Changes in Bay of Plenty frost flat heathland, 2012–2018

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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. 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 the substantial frost flat heathlands remaining in the Bay of Plenty Region.

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. Two larger sites – Rangitaiki Conservation Area (three vegetation types) and Otangimoana Stewardship Area (one vegetation type) – were sampled, as were 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) – a total of 120 plots over all sites.
- Within plots, we recorded quantitative 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, height of the tallest individual of the dominant vascular species, height of the tallest monoao (*Dracophyllum subulatum*) if present, and human and introduced mammal impacts.

  We tested for significant changes in occupancy (proportion of plots) between surveys and cover (between surveys but within plots) for species assigned to three groups: 1) diagnostic frost flat species, 2) forest precursor species and 3) invasive exotic species that occurred at least 15 times across both surveys. Significance testing used a non-parametric test statistic recording the net direction of paired differences.

Results

- *Hypochaeris radicata* was the only species to show a significant change in the proportion of plots occupied between surveys (decrease from 62.5% of plots occupied in 2012 to 45.5% in 2018)
- The most widespread (proportion of plots occupied) diagnostic frost flat species in both surveys were *Dracophyllum subulatum* (95.8% in 2012 and 95.0% in 2018), *Cladia retipora* (90.0% in 2012 and 88.2% in 2018), *Poa cita* (90.8% in 2012 and 85.7% in 2018) and *Rytidosperma gracile* (67.5% in 2012 and 79.0% in 2018)
- The most widespread invasive exotic species were *Holcus lanatus* (18.3% of plots occupied in 2012 and 17.6% in 2018), *Pilosella officinarum* (16.7% in 2012 and 18.5% in 2018) and *Pinus contorta* (14.2% in 2012 and 11.8% in 2018)

- The only forest precursor found in more than 5% of plots in either survey was *Pinus contorta,* both an invasive exotic and a forest precursor
- Mean plot cover of two diagnostic frost flat species, the lichen *Cladia retipora* (mean cover of 34% in 2012 and 38% in 2018) and the caespitose grass *Rytidosperma gracile* (mean cover of 0.6% in 2012 and 1.5% in 2018), increased significantly, while one species, the caespitose grass *Deyeuxia avenoides*, decreased significantly (from 0.3% mean cover in 2012 to 0.2% in 2018)
- No invasive species showed a significant change in mean plot cover and no forest precursor species occurred frequently enough to be included in significance tests.

Conclusions

- The monitored frost flats have largely maintained their ecological integrity between 2012 and 2018. 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. Also, the vegetation seems to be gradually shifting to greater woody dominance, but not at the expense of diagnostic frost flat species.

Recommendations

- The plots should be maintained and remeasured again in 2024 to monitor the response of frost flat species to a warming climate
- Review surveillance and removal plans for major invasive species, primarily *Pinus contorta*, and possibly invasive exotic grasses such as *Agrostis capillaris*
- 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 they can be controlled before reaching cone-bearing age
- Research is needed on the effect 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 vegetation after *P. contorta* removal.

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 compared against the baseline measurements for change in species cover and other indicators of condition 'ecological integrity'.

2 Background

'Frost flat' heathlands comprise short 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 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; this maintains the treeless community (e.g. Figs 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 shrub component – bog pine (*Halocarpus bidwillii*) and mountain toatoa (*Phyllocladus alpinus*) – of frost flat heathland has been severely reduced by burning and now survives only as scattered remnants, mostly on sites like 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 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 ecosystem, frost flat heathland falls within National Priority 3 ('To protect indigenous vegetation associated with 'originally rare' terrestrial ecosystem types') of the National Biodiversity Strategy (Department of Conservation and Ministry for the Environment 2000, Ministry for the Environment and Department of Conservation 2007) and is now a Critically Endangered ecosystem (Holdaway et al. 2012).

The pre-European extent of frost flat heathland is estimated to have been several tens of thousands of hectares (Smale 1990) but 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 topdressing drift. 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* shubland (burnt c. 1964) with groundcover dominated by the lichen *Cladia retipora*, Rangitaiki Conservation Area, March 2018.

3 Objectives

To identify changes in vegetation structure and composition of the substantial frost flat heathlands remaining in the Bay of Plenty Region.

4 Methods

4.1 Permanent plots

Fifteen permanently marked 2 × 2-m permanent plots were established in 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 (e.g. fertility) variation. Plot locations are given in Appendix 1.

Within plots, we recorded the attributes below following Hurst & 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 presence and degree of browsing by species.

The samples sites include two larger, intact sites with apparently good prospects for survival:

- Rangitaiki Conservation Area (CA) and surrounding frost flat: c. 2355 ha (3 vegetation types: monoao shrubland burnt c. 1900), monoao shrubland burnt c. 1964, and silver tussock grassland burnt c. 1990) – native forest and agricultural matrix
- Otangimoana Stewardship Area (SA): c. 328 ha (1 type: shrubland; age unknown) – plantation forest and agricultural matrix.

Four smaller, fragmented sites with apparently poorer prospects for survival were sampled:

- Rangitaiki River Conservation Area (previously Waimarama Conservation Stewardship Land): c. 114 ha (1 type: shrubland: age uncertain but probably c. 120 years) – plantation forest matrix

- Taho, Otupaka Ecological Area (Part of Whirinaki Te Pua-a-Tāne Conservation Park): c. 61 ha (1 type: shrubland: age unknown) – native forest matrix
- Rangitāiki River Scrub (Timberlands/CNI Holdings Ltd), previously Rangitāiki River Marginal Strip: c. 34 ha (1 type: shrubland: age unknown) – plantation forest matrix
- Rangitaiki Station (Landcorp): c. 5 ha (1 type: shrubland: age unknown) – agricultural matrix.

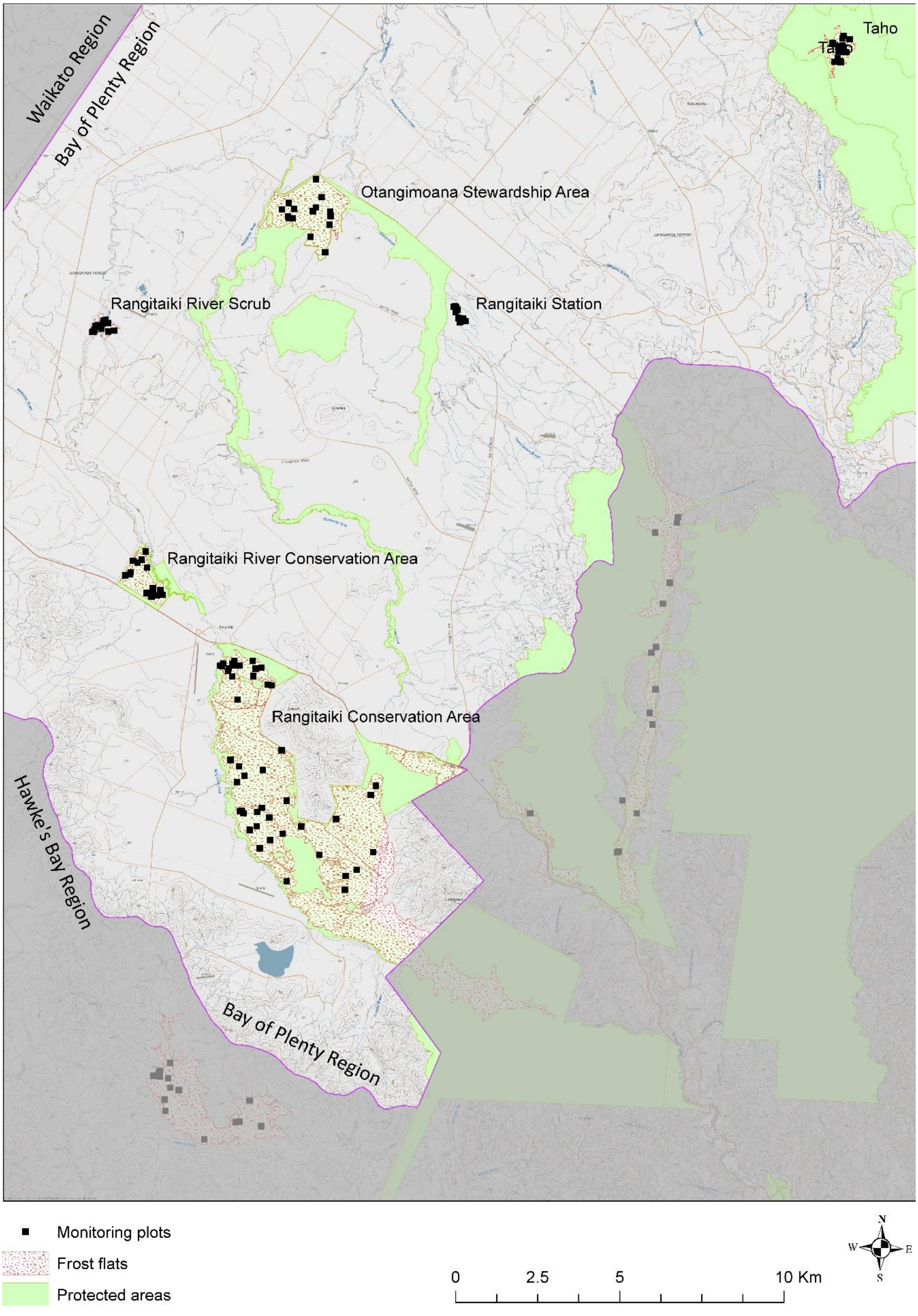

Figure 3 Bay of Plenty frost flat heathland and monitoring plot locations.

4.2 Data analysis

We used a repeated measures design to assess changes in cover between surveys (but within plots) for species assigned to three groups: 1) diagnostic frost flat species, 2) forest pre-cursor species, and 3) invasive exotic species that occurred at least 15 times across both surveys. Mean cover was calculated as the sum of the total cover (sum across all tiers) in all plots, divided by the total number of plots for each sample year. Statistical significance testing was founded on a non-parametric test statistic recording the net direction of paired differences:

$$\text{Tdir} = [N(t2>t1)-N(t1>t2)]/\text{Nplots}$$

Where: N(t2>t1) is the number of plots where sample 2 is greater than sample 1; Nplots is the total number of pairs. The advantage of this test is that, by only documenting the direction of shifts between samples (but within pairs) it provides equal power to detect increases or decreases even in datasets where values are constrained by fixed upper and/or lower values. For cover values, the lower bound is generally zero, and many cover datasets exhibit extremely right-skewed distributions (many small, few large values). For such datasets, test statistics incorporating both the size and direction of shifts within pairs have lower power to detect decreases than increases. We used randomisation tests to test whether observed values of Tdir differed significantly from those expected by chance. These tests randomly allocate data between samples but within pairs (see Mason & Bellingham 2018 for details).

Using this method, we tested for changes in the maximum cover score recorded in any height tier for each species in each plot, as well as the sum of cover scores across height tiers within plots. Both measures gave very similar results. Here we present results for the sum of cover scores across height tiers. We also used Chi-square tests to test for significant changes in the occupancy of different species (using the prop.test() function in R).

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: diagnostic frost flat species, forest precursors and invasive exotic species. 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 total cover of non-frost flat species (both forest pre-cursors 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* in each plot.

5 Results

Of the 120 plots originally established, one plot at Rangitaiki (burnt c. 1990) could not be relocated in 2018. Comparisons between the two measurements were made across the remaining 119 plots. Additionally, three plots were damaged but were reconstructed and broken marker pegs replaced. One plot was partially buried with soil from a power pole replacement following heavy snow in August 2016 (Fig. 4) and the other two had been damaged by off-road vehicles (e.g. Fig. 5).

All species recorded in monitoring plots and their mean cover estimates are listed in Appendix 2.

Figure 4 Vegetation monitoring plot at Rangitaiki (burnt c. 1990) partially buried with soil and recently replaced power pole in the background.

Figure 5 Vegetation monitoring plot at Rangitaiki (burnt c. 1990). The four corner pegs have been broken at ground level and there is extensive vehicle tracking in and around the plot.

Species occupancy

Hypochaeris radicata was the only species to show a significant change in the proportion of plots occupied between surveys (decrease from 62.5% of plots occupied in 2012 to 45.5% in 2018; Table 1). The most widespread diagnostic frost flat species in both surveys were *Dracophyllum subulatum* (95.8% of plots occupied in 2012 and 95.0% in 2018), *Cladia retipora* (90.0% of plots occupied in 2012 and 88.2% in 2018), *Poa cita* (90.8% of plots occupied in 2012 and 85.7% in 2018), and *Rytidosperma gracile* (67.5% of plots occupied in 2012 and 79.0% in 2018). The most widespread invasive exotics were *Holcus lanatus* (18.3% of plots occupied in 2012 and 17.6% in 2018), *Pilosella officinarum* (16.7% of plots occupied in 2012 and 18.5% in 2018), and *Pinus contorta* (14.2% of plots occupied in 2012 and 11.8% in 2018), which is both an invasive exotic and a forest precursor. No other forest precursor species occurred in more than 5% of plots in either survey.

Vegetation cover

The diagnostic frost flat species *Dracophyllum subulatum* (mean total cover 48.1%, 95% C.I. ± 6.4 in 2012 and 46.6% ± 5.4 in 2018) and *Cladia retipora* (mean total cover 34.0% ± 4.1 4 in 2012 and 36.8% ± 4.6 in 2018) had by far the highest mean cover scores of any species in either survey (Table 1). Of the invasive exotics, *Holcus lanatus* and *Pilosella officinarum* had the highest mean cover in 2012 (2.8% ± 1.9 and 1.2% ± 0.8 respectively) but were overtaken in 2018 by *Pinus contorta* (6.6% ± 4.9) and *Agrostis capillaris* (1.8% ± 1.9). The change in mean cover for *Pinus contorta* represents a greater than 10-fold increase. This is due to major increases in cover across a small number of plots (e.g. Fig. 6), as indicated by the comparatively large value for the breadth of the 95% confidence interval 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 18% 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 (Fig. 7).

Figure 6 *Pinus contorta* invading a monitoring plot at Otangimoana Stewardship Area, February 2018.

Figure 7 Wildling pine slash completely covering Otangimoana plot 11, February 2018.

Table 1 Proportion of plots occupied in 2012 (Pocc 2012) and 2018 (Pocc 2018). Significant changes (P <0.05) are in bold

Species	Group	Pocc 2012 (N = 120)	Pocc 2018 (N = 119)	Chi-sq P
Kunzea serotina	Forest precursor	0.050	0.034	0.757
Leptospermum scoparium	Forest precursor	0.042	0.034	1.000
Pseudopanax crassifolius	Forest precursor	0.000	0.008	0.997
Celmisia gracilenta	Diagnostic frost flat	0.333	0.319	0.926
Cladonia capitellata	Diagnostic frost flat	0.450	0.445	1.000
Cladonia confusa	Diagnostic frost flat	0.742	0.739	1.000
Cladia retipora	Diagnostic frost flat	0.900	0.882	0.818
Deyeuxia avenoides	Diagnostic frost flat	0.517	0.420	0.172
Dracophyllum subulatum	Diagnostic frost flat	0.958	0.950	0.989
Hypochaeris radicata	**Diagnostic frost flat**	**0.625**	**0.454**	**0.012**
Leucopogon fraseri	Diagnostic frost flat	0.367	0.328	0.620
Pimelea prostrata	Diagnostic frost flat	0.283	0.235	0.484
Poa cita	Diagnostic frost flat	0.908	0.857	0.303
Racomitrium lanuginosum	Diagnostic frost flat	0.675	0.681	1.000
Rytidosperma gracile	Diagnostic frost flat	0.675	0.790	0.063
Agrostis capillaris	Invasive exotic	0.075	0.109	0.489
Anthoxanthum odoratum	Invasive exotic	0.050	0.084	0.427
Festuca rubra	Invasive exotic	0.017	0.000	0.481
Holcus lanatus	Invasive exotic	0.183	0.176	1.000
Lotus pedunculatus	Invasive exotic	0.033	0.042	0.990
Pilosella officinarum	Invasive exotic	0.167	0.185	0.842
Pinus contorta	Invasive exotic	0.142	0.118	0.719
Trifolium repens	Invasive exotic	0.017	0.008	1.000

The total cover of diagnostic frost flat species increased significantly between surveys, with a net 30% of plots showing a positive change (Table 2). Neither forest precursors nor invasive exotics showed significant change between surveys. Both maximum vegetation height (mean 1.30 m, 95% CI ±0.12 in 2012 and 1.98 m ±0.70 in 2018) and maximum height of *Dracophyllum subulatum* (mean 1.29 m ± 0.09 in 2012 and 1.34 ±0.09 in 2018) increased significantly between surveys, with a net 46% and 40%, respectively, of plots showing a positive change between surveys.

Table 2 Significance test results for change in total cover for each species group and for maximum vegetation height or maximum height of *Dracophyllum subulatum* (DRAsub) within plots but between surveys. Tdir expected is the mean value of the test statistic across randomisations. P obs ≥ exp is the probability that the observed value of the test statistic is greater than expected. P obs ≤ exp is the probability that the observed value of the test statistic is less than expected. Significant changes (P <0.05) are in bold

Group	Mean total cover (95% CI)		Tdir		P obs ≥ exp	P obs ≤ exp
	2012	2018	Observed	Expected		
Diagnostic frost flat species	**102.44 (6.76)**	**105.15 (7.23)**	**0.300**	**0.000**	**0.999**	**0.001**
Forest precursors	1.06 (0.69)	7.20 (4.99)	0.050	0.000	0.911	0.167
Invasive exotics	5.79 (2.59)	11.5 (5.55)	0.042	0.000	0.805	0.285
Non-frost flat species	6.22 (2.62)	12.0 (5.59)	0.067	0.000	0.882	0.179
Max height all			**0.461**	**0.001**	**1.000**	**0.000**
Max height DRAsub			**0.400**	**0.001**	**1.000**	**0.000**

Total cover of two diagnostic frost flat species, the lichen *Cladia retipora* and the caespitose grass *Rytidosperma gracile*, increased significantly, while one species, the caespitose grass *Deyeuxia avenoides*, decreased significantly (Table 3). No invasive species showed a significant change in cover and no forest precursor species occurred frequently enough to be included in significance tests. Among non-classified species, the moss *Camylopus introflexus* decreased in total cover while the lichen *Cladia aggregata*, the moss *Hypnum cupressiforme* , and the large shrubs *Coprosma propinqua* and *Halocarpus bidwillii* increased significantly in cover between surveys.

Table 3 Significance test results for change in total cover for individual species within plots but between surveys. Tests were only performed for species with a total of at least 15 occurrences across both surveys. Tdir expected is the mean value of the test statistic across randomisations. P obs ≥ exp is the probability that the observed value of the test statistic is greater than expected. P obs ≤ exp is the probability that the observed value of the test statistic is less than expected. Significant changes (P <0.05) are in bold

Species	Group	Tdir observed	Tdir expected	P obs ≥ exp	P obs ≤ exp
Celmisia gracilenta	Diagnostic frost flat	0.025	-0.001	0.736	0.373
Cladonia capitellata	Diagnostic frost flat	-0.067	0.000	0.180	0.881
Cladonia confusa	Diagnostic frost flat	-0.033	0.000	0.370	0.710
Cladia retipora	**Diagnostic frost flat**	**0.292**	**0.000**	**1.000**	**0.000**
Deyeuxia avenoides	**Diagnostic frost flat**	**-0.225**	**-0.001**	**0.001**	**1.000**
Dracophyllum subulatum	Diagnostic frost flat	0.042	-0.001	0.736	0.339
Hypochaeris radicata	Diagnostic frost flat	-0.033	0.000	0.360	0.720
Leucopogon fraseri	Diagnostic frost flat	-0.033	0.000	0.321	0.778
Pimelea prostrata	Diagnostic frost flat	-0.033	0.000	0.297	0.812
Poa cita	Diagnostic frost flat	-0.067	0.000	0.245	0.811
Racomitrium lanuginosum	Diagnostic frost flat	-0.067	0.001	0.203	0.860
Rytidosperma gracile	**Diagnostic frost flat**	**0.392**	**0.000**	**1.000**	**0.000**
Agrostis capillaris	Invasive	0.058	0.000	0.982	0.059
Anthoxanthum odoratum	Invasive	0.042	0.000	0.968	0.112
Holcus lanatus	Invasive	-0.050	0.000	0.153	0.921
Pilosella officinarum	Invasive	-0.042	0.000	0.197	0.904
Pinus contorta	Forest precursor, Invasive	0.042	0.000	0.907	0.187
Campylopus introflexus	**NA**	**-0.142**	**0.000**	**0.001**	**1.000**
Cladia aggregata	**NA**	**0.142**	**0.000**	**0.999**	**0.003**
Coprosma propinqua	**NA**	**0.175**	**-0.001**	**1.000**	**0.000**
Androstoma empetrifolia	NA	0.067	0.001	0.964	0.086
Dicranoloma billardierei	NA	0.050	0.000	0.878	0.209
Geranium brevicaule	NA	-0.050	0.000	0.069	0.981
Geranium potentilloides	NA	0.033	0.000	0.932	0.193
Gonocarpus montanus	NA	-0.033	0.000	0.281	0.836
Halocarpus bidwillii	**NA**	**0.058**	**0.000**	**0.998**	**0.018**
Helichrysum filicaule	NA	0.000	0.000	0.612	0.612
Hypnum cupressiforme	**NA**	**0.117**	**0.000**	**0.977**	**0.044**
Lepidosperma australe	NA	0.033	-0.001	0.915	0.207
Lycopodium fastigiatum	NA	0.000	0.000	0.621	0.624
Muehlenbeckia axillaris	NA	0.033	0.000	0.943	0.172
Polytrichum juniperinum	NA	-0.033	0.000	0.241	0.885
Carex punicea	NA	0.008	-0.001	0.686	0.493

6 Discussion

The ecological integrity of the monitored frost flats appears relatively stable. Diagnostic frost flat species were the most widespread species in both 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 cover of the lichen *Cladia retipora* and the grass *Rytidosperma gracile*.

There was no evidence of general increases in occupancy or cover for any of the invasive exotic species. However, there may be cause for local concern at certain sites, with evidence that *P. contorta* and, to a lesser degree, *Agrostis capillaris* have increased greatly in cover in some plots. Because of its potential to invade and oust 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 3 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 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 (Fig. 8). To prevent *in situ* seeding and achieve local eradication, we recommend 1) the frequency of current control methods is reduced to 1–2 yearly, and/or 2) new methods such as high-resolution imagery from unmanned aerial vehicles (UAV/drones) are explored to identify smaller individual trees than is currently achieved. Unmanned aerial vehicles may also provide a cost-effective platform for delivering herbicide to weeds, and research into this is underway (Carol Rolando, Scion, pers comm.).

The long-term effect of wildling pine invasion of frost flats after removal is unknown. Changes in soil structure and fertility 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 restore themselves 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 will help with understanding the long-term prospects for frost flat restoration after *P. contorta* removal and prioritise areas for weed control. Data from the monitoring natural frost flat succession after lightening fires (Smale et al. 2011) may provide a useful baseline against which to compare successional changes in vegetation after *P. contorta* removal.

There was also no evidence for increasing occupancy or abundance of forest precursor species. However, there is some evidence that succession is occurring, with significant increases in maximum height of vegetation and of *D. subulatum* within plots between surveys. Also, two shrubs (*Halocarpus bidwillii* and *Coprosma propinqua*) increased significantly in cover between surveys. Taken together, these results suggest that native woody species are increasing in both stature and abundance – albeit very slowly – across the frost flat sites.

Figure 8 *Pinus contorta* with green and open (seeds have been dispersed) cones growing in frost flat heathland at Rangitaiki River Scrub, January 2018.

7 Conclusions

The monitored frost flats have largely maintained their ecological integrity between 2012 and 2018. 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. Also, the vegetation seems to be gradually shifting to greater woody dominance, but not at the expense of diagnostic frost flat species.

8 Recommendations

- The plots should be maintained and remeasured again in 2024 to monitor the response of frost flat species to a warming climate
- Review surveillance and removal plans for major invasive species, primarily *Pinus contorta*, and possibly invasive exotic grasses such as *Agrostis capillaris*
- 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 they can be controlled before reaching cone-bearing age
- Research is needed on the effect 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 vegetation after *P. contorta* removal.

9 Acknowledgements

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Appendix 1 – Monitoring plot locations

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

Site	Plot	East	North	Altitude (m)	Note
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	Rangitaiki-1900-04	1893137	5687488	733	

Site	Plot	East	North	Altitude (m)	Note
Conservation Area (c. 1900 burn) cont'	Rangitaiki-1900-05	1893090	5689520	732	
	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	Not relocated in 2018
	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	

Site	Plot	East	North	Altitude (m)	Note
Rangitaiki Conservation Area (c. 1990 burn) cont'	Rangitaiki-1990-12	1892800	5690392	722	
	Rangitaiki-1990-13	1893643	5690468	139	
	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	
Rangitaki River Conservation Area	Waimarama-01	1889834	5693402	706	
	Waimarama-02	1890510	5692928	709	
	Waimarama-03	1889908	5693756	708	
Rangitaki River	Waimarama-04	1890516	5692814	711	

Site	Plot	East	North	Altitude (m)	Note
Conservation Area cont'	Waimarama-05	1890471	5692662	711	
	Waimarama-06	1890047	5693699	708	
	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	

Appendix 2 – Species recorded in frost flat monitoring plots

Mean of total cover (summed across height tiers within plots) taken across plots and 95% confidence intervals 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) and 2018 (119 plots). Taxonomy follows Allan Herbarium (2000)

Scientific name	Common name	2012		2018		Origin	Group
		Mean cover	95 % CI	Mean cover	95 % CI		
Agrostis capillaris	browntop	0.35	0.33	1.77	1.87	Exotic	Invasive
Androstoma empetrifolia	bog mingimingi	0.52	0.27	0.88	0.48	Endemic	
Anthoxanthum odoratum	sweet vernal	0.65	1.15	0.37	0.37	Exotic	Invasive
Aporostylis bifolia	odd-leaved orchid	<0.01	<0.01	<0.01	0	Endemic	
Azorella hookeri		<0.01	<0.01	0	0	Endemic	
Blechnum penna-marina	little hard fern	0.37	0.64	0.64	0.82	Native	
Blechnum vulcanicum	mountain hard fern	<0.01	<0.01	0.01	0.02	Native	
Breutelia affinis		0.61	0.92	0.43	0.84	Native	
***Caladenia* sp.**	orchid	<0.01	0	0	0	Native	
Campylopus introflexus	Moss	0.07	0.07	0.06	0.07	Native	
Carex breviculmis	grassland sedge	0.01	0.01	0.03	0.05	Native	
Carex horizontalis	hook sedge	0.04	0.08	0.02	0.03	Endemic	
Carex punicea	red hook sedge	0.06	0.05	0.10	0.10	Endemic	
Carmichaelia australis	North Island broom	0.04	0.07	0.03	0.07	Endemic	
Celmisia gracilenta	common mountain daisy	0.24	0.30	0.24	0.24	Endemic	Diagnostic frost flat
Chaerophyllum ramosum		0.01	0.02	0.09	0.12	Endemic	
Cladia aggregata	lichen	0.11	0.06	0.23	0.11	Native	
Cladia retipora	coral lichen	33.97	4.15	37.69	4.59	Native	Diagnostic frost flat

Scientific name	Common name	2012		2018		Origin	Group
		Mean cover	95 % CI	Mean cover	95 % CI		
Cladia sullivanii	lichen	<0.01	0.01	0.02	0.03	Native	
Cladonia capitellata	lichen	0.53	0.21	0.49	0.19	Native	Diagnostic frost flat
Cladonia coccifera	lichen	<0.01	0	<0.01	<0.01	Native	
Cladonia confusa	lichen	1.82	0.49	1.88	0.49	Native	Diagnostic frost flat
***Cladonia* sp.**	lichen	<0.01	<0.01	0	0	Native	
Clematis forsteri	Forster's clematis	0.02	0.03	0.03	0.07	Endemic	
Clematis quadribracteolata	clematis	<0.01	0	0.01	0.02	Endemic	
Coprosma ×cunninghamii		<0.01	<0.01	0.01	0.02	Endemic	
Coprosma acerosa	sand coprosma	<0.01	0.01	0	0	Endemic	
Coprosma dumosa		0.04	0.05	0.24	0.26	Endemic	
Coprosma propinqua	mingimingi	0.60	0.54	1.60	1.10	Endemic	
Corokia cotoneaster	korokio	0.16	0.21	0.21	0.26	Endemic	
Crepis capillaris	smooth hawksbeard	0.07	0.13	<0.01	<0.01	Exotic	
Deyeuxia avenoides	mountain oat grass	0.26	0.10	0.24	0.10	Endemic	Diagnostic frost flat
Dichondra brevifolia	dichondra	0.01	0.02	<0.01	<0.01	Endemic	
Dicranoloma billardierei	moss	1.91	1.17	2.01	1.12	Endemic	
Dracophyllum subulatum	monoao	48.06	6.37	47.02	5.34	Endemic	Diagnostic frost flat
Epilobium alsinoides subsp. tenuipes	willowherb	<0.01	0.01	<0.01	<0.01	Endemic	
Euphrasia cuneata	North Island eyebright	<0.01	<0.01	0	0	Endemic	
Festuca rubra	Chewing's fescue	0.03	0.05	0	0	Exotic	Invasive
Galium palustre	marsh bedstraw	0	0	0.01	0.02	Exotic	
Galium perpusillum	dwarf bedstraw	<0.01	0.01	<0.01	0	Endemic	

Scientific name	Common name	2012		2018		Origin	Group
		Mean cover	95 % CI	Mean cover	95 % CI		
Gaultheria depressa* var. *novae-zealandiae	snowberry	0.04	0.08	0.03	0.05	Endemic	
Gentianella grisebachii	forest gentian	<0.01	0	<0.01	<0.01	Endemic	
Geranium brevicaule		0.03	0.03	0.01	0.01	Endemic	
Geranium potentilloides		0.02	0.02	0.03	0.03	Native	
Gleichenia dicarpa	tangle fern	0.93	0.99	1.53	1.49	Native	
Gleichenia microphylla	carrier tangle fern	0.08	0.15	0.13	0.25	Endemic	
Gonocarpus micranthus		0.01	0.02	<0.01	0	Native	
Gonocarpus montanus		0.07	0.06	0.16	0.18	Endemic	
Halocarpus bidwillii	bog pine	0.45	0.48	0.94	1.03	Endemic	
Helichrysum filicaule	creeping everlasting daisy	0.01	0.01	0.01	0.02	Endemic	
Herpolirion novae-zelandiae	grass lily	<0.01	0	0	0	Endemic	
Hierochloe redolens	holy grass	0.1	0.20	0.09	0.18	Native	
Histiopteris incisa	water fern	0	0	0.02	0.03	Native	
Holcus lanatus	Yorkshire fog	2.82	1.91	1.60	0.98	Exotic	Invasive
Hydrocotyle elongata		0	0	0.01	0.02	Endemic	
Hydrocotyle novae-zeelandiae* var. *montana		0.01	0.02	<0.01	<0.01	Endemic	
Hypericum humifusum	trailing Saint John's wort	0.03	0.05	<0.01	0	Exotic	
Hypnum cupressiforme		2.59	1.20	2.91	1.24	Native	
Hypochaeris radicata	catsear	0.99	0.36	1.15	0.51	Exotic	Diagnostic frost flat
Jacobaea vulgaris	ragwort	0.01	0.02	0.01	0.02	Exotic	
Kunzea serotina	makahikatoa	0.14	0.17	0.11	0.13	Endemic	Forest precursor
Lepidosperma australe	square sedge	0.04	0.04	0.25	0.41	Endemic	

Scientific name	Common name	2012		2018		Origin	Group
		Mean cover	95 % CI	Mean cover	95 % CI		
Leptecophylla juniperina	prickly mingimingi	0.08	0.13	0.14	0.2	Endemic	
Leptospermum scoparium	manuka	0.29	0.42	0.40	0.59	Endemic	Forest precursor
Leptostigma setulosum	nertera	0.08	0.16	0.01	0.02	Endemic	
Leucopogon fraseri	patotara	0.29	0.25	0.17	0.17	Endemic	Diagnostic frost flat
Lotus pedunculatus	lotus	0.16	0.21	0.44	0.55	Exotic	Invasive
Luzula decipiens		0.01	0.02	<0.01	<0.01	Endemic	
Lycopodium fastigiatum	alpine clubmoss	0.06	0.06	0.08	0.07	Native	
Lycopodium scariosum	creeping clubmoss	0.17	0.33	0.13	0.25	Native	
Machaerina tenax		0	0	0.01	0.02	Endemic	
Microseris scapigera		0.01	0.01	<0.01	<0.01	Native	
Muehlenbeckia axillaris	creeping pohuehue	0.31	0.30	0.53	0.46	Native	
Mycelis muralis	wall lettuce	0	0	0.01	0.02	Exotic	
Myrsine divaricata	weeping mapou	0.02	0.03	0.03	0.05	Endemic	
Olearia virgata	twiggy tree daisy	0.01	0.01	0.29	0.58	Endemic	
Oreobolus pectinatus	comb sedge	0.02	0.03	<0.01	0.01	Endemic	
Ozothamnus leptophyllus	tauhinu	0.07	0.10	0.12	0.18	Endemic	
Pilosella officinarum	mouse-ear hawkweed	1.16	0.77	0.64	0.33	Exotic	Invasive
Pimelea prostrata	New Zealand daphne	1.27	0.55	1.17	0.57	Endemic	Diagnostic frost flat
Pinus contorta	contorta pine	0.63	0.47	6.68	4.92	Exotic	Forest precursor, Invasive
Poa cita	silver tussock	4.34	1.31	4.07	1.35	Endemic	Diagnostic frost flat
Polytrichum juniperinum	moss	0.09	0.09	0.11	0.17	Native	
Prasophyllum colensoi	leek orchid	<0.01	0	0	0	Endemic	

Scientific name	Common name	2012		2018		Origin	Group
		Mean cover	95 % CI	Mean cover	95 % CI		
Prunella vulgaris	self-heal	<0.01	<0.01	0	0	Exotic	
Pseudopanax crassifolius	lancewood	0	0	<0.01	0	Endemic	Forest precursor
Racomitrium lanuginosum	woolly moss	10.04	2.34	9.54	2.35	Native	Diagnostic frost flat
Ranunculus reflexus	hairy buttercup	0	0	<0.01	<0.01	Endemic	
Raoulia albosericea		0.01	0.02	<0.01	<0.01	Endemic	
Rumex acetosella	sheep's sorrel	0.01	0.01	<0.01	0	Exotic	
Rytidosperma gracile	dainty bristle grass	0.63	0.25	1.49	0.46	Native	Diagnostic frost flat
Simpliglottis cornuta	green bird orchid	<0.01	<0.01	0.01	0.01	Endemic	
Stackhousia minima		<0.01	<0.01	0.01	0.02	Endemic	
Sticherus cunninghamii	umbrella fern	0	0	0.05	0.10	Endemic	
Trifolium repens	white clover	0.01	0.01	0.02	0.03	Exotic	Invasive
Veronica stricta	koromiko	0.01	0.01	0.01	0.01	Endemic	