Changes in Bay of Plenty frost flat heathland, 2012–2024

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Summary

Project and client

- Permanent vegetation monitoring plots were established in the remaining substantial frost flat heathlands in the Bay of Plenty Region in January–February 2012 and remeasured in January–March 2018 and February–March 2024.
- Bay of Plenty Regional Council contracted Manaaki Whenua – Landcare Research to assess changes in vegetation composition and structure over this period were assessed for the Bay of Plenty Regional Council.

Objectives

- To identify changes in the condition of most of the substantial frost flat heathlands remaining in the Bay of Plenty Region and assess any changes in relation to natural succession and weed invasion.

Methods

- Fifteen permanently marked 2 × 2-m plots were established at pre-selected random sites within major vegetation types at the six largest intact frost flat sites remaining in the Bay of Plenty Region in 2012 and remeasured in 2018 and 2024.
- Two large sites – Rangitaiki Conservation Area (three vegetation types) and Otangimoana Stewardship Area (one vegetation type) – and four smaller sites – Rangitaiki River Conservation Area (one vegetation type), Rangitaiki River Scrub (one vegetation type), Rangitaiki Station (one vegetation type), and Taho, Whirinaki Te Pua-a-Tāne Conservation Park (one vegetation type) – were sampled, making a total of 120 plots over all sites.
- Within plots we recorded: cover estimates of each species in standard height tiers; all vascular species present, as well as prominent bryophytes and lichens; physical parameters such as slope, altitude and aspect; the height of the tallest individual of the dominant vascular species; the height of the tallest monoao (*Dracophyllum subulatum*, the dominant frost flat shrub) if present, and human and introduced mammal impacts.
- We used Generalised Linear Mixed Models to test changes over time in vegetation height, and in occupancy (proportion of plots) and foliar cover for species assigned to three groups (diagnostic frost flat species, forest precursor species, and invasive exotic species) that occurred at least 25 times across all three surveys.

Results

- *Cladonia capitellata* and *Hypochaeris radicata* were the only species to show a significant change in the proportion of plots occupied between surveys: a decrease from 45% of plots occupied in 2012 and 2018 to 28% in 2024 for *C. capitellata*, and a decrease from 63% of plots occupied in 2012 to 46% in 2018 and 48% in 2024 for *H. radicata*.

- The most widespread (proportion of plots occupied) diagnostic frost flat species in all surveys were *Dracophyllum subulatum* (96% in 2012 and 2018, and 93% in 2024), *Pulchrocladia retipora* (90% in 2012, 89% in 2018 and 88% in 2024), *Poa cita* (91% in 2012, 87% in 2018 and 81% in 2024) and *Rytidosperma gracile* (68% in 2012, 80% in 2018 and 73% in 2024).
- The most widespread invasive exotic species were *Holcus lanatus* (18% of plots occupied in all years), *Pilosella officinarum* (17% in 2012, 19% in 2018, and 23% in 2024), and *Pinus contorta* (14% in 2012, 12% in 2018, and 23% in 2024).
- The only forest precursor found in more than 5% of plots in any survey was *Pinus contorta*, which is both an invasive exotic and a forest precursor
- Mean plot cover of five diagnostic frost flat species (*Dracophyllum subulatum*, *Poa cita*, *Celmisia gracilenta*, *Pulchrocladia retipora* and *Rytidosperma gracile*) and two other species (*Cladia* sp. aff. *inflata* and *Coprosma propinqua*) increased significantly.
- *Pinus contorta* showed a significant increase in mean plot cover; no other forest precursor species occurred frequently enough to be included in significance tests.
- The mean height of the tallest of any species in each plot, and of the tallest *Dracophyllum subulatum* in each plot increased significantly between 2012 and 2024.

Conclusions

- The monitored frost flats have largely maintained their ecological integrity between 2012 and 2024.
- However, local areas appear to be experiencing large increases in invasive exotic species abundance, and these species, particularly *P. contorta*, could soon be of major concern.
- The vegetation seems to be gradually shifting to greater woody dominance, but not at the expense of diagnostic frost flat species.

Recommendations

- Maintain and remeasure the plots in 2030 to monitor ecological integrity, natural succession, weed invasion, and the response of frost flat heathland to a warming climate.
- Undertake control of *Pinus contorta* annually or biennially to prevent trees from producing seed.
- Trial the use of high-resolution aerial imagery acquired by unmanned aerial vehicles to identify smaller individual *Pinus contorta* trees than is currently achieved by ground searching in frost flat heathland so that they can be controlled before reaching cone-bearing age.
- Maintain and remeasure existing plots established in 2022 to monitor the effects of *Pinus contorta* invasion and control on soil and vegetation, and the potential to restore frost flat communities following *P. contorta* removal.
- Maintain and remeasure the existing monitoring plots that were established after a lightning-induced fire at Rangitaiki in 1994, to provide a baseline against which to compare successional changes in other areas of frost flat heathland.

1 Introduction

Permanent vegetation monitoring plots were established in the remaining substantial frost flat heathlands in the Bay of Plenty Region by Manaaki Whenua – Landcare Research in January–February 2012 for the Bay of Plenty Regional Council. The plots were remeasured in January–March 2018 and February–March 2024, and changes over time in species cover and other indicators of condition, or 'ecological integrity' (Lee et al. 2005), were assessed.

2 Background

Frost flat heathlands comprise short, evergreen, sclerophyllous shrublands dominated by the ericaceous shrub monoao (*Dracophyllum subulatum*) on well-drained, infertile, volcanic soils. They were characteristic of shallow basins on the North Island Volcanic Plateau, mantled by deep deposits of infertile rhyolitic tephra (Smale 1990). Despite their occurrence well below the regional treeline under climates that are generally amenable for plant growth, the most ecologically stressed sites are subject to a year-round frost regime resulting from cold air ponding, which is thought to maintain the treeless community (e.g., Figures 1 & 2). The potential additional role of soil infertility in excluding native forest from frost flats remains unexplored.

The region has a long history of human burning, which has undoubtedly played a major role – as elsewhere – in reducing taller woody vegetation and replacing it with shorter woody vegetation and grassland. The taller woody component of frost flat heathland – bog pine (*Halocarpus bidwillii*) and mountain toatoa (*Phyllocladus alpinus*) – has been severely reduced by burning and now survives only as scattered remnants, mostly on sites such as dongas (deep, steep-sided erosion gullies) that are protected from fire. The floristic affinities of frost flat heathland with the largely fire-induced short tussock grasslands of the eastern South Island (Smale 1990) emphasise the role fire may have played in helping form and maintain these communities.

The pre-human vegetation of the coldest frost flats in the region may well have been short conifer forest dominated by bog pine and perhaps mountain toatoa, analogous to extant remnants at west Taupo (McKelvey 1963), and the bog pine, mountain celery pine scrub/forest on acidic infertile soils in intermontane basins in the eastern South Island (Singers & Rogers 2014). Bog pine is still quite widespread on the southern Kaingaroa plateau, but mountain toatoa is very rare, and in the absence of palynological studies it is difficult to know the extent to which this scarcity is an artefact of human fires.

The long-term persistence of non-forest communities on well-drained sites under reasonable rainfall is unusual in New Zealand, and frost flats provide habitat for a suite of species that would otherwise be absent from these landscapes. As a historically rare, Critically Endangered ecosystem (Holdaway et al. 2012), local authorities are required to prioritise frost flat heathland for restoration (Ministry for the Environment 2023).

The pre-European extent of frost flat heathland is estimated to have been several tens of thousands of hectares (Smale 1990), but this has been reduced by an order of magnitude since c. 1930 by land development for agriculture and forestry to a few thousand hectares, mostly at one extreme site (Rangitaiki Conservation Area). The few intact remaining frost flats are highly fragmented and susceptible to a range of threats such as weed invasion (especially contorta pine*, Pinus contorta*, and mouse-ear hawkweed, *Pilosella officinarum*) and nutrient enrichment through fertiliser drift. Delich (2020) found a 12.9% reduction in frost flat heathland extent between 2003 and 2016, largely due to pine invasion, with a doubling of areas with >25% pine cover and 8.3% reduction in areas with <1% pine cover. The influence of the surrounding matrix on survival prospects is unknown but likely to be significant.

Figure 1. Frost flat heathland dominated by *Dracophyllum subulatum,* with tall native forest on higher ground in the background and a distinct ecotone between them, Taho, Whirinaki Te Pua-a-Tāne Conservation Park, February 2012.

Figure 2. Vegetation monitoring plot in *Dracophyllum subulatum* shrubland (burnt c. 1964), with ground cover dominated by the lichen *Pulchrocladia retipora,* Rangitaiki Conservation Area, March 2018.

3 Objectives

To identify changes in the vegetation structure and composition of most of the substantial frost flat heathlands remaining in the Bay of Plenty Region in relation to natural succession and weed invasion.

4 Methods

4.1 Permanent plots

Fifteen permanently marked 2 × 2-m permanent plots were established in January–February 2012 in major vegetation types reflecting different structural classes (grassland, shrubland) and fire history across the six substantial frost flat sites remaining in the Bay of Plenty Region (Figure 3; Smale & Fitzgerald 2012). The structural classes, such as grassland and shrubland, represent both developmental stages of community and site variation (e.g. fertility; Yeates et al. 2004) variation. Plot locations are given in Appendix 1.

Within plots we recorded the attributes below, following Hurst and Allen (2007):

- all vascular species present, including invasive weeds, as well as prominent bryophytes and lichens
- quantitative cover estimates of each species in standard height tiers (<0.3 m, 0.3–2 m, 2–5 m, 5–12 m)
- physical parameters such as slope, altitude and aspect
- maximum height of monoao, and the height of the tallest individual of the dominant vascular species if this was not monoao
- human impact (e.g. off-road vehicle tracks)
- introduced mammal impact, including the presence of faecal pellets and trampling and the presence and degree of browsing.

The sampled sites include two larger, intact sites:

- Rangitaiki Conservation Area and surrounding frost flat
- Otangimoana Stewardship Area

and four smaller, fragmented sites:

- Rangitaiki River Conservation Area (previously Waimarama Conservation Stewardship Land
- Taho, Otupaka Ecological Area (Part of Whirinaki Te Pua-a-Tāne Conservation Park)
- Rangitāiki River Scrub (Timberlands/CNI Holdings Ltd), previously Rangitāiki River Marginal Strip
- Rangitaiki Station (Landcorp).

Details of the sites are summarised in Table 1.

Table 1. Characteristics of the sample sites

Site	Approximate area	Vegetation types	Approximate age	Surrounding landcover
Rangitaiki Conservation Area and surrounding frost flat	2355 ha	Monoao shrubland Monoao shrubland Silver tussock grassland	124 years 60 years 34 years	Native forest and pasture
Otangimoana Stewardship Area	328 ha	Shrubland	Unknown	Plantation forest and pasture
Rangitaiki River Conservation Area	114 ha	Shrubland	Uncertain but probably 120 years	Plantation forest
Taho	61 ha	Shrubland	Unknown	Native forest
Rangitāiki River Scrub	34	Shrubland	Unknown	Plantation forest
Rangitaiki Station	5	Shrubland	Unknown	Pasture

All surviving plots were remeasured in January–March 2018 (Fitzgerald et al. 2019) and again in February–March 2024 (this report).

4.2 Data analysis

Foliar cover within each height tier was combined to give a total value within each plot, for each species or species group, using the method of Fischer (2015). This is calculated by multiplying the proportions of each tier not covered by the species and subtracting this from 1. This allows the total proportion of cover within a plot to range from 0–1 (0–100%).

We fitted generalised linear mixed models (GLMMs) to the data using maximum likelihood estimation to assess changes in occurrence (presence) and foliar cover with time for species assigned to three groups (diagnostic frost flat species, forest precursor species, and invasive exotic species) that occurred at least 25 times across all three surveys. Plot ID was included in all models as a random effect to account for the repeated measures nature of the study design. A beta-binomial error distribution was used for modelling the occurrence data, and a lognormal distribution was specified when modelling changes in foliar cover. A zero-inflation parameter was included in models of foliar cover to account for excess zero values.

As well as testing for changes in the cover of individual species, we also tested for changes in the total cover of our three groups. Key threats to frost flat heathland are thought to be natural succession to forest and weed invasion, so we chose these groups as indicators of ecological integrity. Diagnostic frost flat species are 12 key species previously identified as being present in more than 50% of frost flat plots (Smale 1990). We also tested for change in the total cover of non-frost flat species (both forest precursors and invasive exotic species). Finally, we tested for changes in the maximum height of vegetation in each plot as well as changes in the maximum height of *Dracophyllum subulatum*, the dominant frost flat shrub, in each plot.

All models were fitted with the glmmTMB package (Brooks et al. 2017) in the R statistical computing environment (4.4.0; R Core Team 2024). Statistical significance was assessed with approximate Bonferroni adjustment for multiple comparisons, where α = 0.05 divided by the number of comparisons. This is a conservative correction that reduces the likelihood of considering a test result to be a real change when it could simply be due to chance. We used a simulation-based approach to test model fits for residual over- and under-dispersion and residual outliers that might indicate model mis-specification using the DHARMa package (Hartig 2022).

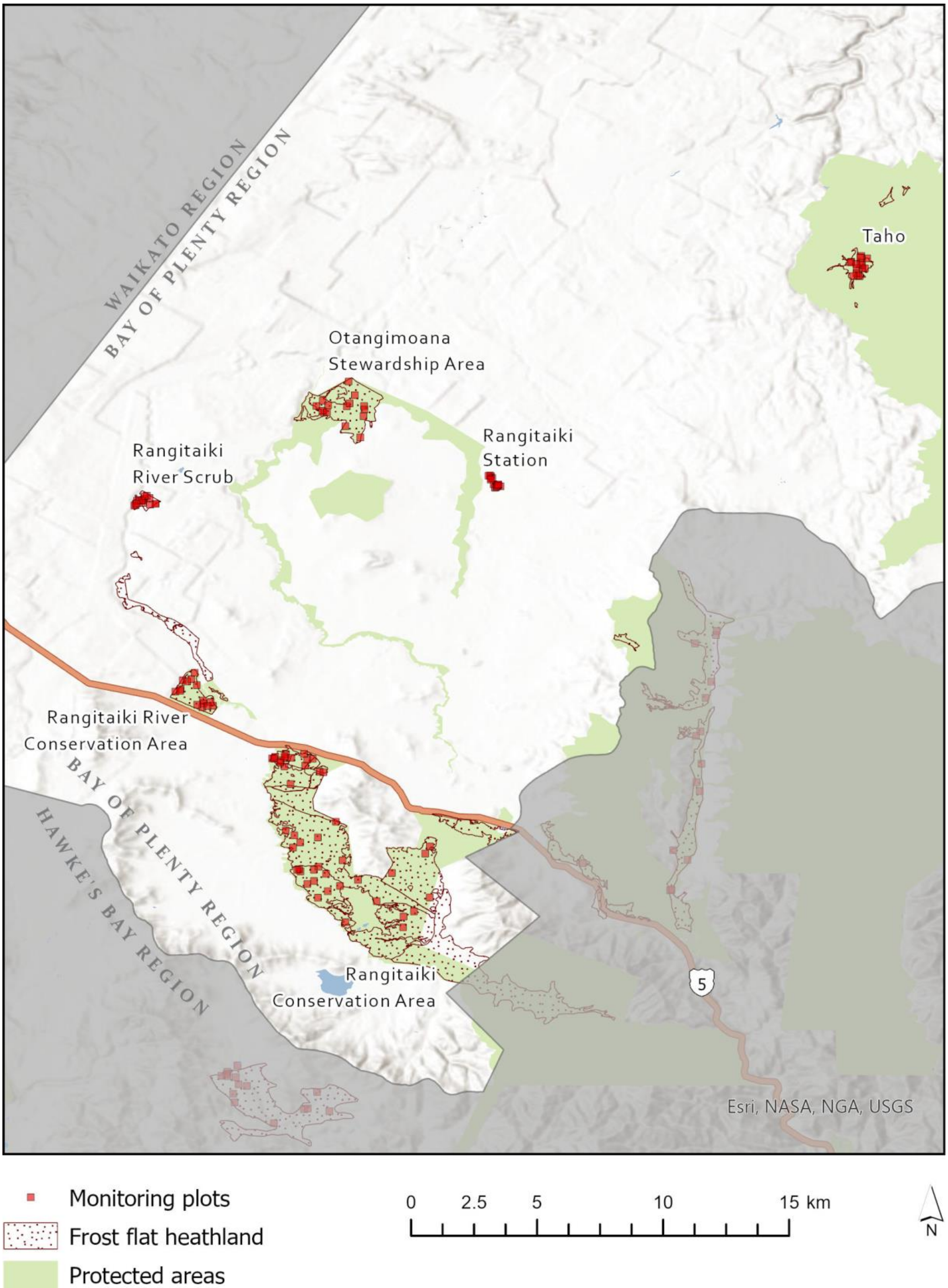

Figure 3. Bay of Plenty frost flat heathland and monitoring plot locations.

5 Results

Of the 120 plots originally established, one plot at Rangitaiki (burnt c. 1990) could not be relocated in 2018 or 2024. This plot was not remeasured in 2018 but was recreated at the same coordinates and measured in 2024.

All species recorded in monitoring plots, their mean cover estimates, and 95% margin of error (MOE_{95}, calculated as 1.96 × the standard error and equivalent to half the 95% confidence interval) are listed in Appendix 2.

5.1 Species occurrence

Only two species showed a significant change in the proportion of plots occupied between 2012 and 2024:

- the native lichen *Cladonia capitellata* – decrease from 45% of plots occupied in 2012 and 2018 to 28% in 2024
- and the adventive herb *Hypochaeris radicata* – decrease from 63% of plots occupied in 2012 to 46% in 2018 and 48% in 2024 (Table 2).

The most widespread diagnostic frost flat species in both surveys were

- *Dracophyllum subulatum* – 96% of plots occupied in 2012 and 2018 and 93% in 2024
- *Pulchrocladia retipora* (previously called *Cladia retipora*) 90% of plots occupied in 2012, 89% in 2018, and 88% in 2024
- *Poa cita* – 91% of plots occupied in 2012, 87% in 2018, and 81% in 2024
- *Rytidosperma gracile* – 68% of plots occupied in 2012, 80% in 2018, and 73% in 2024.

The most widespread invasive exotics were:

- *Holcus lanatus* – 18% of plots occupied in all years
- *Pilosella officinarum* – 17% of plots occupied in 2012, 19% in 2018, and 23% in 2024
- *Pinus contorta* – 14% of plots occupied in 2012, 12% in 2018, and 23% in 2024 (both an invasive exotic and a forest precursor).

Although differences between sites were not included in the models (due to the relatively small number of plots at each site), there were consistent increases in *P. contorta* occurrence at Otangimoana Stewardship Area (33% in 2012, 40% in 2018, and 80% in 2024), and at Rangitaiki River Scrub (7% in 2012, 13% in 2018, and 20% in 2024). No other forest precursor species occurred in more than 5% of plots in any survey.

5.2 Vegetation cover

The diagnostic frost flat species *Dracophyllum subulatum* (mean total cover 40.3% ± MOE_{95} of 4.9 in 2012, 41.4% ± 4.4 in 2018 and 54.9% ± 4.9 in 2024) and *Pulchrocladia retipora* (mean total cover 34.0% ± 4.1 in 2012, 37.7% ± 4.6 in 2018, and 44.2 ± 5.8 in 2024) had by far the highest mean cover scores of any species in either survey (Appendix 2). Of the invasive exotics, *Holcus lanatus* and *Pilosella officinarum* had the highest mean cover in 2012 (2.7% ± 1.8 and 1.2% ± 0.8, respectively), *Pinus contorta* (4.9% ± 3.3) and *H. lanatus* (1.6% ± 1.0) in 2018, and *P. contorta* (6.1% ± 3.6) and *H. lanatus* (2.6% ± 1.8) in 2024. The change in mean cover for *Pinus contorta* represents an order-of-magnitude increase over the past 12 years. This is due to major increases in cover across a small number of plots (e.g. Figure 4), as indicated by the comparatively large margin of error for the estimate of the mean.

The removal of *Pinus contorta* by felling and herbicide adds further to the variance in cover estimates for this species. For example, one plot at Otangimoana Stewardship Area was estimated to have 17% cover of *Pinus contorta* (across three height tiers) in 2012, but in 2018 the then much larger trees had been recently felled and the plot consisted entirely of dead pine slash, with no live vegetation cover recorded. In 2024 the pine slash was largely decomposed and the dominant species was *H. lanatus* (30% cover), with some *Rytidosperma gracile* (16%), *Poa cita* (13%), monoao (10%), *Kunzea serotina* (8%) and *P. contorta* (3%) (Figure 5).

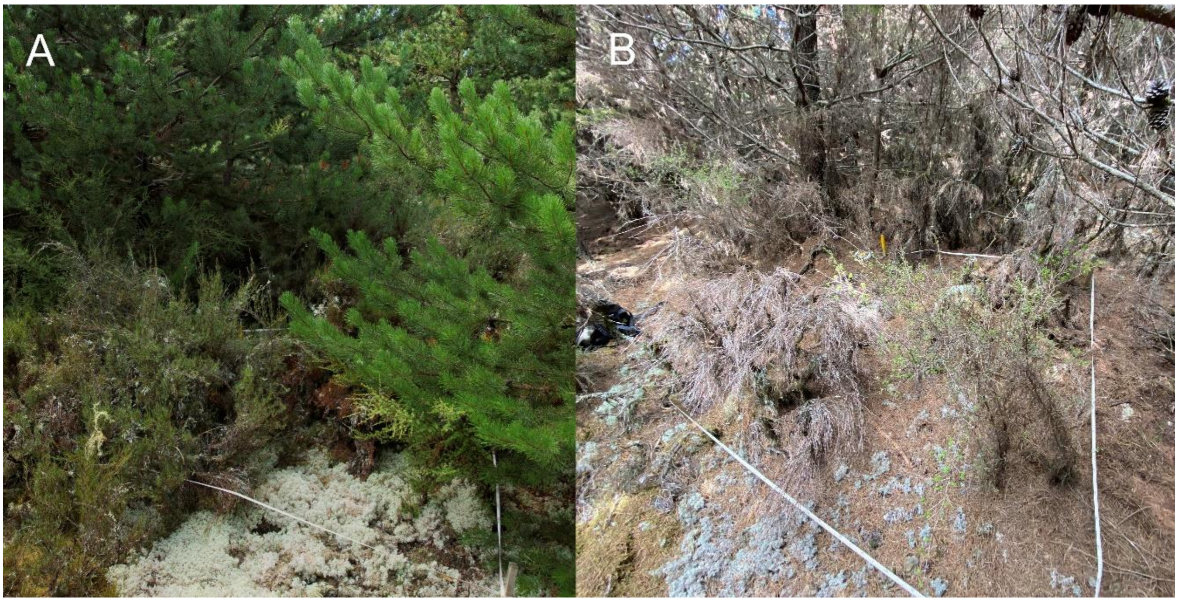

Figure 4. A: *Pinus contorta* (5 m tall) invading monitoring plot 8 at Otangimoana Stewardship Area in February 2018. B: the same plot in 2024. In 2024 all *Dracophyllum subulatum* is dead, and although the lower branches of the pines are dead, the trees are alive and 10m tall. Other live species are mainly lichen (5% cover) and *Kunzea serotina* (6% cover).

Figure 5. A: Wilding pine slash completely covering Otangimoana plot 11, February 2018, looking southwest. B: the same plot in 2024 (looking notheast): the slash has largely decomposed, the vegetation is dominated by *Holcus lanatus,* and other grasses have established.

Table 2. Proportion of plots occupied in 2012, 2018, and 2024

Scientific name	Group	Mean occupancy			*P*-value
		2012	2018	2024	
Kunzea serotina	Forest precursor	0.05	0.034	0.05	NA
Leptospermum scoparium	Forest precursor	0.042	0.034	0.033	NA
Pseudopanax crassifolius	Forest precursor	0	0.008	0	NA
Celmisia gracilenta	Diagnostic frost flat	0.333	0.328	0.333	0.937
Cladonia capitellata	**Diagnostic frost flat**	**0.45**	**0.454**	**0.283**	**0.001**
Cladonia confusa	Diagnostic frost flat	0.742	0.748	0.725	0.798
Deyeuxia avenoides	Diagnostic frost flat	0.517	0.429	0.408	0.044
Dracophyllum subulatum	Diagnostic frost flat	0.958	0.958	0.933	0.104
Hypochaeris radicata	**Diagnostic frost flat**	**0.625**	**0.462**	**0.483**	**0.002**
Pimelea prostrata	Diagnostic frost flat	0.283	0.244	0.258	0.132
Poa cita	Diagnostic frost flat	0.908	0.866	0.808	0.004
Pulchrocladia retipora	Diagnostic frost flat	0.9	0.891	0.875	0.176
Racomitrium lanuginosum	Diagnostic frost flat	0.675	0.681	0.608	0.02
Rytidosperma gracile	Diagnostic frost flat	0.675	0.798	0.733	0.184
Styphelia nesophila	Diagnostic frost flat	0.367	0.336	0.333	0.111
Agrostis sp.	Invasive exotic	0.075	0.109	0.108	0.05
Anthoxanthum odoratum	Invasive exotic	0.05	0.084	0.092	0.022
Cytisus scoparius	Invasive exotic	0	0	0.025	NA
Festuca rubra	Invasive exotic	0.017	0	0	NA
Holcus lanatus	Invasive exotic	0.183	0.176	0.183	1
Lotus pedunculatus	Invasive exotic	0.033	0.042	0.05	NA
Pilosella officinarum	Invasive exotic	0.167	0.185	0.225	0.014
Pinus contorta	Invasive exotic	0.142	0.118	0.225	0.007
Trifolium repens	Invasive exotic	0.017	0.008	0.008	NA

Notes: Changes are statistically significant where the *P*-value is <0.003 (in **bold**). Models were not fitted to species recorded fewer than 25 times across all plots and years (*P*-value = NA).

Total cover of all species groups – diagnostic frost flat species, forest precursor species, invasive species and non-frost flat species – increased statistically significantly ($P < 0.001$) between 2018 and 2024 (Table 3). All of these groups can increase in cover because the vegetation is multi-layered. Both maximum vegetation height (mean 1.30 m in 2012, 1.67 m in 2018, and 1.98 m in 2024) and maximum height of *Dracophyllum subulatum* (mean 1.29 m in 2012, 1.34 in 2018 and 1.40 in 2024) increased significantly between surveys.

Table 3. Model fit significance results for change over time in total cover for each species group and for maximum vegetation height or maximum height of *Dracophyllum subulatum*

Group	Mean total percentage cover (MOE_{95}) 2012	2018	2024	*P*-value
Diagnostic frost flat	69.59 (3.87)	70.73 (4.09)	77.57 (4.86)	**<0.001**
Forest precursor	0.41 (0.43)	0.5 (0.58)	1.26 (1.29)	**<0.001**
Invasive	5.46 (2.34)	8.95 (3.74)	13.32 (4.65)	**<0.001**
Non-frost flat species	8.78 (2.72)	12.13 (3.23)	22.23 (5.11)	**<0.001**
Mean maximum height in m (MOE_{95})				
Max height of all species	1.30 (0.12)	1.67 (0.23)	1.98 (0.34)	**<0.001**
Max height of *D. subulatum*	1.29 (0.09)	1.34 (0.09)	1.4 (0.09)	**<0.001**

Note: Significant changes (*P* <0.01) are in **bold**.

Total cover of six diagnostic frost flat species, *Dracophyllum subulatum*, *Poa cita*, *Celmisia gracilenta*, *Pulchrocladia retipora*, *Rytidosperma gracile* and *Styphelia nesophila* (previously known as *Leucopogon fraseri*), increased significantly in cover (Table 4). Although the measured mean cover of *Styphelia nesophila* decreased, the model fitted to the data suggested a statistically significant increase in cover due to a reduction in the number of plots where this species was absent.

Among invasive species, *Pinus contorta* (also a forest precursor) and *Agrostis* species (previously recorded as one species, *Agrostis capillaris*, but at least two species are present) increased significantly in cover, the latter considerably at Rangitaiki Station and to a lesser extent at Rangitaiki Conservation Area. No forest precursor species occurred frequently enough to be modelled.

Among the remaining species occurring frequently enough to be tested, only *Coprosma propinqua*, *Halocarpus bidwillii*, and *Cladia* sp. aff. *inflata* (previously recorded as *Cladia aggregata*) increased significantly in cover over time.

Table 4. Mean cover and model fit significance results for change in total cover for individual species over time

Species	Group	2012	2018	2024	*P*-value
Celmisia gracilenta	**Diagnostic frost flat**	**0.24**	**0.24**	**0.3**	**<0.001**
Cladonia capitellata	Diagnostic frost flat	0.53	0.49	0.56	0.124
Cladonia confusa	Diagnostic frost flat	1.82	1.88	2.19	0.13
Deyeuxia avenoides	Diagnostic frost flat	0.26	0.24	0.26	0.28
Dracophyllum subulatum	**Diagnostic frost flat**	**40.3**	**41.39**	**54.93**	**<0.001**
Hypochaeris radicata	Diagnostic frost flat	0.99	1.15	1.42	0.03
Pimelea prostrata	Diagnostic frost flat	1.27	1.17	1.45	0.401
Poa cita	**Diagnostic frost flat**	**4.27**	**4**	**7.68**	**<0.001**
Pulchrocladia retipora	**Diagnostic frost flat**	**33.97**	**37.69**	**44.18**	**<0.001**
Racomitrium lanuginosum	Diagnostic frost flat	10.04	9.54	10.66	0.002
Rytidosperma gracile	**Diagnostic frost flat**	**0.63**	**1.48**	**1.96**	**<0.001**
Styphelia nesophila	**Diagnostic frost flat**	**0.29**	**0.17**	**0.17**	**<0.001**
Agrostis sp.	**Invasive**	**0.35**	**1.54**	**2.44**	**<0.001**
Anthoxanthum odoratum	Invasive	0.65	0.37	1.37	0.438
Holcus lanatus	Invasive	2.72	1.57	2.56	0.865
Pilosella officinarum	Invasive	1.16	0.64	1.63	0.086
Pinus contorta	**Forest precursor, invasive**	**0.61**	**4.89**	**6.11**	**<0.001**
Androstoma empetrifolia	NA	0.53	0.88	1.58	0.109
Campylopus introflexus	NA	0.07	0.06	0.03	0.043
Carex punicea	NA	0.06	0.1	0.08	0.105
Cladia sp. aff. inflata	**NA**	**0.11**	**0.23**	**0.27**	**<0.001**
Coprosma propinqua	**NA**	**0.57**	**1.54**	**2.75**	**<0.001**
Dicranoloma billardierei	NA	1.91	2.01	3.91	NA
Geranium brevicaule	NA	0.03	0.01	0.03	0.002
Gonocarpus aggregatus	NA	0	0	0.91	NA
Gonocarpus montanus	NA	0.07	0.15	0	0.383
Halocarpus bidwillii	**NA**	**0.43**	**0.87**	**1.67**	**<0.001**
Helichrysum filicaule	NA	0.01	0.01	0.01	0.07
Hypnum cupressiforme	NA	2.59	2.91	6.65	0.005
Lepidosperma australe	NA	0.04	0.24	1.24	NA
Lycopodium fastigiatum	NA	0.06	0.07	0.4	0.111
Muehlenbeckia axillaris	NA	0.31	0.53	1.03	0.015
Polytrichum juniperinum	NA	0.09	0.11	0.31	0.052

Notes: Tests were only performed for species at least 25 occurrences across all surveys and unreliable models have a I-value of NA. *P*-values <0.002 are considered statistically significant and are shown in bold

5.3 Animal impacts

In 2024, feral pig (*Sus scrofa*) rooting was recorded in two plots at Taho and one at Otangimoana Stewardship Area. Lagomorph – brown hare (*Lepus europaeus*) and rabbit (*Oryctolagus cuniculus*) – pellets were recorded in two plots at Rangitaiki River Conservation Area, four plots at Rangitaiki River Scrub, one plot at Rangitaiki Conservation Area (1900 burn), six plots in the 1964 burn, and four plots in the 1990 burn. Pellets are likely to be largely hidden when *Pulchrocladia retipora* is damp, and more obvious when it is dry and shrunken (revealing bare ground). There was little or no sign of rabbit or hare browse in the vast majority of plots across all sites.

6 Discussion

The ecological integrity of the monitored frost flats appears to be relatively stable. Diagnostic frost flat species were the most widespread species in all surveys, indicating a high level of species occupancy and native dominance. On average, the total cover of diagnostic frost flat species increased between surveys, and this appeared to be largely due to increases in the cover of dominant species, including *Dracophyllum subulatum* and *Pulchrocladia retipora*. The increase in cover may reflect a changing (warming) climate.

The increase in cover of *Pinus contorta* and its presence now in nearly one-quarter of plots is of concern. Because of its potential to invade and displace frost flat heathland altogether, control of *P. contorta* has been undertaken at Rangitaiki Conservation Area since 1989 (Smale et al. 2011), where the Department of Conservation has used herbicide and manual felling rotated over three zones for the past 15 years (Jane Williams, Department of Conservation, pers. comm.). Recent felling of *P. contorta* was also apparent at Otangimoana in 2018.

To eradicate a weed such as *P. contorta*, it is important that all individuals are located and targeted within a period dictated by the species' life cycle (Williams 1997). Once produced, *P. contorta* seed can be dispersed long distances – up to 40 km from exposed windy sites – though most falls close (up to a few tens of metres) to the parent tree (Burns et al. 2001). The seed of *P. contorta* is unlikely to remain viable in the soil beyond 3 years (Richardson 1998), so the apparent failure of efforts to eradicate *P. contorta* is probably due to uncontrolled plants producing seed in – or within dispersal distance of – frost flats.

Pinus contorta is known to produce seed from 4 years old in New Zealand (Burns et al. 2001). However, individual trees can be difficult to see from ground level until they are taller than the surrounding vegetation, meaning they are likely to be 4–5 years old and setting seed before removal on a 3-year rotation. Seeding trees with cones were observed at several sites, including Rangitaiki Conservation Area, Otangimoana Stewardship Area, Rangitaiki River Conservation Area, and Rangitaiki River Scrub.

To prevent *in situ* seeding and achieve local eradication, we recommend that the frequency of current control methods be increased to 1–2 yearly, and new methods such as high-resolution imagery from unmanned aerial vehicles (UAVs/drones) be explored to identify smaller individual trees than is currently achieved.

The long-term effect of wilding pine invasion on frost flats after removal is unknown. Changes in soil structure and fertility caused by deep-rooted trees may promote vegetation shifts away from natural frost flat heathland. A critical question is whether sites occupied by *P. contorta* forest will revert to frost flat heathland following *P. contorta* removal, or whether the ecosystem has been so altered that it shifts to a different state.

Research on the effect of *P. contorta* invasion and control on soil and vegetation is underway, with the establishment of additional monitoring plots in pine-invaded sites in 2022, to help with understanding of the long-term prospects for frost flat restoration after *P. contorta* removal. Data from monitoring natural frost flat succession after lightning fires (Smale et al. 2011) may provide a useful baseline against which to compare successional changes in vegetation after *P. contorta* removal.

The increase in the cover of the invasive adventive grass bent (*Agrostis* species) at Rangitaiki Station and Rangitaiki Conservation Area is also concerning. Although species of low-fertility sites, they are absent from intact frost flat heathland and their increase may be related to elevated soil fertility, most likely caused by fertiliser drift from neighbouring farmland, or high propagule pressure from the surrounding area which is now dominated by exotic grasses following *P. contorta* invasion and subsequent removal between 2006 and 2011. Measurement of soil nutrients in the Rangitaiki Station frost flat and the surrounding area that was previously invaded with *P. contorta* may help to identify the cause of increased *Agrostis* cover.

Forest precursor species remain rare, and although none were common enough to model change by separate species, there was a significant increase in their combined cover. There is evidence of succession back to taller scrub – the supposed pre-human precursor of *Dracophyllum subulatum*-dominant shrubland – occurring, with significant increases in the maximum height of vegetation, and of *D. subulatum* within plots and cover of *Coprosma propinqua* and *Halocarpus bidwillii* over time. Taken together, these results suggest that native woody species are increasing in both stature and abundance – albeit very slowly – across the frost flat sites. Palynological studies would shed further light on the history of frost flat heathland and their long-term future, but these have not been undertaken to date.

Recent changes at Bay of Plenty frost flat heathlands on the southern Kaingaroa plateau provide an interesting comparison with those occurring over a similar period in similar heathland at west Taupō (Smale et al. 2023). There, many diagnostic frost flat species are less widespread and forest precursor species far more widespread and increasing in cover, indicating slow succession back to forest in many plots and the essentially ephemeral nature of much of the west Taupō frost flat heathland.

7 Conclusions

The monitored frost flats have largely maintained their ecological integrity between 2012 and 2024. However, local areas, especially Otangimoana Stewardship Area and Rangitaiki River Scrub, appear to be experiencing large increases in invasive exotic species abundance, and these species, particularly *P. contorta*, are of major concern. Also, the vegetation seems to be gradually shifting very slowly towards greater woody dominance, but not at the expense of diagnostic frost flat species.

8 Recommendations

- Maintain and remeasure the plots in 2030 to monitor the response of frost flat species to a warming climate.
- Undertake control of *Pinus contorta* annually or biennially to prevent trees from producing seed.
- Trial the use of high-resolution aerial imagery acquired by unmanned aerial vehicles to identify smaller individual *Pinus contorta* trees than is currently achieved by ground searching in frost flat heathland, so that they can be controlled before reaching cone-bearing age.
- Maintain and remeasure existing plots established in 2022 to monitor the effects of Pinus contorta invasion and control on soil and vegetation, and the potential to restore frost flat communities following *P. contorta* removal.
- Maintain and remeasure the existing monitoring plots that were established after a lightening-induced fire at Rangitaiki in 1994, to provide a baseline against which to compare successional changes in other areas of frost flat heathland.

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Appendix 1 – Frost flat monitoring plot locations

Table A1. Bay of Plenty frost flat vegetation monitoring plot locations (NZTM)

Site	Plot	East	North	Altitude (m)
Rangitaiki Station	Matea-01	1899749	5701486	677
	Matea-02	1899724	5701510	680
	Matea-03	1899859	5701017	685
	Matea-04	1899964	5701139	690
	Matea-05	1899941	5701093	689
	Matea-06	1899821	5701156	680
	Matea-07	1900034	5701066	686
	Matea-08	1899972	5701107	687
	Matea-09	1899900	5701038	686
	Matea-10	1899931	5701087	688
	Matea-11	1899968	5701140	687
	Matea-12	1899791	5701408	676
	Matea-13	1899741	5701387	676
	Matea-14	1899674	5701500	675
	Matea-15	1899736	5701342	677
Otangimoana	Otangimoana-01	1894661	5704193	644
	Otangimoana-02	1895891	5704003	655
	Otangimoana-03	1894626	5704261	643
	Otangimoana-04	1895922	5704406	653
	Otangimoana-05	1895762	5703166	664
	Otangimoana-06	1895389	5704415	651
	Otangimoana-07	1894447	5704463	644
	Otangimoana-08	1895480	5704528	649
	Otangimoana-09	1895482	5705389	636
	Otangimoana-10	1895316	5703632	665
	Otangimoana-11	1895655	5704846	650
	Otangimoana-12	1894653	5704663	648
	Otangimoana-13	1895930	5704265	654
	Otangimoana-14	1894814	5704481	643
	Otangimoana-15	1894767	5704201	646
Rangitaiki Conservation Area (c. 1900 burn)	Rangitaiki-1900-01	1895581	5684785	732
	Rangitaiki-1900-02	1893077	5687005	731
	Rangitaiki-1900-03	1892929	5690226	719
	Rangitaiki-1900-04	1893137	5687488	733
	Rangitaiki-1900-05	1893090	5689520	732

Site	Plot	East	North	Altitude (m)
Rangitaiki Conservation Area (c. 1900 burn) cont'	Rangitaiki-1900-06	1893861	5687377	731
	Rangitaiki-1900-07	1897154	5686613	742
	Rangitaiki-1900-08	1895034	5685653	738
	Rangitaiki-1900-09	1897224	5684871	746
	Rangitaiki-1900-10	1892878	5687684	730
	Rangitaiki-1900-11	1894436	5687979	740
	Rangitaiki-1900-12	1893307	5687202	732
	Rangitaiki-1900-13	1896093	5685884	749
	Rangitaiki-1900-14	1897310	5686896	747
	Rangitaiki-1900-15	1894589	5686441	738
Rangitaiki Conservation Area (c. 1964 burn)	Rangitaiki-1964-01	1893835	5686219	733
	Rangitaiki-1964-02	1893271	5686053	730
	Rangitaiki-1964-03	1893463	5685547	733
	Rangitaiki-1964-04	1893226	5686139	730
	Rangitaiki-1964-05	1894058	5685926	730
	Rangitaiki-1964-06	1894470	5685434	728
	Rangitaiki-1964-07	1896721	5684334	748
	Rangitaiki-1964-08	1894086	5685238	726
	Rangitaiki-1964-09	1896388	5684146	743
	Rangitaiki-1964-10	1893689	5686098	732
	Rangitaiki-1964-11	1893677	5685657	735
	Rangitaiki-1964-12	1893170	5686114	728
	Rangitaiki-1964-13	1894587	5683988	721
	Rangitaiki-1964-14	1893771	5684988	722
	Rangitaiki-1964-15	1896361	5683722	747
Rangitaiki Conservation Area (c. 1990 burn)	Rangitaiki-1990-01	1892996	5690700	725
	Rangitaiki-1990-02*	1892563	5690562	711
	Rangitaiki-1990-03	1894016	5689978	739
	Rangitaiki-1990-04	1893817	5690496	741
	Rangitaiki-1990-05	1892966	5690564	724
	Rangitaiki-1990-06	1893150	5690561	727
	Rangitaiki-1990-07	1894129	5689952	740
	Rangitaiki-1990-08	1893571	5690239	732
	Rangitaiki-1990-09	1892826	5690475	724
	Rangitaiki-1990-10	1892656	5690620	716
	Rangitaiki-1990-11	1892618	5690552	710
	Rangitaiki-1990-12	1892800	5690392	722
	Rangitaiki-1990-13	1893643	5690468	139

Site	Plot	East	North	Altitude (m)
Rangitaiki Conservation Area (c. 1990 burn) cont'	Rangitaiki-1990-14	1892943	5690623	723
	Rangitaiki-1990-15	1893553	5690700	737
Rangitaiki River Scrub	RRS-01	1888926	5700916	680
	RRS-02	1889326	5700769	685
	RRS-03	1888982	5700986	685
	RRS-04	1888706	5700741	675
	RRS-05	1889151	5700745	682
	RRS-06	1888665	5700730	672
	RRS-07	1888754	5700909	677
	RRS-08	1889320	5700770	688
	RRS-09	1888946	5700826	684
	RRS-10	1889149	5701005	686
	RRS-11	1889068	5701102	684
	RRS-12	1888818	5700942	679
	RRS-13	1888895	5700911	686
	RRS-14	1889001	5701084	685
	RRS-15	1888731	5700798	677
Taho	Taho-01	1911478	5708958	690
	Taho-02	1911438	5708988	691
	Taho-03	1911578	5709270	688
	Taho-04	1911522	5709472	677
	Taho-05	1911240	5709541	685
	Taho-06	1911567	5709399	679
	Taho-07	1911400	5709282	688
	Taho-08	1911384	5709082	688
	Taho-09	1911742	5709659	694
	Taho-10	1911656	5709263	690
	Taho-11	1911284	5708968	690
	Taho-12	1911226	5709517	687
	Taho-13	1911560	5709756	686
	Taho-14	1911528	5709682	689
	Taho-15	1911396	5709437	683
Rangitaiki River Conservation Area	Waimarama-01	1889834	5693402	706
	Waimarama-02	1890510	5692928	709
	Waimarama-03	1889908	5693756	708
	Waimarama-04	1890516	5692814	711
	Waimarama-05	1890471	5692662	711
	Waimarama-06	1890047	5693699	708

Site	Plot	East	North	Altitude (m)
Rangitaiki River Conservation Area cont.	Waimarama-07	1890175	5693787	708
	Waimarama-08	1890338	5693543	707
	Waimarama-09	1890802	5692712	713
	Waimarama-10	1889667	5693312	709
	Waimarama-11	1890289	5694039	705
	Waimarama-12	1889812	5693337	709
	Waimarama-13	1890742	5692861	710
	Waimarama-14	1890636	5692700	713
	Waimarama-15	1890322	5692768	714

*Not relocated in 2018

Appendix 2 – Mean foliar cover of species recorded in frost flat monitoring plots

Table A2. Mean of total cover across plots, combining height tiers within plots following Fischer (2015), and 95% margin of error (MOE95) of the mean estimates (calculated as 1.96 x standard error) of plants and lichens recorded in Bay of Plenty frost flat vegetation monitoring plots in 2012 (120 plots), 2018 (119 plots), and 2024 (120 plots)

Scientific name	Common name	2012		2018		2024		Origin	Group
		Mean cover	MOE_{95}	Mean cover	MOE_{95}	Mean cover	MOE_{95}		
Agrostis sp.		0.35	0.33	1.54	1.5	2.44	2.24	Exotic	Invasive
Androstoma empetrifolia	bog mingimingi	0.53	0.27	0.88	0.48	1.58	1.09	Endemic	
Anthoxanthum odoratum	sweet vernal	0.65	1.15	0.37	0.37	1.37	1.44	Exotic	Invasive
Aporostylis bifolia	odd-leaved orchid	<0.01	<0.01	0	0	0	0	Endemic	
Aristotelia fruticosa	mountain wineberry	0	0	0	0	<0.01	<0.01	Endemic	
Asplenium flaccidum	drooping spleenwort	0	0	0	0	<0.01	<0.01	Native	
Azorella hookeri		<0.01	<0.01	0	0	0	0	Endemic	
Blechnum penna-marina	little hard fern	0.37	0.64	0.63	0.82	0.8	0.95	Native	
Blechnum vulcanicum	mountain hard fern	<0.01	<0.01	<0.01	0.02	0	0	Native	
Breutelia affinis		0.61	0.92	0.43	0.84	0.21	0.41	Native	
Breutelia sp.		0	0	0	0	0.06	0.09	Native	
Caladenia species	orchid	<0.01	<0.01	0	0	0	0	Native	
Campylopus introflexus	moss	0.07	0.07	0.06	0.07	0.03	0.04	Native	
Campylopus sp.	moss	0	0	0	0	0.02	0.03	Native	
Carex breviculmis	grassland sedge	<0.01	<0.01	0.03	0.05	<0.01	<0.01	Native	
Carex horizontalis	hook sedge	0.04	0.08	0.02	0.03	0	0	Endemic	

Scientific name	Common name	2012		2018		2024		Origin	Group
		Mean cover	MOE_{95}	Mean cover	MOE_{95}	Mean cover	MOE_{95}		
Carex punicea	red hook sedge	0.06	0.05	0.1	0.1	0.08	0.06	Endemic	
Carex sp.		0	0	0	0	<0.01	<0.01	NA	
Carmichaelia australis	North Island broom	0.04	0.07	0.03	0.07	0.05	0.1	Endemic	
Celmisia gracilenta	common mountain daisy	0.24	0.3	0.24	0.24	0.3	0.22	Endemic	Diagnostic frost flat
Cerastium fontanum	chickweed	0	0	0	0	<0.01	<0.01	Exotic	
Chaerophyllum ramosum		0.01	0.02	0.08	0.12	<0.01	<0.01	Endemic	
Chiloglottis cornuta	green bird orchid	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	Endemic	
Cladia sp. aff. *inflata*	lichen	0.11	0.06	0.23	0.11	0.27	0.13	Native	
Cladia sullivanii	lichen	<0.01	<0.01	0.02	0.03	<0.01	<0.01	Native	
Cladonia capitellata	lichen	0.53	0.21	0.49	0.19	0.56	0.42	Native	Diagnostic frost flat
Cladonia coccifera	lichen	<0.01	<0.01	<0.01	<0.01	0.02	0.03	Native	
Cladonia confusa	lichen	1.82	0.49	1.88	0.49	2.19	0.48	Native	Diagnostic frost flat
Cladonia species	lichen	<0.01	<0.01	0	0	0	0	Native	
Clematis forsteri	Forster's clematis	0.02	0.03	0.03	0.07	0.04	0.08	Endemic	
Clematis quadribracteolata	clematis	<0.01	<0.01	<0.01	0.02	<0.01	0.02	Endemic	
Coprosma acerosa	sand coprosma	<0.01	<0.01	0	0	0.03	0.06	Endemic	
Coprosma cheesemanii		0	0	0	0	0.03	0.06	Endemic	
Coprosma dumosa		0.04	0.05	0.23	0.26	0.75	1.02	Endemic	
Coprosma propinqua	mingimingi	0.57	0.52	1.54	1.03	2.75	1.9	Endemic	
Coprosma ×cunninghamii		<0.01	<0.01	0.01	0.02	0.02	0.03	Endemic	
Corokia cotoneaster	korokio	0.16	0.21	0.2	0.25	0.06	0.08	Endemic	

Scientific name	Common name	2012		2018		2024		Origin	Group
		Mean cover	MOE_{95}	Mean cover	MOE_{95}	Mean cover	MOE_{95}		
Crepis capillaris	smooth hawksbeard	0.07	0.13	<0.01	<0.01	0.02	0.02	Exotic	
Cytisus scoparius	broom	0	0	0	0	0.03	0.06	Exotic	Invasive
Deyeuxia avenoides	mountain oat grass	0.26	0.1	0.24	0.1	0.26	0.11	Endemic	Diagnostic frost flat
Dichondra brevifolia	dichondra	<0.01	0.02	<0.01	<0.01	0.01	0.02	Endemic	
Dicranoloma billardierei	moss	1.91	1.17	2.01	1.12	3.91	2	Endemic	
Dicranoloma sp.		0	0	0	0	<0.01	0.02	NA	
Dracophyllum subulatum	monoao	40.3	4.88	41.39	4.37	54.93	4.86	Endemic	Diagnostic frost flat
Epilobium alsinoides subsp. Tenuipes	willowherb	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	Endemic	
Erigeron sumatrensis	broad-leaved flea-bane	0	0	0	0	<0.01	<0.01	Exotic	
Euphrasia cuneata	North Island eyebright	<0.01	<0.01	0	0	<0.01	<0.01	Endemic	
Festuca rubra	Chewing's fescue	0.03	0.05	0	0	0	0	Exotic	Invasive
Galium palustre	marsh bedstraw	0	0	<0.01	0.02	0	0	Exotic	
Galium perpusillum	dwarf bedstraw	<0.01	<0.01	<0.01	<0.01	0	0	Endemic	
Galium propinquum	māwe	0	0	0	0	<0.01	0.02	Endemic	
Gaultheria depressa var. novae-zealandiae	snowberry	0.04	0.08	0.03	0.05	0.27	0.52	Endemic	
Gentianella grisebachii	forest gentian	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	Endemic	
Geranium brevicaule		0.03	0.03	0.01	0.01	0.03	0.02	Endemic	
Geranium potentilloides		0.02	0.02	0.03	0.03	<0.01	0.01	Native	
Geranium sp.		0	0	0	0	<0.01	<0.01	NA	
Gleichenia alpina	alpine tangle fern	0	0	0	0	2.03	2.21	Native	
Gleichenia dicarpa	tangle fern	0.89	0.94	1.42	1.37	0.4	0.78	Native	

Scientific name	Common name	2012		2018		2024		Origin	Group
		Mean cover	MOE_{95}	Mean cover	MOE_{95}	Mean cover	MOE_{95}		
Gleichenia microphylla	carrier tangle fern	0.07	0.14	0.12	0.24	0	0	Endemic	
Gonocarpus aggregatus		0	0	0	0	0.91	0.9	Endemic	
Gonocarpus micranthus		0.01	0.02	<0.01	<0.01	0.01	0.02	Native	
Gonocarpus montanus		0.07	0.06	0.15	0.18	0	0	Endemic	
Grass species		0.01	0.02	0	0	0	0	NA	
Halocarpus bidwillii	bog pine	0.43	0.46	0.87	0.93	1.67	1.52	Endemic	
Helichrysum filicaule	creeping everlasting daisy	<0.01	<0.01	0.01	0.02	<0.01	<0.01	Endemic	
Herpolirion novae-zelandiae	grass lily	<0.01	<0.01	0	0	0	0	Endemic	
Hierochloe redolens	holy grass	0.1	0.19	0.09	0.18	0.37	0.71	Native	
Histiopteris incisa	water fern	0	0	0.02	0.03	0.27	0.52	Native	
Holcus lanatus	Yorkshire fog	2.72	1.82	1.57	0.95	2.56	1.79	Exotic	Invasive
Hydrocotyle elongata		0	0	<0.01	0.02	0	0	Endemic	
Hydrocotyle moschata	hairy pennywort	0	0	0	0	<0.01	<0.01	Endemic	
Hydrocotyle novae-zeelandiae var. montana		0.01	0.02	<0.01	<0.01	<0.01	<0.01	Endemic	
Hymenophyllum sanguinolentum		0	0	0	0	<0.01	<0.01	Endemic	
Hypericum humifusum	trailing Saint John's wort	0.03	0.05	<0.01	<0.01	<0.01	<0.01	Exotic	
Hypnum cupressiforme		2.59	1.2	2.91	1.24	6.65	2.41	Native	
Hypochaeris radicata	catsear	0.99	0.36	1.15	0.51	1.42	0.76	Exotic	Diagnostic frost flat
Jacobaea vulgaris	ragwort	0.01	0.02	<0.01	0.02	<0.01	<0.01	Exotic	
Kunzea serotina	makahikatoa	0.13	0.17	0.11	0.13	0.38	0.41	Endemic	Forest precursor
Lepidosperma australe	square sedge	0.04	0.04	0.24	0.4	1.24	1.1	Endemic	

Scientific name	Common name	2012		2018		2024		Origin	Group
		Mean cover	MOE_{95}	Mean cover	MOE_{95}	Mean cover	MOE_{95}		
Leptecophylla juniperina	prickly mingimingi	0.08	0.13	0.14	0.2	0.07	0.12	Endemic	
Leptospermum scoparium	mānuka	0.28	0.4	0.39	0.56	0.88	1.23	Endemic	Forest precursor
Leptostigma setulosum	nertera	0.08	0.16	<0.01	0.02	<0.01	0.01	Endemic	
Lichen species	lichen	<0.01	<0.01	0	0	0	0	Native	
Lotus pedunculatus	lotus	0.16	0.21	0.44	0.55	0.42	0.45	Exotic	Invasive
Luzula decipiens	woodrush	<0.01	0.02	<0.01	<0.01	0	0	Endemic	
Luzula sp.	woodrush	0	0	0	0	<0.01	<0.01	Native	
Lycopodium fastigiatum	alpine clubmoss	0.06	0.06	0.07	0.07	0.4	0.52	Native	
Lycopodium scariosum	creeping clubmoss	0.17	0.33	0.13	0.25	0.08	0.16	Native	
Machaerina tenax		0	0	<0.01	0.02	0	0	Endemic	
Microseris scapigera		<0.01	<0.01	<0.01	<0.01	0.02	0.02	Native	
Moss species	moss	<0.01	<0.01	0	0	0	0	Native	
Muehlenbeckia axillaris	creeping pōhuehue	0.31	0.3	0.53	0.46	1.03	1	Native	
Mycelis muralis	wall lettuce	0	0	<0.01	0.02	<0.01	<0.01	Exotic	
Myrsine divaricata	weeping māpou	0.02	0.03	0.03	0.05	0.02	0.03	Endemic	
No species present		0	0	0	0	0	0	NA	
Notogrammitis ciliata	strapfern	0	0	0	0	<0.01	<0.01	Endemic	
Olearia virgata	twiggy tree daisy	<0.01	0.01	0.27	0.53	0.72	1.41	Endemic	
Oreobolus pectinatus	combsedge	0.02	0.03	<0.01	<0.01	<0.01	<0.01	Endemic	
Ozothamnus leptophyllus	tauhinu	0.07	0.1	0.12	0.17	0.05	0.07	Endemic	
Pilosella officinarum	mouse-ear hawkweed	1.16	0.77	0.64	0.33	1.63	0.82	Exotic	Invasive

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Pimelea prostrata	New Zealand daphne	1.27	0.55	1.17	0.57	1.45	0.69	Endemic	Diagnostic frost flat
Pinus contorta	contorta pine	0.61	0.46	4.89	3.29	6.11	3.57	Exotic	Forest precursor, Invasive
Pittosporum tenuifolium	kōhūhū	0	0	0	0	<0.01	0.02	Endemic	
Poa cita	silver tussock	4.27	1.22	4	1.26	7.68	1.8	Endemic	Diagnostic frost flat
Poa sp.	meadow grass	0	0	0	0	0.21	0.41	Native	
Polytrichum juniperinum	moss	0.09	0.09	0.11	0.17	0.31	0.57	Native	
Prasophyllum colensoi	leek orchid	<0.01	<0.01	0	0	0	0	Endemic	
Prunella vulgaris	self-heal	<0.01	<0.01	0	0	<0.01	<0.01	Exotic	
Pseudopanax crassifolius	lancewood	0	0	<0.01	<0.01	0	0	Endemic	Forest precursor
Pulchrocladia retipora	coral lichen	33.97	4.14	37.69	4.59	44.18	5.8	Native	Diagnostic frost flat
Racomitrium lanuginosum	woolly moss	10.04	2.34	9.54	2.35	10.66	2.85	Native	Diagnostic frost flat
Ranunculus reflexus	hairy buttercup	0	0	<0.01	<0.01	0	0	Endemic	
Ranunculus repens	creeping buttercup	0	0	0	0	<0.01	<0.01	Exotic	
Raoulia albosericea		0.01	0.02	<0.01	<0.01	0	0	Endemic	
Rumex acetosella	sheep's sorrel	<0.01	<0.01	<0.01	<0.01	0	0	Exotic	
Rytidosperma gracile	dainty bristle grass	0.63	0.25	1.48	0.46	1.96	0.71	Native	Diagnostic frost flat
Stackhousia minima		<0.01	<0.01	<0.01	0.02	<0.01	<0.01	Endemic	
Sticherus cunninghamii	umbrella fern	0	0	0.05	0.1	0.06	0.12	Endemic	
Styphelia nesophila	pātōtara	0.29	0.25	0.17	0.17	0.17	0.1	Endemic	Diagnostic frost flat
Thelymitra sp.	sun orchid	0	0	0	0	<0.01	<0.01	Native	

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Thuidiopsis furfurosa		0	0	0	0	<0.01	<0.01	Native	
Trifolium repens	white clover	<0.01	<0.01	0.02	0.03	<0.01	<0.01	Exotic	Invasive
Veronica stricta	koromiko	<0.01	<0.01	<0.01	0.01	0.02	0.02	Endemic	