Manaaki Whenua
Landcare Research

Prioritising regional-scale permanent forest plot networks

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Prioritising regional-scale permanent forest plot networks

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Manaaki Whenua – Landcare Research

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Summary

Project and client

- The Department of Conservation (DOC) requested a review of regional- or catchment-scale forest plot networks. The purpose of this review was to support a joint programme of research with the Ministry for Primary Industries (MPI) to understand opportunities for maximising carbon storage in indigenous forest ecosystems.

Objectives

- Outline criteria that define a long-term, regional- or catchment-scale forest plot network; then extract qualifying plot networks from the National Vegetation Survey (NVS) Databank; and summarise each plot network.
- Outline a rationale for evaluating each qualifying plot network in terms of its longevity, coverage, and utility for delivering knowledge on the relationship between forest carbon stocks and browsing animal impacts, climate-related disturbance events, and ongoing pressure from climate change.
- Use this rationale to prioritise plot networks for remeasurement. Provide maps showing the locations of highly prioritised plot networks.
- Provide advice on the critical actions that should be considered in any strategic plan for remeasuring and maintaining long-term regional- or catchment-scale plot networks.

Methods

- We used an earlier review of forest plot networks to guide our choice of criteria, and we used that review alongside current literature and climate-change forecasts to outline a rationale for evaluating each plot network.
- We searched the NVS Databank for all projects that that met our criteria.
- We summarised and prioritised each plot network in terms of how well it would deliver knowledge on browsing animal impacts, climate-related disturbance events, and ongoing pressure from climate change.

Results

- We identified > 5,000 plots with > 20,000 plot measures.
- We identified up to 921 plots from 25 networks as high priority plot networks.
- From our high priority plot networks, we selected 249 plots across 11 high priority plot networks for remeasurement in the coming year.

Recommendations

- Remeasure 249 plots across 11 high priority plot networks in the coming year in the following places:

    - Bench Island/Te Wāhitauā[1] (off Stewart Island/Rakiura)
    - Ulva Island (off Stewart Island/Rakiura)
    - Exclosure plots on Stewart Island/Rakiura
    - Chew Tobacco Bay (Off Stewart Island/Rakiura)
    - Port Adventure (off Stewart Island/Rakiura)
    - Northern Coastal plots on Stewart Island/Rakiura
    - Isolated Hill (Marlborough)
    - Mount Fyffe (Canterbury)
    - Paparoa National Park (Nelson)
    - Whitcombe River valley (Westland)
    - Mount Taranaki (western North Island).
- Invest in existing long-term permanent plot networks in northern and north-eastern North Island, notably those in Puketītī, Waipoua Forest, Great Barrier Island (Aotea Island), and Pirongia.
- Invest in existing long-term permanent plot networks in the central and southern North Island on Mount Taranaki, Pureora Forest Park, Rotorua Lakes, Kaweka Range, and the Tararua and Remutaka Ranges.
- Invest in existing long-term permanent plot networks in the South Island in the Harper and Avoca River valleys, Kokatahi, Stafford Bay and the Hope River, Caple and Greenstone River valleys, Fiordland North (includes the Murchison Mountains) areas, and on Secretary Island.
- Establish new permanent forest plots on Whenua Hou[2] in partnership with Rakiura Māori.
- Review, summarise, and evaluate available exclosures to select a national network and identify gaps. Identify the key animal abundance measures that need to be collected around each exclosure so we can attribute exclosure effects to known densities of specific animals with greater confidence.
- Identify a network of large permanent plots that only measure large trees.
- Coordinate investment with regional councils to broaden the consortia of agencies who benefit from maintaining regional-scale plot networks.
- Measure birds and pest mammals on regional-scale plot networks, and collect soil chemistry data, so that data are maximally comparable with data from the Tier One plot network.
- Align remote-sensing research to sites with regional-scale plot networks to maximise data integration across these two approaches to forest monitoring.

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[1] Names as in New Zealand Gazetteer (NZG) (see https://gazetteer.linz.govt.nz/place/16422), where possible. Where one or more official or unofficial place name is known, we have chosen at times to show both te reo and English names separated by a spaced oblique in this report. This is not to be confused with the official dual name notation of NZG which uses obliques or brackets for official dual names (e.g. Stewart Island/Rakiura).

[2] We use Whenua Hou in this report to refer to Codfish Island/Whenua Hou

1 Introduction

The Department of Conservation (DOC) and Ministry for Primary Industries (MPI) are co-leading a programme of research to understand opportunities for maximising carbon storage in indigenous forest ecosystems[3]. Central to the success of this programme is a robust understanding of how natural disturbance and management interventions drive changes in forest carbon stocks over time. Long-term permanent plot networks provide vital information about changes in forest carbon stocks that can be interpreted alongside additional environmental data, and data on pest animal abundance, to reveal key drivers of change.

Monitoring activities within DOC are organised within a hierarchical framework (Figure 1).

Tier One monitoring is broad in scale, and includes a network of permanent vegetation plots across Public Conservation Land (PCL) on an 8 km grid (Bellingham et al. 2020). This grid of Tier One plots provides data on forest state and trend from an unbiased sample (MacLeod et al. 2024). Some parts of New Zealand are well served by Tier One; others much less so. The northern North Island is poorly served by Tier One, relative to other parts of NZ that have extensive areas of public conservation lands with indigenous forest (e.g. Kahurangi National Park, West Coast of the South Island, Fiordland).

Tier Two monitoring is more targeted than Tier One and includes regional- or catchment-scale networks of vegetation plots installed to understand the outcomes of specific management activities or the responses by ecosystems to natural disturbance events. These plot networks were often installed to address a specific pest animal species or forest type. Often there are detailed records of management activities available, or data on pest animal abundance that support robust interpretation of changes in the vegetation.

Tier One and Tier Two complement one another; Tier One reveals spatial patterns and emerging trends (the 'big picture') while Tier Two allows managers and researchers to investigate particular forest types, sites, events, and to assess the effectiveness and outcomes of management activities. Tier One monitoring provides essential interpretive context for Tier Two monitoring; for example, data from Tier Two networks might suggest that management activities have caused observed changes, and Tier One data (e.g. from unmanaged sites in the same region or environmental range) may or may not provide support for that assumption. Conversely, Tier Two data can provide the information to show local variation about any derived from Tier One data alone (e.g. variation in carbon stocks and flux in particular regions or forest types).

Tier Two plot networks are replicated at a regional- or catchment scales, allowing greater statistical power to quantify change and power to attribute that change to specific drivers at smaller spatial scales than can be achieved with Tier One. Tier One plots have been measured since 2002; many Tier Two plot networks were installed in the 1970s or 1980s

[3] See: https://www.mpi.govt.nz/dmsdocument/54544/direct

providing a longer record of change that can be vital for interpreting change in forest ecosystems (Phillips 2023).

One of the original intentions of the national monitoring framework (Lee et al. 2005) was that data from a national-scale plot network (Tier One) would be integrated with data from regional-scale plot networks (Tier Two). This would place regional trends in a national context to support attribution of trends to national-scale or regional-scale drivers.

The remit of this report is to focus on Tier Two permanent forest plot networks.

Figure 1. The Department of Conservation's Biodiversity Monitoring and Reporting System[4].

DOC and MPI requested research to identify 'Tier Two' long-term permanent plot networks in forest ecosystems that should be prioritised for measurement. They have requested plot networks that could tell them about how carbon stocks respond to a suite of pressures and historical disturbance events that occur individually and in combination with each other with a particular interest in:

- browsing by non-native herbivorous mammals (ungulates, possums), including in secondary forests that established after anthropogenic disturbance
- episodic drought events and progressive shifts in climate
- canopy-replacing storm and cyclone events.

[4] Image sourced from https://www.doc.govt.nz/our-work/monitoring-and-reporting-system/, April 2024.

Some of these pressures are widespread (e.g. possums are ubiquitous throughout indigenous forests on public conservation lands (Bellingham et al. 2000) while others are more localised (e.g. cyclone-affected forests). The focus here is on finding long-term permanent plot networks that can provide information on how forest carbon stocks have responded to, and are continuing to respond to, these pressures and events.

There is no substitute for remeasuring permanent plots in forests to provide the fundamental data to quantify change in forest structure and carbon stocks, and to allow correct attribution to the dynamic drivers of change in forests (Phillips 2023). New Zealand cannot rely on data from other countries to provide this understanding of changes in our forests because (for example): 93% of our woody plants occur nowhere else (McGlone et al. 2001); growth rates of our trees are slower than in many temperate climates (Bee et al. 2007); and New Zealand is one of the very few places in the world where mammalian herbivores are all non-native.

We delivered interim advice to the Department of Conservation in October 2023. In that interim advice, we focused on Stewart Island/Rakiura[5] and recommended a set of permanent plots there. To maintain consistency with that interim advice, we have retained our interim advice here (see Section 4.3 Stewart Island/Rakiura) and added further recommendations for the North and South Island. This report is the full and final version.

2 Objectives

- Outline criteria that define a long-term, regional- or catchment-scale forest plot network; then extract qualifying plot networks from the National Vegetation Survey (NVS) Databank; and summarise each plot network.
- Outline a rationale for evaluating each qualifying plot network in terms of its longevity, coverage, and utility for delivering knowledge on the relationship between forest carbon stocks and browsing animal impacts, climate-related disturbance events, and ongoing pressure from climate change.
- Use this rationale to prioritise plot networks for remeasurement. Provide maps showing the locations of highly prioritised plot networks.
- Provide advice on the critical actions that should be considered in any strategic plan for remeasuring and maintaining long-term regional- or catchment-scale plot networks.

[5] As noted in the Summary (note 1). This report will use place names as in New Zealand Gazetteer (NZG) (see https://gazetteer.linz.govt.nz/place/16422), where possible. Where one or more official or unofficial place name is known, we have chosen at times to show both te reo and English names separated by a spaced oblique in this report. This is not to be confused with the official dual name notation of NZG which uses obliques or brackets for official dual names (e.g. Stewart Island/Rakiura).

3 Approach

3.1 Criteria that define a long-term, regional- or catchment-scale forest plot network

We used an earlier review of permanent forest plot networks (Bellingham et al. 2000) and metadata available from the National Vegetation Survey (NVS) Databank (www.nvs.landcareresearch.co.nz) to identify the following criteria that defined a long-term, regional- or catchment-scale forest plot network.

- Plots must sample naturally occurring indigenous forests.
- Plots must sample at regional, local, or catchment scales. A 'region' was defined here as a local-government region (e.g. Westland). 'Local' was defined as any scale less than a region and greater than an individual catchment.
- Plots must be permanently marked.
- Plots must have been remeasured at least once, with at least 10 years between the first and last measurement. Because the austral summer spans 2 calendar years, we were inclusive and allowed plot networks with a 9-year interval since these may sample an interval close to a decade (e.g. 1981/82 to 1990/91 could include a decade).
- Plots must be larger than 350 m^2. Although the standard forest plot size in New Zealand is 20 m × 20 m, some plots have one or more boundary distances that are < 20 m, hence the true area is slightly less than 400 m^2. Smaller plots are sometimes used to measure forest composition, but as plot size decreases, the variance among plots in the number of large trees increases. Since much of the carbon in tall forest is held in large trees (Slik et al. 2013; Holdaway et al. 2017; Allen et al. 2023a), larger plots are preferable for sampling forest carbon stock dynamics. We did not apply an upper limit on plot size.
- Optimally, plot networks should be designed so that the landscape is sampled objectively by plots. However, this had to be traded-off against the value that can be derived from (longer) time series of data; so we retained subjectively located plots with multiple measures or with >20 years of history;
- Plot networks should not sample forests that have been subject to specific experiments (e.g. wilding pine removal trials; beech thinning trials). However, we retained exclosure plots because the effects of herbivory are one of the three key drivers being considered.
- Plots must be replicated at a site so as to constitute a 'network'. In some instances (e.g. the inclusion of Bench and Ulva Islands) this was achieved by aggregating several small groups of plots to form a network. We excluded data sets that were only represented by a single, large, mapped stand – such as the one in the Ōrongorongo River Valley (Campbell 1990).
- Plots must sample PCL because only these lands are within the remit of this project. Private land, Te Urewera, other lands owned and administered by Māori (e.g. by Te Korowai-o-te-Tonga at the southern end of the Kaipara Harbour), and regional and city council lands were out of scope.

- Plots must have been last visited and measured within the last 25 years (1999). Our rationale was: (i) to focus on those plots where we could be confident that the plot could be reconstructed from corner pegs and seedling pegs; and (ii) to place a time constraint on the amount of stem mortality and recruitment that could have occurred since the last measurement. We recognised that many plot networks would not have been visited over the period since 1998 when the Carbon Monitoring System (CMS), Land Use and Carbon Accounting System (LUCAS), and DOC's Tier One Biodiversity Monitoring Programme have been designed and implemented. While forest plots in New Zealand are often remeasured at intervals of 5–10 years, we adopted the longer (25 year) interval to reduce the risk of excluding key plot networks that could be remeasured now and would continue to yield high quality data.

We made two exceptions to the criteria above when we included the Raukūmara Range and Paparoa National Park, both of which have only been measured once. We justified these exceptions because these sites presented an opportunity to understand the response by forest carbon stocks to canopy-replacing disturbance events under pervasive herbivory from ungulates. As this combination of disturbance and herbivory was a key focus for both MPI and DOC, we chose to include Paparoa National Park (damaged by Cyclone Ita, in 2014) and Raukūmara Range (where landslides are commonplace, including those in the aftermath of Cyclone Gabrielle, in 2023), both of which have high herbivore pressure.

We searched the NVS Databank for all projects that that met our criteria. We identified > 5,000 plots with > 20,000 plot measures. We organised plots by survey (although these have changed over the years, hence we grouped some surveys together). We then summarised:

- project name(s)
- whether plots were objectively or subjectively located
- plot size(s)
- number of plots
- date of each measurement.

Our review focused exclusively on data sets that had been digitised. While the NVS Databank contains digital data on most remeasurements of the plot networks named in this report, some remeasures may be missing, and not all data sets in NVS have been digitised. Hence, our review may have omissions.

3.2 Rationale for prioritising networks

For each of the main islands of New Zealand (North, South, Rakiura), we prioritised networks as high, moderate, or low priority for remeasurement and ongoing maintenance. We achieved this by balancing the following considerations:

Quality of each plot network

We gave greater priority to networks where plots:

- were objectively located within a catchment or region
- had two or more measures
- the most recent measure was within the last 25 years
- had ancillary data available to support interpretation
- spanned back to the 1970s or 1980s (as these long temporal perspectives offer the greatest additional value to national-scale datasets such as LUCAS and Tier One).

Geographic spread across all networks

Storms, droughts, climate change, and pest animals are widespread spatially. Climate change and pest animals impact forests across the country, but impact may vary across regions. By contrast, storms and droughts can affect any part of the country, but individual events are episodic and localised in space and time. This means that focusing plots in a small number of regions is unlikely to produce plot networks in the 'right place' to capture the many, interacting effects of global change on ecosystems. On that basis, we identified plot networks that achieved geographic spread to ensure that they sampled the full range of major forest physiognomic groups and shrublands (Wiser et al. 2011; Wiser & De Cáceres 2013; Bellingham et al. 2020). Geographic spread also helps to achieve an important social aspect of ecological monitoring: meeting regional interests and ensuring that communities have data relevant to their location to inform management activities.

Capacity to reveal browsing mammal impacts

Inferences about browsing animal impacts can be drawn from sites where animals are absent, previously present but now eradicated, at ambient densities, or abundant. However, key to drawing reliable inferences is a knowledge of animal management activities, the species of animals present, and data on palatability of plant species to each animal species. Many plot networks were installed in the 1970s and 1980s to explicitly study animal impacts, and we relied on metadata in NVS to understand these motivations and include them here. We prioritised plot networks that were dominated by palatable tree species, had a long history of management, or were managed for both hunting and conservation.

We considered whether plot networks were likely to be dominated by the tree species kāmahi (*Pterophylla racemosa*), as such forests have been reported to have declining carbon stocks over the period 2002–2014 (Paul et al. 2021). Kāmahi is palatable to and preferred over many other species by ungulates (Forsyth et al. 2002); and is palatable to and sometimes preferred over other species by possums (Nugent et al. 2001). Browsing has been implicated as a cause of carbon stock decline in kāmahi-dominated forests (Hackwell & Robinson 2021).

Many high-quality plot networks sample beech-dominated forests (e.g. the Murchison Mountains, Kaweka Range) with a long history of deer management that are also of great value. It has been hypothesised that pervasive herbivory following canopy disturbance events could limit beech forest recovery and lead to a decline in forest carbon stocks (Duncan et al. 2006).

Some regions have a particularly active hunting culture, or a (potential) deer herd of national interest. Quantitative, unbiased data on forest dynamics may be valuable in these places to support an evidence-based approach to forest management. Although we lack a spatial layer of where our hunting culture is most active, we can draw on the distribution of prized deer species (e.g. sika, white-tailed) to prioritise areas likely to be considered valuable for hunting.

Evidence suggests that the greatest benefits for forest carbon stocks from controlling herbivores can be achieved in regenerating forests (Holdaway et al. 2012; Carswell et al. 2015) because management interventions may re-direct the course of forest succession. Accordingly, we prioritised plot networks in regenerating forests.

Capacity to reveal the effects of episodic droughts and progressive shifts in climate

Projected changes in rainfall across New Zealand vary according to season and region and all are highly uncertain (Ministry for the Environment 2018). Using a projection for 2040 based on a Representative Concentration Pathway (RCP) of 8.5 (Figure 2), climate change models predict the largest changes are likely to be during winter when it is forecast to be wetter in the western South Island, and drier in eastern New Zealand. More modest changes are forecast for spring with wetter conditions in the southern and western South Island, and drier conditions in eastern and northern New Zealand (Figure 2).

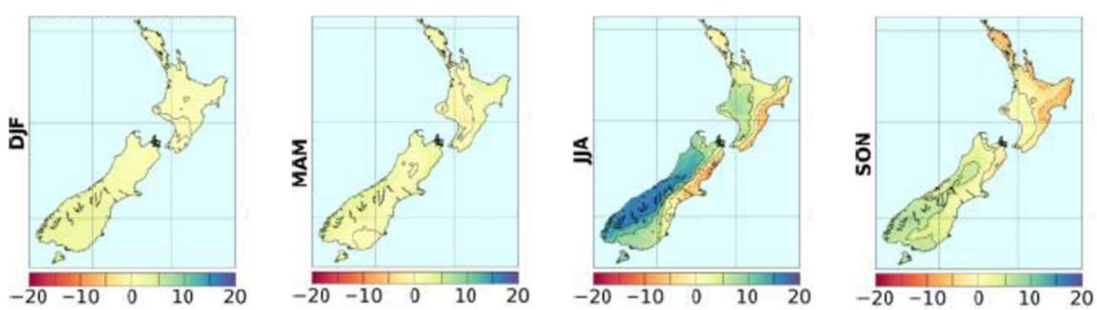

Figure 2. Projected changes in seasonal precipitation (as a %) derived by downscaling the 2013 IPCC (Intergovernmental Panel on Climate Change) Fifth Assessment Report's climate model simulations (known as the CMIP5 models) for 2040 under the Representative Concentration Pathway (RCP) 8.5. DJF (December, January, February i.e. summer); MAM (March, April, May i.e. autumn); JJA (June, July, August i.e. winter); SON (September, October, November i.e. spring). Note that changes in winter (JJA) precipitation are >20%. (Source: Adapted from Ministry for the Environment 2018, Fig. 39[6])

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[6] This report was published under Crown copyright. The Ministry for the Environment state on their website that 'Unless indicated otherwise for specific items or collections of content (either below or within specific items or collections), this copyright material is licensed for re-use under the Creative Commons Attribution 4.0 International licence' (https://environment.govt.nz/about-this-site/copyright/, accessed May 2024).

The ecological consequences of these changes will include interacting direct and indirect effects (Macinnis-Ng et al. 2021) making it challenging to predict outcomes and prioritise monitoring networks. While there may be only small direct effects of large increases in rainfall in regions that already receive annual precipitation of >10,000 mm, the indirect effects via more frequent landslides (Glade 1998) and reduced solar radiation and photosynthetic activity may be substantial. Conversely, small reductions in rainfall in regions that already receive annual precipitation of < 1,000 mm may have strong, direct effects on tree growth, tree mortality rates, and ecosystem function.

We also took a retrospective approach and considered the extent to which plot networks had already experienced a change in moisture availability. We calculated the trend in the Standardised Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al. 2010) at a plot level over the period 1910–2019 using interpolated open-source weather data on a 1 km scale (Etherington et al. 2022). The SPEI was calculated over a 24-month interval. Statistical trends were estimated using Spearman rank correlation coefficients (r_s) between year and the SPEI values, and, where they were statistically significant, we mapped these coefficients as either positive or negative to identify regions and plot networks where moisture availability has already declined or increased over the last century (Figure 3). From 4,101 plot locations, 91% had a significant trend ($P \leq 0.05$) and of those, 63% trended drier and 37% trended wetter. In the North Island, there was an indication that plot networks in western regions were likely to trend wetter, but central eastern regions were a mixture of both wetter and drier (Figure 3). No spatial pattern was apparent in the South Island. These analyses are based on interpolated weather data and the paucity of climate stations in those parts of the South Island where we have plot data contribute substantial uncertainty to these analyses (Etherington et al. 2022).

Based on future projections, and to a lesser extent on trends to date, we considered plot networks in western and north-eastern South Island, and north and eastern North Island, as those where changes in seasonal precipitation may have pronounced effects on forest carbon stock.

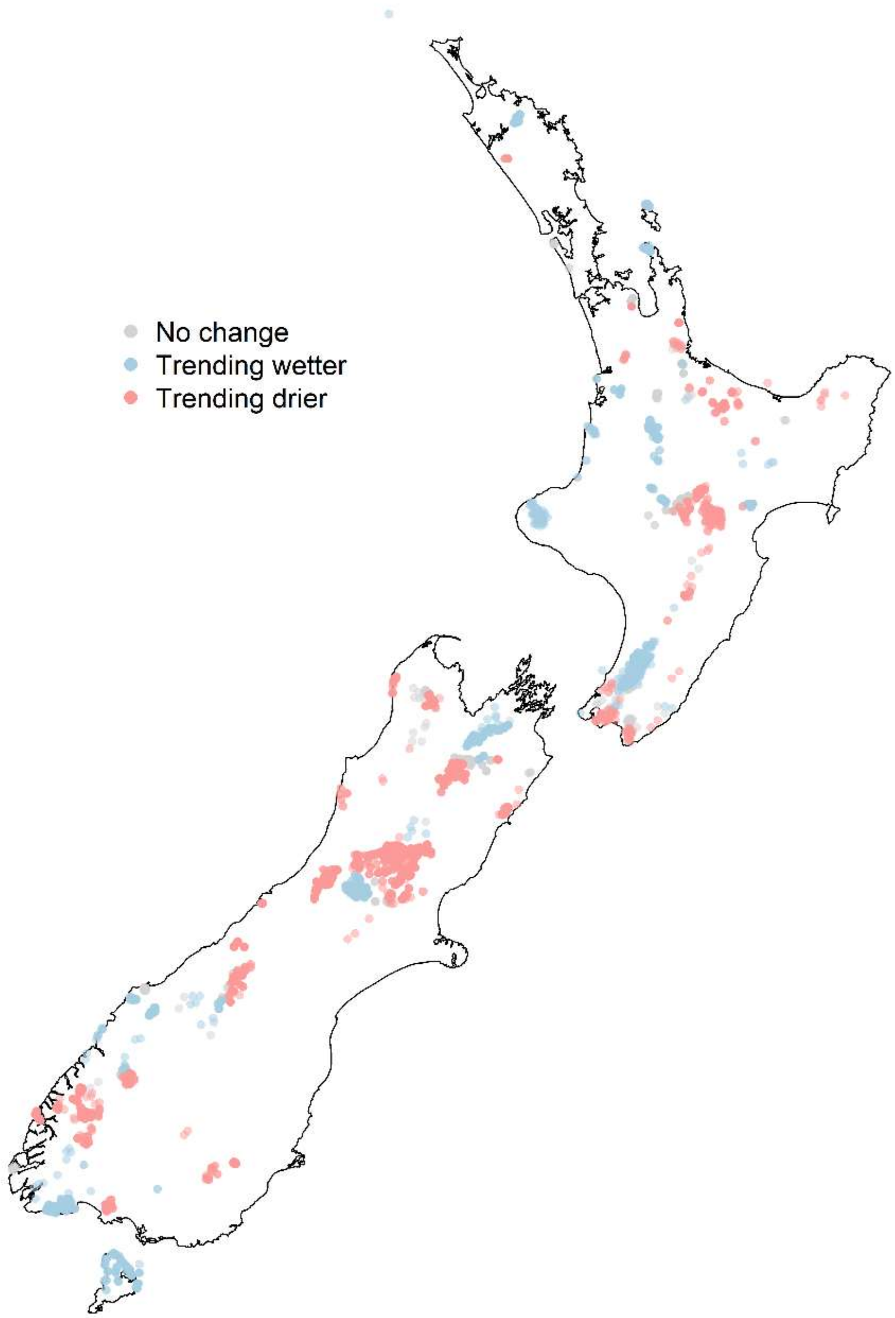

Figure 3. Map showing plot-level 100-year trends in the 24-month lagged Standardised Precipitation Evapotranspiration Index (SPEI). The trend for each plot has been categorised as unchanged, trending towards wetter conditions (a significant positive correlation), or trending towards drier conditions (a significant negative correlation). We considered a trend to be statistically significant if the *P* value from a Spearman Rank Correlation test was $P \leq$ 0.05.

Capacity to quantify the effects of canopy-replacing storm and cyclone events

Storms occur throughout New Zealand but those that are related to ex-tropical cyclones are typically concentrated in the warmer north (Wyse et al. 2018). However, damage to indigenous forests varies widely among these storm events. Cyclone Ita in 2014 caused widespread damage to indigenous forests throughout the western South Island (Platt et al. 2014), while Cyclone Gabrielle in 2023 did little damage to indigenous forests (Unpublished data, Warwick Allen, Manaaki Whenua – Landcare Research 2024) despite being catastrophic in terms of loss of human life and infrastructure. While difficult to pinpoint geographically, we assumed that ex-tropical cyclones would have their greatest impacts in regions with warmer sea surface temperatures and hence we prioritised networks in coastal regions with a strong focus on those in northern New Zealand (i.e. northern West Coast, Nelson, Tasman, Marlborough, Bay of Plenty, Hawkes Bay, Gisborne, Auckland, and Northland regions).

4 Results

4.1 The North Island

Across the North Island (also known as Te-ika-ā-Maui, see footnotes 1,3) , we identified 9 plot networks of high priority (Figure 4 and Table 1).

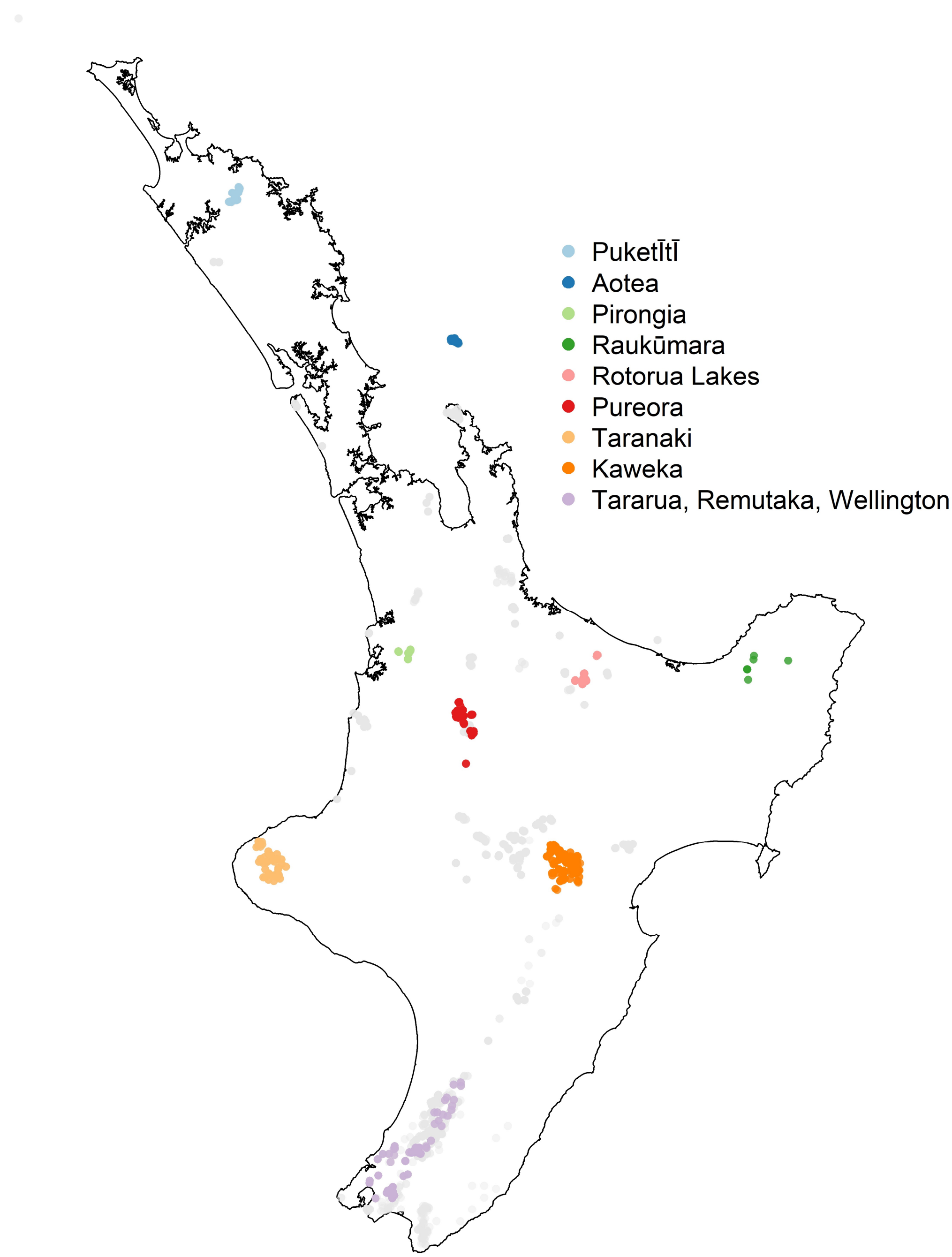

Figure 4. Map of the North Island showing the location of permanent forest plots that are highly prioritised for remeasurement. Grey symbols show plot locations that were not highly prioritised.

Table 1. Permanent forest plot networks in the North Island. Networks are sorted by priority (high, mod, low), then from north to south (for N–S #, the smaller numbers are further north). Plot networks names in NVS are reproduced here in upper case, as they appear in the NVS databank.

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
1	Puketī [7] Forest, Northland	PUKETI FOREST, Puketi Traitspace	Objective & subjective	The only long-term, repeated measures data from warm temperate forests in northern NZ. A history of cyclone damage to forest canopies (Conway 1959), potentially vulnerable to drought.	high	40 30 objectively located + 10 subjectively located to sample kauri stands (Jager et al. 2015)	2003, 2011, 2022 (objectively located plots) 2012 and 2022 (subjectively located plots)
3	Great Barrier Island (Aotea Island) – Te Paparahi Stewardship Area, Northland	GREAT BARRIER ISLAND (Te Paparahi Stewardship Area) FOREST	Objective	Goat eradication on an island; complements Moehau Range and Mount Taranaki.	high	36	1987, 2002/3
7	Pirongia, Waikato	PIRONGIA FOREST, Pirongia, PIRONGIA UNDERSTOREY SURVEY	Objective	Pirongia forest is a relatively large area of indigenous forest in the Waikato region. Both possums and mammalian predators are managed for conservation of vulnerable tree and bird species, respectively.	high	16	Measured 5 times (1979, 1987, 1999, 2004, 2008)

[7] Also called Puketītī

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
8	Raukūmara Range	RAUKUMARA FOREST, EAST COAST EXCLOSURES FOREST, RAUKUMARA EXCLOSURES FOREST	Objective & subjective	Even though this survey has not been remeasured, the region is receiving much attention because of depauperate forest understories[8]. We lack regional-scale plot data to identify possible drivers and to understand whether management interventions (e.g. possum or ungulate control operations) are resulting in higher rates of tree recruitment.	high	16 plots in 1982/83 (not remeasured) 18 plots in 1984 (not remeasured) 1 exclosure and 1 control plot (1980/81), not remeasured 2 exclosures and 2 controls (1985, one remeasured 2002)	Plots were installed over the period 1980-1984, but only 1 exclosure and control plot have been remeasured (2002)
11	Pureora Forest Park	PUREORA FOREST, PUREORA EXCLOSURES FOREST, PUREORA STH EXCLOSURES	Objective & subjective	One of the largest and most comprehensive surveys in the central North Island (n = 57 plots and n = 20 exclosures and controls). Focus is red deer management.	high	32 plots with 5 measurements. A further 25 plots were added in 1981-1982. 10 subjectively located exclosures and 10 paired control plots (also with 5 measurements)	Plots span 1974/1975 to 2001/3 50 plots measured 5 times 25 plots measured 4 times 2 plots measured twice
9	Rotorua Lakes, [Lake Ōkataina/ Te Moana i kataina ā Te Rangitakaroro, Rotoehu, Rotomā, Rotomahana]	Lake Okataina Exclosures, LAKE ROTOMAHANA MANAGEMENT AREA (PATITI ISLAND), ROTOEHU EXCLOSURES FOREST, ROTOEHU FOREST, Rotomā Forest Health Assessment FOREST, ROTORUA LAKES FOREST	Subjective (n = 34) and Objective (n = 14) or not stated (n = 2)	Understanding canopy tree replacement in the presence of wallaby browse. Includes plots around Lake Ōkataina where wallabies have been resident since the 1940s and plots around other lakes in the area where wallabies have spread more recently.	high	50 plots measured across 6 projects (plots change project membership across years); 43 plots have ≥3 measurements.	1983-1999 for most plots, but some exclosure plots have been measured up to 2017.

[8] See: https://www.nzgeo.com/stories/how-to-fix-the-raukumara/

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
14	Mount Taranaki, Pouakai Range, and Kaitake Range (Egmont National Park)	Egmont, Mount, EGMONT, MOUNT FOREST, Egmont, Mount MIXED	Objective	Sampling forests where goats have been eradicated, thus a valuable complement to Moehau Range and Great Barrier Island (Aotea Island). Supports predator reduction activities on Taranaki Mounga.	high	Up to 43 plots	1976-1979 (*n* = 36 plots installed), remeasured 1985, 2001/2, and 2010/11. A further 7 plots were added in 2010/11.
16	Kaweka	KAWEKA - IHAKA EXCL FOREST, KAWEKA - LOTKOW EXCL FOREST, KAWEKA - MOHAKA EXCL FOREST, KAWEKA - TE PUKE EXCL FOREST, KAWEKA (Cathy Allan plots) FOREST, KAWEKA FOREST, KAWEKA MIXED	Objective & subjective	A region of historical and ongoing debate surrounding management of sika deer; some ancillary data available (e.g. tagged seedlings, pellet counts), strong value culturally, many plots objectively located and many exclosure plots with paired controls; tagged seedling data available.	high	c. 80 plots	3 or more measurements spanning 1979 to the early 2000s (with potentially more recent measurements available (Husheer & Tanentzap 2024)
18	Tararua Range, Remutaka Range, Wellington region		Objective & subjective	Many of these have been incorporated into regional-scale monitoring by GWRC; others have been measured by DOC staff. A review of vegetation monitoring over the period 1958-1985 (Husheer 2005) recommended a stratified approach for prioritising plots by selecting a random and representative sample of 30 plots each in kāmahi and silver beech forest types. Many plots have been measured since that review and any decisions on this region would be best made in partnership with GWRC.	high	NVS has data for 325 unique plot IDs from the region around Tararua (including Akatarawa and surrounding hills) 78 were cruciform plots that have not been visited in decades Of the remaining plots (*n* = 247), that are standard shapes, there are 67 (7 subjective; 60 objective) that have been measured 3 or more times that form a core set for remeasurement.	1973-2023

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
2	Waipoua, Northland	WAIPOUA EXCLOSURES FOREST	Subjective	If all plots were aggregated into a single survey, this would be a valuable complement to Puketītī.	mod	31 plots including 8 exclosures and paired controls; only the 8 pairs have been remeasured	
4	Moehau Range, Waikato	MOEHAU, Moehau, MOEHAU FOREST, Moehau Range	Objective & subjective	Monitoring forest recovery following goat eradication	mod	8 plots measured 4 times + 16 plots measured 3 times	1991 to 2021
6	Karioi, Waikato	Karioi, KARIOI FOREST	Subjective	Impacts of goats and possums, and recovery of vegetation following control of those animal species.	mod	4 plots	5 times between 1979 and 2007/8
10	Waipapa River valley	WAIPAPA FOREST	Objective	Located in one forest type and one shrubland type hypothesised to be vulnerable to browsing damage by deer (Leathwick 1987).	mod	16 plots	1991 to 2000
12	North Island Ecological Transects (NIETs), Central North Island	NORTH ISLAND ECOLOGICAL TRANSECTS	Objective	Some of the oldest plots in NVS; sample indigenous forests across the Central North Island; key strength is large tree mortality and growth.	mod	54 plots (mostly 0.40 ha/1 acre), some with 7 measurements	1957 to 2006
13	Boundary Stream Mainland Island	BOUNDARY STREAM EXCLOSURES FOREST, BOUNDARY STREAM MAINLAND ISLAND MIXED, BOUNDARY STREAM SCENIC RESERVE, BOUNDARY STREAM SCENIC RESERVE FOREST	Subjective	In a mainland island reserve (including the Poutiri Ao ō Tāne initiative), a region susceptible to cyclones and future droughts.	mod	27 plots	Measured 5 times between 1996/7 and 2009

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
15	Kaimanawa Forest Park	KAIMANAWA, NORTH FOREST, KAIMANAWA, WEST FOREST, KAIMANAWA, WEST FOREST, KAIMANAWA/RANGITIKEI FOREST, RUAHINE NORTH/KAWEKA KAIMANAWA FOREST, TONGARIRO EX KAIMANAWA,	Objective & subjective	Potential to inform on management of sika and red deer populations and maintenance of forest canopies.	mod	107 plots measured twice. Also many exclosure plots and controls with 3, 4, or 5 measurements	Possible that remeasures from the late 1990s and early 2000s are not all in NVS (Husheer et al. 2003)
17	Ruahine, Pohangina	RUAHINE, POHANGINA FOREST	Objective (& subjective exclosures)	These plots contributed to a review of possum effects on tree mortality and canopy dieback (Bellingham et al. 1999); while only a small sample size, they complement other plot networks with the similar (enduring) issue of understanding tree mortality and the potential role by possums in accelerating canopy dieback in forests where beech is a minor component.	mod	7-14 plots	1975 (*n* = 14 plots); 1983 (*n* = 13 plots); 1996 (*n* = 7 plots)
5	Hunua Ranges	HUNUA FOREST	Subjective	Most of the historical plots have not been maintained but Auckland Council have new plot networks in this region that now serve this region.	low	66 plots with 2 measurements	Installed 1966-1971 and remeasured 1988-1989
19	Aorangi	AORANGI FOREST PARK FOREST	Objective (& subjective exclosures)	Dry, vulnerable to storm damage, and with abundant browsing mammals.	low	25 cruciform plots	*n* = 2 historical measurements (possibly 3?)

4.2 The South Island

Across the South Island (also known as Te Waipounamu, see notes 1,3) we identified 10 high priority plot networks (we considered the paired catchments of Stafford and Hope as a single network) (Figure 5 and Table 2).

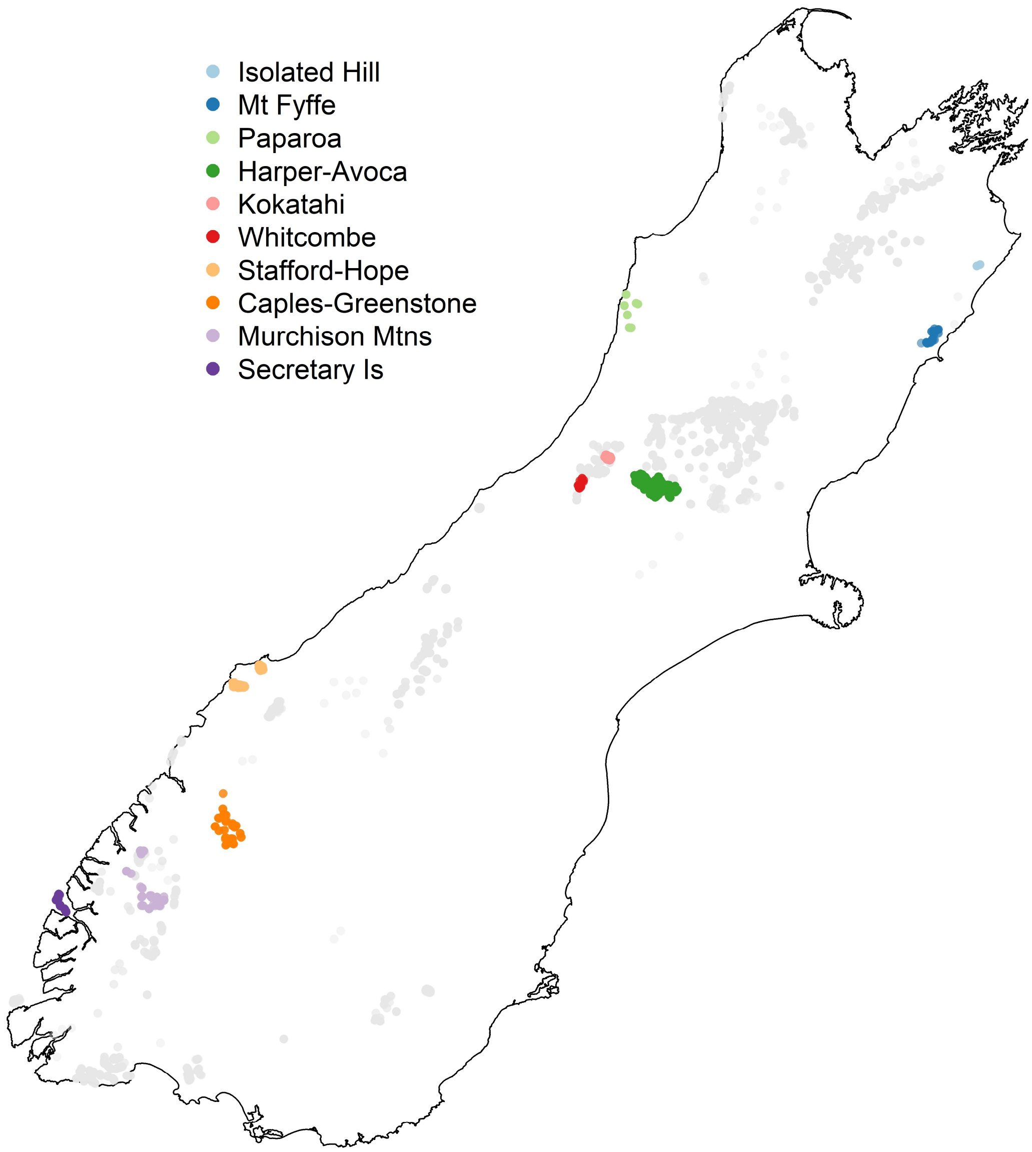

Figure 5. Map of the South Island showing the location of permanent forest plots that are highly prioritised for remeasurement. Grey symbols show plot locations that were not highly prioritised.

Table 2. Permanent forest plot networks in the South Island. Networks are sorted by priority (high, mod, low), then from north to south (N-S #, smaller numbers are further north). Plot networks names in NVS are reproduced here in upper case, as they appear in the NVS databank.

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
5	Isolated Hill Scenic Reserve	ISOLATED HILL FOREST	Subjective	Useful for determining the effects of pervasive herbivory by goats (Hayward 1985; Cochrane 1999; Adkins 2012; Hamling et al. 2017), and recovery after disturbance from a magnitude 7.8 earthquake in 2016. Subjectively located in sites where impacts of goat browse and speed of recovery from goat culling were predicted to be greatest. Māhoe/mataī communities were selected on gentler slopes where soil was predicted to be more stable so seedlings could develop rapidly in response to goat control. Later work (Cochrane 1999) used unbiased relevé plots (Hurst et al. 2022) to put the subjective permanent plots into a wider context but NVS is missing those relevé data, as well as a 2011/2 remeasurement of the permanent plots (Adkins 2012).	high	32 plots installed, fewer measured over time. Includes 3 exclosure plots	1985 1992/3 (or 1994?), 2011
7	Mt Fyffe (Hāpuku and Kōwhai River valleys)	FYFFE, MOUNT FOREST	Objective	Pervasive herbivory from goats, and recovery after disturbance from a magnitude 7.8 earthquake in 2016. Uniquely placed to assess recovery from a large and recent earthquake under ambient browse.	high	43 plots	1980, 2007/08

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
8	Paparoa National Park	Paparoa Exclosures, PAPAROA EXCLOSURES FOREST, PAPAROA NATIONAL PARK	Objective (& subjective exclosures)	Interaction between pervasive herbivory from goats, and recent disturbance from Cyclone Ita in 2014 (Platt et al. 2014). The contrast between fenced and unfenced plots, and the wider context from the regional plots will be unrivalled for informing us on forest recovery following a cyclone, in the presence or absence of browsing animals.	high	28 plots + 4 exclosures and 7 control plots	Only one measurement for the core plots (2007/08) Multiple remeasures for the exclosure and control plots: 1989-1991, 1995-1997, 2002-2003, 2008
18	Harper and Avoca River valleys	HARPER/AVOCA FOREST, WAIMAKARIRI FOREST	Objective	One of the largest plot-based surveys in NZ. These plots have formed the basis of conceptual research on forest dynamics, stand structural development, responses by forest ecosystems to disturbance, and predicting patterns of invasive plant spread.	high	251 plots A core set of 62 plots in two catchments (Back Basin Creek, and Broken River could be maintained from the larger survey)	Up to 20 times, spanning the period 1970/71 through to 2009-2011 (full remeasure) and 2015 (62 plots remeasured).
20	Kokatahi River valley	HOKITIKA/KOKATAHI FOREST, KOKATAHI PERMANENT FOREST PLOTS, HOKITIKA FOREST	Objective	A key plot network for understanding the determinants of rātā-kāmahi canopy dieback and the potential role of possum browse. Much ancillary data available (e.g. tagged seedlings, tree fern heights, soil chemistry data, litterfall biomass, estimates of understorey light availability)	high	23 plots	6 measures (1972, 1979/80, 1995-1998, 2001/02, 2010, 2018)
21	Whitcombe River valley	HOKITIKA FOREST, HOKITIKA/WHITCOMBE FOREST	Objective	Focus was canopy dieback, similar to the Kokatahi.	high	23 plots	4 measures (1971-1972, 1979-1980, 1998-1999 2009)

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
25	Stafford Bay and the Hope River valley (South Westland)	STAFFORD, Hope River vegetation plot survey	Objective	Installed to compare forest condition in an area where possums have only recently invaded (Hope) with an area where possums have been present for a long time (Stafford). Stored in NVS as two separate projects, but here considered as one.	high	58 plots	2005 and 2006, 2016 and 2018
28	Caples and Greenstone River valleys	CAPLES/GREENSTONE FOREST	Objective	Overlapping distribution with fallow deer (potential herd of national interest).	high	49 plots	1976, 1982, 1989, 1997-2002
29	Fiordland North (includes Windward Forest, Murchison Mountains)	FIORDLAND NTH FOREST, WINDWARD FOREST, MURCHISON MTS EXCL FOREST, FIORDLAND EXCLOSURES FOREST	Objective & subjective	Outstanding value because of sustained red deer control, adjacent Wapiti herd of national interest, and the takahē population.	high	149 plots – but only subsets have been subsequently remeasured, with progressively fewer plots over time, now concentrated on the Murchison Mountains (*n* = 33 plots). Also exclosure and control plots (potentially 3 pairs still intact) (Ledgard 2017).	1969-70 and subsets of those plots were remeasured in 1975-76, 1984-85, 1998, and 2008-09

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
30	Secretary Island	SECRETARY ISLAND FOREST	Objective	Secretary Island 'until 1967 was essentially unmodified by browsing mammals' (Mark & Bayliss 1975, p. 19). Plots were installed shortly after red deer colonised and span the period of their impact on vegetation and include the period over which red deer have been eradicated in 2014 (Macdonald et al. 2019). Earthquakes in 1993 (magnitude 6.8) and 2003 (magnitude 7.2) resulted in landslides and canopy damage, captured by a subset of the plots.	high	35 plots	1975, 1988, 2003/04, 2017-2019
1	Heaphy River valley	HEAPHY	Objective	Lowland forest communities around the mouth of the Heaphy (Whakapoāi) River.	mod	19 plots	2009/10, 2020
9	Hurunui River valley	HURUNUI FOREST	Objective	Recreational hunting area (RHA) that complements the mainland island in the Hurunui River South Branch valley.	mod	101 plots	1975, 1999-2001
10	Hurunui River South Branch valley	HURUNUI SOUTH FOREST	Objective	One of the largest surveys in NVS. A mainland island site.	mod	429 plots – with 25 maintained until 2001/02	1976/77, 1986/87, 2001/02 (*n* = 25 measured three times)
11	Taramakau River valley	TARAMAKAU FOREST, TARAMAKAU- HUTT CREEK FOREST, TARAMAKAU-OTIRA DECEPTION UPPER TARAMAKAU FOREST	Subjective	A valuable dataset from 3 sub surveys on rātā-kāmahi forest dynamics in relation to endogenous canopy replacement processes and possum browse. The only plots sampling this forest type on greywacke cf. schist and semi-schist in the Kokatahi and Whitcombe River valleys.	mod	Taramakau River valley (10-15 plots) Hut Creek valley (12-14 plots) Ōtira and Deception River valleys (63 plots)	1968-69, 75, 78, 79 1978-79, 1984, 1992 1987/88, 92/93, 2001-2003

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
16	Chatham Island	CHATHAM ID - PITT ISLAND FOREST, CHATHAM ID - PITT ISLAND MIXED, CHATHAM ID - TUKU BUSH FOREST, CHATHAM ISLAND MIXED	Subjective	Installed to quantify rates of vegetation change. Remeasured plots are part of larger plot networks that include exclosures.	mod	2 plots – Tuku Nature Reserve 10 plots – Pitt Island (Rangiauria)	1996, 2005 1989, 1998
22	Ōkarito Forest	OKARITO FOREST	Objective	Lowland terrace forest in the centre of the rowi (Ōkarito brown kiwi) distribution. Originally coupled with bird surveys to determine habitat use by forest birds in areas that were proposed for timber harvesting. Damaged by Cyclone Ita in 2014.	mod	32 plots	1983/84 and 1997
23	Karangarua and Copland River valleys	KARANGARUA/COPLAND (Westland National Park) FOREST	Subjective		mod	45 plots	1978/79, 1984, 1992, 2004
24	Arawhata River valley	HAAST/ARAWHATA, HAAST/ARAWATA FOREST	Subjective		mod	49 plots. A subset (but not a consistent subset) have been remeasured since.	1970/71, 1998-2000, 2010-2012
27	Kaipo [9]River valley (Fiordland)	KAIPO FOREST, Kaipo FOREST	Subjective	Focus would be red deer impacts on seral forests, and forests dominated by tree ferns and seral hardwood species on rich, alluvial, colluvial soils.	mod	10 plots	1977, 1984, 1999/00
31	Pomona Island	POMONA ISLAND	Objective	Installed as baseline for planned pest animal control operations	mod	5 plots	2005, 2016

[9] Also known as Kaikākāpō

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
32	Rona Island	Rona Island	Subjective	Installed as baseline for planned pest animal control operations	mod	2 plots	2005, 2016
33	Blue Mountains	BLUE MOUNTAIN EXCLOSURES FOREST, BLUE MOUNTAINS FOREST	Subjective	A strength of this site is the network of exclosures and various control plots. Overlaps with a potential herd of national interest (fallow deer).	mod	29 plots measured in 1982 and 1984, but most not revisted since. 7 exclosures and various control plots	1982, 1984 Exclosures and control plots measured up to 4 times
34	Anchor Island	ANCHOR ISLAND, ANCHOR ISLAND FOREST	Subjective	Measuring forest ecological integrity from a predator-free island.	mod	9 plots	2001, 2007, 2012
37	Waitutu Forest	Waitutu Exclosures, WAITUTU EXCLOSURES FOREST, WAITUTU FOREST	Objective	Sample wide soil fertility gradients in lowland forest. Also a site of ecological research and predator control operations, with ancillary experiments including 4 exclosures and 4 control plots, and a fertiliser addition experiment.	mod	157 plots	1978/9, 1996-1998
38	Longwood Forest	LONGWOOD FOREST	Objective		mod	42 plots	1977/78, 1997
2	Cobb River valley	COBB FOREST	Objective	Not maintained or remeasured for >30 years	low	40 plots	1977-1980, 1986.
3	Mount Arthur	ARTHUR, MOUNT FOREST	Objective	Not maintained or remeasured for >30 years	low	24 plots	1978, 1987

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
4	Wairau River North Bank and Wairau River South Bank (both Marlborough)	WAIRAU NORTH BANK FOREST, WAIRAU SOUTH BANK FOREST	Objective	Wairau South Bank is species-poor beech forest while Wairau North Bank is more diverse and includes extensive secondary forests. Most plots have not been remeasured since 1984 (the exceptions are those that have been incorporated into CMS/LUCAS/Tier One hence they are a low priority dataset (only sample an 11-year period, not remeasured since 1984).	low	355 plots	1972-1973 and 1982-1984
6	Cupola	CUPOLA FOREST	Objective & subjective	Two surveys in this catchment. None of these plots have been remeasured since 1986, and both surveys only span a decade (± a year), hence we do not recommend remeasurement.	low	23 plots (subjective) 72 plots (objective)	1976, 1986 1970, 1981
12	Ashley River and Puketeraki Range	ASHLEY/PUKETERAKI FOREST	Objective	Not maintained or remeasured for 40 years.	low	28 plots in 1962, 51 plots in 1973, 10 plots in 1979, 34 plots in 1984	1962, 1973, 1979, 1984
13	Mount Grey/Maukatere	GREY, MOUNT FOREST	Unknown	Not maintained or remeasured for >30 years	low	?16 plots	1978, 1986/87
14	Mount Oxford	OXFORD, MOUNT FOREST	Objective	Not maintained or remeasured for >30 years	low	8 plots	1977/78 and 1985/86
15	Mount Thomas Forest	THOMAS, MOUNT FOREST	Objective	Not maintained or remeasured for >30 years	low	23 plots	1978/79, 1986

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
17	Waimakariri River valley	WAIMAKARIRI FOREST	Objective	Not maintained or remeasured for >30 years	low	100 plots. Only 18 of the original plots have been remeasured since 1984 because they were incorporated into the Harper and Avoca River valleys survey.	1971/72, 1983/84
19	Hokitika River catchment (excluding Kokatahi and Whitcombe River valleys)	HOKITIKA FOREST, HOKITIKA MIXED, HOKITIKA/KOKATAHI FOREST, HOKITIKA/WHITCOMBE FOREST	Objective & subjective	Unlikely to be valuable given the available data from the Kokatahi, Whitcombe, and Taramakau River valleys	low	155 plots >100 of which have 3 measurements (but not in the recent past)	1957-1958 to 1985-1986, including remeasures during 1963-1964 and 1971-1972.
26	Waitaki River valley	WAITAKI FOREST	Objective & subjective	Not remeasured in >30 years	low	118 plots	1973/74, 1985/86
35	Grebe River	GREBE FOREST	Objective	Not remeasured for >30 years.	low	80 plots	1976, 1981/82
36	Eastern Princess Mountains	EASTERN PRINCESS MTNS FOREST	Objective	Not remeasured for >30 years.	low	62 plots	1975, 1982

4.3 Stewart Island/Rakiura

Stewart Island/Rakiura has a long history of informing the debate around deer impacts in mixed indigenous forests (Veblen & Stewart 1980; Nugent & Challies 1988; Stewart & Burrows 1989; Bellingham & Allan 2003; Clayton et al. 2008; Duncan et al. 2010), especially those where kāmahi is a significant component of the canopy.

Historical investment in permanent plot networks has provided an unrivalled mixture of:

- plots on offshore islands where deer have never occurred (Bench Island / Te Wāhitauā) or where they have been eradicated (Ulva Island)
- fenced and unfenced experimental plots across the main island
- plots under ambient deer densities across the main island.

We identified 6 high priority plot networks that we have aggregated into 4 groups (Bench and Ulva (Islands); Stewart Island Exclosures; Chew Tobacco Bay and Port Adventure; Northern Coastal survey) see (Figure 6 and Table 3).

There were no permanent plots on Codfish Island/Whenua Hou. We recommend consideration of establishing new permanent forest plots there in partnership with Rakiura Māori. This island has received considerable conservation investment, and is the exemplary non-native mammal-free ecological analogue to mainland Stewart Island/ Rakiura.

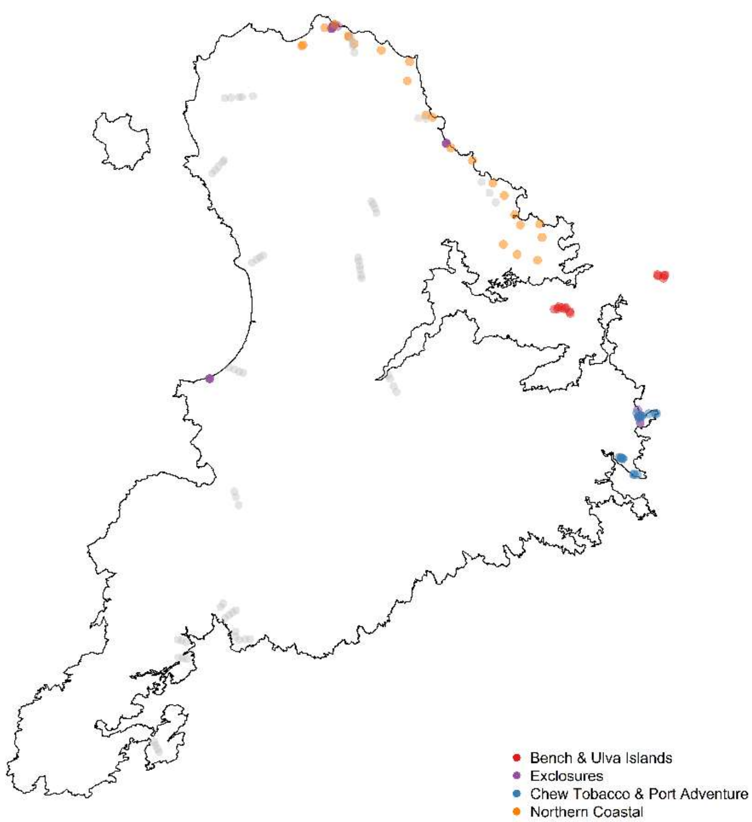

Figure 6. Map of Stewart Island/Rakiura showing the location of permanent forest plots that are highly prioritised for remeasurement. Grey symbols show plot locations that were not highly prioritised.

Table 3. Plot networks on Stewart Island/Rakiura that are prioritised for remeasurement. Networks are sorted by priority (high, mod, low), then from north to south (N-S #, smaller numbers are further north). Plot networks names in NVS are reproduced here in upper case, as they appear in the NVS databank.

N-S #	Site, Region	Plot network name in NVS	Plot placement	Justification for remeasurement	Priority	No. plots	Years measured
2	Northern Coastal survey	STEWART ISLAND NORTH (STEWN) FOREST	Subjective	The longest-running plot network on Stewart Island/Rakiura (1976–2023) providing a 47-year perspective on lowland, coastal forests (Bellingham & Allan 2003)	high	24 plots	1976, 1980/1, 1985/6, 1999/2000
4	Stewart Island Exclosures	STEWART ISLAND EXCLOSURES FOREST, WACEM PROJECT	Subjective	Experimental exclosures provide a robust comparison with adjacent forest plots; exceptional number of measurements (often 6) (Stewart & Burrows 1989; Duncan et al. 2010)	high	12-15 plots (varies by measurement year	1979/80, 1984, 1999, 2007, 2009-2010 (WACEM)
5	Bench Island, Te Wāhitauā	STEWART ISLAND EAST Bench Is FOREST, Stewart Island East Bench Is	Subjective	An island analogue for mainland Stewart Island/Rakiura that has never had non-native mammals (Stewart & Burrows 1989; Duncan et al. 2010)	high	5 plots	1979/80, 1985, 1998/9, 2008
6	Ulva Island	Ulva Island, ULVA ISLAND FOREST	Objective & subjective	Predator-free island; inferences will need to account for rat and possum removal, alongside deer (Clayton et al. 2008; Duncan et al. 2010)	high	8 plots	1999, 2008
7	Chew Tobacco Bay	STEWART ISLAND EAST Chew Tobacco Bay FOREST, Stewart Island East Chew Tobacco Bay	Subjective	Ambient herbivory, these plots were established concurrently with Bench Island to serve as a direct contrast to it (Stewart & Burrows 1989; Duncan et al. 2010)	high	8 plots (the original survey was n = 33 but many have been discontinued)	1979/80, 1985, 1999/2000, 2008
8	Port Adventure	STEWART ISLAND EAST Port Adventure FOREST, Stewart Island East Port Adventure	Subjective	Ambient herbivory, these plots were established concurrently with Bench Island to serve as a direct contrast (Stewart & Burrows 1989; Duncan et al. 2010)	high	9 plots (the original survey was 31 but many have been discontinued)	1979/80, 1985, 1999/2000, 2008
3	Northern Widespread survey	STEWART ISLAND NORTH (STEWRT) FOREST, Stewart Island North (STEWRT)	Objective	Widespread, objective (unbiased) survey with plots on transects (Bellingham & Allan 2003; Duncan et al. 2010)	mod	44-57 plots (varies by measurement year)	1980/81, 1998/1999, 2008/2009
9	Stewart Island South Port Pegasus	STEWART ISLAND SOUTH Port Pegasus FOREST, Stewart Island South Port Pegasus	Objective	Valuable network for extending spatial coverage to the SW part of Rakiura	mod	21 plots	1999/2000, 2008

5 Discussion and recommendations

We first identify a subset of high priority plot networks for remeasurement, and then discuss the critical actions that should be considered in any strategic plan for remeasuring and maintaining long-term regional- or catchment-scale plot networks. We do this by evaluating each region, exclosure plots across all regions, the adequacy with which current plot networks sample large trees that are infrequent on the landscape, and then by considering how best to derive value from Tier Two data.

5.1 Selection of the first group of high priority plot networks for remeasurement

We identified high priority plot networks that achieved geographic spread and coverage of the major global change drivers, with long measurement intervals, multiple remeasures (ideally, but not always), and valuable ancillary data (e.g. soil chemistry data) or experimental plots (e.g. exclosures). From that pool of potential networks and based on the current interest in understanding the resilience of forest carbon stocks to browsing and storm events, we identified a subset of 11 high priority plot networks that could be measured first, to deliver key information on forest carbon stocks and stock changes (Table 4).

Recommendations:

We recommend remeasurement of 249 plots across 11 high priority plot networks (Table 4). Because the goal of this research is to understand opportunities for maximising carbon storage in indigenous forest ecosystems, we recommend undertaking a full inventory of forest carbon pools (live trees, coarse woody debris, fine woody debris, litter, organic and mineral soils) using established protocols in the Tier One/LUCAS (Department of Conservation 2019; Hurst et al. 2022) and Wild Animal Control and Emissions Management (WACEM) (Stevenson & St John 2008) manuals.

Measures of herbivore abundance are critical interpretive data; we recommend collecting data on the relative abundance of ungulates and possums following the Tier One/LUCAS protocols (Department of Conservation 2019). Where more than one species of ungulate is present at a site (e.g. both white-tailed and red deer are present on Stewart Island/Rakiura) we recommended collecting a subsample of fresh pellets for molecular analyses to attribute browsing effects to each ungulate species.

We recommend collecting an additional soil sample for analysis of plant-available nutrients as differences among sites in soil fertility can determine spatial variability in deer impacts and rates of forest recovery (Duncan et al. 2010; Forsyth et al. 2015).

Table 4. Plot networks prioritised for remeasurement

Island	Name	Number of plots	Priority
Stewart Island/ Rakiura	Bench Island, Te Wāhitauā	5	Funded for remeasurement April 2024
	Ulva Island	8	Funded for remeasurement April 2024
	(Stewart Island) Exclosures	12-15	Funded for remeasurement April 2024
	Chew Tobacco Bay	8	Funded for remeasurement April 2024
	Port Adventure	9	Funded for remeasurement April 2024
	Northern Coastal	24	Funded for remeasurement April 2024
South Island	Isolated Hill	32	Joint 1st
	Mt Fyffe	43	Joint 1st
	Paparoa National Park	28 + 4 exclosures and 7 control plots	2nd
	Whitcombe River valley	23	4th
North Island	Mount Taranaki	43	3rd

5.2 The North Island

Northern North Island

The northern North Island is poorly served by Tier One/LUCAS/CMS, relative to other parts of NZ that have extensive areas of public conservation lands with indigenous forest (e.g. Kahurangi National Park, West Coast of the South Island, Fiordland). Northern NZ has higher tree species richness than other regions (Bellingham et al. 1999; McGlone et al. 2010), supports tree species and lineages not found elsewhere in NZ (McGlone et al. 2010). It has been – and is increasingly – co-managed by mana whenua. Because of the warm temperate climate in northern New Zealand (Grubb et al. 2013) the area is already facing the consequences of novel invasive species, droughts, more frequent storm events, and perhaps fire sooner and more aggressively than other regions of NZ (Macinnis-Ng et al. 2021). Our evidence base for informing management of northern forests is currently limited to a few sites. Forests in the northern North Island are naturally more dynamic, i.e. trees have naturally higher rates of mortality and recruitment, and many trees are likely to grow more rapidly than forests in southern New Zealand (Bellingham et al. 1999), hence more frequent measurement of plots is merited.

Recommendations:

Invest in existing long-term permanent plot networks in northern and north-eastern North Island, notably those in Puketītī, Waipoua Forest, Great Barrier Island (Aotea Island), and Pirongia. Mana whenua have key roles in managing many of these forests and their involvement is critical in remeasurement of many of the plot networks. Investment in these plot networks needs to be coordinated with regional councils, since some, like Auckland Council, maintain plot networks of their own. The kauri protection programme Tiakina Kauri (MPI) is also potentially an interested party.

Central and southern North Island

The central and southern North Island has large areas of indigenous forest on public conservation land, including National Parks and Forest Parks, and is better covered by Tier One/LUCAS/CMS than the northern North Island. Forests range from species-rich lowland rain forests to one- and two-species mixtures of beech in the axial ranges. Some plot networks afford opportunities to evaluate effects of management for ungulates, such as consequences of goat eradication on Mount Taranaki (announced as successful in 2022), and the 2023 adaptive management plan of the Central North Island Sika Foundation for the Kaimanawa and Kaweka Forest Parks. These forests and others, including the diverse forests of Pureora Forest Park, are well served by plot networks that could now provide > 40 years of critical historical context to inform current management. Of these networks, we chose the plot network on Mount Taranaki for remeasurement (Table 4). Plot networks in the Rotorua Lakes region will provide the evidence needed to evaluate the outcome of MPI's Wallaby-free Aotearoa programme, which is premised on improving forest regeneration and biodiversity. For example, dama wallabies have occupied forests around Lake Ōkataina since the 1940s (Warburton 2005). Networks in the Rotorua Lakes region will also provide improved understanding of carbon sequestration in secondary forests, since many of the forests in the area developed after recent vulcanicity, fires, and logging (Nicholls 1959, 1991).

There are few plots and no recent history of their measurement to inform management of forests in the Raukūmara Range, where mana whenua are leading management of ungulates and pest mammals. The unstable geology and very steeply incised terrain, where tropical cyclones (Bola in 1988, Gabrielle in 2023) caused major disturbances to the forests, including landslides, make remeasurement of existing plots an imperative for understanding forest dynamics, carbon stocks and stock changes under multiple global change drivers. Other areas that have been subject to historical drought (e.g. high-elevation forests in the Ruahine Forest Park) (Grant 1984) have few plots in them and have no recent history of measurement. There are also notable gaps in the coverage of catchment-scale plot networks, for example in two of the region's National Parks (Tongariro and Whanganui).

Recommendations:

Invest in existing long-term permanent plot networks in the central and southern North Island on Mount Taranaki, Raukūmara Range, Pureora Forest Park, Rotorua Lakes, Kaweka Range, and the Tararua and Remutaka Ranges. These now provide >40 years of historical change, hence they can inform future management of carbon and forest biodiversity. The plot network on Mount Taranaki should be a high priority for remeasurement, in partnership with Taranaki Whānui ki te Upoko o te Ika collective, to guide the outcomes of goat eradication and ongoing pest reduction activities across the mountain. For some of the other networks, partnerships with regional councils will be key for investment (e.g. with Greater Wellington Regional Council in the Tararua and Remutaka Ranges, with Bay of Plenty Regional Council and, perhaps, MPI in the Rotorua Lakes). Consider partnering with mana whenua to enhance and extend the plot network in the Raukūmara Range to provide the evidence base needed to assess the effectiveness of management in a highly dynamic landscape.

5.3 The South Island

Forests in the South Island span major climatic gradients (temperature and rainfall), have compositional differences that reflect past glaciation and geology, and are subject to a range of disturbances, including drought, earthquakes, and even tropical cyclones. In general, the forests of the South Island are better represented by networks of permanent plots than in the North Island. Nonetheless, there are gaps in representation of catchment-scale plot networks in forests in its National Parks (e.g., Mount Aspiring, Aoraki/Mount Cook) and little through the northern part of the Te Wāhipounamu – South West New Zealand World Heritage Area.

In prioritising which networks to remeasure, latitudinal patterns of greater natural dynamism in the north prevail, so an emphasis on forests at lower elevations in the northern South Island is merited. The network of plots in the northeast of the South Island at Isolated Hill and Mount Fyffe are a very high priority (see Table 4) because they are in one of the few regions with sustained ungulate control. These forests are also likely to have high natural dynamism, because successional forests are widespread over areas that were deforested in the 19th century and forests were strongly affected by the 2016 Kaikōura earthquake (Hamling et al. 2017). The base-rich soils and coastal climate are also likely to promote rapid rates of change (Wardle 1971) and possibly invasion by non-native plants (Bellingham et al. 2005). If this region became a major focus of remeasurement, then there are additional plots in the Clarence River Valley and along the coast of the Seaward Kaikōura Range, which were installed in the 1980s and have not been remeasured since. These could extend the historical range for interpretation.

The second highest priority network for remeasurement is the plot network in Paparoa National Park (Table 4). Especially in the inland syncline basin, Cyclone Ita (2014) caused significant damage to forest canopies. A decade after the disturbance, there is an opportunity to capture the consequences of that disturbance under ambient goat browse and inside and outside exclosure plots. This will inform local management and optimise responses to ensure carbon sequestration after storms. Other plot networks in forests in the northern South Island in Kahurangi National Park could be considered as priorities for remeasurements, for example, around the Heaphy River, where forests were affected by ex-tropical Cyclone Fehi (2018) and by a major storm in February 2022.

Further south in the South Island, the network of plots in the Whitcombe River valley is a priority (Table 4) because it is an exemplar of the kāmahi-dominated forests that (Hackwell & Robinson 2021) considered are losing carbon because of possum browsing; and because it has a long history with three measurements since the network's establishment in 1972. The forests complement the network in the nearby Kokatahi River valley, which were established at the same time, and which have a history of measurement by Manaaki Whenua – Landcare Research (most recently in 2018). The network of plots in the Murchison Mountains, including deer exclosures, is also a priority because of the sustained management of deer in the forests and their long history of measurement.

Recommendations:

We recommend high priority plot networks from the South Island for remeasurement (Table 4). Our rationale was: (i) at Mount Fyffe and Isolated Hill because they afford opportunities to determine effects of sustained control of ungulates in old-growth and successional forests, in a region affected in 2016 by a major earthquake, and where the climate is likely to become drier; (ii) in Paparoa National Park to determine the consequences of goat browsing on forests affected by a major cyclone; and (iii) in the Whitcombe River valley to shed further light on whether kāmahi-dominated forests chronically affected by possum browse are losing carbon.

We also recommend investing in existing long-term permanent plot networks the South Island in the Harper and Avoca River valleys, Kokatahi, Stafford Bay and the Hope River, Caple and Greenstone River valleys, Fiordland North (includes the Murchison Mountains) areas, and on Secretary Island.

5.4 Stewart Island/Rakiura

Stewart Island/Rakiura has a long history of research into the ecology of white-tailed deer, and the effects of browsing by white-tailed deer and possums on forest ecological integrity (Veblen & Stewart 1980; Nugent & Challies 1988; Stewart & Burrows 1989; Bellingham & Allan 2003; Clayton et al. 2008). This research has supported some of the objectives of the Stewart Island/Rakiura Conservation Management Strategy and the Rakiura National Park Management Plan 2011-2021 (Department of Conservation 2012). These two documents include a 10-year milestone that the Department of Conservation will produce a 'report detailing the forest health of Stewart Island/Rakiura'. The last report of the state of forest vegetation from Rakiura was delivered in 2010 (Duncan et al. 2010). Remeasuring the plot networks recommended here (Table 3 and Table 4) will support the delivery of an updated report on forest health.

In addition to ongoing interest in the management of white-tailed deer, Rakiura has recently become the focus of sustained predator control operations with a view to achieving a predator-free status (Russell et al. 2015). Such investment in management interventions further supports the need for an evidence base from which we can quantify management outcomes and assess the ecological integrity of indigenous forests across the island.

Stewart Island/Rakiura is ideally placed to enrich our understanding of the relationship between browsing animals and forest carbon stocks because there are long-term forest plot networks on offshore islands where deer and possums have never occurred, where deer and possums have been eradicated, where deer and possums are under ambient densities, and where deer have been excluded with fences. However, the absence of forest monitoring plots on Codfish Island/Whenua Hou is a surprising omission. The island has immense cultural significance to Rakiura Māori and Ngāi Tahu more widely, and has outstanding conservation values (Department of Conservation 2012). Deer never established on Codfish Island/Whenua Hou (Nugent 2005), possums were eradicated between 1984 and 1987 (Department of Conservation 2012) and native rats/kiore in 1998 (Department of Conservation 2012). As such, Codfish Island/Whenua Hou provides a browsing mammal- and predator-free ecological analogue for Stewart Island/Rakiura, and systematic forest monitoring plots would provide a benchmark for monitoring and reporting on Stewart Island/Rakiura and across southern, lowland New Zealand.

Recommendations:

We recommend remeasuring the high priority plot networks on Stewart Island/Rakiura (Figure 6; Table 3 and Table 4).

We additionally recommend establishing new permanent forest plots on Codfish Island/ Whenua Hou in partnership with Rakiura Māori. This island has received considerable conservation investment and is the exemplary ungulate-, possum-, and rodent-free ecological analogue to mainland Stewart Island/Rakiura.

5.5 Formalise a national ungulate exclosure network

New Zealand's network of fenced exclosure plots has allowed quantitative assessment of the effects of ungulates on soil processes and on carbon stocks at a national scale (Wardle et al. 2001; Allen et al. 2023a) that few other countries could match (see (Tanentzap & Coomes 2012). Ungulate exclosures together with paired unfenced control plots provide the strongest evidence for the effects of sustained, long-term reduction in ungulate abundance on biodiversity and ecosystem processes including the ability to sequester carbon across different forest vegetation types (Peltzer et al. 2024). By contrast, nearly all ungulate management on PCL using ground-based or aerial approaches is ad hoc and short term; and only a few sites receive long-term (10 yr) sustained (repeated) management (Peltzer et al. 2024). This undermines our ability to attribute changes in tree populations or indigenous forest properties to ungulate management or abundance.

Fenced ungulate exclosures represent the best-case scenario for sustained management, by effectively reducing animal abundance to zero over the long term (i.e. decades). The national network of exclosures have been used to quantify how tree size class distributions, and thus population structure, are related to species' palatability (Husheer et al. 2005; Wright et al. 2012; Peltzer et al. 2014). Exclosures can also reveal changes in long-term forest ecosystem processes linking palatability to nutrient cycling that occur when herbivory alters the suite of plant functional traits present at a site (Mason et al. 2010; Allen et al. 2023a). Repeated measures of tree populations inside and outside exclosures also provide data for estimates of canopy collapse or recovery over the long term (Duncan et al. 2006; Husheer & Tanentzap 2024).

Despite the crucial importance of exclosures for understanding how reductions in ungulate abundance affect diversity, tree population dynamics, and C stocks, there is currently no systematic effort to maintain or remeasure exclosures. The most recent measurements taken from most exclosures (and paired unfenced control plots) were taken > 10 years ago. As a consequence, the current condition of exclosure fencing and changes in either animal abundance or disturbance (e.g. from cyclones) is largely unknown. The current state of all exclosures requires urgent assessment and a plan is needed to treat the national network of exclosures as an asset base, with all the best practice that attends evaluation and maintenance of other assets (e.g. huts, bridges, etc.). We know that some fences have corroded to the stage that they are no longer acting as exclosures, and others have been breached because of treefalls. For example, only 3 of 11 exclosure plots in the Murchison Mountains are now still functioning; the others have all been breached by treefalls or flood damage (Ledgard 2017). Likewise, in 2019, all exclosure plots in Woodhill

Forest (not on PCL) had either corroded to admit deer or had been breached by trees that fell in a storm in 2018.

The exclosure network has some important limitations, including:

- subjective placement in areas perceived to have high animal impacts including forest margins (Allen et al. 2023b)
- no central metadata or co-ordinated establishment of ungulate exclosures
- ad hoc remeasurement based on needs for individual studies or local area monitoring
- few exclosures in disturbed forests or successional environments
- small plot size which means that plots do not effectively capture herbivory effects on large trees or reliably capture changes in carbon regeneration after large trees die
- lack of data on ungulate abundance outside exclosures and in control plots.

If the current state of most exclosures that were established in the 1970s to 1980s is such that the asset is severely degraded, then DOC (and partner agencies and mana whenua) might view this as an opportunity to initiate a new national network of exclosures. A new network could address these criticisms of their design, and regular maintenance and appraisal of the asset could ensure that breaches were less likely. A better design would involve placing exclosures and controls randomly through forest areas of interest (e.g. Bellingham et al. 2016). The next phase of research also needs to include direct quantification of ungulate abundance around the exclosures and paired control plots to account for what is outside a fence. Exclosure plots and control plots should form only part of a research investment in understanding impacts of ungulates on forest ecosystems because there are limitations in inference about ungulate impacts. The plots are not a surrogate for long-term, forest-wide management experiments but they are one of the most powerful experimental tools available for quantifying ungulate effects on forest understoreys.

Recommendations:

Review, summarise, and evaluate available exclosures to select a national network and identify gaps. Identify the key animal abundance measures that need to be collected around each exclosure so we can more confidently attribute exclosure effects to known densities of specific animals.

5.6 Sampling large trees

Large trees are infrequent on the landscape, but they contribute disproportionately to seed production, habitat complexity, and forest carbon stocks. Stems with a diameter at breast height (DBH) of ≥ 60 cm account for just 0.77% of stems in New Zealand’s indigenous forests, yet they account for 41% of biomass carbon (Holdaway et al. 2017). Because large trees have very low mortality rates (often < 1% of individuals die each year) (Richardson et al. 2009), and are infrequent on the landscape, standard sampling approaches based on 20 m × 20 m plots (400 m^2), measured over a few decades, often lack statistical power to detect changes in mortality rates (Peltzer et al. 2005).

Internationally, larger plot sizes are common in forest ecosystems, but in New Zealand, the complex terrain favours 'many small' plots rather than 'fewer large' ones. A critical action that DOC and MPI should consider is whether to invest in maintaining a network of large permanent plots that only measure large trees. This would increase the sample size for large trees and strengthen our statistical confidence to report on change in this important subset of trees.

The North Island Ecological Transects (NIETs) are a network of 54 × 1-acre permanent plots in mature forests across the central North Island on both private and public conservation land (McKelvey & Cameron 1958; Richardson et al. 2009; Smale et al. 2016). These plots originally had a strong focus on quantifying the timber resource in large trees. Established between 1957 and 1964, and remeasured up to 7 times through to 2006/2007, these plots provide an unrivalled source of data on and insight into large tree mortality and growth rates over long time scales.

Recommendations:

Identify a network of large permanent plots that only measure large trees. Focus initially on remeasuring large trees on the NIETs every 25 years. This can only be achieved with involvement of mana whenua who either own the forest(s) (e.g., many are in Te Urewera) or are their guardians/kaitiaki.

Extend NIETs to include other parts of the North Island, and the South Island, and Stewart Island/Rakiura. Build on past and current investments in large, mapped stands (e.g. Ōrongorongo River Valley, Waitutu Forest, Ōkarito Forest, Waipapa River valley). This will yield stronger quantitative estimates for the 'slow-to-change' large tree demographic parameters, including species under threat (e.g. kauri, from *Phytophthora agathidicida*) for which data are poor.

5.7 Maximising the value from a Tier Two forest plot network

Build consortia

Regional scale plot networks are valuable to many agencies who have a responsibility for managing indigenous forests. An increasing number of plots are being installed and maintained by regional council. For some regions – such as Auckland (Griffiths et al. 2021), Bay of Plenty, and Greater Wellington (Uys 2019) – partnerships between DOC and those councils are already in place. Coordinated investment across a broader pool of agencies will almost certainly yield cost savings and safeguard plot networks against being neglected. This activity needs to include mana whenua and NGOs (e.g. Sika Foundation) so as to share responsibility for plot maintenance, and gain wider 'ownership' of the data that derive from them. Furthermore, relocating and remeasuring permanent plots can provide a means to build capacity in the regions.

Integrate Tier One and Tier Two data streams and integrate permanent plots with emerging technologies

Remeasuring regional-scale plot networks provides the opportunity to integrate data across Tier One and Tier Two and demonstrate the power of having data at both scales. For this to succeed, it is important that both Tier One and Tier Two collect comparable data using the same methods. In addition to measuring vegetation using standard protocols (Hurst et al. 2022), we recommend concurrent measurements of birds and pest mammals as part of revitalising these neglected Tier Two networks. Comparable data based on standard protocols will facilitate comparisons among Tier Two sites, an approach that has been used to understand potential drivers of canopy tree recruitment across regions (Bellingham et al. 1999; Husheer et al. 2006). Soil chemistry data from Tier One plots have been used to interpret spatial variation in vegetation functional traits (Simpson et al. 2016) and tree demographic rates (Ministry for the Environment & Stats NZ 2018). Collecting soil chemistry data from Tier Two plots will strengthen our capacity to interpret pattern and change in vegetation communities at regional scales.

Recent advances in remote sensing may enable us to measure aspects of forest structure and function at large scales (e.g. large-tree densities, carbon stocks, flowering phenology). However, these new initiatives will require ground-based data as validation data sets, for compositional data and to provide data at finer scales than can be acquired remotely (Phillips 2023). Regional-scale plot networks have great potential to support remote-sensing research and we recommend investing in locations where both types of data can be collected.

Recommendations:

Coordinate investment with Regional Councils to broaden the consortia of agencies who benefit from maintaining regional-scale plot networks.

Measure birds and pest mammals on regional-scale plot networks, and collect soil chemistry data, so that data are maximally comparable with data from the Tier One plot network.

Align remote-sensing research to sites with regional-scale plot networks to maximise data integration across these two approaches to forest monitoring.

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