Manaaki Whenua
Landcare Research

Power to detect change in forest composition and populations of individual tree species in the Bay of Plenty region.

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Manaaki Whenua – Landcare Research

Contents

Summary

Project and Client

- Changes in forest community composition (i.e. proportional richness and abundance of palatability groups) and populations of individual tree species between the first two LUCAS survey periods (2002–2007 and 2009–2014) were assessed for the Bay of Plenty Regional Council. Changes in community composition were also assessed for individual forest types

Objectives

- To assess power to detect changes in composition-based indicators of forest health and populations of individual tree species in the Bay of Plenty Region using the LUCAS monitoring network.

Methods

- We analysed data from 73 20 x 20 m LUCAS plots within the Bay of Plenty Region measured in the first and second LUCAS survey period.
- We assessed changes in the mean tree diameter of all plots, and plots within each forest type.
- We estimated changes in tree populations of plots within each forest type and for individual species across all plots.
- We estimated changes in the contribution of each ungulate palatability group to total plot richness and the abundance of these groups in tree, sapling and seedling size classes.
- We compared changes observed in the BOP region with those across the entire LUCAS network to place our results in a national context.
- We also assessed power to detect an increase in the abundance of palatable species in the eastern BOP goat control zone.

Results

- There was no evidence for widespread decrease in tree diameters or an increase in the total number of stems. This suggests it is very unlikely that either widespread stand-level disturbance or regeneration occurred in forests of the Bay of Plenty region between survey periods.
- Populations of tree species preferred by ungulates (*Melicytus ramiflorus*, *Coprosma grandifolia*, *Wienmania racemosa* and *Ixerba brexioides*) decreased, while those for species avoided by ungulates (*Pseudowintera axillaris*, *Leucopogon fasiculatum* and various tree ferns) increased.
- The proportional abundance of species avoided by ungulates increased, while that for species preferred by ungulates decreased in sapling and tree size classes, indicating a decline in populations of palatable species.
- Changes in the abundance of palatability groups in the BOP region were more extreme than for the entire LUCAS network.

- Species preferred by ungulates declined significantly for each of the size classes in at least one of the forest types studied.

Conclusions

- There are enough LUCAS plots to detect changes in composition-based indicators of forest health in the Bay of Plenty Region as a whole, but more plots would be needed to detect changes for some individual forest types.

- Observed community and species-level changes are consistent with more intense ungulate impacts on forest species composition in the Bay of Plenty than the rest of New Zealand. However, the contribution of other factors to apparent ungulate impacts in the Bay of Plenty, particularly possum browsing, cannot be ruled out.

- Results for changes in tree diameter (increasing for two forest types) and tree populations (no change in any forest type) indicate that forests in the region have not experienced any widespread canopy disturbance or tree recruitment events between the first two LUCAS survey periods.

- The LUCAS plot network will be capable of detecting recovery in the eastern Bay of Plenty goat control area if positive responses of palatable species to management are widespread (i.e. across 80% of the total area). For less widespread changes, more plots will be needed.

Recommendations

- These analyses should be repeated when a full dataset for the third LUCAS survey period is available, particularly to test whether trends for declines in palatable plant species are continuing and whether these can be more accurately related to the relative abundance of herbivores.

- Further consideration is needed on how best to benchmark changes in composition-based metrics of forest health in the Bay of Plenty against changes across the entire LUCAS plot network.

- Consideration is needed around the desired minimum detectable effect-size to determine whether current sampling intensity provided by LUCAS provides adequate power to detect the impacts of the Eastern BOP goat control programme on palatable plant species.

- Extension of Tier1 animal indicators (particularly for ungulates and possums) to LUCAS plots outside public conservation land would help assess the effects of goat (and deer) impacts and goat control efforts (in the eastern Bay of Plenty) on forest health.

1   Introduction

The LUCAS plot network samples all woody vegetation in New Zealand on an 8-km grid (Holdaway et al., 2016). As a heavily forested region, the Bay of Plenty contains a reasonable number (73) of LUCAS plots that have been surveyed twice (2002-2007; 2009-2014). This should provide good power to detect change in forest health indicators for the region as a whole (Mason & Bellingham 2018), but it is not clear whether this is true for individual forest types occurring within the region. This report assesses change in selected composition-based forest health indicators across the Bay of Plenty region and within its major forest ecosystem types.

2   Background

The 8-km national grid was originally designed as a system for providing an unbiased estimate of the carbon stored in New Zealand's natural forest and shrubland (Coomes et al. 2002; Payton et al. 2004). The grid size (8 km) was determined based on the sample size required to estimate national carbon stock to a certain level of precision (i.e. a 95% probability that carbon stock estimates will be within 5% of the mean (+/– 10 Mg ha) (Payton et al. 2004). Plots were randomly allocated a year to be sampled based on a theoretical 5-year cycle with no geographical stratification (Payton et al. 2004). With revisions of the mapped area of forest and shrubland (e.g. the creation of the LUCAS Land Use Map), new plots have been added to the grid. These were also allocated an ideal year of measurement using random sampling. Repeat measurements (i.e. in both survey periods) were made in over 700 LUCAS plots.

Remnant woody vegetation in the Bay of Plenty region primarily occurs on the steeper, wetter, and higher altitude areas (Table 1). Most remeasured LUCAS plots in the Bay of Plenty (53/73) are within Public Conservation Land (PCL, Fig. 1) and primarily occur on podzolized pumice soils (55 plots) or recent soils (8 plots) (nomenclature follows NZ soil classification, Hewitt 2003).

Table 1: Mean environmental values for LUCAS plots in the Bay of Plenty region (Mean LUCAS) and for the whole region (Mean BOP). Data are from Leathwick et al. (2003)

Variable	Mean LUCAS	Mean BOP
Mean annual temp. (°C)	11.3	11.9
Mean temp coldest month (°C)	2.0	2.2
Mean annual rainfall (mm)	2046	1863
Elevation (m)	499	379
Slope (°)	22	15

A regional ecosystem classification has been developed for the Bay of Plenty (Singers 2014), based on a national ecosystem classification system (Singers & Rogers 2014). This classification system amalgamates previous classifications and ecological studies within an abiotic framework. It describes potential ecosystem types at a variety of scales. Singers (2014) amalgamated three datasets to form an "ecosystem unit" layer – the New Zealand Fundamental Soil layer (https://soils.landcareresearch.co.nz/soil-data/fundamental-soil-layers/), S-Map (https://smap.landcareresearch.co.nz/) and the New Zealand Forest Service map series 6 (https://koordinates.com/layer/300-nz-fsms6-north-island/). Distributional information (sourced from the New Zealand Plant Conservation Network – http://www.nzpcn.org.nz/) for a range of diagnostic species (*Fuscospora truncata*), pōhutukawa (*Metrosideros exselsa*), mangeao (*Litsea calicaris*), kohekohe (*Dysoxylum spectabile*), kauri (*Agathis australis*), tawa (*Beilschmedia tawa*), taraire (*Beilschmedia tarairi*), pūriri (*Vitex lucens*), and pukatea (*Laurelia novae-zelandiae*) – was used to refine ecosystem unit boundary determination. Finally, the impacts of recent (post-Taupo A.D. 232) volcanism were used to further refine ecosystem unit boundaries.

Forest areas within the Bay of Plenty fall primarily into the following "Zonal" ecosystems (*sensu* Singers & Rogers 2014): Warm temperate forest (WF), Mild Forest (MF), Cool Forest and Scrub (CLF) and Cold Forest and Scrub (CDF). Singers (2014) provides a detailed description of all ecosystem types identified using the classification framework. Below we present information for the six types containing enough LUCAS plots for analyses of forest health indicators in the Bay of Plenty region (Table 2).

Table 2: Description of most common forest ecosystem types in the Bay of Plenty region (adapted from Singers 2014)

Ecosystem	Description
CLF9: **Red beech, podocarp forest**	This type occurs in the main axil ranges from the Ahimanawa in the south to the Raukumara in the north. Typically, it occurs above (in altitude) MF8: Kamahi broadleaved podocarp forest and below pure beech forest. Depending on altitude and landform it has a variable abundance of podocarp trees and locally, such as on steep ridge lines is dominated by red beech. Throughout its range red beech is always present though in some locations silver beech also occurs.
	It is equivalent to NZFS MS 6 forest class I "Rimu General Hardwoods Beeches" and especially NZFS MS 2 types I1, I2 & I4 and K3 (Nicholls 1966b, 1969a 1969b), which were primarily used to map its distribution.
MF7-1: **Tawa, mangeao, podocarp forest;** MF7-2: **Rata, tawa, kamahi, podocarp forest**	This type was arguably the most common forest ecosystem unit within the region — despite being displaced from large areas of suitable habitat as a result of Maori fires. It occurs within central and inland areas and merges into WF13: Tawa, kohekohe, rewarewa, hīnau, podocarp forest at lower altitude and often MF8: Kāmahi broadleaved podocarp forest at higher altitude — often forming the lower and upper distributional limits.
	It has partial correspondence with NZFS MS6 Rimu – tawa class, though this class is broader and required subdivision to map. It occurs in areas with a mild climate and low soil moisture deficit (<70mm).
	Two variants were recognised which were mapped (MF7.1: Tawa, mangeao, podocarp forest and MF7.2: Rata, tawa, kāmahi, podocarp forest). These two variants were mapped because they occur in geographically distinct parts of the region and have slightly different species compositions.
MF8: **Kamahi broadleaved podocarp forest**	This type primarily occurs in the southern Ikawhenua and Whirinaki Ranges, with smaller examples elsewhere. It usually occupies a zone above the altitudinal limit of tawa at approximately 700m a.s.l. or in areas where it was extirpated by the Taupo 232AD eruption and has not re-colonised fully (McKelvey 1973).
	MF8 is equivalent to types within the broader forest class M "Rimu, matāī, general hardwoods", e.g. M1 (Nicholls 1969a).
MF22: **Tawa, rimu, northern rātā, beech forest**	This ecosystem unit occurs predominantly in the eastern Bay of Plenty steep hill-country within the mild climatic zone (Singers & Rogers 2014). It is partially equivalent to the NZFM MS6 (Nicholls 1976) forest classes H "Rimu-tawa-beeches" and the logged variant class O "Tawa-beeches". It usually merges into WF14-1 in the warm climatic zone. These two types were separated using the distribution of kohekohe as a surrogate for the warm – mild temperature boundary.
WF13: **Tawa, kohekohe, rewarewa, hīnau, podocarp forest**	This type occurs in lowland and climatically warm areas, often on moderate to steep hill slopes which experience limited frost. It is partially equivalent to the NZFM MS6 (Nicholls 1976) forest class D "Rimu-tawa".

There are concerns in the Bay of Plenty, about the impact of invasive mammalian herbivores – particularly ungulates (mainly goats and deer), but also marsupials (dama wallabies and brushtail possums) – on indigenous forest health. This relates to **species richness** and **abundance** of plant species **preferred by mammalian herbivores** relative to those that are **avoided** (primarily following Forsyth et al. 2002). In this report, we examine temporal changes in the contribution of different palatability groups to species richness and abundance in tree, sapling and seedling size classes. We also examine

temporal changes in the plot-level populations of individual tree species differing in palatability to mammalian herbivores.

There is particular concern in the Eastern Bay of Plenty over the impacts of goats on forests, with a major control effort instigated to reduce these impacts. However, it is unclear whether existing LUCAS plots in areas where goats are controlled provide a large enough sample size to confidently detect expected positive changes in forest health indicators resulting from reduced goat browsing pressure. We therefore conduct power analyses to assess what level of change in the abundance of species preferred by ungulates in tree, sapling and seedling size classes can be detected with the current sampling design.

Interpretation of forest health indicators may be complicated by forest stand dynamics. For instance, Mason et al. (2010) found the positive impacts of ungulate exclosures on composition-based forest health indicators (mean community-level valuers for leaf traits linked to palatability) were greater in stands experiencing canopy disturbance where recruitment of young trees occurred. The overriding impact of forest stand development processes (i.e. canopy mortality, recruitment and succession) on size-based indicators of forest health has also been dealt with at length (Coomes & Allen 2007; Peltzer et al. 2014). For these reasons, we interpret changes in forest composition within the context of changes in total tree abundance and mean tree size (stem diameter at breast height (DBH) – 1.35 m). Widespread competitive thinning (i.e. death of smaller individuals as canopy cover increases) should cause a decrease in total tree abundance but an increase in mean tree size (Coomes & Allen 2007). By contrast, widespread canopy disturbance should increase total tree abundance and decrease mean tree size (through recruitment of small individuals and death of larger individuals). To place results for the Bay of Plenty in a national context, we also examine changes in total tree abundance, mean tree size and abundance of 'preferred' species across the entire LUCAS network.

Based on DOC's national (Tier 1) inventory and monitoring system for public conservation land, it appears that ungulate relative abundance is higher in the Bay of Plenty than in the rest of New Zealand, so that we might expect evidence for ungulate impacts on forest health to be more pronounced in the Bay of Plenty (Appendix 1). However, possum relative abundance in Tier 1 locations within the Bay of Plenty is also higher than for the rest of New Zealand (Appendix 1). Peltzer et al. (2014) found little evidence for possum impacts on tree size distributions through time. There is some evidence that apparent ungulate impacts on canopy dominant tree species could partially be due to possum-induced mortality, especially for kāmahi when possums occur at very high densities (e.g. Duncan et al. 2011: Gormley et al. 2012). However, increased tree mortality due to high possum densities may be contingent on other factors, especially the presence of high quality food sources (such as flowers and fruit) to supplement a foliage based diet, to which possums are poorly adapted (Nugent et al. 2001). Indeed, at one site (Haast, non-treatment) studied by Gormley et al. (2012), none of the 221 kamahi trees monitored died between surveys, despite relatively high possum abundances (Trap Catch Index > 20%) at the start of the study period. In sum, available evidence suggests that while possums may have severe impacts on individual species in certain locations, they are unlikely to be the main driver of forest composition change throughout the entire Bay of Plenty region. Dama wallabies are thought to have a fairly localised distribution in the Bay of Plenty

(mainly in forests around the Rotorua lakes, Latham et al. 2019), feed primarily on pasture species (which contribute around 70% of their diet) and appear to have no discernible long-term effect (beyond the impacts of red deer) on the abundance of palatable species in seedling and sapling size classes (Wright 2017). This suggests that they are unlikely to have a widespread impact on forest composition in the Bay of Plenty. Unfortunately, it is not possible to fully tease apart the relative impact of ungulates and possums on forest composition in this report, as abundance data for these species are only available for public conservation lands.
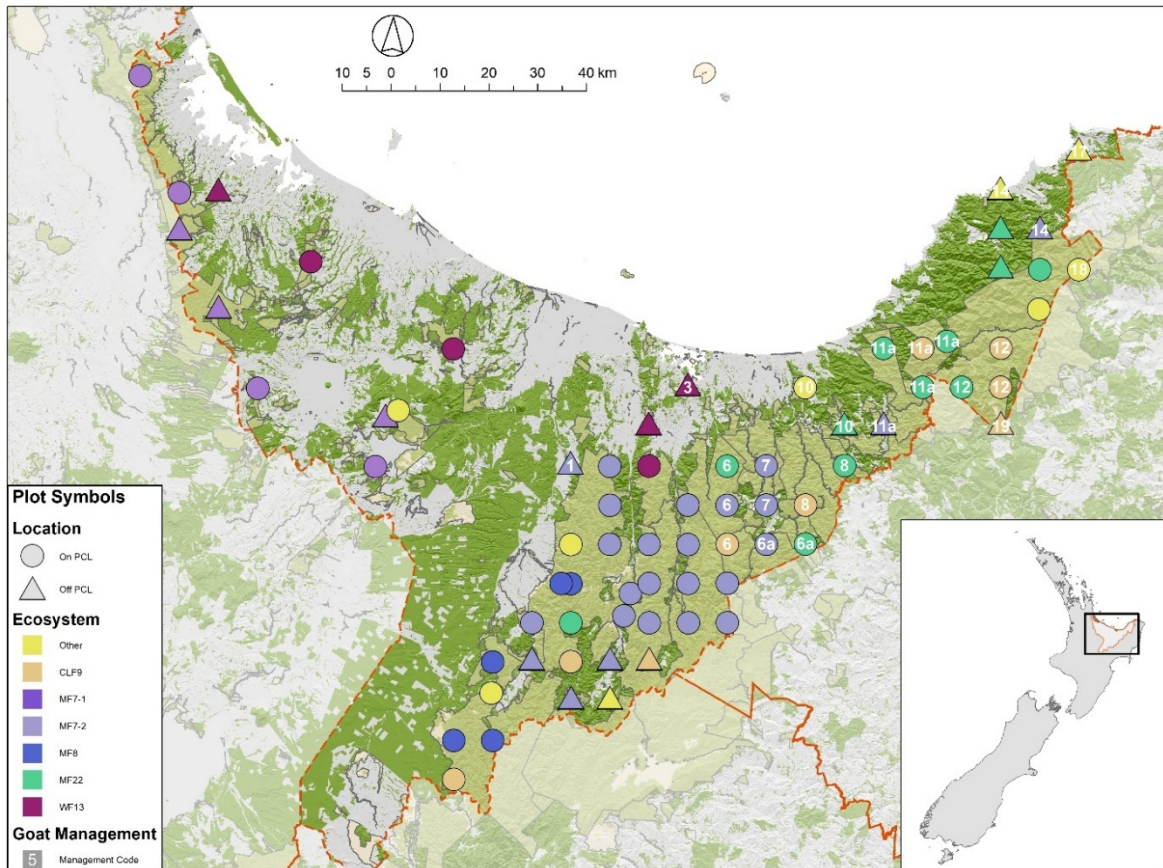

Figure 1: Map of LUCAS plots within the Bay of Plenty Region. Colours indicate ecosystem type (following Singers 2014), circles indicate plots on public conservation land (PCL) while triangles indicate plots not on PCL. Numbers indicate the plots which occur in the corresponding zones of the Eastern Bay of Plenty goat control programme. Ecosystem codes in the map legend correspond to the ecosystem types described in Table 2.

3   Objectives

To assess power to detect changes in forest composition indicators in the Bay of Plenty Region, and for individual forest ecosystems using the LUCAS monitoring network.

4   Methods

4.1   Data used and plot-level indicators

We used vascular plant species lists, stem diameter at breast height (1.35 m) measurements, and seedling and sapling counts from LUCAS plots in the region with measurements from both the 2002–2007 and 2009–2014 survey periods. Only live stems recorded within the main 20 × 20 m plot with a valid National Vegetation Survey (NVS) databank code were included. Only plots within the region with live stems recorded in both survey periods (n = 73) were analysed. We made this choice as vital rates – mortality and recruitment – cannot be annualised (following Kohyama et al. 2018) unless live stems occur in both survey periods (note this does not exclude plots where all stems present in the first survey period die, so long as there is some recruitment). Methods for plot measurements followed standard LUCAS protocols (Payton et al. 2004). Vital rates are presented for all species with >50 stems in both survey periods across LUCAS plots in the region. LUCAS plots in the Bay of Plenty were assigned to forest types following the ecosystem classification system of Singers (Singers, 2014). Individual tree species were assigned to ungulate palatability classes ('Avoided', 'Preferred', 'Not selected' or 'Unclassified') using classifications available from the New Zealand plant species names database (https://www.landcareresearch.co.nz/resources/data/nzplants). In all analyses, plots in Te Urewera National Park were excluded.

We calculated mean tree diameter, species richness (as proportion of total plot richness) and proportional abundance of each palatability class. Abundance of palatability classes was estimated as counts of tree stems, saplings and seedlings. We used tree tags to estimate the number of measured tree stems surviving, dying, or recruited between survey periods. Tag matching and corrections are documented in the file "BOPMatchTags.r". Methods are available for simulating the amount of uncertainty due to measurement errors for mean diameter and species richness (Mason et al. 2018). For both measurements, we present results both with and without uncertainly due to measurement error.

4.2   Data analysis

4.2.1   Tests for significant changes within plots between surveys

We used a repeated measures design to assess changes in mean DBH of trees and proportional abundance of palatability groups between surveys. Statistical significance testing was based on a non-parametric test statistic (*Tdir*) recording the net direction of

paired differences (expressed as a proportion of the total number of pairs, in this report equal to the number of remeasured plots):

$$Tdir = \frac{N(t_2>t_1)-N(t_2<t_1)}{Nplots} \qquad (1)$$

where $N(t_2>t_1)$ is the number of plots where the measurement in sample 2 (the second LUCAS survey period, 2009–2014) is greater than in sample 1 (the first LUCAS survey period 2002–2007); $N(t_1>t_2)$ is the number of plots where the measurement in sample 1 is greater than in sample 2; and $Nplots$ is the total number of plots. The advantage of this test is that, by only documenting the direction of shift between survey periods (but within plots) it provides equal power to detect increases or decreases even in datasets where values are constrained by fixed upper and/or lower values. For proportional abundance values, the lower bound is generally zero, and many such datasets exhibit extremely right-skewed distributions (many small values, few large values). Test statistics incorporating both the magnitude and direction of shift within pairs have lower power to detect decreases than increases for right-skewed datasets with a fixed lower bound (Mason & Bellingham 2018). We used randomisation tests to test whether observed values of *Tdir* differed significantly from those expected by chance. These tests randomly allocate data between surveys but within plots, thus retaining the repeated measures structure of the data (see Mason & Bellingham 2018 for details).

Using this method, we tested for changes between survey periods in the plot-level mean tree diameter, as well as proportional species richness and abundance of palatability groups. These analyses were performed across all plots in the region and across individual forest types. Tests were performed both for LUCAS plots in the Bay of Plenty region and for all LUCAS plots across New Zealand (to place trends in the Bay of Plenty in a national context).

In reporting the results of these tests, we also provide actual values for the difference between survey periods for each plot (e.g. the open circles in Fig. 2), as well as the Probability distribution function for these differences (generated using kernel density estimators, e.g. the solid line in Fig. 2). Finally, we use bootstrapping (i.e. resampling observed plot-level differences *with replacement* a total of 10, 000 times) to estimate the median and the 95% confidence interval (across resampled datasets) of the mean plot-level difference between survey periods (e.g. the solid circle and error bars surrounding it in Fig. 2).

4.2.2 Changes in tree populations

In this report, we use international best practice (Kohyama et al., 2018) to estimate annual rates of population change for a range of native tree species which are common in the region. We use bootstrapping (i.e. resampling of plots *with replacement*) to generate confidence intervals for the mean rate of population change for each species. Statistically significant population change ($\alpha=0.05$, one-tailed test) is assumed if the 95% confidence interval does not include zero.

4.2.3 Power to detect increase in palatability in eastern BOP goat control zone

We used a simulation approach to estimate power of the current sampling design in the eastern BOP goat control zone to detect an increase in abundance of species in the 'Preferred' palatability group. This was based on the non-parametric significance test outlined in 4.2.1. We used the proportional abundance of preferred species (separately for seedling, sapling and tree size classes) from the second LUCAS measurement period as our starting data. Since the significance test only considers the direction of change and not the magnitude, we simulated positive or negative changes of a fixed size in proportional abundance, based on different target values for *Tdir*. For instance, with a *Tdir* target value of 0.4, the probability of each plot experiencing an increase or decrease in proportional abundance may be calculated as:

$$P_{pos} = 0.5 + \frac{Tdir}{2} = 0.5 + 0.2 = 0.7 \tag{2}$$

$$P_{neg} = 1 - P_{pos} = 0.3 \tag{3}$$

where P_{pos} is the probability of a plot experiencing a positive change (i.e. an increase) and P_{neg} is that of a negative change. These probabilities were used to simulate increases or decreases in the proportional abundance of 'preferred' species (in plots where preferred species were present during the second survey period) for different target effect sizes (i.e. target *Tdir* values) and sample sizes. For each combination of effect and sample size, we recorded the median and 95% confidence interval of observed *Tdir* values (i.e. the observed effect size) across simulations as well as the proportion of simulations yielding a significant result.

5 Results

5.1 Mean tree diameter

There was a significant increase in mean tree diameter across all plots (Figure 2) and for plots in two of the six forest types analysed (Table 3). This indicates that forests in the region have not been impacted by widespread canopy disturbance or recruitment of smaller individuals. Results for changes in mean DBH across all LUCAS plots in New Zealand were in the same direction as for BOP plots (Figure 3). However, a larger proportion of BOP plots experienced an increase in mean tree diameter compared with all LUCAS plots. This argues against widespread possum-induced tree mortality, since possum browsing tends to be concentrated in large trees (Gormley et al. 2012), which should lead to a decrease in mean DBH (through increased mortality of large trees), if not for the entire region, at least for individual forest types.

Table 3: Results of significance tests for paired differences in mean tree diameter between surveys. Tdir is the observed value of the test statistic (which measures the net direction of paired differences expressed as a proportion of the total number of plots), P≤ is the proportion of randomisations giving values of Tdir less than or equal to the observed value. Sim P≤ is the same as P≤, except it is obtained from data simulated to incorporate uncertainty due to measurement error. Significant results are highlighted in bold

| Forest Type	Tdir	P≤	P≥	Sim P≤	Sim P≥
CLF9, Red beech, podocarp forest	**0.778**	**0.998**	**0.021**	**0.997**	**0.025**
MF22, Tawa, rimu, northern rata, beech forest	0.000	0.587	0.643	0.609	0.614
MF7-1, Tawa, mangeao forest	0.429	0.935	0.214	0.937	0.227
MF7-2, Rātā, Tawa, kāmahi, podocarp forest	**0.680**	**1.000**	**0.002**	**1.000**	**0.001**
WF13, Tawa, kohekohe, rewarewa, etc.	0.667	0.990	0.106	0.984	0.109
MF8, Kāmahi, broadleaved podocarp	0.600	0.968	0.198	0.941	0.243
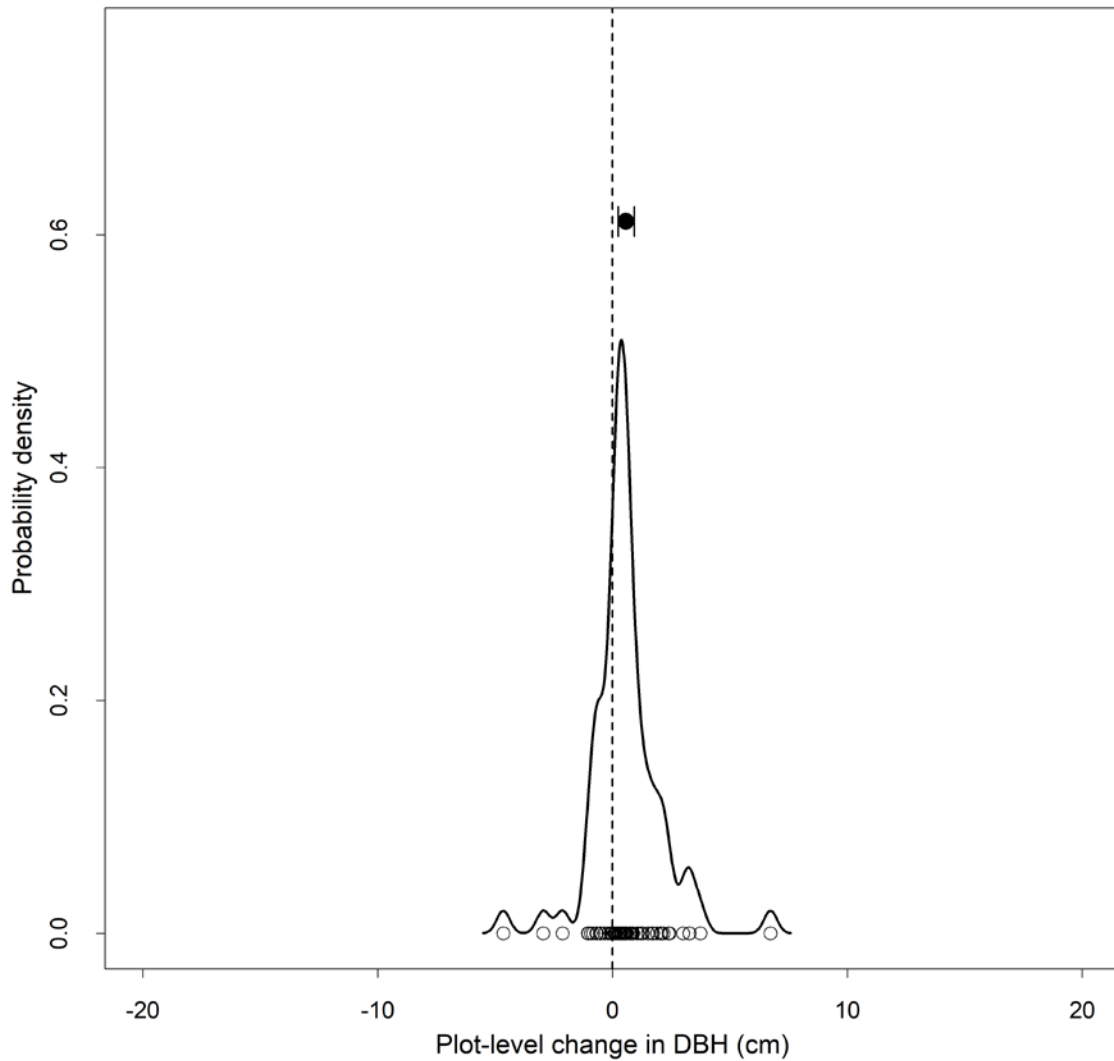
Figure 2: Probability distribution of paired differences in mean tree diameter at breast height (DBH) between surveys for LUCAS plots in the Bay of Plenty region. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, p <0.05; **, p < 0.01; ***, p < 0.001. Open circles indicate the magnitude of change for individual plots. The solid circle and error bars indicate median and 95% confidence limits (taken across resampled datasets) for the mean plot-level change in DBH between surveys.
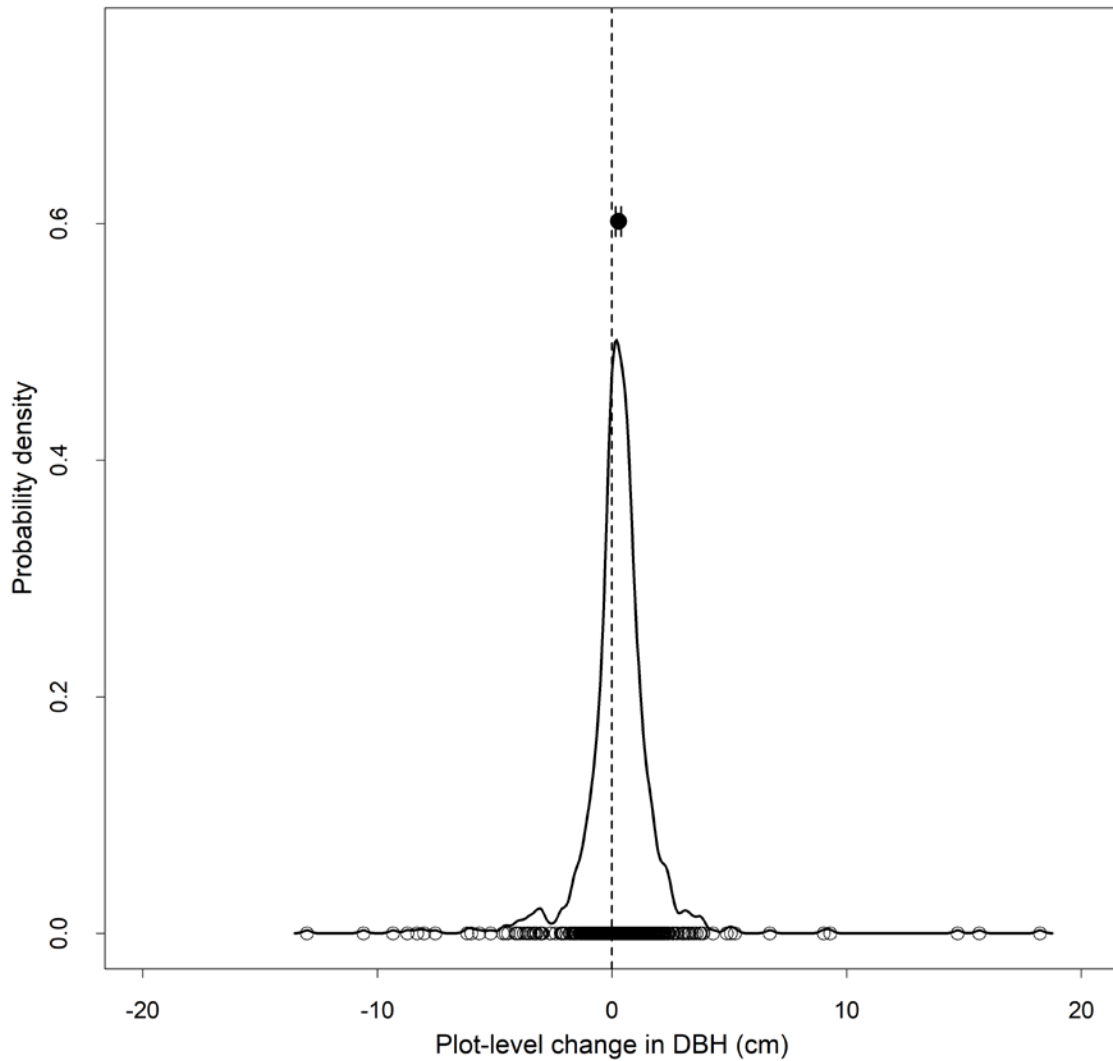
Figure 3: Probability distribution of paired differences in mean diameter at breast height (DBH) between surveys but within plots for all LUCAS plots in New Zealand. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$. Open circles indicate the magnitude of change for individual plots. The solid circle and error bars indicate median and 95% confidence limits (taken across resampled datasets) for the mean plot-level change between surveys.

5.2 Change in tree populations

There was no evidence for significant changes in plot-level tree populations across the region (Fig. 4), nor for any of the forest types (Fig. 5). Results for all LUCAS plots in New Zealand were similar to those for the BOP plots (Fig. 6).
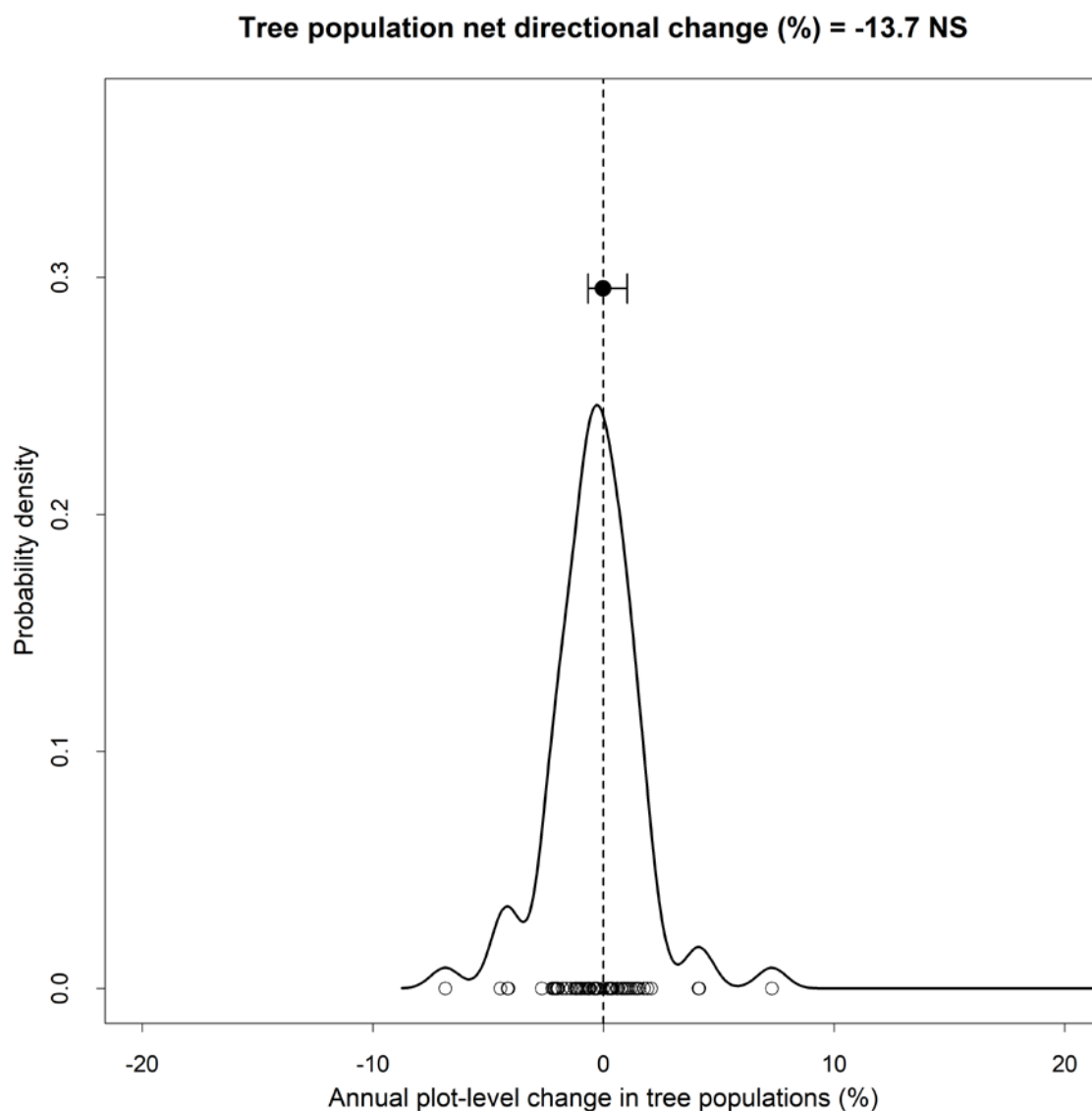

Figure 4: Probability distribution for annual plot level change in tree populations between survey periods for LUCAS plots in the Bay of Plenty region. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, p <0.05; **, p < 0.01; ***, p < 0.001. Open circles indicate the size of change for individual plots. The solid circle and error bars around it indicate median and 95% confidence limits for the mean plot-level change between surveys.
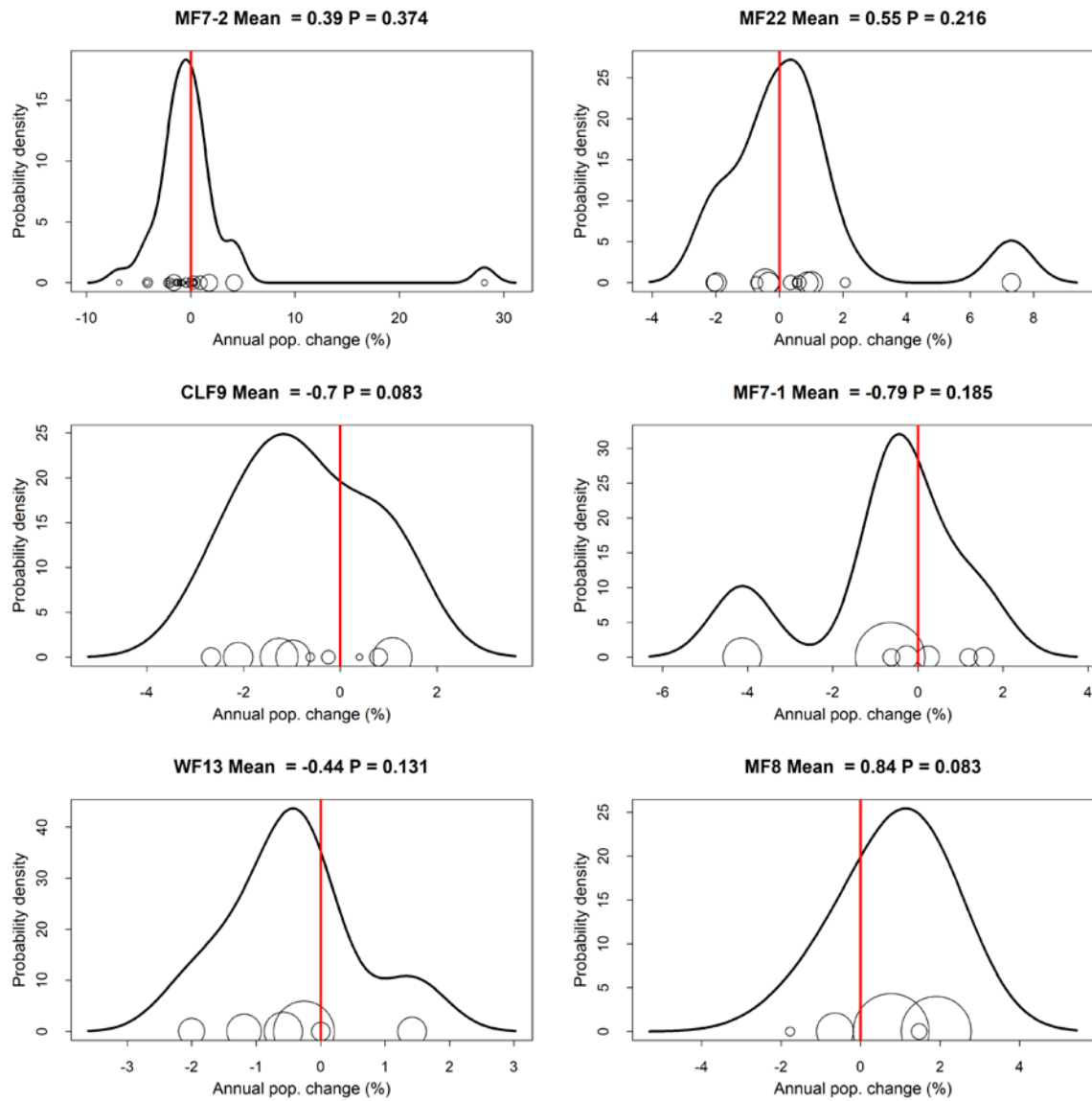
Figure 5: Weighted probability distribution for the change between surveys in the number of trees per plot for each ecosystem type in the BOP region. The alphanumeric codes in the sub-figure headings (e.g. MF7-2) correspond to the ecosystem types described in Table 2. Contribution of plots to the calculation of mean plot-level differences was weighted by the total number of stems measured in them across both surveys. Each circle represents a plot and weights are proportional to circle size. P values indicate the probability that the mean differs from zero and were estimated through bootstrapping (i.e. resampling *with replacement* from observed plot-level differences).

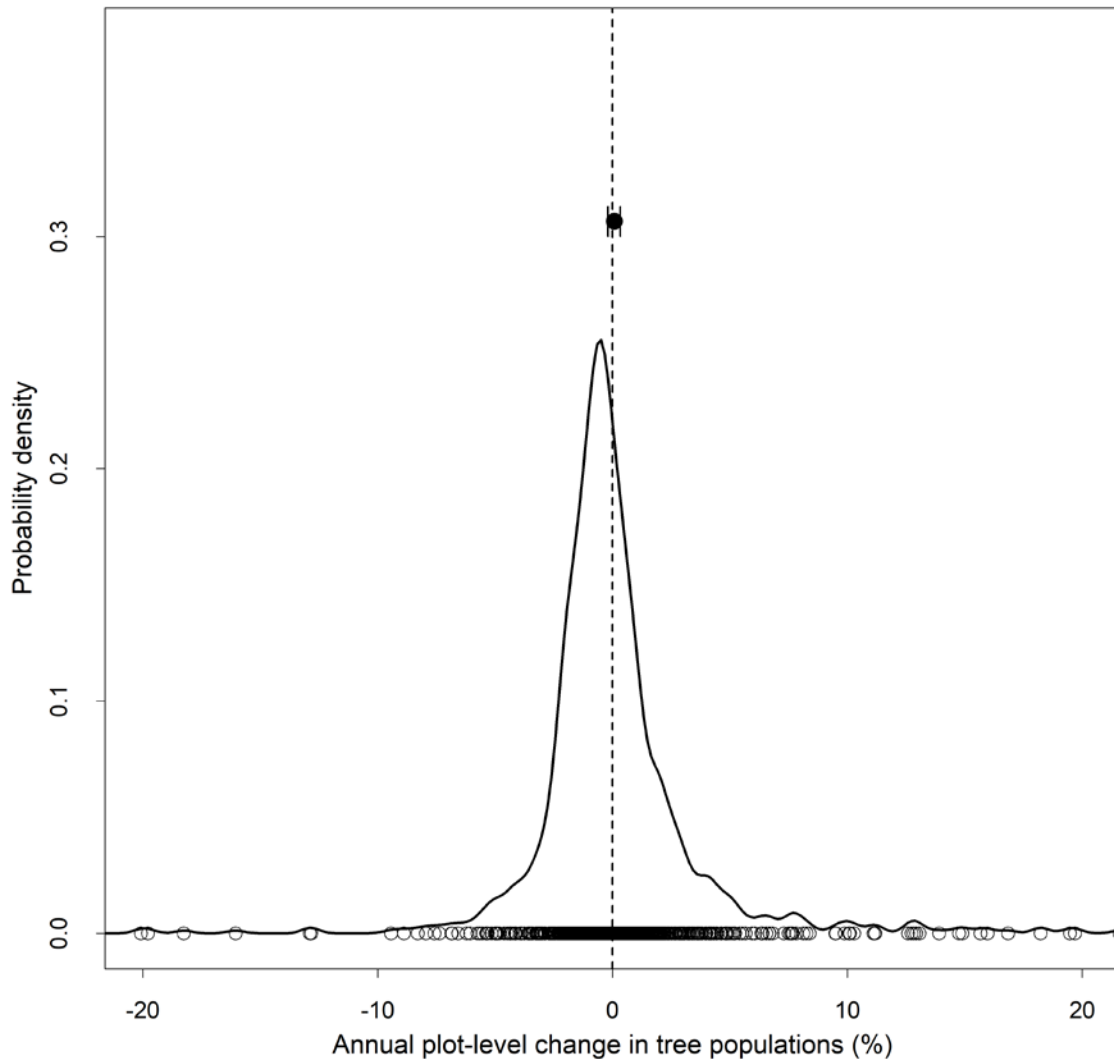**Tree population net directional change (%) = -17.5*****

Figure 6: Probability distribution for annual plot level change in tree populations between survey periods for all LUCAS plots in New Zealand. Open circles represent individual plots. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, p <0.05; **, p < 0.01; ***, p < 0.001. Open circles indicate the size of change for individual plots. The solid circle and error bars around it indicate median and 95% confidence limits for the mean plot-level change between surveys.

A number of species experienced significant changes in the number of stems recorded within plots across the region (Table 4). Three of the six species experiencing significant declines (*Coprosma grandifolia, Weinmannia racemosa, Melicytus ramiflorus*, Table 4) are classified as 'Preferred' by ungulates, which is consistent with impacts of deer and goat browse, although possum browsing might also contribute to declines in these species in locations with high abundance, particularly *Weinmannia racemosa*. Of the others, *Brachyglottis repanda* is a forest-edge or early successional species, and its decline could be the result of increasing canopy closure between surveys in the plots where it occurs. Similarly, available evidence (e.g. Bystriakova et al. 2011) suggests *Cyathea medullaris* mainly establishes following large-scale disturbances (particularly landslides which expose

bare earth), while also being among the fastest-growing and shortest lived tree fern species. Thus, the observed population decline for *C. medullaris* is probably due to the death of established individuals and a lack of recruitment opportunities (consistent with the lack of evidence for wide-spread disturbance across LUCAS plots in the Bay of Plenty). The reason for the decline in *Ixerba brexioides* is not immediately obvious either from the palatability classification we used or successional processes. However, at least one previous study has suggested this species is preferred by ungulates (Beadle 1991), so that its decline might also be attributable to ungulate browsing pressure. All species experiencing significant population increases are classified as avoided by ungulates (except *Dicksonia squarossa*, which is 'Not selected'). This is also consistent with ungulates impacting on tree populations.

Table 4: Median and 90% confidence intervals for estimates of mean plot-level annual population change for individual species obtained from bootstrap resampling (i.e. resampling observed plot-level population changes *with replacement*). Species where the confidence intervals do not include zero (i.e. mean population change is significantly different from zero) are highlighted in bold. Species with significantly decreasing populations are shaded in red, while those with significantly increasing populations are shaded in green

Species	Median	Lower	Upper
Brachyglottis repanda	**-6.0**	**-11.6**	**-2.4**
Coprosma grandifolia	**-3.5**	**-5.6**	**-1.7**
Cyathea medullaris	**-1.8**	**-3.9**	**-0.5**
Ixerba brexioides	**-1.5**	**-2.5**	**-0.8**
Olearia rani	-1.1	-3.1	1.0
Weinmannia racemosa	**-0.8**	**-1.5**	**-0.1**
Melicytus ramiflorus	**-0.7**	**-1.2**	**-0.1**
Carpodetus serratus	0.1	-1.3	1.5
Beilschmiedia tawa	0.3	-0.1	0.7
Hedycarea arborea	0.6	-0.4	1.4
Knightia excelsa	0.7	-0.1	1.5
Dicksonia squarrosa	**1.0**	**0.3**	**1.7**
Pseudowintera colorata	1.0	-0.1	2.2
Cyathea smithii	**1.2**	**0.6**	**1.9**
Pseudowintera axillaris	**1.9**	**1.2**	**3.1**
Cyathea dealbata	**2.5**	**1.6**	**3.5**
Leucopogon fasiculatus	**3.7**	**0.8**	**6.1**
Fuscospora truncata	8.2	-1.9	15.2

5.3 Changes in richness and abundance of species in palatability classes

5.3.1 Proportional richness

There were no significant changes in the proportional richness of palatability groups (i.e. the contribution of each palatability group to total plot-level species richness) when considering all plots in the region (Table 5). Nor were there any significant changes for individual forest types.

Table 5: Results for significance tests for paired differences in the proportional richness of palatability groups between surveys. Tdir is the observed value of the test statistic (which measures the net direction of paired differences expressed as a proportion of the total number of plots), P≤ is the proportion of randomisations giving values of Tdir less than or equal to the observed value. Sim P≤ is the same as P≤, except it is obtained from data simulated to incorporate uncertainty due to measurement error

Palatability group	Tdir	P≤	P≥	Sim P≤	Sim P≥
Unclassified	0.070	0.765	0.307	0.586	0.487
Preferred	-0.056	0.382	0.719	0.303	0.763
Avoided	0.000	0.569	0.524	0.550	0.528
Not selected	0.155	0.931	0.109	0.759	0.305

5.3.2 Tree abundance

The relative abundance of trees in the 'avoided' palatability class increased in tree populations (i.e. >2.5-cm diameter at breast height) across a net 64% of BOP plots (Fig. 7). By contrast, the relative abundance of trees in the 'preferred' group declined across a net 45% of plots. These effects were stronger than for all LUCAS plots, where abundance of avoided species increased in a net 22% of plots, while preferred species decreased in a net 10% of plots (Fig. 8). Taken at face value, this suggests that forests in the BOP have experienced relatively intense ungulate herbivore impacts compared with the rest of New Zealand. The relative abundance of preferred tree species significantly declined in three of the six forest types studied and did not increase in any of them (Fig. 9).
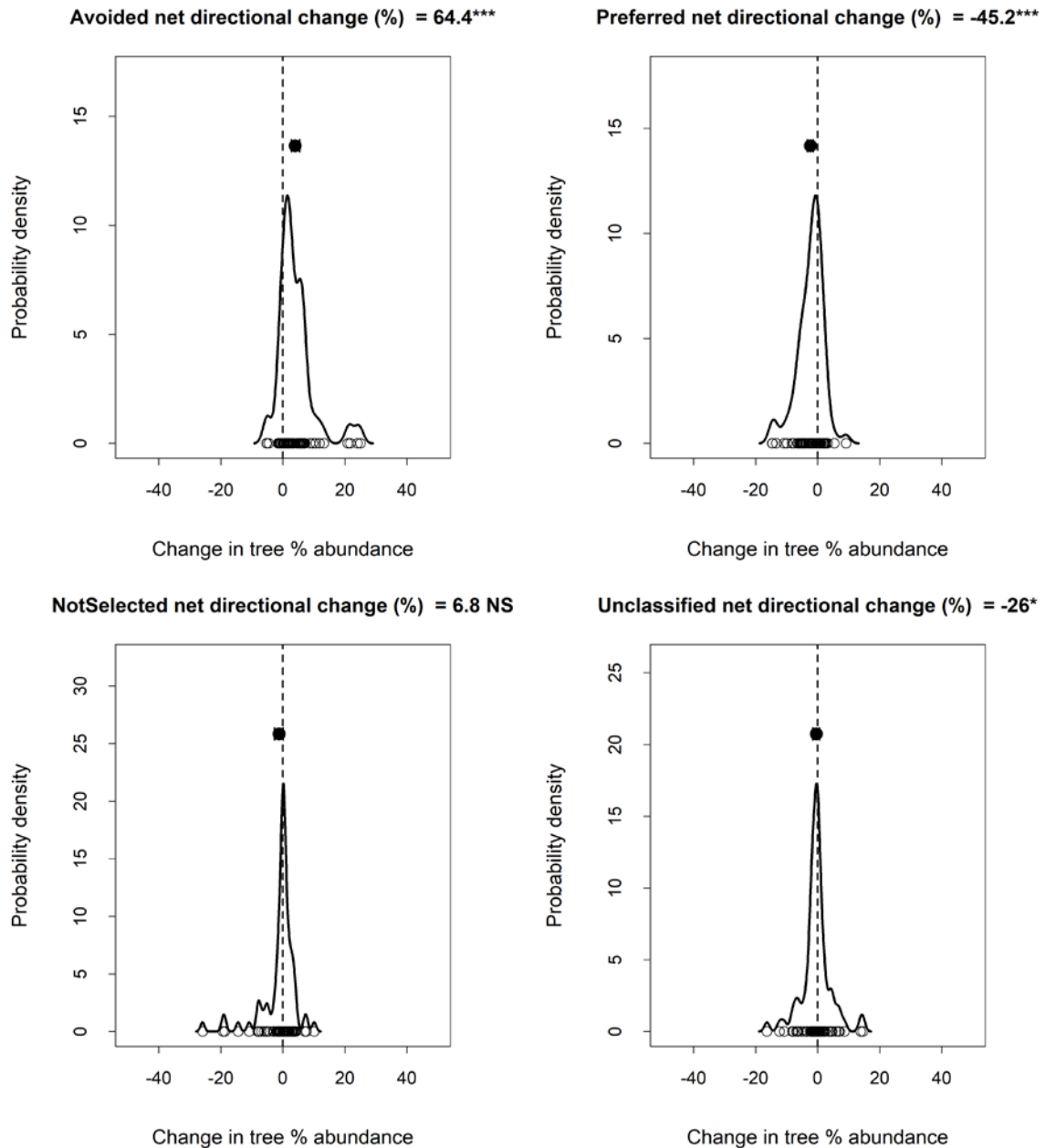
Figure 7: Probability distributions for pairwise (within plot) change between surveys in the relative abundance of tree (i.e. >2.5 cm diameter at breast height) species in different palatability groups within the BOP region. Open circles represent individual plots. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$. Open circles indicate the size of change for individual plots. The solid circle and error bars around it indicate median and 95% confidence limits for the plot-level change between surveys.
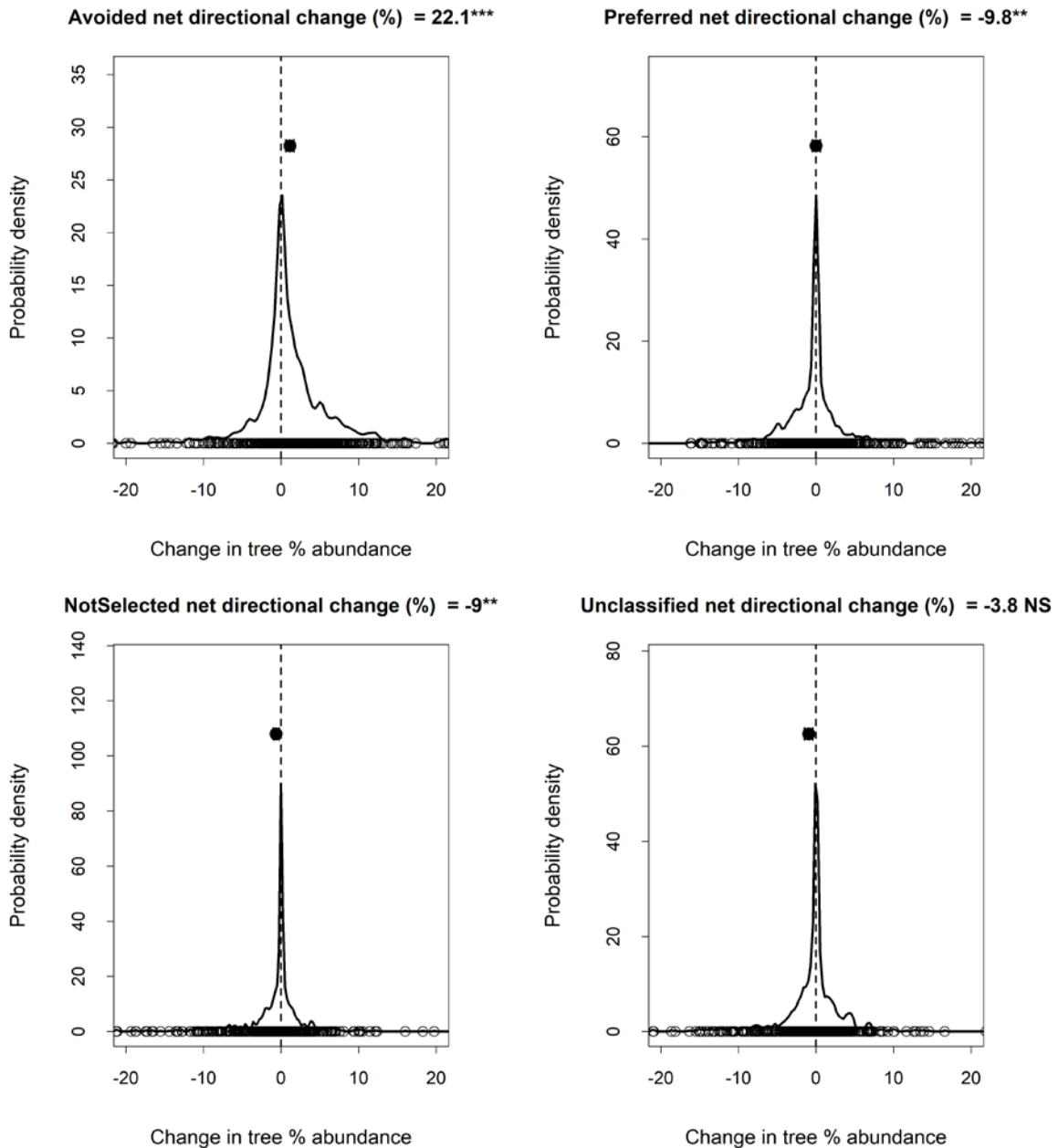
Figure 8: Probability distributions for pairwise (within plot) change in relative abundance of palatability groups in the 'tree' size class between surveys for all remeasured LUCAS plots. Open circles represent individual plots. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$. Open circles indicate the size of change for individual plots. The solid circle and error bars around it indicate median and 95% confidence limits for the mean plot-level change between surveys.
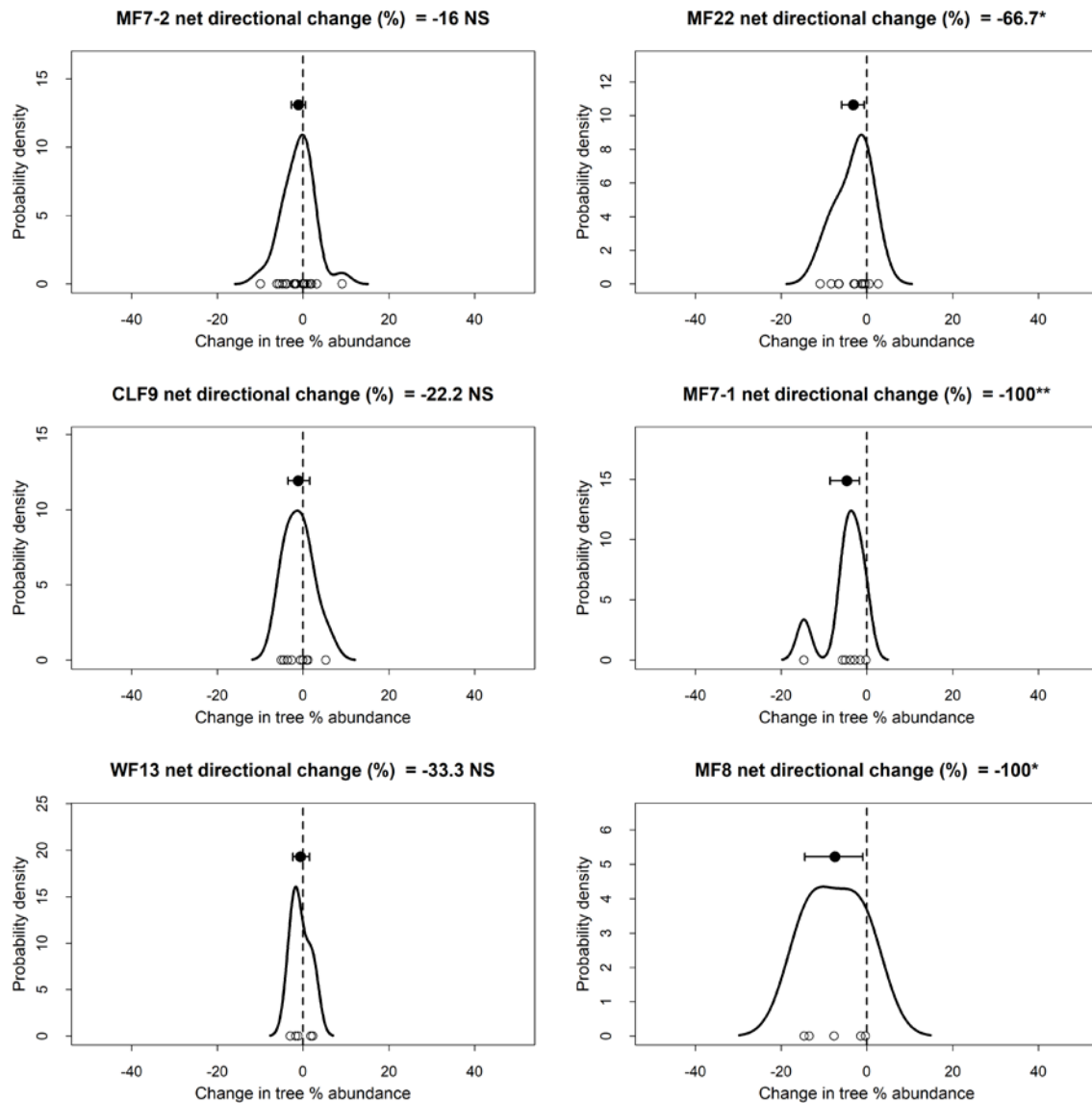
Figure 9: Probability distributions for pairwise (within plot) change between surveys in the relative abundance of tree species in the 'preferred' palatability class for each forest type present in the BOP region. The alphanumeric codes in the sub-figure headings (e.g. MF7-2) correspond to the ecosystem types described in Table 2. Open circles represent individual plots. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, $p <0.05$; **, $p < 0.01$; ***, $p < 0.001$. Open circles indicate the size of change for individual plots. The solid circle and error bars around it indicate median and 95% confidence limits for the mean plot-level change between surveys.

5.3.3 Sapling abundance

The relative abundance of saplings of species in the 'avoided' palatability class increased across a net 71% of plots in the BOP region (Fig. 10). By contrast, the abundance of saplings of species in the 'preferred' class declined across a net 48% of plots. These effects were stronger in BOP than for all LUCAS plots in New Zealand, where abundance of saplings of avoided species increased in a net 30% of plots, while saplings of preferred species decreased in a net 25% of plots (Fig. 11). This further suggests that forests in the

BOP have experienced relatively intense ungulate herbivore impacts compared with the rest of New Zealand. The abundance of preferred species declined significantly in two of the six forest types studied and did not increase in any of them (Fig. 12).
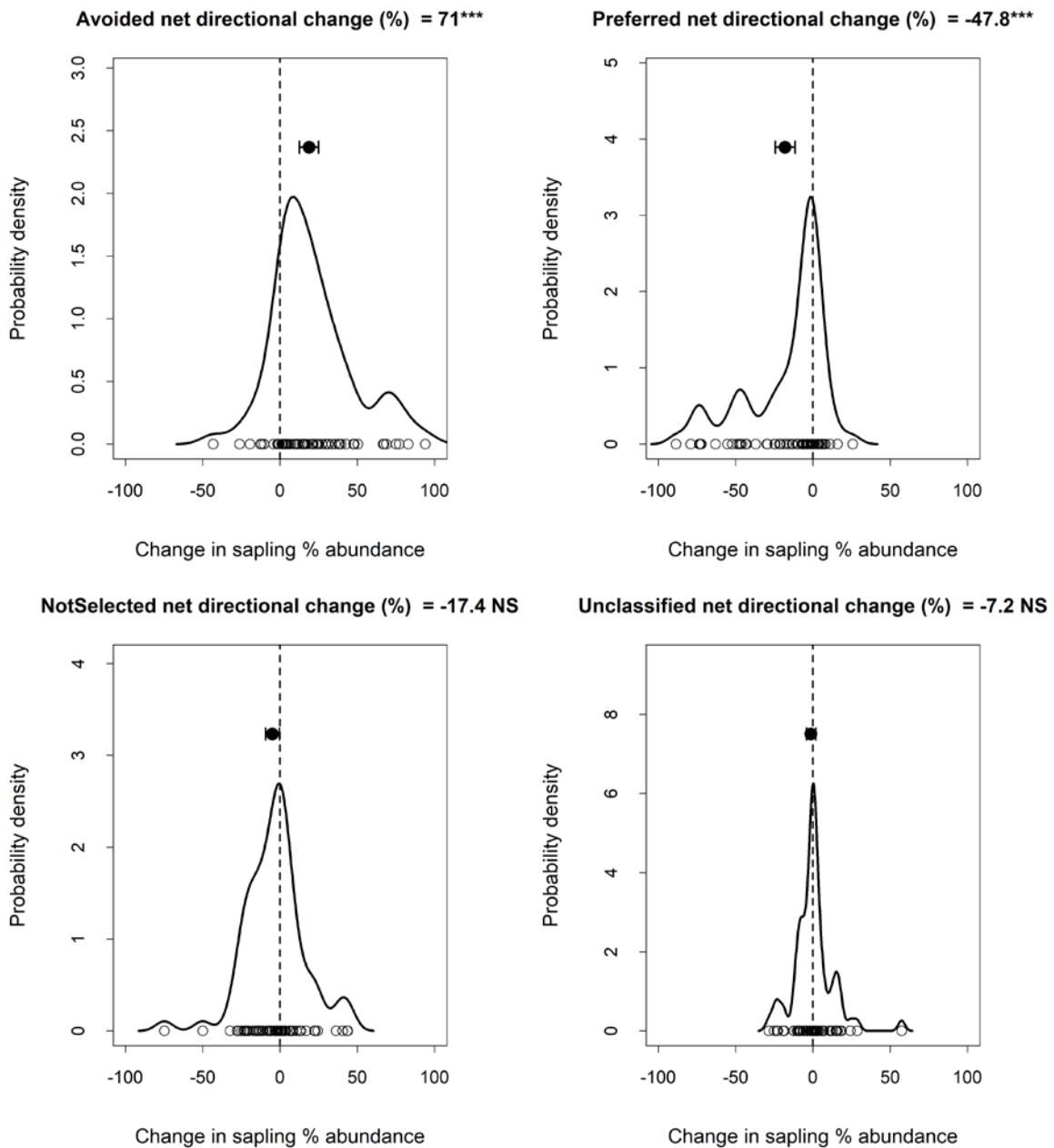

Figure 10: Probability distributions for pairwise (within plot) change between surveys in the relative abundance of saplings of species in different palatability classes in the BOP region. Open circles represent individual plots. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$. Open circles indicate the size of change for individual plots. The solid circle and error bars around it indicate median and 95% confidence limits for the mean plot-level change between surveys.
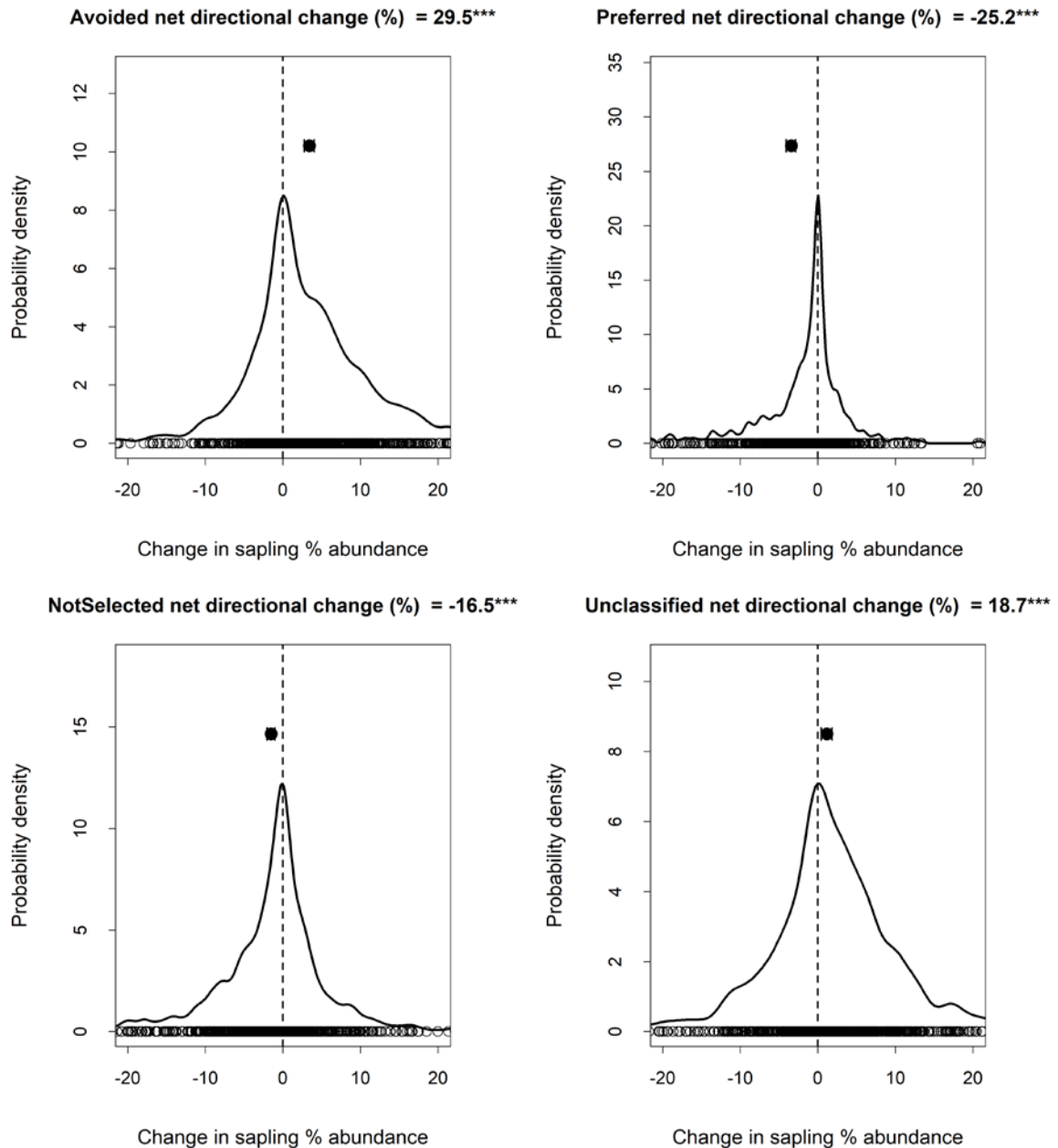
Figure 11: Probability distributions for pairwise (within plot) change in relative abundance of palatability groups in the 'sapling' size class between surveys for all remeasured LUCAS plots. Open circles represent individual plots. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, *p* <0.05; **, *p* < 0.01; ***, *p* < 0.001. Open circles indicate the size of change for individual plots. The solid circle and error bars around it indicate median and 95% confidence limits for the mean plot-level change between surveys.
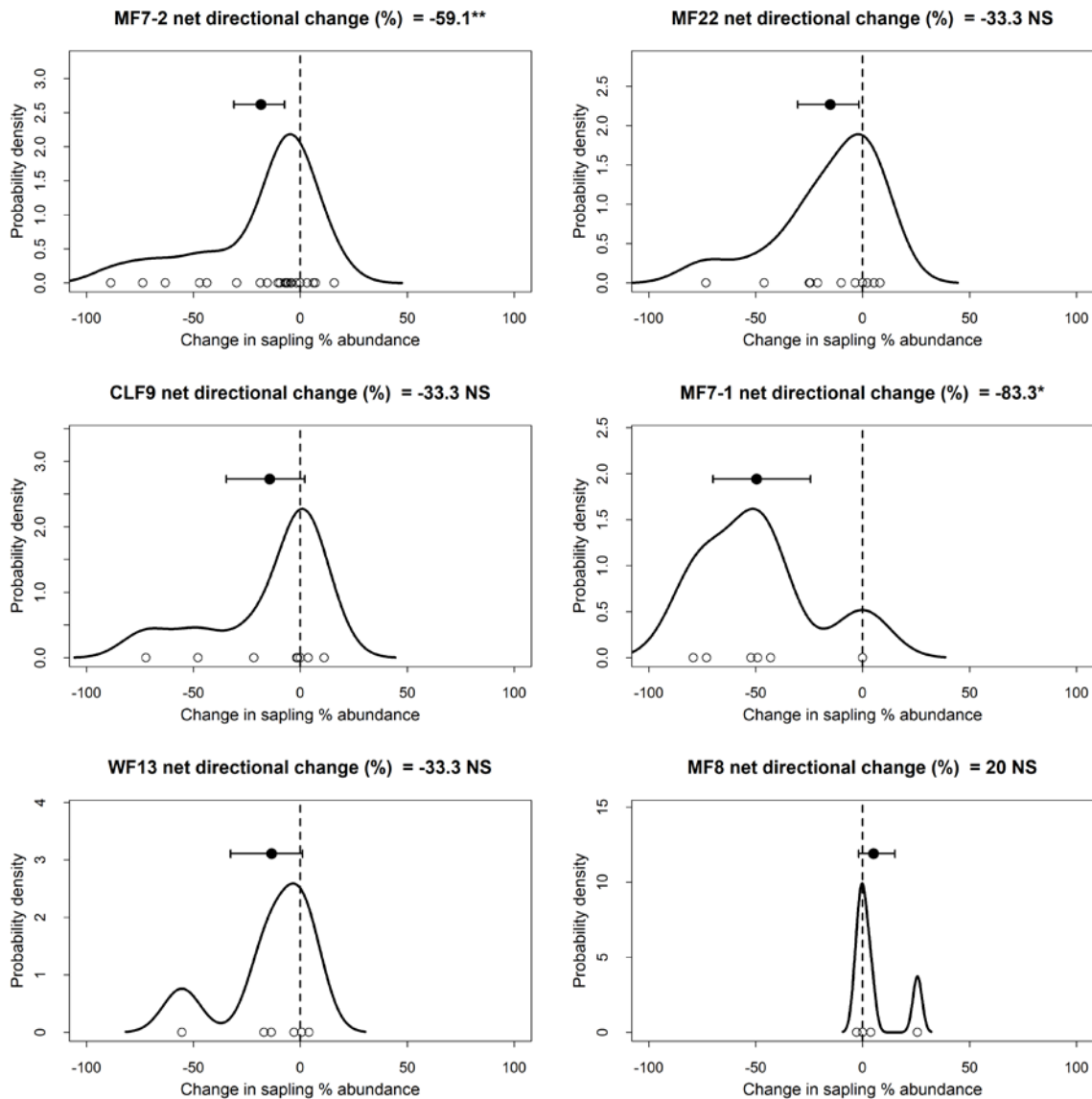
Figure 12: Probability distributions for pairwise (within plot) change in relative abundance of palatability groups in the 'sapling' size class between surveys for each forest type. The alphanumeric codes in the sub-figure headings (e.g. MF7-2) correspond to the ecosystem types described in Table 2. Open circles represent individual plots. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, *p* <0.05; **, *p* < 0.01; ***, *p* < 0.001. Open circles indicate the size of change for individual plots. The solid circle and error bars around it indicate median and 95% confidence limits for the mean plot-level change between surveys.

5.3.4   Seedling abundance

Changes in the abundance of species in each palatability class were smaller for the seedling size class compared to the other two size classes (adult trees and saplings), with only the preferred class showing a marginally significant decrease (*p*=0.1). Despite this, the net change in the number of plots in BOP where abundance of saplings of preferred species decreased (20%) was more than double that for all LUCAS plots in New Zealand (8%, Figs 13 and 14). The abundance of saplings of species in the preferred class declined

significantly in one of the six ecosystem types studied and did not significantly increase in any of them (Fig. 15).
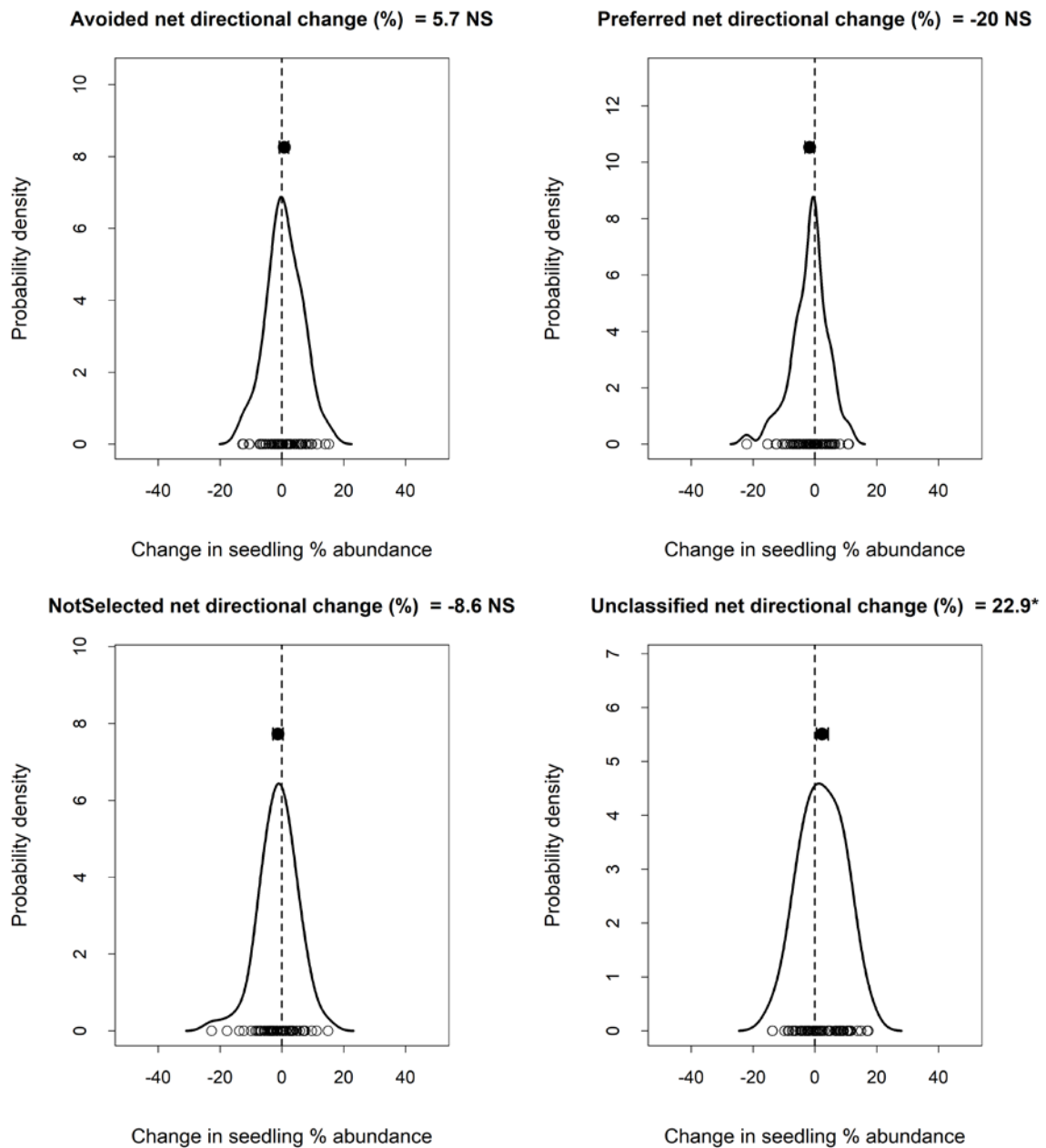

Figure 13: Probability distributions for pairwise (within plot) change in relative abundance of palatability groups in the 'seedling' size class between surveys. The circles represent individual plots. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, p <0.05; **, p < 0.01; ***, p < 0.001. Open circles indicate the size of change for individual plots. The solid circle and error bars around it indicate median and 95% confidence limits for the mean plot-level change between surveys.
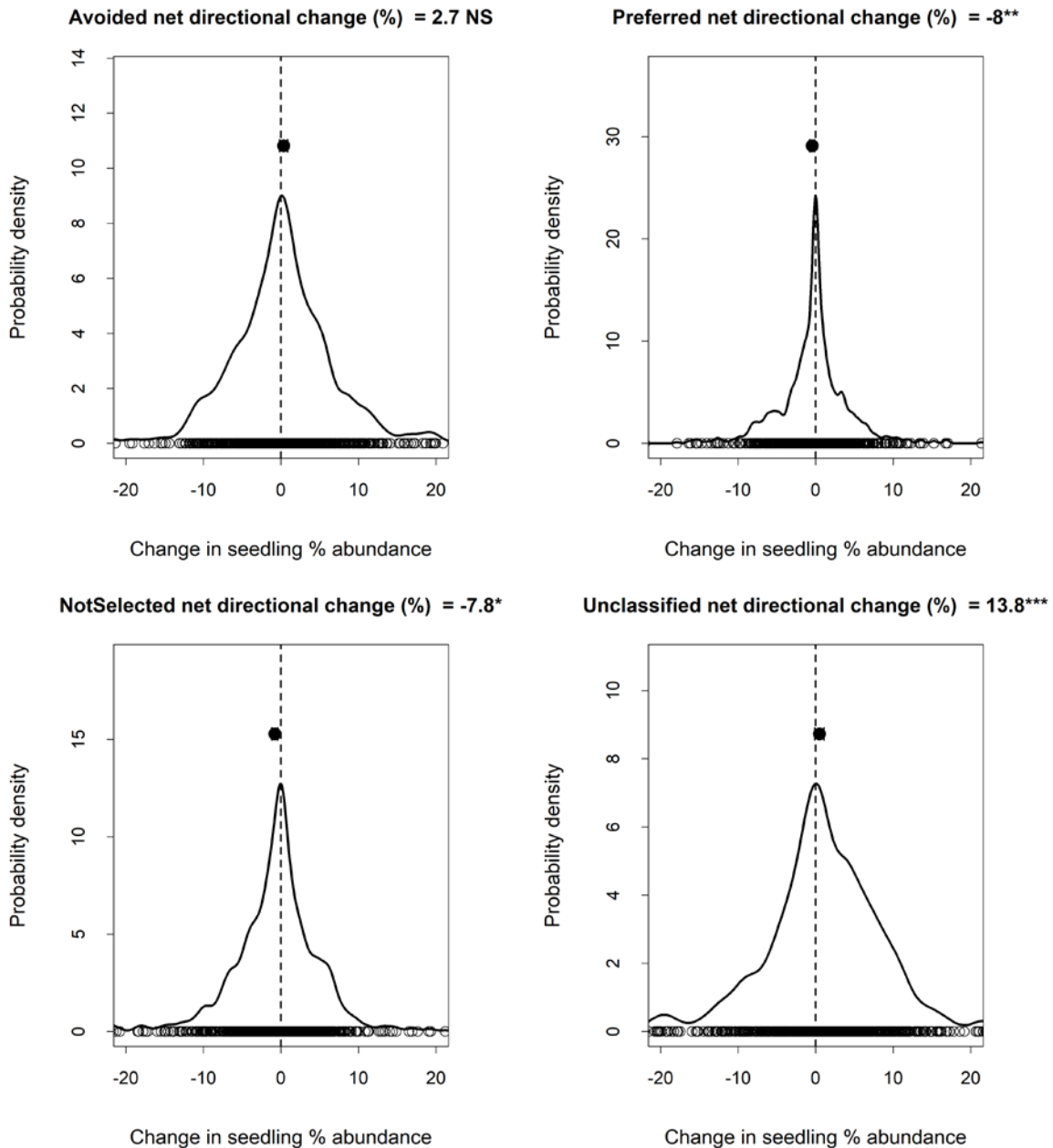
Figure 14: Probability distributions for pairwise (within plot) change in relative abundance of palatability groups in the 'seedling' size class between surveys for all remeasured LUCAS plots. Open circles represent individual plots. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, p <0.05; **, p < 0.01; ***, p < 0.001. Open circles indicate the size of change for individual plots. The solid circle and error bars around it indicate median and 95% confidence limits for the mean plot-level change between surveys.
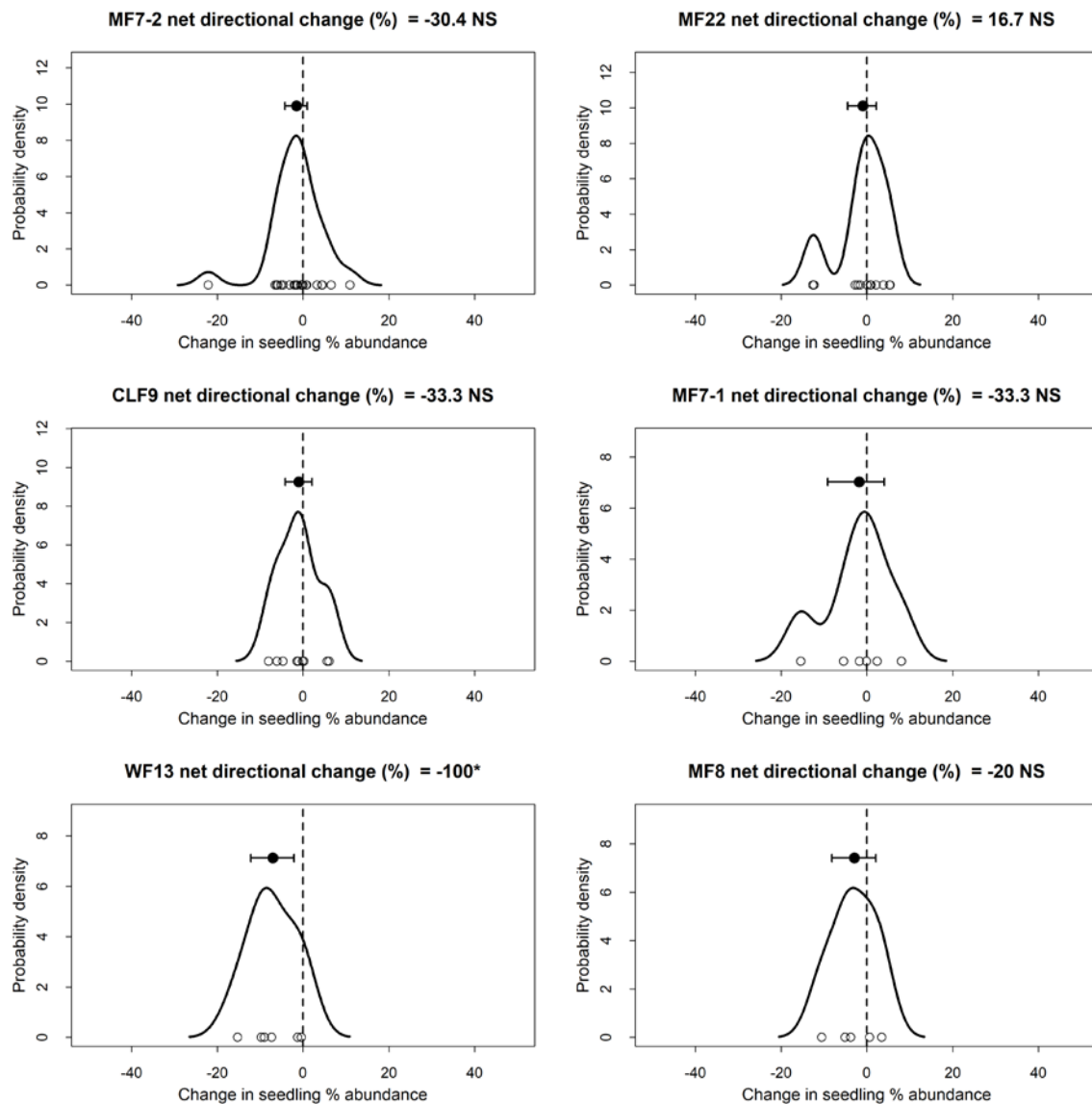
Figure 15: Probability distributions for pairwise (within plot) change in relative abundance of palatability groups in the 'seedling' size class between surveys for each forest type. The alphanumeric codes in the sub-figure headings (e.g. MF7-2) correspond to the ecosystem types described in Table 2. Open circles represent individual plots. Net directional change is 100 x Tdir (which measures the net direction of paired differences expressed as a proportion of the total number of plots). Significance codes are as follows: NS, not significant; *, _p_ <0.05; **, _p_ < 0.01; ***, _p_ < 0.001. Open circles indicate the size of change for individual plots. The solid circle and error bars around it indicate median and 95% confidence limits for the mean plot-level change between surveys.

5.4   Power to detect change in eastern BOP goat control area

Only 26 remeasured LUCAS plots occur within the eastern BOP goat control area. Results from power analyses were very similar for seedlings, saplings and trees size classes (Fig. 16). At current sampling intensity, the 95% confidence interval for the estimated mean observed effect included zero for all effect sizes <0.4 (see small black circles in left-hand column of panels in Fig. 16). This means 70% of plots would need to experience an increase in the relative abundance of species in the "preferred" palatability group to reliably obtain a mean estimate significantly greater than zero (based on equation 2). In all cases, current sampling intensity provides reasonable (~0.9) power to detect a significant

increase in the relative abundance of species in the "preferred" palatability class when a net 60% of plots or more experience an increase (Fig. 16). Thus, with current sampling intensity, the **abundance of preferred species would need to increase in ≥80% of plots to produce a significant result**.
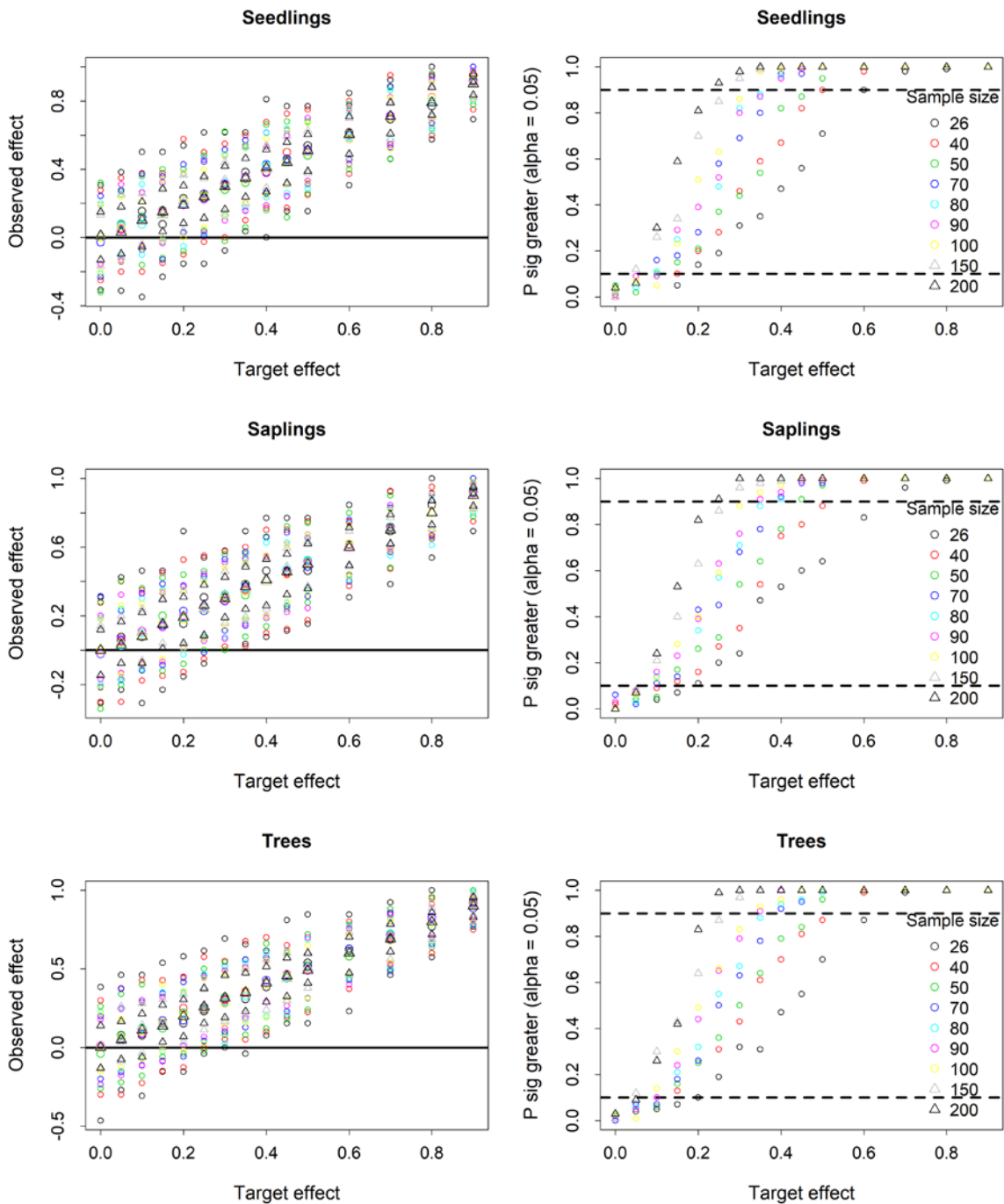

Figure 16: Results from power analyses to assess of LUCAS plots to detect an increase in the proportional abundance of seedlings, saplings and trees for the 'preferred' palatability group. Points of different colour and/or shape indicate different sample sizes. The black circles indicate the sample size currently provided by LUCAS plots in the BOP goat control area. The left-hand column of panels shows the median and 95% confidence intervals for observed effect (i.e. observed *Tdir* values) for each combination of effect and sample sizes simulated. The right-hand column of panels shows the proportion of simulations where a significant increase in the abundance of species in the 'preferred' palatability group was detected. Points occurring above the upper dashed line indicate a >0.9 probability (>90% chance) of detecting a significant result.

6   Discussion

There is strong *prima facie* evidence that forests in the Bay of Plenty (BOP) region have been impacted by ungulate browsing between the first and second LUCAS survey periods and that the level of impact is greater than for the rest of New Zealand's forests. This is visible in the population changes for individual tree species, where those preferred by ungulates tended to decline, while those avoided by ungulates tended to increase. This is further supported by community-level results where the proportional abundance of trees and saplings for the "Preferred" palatability group declined significantly, while that for the "Avoided" group increased (see Table 6 for a summary). Changes in palatability group abundance were greater in the BOP than for New Zealand as a whole. There was little evidence that stand development processes in the BOP differed markedly from the rest of New Zealand, suggesting that the more intense herbivore impacts observed cannot be explained by a greater tendency for transition from early- to late-successional communities in the region.

Table 6: Summary of significant results for changes in tree diameter (DBH) tree populations and 'preferred' palatability group species richness and abundance for a) all LUCAS plots in the Bay of Plenty, b) all LUCAS plots in NZ and c) LUCAS plots within selected forest ecosystem types of the Bay of Plenty

	DBH	Tree pop.	Richness	Preferred species		
				Trees	Saplings	Seedlings
All BOP plots	+	NS	NS	-	-	NS
All NZ LUCAS plots	+	-	NS	-	-	-
CLF9, Red beech, podocarp	+	NS	NS	NS	NS	NS
MF22, Tawa, rimu, northern rata, beech	NS	NS	NS	-	NS	NS
MF7-1, Tawa, mangeao forest	NS	NS	NS	-	-	NS
MF7-2, Rātā, Tawa, kamahi, podocarp	+	NS	NS	NS	-	NS
WF13, Tawa, kohekohe, rewarewa, etc.	NS	NS	NS	NS	NS	-
MF8, Kāmahi, broadleaved podocarp	NS	NS	NS	-	NS	NS

There is sufficient power in the LUCAS plot network to detect region-wide changes in stand structure and palatability of forests in the Bay of Plenty. However, the ability to detect changes for some of the forest types identified by Singers (2014) is marginal. Among individual forest types, the MF7-1, MF7-2, MF-8 and W13 types all showed a significant decline in the abundance of species preferred by ungulates in at least one size class. However, with the low replication for some types, it is difficult to know whether the lack of a significant result is simply due to small sample size. The **number of additional plots** required will depend on the **indicators, forest types and effect size for which power to detect change is desired**. LUCAS provides adequate power to detect widespread increases **(i.e. 80% of plots experiencing an increase)** in the abundance of 'Preferred' species in the **eastern BOP goat control zone**. Detection of less widespread increases will require greater replication. Below we discuss alternative options for benchmarking the BOP region against the rest of LUCAS and sampling design for increasing replication in the eastern BOP goat control zone or for individual forest ecosystem types.

6.1 Better evidence for ungulate impacts

Although ungulates are highly likely to be the main herbivore group driving observed changes in species and community-level indicators in Bay of Plenty forests, without information on ungulate and marsupial (i.e. possums and dama wallabies) abundance for the entire region, it is difficult to quantify the relative impact of either group on indicators. We currently only have systematically collected data on ungulate and possum abundance for LUCAS plots on Public Conservation Land (PCL), which are part of the Department of Conservation Tier 1 monitoring programme. Interpreting changes in forest composition indicators (both for the entire region, and for individual forest types) would be greatly aided by extending Tier 1 ungulate monitoring to all LUCAS plots in the Bay of Plenty Region. The Tier1 data do suggest that ungulate abundance is much higher in the Bay of Plenty than for the rest of New Zealand (Appendix 1), which supports the interpretation of our results as indicative of ungulate browsing patterns. However, possum abundance in the Bay of Plenty is also comparatively high, so it is probable that some of the apparent ungulate impacts are partially due to possums. A further complication is that the animal abundance data we have are for a later time period than that for which vegetation changes where analysed. A full dataset for the third LUCAS survey period should be available in the next 2 years, and this will align much more closely with the time period for which animal data are available. Thus, the analyses presented in this report, should be applied in examining changes between the second and third survey period to provide an updated picture of trends in forest composition for the Bay of Plenty region. Obtaining systematic data on ungulate abundance across the entire region will also greatly aid interpretation of these analyses.

Finally, new methods are required to fully account for forest stand development processes when interpreting change in forest composition indicators. Past studies (Mason et al. 2010) have shown that recovery following removal of ungulates is greatest in forests where recruitment is highest (i.e. the total number of trees increases), so that changes in forest composition indicators may be dependent on stand development processes. To date, we lack analytical methods directly accounting for stand development processes when assessing change in forest composition indicators. In this report we have addressed the question in an indirect way, by assessing evidence for widespread competitive thinning, disturbance and recruitment in the Bay of Plenty, relative to the rest of New Zealand. Directly accounting for stand development processes requires information on how individual species respond to these processes in the absence of intense ungulate herbivory.

6.2 Benchmarking forest composition in the Bay of Plenty against the rest of NZ

We compared results for the Bay of Plenty with those for the entire LUCAS network to place observed changes in a national context. One drawback of this approach is that it compares plots in the Bay of Plenty with plots that differ in some important aspects.

Probably the biggest problem is that large numbers of LUCAS plots occur in regions where there is a restricted pool of palatable tree species (McGlone et al. 2010) to colonise stands where ungulate browsing pressure has been reduced by management. In such areas, there

will be limited scope for forest composition indicators based on palatability groups to change in response to ungulate management. We currently lack reliable data on regional species pools for individual LUCAS plots and analytical methods to account for differences in species pools in assessing change in indicator values.

Until suitable data and analytical methods are available for this, there are two primary options to refine our benchmarking approach to more accurately place forest composition changes in the Bay of Plenty in a national context. First, we can use the national woody vegetation classification system (based on species composition data collected as part of LUCAS, Wiser et al. 2011) to match plots in the Bay of Plenty with plots of the same type in LUCAS. This would have the advantage of benchmarking Bay of Plenty plots against those throughout New Zealand containing similar vegetation. This would be relatively easy to implement, as all LUCAS plots have been assigned to vegetation types within this classification. Further this would aid interpretation of changes for individual forest types, as well as the region as a whole.

The other option is based on the 'propensity scores' approach developed for the Department of Conservation, which is intended to account for environmental differences when comparing indicators between datasets from different areas. This approach would be relatively cumbersome, as it requires selection of predictor variables that are most relevant to the metric being examined. Further, this method is still the object of active research and it remains unclear under which contexts it can be used with confidence.

6.3   Increasing replication in the eastern Bay of Plenty goat control zone

Although we have provided advice on the power of LUCAS plots to detect changes in the goat control zone, the question of how many plots are needed really depends on the effect size it needs to detect. With the current sampling intensity provided by LUCAS, we have power to detect change when at least 80% of the goat control zone experiences an increase in the abundance of species preferred by ungulates. This may represent a very ambitious target for the effects of goat control on vegetation, especially in the short term (i.e. 5–10 years). Identifying the necessary level of replication requires further consideration in the effect size we can reasonably expect from goat control efforts. If further plots are required, we suggest that these follow the balanced acceptance sampling (BAS) approach employed by the Department of Conservation (van Dam-Bates et al. 2018).

7   Conclusions

- Ungulate impacts on forest species composition appear to be more intense in the Bay of Plenty Region than the rest of New Zealand.
- There are enough LUCAS plots to detect changes in indicators of forest composition in the Bay of Plenty Region as a whole, but more plots would be needed to detect changes for some individual ecosystem types.
- Changes in tree diameter (increasing significantly for two forest types) and tree population size (no significant change in any forest type) indicate that forests in the region have not experienced widespread canopy disturbance or changes in tree

recruitment or tree population size due to competitive thinning. This indicates that apparent ungulate impacts are unlikely to be driven primarily by natural forest dynamics.

- The LUCAS plot network will be capable of detecting recovery in the eastern Bay of Plenty goat control area if positive responses to management are widespread (i.e. across 80% of the total area). For smaller widespread changes, more plots will be needed.

8   Recommendations

- Consideration should be given to increasing ungulate and possum control efforts in the Bay of Plenty to reverse declines in species preferred by ungulates.
- These analyses should be repeated when a full dataset for the third LUCAS survey period is available, particularly to test whether trends for declines in palatable species are continuing and whether these can be more accurately related to changes in the relative abundance of herbivores
- Trends in the forest composition of LUCAS plots in the Bay of Plenty should be benchmarked against changes in LUCAS plots of the same vegetation type elsewhere in New Zealand
- Further consideration is needed to determine whether current sampling intensity provided by LUCAS provides desired power to detect changes for individual forest types or the impacts of the Eastern BOP goat control programme on forest communities.
- Any new monitoring plots established should be located following the balanced acceptance sampling approach employed by the Department of Conservation.
- Extension of Tier1 animal indicators (particularly for ungulates and possums) to LUCAS plots outside public conservation would help in confirming the effects of goat (and deer) impacts and goat control efforts on forest composition in the Bay of Plenty.

9   Acknowledgements

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Appendix 1 – Tier 1 possum and ungulate abundance in the Bay of Plenty and for all of New Zealand.

Tier 1 possum abundance

Tier 1 ungulate abundance
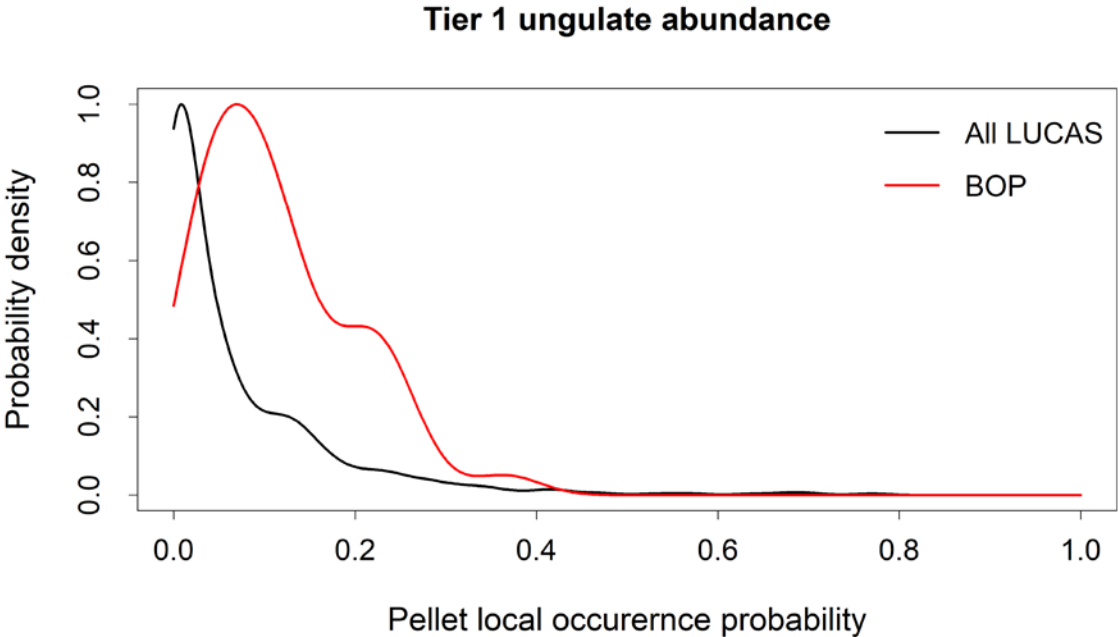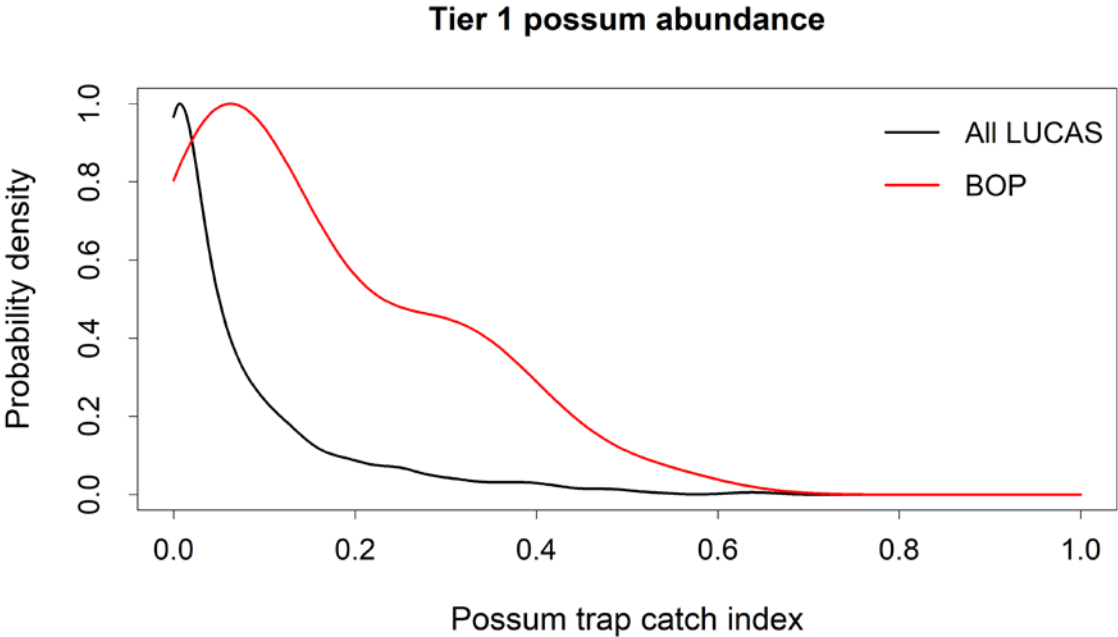
Tier 1 abundance estimates for possums and ungulates at LUCAS indigenous forest and shrubland survey locations in the Bay of Plenty (BOP) and across New Zealand (All LUCAS). In both cases, the peak of the Probability distribution curve for the Bay of Plenty (the red curve) occurs at higher values than (i.e. to the right of) that for the whole of New Zealand. This shows that possum and ungulate relative abundance in the Bay of Plenty is, on average, higher than for the rest of New Zealand. See Mason and Bellingham (2018) for details of Tier 1 data collection and analyses.