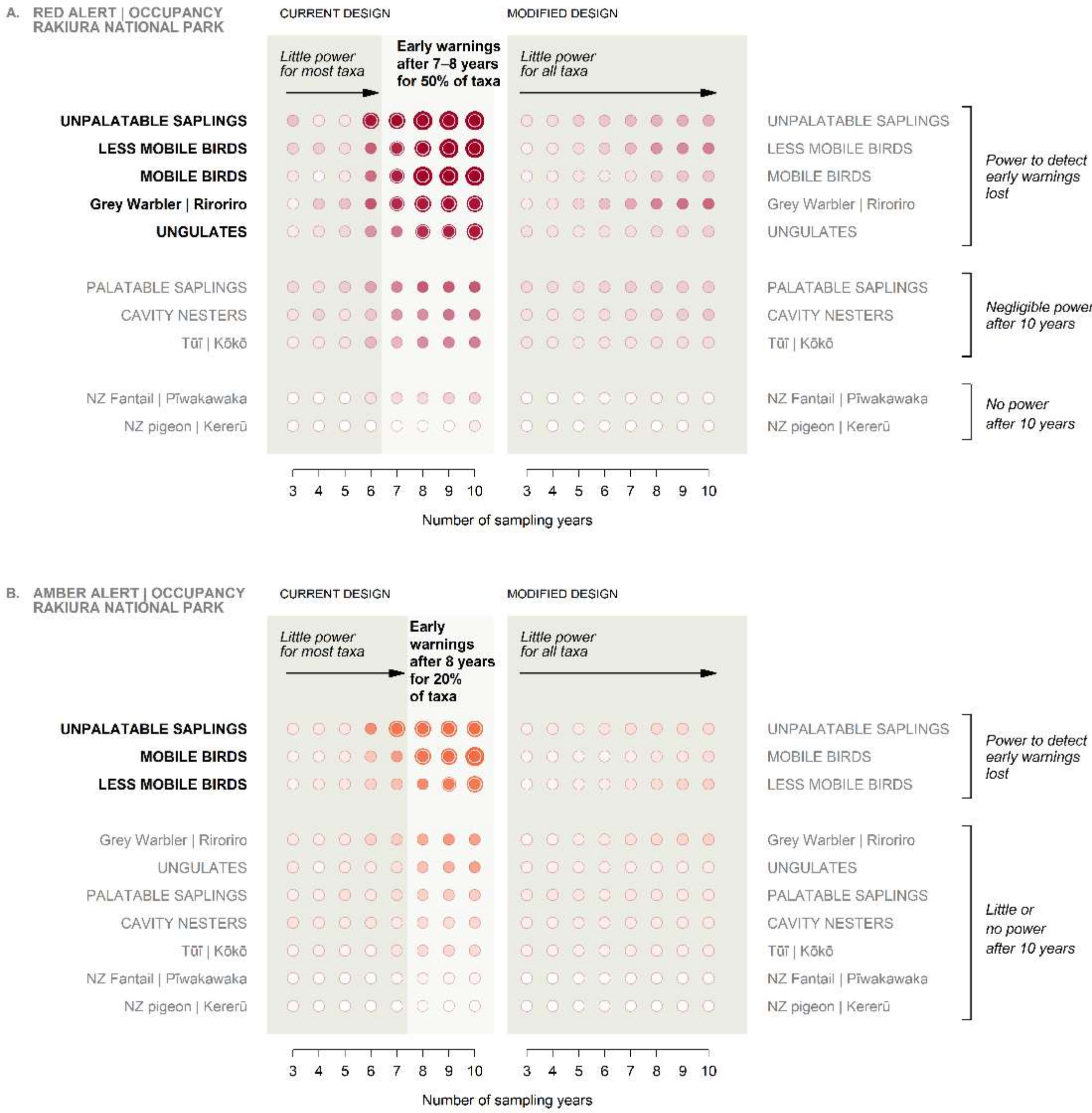
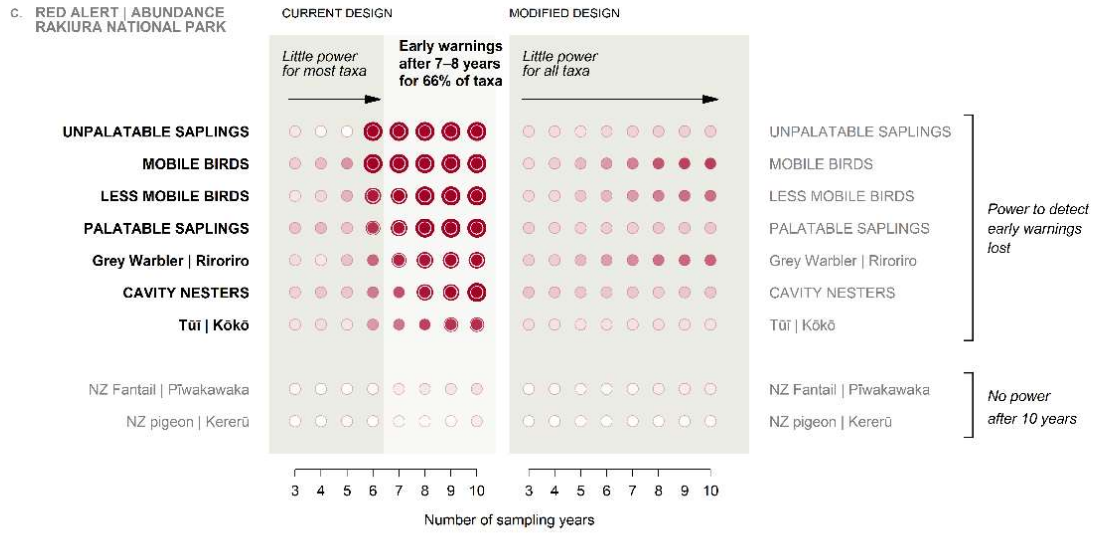


Figure 25. Time taken to detect an early warning for a red or amber alert in Rakiura National Park (simulated as a rapid or moderate deterioration over 10 years).

Notes: Power estimates are presented for occupancy (A & B) and abundance (C & D) of up to 10 focal guilds or species for different sampling periods (3–10 years, with 1-year increments) under Tier One's current design versus the proposed modified design. Shading of dots is proportional to the power estimate, with the outer rings signalling when the estimate is ≥80% (fine ring), ≥90% (intermediate ring) or 100% (thick ring). The power estimate for each scenario was derived using the respective base model ~ Ys + (1|Place), with 50 simulations and a standard confidence level of 95%. For the modified design the power estimate is the median value across the 50 replicates. (See Table 3 for sample sizes.)



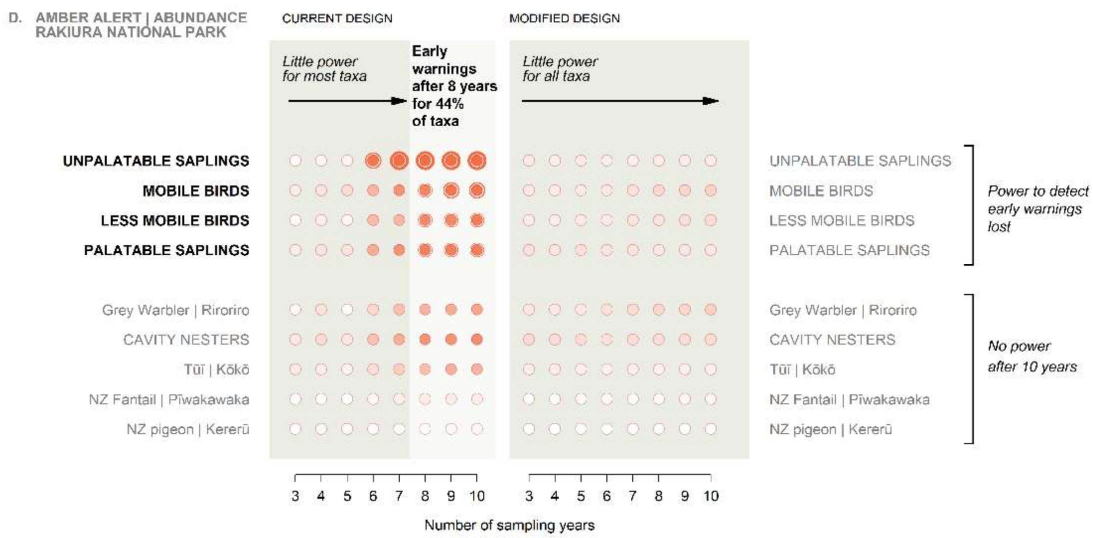
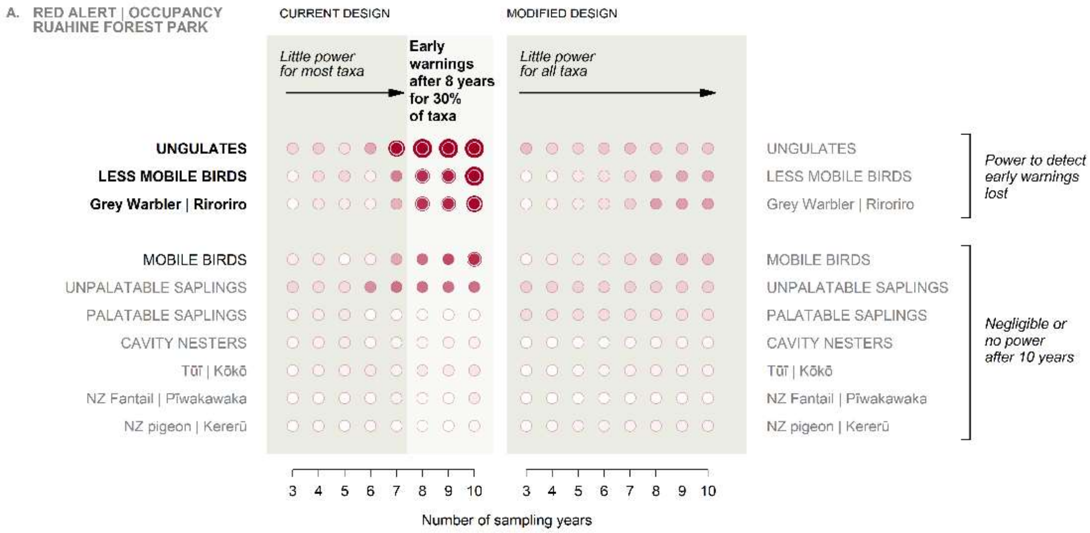


Figure 25 (continued)



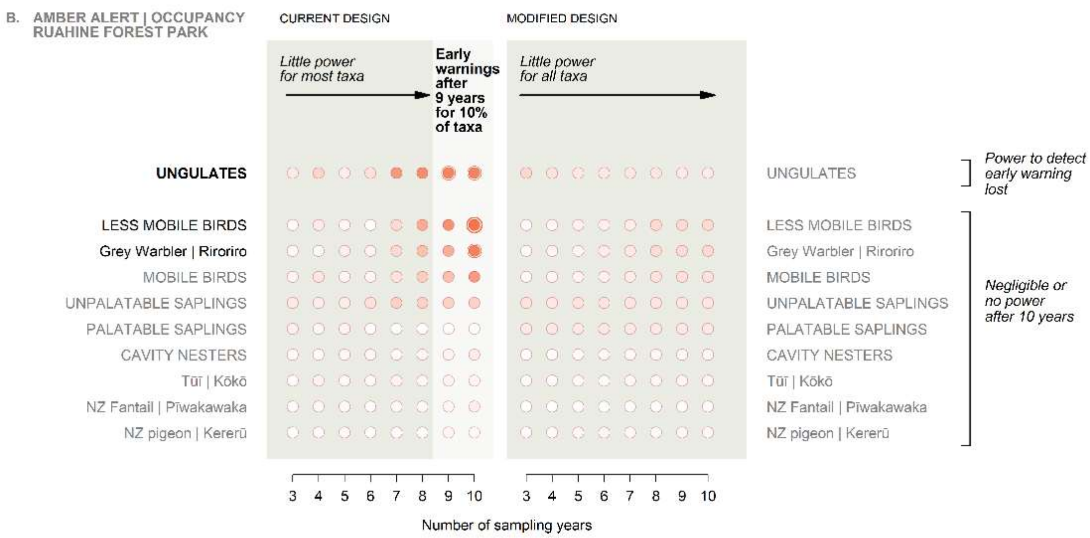


Figure 26. Time taken to detect an early warning for a red or amber alert in Ruahine Forest Park (simulated as a rapid or moderate deterioration over 10 years).

Notes: Power estimates are presented for occupancy (A & B) and abundance (C & D) of up to 10 focal guilds or species for different sampling periods (3–10 years, with 1-year increments) under Tier One's current design versus the proposed modified design. Shading of dots is proportional to the power estimate, with the outer rings signalling when the estimate is ≥80% (fine ring), ≥90% (intermediate ring) or 100% (thick ring). The power estimate for each scenario was derived using the respective base model ~ Ys + (1|Place), with 50 simulations and a standard confidence level of 95%. For the modified design the power estimate is the median value across the 50 replicates. (See Table 3 for sample sizes.)

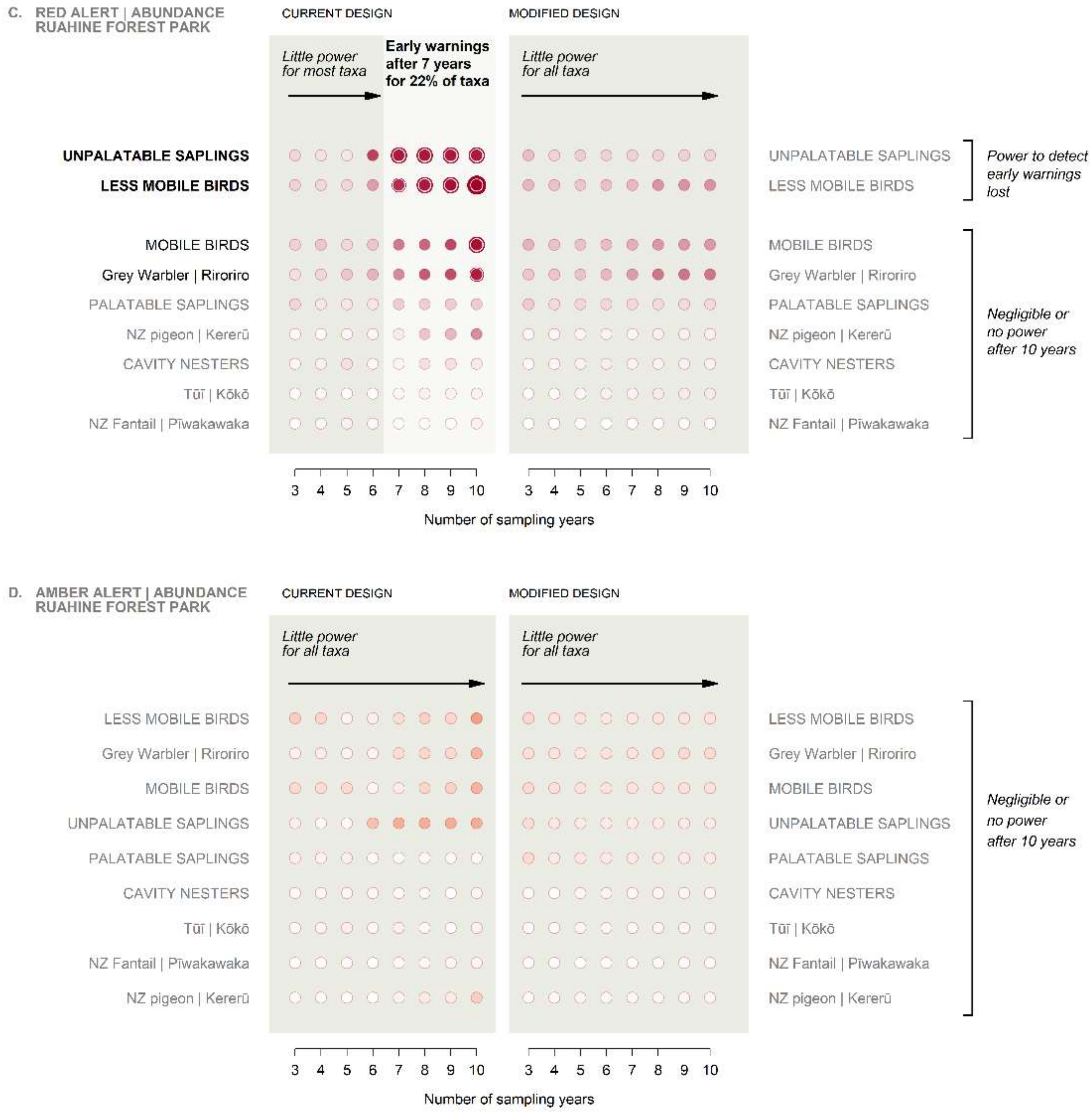


Figure 26 (continued)

8 Discussion

This report assessed the efficacy of the DOC Tier One monitoring framework for providing robust and timely information to support the goals of DOC's BMRS. More specifically, it evaluated two designs for the Tier One framework: the current design versus the proposed modified design. Here we summarise our findings to highlight:

- how biodiversity data gathered from the current design of the Tier One framework can be used to support the BMRS goals
- the statistical and ecological consequences of shifting all or some of the Tier One field measures from a 5-year measurement cycle to a 10-year one
- ways to improve our analytical approach in the future.

8.1 Supporting the goals of the Biodiversity Monitoring and Reporting System

This report has shown how a standardised framework for data analyses, interpretation, and visualisation (Figure 7) can be applied to provide a hierarchical assessment of biodiversity trends to support the goals of the BMRS. It has also highlighted 'mental roadmaps' for helping users to quickly identify trends of conservation concern (Travers et al. 2021; World Bank 2015) by tackling the challenges of communicating uncertainty in trend alerts (Fraixedas et al. 2020) and detecting early warning signals to better inform and enable proactive conservation responses (Schmeller et al. 2018).

Using two BMRS indicators as examples – 'Exotic weed and pest dominance' and 'Ecosystem composition' – this report has provided a proof-of-concept for meeting three of the goals of the BMRS:

- national and regional reporting of status and trend in ecological integrity
- evaluating the effectiveness of conservation management and policy
- providing an early warning system.

More specifically, the hierarchical assessment reports 125 trend estimates for the occupancy and abundance of 15 focal guilds and species, and trend alerts for up to four sets of sampling locations.

8.1.1 Ability to report national and regional biodiversity trends

To demonstrate how to meet the goal of national and regional reporting, this study presented 10-year trends (2013–2022) for all public conservation land as well as for woody and non-woody habitats. Key trends emerging from the occupancy analyses based on Tier One's current design included:

- changes in pest dominance across all public conservation land in the last 10 years:
  - ungulate occupancy increased moderately

  - weed occupancy was largely unchanged (albeit with variable trends in woody and non-woody habitats)
- trends for 12 guilds and species in woody habitats:
  - four alerts for deteriorating trends, with pest dominance increasing moderately (as ungulate occupancy increased), and, for the ecosystem composition indicator, rapid or moderate declines in common and widespread birds (cavity-nesting birds, including riflemen, as well as a less-mobile bird species, the grey warbler)
  - three improvement alerts: a decline in weed dominance and increases in two mobile birds (kererū and fantail)
  - five guilds or species showing little to no change (tūī, and guilds of less-mobile and mobile birds, as well as palatable and unpalatable saplings)
- deteriorating trend alerts for all five focal guilds and species in non-woody habitats:
  - for the exotic pest and weed dominance indicator, ungulate and exotic saplings increased
  - for the ecosystem composition indicator, shallow declines in the guild of open-habitat birds (including New Zealand pipit) were detected, in addition to a rapid decline in swamp harriers.

8.1.2 Evaluating the effectiveness of conservation management and policy

To demonstrate how to evaluate the effectiveness of management, this study reports 10-year trends (2013–2022) for public conservation land inside and outside national parks. Using biodiversity occupancy data gathered from relevant sets of sampling locations, it identified:

- three consistent, deteriorating trends inside and outside national parks within woody habitats for the pest dominance indicator (as ungulates increased moderately) and ecosystem composition indicator (as cavity-nesting birds and rifleman declined rapidly, except inside national parks, where cavity nesters declined moderately)
- that ecosystem composition is deteriorating more broadly outside national parks in woody habitats, as indicated by declines in palatable saplings, grey warblers, and tūī, while fantail and exotic sapling trends improved in these areas
- that in non-woody habitats, ecosystem composition metrics were declining consistently inside and outside national parks (for open-habitat birds, New Zealand pipits, and swamp harriers), while pest dominance (ungulates) was increasing much more rapidly inside national parks but weed dominance (exotic saplings) was potentially reduced.

8.1.3 Providing an early-warning system

To demonstrate how to flag early warnings, this study highlights how to identify such warnings through visual inspections of the trend summaries. For ungulates, for example, there was only a weak signal for an amber alert across all public conservation land (Figure

10), because the alert signal was straddling both amber and red alerts. Hence the reader can be confident that this guild is increasing at least moderately, but also see that an early warning has been flagged for an emerging red alert (which could then be closely monitored in subsequent 10-year timeframes, 2014–2023, 2015–2024, etc.).

Furthermore, the habitat-level alerts indicate that rapid increases are already underway in non-woody habitats (Figure 12). Hence conservation managers can use this evidence to inform their decisions about which habitat to prioritise for management and which areas within those habitats (e.g. inside or outside national parks; Figure 15) to monitor more closely in the future.

8.2 Informing the future of Tier One monitoring

This report used power analyses to evaluate the effectiveness of two designs for DOC's Tier One framework for monitoring changes in vegetation and animal (birds, exotic mammals) measures. Specifically, the analyses quantified:

- the power to detect rapid to moderate changes after 10 years of monitoring in the future, using simulated trends applied to the current design and the proposed modified design, across all public conservation land, a given habitat, or a focal site
- the expected time taken to raise early warnings for rapid to moderate changes in the future, using simulated 10-year trends applied to the current design and proposed modified design, across all public conservation land, a given habitat, or a focal site.

Below we highlight our key findings and then consider whether there is scope to decouple the vegetation and animal measures and measure vegetation on the proposed modified design (i.e. a 10-year measurement cycle), and animals using the current design (a 5-year measurement cycle).

8.2.1 Power to detect change across all public conservation land

Following are the key findings emerging from the power analyses.

- For a handful of guilds or species that are either increasing or decreasing very rapidly and consistently throughout the country (e.g. increasing ungulate pellets, declining cavity nesters), either a 5-year or a 10-year measurement cycle will be sufficient to detect change, but the warning signal is delayed by having a 10-year measurement cycle, and this will forestall the option to intervene in a timely and effective manner.
- For most guilds or species, where changes are moderate, the 5-year measurement cycle has greater statistical power to detect change with confidence (compared to the 10-year measurement cycle).
- In all cases a 10-year measurement cycle takes longer to yield insights, and in most cases managers may be unaware of changes even after 10 years.
- Transitioning from a 5-year to a 10-year measurement cycle will reduce our power to detect trends for many metrics and lessen our ability to detect declines early enough

to implement timely management interventions. This may limit our ability to prevent declines in vulnerable species or groups of species.

- Notable results include the finding that transitioning to the 10-year measurement cycle would remove the power to detect rapid declines for the following guilds and species:
  - *riflemen:* one of only two species in a New Zealand endemic family of ancient wren species
  - *tūī/kererū:* iconic bird species with massive cultural significance
  - *palatable saplings:* vulnerable to exotic herbivores
  - *exotic saplings:* early warning of invasions in woody ecosystems.

8.2.2 Potential to measure vegetation on a 10-year cycle and animals on a 5-year cycle

This report has also evaluated the statistical and ecological consequences of shifting all or some of the Tier One field measurements from a 5-year to a 10-year measurement cycle. The work was motivated, in part, by the need to consider potential cost savings. One potential saving would be to move vegetation measures to a 10-year cycle while retaining a 5-year cycle for the animal measures. Because the Ministry for the Environment currently measures indigenous forest plots on a 10-year cycle to deliver estimates of forest carbon stocks and stock changes (Paul et al. 2021), shifting Tier One vegetation measures to a 10-year cycle would align the reporting cycles for these two agencies.

Also, many temperate tree demography studies rely on decadal measurements. Frequent measurements to plots can be damaging and potentially introduce 'visitation bias'; that is, the act of repeatedly visiting the plot can change the composition or structure of vegetation and thus bias the inferences drawn from those plots (Ferretti 2014; Semboli et al. 2014).

However, shifting Tier One to a 10-year cycle from a 5-year cycle will incur a loss of statistical power to detect change and make it more difficult to link changes in measures to specific management interventions, and perceptions of baselines will move.

In this report we used sapling count data to assess statistical power for two vegetation measures (weeds and maintenance of plant functional types), and we also calculated the number of tree mortality events that would be detected with a 5-year measurement interval but missed with a 10-year measurement interval (see Appendix 3).

- **Weeds:** On the basis of exotic sapling occupancy, statistical power is currently adequate to detect rapid increases, but this power would be lost with a 10-year measurement cycle.
- **Maintenance of plant functional types:** The current design has very high statistical power to report on rapid and moderate changes in palatable and unpalatable sapling occupancy and abundance. If Tier One were shifted to a 10-year cycle, then this power would be retained for unpalatable saplings, but only rapid changes in palatable sapling abundance would be detected with a high confidence level, and moderate changes would either be lost (occupancy) or only possible with a relaxed confidence

level for moderate increases (abundance). At our two focal sites, statistical power was adequate for both palatable and unpalatable saplings at Rakiura with the current design, but this power was lost with a 10-year measurement cycle. Power was weak with the current design in Ruahine and was lost with the 10-year measurement cycle.

- **Tree mortality events:** Previous work by Mason and Bellingham (2018) used data from the Land Use and Carbon Analysis System / Tier One plot network to evaluate an optimal measurement interval to report on stem mortality, recruitment, and turnover rates. They found that a substantial amount (35%) of stem turnover occurred over the 10-year interval compared to the 5-year interval (22%), and argued that a 5-year measurement cycle was prudent to support robust conclusions about responses by stem demographic processes to natural disturbance events and management interventions. We repeated one of their analyses with plots used in this report and found that around 8% of stem mortality events would be missed by changing from a 5-year to a 10-year measurement cycle (see Appendix 3).

Thus, the key results regarding shifting from a 5-year to a 10-year cycle for Tier One are:

- reduced power for reporting on changes in palatable saplings
- a loss of statistical power for focal sites
- reduced visibility of stem turnover processes, which would limit our ability to link stem mortality to specific events (e.g. those caused by natural disturbances such as cyclones or earthquakes) over the 10-year period.

Additional motivations for a 5-year cycle are knowing soon enough to act on early warning signals, and avoiding the risk that people will adjust to ecological changes (the paired phenomena of 'shifting baselines' and 'ecological amnesia'; Lyver et al. 2021), thus weakening the social process that will be required to reverse any undesirable trends. Any call to action will require time to explain the trend and persuade people to act, and action is stalled further with a longer measurement cycle.

A final consideration for Tier One is whether and how animal and vegetation measures could be combined at a plot level if the two were measured on different cycles. In principle, as long as measures are coupled in the same year every 10 years this would not be an issue. However, if the two sets of measures were always collected in a different year this would preclude integration of the measures at a plot level in a specific year. Hence it is important to adhere to a strict plot measurement cycle.

In conclusion, decoupling the vegetation and animal field measurements to 10-year and 5-year cycles, respectively, would incur disadvantages in terms of statistical power and the capacity to link change in vegetation measures to specific events (e.g. cyclones, management interventions) but would not compromise the integrity of the monitoring framework.

8.3 Ways to improve our analytical approach

This project gained a fast start by capitalising on three existing resources:

- DOC's existing analytical protocols, to calculate trends using generalised linear mixed models (from the R-package lme4; Bates et al. 2015) to develop a standardised analytical framework, which was then applied to all 15 focal guilds and species
- an existing alert classification protocol (applied by the British Trust for Ornithology; Baillie & Rehfish 2006) and adapted for the New Zealand Garden Bird Survey; MacLeod et al. 2022), which aligns with recommendations to use 'strength-of-evidence' approaches to inform environmental management (McBride et al. 2014)
- an open-source R-package for power analyses, simr, which makes it easy for users to calculate power for generalised linear mixed models from the lme4 package (Green & MacLeod 2016).

Below we outline some of the issues encountered when applying these resources and highlight some potential solutions.

8.3.1 Guidelines to facilitate meaningful reporting

We recommend that our analytical framework be evaluated more systematically to develop a refined set of rules for determining how to apply it and when it is appropriate to report the derived trend alerts for different locations, guilds or species (e.g. setting thresholds for flagging metrics that are data deficient versus excluding them altogether).

Set of sampling locations

Although measures derived from the Tier One framework can be applied at many spatial scales, they were originally designed to have a national focus (measuring changes in ecological integrity across all public conservation land; Allen et al. 2013) and it was anticipated that they would usually be inadequate for meaningful reporting at local scales (e.g. area offices). In general, our findings align with these initial design guidelines.

As expected from statistical first principles, alert signal strengths and the power to detect changes in occupancy and abundance were generally weaker when sampling location sets were smaller. For example, under the current design the signal strengths tended to be weaker overall in non-woody habitats relative to woody ones (Figure 27), where the sampling effort was four times higher (Figure 3). Hence, there was sufficient power for the current design to detect moderate or rapid moderate changes in occupancy over 10 years for only one or two of the three focal guilds or species in non-woody habitats, but all 10 of the focal guilds and species in woody habitats (Figure 18). In both habitats the likelihood of detecting such changes was significantly reduced when shifting to the proposed modified design (where the sampling effort would be halved, and no repeat measures would be implemented over a 10-year measurement cycle). Only open-habitat birds would retain sufficient power to detect rapid (but not moderate) changes in occupancy in non-woody habitats. Of the 10 focal guilds and species in woody habitats, only seven would have sufficient power to detect rapid changes in occupancy over 10 years, but just five for moderate changes over a similar period.

Alert signals in woody habitats were generally stronger for the trend estimates outside national parks than in national parks (Figure 27), where half as many sampling locations were monitored (Table 3; Figure 4), but the reverse pattern was observed for non-woody habitats, where fewer focal guilds or species were considered. Although we did not explicitly quantify power to detect change within these domains, it is reasonable to expect that the power to detect rapid to moderate changes within them will also be reduced, if the modified design is implemented.

In line with the original Tier One framework design guidelines (Allen at al. 2013), the power to detect changes at local scales was low. Roughly only a third of the guilds or species assessed at each focal site had sufficient power to detect a rapid or moderate change in occupancy over 10 years (Figure 20 and Figure 22). Furthermore, alert signal strengths for Ruahine Forest Park were generally lower than for Rakiura National Park, which had a larger set of sampling locations (Figure 27).

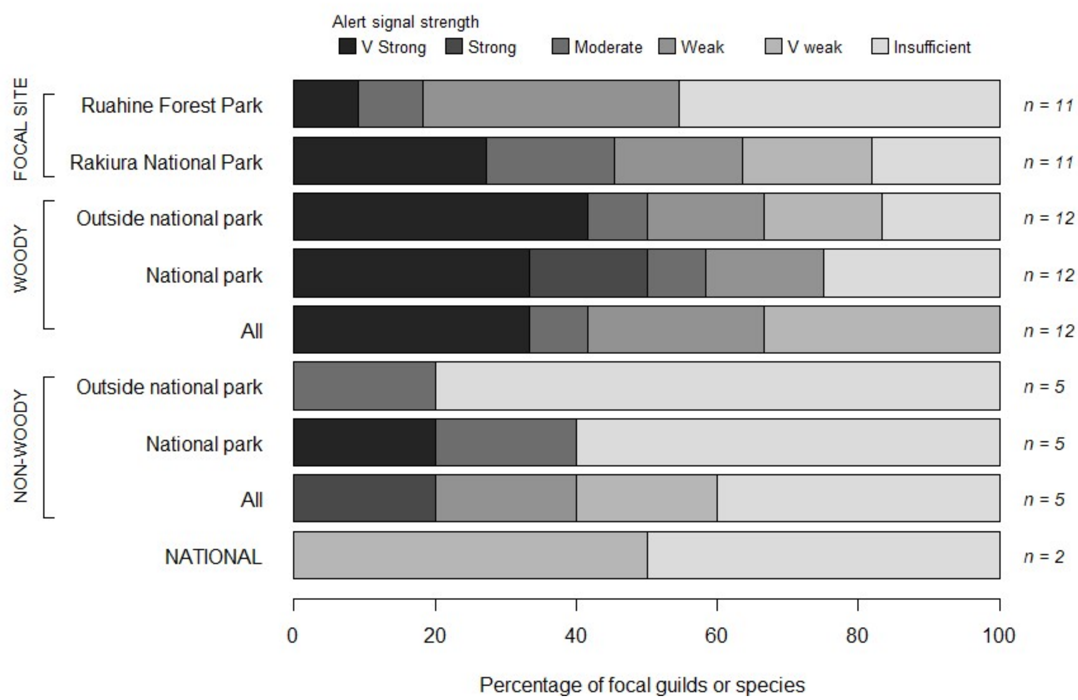


Figure 27. Proportion of occupancy trend alerts for each signal strength category, where *n* is the number of focal guilds or species where models were fitted for each set of sampling locations.

Focal guilds and species

It was also anticipated that the Tier One framework would usually be inadequate for meaningful reporting for uncommon taxa (Allen et al. 2013). However, the measures were expected to be able to detect common taxa that become uncommon, or uncommon taxa that become common. In broad terms, we found that the current design of Tier One performed well for the 15 focal guilds or species considered, but in some cases it struggled to measure change for some species that we might consider to be common and widespread, especially under scenarios where the proposed modified design was implemented.

When the chance of recording a guild or species was particularly low, alert signals were typically weak or insufficient (Figure 28). For example, the probability of recording an exotic sapling in a subplot was roughly 1 in a million under the current design for Tier One. Hence, for this guild, the current design would take at least 8 years to flag an early warning for a rapid change in occupancy, and would fail to detect moderate changes within 10 years (Figure 24). Shifting to the proposed modified design for Tier One would result in a complete loss of power to detect rapid changes.

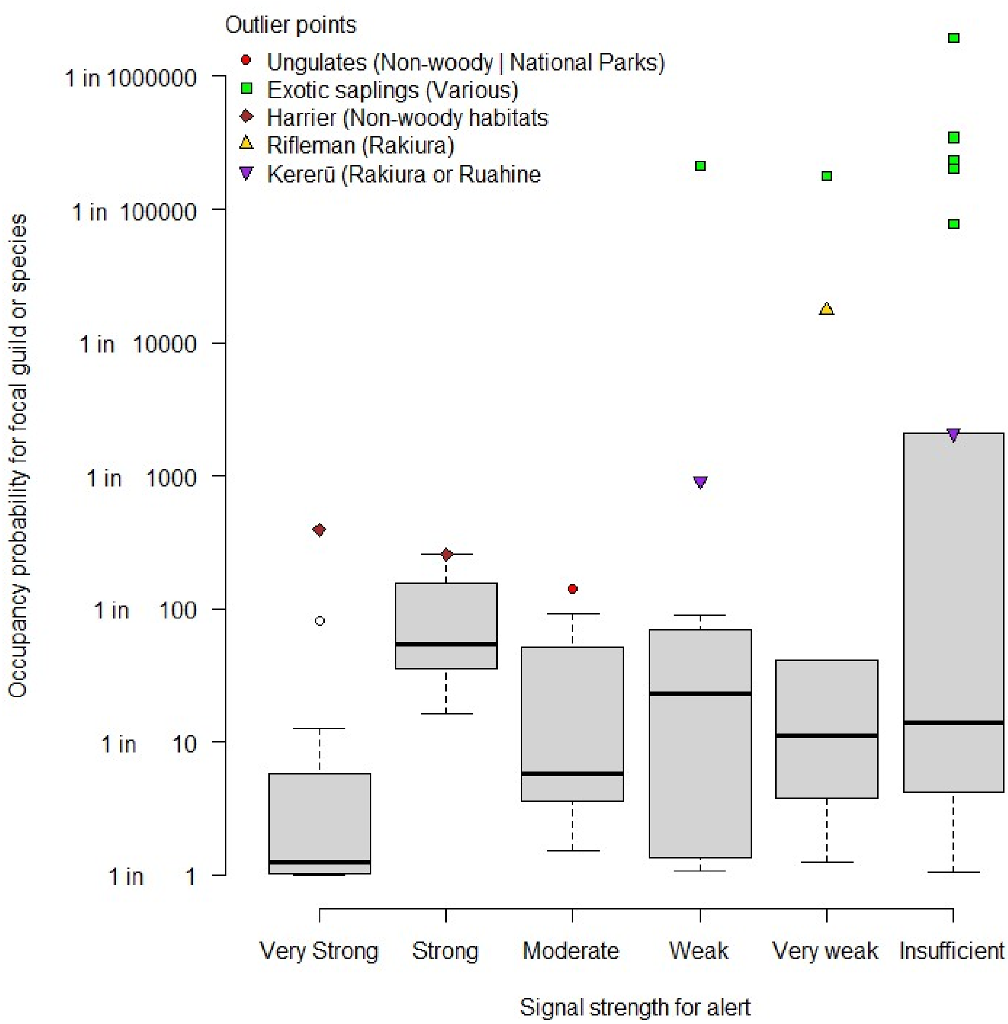


Figure 28. Occupancy estimates (i.e. chance of recording a focal species or guild) in the initial year of monitoring under the current design of the Tier One framework.

Notes: The box plots summarise the distribution of the occupancy estimates (*n* = 75, for all combinations of guilds or species and sampling location sets considered; Table 6), grouped according to whether their respective alert signal strength was classified as either 'very strong to moderate' or 'weak to insufficient'. The colour-coded outlier points highlight those scenarios where the chance of recording a focal guild or species was lower than 1 in 100 (see legend for details).

Our analyses have started to *refine our understanding of the limitations of the Tier One framework* for detecting even relatively large changes in occupancy or abundance for common and widespread species over 10 years. The swamp harrier is one such example. It is a species that is often perceived to be common and widespread.[6] However, in non-woody habitats overlapping the Tier One framework, swamp harriers only had a 1 in 250 chance of being recorded at a count station in the initial year of monitoring (Figure 28). Although the current design was able to detect rapid changes (supported by strong alert signals) in swamp harrier occupancy over the last 10 years, the power analyses indicate that detecting trends of this size for this species was at the edge of the Tier One framework's monitoring capabilities (Figure 18). There is insufficient power to detect moderate changes in this species' occupancy under the current design of the Tier One framework, but no power for even a rapid change under the proposed modified design.

Here we highlight an example where we sought to report trends at local scales but, as expected (Allen et al. 2013), found that *the Tier One framework was being stretched beyond its intended utility of national (broad-scale) monitoring* (Figure 29). Tier One was intended to provide a national context for data obtained from focal sites (or managed areas, Tier Two in Figure 29), where DOC has a networks of Tier Two sampling locations that have not been measured (Richardson et al. 2024). The current design struggled to measure 10-year trends for bird species infrequently recorded at the focal sites (despite them being considered common and widespread nationally). For example, in Rakiura National Park the chance of detecting kererū was roughly 1 in 900 in the initial year of monitoring (Figure 28), but even lower for riflemen (1 in 1,750).

As a first step towards addressing this issue more broadly, we flagged poorly fitting statistical models (based on a visual inspection of diagnostic plots for the bootstrap estimates). In the case of kererū and riflemen in Rakiura National Park, the species' respective models were poorly fitting (Figure 16 and Figure 17) and tended to predict very large changes in occupancy (with high levels of uncertainty) over 10 years (Figure 28)

[6] https://nzbirdsonline.org.nz/species/swamp-harrier

Figure 29. The New Zealand Biodiversity Monitoring and Reporting System's hierarchical structure, from national (broad-scale) monitoring through to site-specific research studies. (Source: Wright et al. 2020)

Potential solutions

When sample sizes are small, or guilds or species are infrequently recorded, potential solutions for increasing the power to detect trends could include the following.

- Fit more complex spatial models that draw on the power of the larger Tier One data set (rather than just the subset of sampling locations for a given focal site), and allow trends to vary across sets of sampling locations that are subject to similar management regimes or ecological processes, or that encompass individuals from the same population. For riflemen, for example, fitting such models provided a much more conservative (and realistic) trend estimate, with a tighter confidence interval, for Rakiura National Park, although no clear alert signal was determined (see Appendix 4). Furthermore, models could be applied to explicitly estimate detection probabilities (i.e. the complement of the probability of falsely recording an absence; MacKenzie & Royle 2005; Tingley & Beissinger 2009; Zipkin et al. 2010), which may vary across habitat types. Alternatively, measurement errors when estimating trends could improve the robustness of the indicators by improving the model fit, providing more accurate occupancy and abundance estimates, and reducing uncertainty in trend estimates (Fraixedas et al. 2020; Holdaway et al. 2014; Mason et al. 2018). The bird monitoring design for Tier One, for example, includes repeat measures (i.e. five count stations) at each sampling location for this purpose (MacLeod et al. 2012).

- Only present trend estimates for occupancy (not abundance) when species are infrequently encountered or often occur as single individuals (e.g. swamp harrier). Presenting both occupancy and abundance may be unnecessary for these taxa, but for others the loss of abundance without a reduction in occupancy will be a vital early warning signal of species loss. Conversely, an increase in abundance without an increase in occupancy can precede invasion (Gaston & Curnutt 1998).
- Either install or reactivate Tier Two networks at focal sites at a frequency of measurement adequate to inform management (models are available to determine the best frequency) and interpret whether management interventions result in trends that differ from national-scale (Tier One) measurements (Wright et al. 2020).

8.3.2 Gain deeper insights by refining alert thresholds and contextualising the results

For the purposes of this report a standardised set of trend thresholds was applied to flag alerts for all the focal guilds and species. These alert thresholds were based on criteria originally designed for monitoring birds (Baillie & Rehfish 2006; MacLeod et al. 2022), which could be tailored and refined in the future to better reflect the life-history traits of different taxa (e.g. a coarser thresholds for mammals with longer breeding cycles) and relevant ecological thresholds (e.g. finer thresholds for plants where small changes in composition are known to have long-term detrimental impacts).

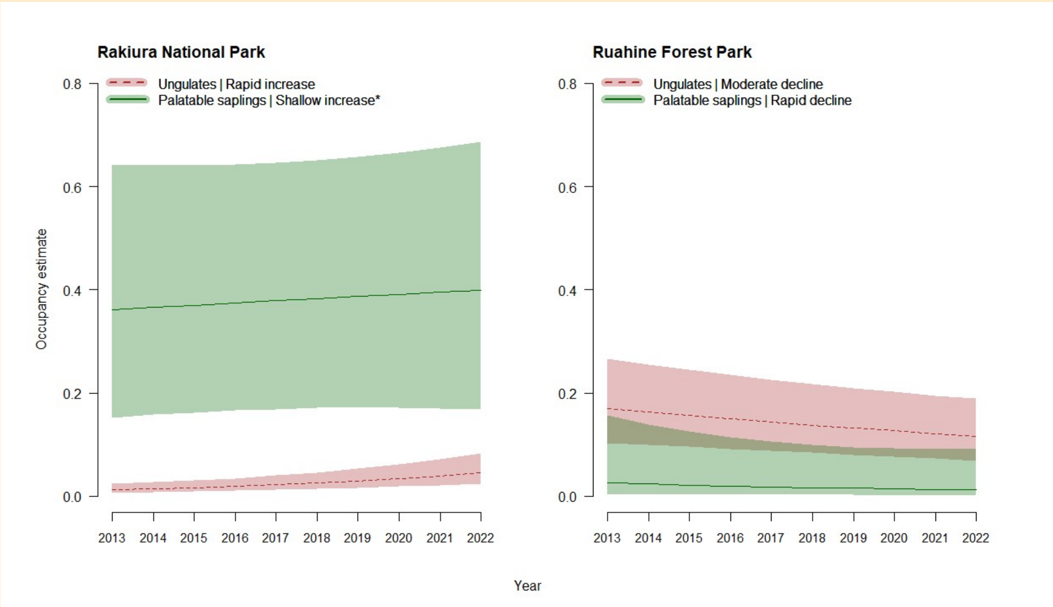
Refinements could also be applied to the colour coding of trend alerts. In this report, for example, the colour codes were reversed for the 'Exotic pest and weed dominance' indicator to acknowledge that increases in these taxa were likely to be detrimental to ecological integrity. Such colour-coding adjustments may be relevant for a range of other indicators. For the 'Ecosystem composition' indicator, for example, there may be cases where increases in indigenous species indicate a detrimental change that needs to be flagged (e.g. small increases in unpalatable saplings in woody habitats highlight the risk of long-term changes in forest canopy composition).

Deeper insights could be gained by expanding the alert classification protocol to apply the alert rating to state as well as trend, which would provide more context for interpreting observed trends. Box 3, for example, highlights opposing and apparently contradictory trends in occupancy of ungulates and palatable saplings at two focal sites, where an inspection of the baseline measures of occupancy provides valuable insights for management.

Objectively derived alert ratings of state and trend could also provide the necessary evidential basis for a more comprehensive and structured evaluation of the overall conservation status of a species or guild for a given set of sampling locations (akin to the New Zealand Threat Classification System; Townsend et al. 2008), which in turn could be used to derive composite measures and indicators for the BMRS. A key challenge will be setting meaningful thresholds without overcomplicating the alert system, so that the user can still readily understand it and identify trends of conservation concern.

Box 3. State metrics help explain opposing and apparently contradictory trends in occupancy of ungulate and palatable saplings at two focal sites

In Rakiura National Park, ungulates increased rapidly in parallel with a possible shallow increase in palatable saplings. Conversely, in Ruahine Forest Park, palatable saplings declined rapidly in parallel with a moderate decline in ungulates. However, at the outset of the monitoring period, occupancy estimates for ungulates were 14-fold higher in Ruahine Forest Park than in Rakiura National Park (17% vs 1.2%, respectively), but for palatable saplings were much lower (3% vs 36%).



Occupancy trends for ungulates and palatable saplings in Rakiura National Park and Ruahine Forest Park for the 10-year period (2013–2022). The trend estimates (95% confidence intervals) are based on biodiversity data gathered from the current design of the Tier One monitoring framework. The asterisk indicates a poorly fitting model.

9 Recommendations

Based on our findings we make four key recommendations.

- Apply a hierarchical assessment of trend alerts to support the goals of the BMRS by helping users quickly identify trends of conservation concern (and uncertainty about their estimates), as well as early warning signals.
- Maintain national monitoring at a 5-year cycle so that we can track trends in biodiversity and threats to it. This gives better options to intervene to enhance positive trends or mitigate declines in indigenous biodiversity. Shifting to a 10-year cycle reduces the power to detect trends and, at worst, would result in management to prevent declines being far too late.
- Develop a standardised framework for data analyses, interpretation, and visualisation that evaluates both biodiversity state and biodiversity trend. This framework should include a transparent set of rules for when it is appropriate to report alerts for different locations, as well as for species, guilds aligned to the BMRS measures, and indicators.
- Use Tier One sampling locations to estimate state and trend at scales other than the national one only when sample sizes are large. The original design of the BMRS relied on three inter-related tiers of measurement, with an emphasis on local Tier Two networks of sampling locations to inform managers of state and trend (including in response to management). Significant departure from national trends in response to particular pressures or management interventions could be judged by comparing Tier Two networks against the national (Tier One) network. In the case of management units with as few samples as Ruahine Forest Park, Tier One sampling locations might be used to supplement Tier Two networks of sampling locations, but would not give the statistical confidence needed to inform management.

10 Acknowledgements

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Appendix 1 – Regional variation in sampling effort over time

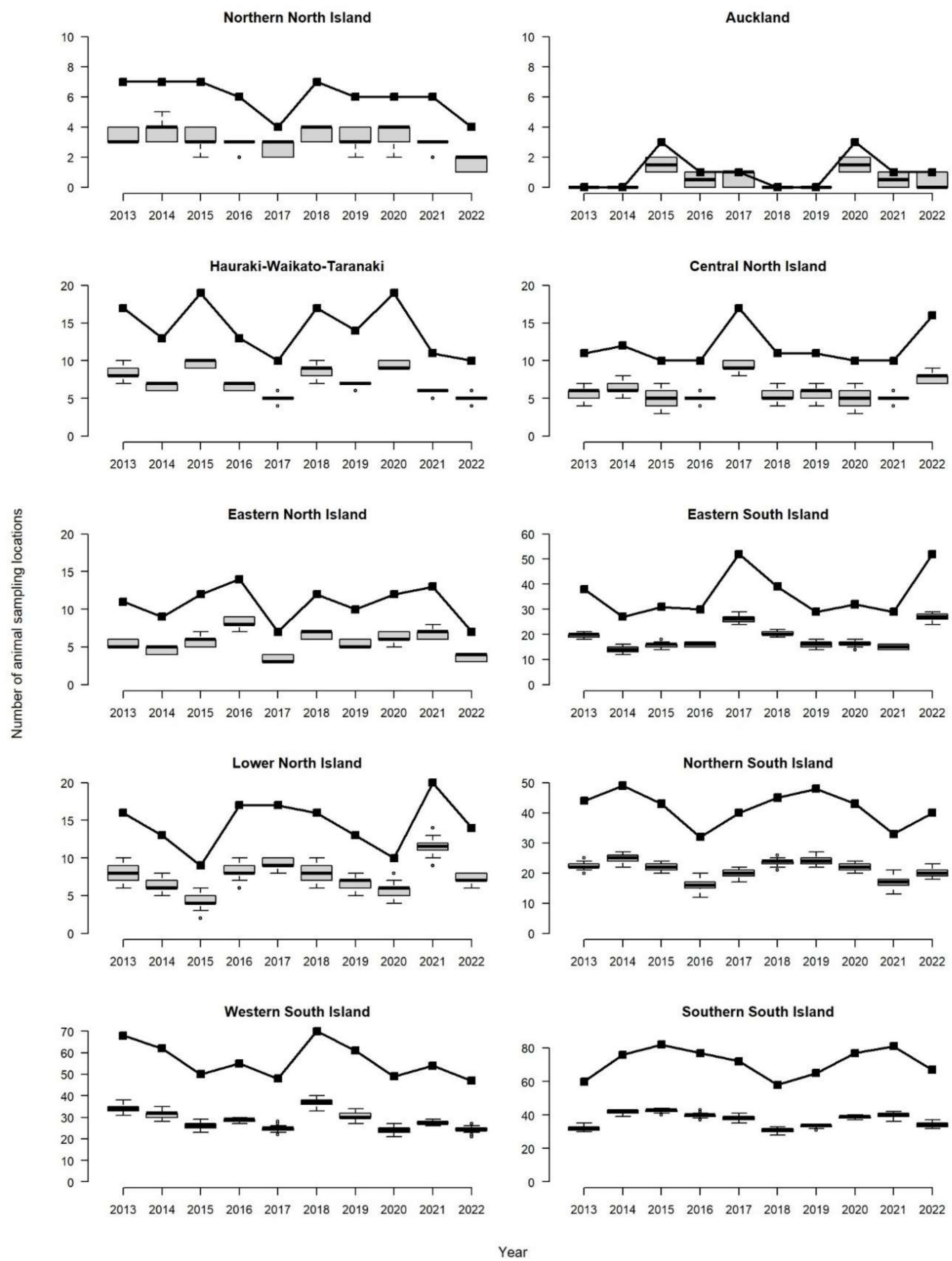

Figure A1.1. Number of animal sampling locations for the current design (squares) and proposed modified design (boxplots showing variation in effort across the 50 replicates), for each year and operating region.

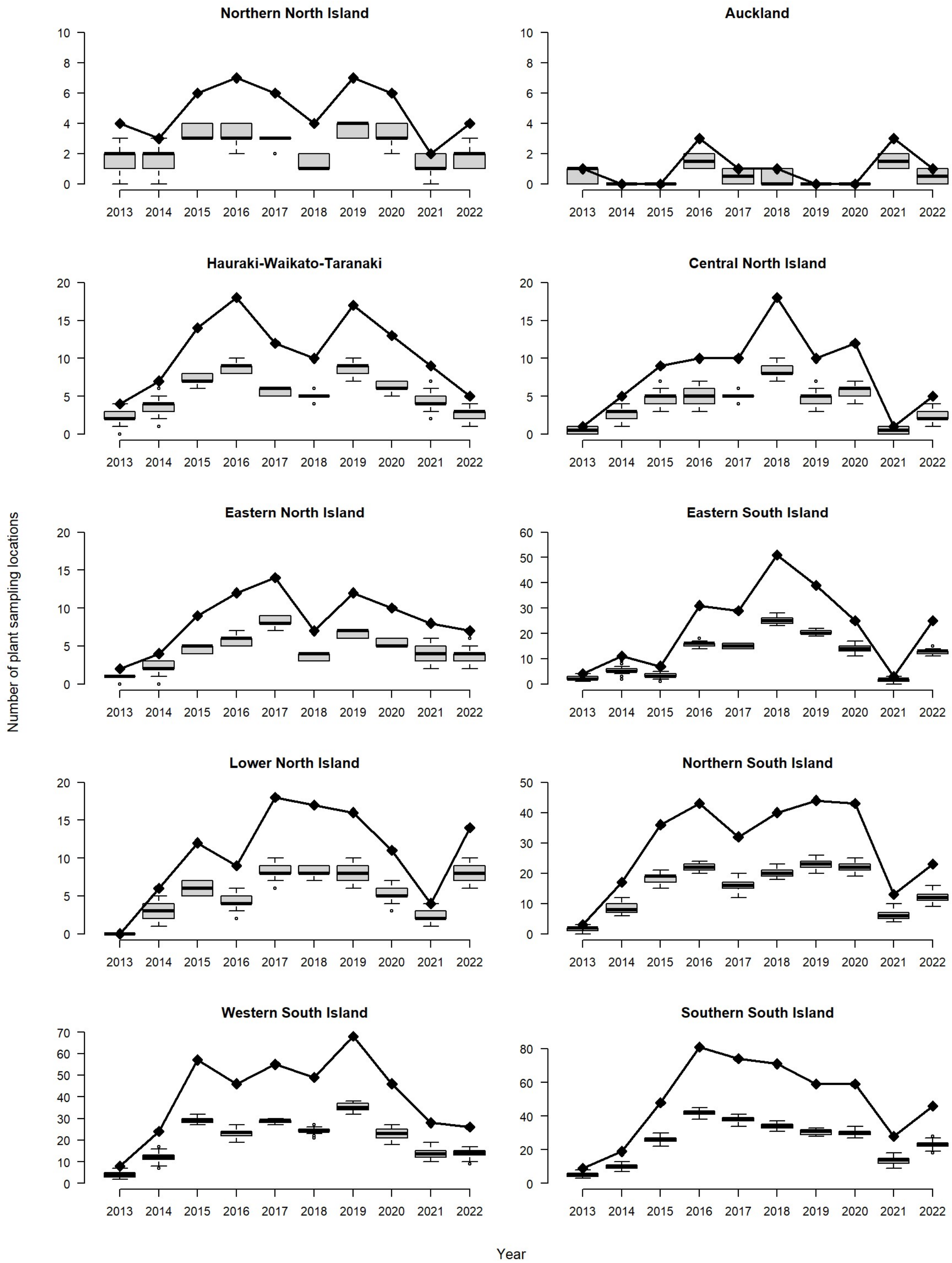

Figure A1.2. Number of plant sampling locations for the current design (diamonds) and proposed modified design (boxplots showing variation in effort across the 50 replicates), for each year and operating region.

Table A1.1. Number of sampling locations, by management area (based on ungulate data)

Area classification	No. of sampling locations		
	Total	Non-woody	Woody
Totals	**1,354**	**388**	**966**
National parks	**437**	**108**	**329**
Fiordland National Park	185	49	136
Kahurangi National Park	77	5	72
Mount Aspiring National Park	48	19	29
Rakiura National Park*	23	1	22
Westland National Park / Tai Poutini National Park	21	5	16
Arthur's Pass National Park	18	9	9
Nelson Lakes National Park	15	7	8
Tongariro National Park	13	4	9
Whanganui National Park	11		11
Aoraki/Mount Cook National Park	9	8	1
Paparoa National Park	7		7
Egmont National Park	6	1	5
Abel Tasman National Park	4		4
Outside national parks	**917**	**637**	**280**
Western South Island | Other PCL areas	146	26	120
Eastern South Island | Other PCL areas	145	95	50
Southern South Island | Other PCL areas	138	69	69
Northern South Island | Other PCL areas	85	25	60
Hauraki-Waikato-Taranaki | Other PCL areas	66	3	63
Eastern North Island | Other PCL areas	47		47
Central North Island | Other PCL areas	36	1	35
Lower North Island | Other PCL areas	33	2	31
Victoria Forest Park	33	3	30
Northern North Island | Other PCL areas	31	3	28
Conservation Area – Cook River/Weheka to Haast River	29	7	22
Molesworth Recreation Reserve	28	25	3
Mount Richmond Forest Park	28	3	25
Tararua Forest Park	18		18
Ruahine Forest Park*	17	2	15
Raukumara Conservation Park	16		16
Te Kahui Kaupeka Conservation Park	16	15	1
Auckland | Other PCL areas	5	1	4

Note: Asterisks indicate our focal sites. PCL = public conservation land.

Appendix 2 – R-code for data editing, analyses, classification, and graphics

Table A2.1. R-code for simulating the modified design (and related figures)

Step	R-code pathway and file	Input pathway and file	Output pathway and files	Report figure
Generate replicates for modified design	Analysis/Sampling locations/BalancedSampling_v2.0.R		T1_sampling_locations_2013-2022_balanced10Y.csv	
Plot number of sampling locations per year for animal surveys at different spatial scales	Analysis/Sampling locations/Figures/Sampling locations figures balanced set v3.R	T1_sampling_locations_2013-2022_balanced10Y.csv Birds/Bird_analysis/species raw/focal_spp5.csv"	Sampling locations/Balanced design/Temporal variation in sampling location numbers_balanced.png	Box 1 Figure 2
			Sampling locations/Balanced design/Woody and temporal variation in sampling location numbers_balanced.png	Figure 3
			Sampling locations/Balanced design/Parks and temporal variation in sampling location numbers_balanced.png	Figure 4
			Sampling locations/Balanced design/Focal parks and temporal variation in sampling location numbers_balanced.png	Figure 5
			Sampling locations/Balanced design/Regional and temporal variation in sampling location numbers_balanced.png	Appendix 1
Plot number of sampling locations per year for plant surveys at different spatial scales	Analysis/Sampling locations/Figures/Sampling locations figures balanced set PLANTS v2.R	T1_sampling_locations_2013-2022_balanced10Y.csv Plants/ExoticSpeciesSaplingCounts_5.csv	Sampling locations/Plants/Temporal variation in sampling location numbers_balanced.png	Box 1 Figure 2
			Sampling locations/Plants/Woody and temporal variation in sampling location numbers_balanced.png	Figure 3
			Sampling locations/Plants/Parks and temporal variation in sampling location numbers_balanced.png	Figure 4
			Sampling locations/Plants/Focal parks and temporal variation in sampling location numbers_balanced.png	Figure 5
			Sampling locations/Plants/Regional and temporal variation in sampling location numbers_balanced.png	Appendix 1

Note: R-code is stored in the 'Analysis' folder. All input and output files are in the 'Data' folder (see R-code for more information).

Table A2.2. R-code for editing biodiversity monitoring data

R-code file	Step	Input	Output
Sampling locations/BalancedSampling_v2.0.R	Generate replicates for modified design	T1_sampling_locations_2013-2022.csv	T1_sampling_locations_2013-2022_balanced10Y.csv
Birds/Data edits/Extract bird count datasets v2.0.R	Edit bird data ready for analyses	Birds/Birds_diurnal/data/birddata-processed.Rdata†	Birds/Bird_analysis/species raw/focal_spp5.csv
Ungulates/data edit/Extract ungulate pellet counts.R	Edit ungulate faecal pellet count data ready for analyses	Ungulates/data/ungulateData.Rda† Ungulates/data/meta_info.Rda†	Ungulates/Ungulate analyses/raw data/Ungulates_5.csv
Plants/data edit/Edit exotic plants data.R	Edit exotic sapling data	Plants/ExoticSpeciesSaplingCounts.csv*	ExoticSpeciesSaplingCounts_5.csv
Plants/data edit/palatable_plants_edit_v1.0.R	Edit palatable and unpalatable sapling data ready for analyses	Plants/PalgroupSaplingCounts.csv*	Plants/PalgroupSaplingCounts_5.csv

* Plant data input files prepared by Norman Mason. † Animal data provided by DOC.

Note: R-code is stored in the 'Analysis' folder. All input and output files are in the 'Data' folder (see R-code for more information).

Table A2.3. R-code for the trend analysis and alert classification processes

Step	R-code file	Input	Sub step	Output
Estimate trend and bootstrap replicates	Analysis/Ungulates/boot/National/Ung_boot_occ5_national_v1.0.R	Data/Ungulates/raw data/Ungulates_5.csv	Fit base model (~ Ys + (1|Place))	pt estimates/National trend/By habitat/Ung5_occ_m1_point_est_national.csv
			Simulate 1001 new datasets from the base model	species sim/Ung5.occ.sim.national.rds
			Run bootstrap process (*n* = 1,001).	/boot/National trend/By habitat/Ung5_occ_m1_boot_national.csv
Calculate percent change	Analysis/Ungulates/alerts/Ung_all_national_trend_pe_pc_adj5_2013-2022_v1.1.R	Data/Ungulates/pt estimates/National trend/By habitat/Ung5_occ_m1_point_est_national.csv	Calculate percent change in point estimates	pt estimates/National trend/By habitat/percent change/National_trend_m1_pcpe.csv
		Ungulates/Data/boot/National trend/By habitat/Ung5_occ_m1_boot_national.csv	Calculate percent change in bootstrap estimates	boot/National trend/By habitat/percent change/Ung5_occ_m1_pcboot_national.csv
			Recentre and bias correct bootstrap estimates	boot/National trend/By habitat/percent change adjusted/Ung5_occ_m1_pcboot_adj_national.csv
Classify trend alerts	Analysis/Ungulates/alerts/Ung_all_national_trend_alert_classification_2013-2022_v1.0.R	Data/Ungulates/pt estimates/National trend/By habitat/percent change/National_trend_m1_pcpe.csv	Classify trend alerts and signals	alerts/Ung_alerts_m1_national_trend.csv
		Data/Ungulates/boot/National trend/By habitat/percent change adjusted/Ung5_occ_m1_pcboot_adj_national.csv		

Note: The R-code files in the table above include detailed annotations for calculating and classifying observed trends ungulate occupancy at the national scale. For the other guilds and species (and relevant metrics and spatial scales), see their respective taxon subfolder in the 'Analysis' folder.

Table A2.4. R-code for the power analyses and calculating the time taken to detect early warnings

Step	R-code file	Input data	Sub step	Output data
Power to detect a simulated trend after 10 years	Analysis/Ungulates/Power/power_ungulates_occupancy_national_fx_v2.0.R	Data/Ungulates/Ungulate analyses/raw data/Ungulates_5.csv	Power analyses for current design for rapid to moderate declines and increases while varying the confidence level	Data/Ungulates/Ungulate analyses/power/National trend/Ung5_occ_m1_power_50sim_v2.csv
		Data/T1_sampling_locations_2013-2022_balanced10Y.csv	Power analyses for 50 replicates of the modified design for rapid to moderate declines and increases while varying the confidence level	Data/Ungulates/Ungulate analyses/power/National trend/Ung10_occ_m1_power_50sim_tailored_v2.csv
Time taken to detect an early warning for a simulated trend	Analysis/Ungulates/powercurve/powerCurve_ungulates_occupancy_national_v4.0.R	Data/Ungulates/Ungulate analyses/raw data/Ungulates_5.csv	Power curve analyses for current design for rapid to moderate declines and increases	Data/ Ungulates/Ungulate analyses/powercurve/National trend/By habitat/Ung5_occ_m1_powercurve_50sim_v2.csv
		Data/T1_sampling_locations_2013-2022_balanced10Y.csv	Power curve analyses for 50 replicates of the modified design for rapid to moderate declines and increases	Data/ Ungulates/Ungulate analyses/powercurve/Ung10_occ_m1_powercurve_xj_sim_balanced_updated_v2.csv*

* xj = simulated trend

Note: The R-code files in the table above include detailed annotations for calculating the power to detect a simulated trend after 10 years and the time taken to detect early warnings for ungulate occupancy. Related R-code for other guilds and species (and relevant metrics and spatial scales) can be found within their respective taxon subfolder in the 'Analysis' folder. All input and output files are in the 'Data' folder (see R-code for relevant data files).

Table A2.5. R-code for collating for the results for the trend alerts, power analyses and early warnings

Step	Sub step	R-code file path and name	Output data file path and name
Collate alert files for all the focal guilds and spatial scales		Analysis/Infographics/Trend alerts/ DOC_T1_trend_alert_summary_v2.0.R	Data/Infographic/Alert summary/Alert_summary_v2.csv
Collate power estimates for detecting the simulated trends after 10 years (with varying confidence levels)	Palatable and unpalatable saplings at habitat and focal site scales.	Analysis/Plants/power/palatables_power_10y_summary_v4.0.R	Data/Plants/power/Palatables_power_10y_summary_v2.csv
	Birds at habitat and focal site scales.	Analysis/Birds/power/birds_power_10y_summary_v5.0.R	Data/Birds/Bird_analysis/power/birds_power_10y_summary_v2.csv
	All guilds and species for national, habitat and focal sites	Analysis/Infographics/power/DOC_T1_power_analysis_summary_v3.0.R	Data/Infographic/Power summary/Power_summary_v2.csv
Collate time taken to detect early warnings for simulated trends after 3-10 years	Palatable and unpalatable saplings at habitat scales.	Analysis/Plants/powercurve/palatables_powercurve_10y_summary_v2.0.R	Data/Plants/powercurve/National trend/By habitat/Palgroup_m1_powercurve_ALL_v2.csv
	Palatable and unpalatable saplings at Rakiura	Analysis/Plants/powercurve/Rakiura/palatables_powercurve_10y_summary_Rakiura_v2.0.R	Data/Plants/powercurve/Focal sites/Palgroup_m1_powercurve_Rakiura_ALL_v2.csv
	Palatable and unpalatable saplings at Ruahine	Analysis/Plants/powercurve/Ruahine/ palatables_powercurve_10y_summary_Ruahine_v2.0.R	Data/Plants/powercurve/Focal sites/Palgroup_m1_powercurve_Ruahine_ALL_v2.csv
	Birds at Rakiura	Analysis/Birds/powercurve/Focal sites/birds_powerCurve_summary_Rakiura_v2.0.R	Data/Birds/Bird_analysis/powercurve/Focal sites/birds10_m1_powercurve_ALL_Rakiura_v2.csv
	Birds at Ruahine	Analysis/Birds/powercurve/Focal sites/ birds_powerCurve_summary_Ruahine_v2.0.R	Data/Birds/Bird_analysis/powercurve/Focal sites/ birds10_m1_powercurve_ALL_Ruahine_v2.csv
	All guilds and species for national, habitat and focal sites	Analysis/Infographics/powercurve/DOC_T1_powercurve_summary_v3.0.R	Data/Infographic/Power summary/Powercurve_summary_v3.csv

Note: The R-code files in the table below describe the steps for collating the results for the trend alerts, power analyses and early warnings (see R-code for more information on the input files).

Table A2.6. R-code for generating the trend alert key, infographics and dot plots

Report figure	Dot plot	R-code name	Output name
Box 2	Simplified key for alert summary classification	DOC_T1_trend_alert_infographic_key_simplified_v1.0.R	Trend alert key simplified.png
Summary	Infographic for trend alerts for occupancy across all guilds/species and spatial scales	DOC_T1_trend_alert_infographic.R	Trend alert summary with simplified key REPORT BOX TITLED v9.png
Figure 10	National scale (Ungulates, exotic saplings)	dotplot_AllPCL_v1.0.R	All PCL observed trends v1.png
Figure 11	Woody habitats (Ungulates, plants, birds)	dotplot_Woody_v1.0.R	Woody habitats - parks - observed trends v1.png
Figure 12	Non-woody habitat (Ungulates, exotic saplings, open habitat birds)	dotplot_NonWoody_v1.0.R	Nonwoody habitats observed trends v1.png
Figure 13	Parks in woody habitat (Ungulates, plants, cavity nesting birds)	dotplot_Woody_parks_A_v1.0.R	Woody habitats - parks - observed trends A v1.png
Figure 14	Parks in woody habitats (mobile, less mobile, open habitat birds)	dotplot_Woody_parks_B_v1.0.R	Woody habitats - parks - observed trends B v1.png
Figure 15	Parks in non-woody habitats (Ungulates, exotic saplings, open habitat birds)	dotplot_NonWoody_parks_v1.0.R	NonWoody habitats - parks - observed trends v1.png
Figure 16	Rakiura National Park (Ungulates, plants, birds)	dotplot_Rakiura_v1.0.R	Rakiura observed trends v1.png
Figure 17	Ruahine Forest Park (Ungulates, plants, birds)	dotplot_Ruahine_v1.0.R	Ruahine observed trends v1.png

Note: The infographic and dot plots for trend alert were all drawn using data from the input file 'Data/Infographic/Alert summary/Alert_summary_v2.csv'. The first two R-code files in the table below are stored in 'Analysis/Infographics/Trend alerts/' folder. All other R-files listed in the table below are stored in the 'Analysis/Infographics/Trend dotplots/' folder. The first two output files in the table below are stored in the 'Data/'Infographics/Graphics/Trend summary/' folder. All other output files listed in the table below are stored in the 'Data/'Infographics/Graphics/Trend dotplots/' folder.

Table A2.7. R-code for generating the dot plots summarising the power estimates for detecting simulated 10-year trends

Report figure	Dot plot	R-code name	Output name
Summary	Simulated red and amber alert at national and focal site scales (standard confidence level only)	Box summary/DOC_T1_power_analysis_infographic_all scales_TRANSPARENT_v6.0.R	Power summary - all scales - alpha_0.05 - transparent bg – v6.png
Figure 18	Four simulated occupancy trends at national scale	National/DOC_T1_power_infographic_national_occupancy_v5.0.R	Power summary - national occupancy - v3.png
Figure 19	Four simulated abundance trends at national scale	National/DOC_T1_power_infographic_national_abundance_v5.0.R	Power summary - national abundance - v3.png
Figure 20	Four simulated occupancy trends on Rakiura	Rakiura/DOC_T1_power_infographic_rakiura_occupancy_v5.0.R	Power summary - rakiura occupancy - v3.png
Figure 21	Four simulated abundance trends on Rakiura	Rakiura/DOC_T1_power_infographic_rakiura_abundance_v4.2.R	Power summary - rakiura abundance - v3.png
Figure 22	Four simulated occupancy trends in Ruahine	Ruahine/DOC_T1_power_infographic_ruahine_occupancy_v5.0.R	Power summary - ruahine occupancy - v3.png
Figure 23	Four simulated abundance trends in Ruahine	Ruahine/DOC_T1_power_infographic_ruahine_abundance_v5.0.R	Power summary - ruahine abundance - v3.png

Notes: The dot plots summarising the power estimates for detecting simulated 10-year trends (see table below) were drawn using data from the input file 'Data/Infographic/Power summary/Power_summary_v2.csv'. All R-code files listed in the table below are stored in the 'Analysis/Infographics/power/' folder. All output files listed in the table below are stored in the 'Data/Infographic/Graphic/Power summary/' folder.

Table A2.8. R-code for generating the dot plots for the time taken to detect early warnings for simulated trends

Figure	Alert	Metric	Scale†	R-code name	Output name
Summary	Red	Occupancy	National*	DOC_T1_powercurve_infographic_RAPID_occupancy_BOX_v5.0.R	Powercurve box - RAPID occupancy - national v3.png
	Amber	Occupancy	National*	DOC_T1_powercurve_infographic_MODERATE_occupancy_BOX_v5.0.R	Powercurve box - MODERATE occupancy - national v3.png
Figure 24	Red	Occupancy	National	DOC_T1_powercurve_infographic_RAPID_occupancy_v5.0.R	Powercurve summary - RAPID occupancy - national v3.png
	Amber	Occupancy	National	DOC_T1_powercurve_infographic_MODERATE_occupancy_v5.0.R	Powercurve summary - MODERATE occupancy - national v3.png
	Red	Abundance	National	DOC_T1_powercurve_infographic_RAPID_abundance_v5.0.R	Powercurve summary - RAPID abundance - national v3.png
	Amber	Abundance	National	DOC_T1_powercurve_infographic_MODERATE_abundance_v5.0.R	Powercurve summary - MODERATE abundance - national v3.png
Figure 25	Red	Occupancy	Rakiura	DOC_T1_powercurve_infographic_RAPID_occupancy_Rakiura_v5.0.R	Powercurve summary - RAPID OCCUPANCY - RAKIURA v3.png
	Amber	Occupancy	Rakiura	DOC_T1_powercurve_infographic_MODERATE_occupancy_Rakiura_v5.0.R	Powercurve summary - MODERATE ABUNDANCE - RAKIURA v3.png
	Red	Abundance	Rakiura	DOC_T1_powercurve_infographic_RAPID_abundance_Rakiura_v5.0.R	Powercurve summary - RAPID ABUNDANCE - RAKIURA v3.png
	Amber	Abundance	Rakiura	DOC_T1_powercurve_infographic_MODERATE_abundance_Rakiura_v5.0.R	Powercurve summary - MODERATE ABUNDANCE - RAKIURA v3.png
Figure 26	Red	Occupancy	Ruahine	DOC_T1_powercurve_infographic_RAPID_occupancy_Ruahine_v5.0.R	Powercurve summary - RAPID OCCUPANCY - RUAHINE v3.png
	Amber	Occupancy	Ruahine	DOC_T1_powercurve_infographic_MODERATE_occupancy_Ruahine_v5.0.R	Powercurve summary - MODERATE OCCUPANCY - RUAHINE v3.png
	Red	Abundance	Ruahine	DOC_T1_powercurve_infographic_RAPID_abundance_Ruahine_v5.0.R	Powercurve summary - RAPID ABUNDANCE - RUAHINE v3.png
	Amber	Abundance	Ruahine	DOC_T1_powercurve_infographic_MODERATE_abundance_Ruahine_v5.0.R	Powercurve summary - MODERATE ABUNDANCE - RUAHINE v3.png

† Graphics are stored in Folder with same name as spatial scale. * Graphic designed for summary with long title and transparent background.

Note: The table below lists the R-code files used to generate the dotplots summarising the time taken to detect an early warning for a simulated red or amber alert. These dot plots were generated using data from the input file 'Data/Infographic/Power summary/Powercurve_summary_v3.csv'. All R-code files are stored in the 'Analysis/Infographics/powercurve/' folder. All output files are stored in the 'Data/Infographic/Graphic/Powercurve/' folder.

Appendix 3 – Updated analysis of tagged stem mortality across Tier One forest plots using either a 5-year or 10-year measurement interval (following Mason & Bellingham 2018)

Many ecological monitoring systems use repeat census data from marked individuals. These data are commonly used to estimate vital rates, such as mortality. Even with frequent repeat measurements some individuals will recruit and die during the interval between measures, so those individuals are 'missed' by the monitoring system (Lewis et al. 2004). The schema below illustrates this concept for four types of tagged stems in forest plots with three measures (Figure A3.1). If only the first and third measure were undertaken, the stems shown in red would be 'missed'.

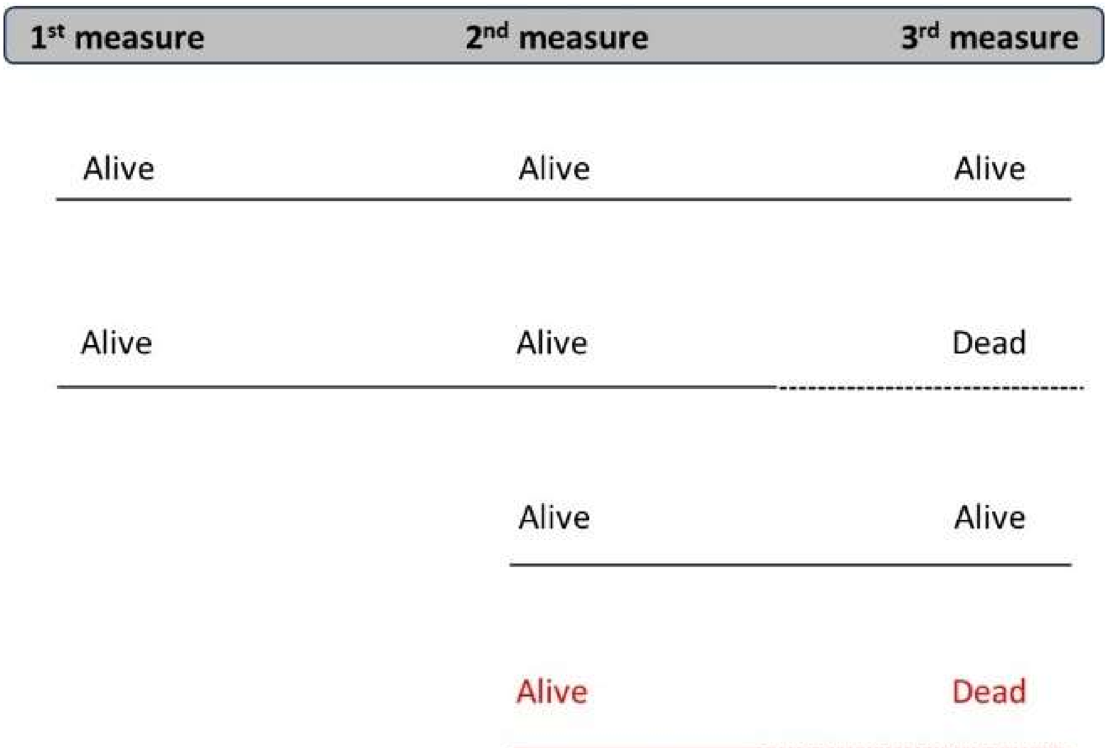

Figure A3.1. Schematic representation of mortality events missed if transitioning from a 5- to 10-year measurement cycle. Stems recruited between the first and second measurements and dying between the second and third measurements would not be recorded under the 10-year measurement cycle.

A previous report (Mason & Bellingham 2018) used plot-based Tier One and LUCAS (Land Use and Carbon Analysis System) data from 2002 to 2017 to evaluate the effect of missed stems on estimates of vital rates using 5- and 10-year measurement intervals. Here we repeated those analyses using only the Tier One plots analysed elsewhere in this report, but including earlier measures from LUCAS, where available. Across all plots the mean number of missed stems was 97.5 stems/ha, or 7.8% of all mortality events. However, in some plots all the dying stems were recruited between the first and second measurement, so the effect was substantial on those plots. Results are shown in Figure A3.2:

PmissedMort is the % of dying stems that would be missed if only the first and last measurements of the three-times-measured plots were performed; *NmissedMort* is the number of dying stems that would be missed.

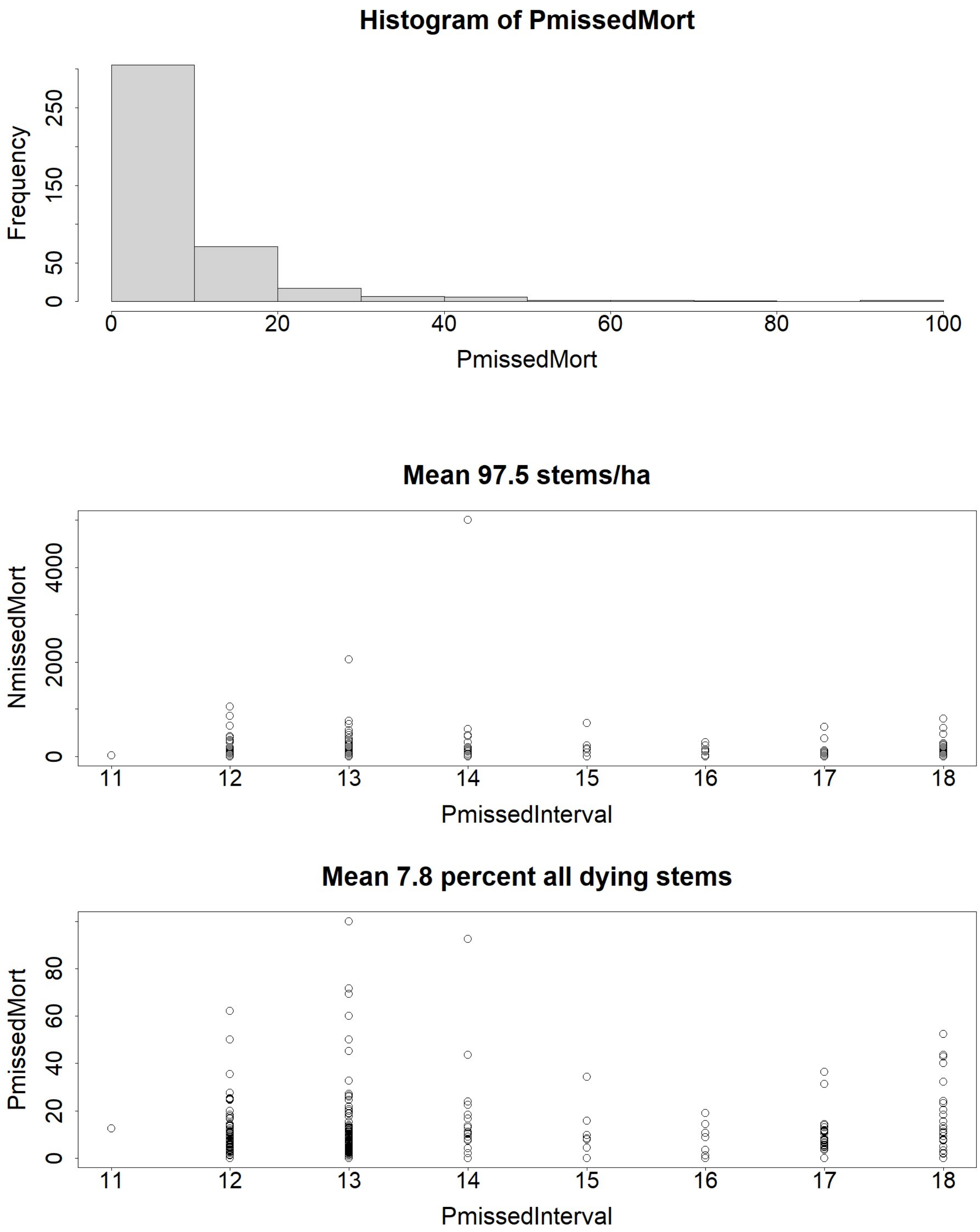

Figure A3.2. Histogram of plot-level percentage of dying stems that would be missed under the 10-year measurement cycle (PmissedMort) and against interval length between first and third measurements of Tier 1 plots.

Appendix 4 – Trend estimates derived using spatial models

For a subset of guild (ungulates and cavity-nesting birds) and bird species (riflemen and tūī), we also estimated trends using a set of spatial models, whereby trends were permitted to differ across sampling locations grouped by focal sites (or management areas, which for the purposes of our analyses included sets of sampling locations grouped by individual national parks and any other park encompassing ≥15 sampling locations. All remaining sampling locations were grouped by their respective operating region. (See Table A4.2 for more information.)

The intention of these spatial models is to incorporate potential effects of differences in conservation management in different areas of public conservation land. These models allowed each sampling location ('Place') to have its own intercept (thus also accounting for repeated measures from each sampling location), but also allowed for trends to vary spatially in relation to 31 management units (by including Ys|Mgt_area as a random effect in the model).

- *All public conservation land:* only survey year was used as a fixed effect to estimate the trend across all public conservation land.
- *Woody vs. non-woody habitats:* year, woody classification, and their interaction were included as fixed effects to estimate the trends within woody and non-woody habitats.
- *Within vs. outside parks:* year, national park or not, and their interaction were included as fixed effects to estimate trends inside and outside of national parks. These models were fitted for woody and non-woody habitats independently

Table A4.1. Spatial model specifications

Model	Model specifications	Family	
		Occupancy	Abundance
National[a]	~ Ys + (Ys| Mgt_area) + (1|Place)	Binomial	Poisson
Habitat	~ Ys*Woody + (Ys| Mgt_area) + (1|Place)	Binomial	Poisson
Parks[b]	~ Ys*park + (Ys| Mgt_area) + (1|Place)	Binomial	Poisson

Notes: Ys = standardised year centred around zero. Woody and parks were both specified as two-level factors. Management area (Mgt_area) was specified as a factor with up to 31 levels, as these varied depending on the habitat type.

[a] Only fitted for ungulates, as other models were generally unstable.

[b] Models were fitted to woody and non-woody habitats separately. In most cases these analyses focused on key habitat associations

Ungulates

The amber alert raised for ungulate occupancy at the national scale was supported by a slightly stronger signal when the modelling accounted for spatial variation in trends (across 31 management units; Table A1.1) relative to the base model (Figure A4.1). Both woody and non-woody habitats also raised amber alerts, with red alerts raised for outside of national parks in woody habitats, and inside and outside of national parks in non-woody habitats.

Within the focal parks a red alert was raised for Rakiura National Park (supported by a strong signal; Figure A4.2). By contrast, only a very weak signal for a decline in ungulate occupancy was detected in Ruahine Forest Park, where there was insufficient evidence to classify the trend alert.

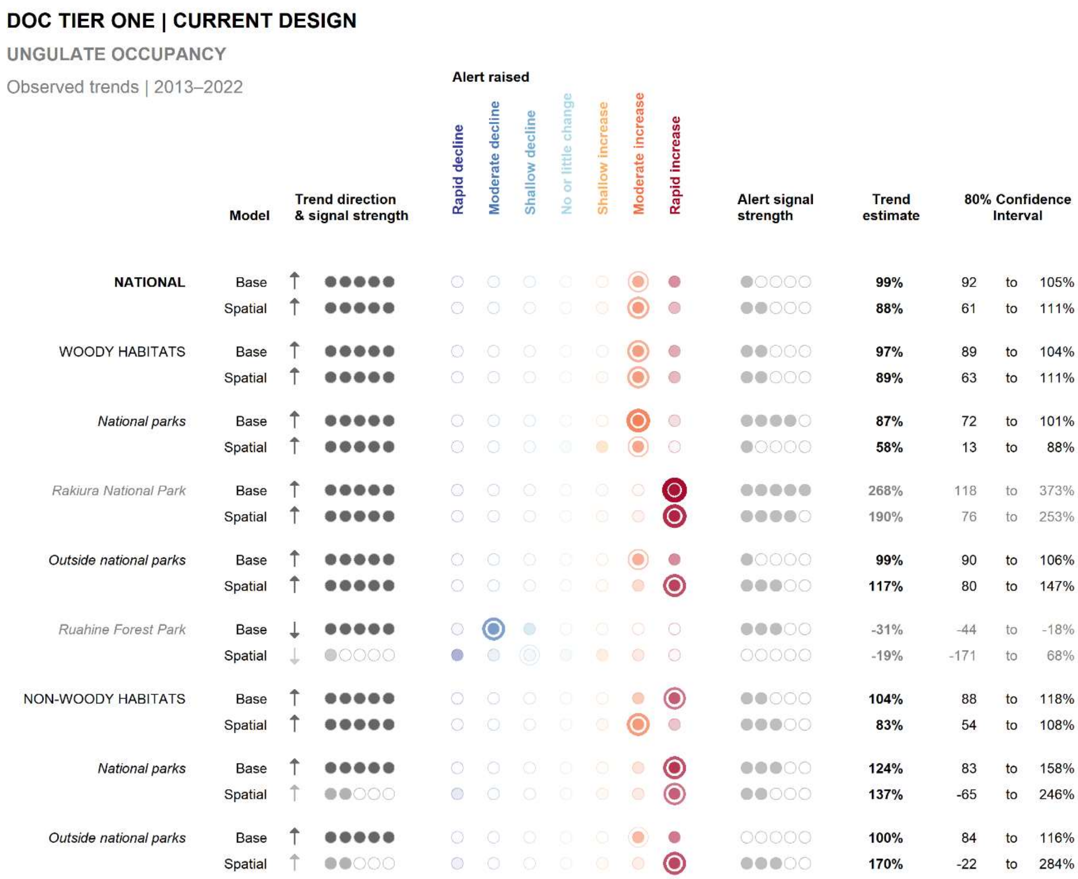

Figure A4.1. Trend summary (2013–2022) for ungulate occupancy derived from the base and spatial models at the national scale (~ Ys + (Ys| Mgt_area) + (1|Place)), within woody and non-woody habitats (derived from the spatial model ~ Ys*Woody + (Ys| Mgt_area) + (1|Place)), within and outside national parks, as well as two focal parks (derived from the spatial model ~ Ys*park + (Ys| Mgt_area) + (1|Place)).

Notes: These trend estimates were calculated based on faecal pellet counts sampled twice across the DOC Tier One framework (i.e. two full 5-year measurement cycles; N = number of unique sampling locations surveyed). (For information on the alert and signal classification system, see Figure 7.)

Common and widespread birds

Cavity nesters and riflemen declined in both occupancy and abundance, most rapidly outside national parks, where red alerts (with strong signals) were most likely to be raised (Figure A4.2.Figure A4.2 & Figure A4.3). In Ruahine Forest Park red alerts (with moderate to very strong signals) were flagged for cavity-nester and rifleman occupancy, with weak signals for moderate declines in these birds' abundance over the same period.

Within national parks there were weak signals for shallow to moderate declines in cavity nesters and riflemen. In Rakiura National Park moderate declines were flagged for cavity nesters (Figure A4.2), but there was insufficient evidence to classify trend alerts for riflemen (Figure A4.3). By contrast, a rapid increase in tūī occupancy was detected in national parks, but with insufficient evidence to classify their status within Rakiura National Park or outside national parks (Figure A4.4). Moderate increases in tūī occupancy were flagged for Ruahine Forest Park, but this trend classification was only supported by a very weak signal.

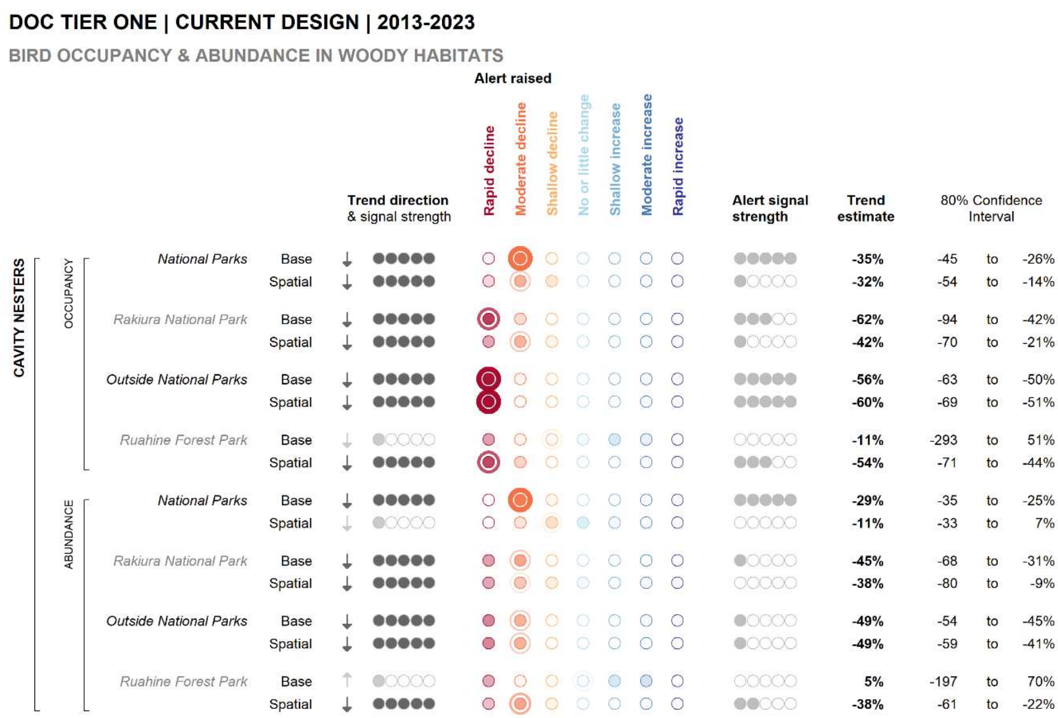

Figure A4.2. Trend summary (2013-2022) for the guild of cavity-nesting birds within and outside national parks as well as two focal parks (derived from their respective spatial models ~ Ys*park + (Ys| Mgt_area) + (1|Place)).

Notes: These trend estimates for occupancy and abundance were calculated based on bird counts sampled twice across the DOC Tier One framework (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system, see Figure 7.)

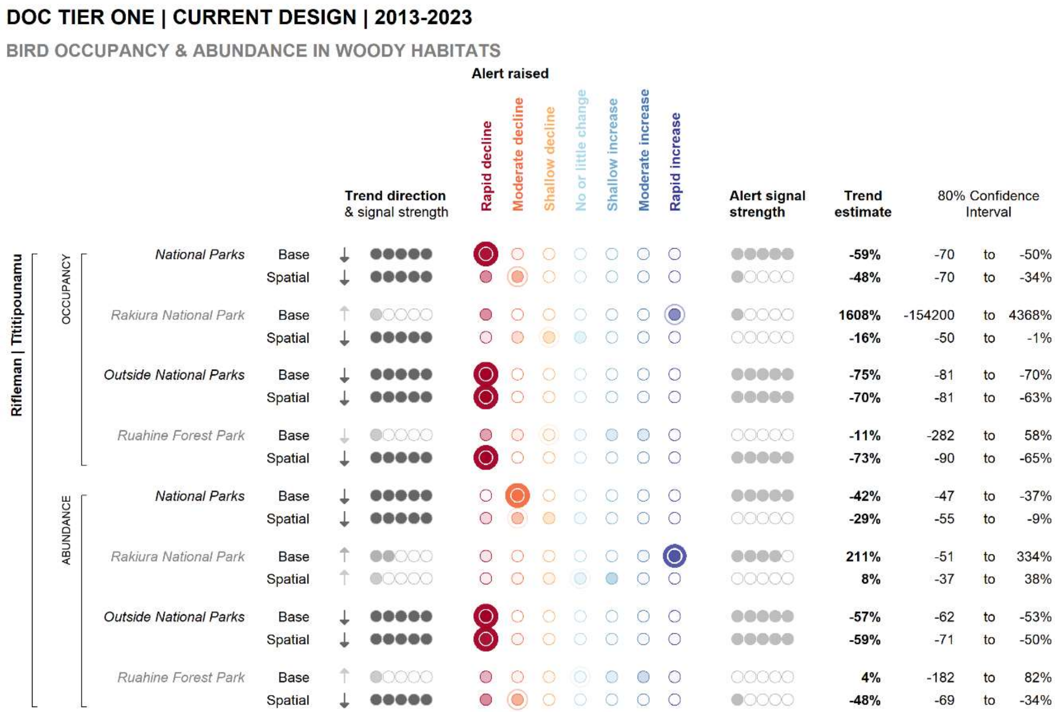

Figure A4.3. Trend summary (2013–2022) for the guild of riflemen within and outside national parks as well as two focal parks (derived from their respective spatial models ~ Ys*park + (Ys| Mgt_area) + (1|Place)).

Notes: These trend estimates for occupancy and abundance were calculated based on bird counts sampled twice across the DOC Tier One framework (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system, see Figure 7.)

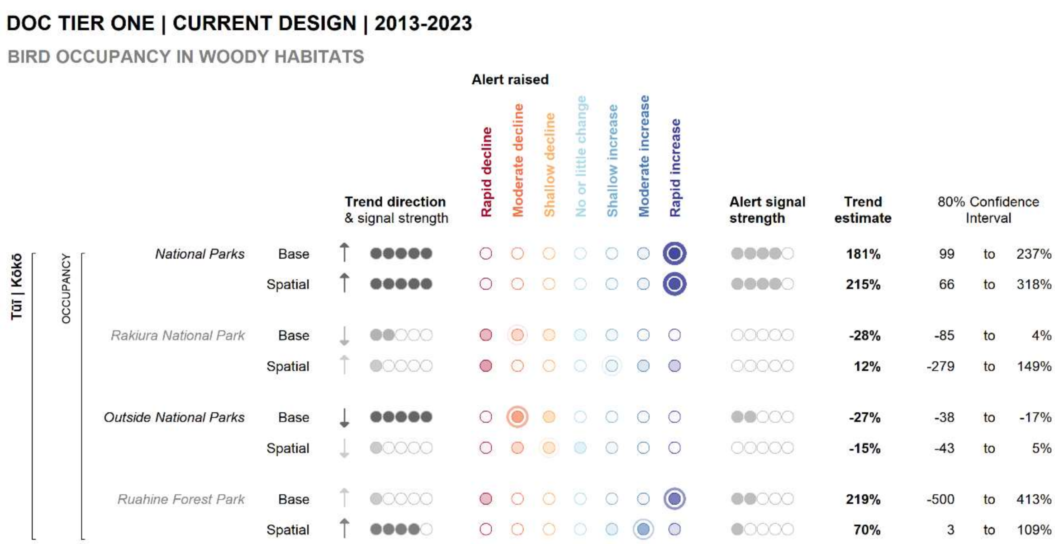

Figure A4.4. Trend summary (2013–2022) for the guild of tūī within and outside national parks as well as two focal parks (derived from their respective spatial models ~ Ys*park + (Ys| Mgt_area) + (1|Place)).

Notes: These trend estimates for occupancy were calculated based on bird counts sampled twice across the DOC Tier One framework (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system, see Figure 7.)