Manaaki Whenua
Landcare Research

Ungulate effects on saplings in Bay of Plenty and Kaimai Mamaku forests

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Ungulate effects on saplings in Bay of Plenty and Kaimai Mamaku forests

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Summary

Project and client

Bay of Plenty Regional Council contracted Manaaki Whenua – Landcare Research to assess indigenous forests in their region and in the Kaimai Mamaku Restoration Project Area (hereafter, the 'Project Area') with respect to two key questions.

- Whether the vegetation composition has been affected by ungulate (mainly deer and goats, but also pigs) browsing between 2013 and 2022.
- What might be the impact of modifying an existing biodiversity monitoring design (from 5-year vs 10-year return time) on the statistical power to detect future trends in saplings (grouped by ungulate palatability).

Objectives

Specifically, this research aimed to quantify the following parameters.

- Ten-year trends observed for sapling occupancy and abundance (grouped by ungulate palatability) observed in the Bay of Plenty Region and Project Area, as well as ungulate occupancy in the Region.
- The effect of shifting to a modified, less frequent monitoring design on:
  - the statistical power to detect simulated trends after 10 years for saplings (grouped by ungulate palatability) in the Bay of Plenty Region and Project Area
  - the expected time taken to detect moderate to rapid trends in sapling occupancy and abundance under the current design versus the proposed modified design in the Bay of Plenty Region and Project Area
  - the feasibility of detecting known changes in trend trajectories for palatable and unpalatable saplings in the future, if the existing monitoring design is modified in the Bay of Plenty Region and Project Area.
- The relationship between ungulate occupancy and measured trends in sapling occupancy and abundance (that are palatable to ungulates) across the Bay of Plenty Region only.
- Any differences in trend trajectories between saplings that are palatable to ungulates versus those that are unpalatable in the Bay of Plenty Region and Project Area.

Information sources

- The analyses were based on vegetation and ungulate data gathered over a 10-year period (2013–2022) from sampling locations overlapping indigenous forests in the Bay of Plenty Region (n = 43) or Project Area (n = 13). These sampling locations, which are situated on a national 8 km × 8 km grid, were surveyed using standardised protocols implemented either under the Department of Conservation's (DOC's) Tier 1 biodiversity monitoring system or the Ministry for Environment's Land Use and Carbon Analysis System.
- Two monitoring designs were evaluated in this report.

  - *Current design:* where each sampling location is surveyed once every 5 years. During a 5-year measurement cycle roughly a fifth of the sampling locations is measured each year.
  - *Modified design:* where each sampling location is surveyed only once every 10 years. During a 10-year measurement cycle roughly a tenth of the sampling locations is measured each year. For our analyses, 50 replicates were simulated for the proposed modified design.
- At each sampling location, the following metrics were quantified.
  - *Sapling occupancy or abundance:* the probability or total count of a sapling group (those that were either palatable or unpalatable to ungulates) being recorded in a subplot.
  - *Ungulate occupancy:* the probability of faecal pellets being recorded on a transect (note: data were only available for a subset of sampling locations).

Analytical approach

<u>Ten-year trends (2013–2022) for saplings and ungulates</u>

- *Do vegetation indicators (saplings) suggest ungulate impacts?* We calculated the observed 10-year trends for palatable and unpalatable saplings in the Bay of Plenty Region or the Project Area, and for ungulates at the regional scale, using field data gathered by the current monitoring design with the data treated as annual samples. An alert system was then applied to draw attention to trends of conservation concern.
- *What will be the effect of shifting to a 10-year monitoring cycle for detecting trends in saplings?* We assessed the power to detect moderate to rapid changes in the future after 10 years of monitoring. Power was estimated as the probability of detecting simulated trends for each sapling group applied to the current design and the proposed modified design, across the Bay of Plenty Region or the Project Area.
- *What will be the effect of shifting to a 10-year monitoring cycle on the expected time taken to detect early warnings of moderate to rapid changes saplings in the future?* We evaluated any effects by varying the duration of the survey periods (3–10 years, with 1-year increments) for the current and modified monitoring designs in the Bay of Plenty Region and Project Area. For each scenario, we then quantified the power to detect simulated moderate to rapid 10-year trends in occupancy and abundance.

<u>Ungulate and palatable sapling relationships</u>

- *Is there any evidence of a relationship between ungulate occupancy and sapling trends?* In these analyses we tested for an interaction between direct evidence of ungulate occupancy (presence or absence of faecal pellet counts) and trends in palatable saplings (occupancy or abundance) over a 10-year period (2013–2022) in the Bay of Plenty Region only.

<u>Differences in sapling trend trajectories</u>

- *Is there any evidence of a difference in the trend trajectories between palatable and unpalatable saplings?* In these analyses we tested for an interaction between the sapling

group identity and survey year over a 10-year period (2013–2022) in the Bay of Plenty Region and Project Area.
- *What will be the effect of shifting to a 10-year monitoring cycle for detecting a difference in the trend trajectories between the sapling groups?* We assessed any effects by simulating rapid to shallow changes in occupancy and abundance for palatable saplings over a 10-year period, but no change in unpalatable saplings. The power to detect these simulated differences in trend trajectories was then evaluated under scenarios where the current design and the proposed modified design was implemented across the Bay of Plenty Region and Project Area.

Results

<u>Ten-year trends (2013–2022) for saplings and ungulates</u>

- *Observed 10-year trends provide strong evidence that ungulate browsing has affected the understorey composition of indigenous forests*.
  - *Palatable saplings*: occupancy and abundance declined moderately across the Bay of Plenty Region, thus triggering 'amber alerts' (moderate deterioration) for ungulate browsing impacts. In the Project Area, occupancy declined rapidly, while abundance declined moderately (flagging red and amber alerts respectively).
  - *Unpalatable saplings*: occupancy and abundance showed little change across the Bay of Plenty Region and in the Project Area.
  - *Ungulates*: occupancy increased slightly in the Bay of Plenty Region (which was the only area assessed for ungulate occupancy).
- *Modifying the existing monitoring design will significantly reduce power to detect moderate to rapid changes in saplings within 10 years.*
  - *Current design (5-year cycle):* has high power to detect moderate to rapid changes in the palatable saplings (abundance) and unpalatable saplings (occupancy and abundance) in 10 years in the Bay of Plenty Region and Project Area. The current design can also detect rapid changes in the occupancy of palatable saplings in the Region and Project Area.
  - *Modified design (10-year cycle):* will have the power to detect only rapid declines in unpalatable sapling occupancy and abundance within 10 years at the regional scale (but not in the Project Area).
- *It will take longer to detect trends of conservation concern for saplings if the existing monitoring design is modified.*
  - *Current design (5-year cycle):* will be able to detect trends in the Bay of Plenty Region and Project Area after 5–7 years for rapid to moderate changes in unpalatable saplings (occupancy or abundance). However, it will generally take a year longer to detect similar changes in palatable sapling abundance.
  - *Modified design (10-year cycle):* will only be able to detect trends at the regional and Project Area scales for rapid changes in the abundance of unpalatable saplings (after 5 years) – and not at all for palatable saplings.

Ungulate and palatable relationships

- *Palatable saplings (occupancy and abundance) were negatively associated with ungulate occupancy, and survey year.*
  - The negative association indicates that the direction of temporal change in palatable sapling occupancy and abundance varied with mean ungulate occupancy.
  - Overall, occupancy and abundance of palatable saplings increased over time at low ungulate occupancy but declined at moderate to high levels of ungulate occupancy.

Differences in sapling trend trajectories

- *Unpalatable saplings are more likely to occur in indigenous forests, and to be more abundant, than palatable saplings. This gap widened over the 10-year study period, as palatable saplings declined while unpalatable saplings increased slightly or showed little change.*
  - *In 2013:* unpalatable saplings were twice as abundant as palatable saplings in the Bay of Plenty Region and in the Project Area; they were also twice as likely to occur in the Region, and about three-quarters as likely in the Project Area.
  - *By 2022:* unpalatable saplings were up to seven times as abundant and seven times more likely to occur in the Region; they were also four times more abundant and five times more likely to occur in the Project Area.
- *Modifying the existing monitoring design will significantly reduce power to detect differences in 10-year trend trajectories of sapling groups.*
  - *Current design (5-year cycle):* There is high power to detect a difference in trend trajectories equivalent to a rapid or moderate change in the occupancy and abundance of palatable saplings (relative to unpalatable saplings) within 10 years at regional and Project Area scales. Shallow changes will be detectable for abundance at the regional scale but only if the confidence level is relaxed for the Project Area.
  - *Proposed modified design (10-year cycle):* will retain power to detect differences in trend trajectories for abundance (equivalent to rapid or moderate changes) and occupancy (but only for rapid changes and moderate increases) of palatable saplings (relative to unpalatable saplings).
  - However, differences equivalent to a rapid decline will only be detectable for occupancy in the Project Area, and then only if the confidence level is relaxed.

Conclusions

- Palatable saplings have declined rapidly in the Region and the Project Area. They are also less likely to occur, and are less abundant, than unpalatable saplings in indigenous forests in both areas. Unpalatable sapling occupancy and abundance has shown little to no change over the same period in both areas.
- Trends in occupancy and abundance of palatable saplings at the region scale were modulated by ungulate occupancy, with palatable saplings declining at moderate and

high ungulate occupancy, suggesting that the results for the Project Area can be interpreted as indicating ungulate effects in plant communities.

- Moving from a 5- to a 10-year measurement cycle will greatly reduce the statistical power to detect changes in saplings of both the palatable and unpalatable palatability groups in the Region and the Project Area.
- Future studies could consider refining the alert classifications for different contexts and taxa. For example, a decrease in the abundance of unpalatable saplings might be interpreted as a shallow improvement in forest understorey health (rather than a shallow deterioration, as presented using the alert framework applied in this report).

1 Introduction

This report evaluates data for indigenous forests in the Bay of Plenty Region and the Kaimai Mamaku Restoration Project Area (the 'Project Area') relating to the following questions.

- Whether the vegetation composition has been affected by ungulate (mainly deer and goats, but also pigs) browsing between 2013 and 2022.
- What might be the impact of modifying an existing biodiversity monitoring design (from 5-year vs 10-year return time) on the statistical power to detect future trends in saplings (grouped by ungulate palatability).

1.1 Objectives

This research aimed to quantify the following parameters.

- Ten-year trends observed for sapling occupancy and abundance (grouped by ungulate palatability) observed in the Bay of Plenty Region and Project Area, as well as ungulate occupancy in the Region.
- The effect of shifting to a modified, less frequent monitoring design on:
  - the statistical power to detect simulated trends after 10 years for saplings (grouped by ungulate palatability) in the Bay of Plenty Region and Project Area
  - the expected time taken to detect moderate to rapid trends in sapling occupancy and abundance under the current design versus the proposed modified design in the Bay of Plenty Region and Project Area
  - the feasibility of detecting known changes in trend trajectories for palatable and unpalatable saplings in the future, if the existing monitoring design is modified in the Bay of Plenty Region and Project Area.
- The relationship between ungulate occupancy and measured trends in sapling occupancy and abundance (that are palatable to ungulates) across the Bay of Plenty Region.
- Any differences in trend trajectories between saplings that are palatable to ungulates versus those that are unpalatable in the Bay of Plenty Region and Project Area.

1.2 Report structure

The main report consists of eight sections. Following this Introduction, Section 2 (Background) introduces the study areas.

Section 3 (Information sources) describes the monitoring framework, which provides an unbiased sample of locations for indigenous forests in the Bay of Plenty Region and Project Area, and the two designs this report sets out to evaluate: the current design (which has been implemented over the last 10 years, 2013–2022), and a modified design (which proposes to reduce the sampling intensity and frequency in the future).

Section 4 (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; the time taken to raise alerts for the simulated trends for the current versus the modified designs; and test for interactions between different indicators over time and power to future differences in trend trajectories.

Section 5 (Ten-year trends for saplings and ungulates) summarises data for the Bay of Plenty Region and the Project Area: the 10-year trends (2013–2022) derived from the current design; and the power to detect rapid to moderate changes in sapling groups after 10 years of monitoring, and the time taken to detect early warnings for those changes, in the future, using simulated trends applied to the current design and proposed modified design.

Section 6 (Ungulate and palatable sapling relationships) evaluates the evidence for any interactions between ungulate occupancy and trends in palatable saplings (occupancy and abundance) across the Bay of Plenty Region.

Section 7 (Differences in sapling trend trajectories) summarises findings for the Bay of Plenty Region and the Project Area: evidence for any differences in trends between the sapling groups over the 10-year period; and the power to detect any differences in trend trajectories between the sapling groups that equivalent to rapid to moderate changes after ten years of monitoring, using simulated trends applied to the current design and proposed modified design.

Section 8 (Conclusions) reviews the evidence for ungulate browser effects on indigenous forest understorey and the risks of shifting from a 5-year to 10-year measurement cycle for detecting future trends in sapling and ungulate abundance.

2 Background

2.1 Bay of Plenty Region

In a previous report (Mason & Price 2019) we obtained strong evidence for a decline in the abundance of tree species preferred by ungulate herbivores (often referred to as 'palatable') in the Bay of Plenty, with this decline apparently being disproportionately severe relative to national-scale trends (Figure 1). That report's authors attributed this to the high abundance of ungulates in the Bay of Plenty, although it was impossible to rule out the effects of high possum abundance (Figure 2).

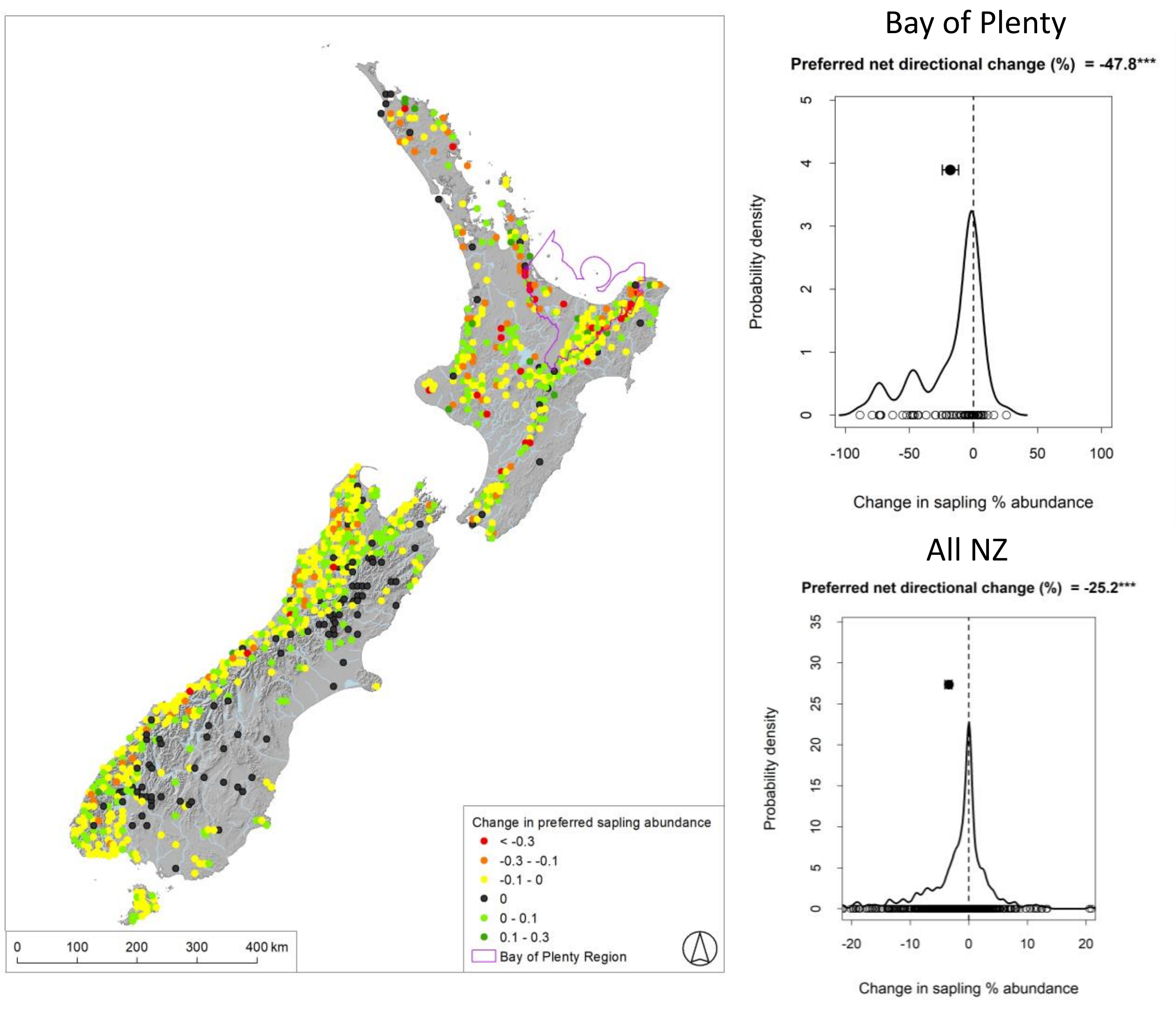

Figure 1. (Left) Map of changes in the proportional abundance of species in the 'preferred' (i.e. palatable) ungulate palatability group within the sapling size class (sensu Hurst & Allen 2007a) in LUCAS survey plots. (Right) the top and bottom right panels show the associated probability density distribution (solid lines) and significance test results (* indicates *P* >0.001) for plot-level changes in preferred sapling abundance in the Bay of Plenty Region and all of New Zealand. Open circles represent individual LUCAS survey plots and closed circles indicate bootstrapped mean estimate of plot-level change. See Mason and Price (2019) for further details.**

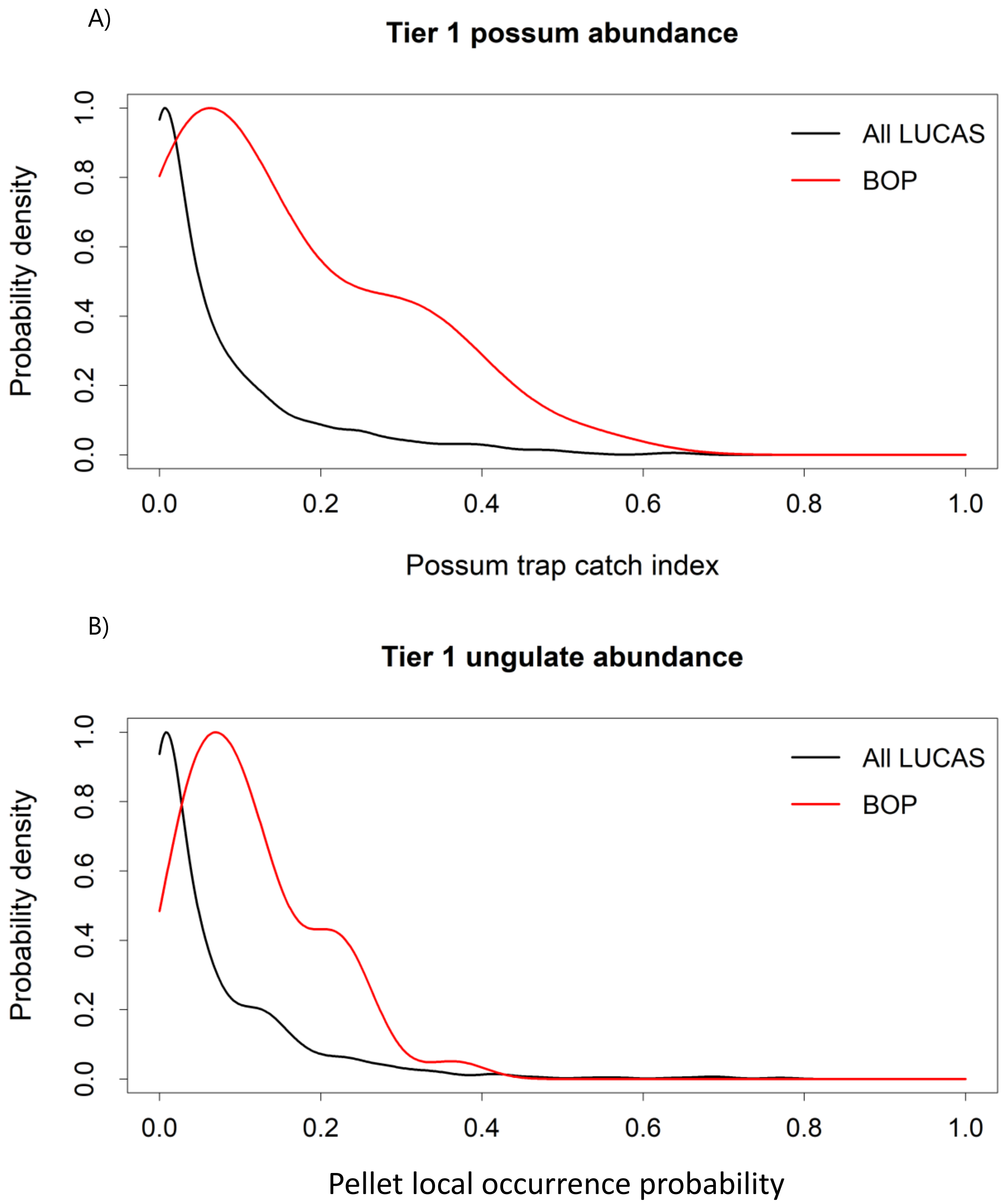

Figure 2. Tier 1 abundance estimates at LUCAS indigenous forest and shrubland survey locations in the Bay of Plenty (BOP) and across New Zealand (All LUCAS). A) Possums; (B) Ungulates. In both cases the peak of the probability distribution curve for the BOP (the red curve) occurs at higher values than (i.e. to the right of) that for the whole of New Zealand. This shows that possum and ungulate relative abundance in the BOP is, on average, higher than for the rest of New Zealand. (Source: adapted from Mason & Price 2019.)

2.2 Kaimai Mamaku Restoration Project Area

The Kaimai Mamaku Restoration Project Area (the 'Project Area') covers over 300,000 ha, spanning two regional councils (the Bay of Plenty and Waikato), four district councils, and more than 30 iwi and hapū.

One issue of concern for this Project Area is the potential impact of invasive mammalian herbivores on forest communities. The Project Area has experienced severe declines in saplings of preferred (i.e. palatable) species (Figure 3). Consequently, arresting and reversing ungulate impacts on vegetation in the Kaimai Mamaku Conservation Park and surrounding areas is a major focus of the Kaimai Mamaku Restoration Project.[1]

Permanent forest survey plots are currently the main tool for monitoring vegetation change in response to mammalian herbivory in New Zealand (Ramsey et al. 2019). Currently the Project Area contains 13 such plots (i.e. points intersection green shaded area in Figure 4), but there are concerns that this level of replication will be insufficient to detect all but the largest, most consistent changes in relevant metrics across the Project Area.

[1] See: https://www.beehive.govt.nz/release/jobs-nature-boosts-efforts-restore-kaimai-mamaku

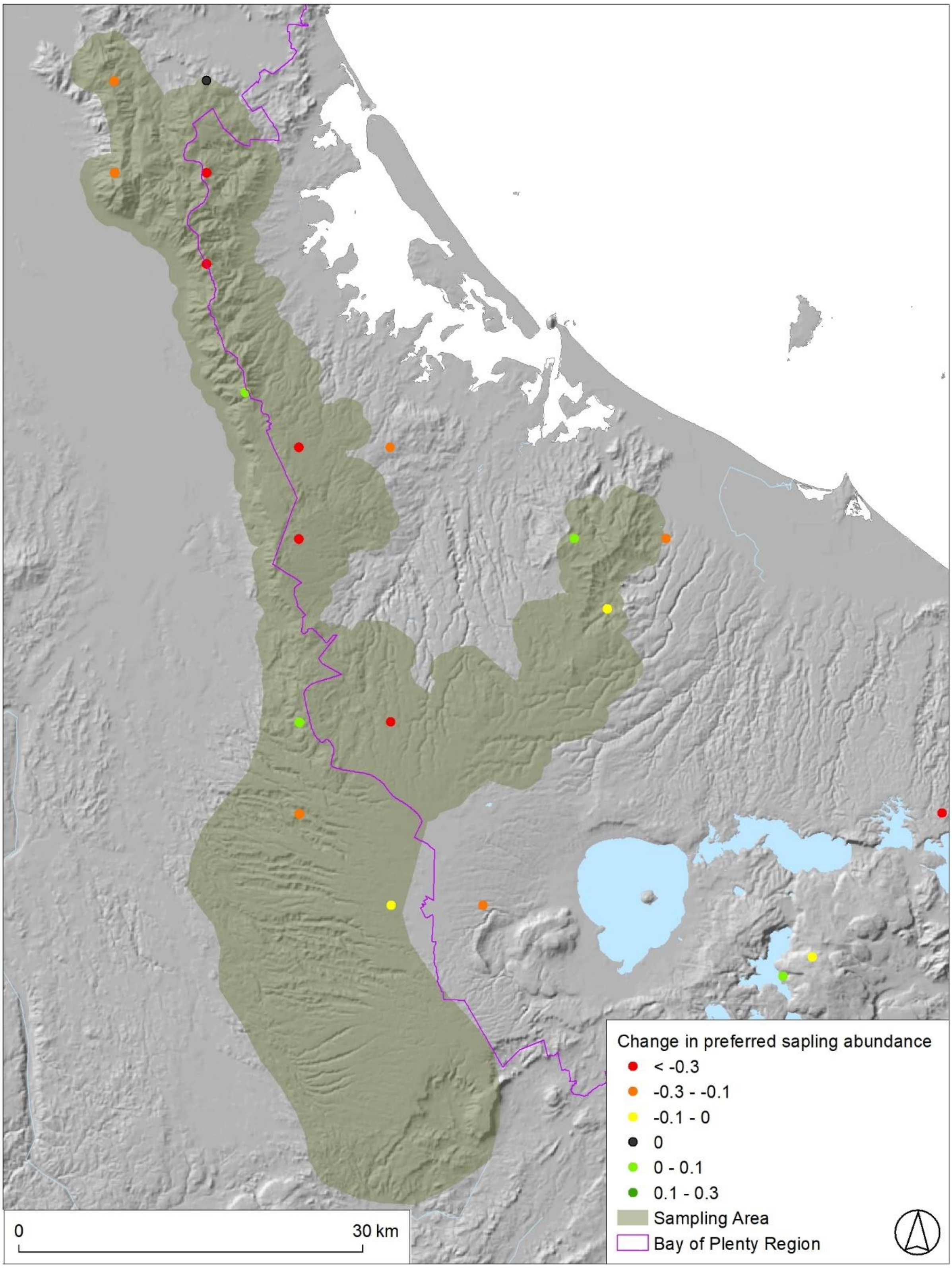

Figure 5. Changes in the proportional abundance of species in the preferred (i.e. palatable) ungulate palatability group within the sapling (sensu Hurst & Allen 2007a) size class in LUCAS survey plots in the Kaimai Mamaku Restoration Project Area. The Project Area ('Sampling Area' in the map above) straddles the boundary between the Waikato and Bay of Plenty Regions. (Source: adapted from Mason & Price 2019.)

3 Information sources

3.1 Current design

To evaluate the current design, our analyses focused on field data gathered from sampling locations overlapping the Bay of Plenty Region and Project Area between 2013 and 2022. These sampling locations, which are situated on a national 8 km × 8 km grid, were surveyed using standardised protocols implemented by either the Department of Conservation's (DOC) Tier 1 biodiversity monitoring system or the Ministry for Environment's Land Use and Carbon Analysis System.

For the Bay of Plenty Region, vegetation data included 1,360 sapling counts gathered from 688 vegetation subplots over 43 sampling locations (with between 6 and 13 locations sampled each year; Figure 6).

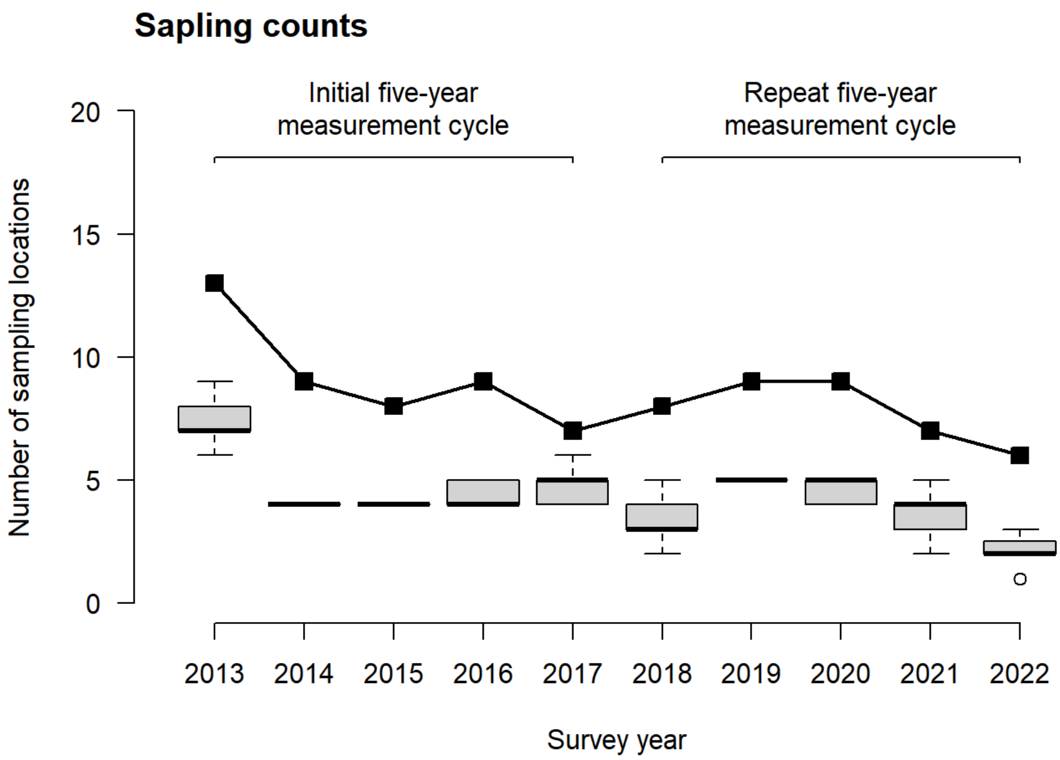

Figure 6. Total number of sampling locations per year (square black boxes and solid line) for sapling counts within the Bay of Plenty Region using the LUCAS and Tier 1 monitoring framework's current design and modified design. The grey-filled box plots show how the total number of sampling locations per year varied across the 50 simulated replicates of the modified (10-year) design; the grey boxes contain the 25th and 75th percentiles and the line within the box is the median. The whiskers extend to the most extreme data point (which is no more than 1.5 times the interquartile range from the box).

In the Project Area, vegetation field data included 384 sapling counts across 208 subplots gathered from 13 sampling locations (with between 1 and 5 locations surveyed each year; Figure 7).

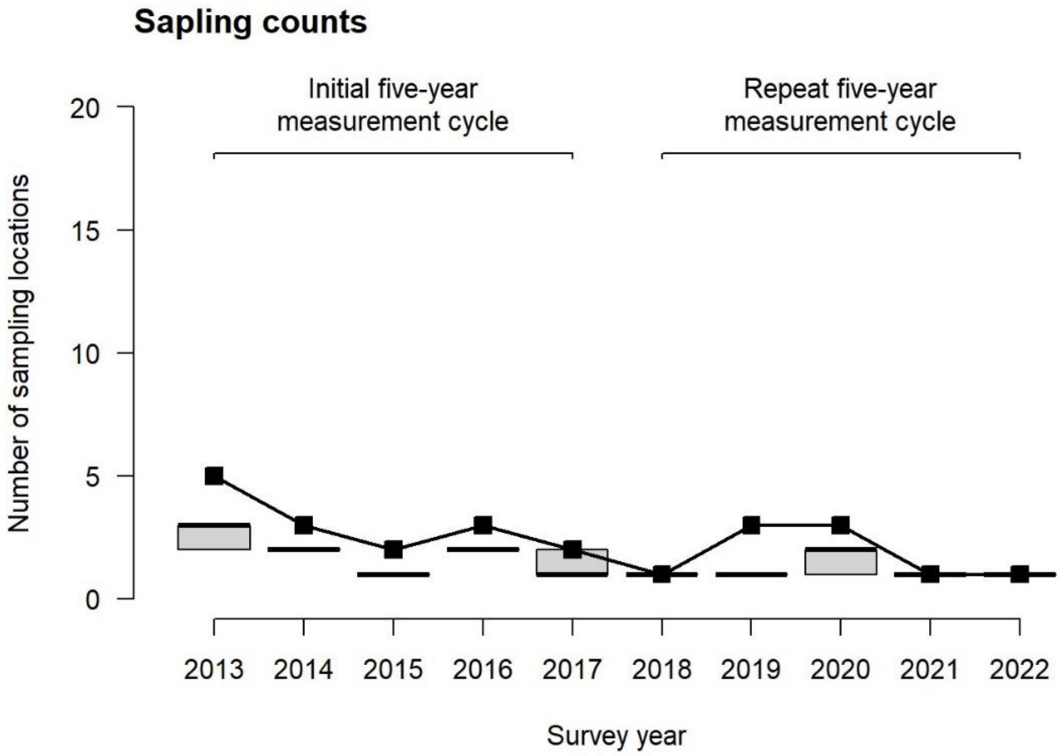

Figure 7. Total number of sampling locations per year (shown with the square black boxes and solid line) for sapling counts within the Kaimai Mamaku Restoration Project Area using the LUCAS and Tier 1 monitoring framework's current (5-year) design. The grey-filled box plots show how the total number of sampling locations per year varied across the 50 simulated replicates of the modified (10-year) design; the grey boxes contain the 25th and 75th percentiles and the line within the box is the median. The whiskers extend to the most extreme data point (which is no more than 1.5 times the interquartile range from the box).

For ungulates, field data for the Bay of Plenty Region included 6,696 faecal pellet counts gathered from 227 transect surveys over 32 sampling locations (with between one and eight sampling locations surveyed each year; Figure 6). Faecal pellet data for the Project Area were only available for two Tier 1 locations, so analyses involving faecal pellet counts were only performed for the Bay of Plenty Region.

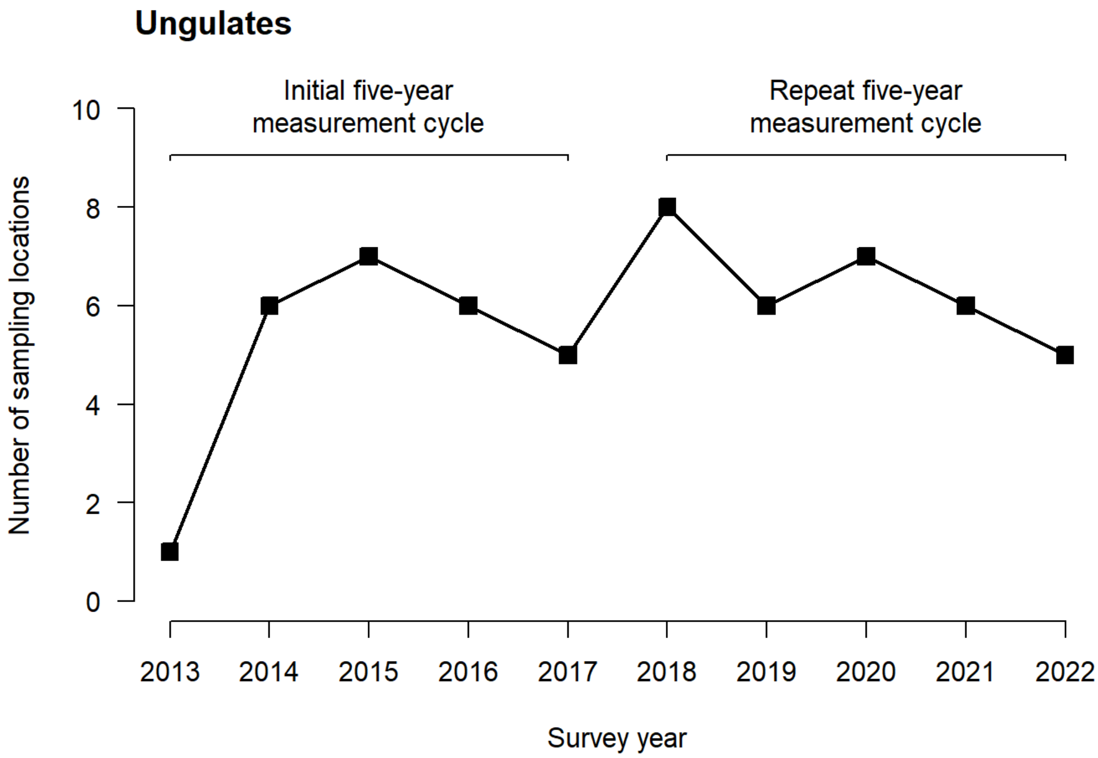

Figure 8. Total number of sampling locations per year for ungulate surveys within the Bay of Plenty Region using the Tier 1 monitoring framework's current (5-year) design.

3.2 Proposed modified design

The proposed modified design for saplings extends the measurement cycle to a 10-year cycle (Figures 4 and 5), halving the number of locations sampled each year, which allows no repeat measures within a decade.

To run our simulation analyses, we created 50 replicates for the proposed modified design (i.e. a single 10-year cycle). For each of the 50 replicates, half the sampling locations were randomly selected from the initial 5-year measurement period but excluded from the second 5-year cycle, thus providing a unique set of locations for each year in the 10-year measurement period (i.e. no repeat measures).

3.3 Vegetation and ungulate metrics

At each sampling location, we quantified the following metrics.

- *Sapling occupancy or abundance:* the probability or total count of a sapling group being recorded in a 5 × 5 m subplot (where there were 16 subplots within a 20 × 20 m plot; Hurst & Allen 2007a,b). Before the analyses, tree species were assigned to ungulate palatability groups (i.e. "preferred" – palatable; "avoided" – unpalatable; "not selected" – neither unpalatable or palatable and "Unclassified") according to classifications in the

National Vegetation Survey Databank plant names database.[2] Only the "preferred" and "avoided" groups were included in analyses of sapling occupancy and abundance.

- *Ungulate occupancy:* the probability of faecal pellets being recorded on a transect (based on the number of up to 30 circular subplots per transect where the pellets were recorded as present or absent; Forsyth et al. 2011).

4 Analytical approach

4.1 Ten-year trends for saplings and ungulates

This section applies analytical protocols for identifying biodiversity trends of conservation concern, previously applied within urban landscapes (MacLeod et al. 2022) and on public conservation land (MacLeod et al. 2024). It also applies a simulation-based power analysis method for comparing the ability of alternative sampling designs (5-year vs 10-year) to detect simulated trends in a timely manner (Green & MacLeod 2016; MacLeod et al. 2024).

Observed trends

Here we outline the protocols for calculating, interpreting, and visualising the 10-year trend estimates (2013–2022) for ungulates and sapling groups in the Bay of Plenty Region and for sapling groups in the Project Area. These analyses were based on field data gathered using the current design for the LUCAS and DOC Tier 1 monitoring frameworks (i.e. 5-year measurement cycle, where most sampling locations were measured twice during the 10-year period; Figures 4–6). All analyses were undertaken using R (R Core Team 2023), with the data treated as annual samples.

Specifying models to calculate observed trend estimates

We fitted separate models to estimate the trends for occupancy and abundance of palatable saplings and unpalatable saplings in the Project Area, as well as for ungulate occupancy and the occupancy and abundance of palatable saplings and unpalatable saplings in the Bay of Plenty Region. For the purposes of these analyses, we assume detection probability is equivalent to 1 (i.e. observers accurately recorded all the pellets and saplings present at each sampling location). Note that abundance models were not fitted for ungulates (which had very highly skewed counts), and occupancy models have performed well as surrogates of abundance in other research (A Gormley, Manaaki Whenua – Landcare Research, pers. comm.).

All models (~ Ys + (1|Place)) were fitted using the glmer function from the R package lme4 (Bates et al. 2015). This is commonly used for study designs with repeated measures (and permitted us to use an existing simulation method – implemented in the R package simr (Green & MacLeod 2016) – to estimate uncertainty in trend estimates and perform power

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[2] See: https://nvs.landcareresearch.co.nz/Resources/NVSNames (accessed 22 November2023.)

analyses in subsequent sections of this report). Binomial and Poisson error distributions were specified for occupancy and abundance, respectively. Year was standardised (Ys) for the 10-year period (on a scale of 0 to 9) to help model fitting. The fitted models assumed all sampling locations followed the same trend but allowed each sampling location (Place) to have its own intercept (accounting for differences in mean values over survey periods between locations).

Parametric bootstrapping was used to measure uncertainty in the fitted coefficients, referred to here as 'point estimates' (Davison & Hinkley 1997; Canty & Riple 2020). 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.

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. Percentage changes were selected for reporting, as these can be readily compared across different metrics (occupancy vs abundance), taxa, and spatial scales. 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 7A).[3]

Classifying trend direction and signals

The trend direction was classified based on the point estimate (Figure 7). 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 7). 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.

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

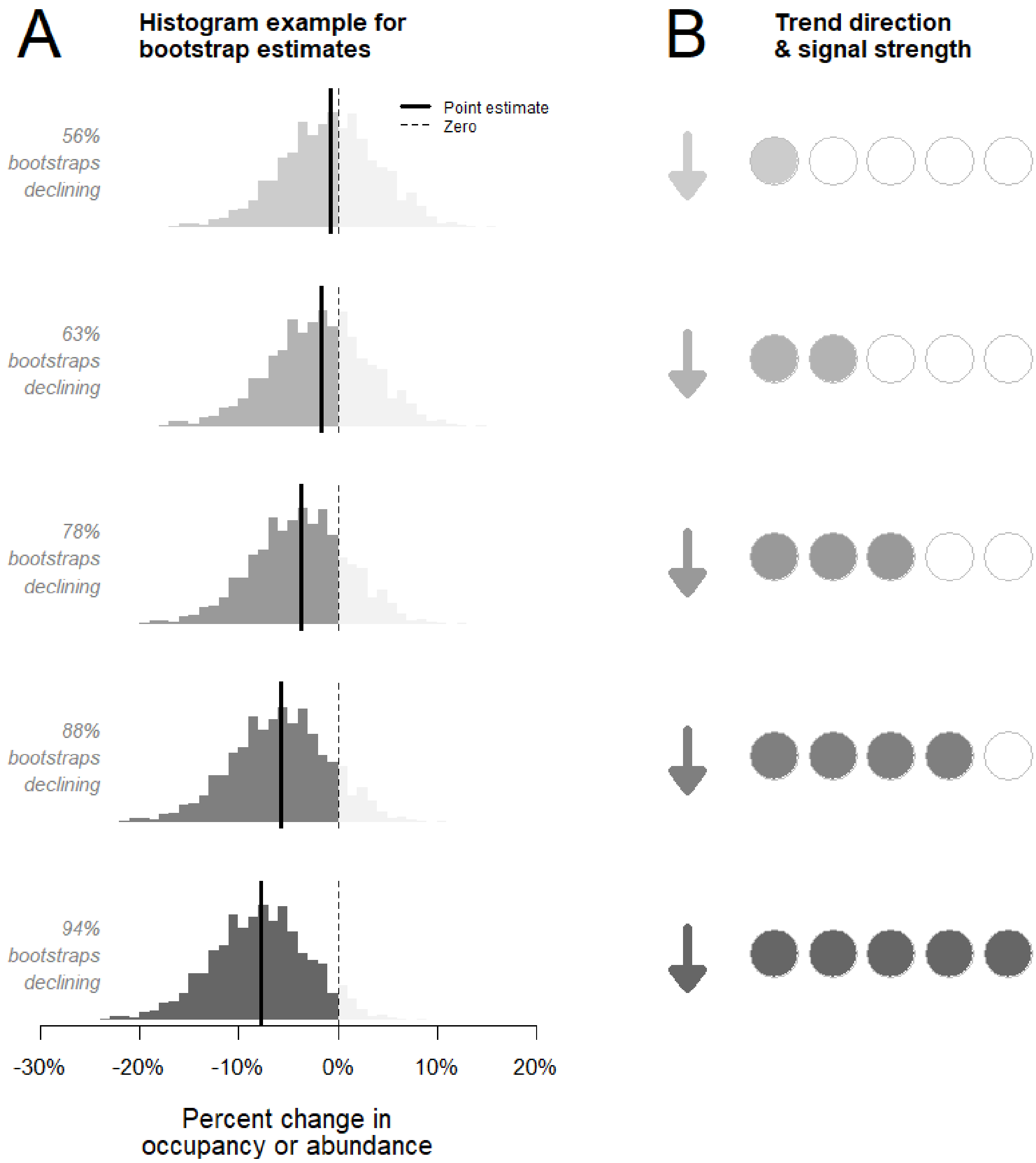

Figure 9. Trend direction and signal strength classification process for five hypothetical trends, where the derived point estimate determines the trend direction. (A) Histograms with solid lines – these examples are all declining; (B)The declines are depicted as downward-pointing arrows. The proportion 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), while five dark-shaded dots indicate a very strong signal (when at least 90% of bootstraps match). Arrows are shaded to match the signal strength. (The arrow direction would be reversed for increasing trends, and a double-headed horizontal arrow used when there are an equal number of declining and increasing bootstrap estimates.)

Classifying trend alert and signals

We used a standardised protocol (adapted from MacLeod et al. 2022) to help the user readily identify trends of interest or conservation concern. (It was also useful for informing the power analyses in Sections 5.2, 5.3 and 7.2 of this report.) This protocol classified the trend sizes (see example in Figure 8A) 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 blue to indigo), and little or no change (indicated by a pale blue shade) over 10 years (Figure 8B). The signal strength of each colour-coded alert was ranked from insufficient or very weak to very strong; these rankings were based on the distribution of the bootstrap estimates in relation to specified trend threshold criteria and/or whether they overlapped zero (Figure 8C). Species with smaller variance will have stronger signals. The resulting alert category classifications are shown in Figure 8D.

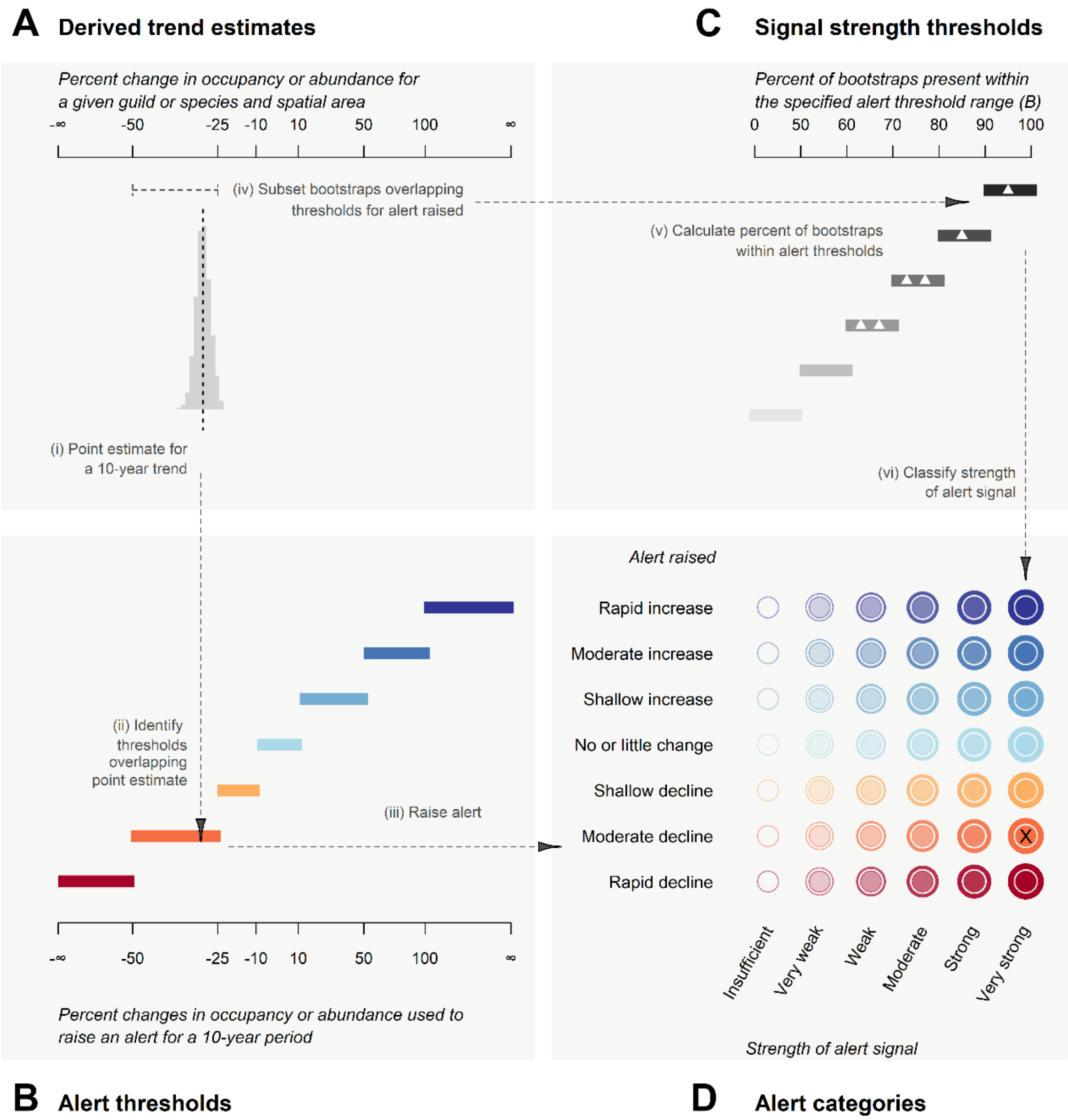

Figure 10. Alert classification process for 10-year trends (2013–2022). (A) Initial point and bootstrap estimates (black dotted line and grey histogram, respectively) are derived for each guild and location; (B and C) The estimates are independently overlaid on standardised alert (B) and signal strength (C) thresholds. (D) The overlays allow identification of their relevant alert category and colour code. 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 a single white triangle in C) and for moderate or weak classes to a very weak one (double white triangle in C). (Colour codes red, amber, light amber for rapid, moderate and shallow declines; pale blue for little to no change; light blue, medium blue and indigo for shallow, moderate and rapid increases. For exotic species, the colour coding is reversed [e.g. a red alert is raised when the taxon is increasing rapidly].)

(Source: Figure adapted from MacLeod et al. 2022.)

Power to detect simulated trends: current vs proposed 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 frequency affect our ability to detect trends? The analyses considered scenarios where the palatable and unpalatable sapling occupancy and abundance are monitored either under the current design (locations measured on a 5-year cycle, so 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. These analytical protocols are consistent with those previously applied to the DOC Tier 1 monitoring framework evaluation (MacLeod et al. 2024).

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), which facilitates simulation-based power analyses for complex sampling designs (e.g. those with repeated measures as used in this study). For each guild and metric, power analyses were implemented as described below.

- An 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 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, with the trend being adjusted as appropriate for the logit scale). 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 the power estimates.

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[4] Note that the random effects (1|Place) for the current design encompass both spatial and temporal repeat measures, but for the modified design encompass 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.

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 11), by:

- colour coding the power estimates (%) to reflect the simulated trend (using the same scheme as applied in Figure 10D), 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).

POWER TO DETECT SIMULATED TRENDS AFTER 10 YEARS

A

	RED ALERT *(Rapid deterioration)*						AMBER ALERT *(Moderate deterioration)*					
	CURRENT DESIGN			MODIFIED DESIGN			CURRENT DESIGN			MODIFIED DESIGN		
GUILD OR SPECIES	*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
NZ pigeon | Kererū	100	100	100	2	6	25	68	88	92	0	0	6

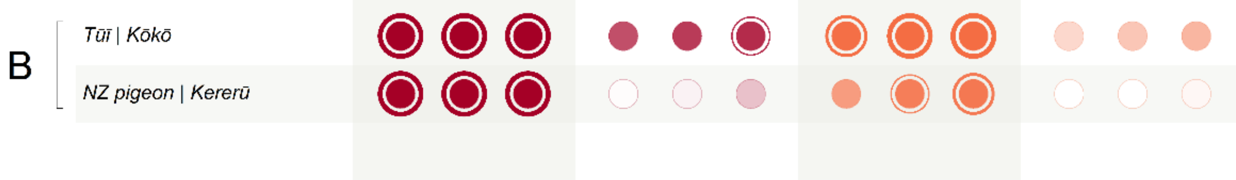

Figure 11. Power estimates after 10 years under the current and proposed modified designs for LUCAS and DOC's Tier 1 framework when red or amber alerts were simulated and the confidence level was specified as standard (95%), liberal (90%) or very liberal (80%) (MacLeod et al. 2024). (A) Numerical output for hypothetical scenarios for tūī and kererū (using artificially generated percentages); (B) Colour coded to highlight where there is sufficient power to detect rapid or moderate changes in occupancy or abundance. The shading of dots (in 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).

Time taken to detect trends for current vs modified designs

In this section we outline our analytical protocols for identifying the earliest point in time that an early warning could be flagged for simulated rapid to moderate trends. These analytical protocols are consistent with those previously applied to the DOC Tier One monitoring framework evaluation (MacLeod et al. 2024).

Calculating time taken to detect a trend

To calculate the time taken to detect a given trend alert, we carried out power analyses using the powerCurve function in the simr package in R (Green & MacLeod 2016). We implemented the following steps for each metric (occupancy and abundance of each palatability group).

1. The base model (~ Ys + (1|Place)) was fitted with the focal guild's occupancy or abundance as the response variable using the glmer function in the lme4 package in R.
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 rapid increase (115% over 10 years) was simulated. (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 a trend

We used dot plots to help the reader quickly identify the time taken to flag an early warning (i.e. when there was sufficient power to detect the simulated trends; Figure 10), by:

- colour coding the power estimates (%) for each year to reflect the simulated trend (using the same scheme as applied in Figure 8), 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).

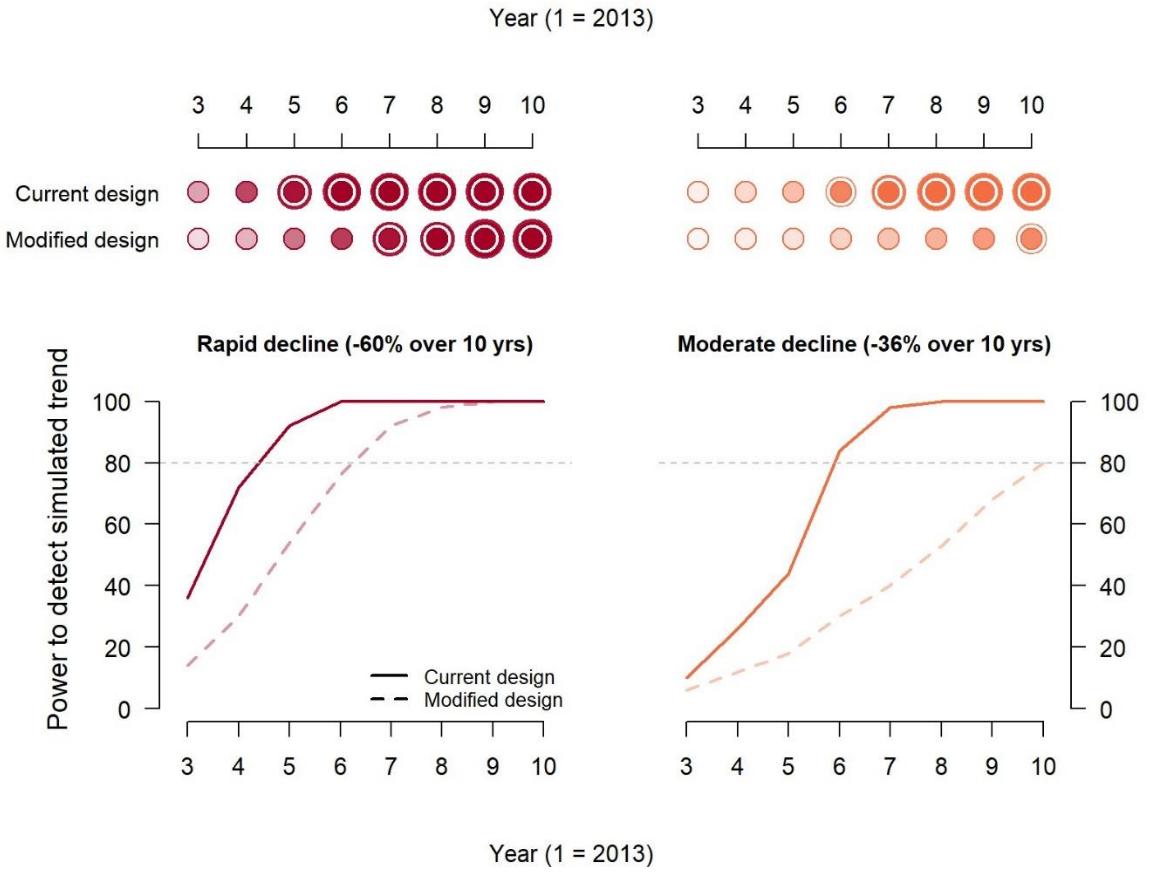

Figure 12. Conversion of power curves into summary dot plots (using the power curves for fantail occupancy in woody habitats on public conservation land as an example; MacLeod et al. 2024). The shading of dots is proportional to the power estimate (%), with the outer rings signalling when the power estimate is ≥80% (fine ring), ≥90% (intermediate ring) or 100% (thick ring). A red colour indicates red alert/rapid decline; amber colour indicates an amber alert/moderate decline.

4.2 Ungulate and palatable sapling relationships

Data on plant communities and ungulate population density are both collected within Tier 1 monitoring framework, but relationships between them are seldom analysed. We tested whether measures of ungulate abundance affect state and trend in plant communities. If so, this would provide evidence for ungulate impacts on plant communities.

Observed relationships

Two hypotheses were tested for the Bay of Plenty Region only.

1 The abundance (and occupancy) of palatable saplings will be lowest where the probability of ungulate occupancy is highest (i.e. high ungulate occupancy negatively affects the state of understorey plant communities).

2 Declines in palatable saplings will be most intense where ungulate occupancy is highest (i.e. higher ungulate occupancy negatively affects the trend in understorey plant communities).

To test these hypotheses, we fitted a series of linear mixed-effects models (using the glmer function in R package lme4; Bates et al. 2015) with either palatable species abundance or occupancy as the response variable and location as the random factor. For occupancy a binomial error distribution with logit link function was used. For abundance, a Poisson error distribution with log link function was used. Models were fitted with: (a) no fixed effects; (b) ungulate occupancy; (c) survey year; (d) survey year and ungulate occupancy; (e) survey year, ungulate occupancy, and their interaction. For these analyses, ungulate occupancy was calculated for each sampling location as the mean faecal pellet occupancy (proportion of subplots containing faecal pellets) across all surveys.

Model goodness of fit was compared using the Akaike Information Criterion (AIC) and log likelihood using the aictab function of the AICcmodavg package in R (R Core Team 2023). We also report coefficient values for the full models (ungulate occupancy, survey year, and their interaction).

Evidence for ungulate density impacts on the state of plant communities would be provided if the model containing faecal pellet occupancy receives stronger AIC support than the model with no fixed effects, and the coefficient for the main effect of faecal pellet occupancy is significantly less than zero. Evidence for ungulate density impacts on the trend of plant communities would be provided if the full model receives stronger AIC support than the model containing faecal pellet occupancy and survey year, but not their interaction, and the coefficient for the faecal pellet occupancy survey year interaction is significantly less than zero.

4.3 Differences in sapling trend trajectories

Past authors have suggested that extraneous factors such as canopy disturbance and competitive thinning may affect the abundance of palatable plant species in forest understories (Mason et al. 2010). One way to control for this is to compare differential trends between palatable and unpalatable species within locations. We took this approach, which is possible using appropriately defined linear mixed effects modelling.

Observed differences

Linear mixed-effects models (~ Ys *PalGroup+ (1|Place)) were fitted (using the glmer function in R package lme4; Bates et al. 2015) with either sapling abundance or occupancy as the response variable and location as the random factor. For occupancy a binomial error distribution with logit link function was used. For abundance, a Poisson error distribution with log link function was used.

Year was standardised (Ys) for the 10-year period (on a scale of 0–9) to help model fitting. PalGroup (a two-level factorial variable) specified whether the saplings were classified as palatable or unpalatable to ungulates. The drop1 function (and its corresponding likelihood ratio test) in R was used to assess whether the interaction term was a significant predictor or not. We also report coefficient values for the full models (sapling group, survey year, and their interaction).

Power to detect simulated differences in trajectory

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 metric, power analyses were implemented as follows.

1 An appropriate base model (~ Ys*PalGroup + (1|Place)) was fitted using the glmer function in the lme4 package in R, then specifying (using 'fixef' function in simr; Green & MacLeod 2016).

   a For the occupancy models, intercept values equal to 0.5 for unpalatable and palatable saplings, and the 10-year trend to equal zero for unpalatable saplings (Figure 13). The 10-year trend for palatable saplings was specified as equivalent to either:

      i a rapid decline (74% for the Region; 76% for the Project Area),

      ii a moderate decline (42% for the Region; 46% for the Project Area)

      iii a shallow decline (24% for the Region; 24% for the Project Area)

      iv a shallow increase (24% for the Region; 24% and 46% for the Project Area)

      v a moderate increase (50% and 98% for the Region; 100% for the Project Area).

   b For the abundance models, intercept values equal to 5 for unpalatable and palatable saplings, and the 10-year trend to equal zero for unpalatable saplings. The 10-year trend for palatable saplings was then specified as equivalent to either a rapid decline (60%), moderate decline (36%), shallow decline (20%), shallow increase (25%), moderate increase (64%) or rapid increase (115%).

2 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 the power estimates. The results were visualised using the protocol described in Figure 11.

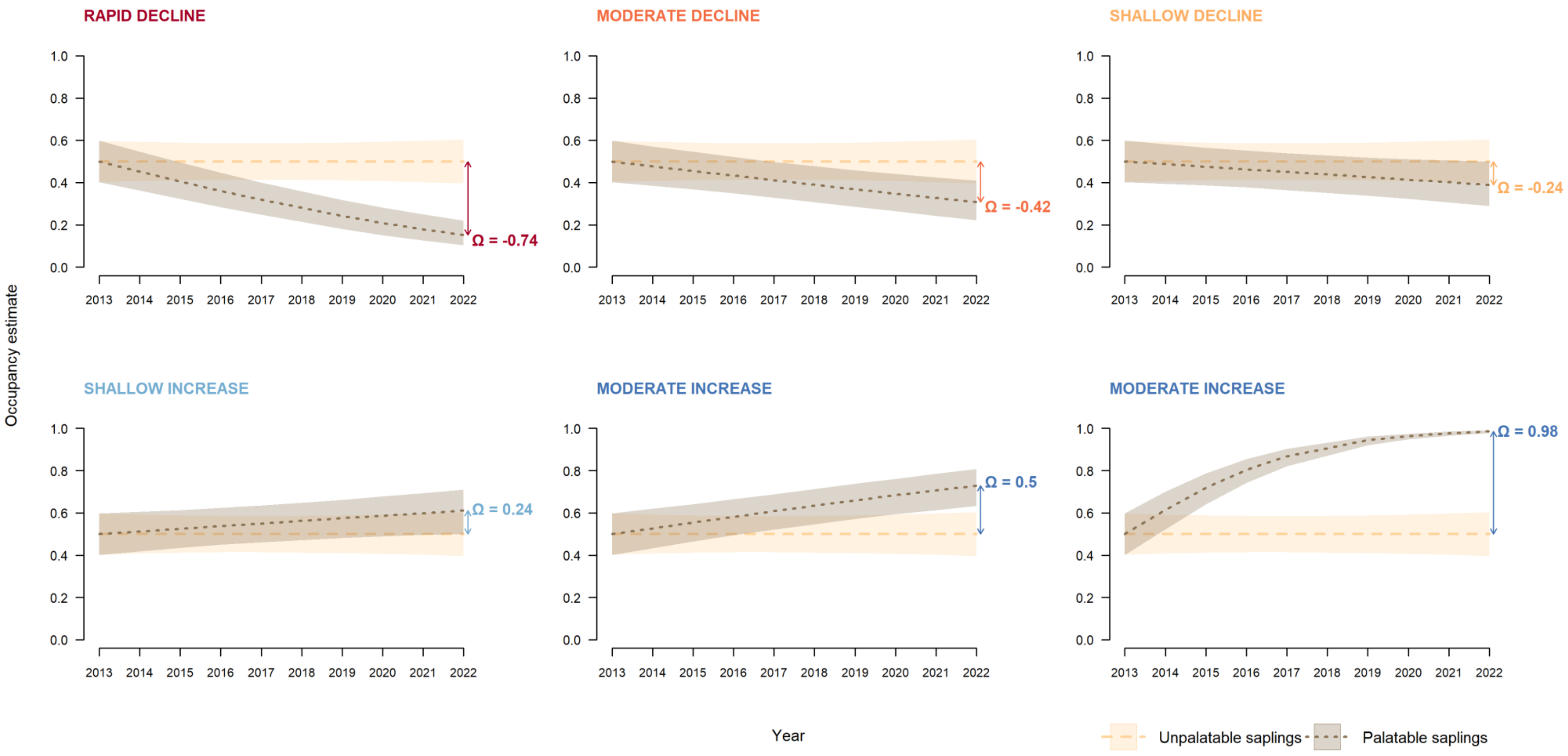

Figure 13. Examples of the different trend trajectories simulated for occupancy of unpalatable and palatable saplings (dashed and dotted lines, respectively, with shading indicating the 95% confidence interval for the trend), which provided the basis for the power analyses. Total changes in occupancy simulated over 10 years (Ω) were calculated for palatable saplings (relative to unpalatable saplings)

5 Ten-year trends for saplings and ungulates

5.1 Observed trends

This section reports 10-year trends (from 2013 to 2022) in sapling occupancy and abundance in the Bay of Plenty Region and the Project Area. It also quantifies the 10-year trend for ungulate occupancy (based on faecal pellet counts) in the Bay of Plenty Region.

Bay of Plenty Region

From 2013 to 2022, ungulate occupancy increased shallowly across the Region (Figure 12), while palatable sapling occupancy and abundance declined moderately (thus flagging an amber alert). During this period there was little change in the occupancy of unpalatable saplings in the Region, but this group's abundance showed a 'shallow deterioration' (i.e. modest reduction; see Figure 12).

These regional trend alerts were only supported by very weak to moderate signals (i.e. low-to-moderate precision in trend estimates), except for unpalatable sapling occupancy, for which a very strong signal (i.e. high level of precision in trend estimate) of no change was detected.

Kaimai Mamaku Restoration Project Area

Palatable sapling occupancy and abundance declined in the Project Area from 2013 to 2022. A red alert (supported by a strong signal) was flagged for their *occupancy*, which declined rapidly over the 10-year period (Figure 13), while an amber alert was raised for their *abundance*, with an early warning for a potential emerging red alert (as the alert signal straddles both amber and red alerts; Figure 13).

During the same period, there was little change in the occupancy and abundance of unpalatable saplings.

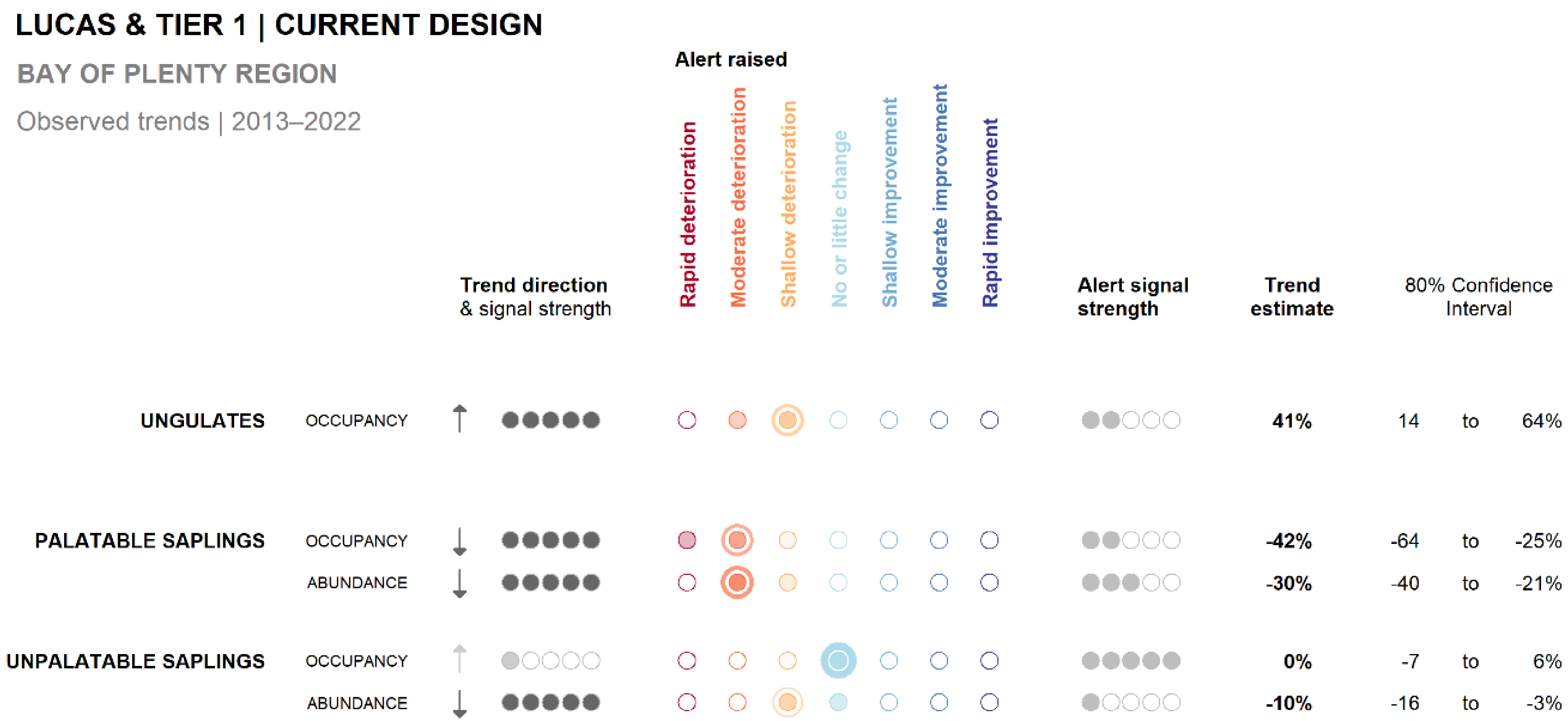

Figure 14. Trend summary (2013–2022) for ungulates and palatable and unpalatable saplings within the Bay of Plenty Region. Trend estimates for occupancy were derived from the respective model for the guild (~ Ys + (1|Place)). These estimates were based on field data gathered on the LUCAS and DOC Tier 1 framework using the current design (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system, see Figure 10, and for information on sampling sizes, see Figure 4 and 6.)

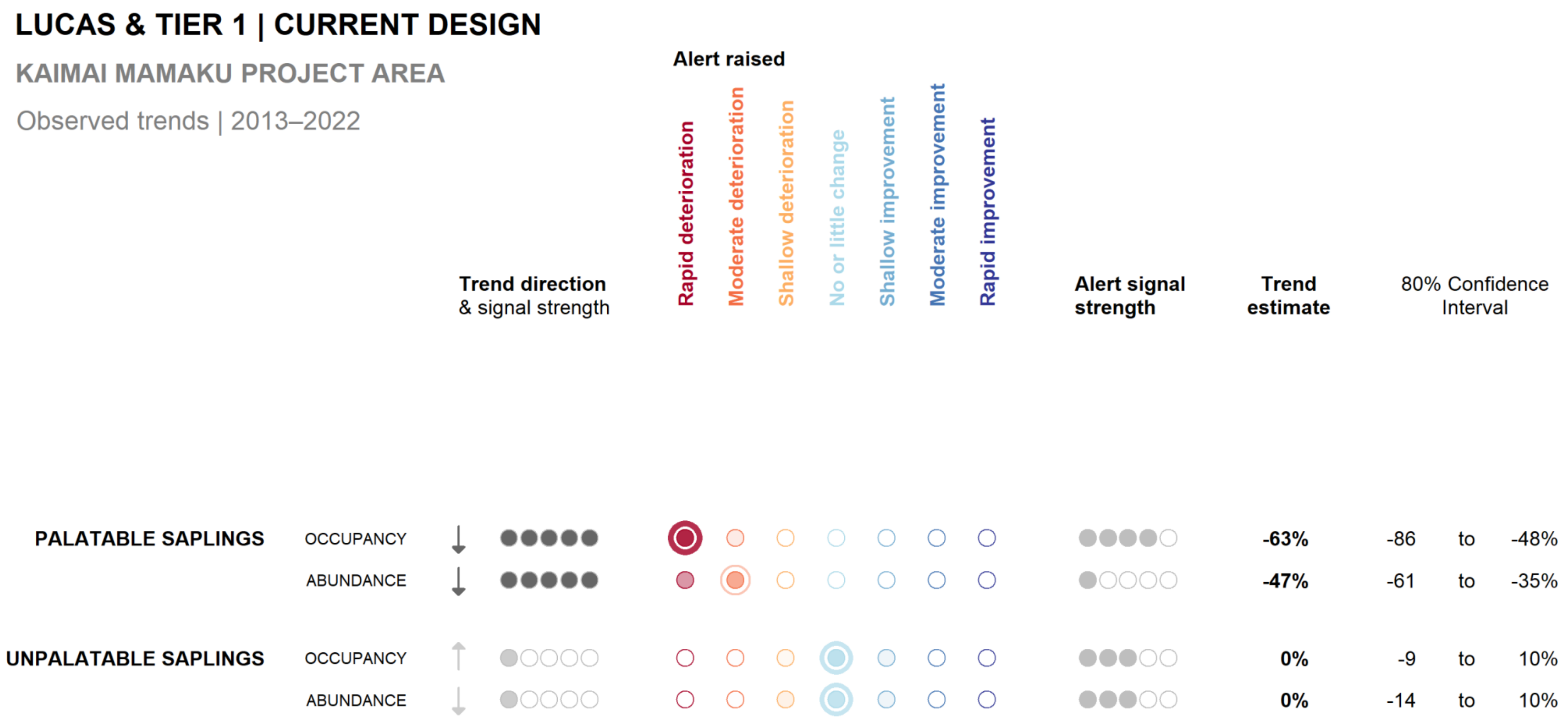

Figure 15. Trend summary (2013–2022) for palatable and unpalatable saplings within the Kaimai Mamaku Project Area. Trend estimates for occupancy were derived from the respective model for the guild (~ Ys + (1|Place)). These estimates were based on field data gathered on the LUCAS and DOC Tier 1 framework using the current design (i.e. two full 5-year measurement cycles). (For information on the alert and signal classification system, see Figure 10, and for sampling sizes, see Figure 7.)

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

In this section we investigate the effect of shifting from the current monitoring design (i.e. a 5-year cycle) to proposed modified design (i.e. a 10-year cycle) on detecting moderate to rapid changes in sapling occupancy and abundance after 10 years. Results are presented for the Bay of Plenty Region and the Project Area.

Bay of Plenty Region

After 10 years of monitoring, the current design will generally have very high power to detect rapid changes in the occupancy and abundance of palatable and unpalatable saplings in the Bay of Plenty Region (Figure 16).

The current design will also have high power to detect moderate changes in the abundance of palatable and unpalatable saplings, as well as moderate declines in the occupancy of unpalatable saplings. However, it will have insufficient power to detect moderate changes in the occupancy of palatable saplings unless the confidence level is relaxed.

The modified design will have sufficient power to detect rapid declines in the occupancy and abundance of unpalatable saplings, but not palatable saplings (Figure 16). It will also have little to no power to detect moderate changes for both sapling groups.

Kaimai Mamaku Restoration Project Area

After 10 years of monitoring, the current design will generally have very high power to detect rapid changes in the occupancy and abundance of palatable and unpalatable saplings in the Project Area (Figure 17).

The current design will also have high power to detect moderate changes in the abundance of palatable and unpalatable saplings, as well as moderate declines in the occupancy of unpalatable saplings. However, it will have insufficient power to detect moderate changes in the occupancy of palatable saplings unless the confidence level is relaxed.

The modified design will have little to no power to detect any alert level for any of the sapling metrics examined (Figure 17).

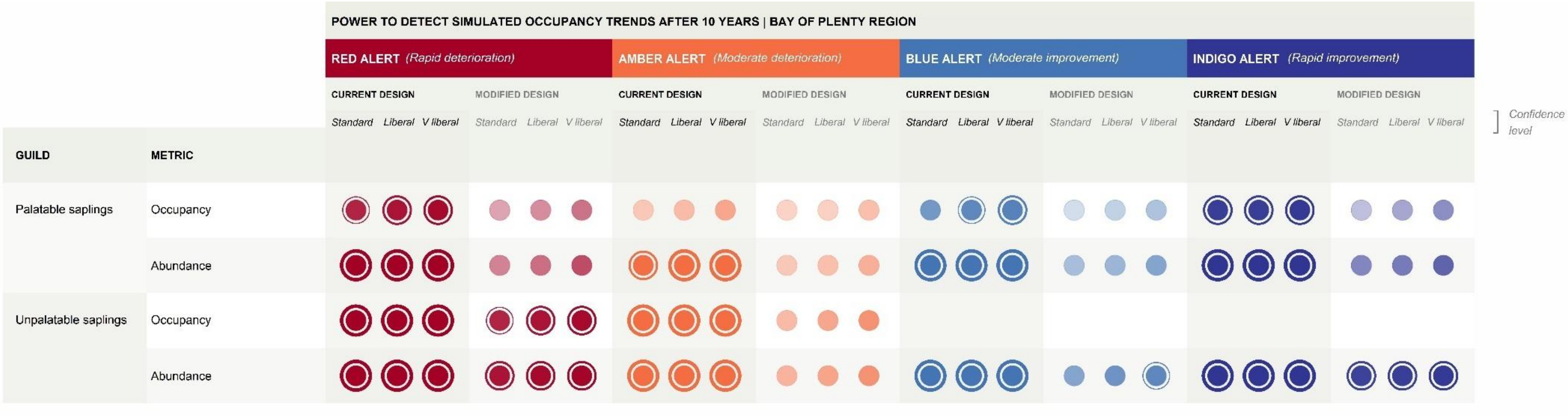

Figure 16. Power (%) to detect rapid or moderate changes in the occupancy and abundance of palatable and unpalatable saplings after 10 years within the Bay of Plenty Region. Power (%) estimates for the current design of LUCAS and DOC's Tier 1 framework versus the proposed modified design when the confidence level is specified as standard (95%), liberal (90%) or very liberal (80%). The 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). (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 – random allocations of locations to survey years.) Note that power analyses were not run for increases when occupancy estimates were high at the outset.

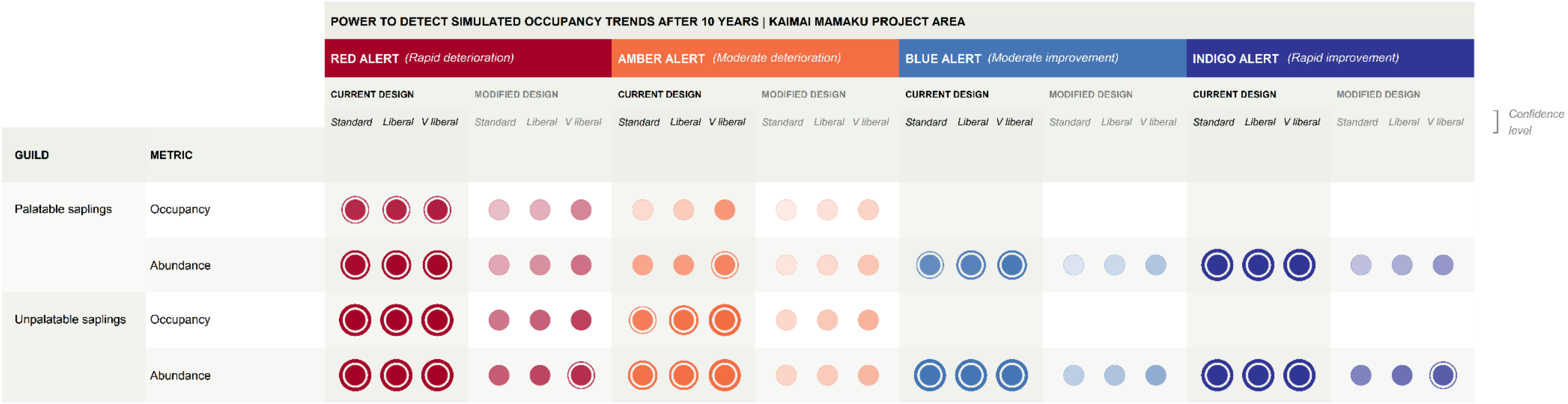

Figure 17. Power (%) to detect rapid or moderate changes in the occupancy and abundance of palatable and unpalatable saplings after 10 years within the Kaimai Mamaku Project Area. Power (%) estimates for the current design of LUCAS and DOC's Tier 1 framework versus the proposed modified design when the confidence level is specified as standard (95%), liberal (90%) or very liberal (80%). The 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). (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 – random allocations of locations to survey years.) Note that power analyses were not run for increases when occupancy estimates were high at the outset.

5.3 Time taken to detect simulated trends: current vs modified designs

This section explores the effect of shifting from the current monitoring design (i.e. a 5-year cycle) to the proposed modified design (i.e. a 10-year cycle) on the time taken to detect an 'early warning of changes' in palatable or unpalatable saplings. Our results are presented for the Bay of Plenty Region and the Project Area.

Bay of Plenty Region

Under the current design, early warnings will be flagged (i.e. power is 90% or greater using standard 95% confidence levels) after 5 to 7 years for unpalatable saplings when their occupancy or abundance is changing rapidly or moderately over 10 years (Figure 18). (Note that power analyses were not run for increases for unpalatable saplings as these occupancy estimates were high at the outset.)

Under the current design, rapid changes and moderate increases in palatable abundance will be detected after 7 years, while moderate declines in palatable abundance will be detected after 8 years. Rapid changes in palatable occupancy will be detected after 10 years, but the current design does not provide power to detect moderate changes in occupancy within 10 years.

Under the modified design, early warnings will only be detectable for rapid changes in the abundance of unpalatable saplings after 5 years (Figure 18).

Kaimai Mamaku Restoration Project Area

Under the current design, trends will be detected (i.e. power is 90% or greater using standard 95% confidence levels) after 6 to 8 years for unpalatable saplings when their abundance is changing rapidly or moderately over 10 years (Figure 19).

Rapid changes in abundance of palatable saplings will be detected after 8 years, but no trend will be detected within 10 years for moderate changes in palatable abundance, or for any alert level for palatable occupancy (Figure 19).

Under the modified design, no trends will be detected for either abundance or occupancy for either palatability group (Figure 19).

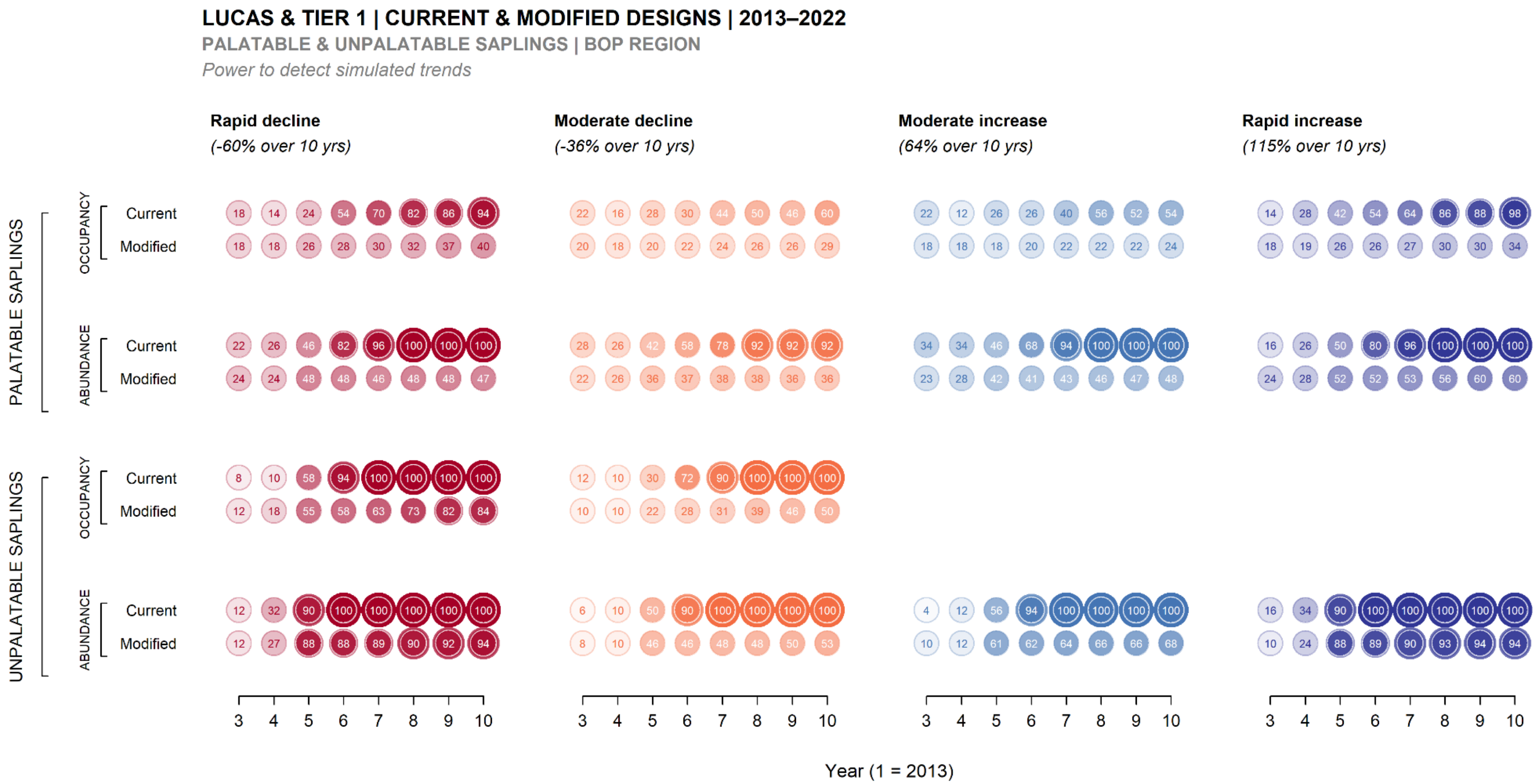

Figure 18. Time taken to detect an early warning for a simulated rapid or moderate change in occupancy and abundance of palatable and unpalatable saplings within the Bay of Plenty Region. Power (%) estimates are presented for different sampling periods (3–10 years, with one-year increments) under the current design of LUCAS and DOC's Tier 1 framework versus the proposed modified design when a standard confidence level was specified (95%). 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). (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 – random allocations of locations to survey years.)

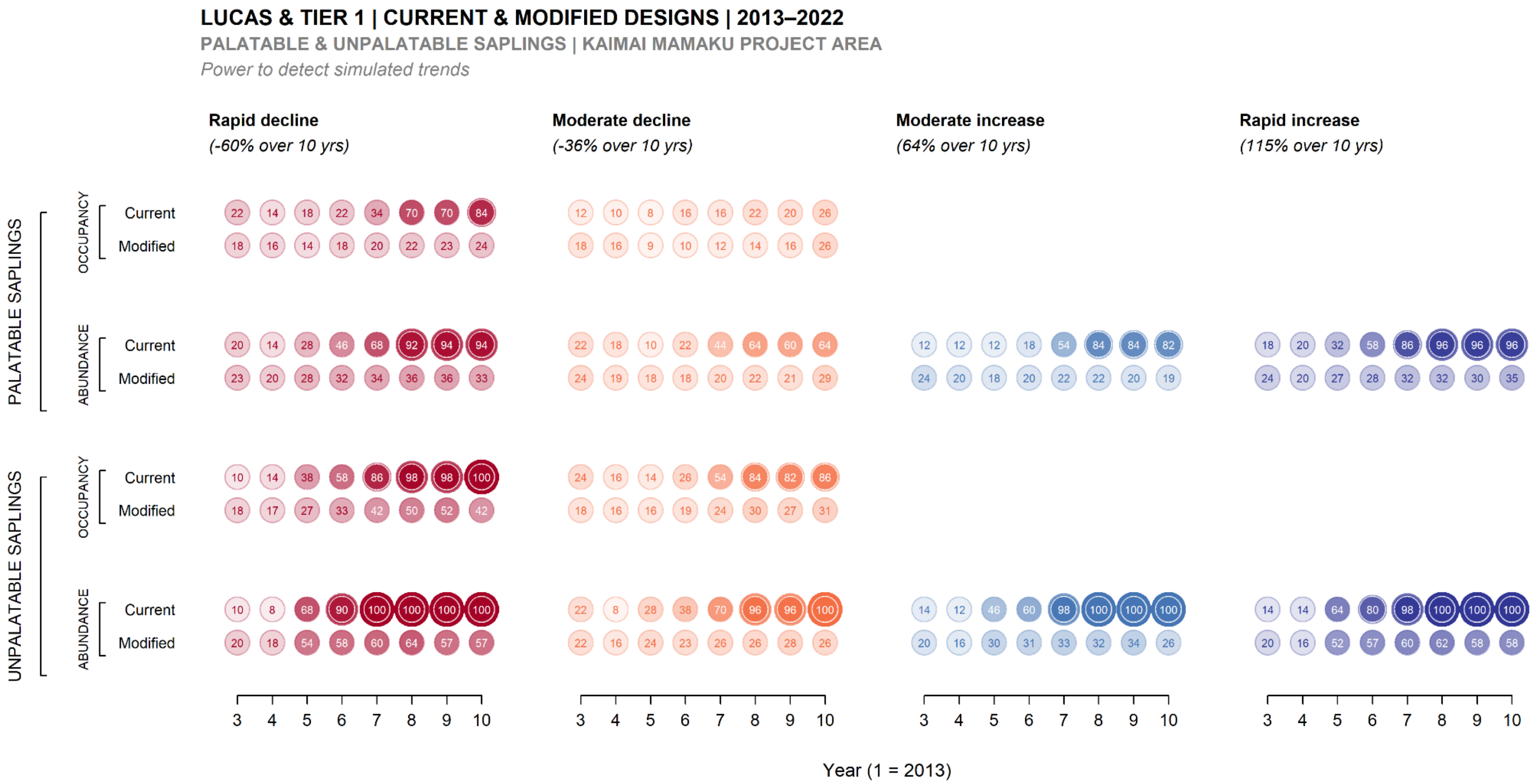

Figure 19. Time taken to detect an early warning for a simulated rapid or moderate change in occupancy and abundance of palatable and unpalatable saplings within the Kaimai Mamaku Restoration Project Area. Power (%) estimates are presented for different sampling periods (3–10 years, with 1-year increments) under the current design of LUCAS and DOC's Tier 1 framework versus the proposed modified design when a standard confidence level was specified (95%). 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). (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 – random allocations of locations to survey years.)

6 Ungulate and palatable sapling relationships

6.1 Observed relationships

This section explores the observed relationship between direct indicators of ungulate abundance and shifts in palatable saplings in the Bay of Plenty Region.

Bay of Plenty Region

Overall, palatable sapling occupancy and abundance increased over time at locations with low ungulate occupancy (Figure 20), and declined at locations with moderate to high levels of ungulate occupancy (Figure 21).

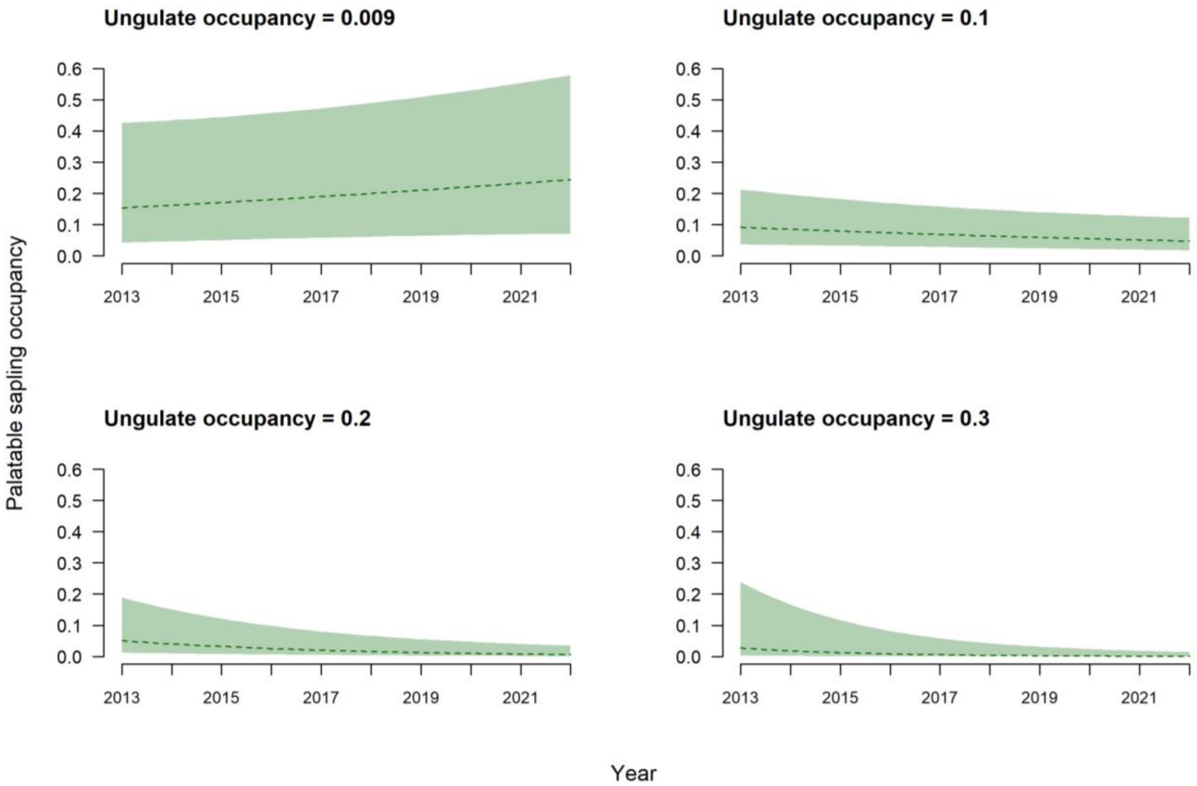

Figure 20. Effect of ungulate occupancy on trends in palatable sapling *occupancy* in the Bay of Plenty Region. Palatable sapling occupancy increases with time at low ungulate occupancy (0.009) (top left panel), but decreases at moderate to high ungulate occupancy (other three panels, with occupancy values increasing from 0.1 to 0.2 to 0.3). Trends (dashed lines) and 95% confidence intervals (shaded areas) were estimated using the predictorEffect() function of the effects R package (Fox & Weisberg 2018). Occupancy is the probability that a subplot is occupied; abundance is the sapling count per subplot.

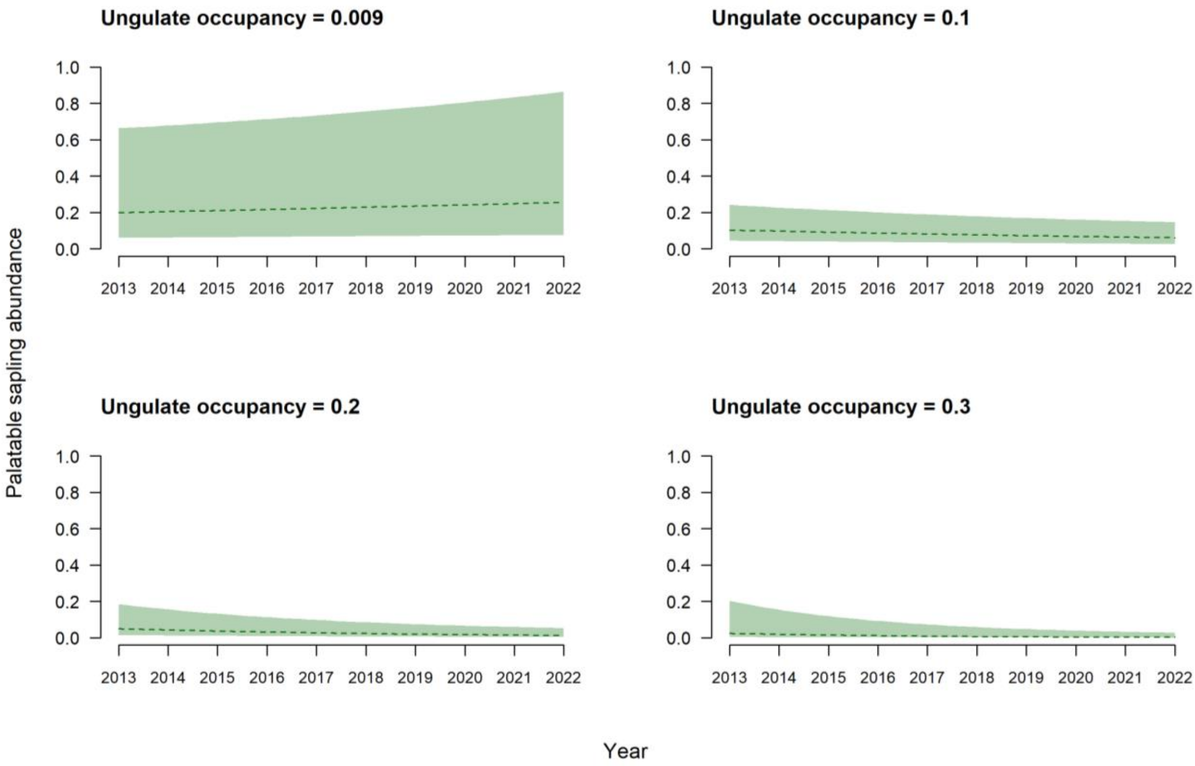

Figure 21. Effect of ungulate occupancy on trends in palatable sapling *abundance* in the Bay of Plenty Region. Palatable sapling occupancy increases with time at low ungulate occupancy (0.009) (top left panel), but decreases at moderate to high ungulate occupancy (other three panels, with occupancy values increasing from 0.1, to 0.2 to 0.3). Trends (dashed lines) and 95% confidence intervals (shaded areas) were estimated using the predictorEffect() function of the effects R package (Fox & Weisberg 2018). Occupancy is the probability that a subplot is occupied; abundance is the sapling count per subplot.

For both the occupancy and abundance of palatable saplings, the model including faecal pellet occupancy, survey year, and the interaction between them received the strongest AICc support (

Table 1). This indicates that the trend of palatable sapling occupancy and abundance varied across LUCAS/Tier 1 locations with mean ungulate occupancy.

Table 1. Multi-model comparison output from the aictab() function of the AICcmodavg package in R for linear mixed-effects models, with the occupancy and abundance of palatable saplings in 5 m × 5 m subplots for the Bay of Plenty Region

Model	K	AICc	Delta_AICc	ModelLik	AICcWt	LL	Cum.Wt
Occupancy							
Year:Ung	5	669.87	0	1	0.93	-329.90	0.93
Ung	3	676.94	7.07	0.03	0.03	-335.46	0.95
Year+Ung	4	677.37	7.51	0.02	0.02	-334.67	0.98
Null	2	678.30	8.43	0.01	0.01	-337.14	0.99
Year	3	678.88	9.01	0.01	0.01	-336.43	1.00
Abundance							
Year:Ung	5	1400.75	0	1	0.92	-695.35	0.92
Ung	3	1407.50	6.75	0.03	0.03	-700.74	0.95
Year+Ung	4	1408.27	7.52	0.02	0.02	-700.12	0.97
Null	2	1408.90	8.15	0.02	0.02	-702.44	0.99
Year	3	1409.75	9.00	0.01	0.01	-701.87	1.00

Notes: K is the number of fitted parameters; AICc is the Akaike Information Criterion; Delta_AICc is the difference between the AICc value of the model in question and the model with the lowest AICc value; ModelLik is the model likelihood relative to other candidate models assessed; AICcWt is the probability that the model provides the most parsimonious fit to the data among the candidate models assessed; LL is log-likelihood and Cum.Wt is the cumulative AICc weight. Fixed effects included in each model are as follows: Null = no fixed effects; Ung = ungulate occupancy; Year = survey year; Year+Ung = survey year and ungulate occupancy; and Year:Ung = survey year, ungulate occupancy, and their interaction. Ungulate occupancy per sampling location was calculated as the mean faecal pellet occupancy (proportion of subplots containing faecal pellets) across all surveys.

In the full models (those including both main effects and the two-way interaction between them) for palatable sapling occupancy and abundance there was a significant negative interaction between mean location (across observation years), ungulate occupancy, and year on palatable sapling occupancy and abundance (Table 2). This provides further evidence that the direction and magnitude of temporal change in palatable sapling occupancy and abundance varied across locations with ungulate occupancy.

Table 2. Coefficients for intercept, main effects, and their interaction in linear mixed-effects models with either palatable sapling occupancy or abundance in 5 m × 5 m subplots as the response variable for the Bay of Plenty Region

	Estimate	Std. error	z value	Pr(>|z|)
Occupancy				
(Intercept)	-1.893	0.677	-2.796	0.005
Ung	-3.198	3.310	-0.966	0.334
Year	0.054	0.052	1.040	0.298
Year:Ung	-0.974	0.345	-2.825	0.005
Abundance				
(Intercept)	-1.901	0.001	-2004	<0.001
Ung	-2.903	0.001	-3161	<0.001
Year	0.023	0.001	25	<0.001
Year:Ung	-0.611	0.001	-644	<0.001

Notes: Estimate is the linear co-efficient estimate; Std.error is the standard error of the linear co-efficient estimate; z value is the z value for the linear co-efficient; Pr(>|z|) is the probability that the co-efficient estimate is equal to zero. Ung = faecal pellet occupancy; Year = survey year; and Year:Ung = the interaction between them.

7 Differences in sapling trend trajectories

7.1 Observed differences

This section explores the observed differences in trend trajectories in the occupancy and abundance of saplings that are palatable and unpalatable to ungulates in the Bay of Plenty Region and the Project Area. The analyses focus on a 10-year period (2013–2022).

Bay of Plenty Region

In 2013, relative to palatable saplings, unpalatable saplings were twice as likely to occupy a sampling location in the Bay of Plenty Region (Figure 22); and they were also twice as abundant. Over the subsequent 10-year period, the trend trajectories of palatable and unpalatable saplings differed significantly for both occupancy (likelihood ratio test [LRT] = 26.576, P <0.001) and abundance (LRT = 100.83, P <0.001): palatable sapling occupancy and abundance decreased, while unpalatable sapling occupancy increased, but their abundance showed little change (Figure 22; Table 3). Hence, by 2022, the gap between the sapling groups' occupancy and abundance estimates had widened, with unpalatable saplings becoming seven times more likely to occupy a sampling location and also being seven times more abundant than palatable saplings.

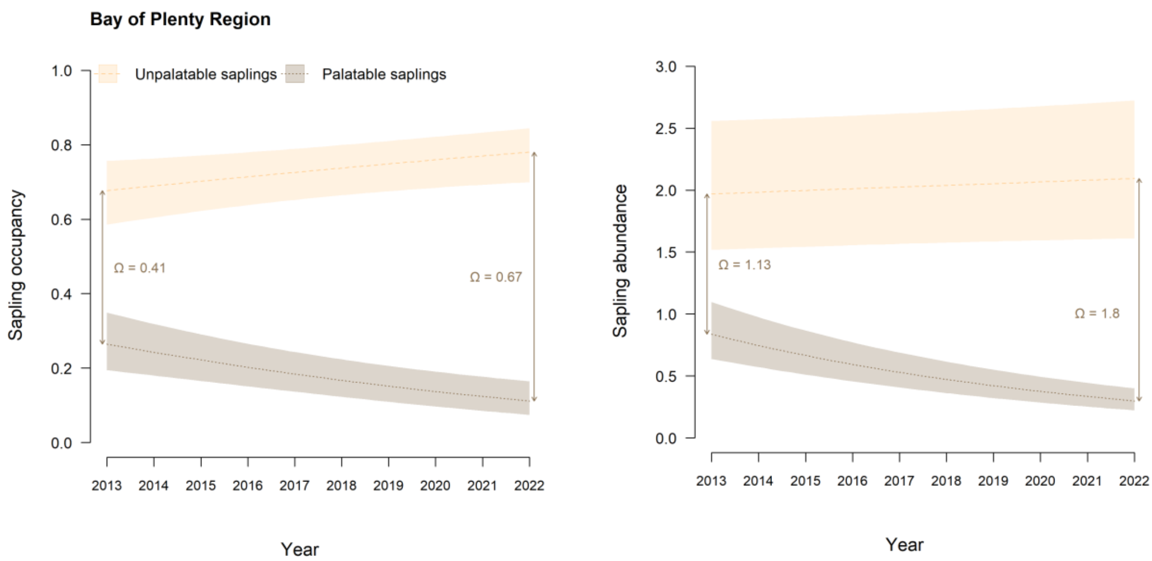

Figure 22. Differences in trend trajectories for palatable and unpalatable saplings in the Bay of Plenty Region for the period 2013 to 2022. (Left) Occupancy; (Right) Abundance. Trends (dashed lines) and 95% confidence intervals (shaded areas) were estimated using the predictorEffect() function of the effects R package (Fox & Weisberg 2018). Ω = the difference in occupancy or abundance estimates for unpalatable versus palatable saplings (see arrows, presented only for 2013 and 2022). Occupancy is the probability that a subplot is occupied; abundance is the sapling count per subplot.

Table 3. Coefficients for intercept, main effects, and their interaction in linear mixed-effects models with sapling occupancy or abundance in 5 m × 5 m subplots as the response variable for the Bay of Plenty Region (where PalGroupPreferred = palatable saplings)

	Estimate	Std. error	z value	Pr(>|z|)
Occupancy				
(Intercept)	0.739	0.200	3.687	<0.001
PalGroupPreferred	-1.760	0.165	-10.680	<0.001
Year	0.059	0.024	2.422	0.015
PalGroupPreferred:Year	-0.175	0.034	-5.114	<0.001
Abundance				
(Intercept)	0.678	0.133	5.094	<0.001
PalGroupPreferred	-0.857	0.054	-15.819	<0.001
Year	0.007	0.006	1.165	0.244
PalGroupPreferred:Year	-0.121	0.012	-9.897	<0.001

Notes: Estimate is the linear co-efficient estimate; Std.error is the standard error of the linear co-efficient estimate; z value is the z value for the linear co-efficient; Pr(>|z|) is the probability that the co-efficient estimate is equal to zero. PalGroupPreferred = palatability group identity; Year = survey year; and PalGroupPreferred:Year = the interaction between them.

Kaimai Mamaku Restoration Project Area

In 2013, unpalatable saplings were about three-quarters more likely to occupy a sampling location and were twice as abundant as palatable saplings in the Kaimai Mamaku Restoration Project Area (Figure 23). Over the subsequent 10-year period, the trend trajectories of palatable and unpalatable saplings differed significantly for both occupancy (LRT = 9.82, P = 0.002) and abundance (LRT = 25.46, P <0.001): palatable sapling occupancy and abundance decreased, while unpalatable sapling occupancy and abundance showed little change (Figure 23; Table 4). Hence, the gap in their respective occupancy and abundance estimates widened, with unpalatable saplings becoming five times more likely to occupy a sampling location and being four times more abundant than palatable saplings by 2022.

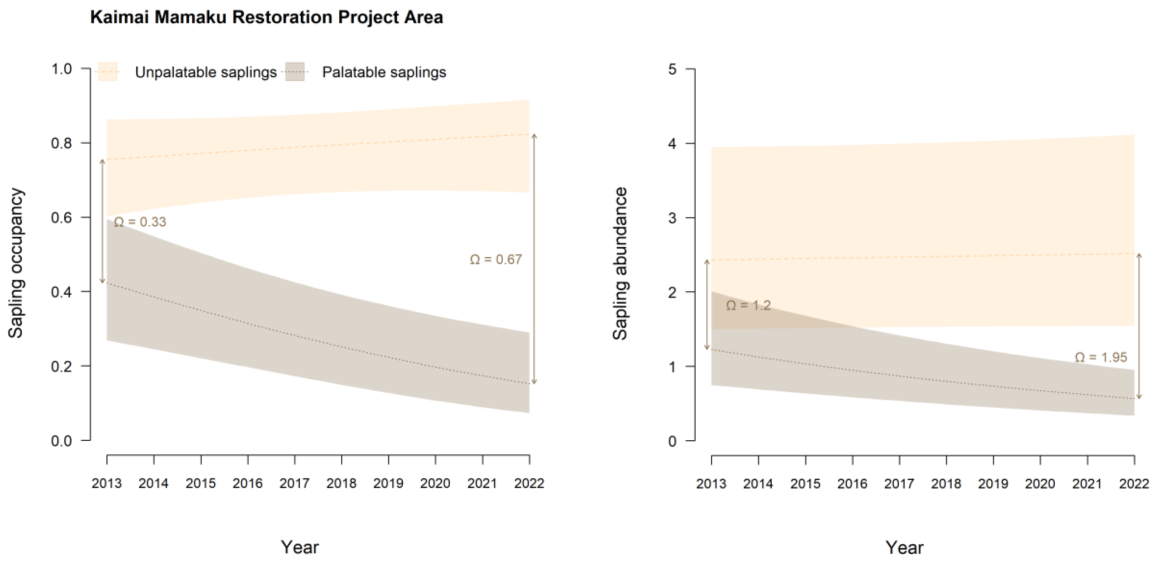

Figure 23. Differences in trend trajectories for palatable and unpalatable saplings in the Kaimai Mamaku Restoration Project Area for the period 2013 to 2022. (Left) Occupancy; (Right) Abundance. Trends (dashed lines) and 95% confidence intervals (shaded areas) were estimated using the predictorEffect() function of the effects R package (Fox & Weisberg 2018). Ω = the difference in occupancy or abundance estimates for unpalatable versus palatable saplings (see arrows, presented only for 2013 and 2022). Occupancy is the probability that a subplot is occupied; abundance is the sapling count per subplot.

Table 4. Coefficients for intercept, main effects, and their interaction in linear mixed-effects models with sapling occupancy or abundance in 5 m × 5 m subplots as the response variable for the Kaimai Mamaku Restoration Project Area (where PalGroupPreferred = palatable saplings).

	Estimate	Std. error	z value	Pr(>|z|)
Occupancy				
(Intercept)	1.125	0.363	3.098	0.002
PalGroupPreferred	-1.435	0.283	-5.074	<0.001
Year	0.046	0.050	0.919	0.358
PalGroupPreferred:Year	-0.202	0.065	-3.098	0.002
Abundance				
(Intercept)	0.889	0.247	3.596	<0.001
PalGroupPreferred	-0.684	0.075	-9.126	<0.001
Year	0.004	0.009	0.415	0.678
PalGroupPreferred:Year	-0.090	0.018	-4.998	<0.001

Notes: Estimate is the linear co-efficient estimate; Std.error is the standard error of the linear co-efficient estimate; z value is the z value for the linear co-efficient; Pr(>|z|) is the probability that the co-efficient estimate is equal to zero. PalGroupPreferred = palatability group identity; Year = survey year; and PalGroupPreferred:Year = the interaction between them.

7.2 Power to detect simulated differences in trajectory

This section explores the power of the current and proposed modified designs to detect a difference in trend trajectory between the palatable and unpalatable saplings equivalent to either a rapid, moderate or shallow change over 10 years. We present results for the Bay of Plenty Region and the Project Area.

Bay of Plenty Region

At the regional scale, the current design will have high power to detect a difference in the occupancy trend trajectory between palatable and unpalatable saplings equivalent to a rapid or moderate change over 10 years (assuming either a standard 95% or liberal [90%] confidence level is required; Figure 24). It will also be able to detect differences in abundance trend trajectories equivalent to either a rapid, moderate or shallow change over the same period.

The modified design will only have sufficient power to detect a difference in the occupancy trend trajectory between palatable and unpalatable saplings equivalent to a rapid decline over 10 years across the Region (Figure 24); it will also have sufficient power to detect differences in abundance trend trajectories equivalent to a rapid, moderate or shallow change over the same period.

Kaimai Mamaku Restoration Project Area

In the Project Area, the current design will have high power to detect a difference in the occupancy trend trajectory between palatable and unpalatable saplings that is equivalent to a rapid decline or moderate increase over 10 years (Figure 25). It will also have power to detect differences in abundance trend trajectories equivalent to a rapid or moderate change over the same period, but shallow changes will only be detectable if the confidence level is relaxed (i.e. a higher chance of false positives).

The modified design will have sufficient power to detect a difference in the occupancy trend trajectory between palatable and unpalatable saplings that is equivalent to a rapid decline (but only if the confidence level is relaxed to 80%) or a moderate increase over 10 years across the Project Area (Figure 25); it will also have sufficient power to detect differences in abundance trend trajectories equivalent to a rapid or moderate change over the same period, but not shallow changes.

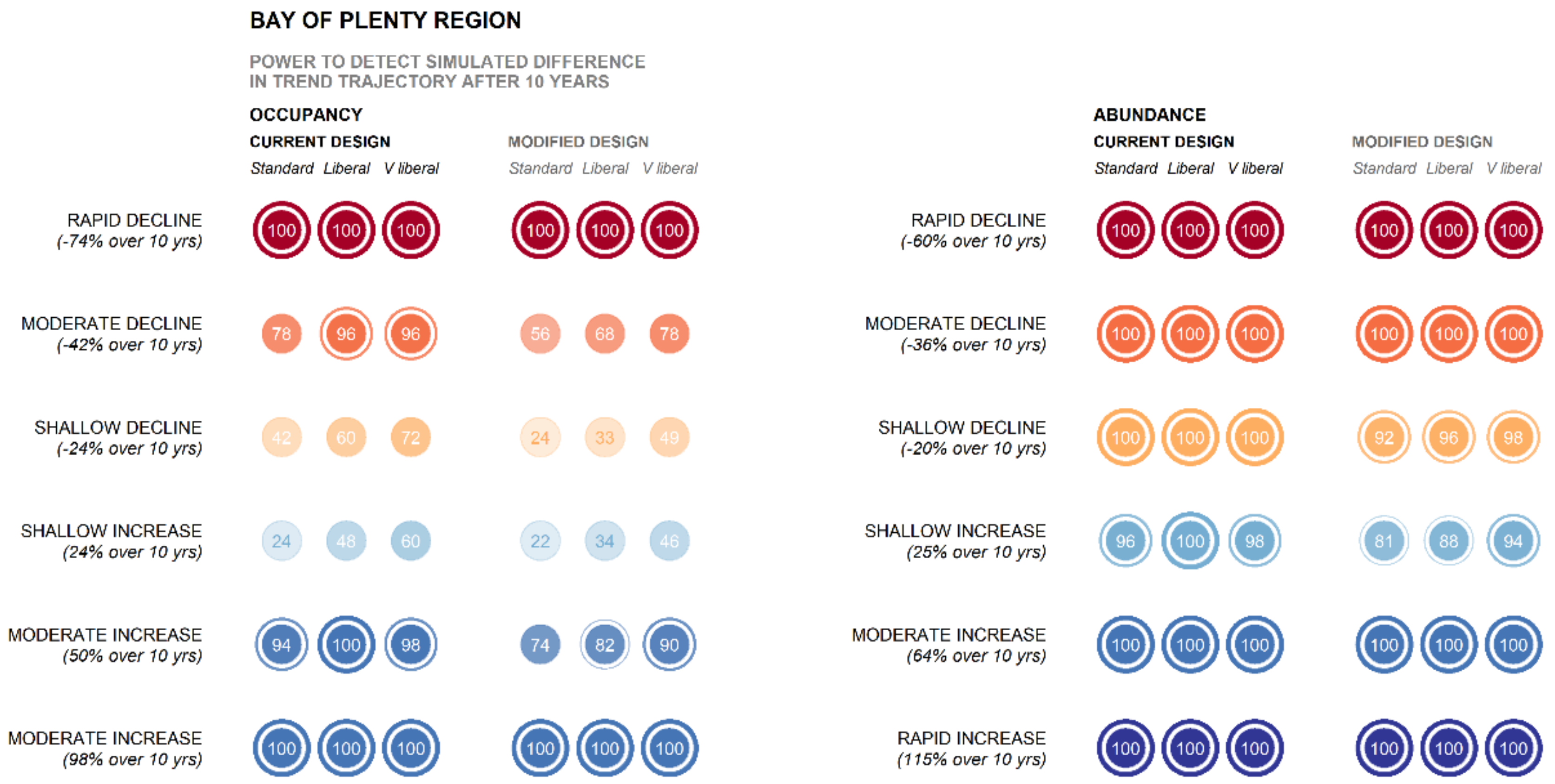

Figure 24. Power (%) to detect a difference in trend trajectories after 10 years within indigenous forests in the Bay of Plenty Region for palatable saplings (relative to unpalatable ones) equivalent to a rapid, moderate or shallow change in: (Left) Occupancy; (Right) Abundance. Power (%) estimates for the current design of LUCAS and DOC's Tier 1 framework versus the proposed modified design when the confidence level is specified as standard (95%), liberal (90%) or very liberal (80%). The shading of dots is proportional to the power estimate (which is specified within the dot), with the outer rings signalling when the power estimate is ≥80% (fine ring), ≥90% (intermediate ring) or 100% (thick ring). (The power estimate for each scenario was derived using their respective base model (~ Ys*PalGroup + (1|Place)), with 50 simulations per scenario. For the modified design, the power estimate is the median value across the 50 replicates – random allocations of locations to survey years.) Dots are colour coded in relation to simulated trend alert (see Figure 8).

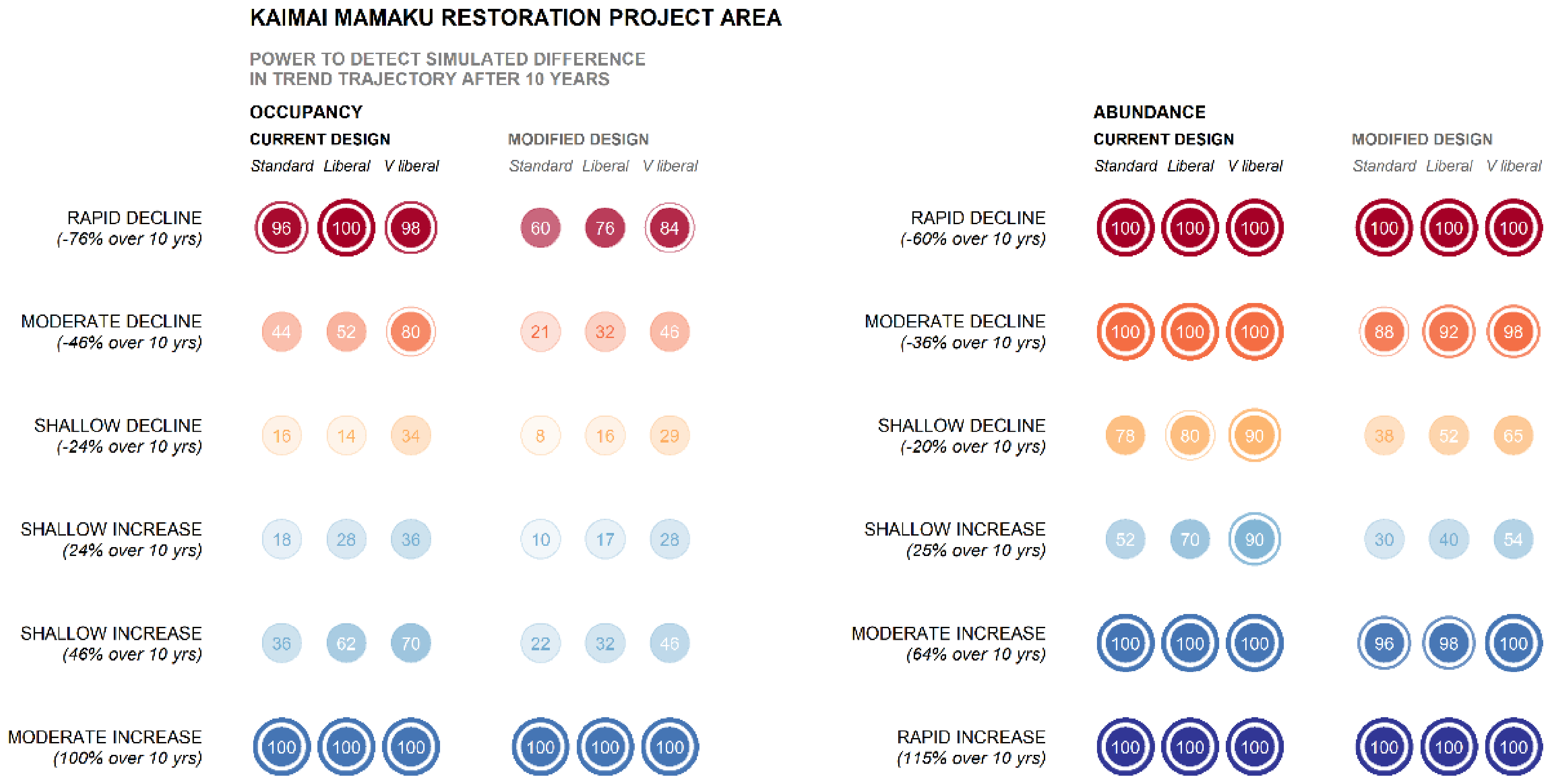

Figure 25. Power (%) to detect a difference in trend trajectories after 10 years within indigenous forests in the Kaimai Mamaku Project Area for palatable saplings (relative to unpalatable ones) equivalent to a rapid, moderate or shallow change in: (Left) Occupancy; (Right) Abundance. Power (%) estimates for the current design of LUCAS and DOC's Tier 1 framework versus the proposed modified design when the confidence level is specified as standard (95%), liberal (90%) or very liberal (80%). The shading of dots is proportional to the power estimate (which is specified within the dot), with the outer rings signalling when the power estimate is ≥80% (fine ring), ≥90% (intermediate ring) or 100% (thick ring). (The power estimate for each scenario was derived using their respective base model (~ Ys*PalGroup + (1|Place)), with 50 simulations per scenario. For the modified design, the power estimate is the median value across the 50 replicates – random allocations of locations to survey years.) Dots are colour coded in relation to simulated trend alert (see Figure 8).

8 Conclusions

- Palatable saplings have declined rapidly in the Region and the Project Area. They are also less likely to occur, and are less abundant, than unpalatable saplings in indigenous forests in both areas. Unpalatable sapling occupancy and abundance has shown little to no change over the same period in both areas.
- Trends in occupancy and abundance of palatable saplings at the region scale were modulated by ungulate occupancy, with palatable saplings declining at moderate and high ungulate occupancy, suggesting that the results for the Project Area can be interpreted as indicating ungulate effects in plant communities.
- Moving from a 5- to a 10-year measurement cycle will greatly reduce the statistical power to detect changes in saplings of both the palatable and unpalatable palatability groups in the Region and the Project Area.
- Future studies could consider refining the alert classifications for different contexts and taxa. For example, a decrease in the abundance of unpalatable saplings might be interpreted as a shallow improvement in forest understorey health (rather than a shallow deterioration, as presented using the alert framework applied in this report).

9 Acknowledgements

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