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Monitoring condition of frost flat heathlands, a critically threatened rare ecosystem in the Waikato region

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Monitoring Condition of Frost Flat Heathlands, a Critically Threatened Rare Ecosystem in the Waikato Region

Landcare Research
Manaaki Whenua

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Executive Summary

A network of permanent plots was established in January–May 2013 for the Waikato Regional Council to establish a baseline for monitoring change in the condition – 'ecological integrity' – of the remaining substantial frost flat heathlands, a Critically Endangered Historically Rare ecosystem in the Waikato Region.

Fifteen permanently marked 2 × 2-m plots were placed at pre-selected random sites at each of the three intact frost flat sites remaining in the Waikato Region: one large site, Whenuakura Plain (72 ha), and two smaller sites, Pokaiora Clearing (38 ha) and Taparoa Clearing (23 ha), all in Pureora Forest Park. A fourth site, Kuratau Clearing in Waituhi-Kuratau Scenic Reserve, was not sampled as originally intended because it proved to be smaller than originally estimated and highly degraded by weed invasion.

Within plots, we recorded quantitative cover estimates of each species in standard height tiers, all vascular species present, including invasive weeds, as well as prominent bryophytes and lichens, physical parameters such as slope, altitude and aspect, height of the tallest individual shrub, usually monoao (*Dracophyllum subulatum*), and human and introduced mammal impacts. Four indicators of ecological integrity – presence of each of 8 diagnostic frost flat species, presence of forest precursor species, invasive weed frequency, and adventive dominance (adventive/indigenous vegetative cover ratio) – were calculated for each site. Forty-two temperature dataloggers were installed (14 per site) at a random selection of the permanent plots and will be left for at least 12 months to investigate how frost regime varies across sites.

Only two of the 12 diagnostic frost flat species – monoao and danthonia (*Rytidosperma gracile*) – were present in more than half of plots, and one of them – woolly moss (*Racomitrium lanuginosum*) – was absent altogether. Eleven potential precursor species of forest were encountered, but only two of them – fivefinger (*Pseudopanax arboreus*) and mountain toatoa (*Phyllocladus alpinus*) – were at all widespread, occurring in >20% of plots. Forest precursors were present in half the plots. Nine invasive weed species were recorded in plots, but only two of them – Yorkshire fog (*Holcus lanatus*) and sweet vernal (*Anthoxanthum odoratum*) – at all widespread. Invasive weed frequencies were high in both the Taparoa and Pokaiora Clearings, but weeds were absent from plots on the Whenuakura Plain. Adventive species contributed minimally to vegetative cover except in the Taparoa Clearing. Whenuakura Plain has high ecological integrity, Pokaiora and Taparoa Clearings moderate ecological integrity.

The list of 12 diagnostic frost flat species was derived from Rangitaiki Conservation Area on the Kaingaroa Plateau, where frost flat heathland is characterised by open short shrubland. In contrast, the west Taupo frost flats are characterised by tall, dense scrub. Forest precursor species are far more common in west Taupo heathlands than on the Kaingaroa Plateau, and a much wider range of species is also present. Invasive weed species are more common in west Taupo heathlands than on the Kaingaroa Plateau and a wider range of species is also present. Contorta pine (*Pinus contorta*), one of the most threatening weeds of frost flat ecosystems, is absent from the west Taupo frost flat heathlands. Although not present in plots, heather (*Calluna vulgaris*) is present and spreading on road verges at Whenuakura and locally at Pokiaora, and broom at Taparoa.

The low frequency of many diagnostic frost flat species and high frequency of forest precursor species highlight the fundamentally different nature of frost flat heathland at west Taupo (Waikato Region) and on the Kaingaroa Plateau (Bay of Plenty Region). Both regions have a long fire history, and other factors such as local climate are likely to be responsible for the differences between them. Succession to native forest is likely in the foreseeable future on many sites at west Taupo.

The remaining substantial frost flat sites in the Waikato Region have moderate to high ecological integrity and are considered worthy of management input in terms of periodic weed control. A robust, comprehensive classification of vegetation types for this rare ecosystem has not been produced and is needed for decisions on resource allocations for future management. This requires a parallel suite of monitoring plots in the two very substantial frost flats remaining in the Hawke's Bay Region: the upper Waipunga and Kokomoka valleys and the upper Ripia Valley. Funding is being sought from the appropriate Regional Council to establish these. Information from temperature loggers should be analysed when available next year or in March 2015 and related to vegetation pattern across the frost flat spectrum. Soil fertility and fire history analyses across both regions would also help elucidate the reasons behind differences in vegetation pattern between them.

The most obvious immediate management priority is woody weed control, particularly heather at Whenuakura, which has the ability to outcompete and largely eliminate native frost flat vegetation. The matrix surrounding remaining frost flat heathlands should be defined and its impact on them assessed. Frost flat heathland in Kuratau Clearing degraded by weed invasion should be monitored to assess the speed and endpoint (in terms of indigenous biodiversity) of the degradation process. Plots should be remeasured on a 5-yearly basis, next in summer of 2018. Whenuakura Plain has the highest priority for conservation management (weed control).

Summary

Project and Client

- A network of permanent plots was established in January–May 2013 for the Waikato Regional Council to establish a baseline for monitoring change in the condition – 'ecological integrity' – of the remaining substantial frost flat heathlands, a Critically Endangered Historically Rare ecosystem in the Waikato Region.

Objectives

- To establish a baseline for monitoring change in the condition – 'ecological integrity' – of substantial frost flat heathlands remaining in the Waikato Region.

Methods

- Fifteen permanently marked 2 × 2-m plots were placed at pre-selected random sites at each of the three intact frost flat sites remaining in the Waikato Region: one large site, Whenuakura Plain (72 ha) in Pureora Forest Park and two smaller sites, Pokaiora Clearing (38 ha) and Taparoa Clearing (23 ha), Pureora Forest Park.
- A fourth site, Kuratau Clearing, Waituhi-Kuratau Scenic Reserve, was not sampled as originally intended because it proved to be smaller than estimated from aerial photographs used to define sampling areas, and highly degraded by weed invasion.
- Within plots, we recorded physical and biological attributes: quantitative cover estimates of each species in standard height tiers, all vascular species present, including invasive weeds, as well as prominent bryophytes and lichens, physical parameters such as slope, altitude and aspect, height of the tallest individual shrub, usually monoao (*Dracophyllum subulatum*), and human and introduced mammal impacts.
- Four indicators of ecological integrity – presence of each of 8 diagnostic frost flat species, presence of forest precursor species, invasive weed frequency, and adventive dominance (adventive/indigenous vegetative cover ratio) – were calculated from biological attributes for each site.
- Forty-two temperature dataloggers were installed (14 per site) at a random selection of the permanent plots and will be left for at least 12 months to investigate how frost regime varies across sites.

Results

- Only two of the 12 diagnostic frost flat species – monoao and danthonia (*Rytidosperma gracile*) – were present in more than half of plots, and one of the species – woolly moss (*Racomitrium lanuginosum*) – was absent altogether.
- Eleven potential precursor species of forest were encountered, but only two of them – fivefinger (*Pseudopanax arboreus*) and mountain toatoa (*Phyllocladus alpinus*) – were at all widespread, occurring in >20% of plots. Forest precursors were present in half the plots.

- Nine invasive weed species were recorded in plots, but only two of them – Yorkshire fog (*Holcus lanatus*) and sweet vernal (*Anthoxanthum odoratum*) – at all widespread.

- Invasive weed frequencies were high in both the Taparoa and Pokaiora Clearings, but weeds were absent from plots on the Whenuakura Plain.
- Adventive species contributed minimally to vegetative cover except in the Taparoa Clearing.
- Whenuakura Plain has high ecological integrity, Pokaiora and Taparoa Clearings moderate ecological integrity.

Conclusions

- The list of 12 diagnostic frost flat species was derived from Rangitaiki Conservation Area on the Kaingaroa Plateau, where frost flat heathland is characterised by open short shrubland. In contrast, the west Taupo frost flats are characterised by tall, dense scrub.
- Forest precursor species are far more common in west Taupo heathlands than on the Kaingaroa Plateau, and a much wider range of species is also present.
- Invasive weed species are more common in west Taupo heathlands than on the Kaingaroa Plateau. A wider range of species is also present.
- Contorta pine (*Pinus contorta*), one of the most threatening weeds of frost flat ecosystems, is absent from the west Taupo frost flat heathlands. Although not present in plots, heather (*Calluna vulgaris*) is present and spreading on road verges at Whenuakura and locally at Pokiaora, and broom at Taparoa.
- The low frequency of many diagnostic frost flat species and high frequency of forest precursor species highlight the fundamentally different nature of frost flat heathland at west Taupo (Waikato Region) and on the Kaingaroa Plateau (Bay of Plenty Region). Both regions have a long fire history, and other factors such as local climate are likely to be responsible for the differences between them.
- Succession to native forest is likely in the foreseeable future on many sites at west Taupo.
- The remaining substantial frost flat sites in the Waikato Region have moderate to high ecological integrity and are considered worthy of management input in terms of periodic weed control.

Recommendations

- A robust, comprehensive classification of vegetation types for this rare ecosystem has not been produced and is needed for decisions on resource allocations for future management. This requires a parallel suite of monitoring plots in the two very substantial frost flats remaining in the Hawke's Bay Region: the upper Waipunga and Kokomoka valleys and the upper Ripia Valley. Funding is being sought from the appropriate Regional Council to establish these.
- Information from temperature loggers should be analysed when available next year or in March 2015 and related to vegetation pattern across the frost flat spectrum.

- Soil fertility and fire history analyses across both regions would also help elucidate the reasons behind differences in vegetation pattern between them.
- The most obvious immediate management priority is woody weed control, particularly heather at Whenuakura, which has the ability to outcompete and largely eliminate native frost flat vegetation.
- The matrix surrounding remaining frost flat heathlands should be defined and its impact on them assessed.
- Frost flat heathland in Kuratau Clearing degraded by weed invasion should be monitored to assess the speed and endpoint (in terms of indigenous biodiversity) of the degradation process.
- Plots should be remeasured on a 5-yearly basis, next in summer of 2018.
- Whenuakura Plain has the highest priority for conservation management (weed control).

1 Introduction

A network of permanent plots was established by Landcare Research in January–May 2013 for the Waikato Regional Council to establish a baseline for monitoring changes in the condition – 'ecological integrity' – of frost flat heathlands remaining in the Waikato Region.

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. The potential additional role of soil infertility in excluding native forest from frost flats remains unexplored.

A long history of human burning has undoubtedly played a major role – as elsewhere – in reducing taller woody vegetation and replacing it by shorter woody vegetation and grassland (Fig. 1). 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. At west Taupo, the Taparoa Clearing and Whenuakura Plain are both likely to have been part of Māori travel routes (A.E. Beveridge, pers. com.) and therefore subject to regular burning in pre-European times. The Pokaiora Clearing lies at the western extremity of formerly extensive secondary communities that surrounded Lake Taupo and resulted from a long history of pre-European burning (Nicholls 1986).

Figure 1 Monoao scrub on frost flat heathland on the Whenuakura Plain, Pureora Forest Park. Short conifer (mountain toatoa) forest in the background. At 790 m asl, this is highest-elevation frost flat on the Volcanic Plateau (January 2013).

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 (MfE/DOC 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. 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 – which varies widely among sites – on survival prospects is unknown, but likely to be significant through its influence on weed invasion and nutrient enrichment.

Until extensive land development after the Second World War, West Taupo was an important centre of frost flat heathland which now survives at only a handful of sites. A network of permanent plots across them will enable us to monitor changes in condition over time, and also to assess the influence of the surrounding matrix on their prospects for survival.

3 Objective

To establish a baseline for monitoring the condition – 'ecological integrity' – of significant frost flat heathlands remaining in the Waikato Region.

4 Methods

4.1 Permanent plots

Fifteen permanently marked 2 × 2-m permanent plots following Hurst and Allen (2007) were placed at each of three sites at pre-selected locations. These were derived by stratified random sampling defined by GIS polygons that were manually derived from aerial photographs. The 2 × 2-m plot size for frost flat heathland was arrived at after deriving the species/area curve at Rangitaiki Conservation Area before beginning the major sampling exercise there in 1988 (Smale 1990).

Within plots, we recorded the following biological and physical attributes (adapted from Hurst & Allen 2007):

- All vascular species present, including invasive weeds, as well as prominent bryophytes and lichens, and quantitative cover estimates of each
- Physical parameters such as slope, altitude and aspect
- Height of the tallest individual of the dominant vascular species (usually monoao)
- Human impact (e.g. off-road vehicle tracking)
- Introduced mammal impact, including the presence of faecal pellets and trampling and presence and degree of browsing by species.

One larger intact site was sampled (Fig. 2):

- Whenuakura Plain, Pureora Forest Park: 72 ha

Two smaller sites were sampled:

- Pokaiora Clearing, Waihaha Ecological Area, Pureora Forest Park: 38 ha
- Taparoa Clearing, Waipapa Ecological Area, Pureora Forest Park (Figs 3, 4): 23 ha (Leathwick 1987).

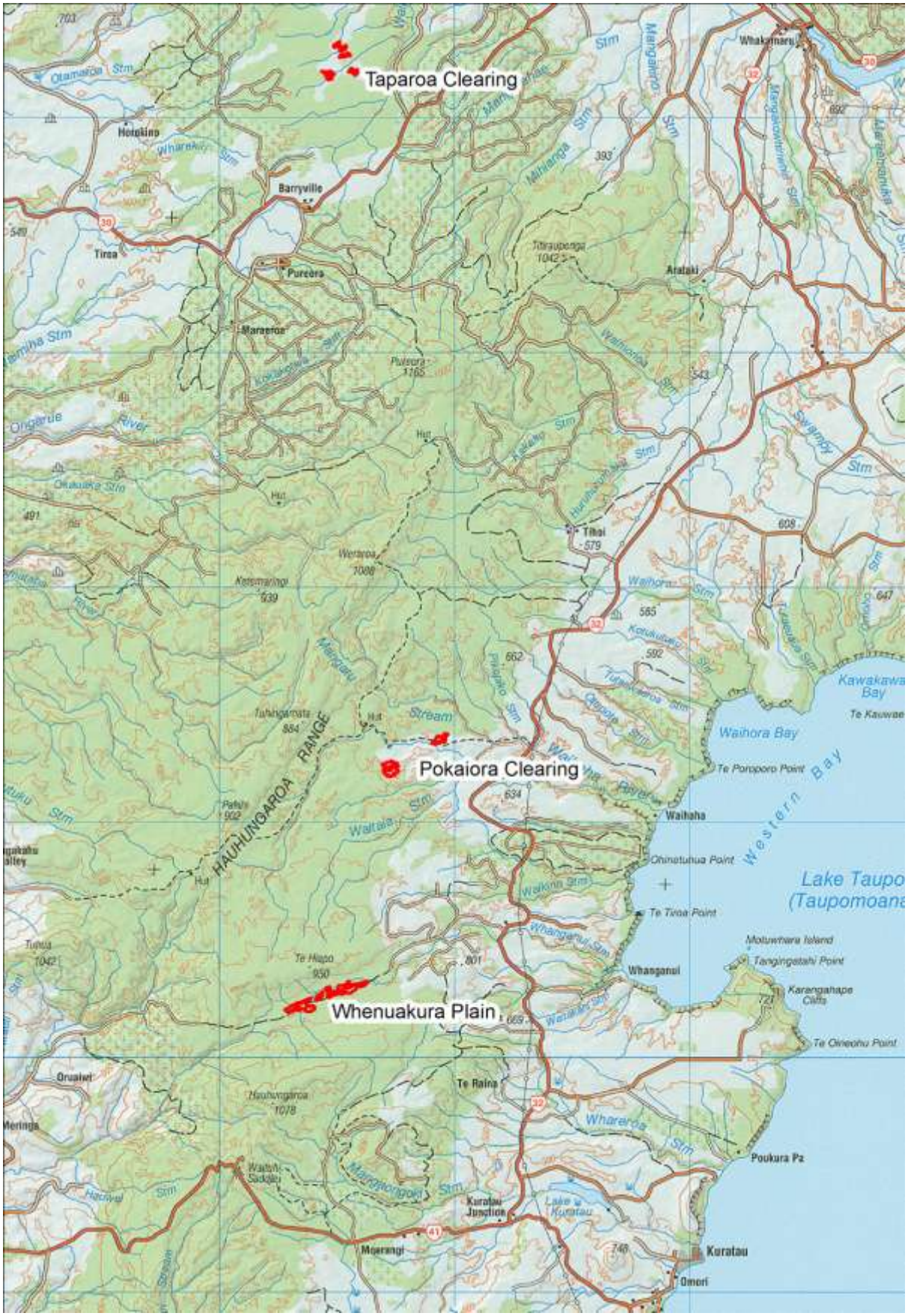

Figure 2 Location of frost flat heathlands sampled.

All sites are in Crown tenure and managed by the Department of Conservation. Another small site, Kuratau Clearing in Waituhi-Kuratau Scenic Reserve, was scheduled for sampling but on closer inspection, proved to be smaller than originally envisaged. It is also highly invaded by weeds, especially heather (*Calluna vulgaris*) and broom (*Cytisus scoparius*), in places to the point where the indigenous frost flat community has been largely ousted (Fig. 5). It was therefore abandoned as a sampling site at the time. However, subsequent discussion with colleagues indicates that it should be sampled to assess the speed and endpoint (in terms of indigenous biodiversity) of the degradation process.

All plots are permanently marked with an inch-square yellow-painted wooden picket at each corner.

Forty-two temperature dataloggers were installed (14 per site) at a random selection of the permanent plots and will be left for 12–24 months to see how frost regime varies across sites.

Figure 3 Monoao scrub in frost flat heathland in Taparoa Clearing, Waipapa Ecological Area, Pureora Forest Park. Manuka (*Leptospermum scoparium*) scrub and conifer forest on the hillslope behind (May 2013).

Figure 4 Understory of monoao scrub with coral lichen and *Uncinia* species in frost flat heathland in Taparoa Clearing, Waipapa Ecological Area, Pureora Forest Park (May 2013).

4.2 Data analysis

The following indicators of ecological integrity were calculated from biological attributes and averaged for each site:

- Mean frequency of each of 12 diagnostic frost flat species (Smale 1990), a measure of 'species occupancy' (Lee et al. 2005).
- Mean frequency of forest precursor species, e.g. fivefinger (*Pseudopanax arboreus*) and mountain toatoa.
- Mean frequency of invasive weeds, e.g. Yorkshire fog (*Holcus lanatus*) and sweet vernal (*Anthoxanthum odoratum*).
- Adventive/indigenous cover ratio, i.e. total indigenous and total adventive[1] cover summed over all tiers, the reverse of 'indigenous dominance' (Lee et al. 2005).

[1] See Appendix 1 for definitions of scientific terms.

Overall, ecological integrity was derived by averaging mean frequencies of individual indicators. Mean frequencies of each of the above indicators below 20% were ranked very low, 20–50% low, 50–70% moderate, and above 70% high.

Figure 5 Frost flat heathland in the Kuratau Clearing, Waituhi-Kuratau Scenic Reserve, grossly modified by weed – heather and broom – invasion (January 2013).

5 Results

5.1 Diagnostic frost flat species

Of the 12 diagnostic frost flat species originally listed for frost flat heathland (Smale 1990), only five – monoao, danthonia (*Rytidosperma gracile*), coral lichen (*Cladia retipora*), *Cladina confusa*, and catsear (*Hypochoeris radicata*) – were at all widespread, and only two of them – monoao and danthonia – occurred consistently, i.e. in over the half of all plots. One of them, woolly moss (*Racomitrium lanuginosum*), was not present at all (Table 1). A total of 94 species (including prominent lichens) was recorded across all plots, including 17 adventives (Appendix 2).

Table 1 Mean frequency (%) of plots in which recorded) of 12 diagnostic frost flat species at three frost flat sites in Waikato Region.

	Species											
Site	*Dracophyllum subulatum*	*Rytidosperma gracile*	*Cladia retipora*	**Hypochoeris radicata*	*Cladina confusa*	*Leucopogon fraseri*	*Celmisia gracilenta*	*Poa cita*	*Cladonia capietallata*	*Pimelea prostrata*	*Deyeuxia avenoides*	*Racomitrium lanuginosum*
Pokaiora Clearing	100	80	47	33	33	60	33	7	7	20	7	-
Whenuakura Plain	100	47	67	7	40	7	7	7	7	-	7	-
Taparoa Clearing	100	100	20	87	47	33	13	33	13	7	-	-
All sites	100	76	44	42	40	33	18	16	9	9	4	-

* denotes adventive

5.2 Forest precursor species

Eleven potential tree and shrub precursor species of forest were recorded in plots (Fig. 6), of which only two – fivefinger and mountain toatoa – were at all widespread, i.e. in >20% of plots (Table 2). No species occurred consistently, i.e. in over the half of all plots. The remaining species were pōkākā (*Elaeocarpus hookerianus*), broadleaf (*Griselinia littoralis*), mānuka, poataniwha (*Melicope simplex*), tānekaha (*Phyllocladus trichomanoides*), Hall's tōtara (*Podocarpus cunninghamii*), tōtara (*Podocarpus totara*), mataī (*Prumnopitys taxifolia*), and lancewood (*Pseudopanax crassifolius*).

Table 2 Mean frequency (%) of the five more widespread and any forest precursor species at three frost flat sites in the Waikato Region

	Species					
Site	Fivefinger	Mountain toatoa	Manuka	Tanekaha	Matai	Any species
Pokaiora Clearing	13	0	13	20	0	40
Whenuakura Plain	13	53	0	0	13	53
Taparoa Clearing	40	7	13	7	7	53
All sites	22	20	9	9	7	49

* denotes adventive

Figure 6 Mātai seedling (lower right) – a precursor of tall forest – developing under monoao scrub in frost flat heathland, Taparoa Clearing, Waipapa Ecological Area, Pureora Forest Park (May 2013).

5.3 Invasive weeds

Eight invasive weed species were encountered in plots, of which the most widespread were Yorkshire fog, sweet vernal, browntop (*Agrostis capillaris*), and blackberry (*Rubus fruticosus*) (Table 3). Only one species, Yorkshire fog, occurred consistently, i.e. in over half of the plots, at any site; and no invasive weed species was recorded in plots on the Whenuakura Plain. The remaining species were Chewing's fescue (*Festuca rubra*), lotus (*Lotus pedunculatus*), mouse-ear hawkweed, and white clover (*Trifolium repens*).

Table 3 Mean frequency (%) of the four most widespread and any invasive weed at three frost flat sites in the Waikato Region

	Species				
Site	Yorkshire fog	Sweet vernal	Browntop	Blackberry	Any species
Pokaiora Clearing	53	33	7	0	73
Whenuakura Plain	0	0	0	0	0
Taparoa Clearing	53	33	27	33	87
All sites	36	22	11	11	60

5.4 Adventive dominance

Adventive species contributed minimally to vegetative cover except in the Taparoa Clearing (Table 4).

Table 4 Adventive dominance at three frost flat sites in the Waikato Region

Site	Adventive/Indigenous cover ratio
Pokaiora Clearing	0.09
Whenuakura Plain	<0.001
Taparoa Clearing	0.11
All sites	0.07

5.5 Ecological integrity

Whenuakura Plain has high ecological integrity, Pokaiora and Taparoa Clearings moderate integrity (Table 5).

Table 5 Ecological integrity of three frost flat sites in the Waikato Region

	Indicator				
Site	Mean frequency, diagnostic frost flat species	Mean frequency, native forest precursors	Mean frequency, invasive weeds	Adventive dominance	Overall
Pokaiora Clearing	Low	Low	High	Very low	Moderate
Whenuakura Plain	Low	Moderate	Absent	Very low	High
Taparoa Clearing	Low	Moderate	High	Very low	Moderate

5.6 Conservation management priorities

Whenuakura Plain has the highest current ecological integrity and is also the only site with heather, the only invasive weed at west Taupo that is amenable to control and still confined to road and track verges. (Blackberry is too widespread and has too low cover in the Taparoa Clearing to allow control). Therefore, Whenuakura has the highest priority for conservation management (weed control).

6 Discussion and conclusions

The list of 12 diagnostic frost flat species ('key' species: Smale 1990) was derived from Rangitaiki Conservation Area on the southern Kaingaroa Plateau, and later reduced to eight after much wider sampling in the region (Smale & Fitzgerald 2012). Frost flat heathland at Rangitaiki is characterised by open short shrubland; denser, taller scrub on more fertile (Yeates et al. 2004) and probably moister sites is much more local. In contrast, the west Taupo frost flats sampled here are characterised by tall, dense scrub; open, shorter communities are much more local. The consistent (i.e. present in more than half of all plots) occurrence of only two diagnostic species – monoao and danthonia – and the absence of one of them – woolly moss – at west Taupo highlights the fundamentally different nature of frost flat heathland between these regions, and the need to revise the list of diagnostic species to accommodate the breadth of communities across the whole frost flat spectrum.

Forest precursor species are far more widespread in west Taupo heathlands (mean frequency of any species 49%) than on the Kaingaroa Plateau (kānuka (*Kunzea ericoides*), the only native precursor, 5%). A much wider range of species, 11 vs 2, is also present (Fig. 7). Thus, succession to native forest is likely in the foreseeable future on much of the west Taupo frost flat heathland.

Figure 7 Tōtara seedling – a precursor of tall forest – developing under monoao scrub in frost flat heathland, Taparoa Clearing, Waipapa Ecological Area, Pureora Forest Park (May 2013).

Invasive weed species are more widespread in west Taupo heathlands (mean frequency of any species 60%) than on the Kaingaroa Plateau (42%). A wider range of species, 9 vs 4, is also present. Notably, however, and in stark contrast to Kaingaroa, contorta pine, one of the most threatening weeds of this ecosystem, is absent from the west Taupo frost flat heathlands. Although not present in plots, heather is present and spreading on road verges at Whenuakura (Fig. 8) and occurs occasionally at Pokaiora, and broom is present at Taparoa. Despite the somewhat higher frequency and species richness of invasive weeds at west Taupo, overall adventive dominance here (mean 0.07) is similar to that on the Kaingaroa Plateau (0.06). It is highly skewed by one site, Taparoa Clearing, whose greater weediness undoubtedly reflects its greater accessibility and heavier human use. With public access via the 1956 logging road ('Fletcher's Road') and secondary tracks that traverse parts of it, Taparoa receives a much higher frequency of human use than relatively remote Pokaiora Clearing (foot and aerial access only). Although Whenuakura Plain is also traversed by a road, it is seldom used and there is no public access.

Figure 8 The invasive weed heather spreading on a foot track on the Whenuakura Plain, Pureora Forest Park (January 2013).

The low frequency of many diagnostic frost flat species and high frequency of forest precursor species highlight the fundamentally different nature of frost flat heathland at west Taupo (Waikato Region) and on the Kaingaroa Plateau (Bay of Plenty Region). Both regions have a long fire history, and other factors are also likely to be responsible for the differences between them. The frost regime in the Taparoa Clearing is significantly milder than at Rangitaiki Conservation Area (Smale 1990). Information from the temperature loggers installed during this study across most of the frost flat spectrum in both regions will help clarify the contribution to differing vegetation pattern of this important limiting aspect of local climate. Soil fertility (not yet tested) may also be a contributing factor.

7 Recommendations

- A robust, comprehensive classification of vegetation types for this rare ecosystem has not been produced and is needed for decisions on resource allocations for future management. This requires a parallel suite of monitoring plots in the two very substantial frost flats remaining in the Hawke's Bay Region: the upper Waipunga and Kokomoka valleys and the upper Ripia Valley. Funding is being sought from the appropriate Regional Council to establish these. Explanatory variables such as soil fertility, fire history, and temperature regimes from a subset of plots would greatly assist interpretation of the classification.
- Information from temperature loggers should be analysed when available and related to vegetation pattern across the frost flat spectrum.
- Soil fertility analyses across both regions would also help elucidate the reasons behind differences in vegetation pattern between them.
- The matrix surrounding remaining frost flat heathlands should be defined and its impact on them assessed.
- The most obvious immediate management priority is the control of woody weeds, particularly of heather at Whenuakura and Pokaiora, which has the ability to outcompete and eliminate frost flat vegetation altogether.
- Frost flat heathland in Kuratau Clearing degraded by weed invasion should be monitored to assess the speed and endpoint of the degradation process.
- Plots should be remeasured on a 5-yearly basis, next in summer 2018.
- Whenuakura Plain has the highest priorty for conservation management (weed control).

8 Acknowledgements

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Appendix 1 – Glossary of scientific terms

Adventive	Accidentally or deliberately introduced from elsewhere into New Zealand
Endemic	Native to New Zealand and nowhere else
Native	Native to New Zealand and other countries as well

Appendix 2 – Flora of frost flat heathland in the Waikato Region

Scientific name	Common Name	Origin	Pokaiora	Whenuakura	Taparoa
Acaena agnipila	sheep's bur	Adventive			Y
Agrostis capillaris	browntop	Adventive	Y		Y
Androstoma empetrifolia	bog mingimingi	Endemic		Y	Y
Anthoxanthum odoratum	sweet vernal	Adventive	Y		Y
Aristotelia fruticosa	mountain wineberry	Endemic	Y	Y	Y
Blechnum penna-marina		Native	Y	Y	Y
Campylopus sp.	moss	Native		Y	
Carex dipsacea		Endemic			Y
Celmisia gracilenta		Endemic	Y	Y	Y
Centella uniflora		Endemic	Y		Y
Chionochloa rubra	red tussock	Endemic		Y	
Cladia aggregata		Native		Y	
Cladia retipora	coral lichen	Native		Y	Y
Cladonia capitellata		Native	Y	Y	Y
Cladonia confusa	reindeer lichen	Native	Y	Y	Y
Clematis quadribracteolata		Endemic	Y		Y
Conyza sp.	fleabane	Adventive			Y
Coprosma ×cunninghamii		Endemic			Y
Coprosma cheesemanii		Endemic		Y	
Coprosma dumosa		Endemic		Y	Y
Coprosma propinqua	mingimingi	Endemic	Y	Y	Y
Crepis capillaris	smooth hawksbeard	Adventive	Y		Y
Deyeuxia avenoides	mountain oat grass	Endemic	Y	Y	
Dichondra brevifolia		Endemic		Y	
Dicranoloma robustum	golden shaggy moss	Native		Y	Y
Dracophyllum subulatum	monoao	Endemic	Y	Y	Y
Elaeocarpus hookerianus	pōkākā	Endemic	Y		
Festuca rubra	Chewing's fescue	Adventive	Y		
Geranium microphyllum	small-leaved cranesbill	Endemic	Y		Y
Gleichenia dicarpa	tangle fern	Native		Y	Y
Gnaphalium sp.	cudweed	Endemic	Y		
Gonocarpus aggregatus		Endemic	Y	Y	Y

Scientific name	Common Name	Origin	Pokaiora	Whenuakura	Taparoa
Gonocarpus micranthus		Native	Y		Y
Griselinia littoralis	broadleaf	Endemic		Y	
Halocarpus bidwillii	bog pine	Endemic		Y	
Helichrysum filicaule	creeping everlasting daisy	Endemic			Y
Hierochloe redolens	kāretu	Native		Y	Y
Histiopteris incisa	water fern	Native		Y	
Holcus lanatus	Yorkshire fog	Adventive	Y		Y
Hydrocotyle moschata		Endemic			Y
Hydrocotyle novae-zeelandiae var. montana		Endemic			Y
Hymenophyllum sanguinolentum		Endemic		Y	Y
Hypericum perforatum	Saint John's wort	Adventive	Y		
Hypnum cupressiforme		Native			Y
Hypochaeris radicata	catsear	Adventive	Y		Y
Lepidosperma australe	square sedge	Endemic		Y	Y
Leptecophylla juniperina	prickly heath	Endemic		Y	
Leptospermum scoparium	mānuka	Endemic	Y		Y
Leptostigma setulosa	scrub nertera	Endemic	Y		
Leucopogon fraseri	patotara	Endemic	Y	Y	Y
Lobelia angulata	panakeake	Endemic		Y	Y
Lotus pedunculatus	lotus	Adventive			Y
Luzula decipiens		Endemic		Y	
Luzula picta var. pallida		Endemic		Y	Y
Luzula sp.	woodrush	Native	Y		
Lycopodium fastigiatum	alpine clubmoss	Native	Y	Y	Y
Melicope simplex	poataniwha	Endemic			Y
Microlaena stipoides	meadow rice grass	Native			Y
Muehlenbeckia axillaris		Native		Y	
Myrsine divaricata	weeping māpou	Endemic	Y	Y	
Notogrammitis angustifolia subsp. nothofageti		Native			Y
Olearia virgata		Endemic	Y	Y	
Oreomyrrhis ramosa		Endemic	Y	Y	Y
Phyllocladus alpinus	mountain toatoa	Endemic		Y	

Scientific name	Common Name	Origin	Pokaiora	Whenuakura	Taparoa
Phyllocladus trichomanoides	tānekaha	Endemic	Y		Y
Pilosella officinarum	mouse-ear hawkweed	Adventive	Y		
Pimelea prostrata	New Zealand daphne	Endemic	Y		Y
Pittosporum tenuifolium	kōhuhu	Endemic			Y
Pittosporum turneri		Endemic		Y	
Poa cita	silver tussock	Endemic	Y		Y
Podocarpus cunninghamii	mountain tōtara	Endemic		Y	
Podocarpus totara	totara	Endemic			Y
Polytrichum juniperinum		Native	Y	Y	Y
Prumnopitys taxifolia	mātai	Endemic		Y	Y
Prunella vulgaris	selfheal	Adventive	Y		
Pseudopanax arboreus	fivefinger	Endemic			Y
Pseudopanax crassifolius	lancewood	Endemic	Y	Y	Y
Pterostylis sp.	greenhood	Native		Y	
Raukaua anomalus		Endemic		Y	Y
Rubus fruticosus	Blackberry	Adventive			Y
Rumex acetosella	sheep's sorrel	Adventive	Y		
Rytidosperma gracile	danthonia	Native	Y	Y	Y
Senecio jacobaea	Ragwort	Adventive	Y		
Simpliglottis cornuta	bird orchid	Native		Y	
Thuidium furfurosum		Native			Y
Trifolium repens	white clover	Adventive	Y		
Trifolium sp.	clover	Adventive	Y		
Uncinia angustifolia		Endemic			Y
Uncinia rubra	red hook sedge	Endemic	Y	Y	Y
Uncinia rupestris		Endemic		Y	
Uncinia sp.	hook grass	Native	Y		
Veronica corriganii		Endemic		Y	
Veronica stricta	koromiko	Endemic		Y	Y
Viola cunninghamii	mountain violet	Native			Y