Manaaki Whenua
Landcare Research

Legacy effects of conifer invasion and control in frost flats: monitoring design

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Neil Fitzgerald

Manaaki Whenua – Landcare Research

Reviewed by:	*Approved for release by:*
Mark Smale Research Associate Manaaki Whenua – Landcare Research	Gary Houliston Portfolio Leader – Plant Biodiversity & Biosecurity Manaaki Whenua – Landcare Research

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Summary

Project and Client

- Bay of Plenty Regional Council contracted Manaaki Whenua – Landcare Research to design a monitoring scheme to monitor legacy effects of non-native conifer invasion and subsequent control of them on frost flat heathland.

Objectives

- Develop a sampling scheme to monitor legacy effects of non-native conifer control on frost flat heathland vegetation.

Methods

- Monitoring methods that have been used in frost flat heathland and other structurally similar ecosystems where invasive conifer research has been undertaken were reviewed and a sampling strategy designed to identify legacy effects of *Pinus contorta*, the main non-native conifer in frost flat heathland in the Bay of Plenty.

Results

- Vegetation condition monitoring in frost flat heathland has mainly used 2× 2-m plots in the past. Plant cover with these plots has been recorded mainly as estimated cover in height tiers. Larger plots (20 × 20 m), with vegetation estimated in height tiers, have also been used to study the legacy effects of *P. contorta* in alpine grassland.
- *Pinus contorta* invasion and subsequent control resulted in increases in soil nitrogen and phosphorous in alpine grassland, and elevated soil nitrogen and phosphorous were correlated with increased growth of *Dracophyllum subulatum* at Rangitaiki Conservation Area.

Discussion

- A nested plot design, with a series of 2× 2-m plots nested within a 10 × 10-m plot, and a 400-m^2 circular plot will allow vegetation and soil changes to be monitored at a range of scales and compared across studies.

Recommendations

- At least 30 recently killed *Pinus contorta* trees should be randomly chosen from areas of <25% pine cover at Rangitaiki Conservation Area and Otangimoana Stewardship Area, and permanent monitoring plots centred on these trees.
- Monitoring plots should also be established at 10 random locations, or at existing monitoring plots, in areas unaffected by pines to provide a baseline against which the effect of *P. contorta* can be reliably assessed.
- The cover of all vascular plants and common lichens and bryophytes should be estimated in standard height tiers (<0.3 m, 0.3–2 m, 2–5 m, 5–12 m) in nested 2 × 2-m and 10 × 10-m plots, and the number and height of *P. contorta* plants within 11.3 m of the focal *P. contorta* plant counted.
- Soil samples should be collected from each 2 × 2 m plot and analysed for bulk density and C, N, P and K.

1 Introduction

Pinus contorta is a the most common non-native conifer invading frost flat heathland in the Bay of Plenty region. Left unchecked, *P. contorta* completely replaces native frost flat vegetation, and the long-term effect of its removal after invasion is unknown (Fitzgerald et al. 2019). This project aims to design a sampling strategy that allows the effects of *P. contorta* control on the ecological integrity and long-term viability of frost flat heathland to be evaluated, and provides evidence to guide management for protecting and restoring frost flat heathland.

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. Despite their occurrence well below regional treeline under climates that are generally considered amenable for plant growth, some sites are subject to year-round frosts resulting from cold air ponding, and this maintains treeless heathland communities (Smale 1990). Monoao growth is positively correlated with phosphorus and nitrogen availability (Yeates et al. 2004), but the potential 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-statured woody vegetation and grassland. The taller shrub component of frost flat heathland dominated by bog pine (*Halocarpus bidwillii*) and mountain toatoa (*Phyllocladus alpinus*) has been severely reduced by burning and now survives as scattered remnants, mostly persisting 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. Frost flats are considered to be a Critically Endangered naturally uncommon ecosystem (Holdaway et al. 2012).

Many introduced *Pinus* species have naturalised from plantations or legacy plantings and are some of the most globally important biological invaders within New Zealand and internationally (Richardson 1998; McGregor et al. 2012). In New Zealand, *Pinus contorta* grows more than 200 m above the natural mountain beech (*Fuscospora cliffortioides*) treeline in the South Island, as it is particularly resistant to summer frosts that limit other species there, as in frost flats (Wardle 1985a, b; Smale 1990). Non-native ('wilding') conifers, including *Pinus contorta*, have important ecosystem effects in New Zealand native grasslands, including changes to soil nutrient cycling (Peltzer 2018). *Pinus contorta* is the main non-native conifer in Bay of Plenty frost flats, present in 14% of 119 permanent vegetation monitoring plots measured there in 2018 (Fitzgerald et al. 2019). Control of *P.*

contorta is regularly undertaken in these frost flats by felling and herbicide. Removal of invasive plants quickly stops further seed production and dispersal and reduces aboveground biomass, but can cause below ground changes that can be more difficult to reverse and can drive changes in subsequent plant community composition and structure (Dickie et al. 2014; Peltzer 2018). The long-term effects of pine invasion and control on native frost flat heathland vegetation are unknown.

3 Objective

Develop a sampling scheme to monitor legacy effects of non-native conifer control on frost flat heathland vegetation.

4 Methods

Monitoring methods used previously in frost flat heathland and other structurally similar ecosystems where invasive conifer research has been undertaken were reviewed. Based on these, a sampling strategy was designed to monitor legacy effects of *Pinus contorta* in frost flat heathland.

5 Results

5.1 Plot size and vegetation measurement

Three plot methodologies used previously in frost flats (to monitor change in native vegetation) and alpine grassland (to determine legacy effects of pine invasion) were reviewed.

5.1.1 Frost flat succession following fire

Smale et al. (2011) used 2 × 2-m plots to monitor frost flat vegetation succession following a lightening-induced fire at Rangitaiki Conservation Area. Point intercepts of the highest plant at 104 predetermined grid points were summed per species per plot and expressed as a percentage of the total number of intercepts per plot to provide a measure of percentage cover. General trends in vegetation change were assessed with relatively few small plots, because frost flat heathland is relatively species poor and homogenous (Smale 1990) and the burn was very small (0.3 ha).

This post-fire succession monitoring was established in 1994, and remeasured annually until 2000, then in 2002, 2005, 2009 (Smale et al. 2011), and 2019 (unpublished).

5.1.2 Frost flat condition monitoring

In 2012, 120 vegetation monitoring plots were established across six Bay of Plenty frost flat sites to monitor change in vegetation condition – 'ecological integrity' – of the remaining substantial frost flat heathlands in the region (Smale & Fitzgerald 2012). Fifteen permanently marked 2 × 2-m plots were placed at locations pre-selected by stratified random sampling within major vegetation structural classes (grassland, shrubland). Vegetation was measured within each plot using methods adapted from permanent vegetation monitoring protocols used widely in the National Vegetation Survey (Hurst & Allen 2007); this included recording all vascular species present, including invasive weeds, as well as prominent bryophytes and lichens, and quantitative cover estimates of each species within standard height tiers (Smale & Fitzgerald 2012). These plots were remeasured in 2018 (Fitzgerald et al. 2019).

Plots were established using the same methodology in the remaining significant frost flats in the Waikato region in 2013 (Smale et al. 2013) and Hawke's Bay regions in 2015 and 2018 (Smale & Fitzgerald 2015, 2018).

The density and height (age) of *Pinus contorta* vary across and within frost flat sites, due to ongoing invasion and control, and distance from seed sources. Current control of *P. contorta* focusses on areas where pines comprise <25% of canopy cover. The majority (63%) of the area of Bay of Plenty frost flats have <1% pine cover and these areas are the highest priority for pine control in order to maintain relatively uninvaded frost flat heathland (Delich 2020). Nine percent of Bay of Plenty frost flat vegetation has 1–5% pine cover, and 6% has 6–25% pine cover.

Of the 119 randomly allocated plots measured in 2018, *P. contorta* occurred in 6 of 95 plots (6%) in areas mapped as <1% pine cover, 5 of 18 plots (28%) in areas of 1–5% pine cover, and 5 of 6 plots (83%) in areas of 6–25% pine cover. The low frequency of *P. contorta* in random plots in areas of sparse infestation illustrates the need to use a different sampling strategy that ensures potential effects of pine removal are detected.

5.1.3 Legacy effects of *Pinus contorta* in alpine grassland

Dickie et al. (2014) investigated legacy effects of *Pinus contorta* invasion and removal on soil nutrients and biota in a New Zealand alpine grassland. Plant cover was measured in 20 × 20-m plots located across a range of *P. contorta* densities using semi-quantitative cover classes and height tiers of Hurst & Allen (2007). Plots were randomly located within stratified areas that differed in the timing of wilding pine removal, i.e., areas in which *P. contorta* was removed as seedlings (i.e., 'uninvaded'), saplings or trees.

5.2 Soil sampling and analysis

To determine below-ground legacy effects of *Pinus contorta* invasion in alpine grassland, Dickie et al. (2014) collected soil cores from the top 10 cm of mineral soil and analysed to determine nutrient concentration (pH, total C, total N, KCl extractable NH_4 –N and NO_3-N, total P and Bray-extractable P) and microbial (bacterial, fungal, and nematode) biomass.

Removal of *P. contorta* resulted in increased nitrogen and phosphorous availability through changes in microbial communities (see also Peralta et al. 2020).

Yeates et al. (2004) took soil samples to 10 cm depth along transects through frost flat heathland for chemical analysis, and carved 10 cm diameter, 7.5 cm deep soil cores to determine bulk density and found a positive correlation between soil nitrogen and phosphorous and *Dracophyllum subulatum* height. However, heterotrophic microbial diversity and nematode diversity were not correlated with *D. subulatum* size.

6 Discussion

Using the same plot measurement methods as the existing frost flat condition monitoring plots (2 × 2 m; Smale & Fitzgerald 2012) will allow direct comparisons to be made between these studies. The permanent plots monitoring succession following lightening-induced fire could also be measured using this method (plant cover estimated in tiers) rather than point intercepts; this will allow comparisons of vegetation succession following natural disturbance with other monitoring sites.

The floristically simple and homogenous nature of frost flat heathlands allows changes in vegetation to be monitored with relatively small plots, which can be measured quickly and allow greater replication and spatial resolution than larger plots. However, it is important to note that there are is no single optimal plot size, and data from different size plots cannot be directly compared (Richardson et al. 2015). Most vegetation monitoring in New Zealand has used larger plots than the 2 × 2-m plots currently used in frost flat heathland (Richardson et al. 2015). Richardson et al. (2015) recommended 10 × 10-m plots for monitoring in shrubland, and the use of nested plots to allow for data integration across studies and to allow for potential changes in vegetation structure over time. As these are important considerations in monitoring the effects of pines in frost flats, nested plots (i.e. 2 × 2 m within 10 × 10 m) seem appropriate.

The impacts of individual trees on vegetation or soils are likely to decrease rapidly with distance, but it is helpful to know how far wilding effects extend. Wardle et al. (2008) found that the effects of large rimu (*Dacrydium cupressinum*) with mean diameter of 137 cm (at approximately 1.4 m above ground) extended to 8 m from the base of the trees. A series of plots at increasing distance up to 9 m from the base of randomly selected *P. contorta* trees will allow the extent of the effect of isolated trees to be measured. However, the influence of individual trees may be confounded by other nearby trees, so it is important to know the density of surrounding *P. contorta* that could influence soil and vegetation changes in the plots.

Control of *P. contorta* in Bay of Plenty frost flats is initially focussed on areas with pine cover <25%, as delineated by Delich (2020), who expressed concern that maintaining control of pines once cover exceeds 5% may not be possible, and that areas with >25% pine cover may not be restorable to heathland that was present before pine invasion. Monitoring of legacy effects should be restricted initially to areas where pine control has been undertaken (i.e. <25% cover) but can be extended to areas of higher pine cover when control is extended there, so that empirical data can be collected to determine whether frost flat heathland is resilient to high levels of pine invasion or is forced into a new state.

Control methods involve either felling or herbicide application, and monitoring plots should include the different control methods if possible. Plot allocation should include areas of low and high pine density. However, mapping and classification of vegetation are inherently scale-dependent, and the unevenness of *P. contorta* within these areas means that the mapped classification of cover (i.e. <1%, 1–5%, 6–25%) should be used only as a guide to achieving coverage of a range of pine densities, with 10–20 plots per cover class. Non-treatment plots should also be measured in areas without *P. contorta*. The ambient density of *P. contorta* that may influence soil and vegetation changes in the monitoring plots should be measured using a circular plot with a 11.3 m radius from the focal tree. A circular plot of this size has an area of 400 m^2, which is the same as that of 20 × 20 m plots widely used in New Zealand forest monitoring.

To monitor potential legacy effects of *P. contorta* invasion and allow comparison between studies, the suggested methodology is to use a 2 × 2-m plot nested within a 10 × 10-m plot, both centred on randomly selected, recently killed, *P. contorta*, with additional 2 × 2-m plots also 1–3 m, 3–5 m, 5–7, and 7–9 m along a randomly oriented transect from the focal pine (Figure 1). The number and height of all *P. contorta* plants >0.75 m tall within 11.3 m of the focal pine should also be measured. Soil samples should be taken from each 2 × 2-m plot and analysed for bulk density (0–7.5 cm depth) and C, N, P, and K content (0–10 cm). Non-treatment plots should also be measured, including the circular plots, 10 × 10-m plots, and a single 2 × 2-m plot at the centre. These non-treatment plots could use existing 2 × 2-m monitoring plots located in comparable frost flat heathland where these are unaffected by *P. contorta* invasion (i.e., >50 m from pine trees) or established at new random locations.

The two largest areas of frost flat heathland remaining in Bay of Plenty – Rangitaiki Conservation Area (c. 2355 ha), and Otangimoana Stewardship Area (c. 328 ha) – are relatively intact and have good prospects for survival (Smale & Fitzgerald 2012), provided *P. contorta* is adequately controlled. The Rangitaiki Conservation Area has <1% cover of *P. contorta* and discrete areas of native vegetation of known age. The cover of *P. contorta* at Otangimoana Stewardship Area ranges from <1% to >75% (Delich 2020), providing an opportunity to investigate pine legacy effects along a density gradient reflecting invasion and control history.

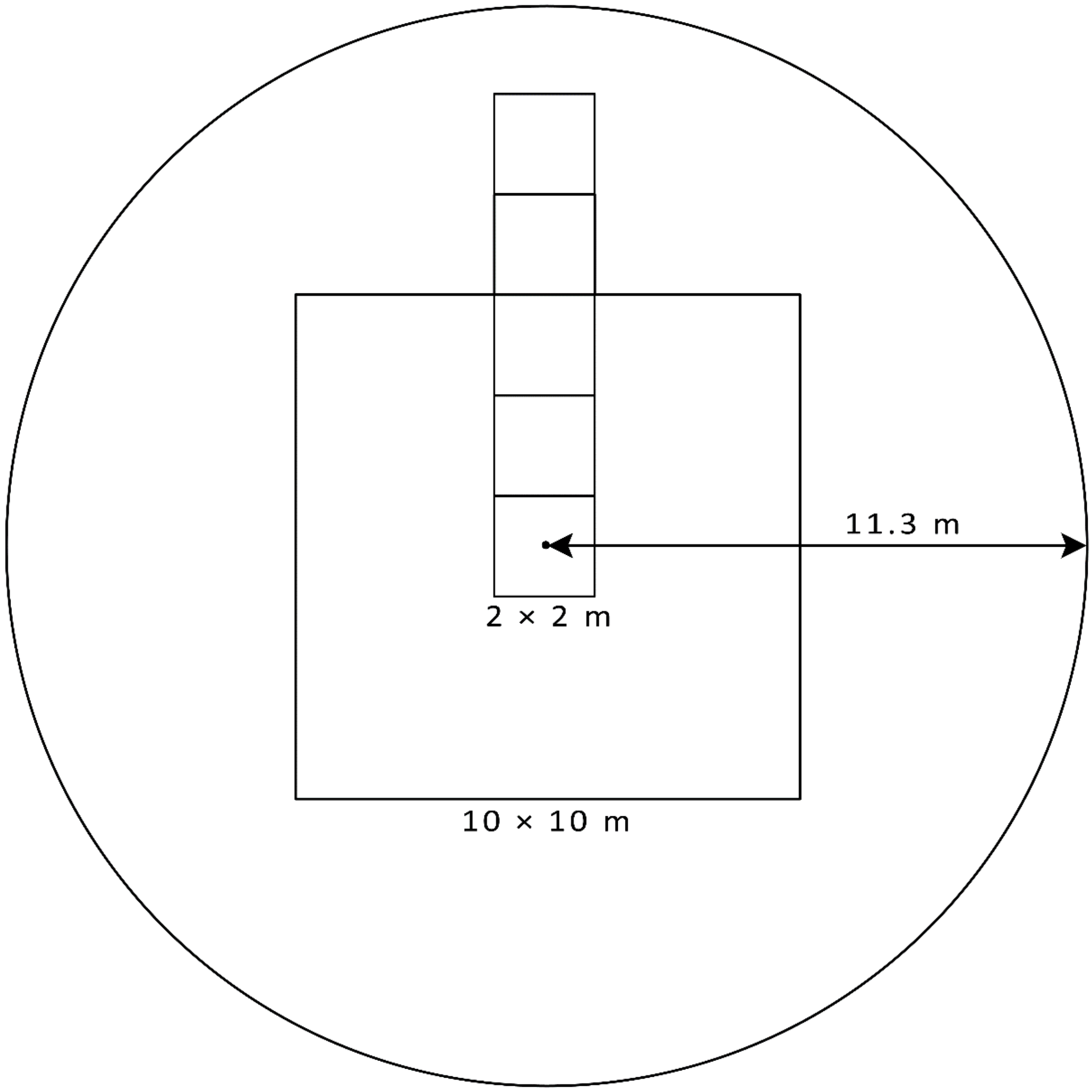

Figure 1. Suggested plot layout for monitoring the legacy effects of pine invasion, consisting of 2 × 2-m plots nested within a 10 × 10-m plot (centred on a randomly selected *Pinus contorta*) in which vegetation cover is measured, and a 11.3-m radius circular plot in which the density of *P. contorta* is measured.

7 Recommendations

At least 30 recently killed *Pinus contorta* trees, should be randomly chosen from areas of <25% pine cover at Rangitaiki Conservation Area and Otangimoana Stewardship Area, and permanent monitoring plots established at these trees. Monitoring plots should also be established at 10 random locations (or existing monitoring plots if these are suitable) to provide a baseline against which data from other plots can be compared.

The cover of all vascular plants and common lichens and bryophytes should be estimated in standard height tiers (<0.3 m, 0.3–2 m, 2–5 m, 5–12 m) in 2 × 2-m plots nested within 10 × 10-m plots, and the number and height of *P. contorta* plants within 11.3 m of the focal *P. contorta* plant counted. Non-treatment plots should consist of a single 2 × 2-m plot nested within 10 × 10-m and circular plots.

Soil samples should be collected from each 2× 2-m plot and analysed for bulk density and C, N, P and K.

The plots should be remeasured annualy or biennialy, at the same time of year, at least three times. The frequency of subsequent measurements could then be reassessed based on the measured rates of change in soil and plant parameters.

8 Acknowledgements

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9 References

Delich A 2020. Changes in extent of Bay of Plenty frost flats: 2003–2017. NSES Ltd report 5:2019/20 for Bay of Plenty Regional Council, Nicholas Singers Ecological Solutions.

Dickie IA, St John MG, Yeates GW, Morse CW, Bonner KI, Orwin K, Peltzer DA 2014. Belowground legacies of *Pinus contorta* invasion and removal result in multiple mechanisms of invasional meltdown. Aob Plants 6. doi: 10.1093/aobpla/plu056

Fitzgerald N. Mason N, Smale M 2019. Changes in Bay of Plenty frost flat heathland, 2012–2018. Manaaki Whenua – Landcare Research Contract Report LC3411 for Bay of Plenty Regional Council.

Holdaway RJ, Wiser SK, Williams PA 2012. Status assessment of New Zealand's naturally uncommon ecosystems. Conservation Biology 26: 619–629. doi: 10.1111/j.1523-1739.2012.01868.x

Hurst JM, Allen RB 2007. The RECCE method for describing New Zealand vegetation – Expanded manual. Version 4. Landcare Research Contract Report LC0708/029 for Department of Conservation.

McGregor, K.F.; Watt, M.S.; Hulme, P.E.; Duncan, R.P. 2012. What determines pine naturalization: species traits, climate suitability or forestry use? Diversity and Distributions 18: 1013-1023. doi: 10.1111/j.1472-4642.2012.00942.x

Peltzer D 2018. Ecology and consequences of invasion by non-native (wilding) conifers in New Zealand. New Zealand Journal of Grasslands 80: 39–46.

Peralta, G.; Dickie, I.A.; Yeates, G.W.; Peltzer, D.A. 2020. Community- and trophic-level responses of soil nematodes to removal of a non-native tree at different stages of invasion. Plos One 15. doi: 10.1371/journal.pone.0227130

Richardson DM 1998. Forestry trees as invasive aliens. Conservation Biology 12: 18–26. doi: 10.1046/j.1523-1739.1998.96392.x

Richardson S, Easdale E, Wiser S 2015. Optimal plot size for vascular plant biodiversity monitoring. Landcare Research Contract Report LC2154 for Department of Conservation.

Smale M, Fitzgerald N 2012. Monitoring condition of frost flat heathlands, a rare ecosystem in the Bay of Plenty Region. Landcare Research Contract Report LC996 for Bay of Plenty Regional Council.

Smale M, Fitzgerald N 2015. Assessing condition of frost flat heathland at Waipunga, a critically threatened rare ecosystem in Hawke’s Bay Region. Envirolink Advice Grant: 1553-HBRC209. Landcare Research Contract Report LC2385 for Hawke's Bay Regional Council.

Smale M, Fitzgerald N 2018. Conservation significance of upper Ripia frost flat heathland, a critically threatened ecosystem in Hawke’s Bay. Envirolink Grant: 1837-HBRC232. Manaaki Whenua – Landcare Research Contract Report LC3132 for Hawke’s Bay Regional Council.

Smale M, Fitzgerald N, Bartlam S 2013. Monitoring condition of frost flat heathlands, a critically threatened rare ecosystem in the Waikato Region. Landcare Research Contract Report LC1628 for Waikato Regional Council.

Smale MC 1990. Ecology of *Dracophyllum subulatum* – dominant heathland on frost flats at Rangitaiki and Pureora, central North Island, New Zealand. New Zealand Journal of Botany 28: 225–248. doi: 10.1080/0028825x.1990.10412311

Smale MC, Fitzgerald NB, Richardson SJ 2011. Resilience to fire of *Dracophyllum subulatum* (Ericaceae) frost flat heathland, a rare ecosystem in central North Island, New Zealand. New Zealand Journal of Botany 49: 231–241. doi: 10.1080/0028825x.2010.526950

Wardle DA, Wiser SK, Allen RB, Doherty JE, Bonner KI, Williamson WM 2008. Aboveground and belowground effects of single-tree removals in New Zealand rain forest. Ecology 89: 1232–1245. doi: 10.1890/07-1543.1

Wardle P 1985a. New-Zealand timberlines. 3. A synthesis. New Zealand Journal of Botany 23: 235–261. doi: 10.1080/0028825X.1985.10425330

Wardle P 1985b. New Zealand timberlines. 1. Growth and survival of native and introduced tree species in the Craigieburn Range, Canterbury. New Zealand Journal of Botany 23: 219–234. doi: 10.1080/0028825x.1985.10425328

Yeates GW, Schipper LA, Smale MC 2004. Site condition, fertility gradients and soil biological activity in a New Zealand frost-flat heathland. Pedobiologia 48: 129–137. doi: 10.1016/j.pedobi.2003.10.003