Waikato Regional Council Technical Report 2015/11

Geothermal vegetation types of the Taupō Volcanic Zone

www.waikatoregion.govt.nz
ISSN 2230-4355 (Print)
ISSN 2230-4363 (Online)

Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato

Prepared by:
Mark C Smale, Neil B Fitzgerald
Landcare Research

For:
Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

November 2014

Document #: 3289638

Peer reviewed by:
Katherine Luketina Date February 2015

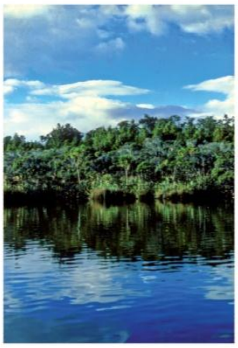
Approved for release by:
Dominique Noiton Date May 2015

Disclaimer

This technical report has been prepared for the use of Waikato Regional Council as a reference document and as such does not constitute Council's policy.

Council requests that if excerpts or inferences are drawn from this document for further use by individuals or organisations, due care should be taken to ensure that the appropriate context has been preserved, and is accurately reflected and referenced in any subsequent spoken or written communication.

While Waikato Regional Council has exercised all reasonable skill and care in controlling the contents of this report, Council accepts no liability in contract, tort or otherwise, for any loss, damage, injury or expense (whether direct, indirect or consequential) arising out of the provision of this information or its use by you or any other party.



Geothermal vegetation types of the Taupō Volcanic Zone

Landcare Research
Manaaki Whenua

Vegetation types of the Taupō Volcanic Zone

Mark C Smale, Neil B Fitzgerald

Landcare Research

Prepared for:

Waikato Regional Council[1], Bay of Plenty Regional Council[2]

[1]Private Bag 3038
Hamilton 3240

[2]5 Quay Street
PO Box 364
Whakatane 3158

August 2014

Landcare Research, Gate 10 Silverdale Road, University of Waikato Campus, Private Bag 3127, Hamilton 3240, New Zealand, Ph +64 7 859 3700, Fax +64 7 859 3701, www.landcareresearch.co.nz

Reviewed by:	Approved for release by:
Norman Mason Researcher Landcare Research	Peter Bellingham Portfolio Leader – Measuring Biodiversity Change Landcare Research

Landcare Research Contract Report:	LC1551

Contents

Summary

Project and Client

Stratified random sampling was undertaken in March–June 2012 for the Waikato and Bay of Plenty Regional Councils, in order to develop a robust, objective classification of geothermal vegetation types in the Taupō Volcanic Zone, and to understand the main environmental drivers of vegetation composition.

Objectives

The objectives of this report were:

- To develop a comprehensive classification of geothermal vegetation in the Taupō Volcanic Zone.
- To understand the main environmental drivers of geothermal vegetation compositional patterns in the Taupō Volcanic Zone.

Methods

- Geothermal vegetation was sampled in 177 plots of varying size at 38 sites on 15 geothermal fields in the Taupō Volcanic Zone. Sampling aimed to place 20 plots randomly in each of nine structural vegetation classes already identified and mapped.
- Within plots, cover of each species were estimated in fixed height tiers; this encompassed all vascular species present, including invasive weeds, and prominent bryophytes and lichens. Attributes such as slope, altitude, aspect, and human and introduced mammal impacts were recorded.
- Subsurface (10 cm depth) soil temperatures were recorded at eight systematic locations within each plot. Soil samples were also collected at these locations and bulked for analysis at plot level.
- Vegetation composition patterns were examined using classification and ordination. Plot data were classified using a fuzzy classification approach. Gradients in composition were derived using Detrended Correspondence Analysis ordination and related to soil physical (temperature, surface substrate texture) and chemical (fertility) parameters using correlation.

Results

Results from this study are outlined below:

- A total of 138 vascular plant species, including 58 adventives, was recorded in plots. Nineteen moss and nine liverwort species were recorded.
- Only seven native species were truly widespread (>20% of plots); only four adventive species were at all widespread (>5% of plots).

- Of 10 threatened species known to occur in geothermal areas, six were recorded from the plots. Apart from very widespread *Kunzea ericoides* var. *microflora*, none occurred in more than 10 plots.
- Subsurface (10 cm depth) soil temperatures ranged from ambient (7 °C) to near-boiling (98.5 °C) and, on average, were nearly 18 °C above ambient.
- Soil chemistry varied considerably amongst plots, and to some extent, localities. On average, soils were strongly acidic, with moderate levels of organic carbon and Olsen phosphorus and moderate cation exchange capacity, but low base saturation and low levels of total nitrogen, calcium, magnesium, potassium and sodium. Most had high levels of aluminium and sulphur.
- Classification identified 16 vegetation types (termed 'associations') in 8 structural classes (tow mossfield, one grassland, three fernland, four shrubland, three scrub, one treefernland, one treeland, and one forest), all but one dominated by indigenous species and 14 of them unique to geothermal fields.
- A substantial number of plots (33) were outliers, i.e. did not conform to any of the associations. A relatively high proportion of these were in urban or peri-urban areas with high weed pressure.
- Over half the associations were recorded on only one or two geothermal fields, and none on all of them.
- Subsurface (10 cm depth) soil temperature was the main factor related to vegetation composition. Vegetation composition was secondarily related to soil chemical factors: base saturation, cation exchange capacity, pH, total nitrogen, organic carbon and aluminium levels.
- Although a large proportion of geothermal vegetation types in earlier classifications do not have equivalent types in our classification, our types cover most (95%) of the mapped geothermal vegetation in the Taupō Volcanic Zone.
- Two associations – *Leptospermum–Leucopogon–Kunzea* shrubland and *Kunzea*/(*Coprosma–Leucopogon–Leptecophylla*) treeland – of limited occurrence on slightly warm to warm ground at geothermal sites are clearly threatened by weed invasion.
- Three associations – *Hypolepis ambigua* fernland, *Hypolepis distans* fernland, and *Leptospermum* successional shrubland – occurring on slightly warm ground at geothermal sites are potentially threatened by weed invasion.

Conclusions

- Geothermal vegetation in the Taupō Volcanic Zone is floristically simple, dominated by a very small suite of species. Apart from *Kunzea ericoides* var. *microflora* and *Campylopus pyriformis*, the most common species are typically widespread in mesic habitats. Although geothermal vegetation is renowned for its unusual fern species that are largely confined to geothermal sites in New Zealand, they contribute minimally to vegetation cover and are very local in occurrence.
- This study generalises site-specific results from earlier studies at Te Kopia and Wairakei geothermal fields.

  - A range of communities mostly unique to geothermal fields occurs across the spectrum of soil temperatures present, most of them – including two that are widespread beyond them – on the extensive slightly heated soils surrounding geothermal features, with a small number on the smaller areas of markedly heated soils.
  - Geothermally-influenced vegetation and soils occur across stress gradients that extend well beyond active geothermal features.
  - Soil temperature is the over-riding factor related to vegetation composition on geothermal sites in the Taupō Volcanic Zone.
- There appear to be distinct regional patterns, with some associations – for example, *Leucopogon* scrub in the northern part of the zone – more common or apparently restricted to parts of the Taupō Volcanic Zone, and others – for example, *Kunzea*/*Campylopus* shrubland at Wairakei – apparently restricted to one geothermal field.
- The relatively large number of unclassified samples reflects both the highly dynamic nature of geothermal environments in space and time and the prevalence of weed invasion at urban and peri-urban sites, strongly influenced by proximity to seed sources.
- Geothermal vegetation on slightly warm to warm ground (above ambient but <30 °C) appears to be particularly susceptible to weed invasion, particularly in urban and peri-urban areas where weed pressure is high.
- The similar canopy appearance of the three main shrubland species may make problematic the mapping of shrubland associations from aerial imagery.

Recommendations

- This classification covers the vast majority of geothermal vegetation in the Taupō Volcanic Zone and because it is based on rigorous quantitative sampling, should be used for all future assessment and monitoring of geothermal sites in it.
- Whether this classification can be mapped from aerial imagery remains to be explored.
- Future plots in geothermal vegetation should be sampled in a manner consistent with the methods used here and assigned to the classes defined here. Plot size should not vary by more than four-fold; alternatively, nested designs can be used.
- Active weed control is necessary to maintain the integrity of geothermal vegetation on slightly warm to warm ground in urban or peri-urban areas where weed pressure is high. Ten sites on five geothermal fields have significant weed problems, six (Arawa Park Racecourse, Arikikapakapa Golf Course, Cemetery Reserve, Kuirau Park, Old Government Gardens, Whakarewarewa) of them in Rotorua City. The others are Parimahana Scenic Reserve (Kawerau), Karapiti (Wairakei), Tikorangi North (Tikorangi), and Waiotapu Thermal Wonderland (Waiotapu).
- Distinctive geothermal vegetation occurs across a wide range of soil temperatures, so protection and management should ensure that the full gradients of composition and environment are protected and managed to prevent their degradation.

1 Introduction and background

A recent re-survey of all significant geothermal vegetation in the Bay of Plenty Region by Landcare Research New Zealand for Bay of Plenty Regional Council (Fitzgerald & Smale 2010) highlighted theoretical and practical deficiencies inherent in the two existing broad-scale classifications of geothermal vegetation, a broad one (Merrett & Clarkson 1999) that defined 15 vegetation types, and a much more detailed one (Wildland Consultants 2005) that defined over 200 vegetation types. Both were based on rapid qualitative inventory and subjective definition of types rather than quantitative sampling and derivation of types using a repeatable, quantitatively-based approach.

The broader classification (Merrett & Clarkson 1999) was based on a less-than-comprehensive sample of geothermal sites, and may have missed some locally or regionally important vegetation types. The more detailed one (Wildland Consultants 2005) is cumbersome and rather unwieldy in use for vegetation typing in the field. There was also a genuine basis for doubt about the validity of at least some of such a large number (>200) of individual vegetation types. There have also been classifications of geothermal vegetation at particular sites: Karapiti/Craters of the Moon (Given 1980) and Te Kopia (Burns 1997). Both sites were included in the present survey.

The current classifications did not provide an overview of the geothermal vegetation of the Taupō Volcanic Zone, and did not allow ready comparisons to be drawn between the vegetation on different geothermal fields in different parts of the region. This is necessary for priorities to be set for conservation and for allocation of management resources amongst geothermal sites.

The adoption of recently developed quantitative approaches to extending existing classification (De Cáceres et al. 2010) will allow plots in new locations to be assigned readily to the types defined here, or used to define new types. This approach integrates the classification with ongoing efforts by Landcare Research and the Department of Conservation to derive a quantitative, plot-based vegetation classification at the national scale. Finally, the underpinning quantitative plot data can be used to derive indicators of vegetation condition (e.g. frequency of threatened species, presence of regeneration of dominant species.

2 Methods

2.1 Sampling

Stratified random sampling of geothermal vegetation was undertaken in March–June 2012 for the Waikato and Bay of Plenty Regional Councils in order to develop a robust objective classification of geothermal vegetation types in the Taupō Volcanic Zone and understand the main environmental drivers of vegetation composition.

Recent mapping of geothermal vegetation in the Waikato (Wildland Consultants 2011) and Bay of Plenty (Fitzgerald & Smale 2010) regions was used as the basis of stratification into nine structural classes: soilfield, mossfield, grassland, fernland, shrubland, scrub, treefernland, treeland, and forest (Atkinson 1985). Within each structural class, random locations were generated for potential plot sampling (Appendix 2). Sampling aimed to place 20 plots in each of the nine structural classes. Thirteen known geothermal sites were excluded from the outset because of physical inaccessibility, access restrictions, small size, wetland nature, or commercial development having obliterated natural vegetation (Appendix 3).

A GPS device was used to locate the pre-selected points. If it was not safe to sample the vegetation at this point, vegetation was sampled at the nearest safe location (using randomly allocated cardinal bearings and fixed distances of multiples of 5 m). After random plot sampling was completed at a site, any vegetation types that were undersampled owing to their rarity (e.g. mossfield) were sampled. Across all sites, 14 such subjective plots were sampled. Two plots at two sites (Karapiti/Craters of the Moon, Waimangu) were not sampled because the vegetation in them lacked any geothermal character. Sample sites are mapped in Figure 1. Geothermal vegetation at another site, Waikite Valley, was much more limited in extent than indicated in the information available, being restricted essentially to heated streamsides, so the site was abandoned.

Varying plot sizes were used, reflecting vegetation stature, and ranging from 1×1-m in soilfield, through 2×2-m in short shrubland and scrub, and 5×5-m in taller shrubland and scrub, to 10×10-m in forest.

Within each plot we recorded (Hurst & Allen 2007):

- Observed structural class.
- Whether it occurred in an urban (i.e. within an urban area), peri-urban (i.e. on the edge of an urban area), or rural area.
- Species abundance in seven fixed height tiers (0–30 cm; >30 cm–2 m; >2 m–5 m; >5 m–12 m; >12 m–25 m; >25 m; epiphyte) using a modified Braun-Blanquet cover-abundance scale (1 = <1%, 2 = 1–5%, 3 = 6–25%, 4 = >26–50%, 5 = >51–75%, 6 = >76–100%; Hurst & Allen 2007).
- All vascular species present, including invasive weeds, bryophytes and lichens.
- Physiography, elevation, slope, aspect and drainage.
- Subsurface soil temperature at 10 cm depth at eight systematically-placed locations. In a small number of instances, for example silica terraces, substrates were too impenetrable for soil temperatures to be measured.
- Human impact, e.g. trampling, deposition of rubbish.
- Introduced mammal impact (including the presence of faecal pellets and trampling) and presence and degree (low, medium, high) of browsing impacts by plant and herbivore species.

Soil samples to 10 cm depth were collected at the same eight systematic locations within each plot and bulked for later analysis.

2.2 Data analysis

Before classification and ordination cover scores within each height tier were converted to the midpoint of the percentage cover range for that cover class, and summed across tiers (e.g. Wiser et al. 2002). This generated an importance value reflecting the volume occupied by each species rather than its projected cover.

The fuzzy classification framework of Noise Clustering was used to classify the vegetation plot data. This framework has three distinct advantages. First, it allows a new classification to be directly integrated with previous classifications that used the framework. Second, it allows plot records that are compositional outliers to be recognized using quantitative criteria (De Cáceres et al. 2010). Third it allows plots that are transitional in composition between defined types (e.g. those occurring on ecotones) to be recognised.

Resemblance between plots was defined using the Chord distance (Orlóci 1967). As a first step, this framework was used to determine whether any of the geothermal vegetation plots were sufficiently similar to woody vegetation associations defined by Wiser et al. (2011, 2013) to be classed as such. All plots were then classified that could not be assigned to the previously defined alliances in such a way that the newly defined types would be as distinct as possible from them. A minimum of 2 plots were reuired to define a vegetation type. Those plots that were too dissimilar from others in the datasets to be included in a set that defined a vegetation type were designated as 'outliers'.

Once vegetation types (here termed 'associations') were defined, they were named based on their dominant species. Dominant species were defined for inclusion in the name by ranking the species in the association according to their relative constancy (% frequency in the type) and relative cover. Species were only listed in name if constancy >85%; if there were more than five species with constancy over 85%, only the top 6 were listed. A '/' indicates the species occur in different tiers (working from the top tier down); '–' indicates they occur in the same tier. Within a tier species are ordered by decreasing constancy. The prefix 'GEO' before the code means it is a new association that has been defined only for geothermal areas. The prefix 'a:' means the association has been defined at the national level by Wiser & De Cáceres (2012). Vegetation types were allocated to structural classes following Atkinson (1985).

To understand how vegetation composition related to environment, gradients in composition were derived using Detrended Correspondence Analysis ordination. Spearman rank correlation was then used to determine whether plot positions along these gradients were related to soil physical (temperature, surface substrate texture) and chemical (fertility) characteristics.

Threat rankings were assigned to associations based on:

- Extent of occurrence across geothermal fields
- Occurrence within protected natural areas
- Occurrence only on cool or slightly heated soils (which are susceptible to weed invasion).

2.3 Soil analysis

Soil samples were analysed for pH, electrical conductivity, cation exchange capacity (CEC), organic carbon, total nitrogen, Olsen phosphorus, exchangeable bases (calcium, magnesium, sodium, potassium) and water-soluble sulphate following the procedures of Blakemore et al. (1987) and calcium chloride-extractable aluminium following Hoyt & Nyborg (1972). Parameter values were rated according to Blakemore et al. (1987).

Subsurface (10 cm depth) soil temperatures were averaged for each plot and the means compared with ambient long-term soil temperatures (10 cm depth) for the same month (New Zealand Meteorological Service 1973) from the nearest climate station (Edgecumbe, Rotorua, Taupō, Wairakei).

3 Results

3.1 Soil chemistry

Soil chemical fertility varied considerably among plots and to some extent, localities. On average, soils were strongly acidic (mean pH 4.3), with moderate levels of organic carbon (7.2 %) and Olsen phosphorus (the best measure of plant-available phosphorus: 25 mg/kg) and moderate cation exchange capacity (CEC: 19.9 cmol/kg), but low base saturation (BS: 24.3 %) and low levels of total nitrogen (0.3%), calcium (2.5 cmol/kg), magnesium (0.6 cmol/kg), potassium (0.5 cmol/kg) and sodium (0.3 cmol/kg). They also had, on average, extremely high levels of aluminium (77 mg/kg) and sulphur (2347 mg/kg). Full soil chemical analyses are presented in Appendix 4.

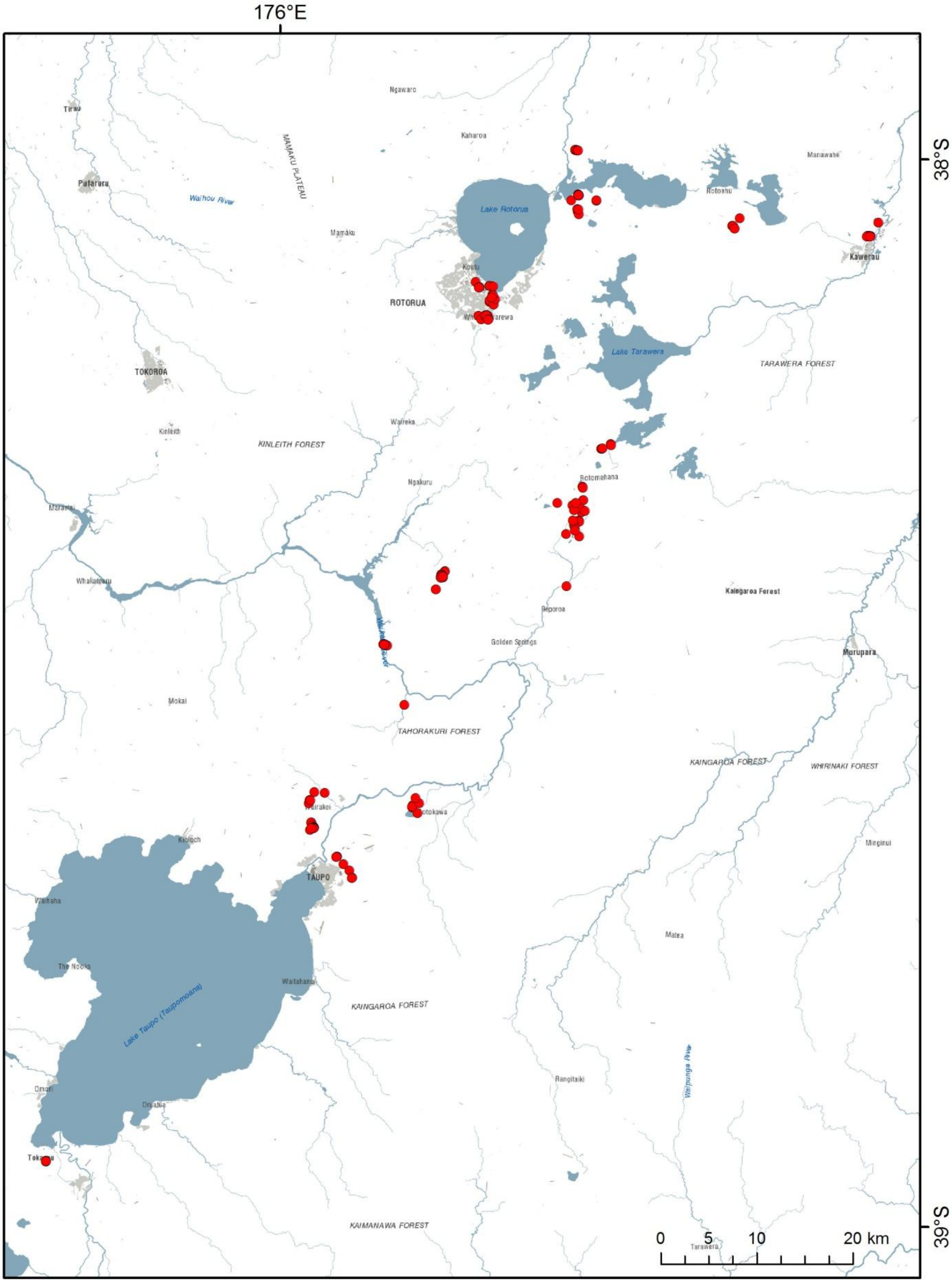


Figure 1 Geothermal sites sampled in the Taupō Volcanic Zone.

3.2 Subsurface soil temperature

Mean soil temperatures in plots ranged from ambient (lowest, 7 °C) to near-boiling (highest, 98.5°C). Most fell in the ambient to slightly heated range of <20 °C (Table 1) and on average, were 17.8°C above ambient temperatures.

Table 1 Soil temperature (10 cm depth) classes in 165 random plots in geothermal vegetation across the Taupō Volcanic Zone

Temperature	Thermal range (°C)	Number of plots
Cool (ambient) or slightly heated	<20	66
Warm	20–30	53
Hot	30–60	35
Very hot	>60	11

3.3 Flora

A total of 138 vascular plant species were recorded in plots, comprising 80 native and 58 adventive species (Appendix 5). A total of 28 bryophyte species were recorded, comprising 19 moss and nine liverwort species (Appendix 6). Only seven native species were truly widespread, occurring in more than 20% of plots (Table 2). The three shrubby species, prostrate kānuka, mingimingi, and mānuka, are all sclerophyllous and typical of heathlands on infertile soils across the country (Burrows et al. 1979).

Table 2 The most widespread native species (occurring in more than 20% of plots) in geothermal vegetation in the Taupō Volcanic Zone

Species	Frequency of occurrence (% of plots)	Mean cover (%)
Kunzea ericoides var. *microflora*[1]	57	44
Leucopogon fasciculatus	52	25
Dianella nigra	39	3
Pteridium esculentum	28	4
Campylopus pyriformis	25	6
Leptospermum scoparium	25	8
Chiloscyphus novae-zelandiae	22	2

[1]Since this project was undertaken, the genus *Kunzea* has been revised for New Zealand by de Lange (2014). Prostrate kānuka (*K. ericoides* var. *microflora*) has been raised to species level as *K. tenuicaulis,* and a number of new species described within the earlier broad concept of kānuka (*K. ericoides*), more than one of which occurs on or near geothermal fields.

Six threatened species (http://www.doc.govt.nz/publications/conservation/nz-threat-classification-system/nz-threat-classfication-system-lists-2012-14) were recorded during sampling, one of which – prostrate kānuka (*Kunzea ericoides* var. *microflora*) (Declining), – was the most widely occurring species of all and the biggest single contributor to vegetation cover. In contrast, the remaining species – *Nephrolepis flexuosa* (Declining), *Cyclosorus interruptus*, *Dicranopteris linearis*, *Hypolepis dicksonioides*, and *Schizaea dichotoma* (all Naturally Uncommon) – occurred very locally and contributed minimally to vegetation cover. Only one, *Dicranopteris linearis*, was locally abundant and then only at two sites, Te Kopia and Orakei-Korako. *Cyclosorus interruptus* and *Hypolepis dicksonioides* (giant hypolepis) were recorded only from Spa/Otumuheke Stream in Taupō, and *Nephrolepis flexuosa* (thermal ladder fern) from only one random plot at Karapiti/Craters of the Moon.

Four adventive species were widespread, occurring in more than 5% of plots (Table 3).

Table 3 The most widespread adventive species (occurring in more than 5% of plots) in geothermal vegetation in the Taupō Volcanic Zone

Species	Frequency of occurrence (% of plots)	Mean cover (%)
Rubus fruticosus	14	2
Axonopus fissifolius	7	<1
Prunus serrulata	6	<1
Agrostis capillaris	6	<1

Half of the 54 adventive species recorded are regarded as 'environmental weeds' (Clayson 2008), but only three of these species, *Rubus fruticosus* (blackberry), *Prunus serrulata* (Japanese hill cherry), and browntop (*Agrostis capillaris*), were at all widespread. On average, individual species occur on only two of the 15 geothermal fields sampled (Appendix 7).

3.4 Vegetation classification

Stratification using existing mapping proved problematic because the structural classes observed at sampling points were not necessarily the same as those indicated by mapping (Table 4). Only in the case of bare ground (soilfield) was mapping entirely accurate. Over one-third of plots fell in the shrubland class (Table 5), a reflection of the discord between mapped and actual vegetation classes and the overwhelming predominance (80% in existing mapping) of shrubland in geothermal vegetation. To some extent, this may also reflect differences of scale between mapped vegetation (1:5000) and sample plots.

Table 4 Relationships between mapped and actual vegetation structural classes encountered (number of plots) in geothermal vegetation in the Taupō Volcanic Zone. Shading indicates those situations where the two matched

	Actual									
Mapped	Soilfield	Mossfield	Grassland	Sedgeland	Fernland	Shrubland	Scrub	Treefernland	Treeland	Forest
Soilfield	8					5	5	1		
Mossfield		0				18	2			
Grassland			6		1	2	1			
Fernland				1	9	8	1		1	
Shrubland					1	9	5	2		
Scrub			1			6	7	2		1
Treefernland		1			12		3	3		1
Treeland		2	3		1	7	2		4	1
Forest						8	1		7	3

Table 5 Actual vegetation structural classes of 168 random plots in geothermal vegetation across the Taupō Volcanic Zone. The remaining plots had no vegetation

Vegetation class	Number of plots	Percentage of plots
Soilfield	12	7
Mossfield	3	2
Grassland	11	7
Sedgeland	1	1
Fernland	23	14
Shrubland	64	38
Scrub	26	16
Treefernland	6	4
Treeland	16	10
Forest	6	4

Classification of the 155 plots (random and subjective) having both vegetation and soil samples identified 16 vegetation types (associations) in eight structural classes (Table 6), all but one of them – *Axonopus fissifolius* grassland – dominated by native species. The definitions of the associations were based on 118 plots; four plots were transitional between two or more defined associations. They comprise two mossfield associations dominated by *Campylopus* species,three fernland associations dominated by *Hypolepis* species or *Lycopodiella cernua*, one grassland association dominated by *Axonopus fissifolius*, one treefernland association dominated by *Dicksonia squarrosa*, four shrubland associations dominated by *Leptospermum scoparium* or *Kunzea ericoides* var. *microflora*, t scrub associations dominated by *Kunzea ericoides* var. *microflora* or *Leucopogon fasciculatus*, one treeland association dominated by *Kunzea ericoides*, and one forest association dominated by *Weinmannia racemosa*. Of these, two – *Leptospermum scoparium* successional shrubland and *Kunzea ericoides*/(*Coprosma–Leucopogon– Leptecophylla*) treeland (termed 'shrubland' in Wiser et al. 2013) – are sufficiently widespread in non-geothermal habitats to have been described in the national-scale plot-based classification of woody vegetation of Wiser et al. (2011, 2013).

Thirty-three plots did not fall within any association (from here referred to as 'outliers'), and a further four were transitional in composition between two or more defined associations. On average, the outlier plots occurred on significantly cooler ground than the plots classified into associations (mean soil temperature = 21 °C versus 32 °C, respectively). A higher proportion of them were in urban or peri-urban areas (38% for outliers versus 24% for classified plots).

Most associations appear to be of relatively restricted occurrence, over half recorded on only one or two geothermal fields in the Taupō Volcanic Zone and none recorded on all of them (Table 7).

Table 6 Vegetation associations of the Taupō Volcanic Zone. Codes beginning with 'GEO' are for associations defined in this project only. Those beginning with 'a' have been defined at the national level in the shrubland classification of Wiser & De Cáceres (2013) and follow the presentation at http://www.landcareresearch.co.nz/publications/factsheets/woody-types/shrublands/list-alliances

Code	Name
GEOm1	*Campylopus pyriformis* mossfield
GEOm2	*Campylopus introflexus* mossfield
GEOg1	*Axonopus fissifolius* grassland
GEOfe1	*Hypolepis ambigua* fernland
GEOfe2	*Hypolepis distans* fernland
GEOfe3	*Kunzea ericoides* var. *microflora*/*Lycopodiella cernua* fernland
a: S1	*Leptospermum scoparium* successional shrubland
GEOsh1	*Leptospermum scoparium–Leucopogon fasciculatus–Kunzea ericoides* var. *microflora/Pteridium esculentum–Dianella nigra–Paesia scaberula* shrubland
GEOsh2	*Kunzea ericoides* var. *microflora–Leucopogon fasciculatus* shrubland
GEOsh3	*Kunzea ericoides* var. *microflora*/*Campylopus pyriformis* shrubland
GEOsc1	*Kunzea ericoides* var. *microflora* scrub
GEOsc2	*Leucopogon fasciculatus* scrub
GEOsc3	*Leucopogon fasciculatus–Kunzea ericoides* var. *microflora*/*Dianella nigra* scrub
GEOtf1	*Dicksonia squarrosa*/*Dianella nigra* treefernland
a: S5	*Kunzea ericoides*/(*Coprosma rhamnoides–Leucopogon fasciculatus–Leptecophylla juniperina*) treeland
GEOf1	*Weinmannia racemosa*/*Leucopogon fasciculatus–Pteridium esculentum–Leptecophylla juniperina*/*Telaranea* species–*Leucobryum javense* forest

Table 7 Distribution of vegetation associations across 15 geothermal fields in the Taupō Volcanic Zone. Y indicates recorded during sampling. Absence of a record does not necessarily imply absence, but means the association – if present – is probably insignificant on the field

	Geothermal field														
Association	**Waimangu**	**Taheke**	**Tikitere**	**Tauhara**	**Rotorua**	**Waiotapu**	**Wairakei**	**Kawerau**	**Te Kopia**	**Tikorangi**	**Reporoa**	**Orakei-Korako**	**Rotokawa**	**Waihi-Tokaanu**	**Ngatamariki**
GEOm1: *Campylopus pyriformis* mossfield		Y					Y								
GEOm2: *Campylopus introflexus* mossfield	Y														
GEOg1: *Axonopus* grassland			Y		Y		Y								
GEOfe1: *Hypolepis ambigua* fernland			Y						Y						
GEOfe2: *Hypolepis distans* fernland		Y	Y		Y										
GEOfe3: *Kunzea/Lycopodiella* fernland				Y			Y								
a: S1: *Leptospermum* successional shrubland					Y	Y									
GEOsh1: *Leptospermum–Leucopogon–Kunzea/Pteridium–Dianella–Paesia* shrubland						Y									
GEOsh2: *Kunzea–Leucopogon* shrubland		Y	Y		Y	Y		Y	Y						
GEOsh3: *Kunzea/Campylopus* shrubland							Y								
GEOsc1: *Kunzea* scrub	Y			Y		Y		Y				Y	Y		
GEOsc2: *Leucopogon* scrub		Y	Y		Y		Y				Y				
GEOsc3: *Leucopogon–Kunzea/Dianella* scrub						Y		Y	Y	Y		Y			
GEOtf1: *Dicksonia/Dianella* treefernland		Y				Y						Y			
S5: *Kunzea/(Coprosma–Leucopogon–Leptecophylla)* treeland								Y							
GEOf1: *Weinmannia/Leucopogon–Pteridium–Leptecophylla/Telaranea–Leucobryum* forest									Y						
Unclassified outliers		Y		Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y

Full descriptions ordered by vegetation structural types are as follows:

GEOm1: *Campylopus pyriformis* mossfield

Structure and composition: Very short mossfield (mean height 0.05 m), dominated entirely by *Campylopus pyriformis*. A floristically poor association, with no other species present.

Habitat: Very hot (mean temperature 72 °C) ground on geothermal sites.

Distribution: Taheke, Wairakei (Karapiti/Craters of the Moon). Also recorded at Karapiti/Craters of the Moon by Given (1980).

Threat status: Not threatened. Despite its apparently restricted occurrence, this association is not threatened because of its occurrence on very hot ground and in at least one protected natural area.

GEOm2: *Campylopus introflexus* mossfield

Structure and composition: Very short (mean 0.03 m, range 0.03–0.04 m) mossfield, dominated by *Campylopus introflexus*. No other species are consistently present (i.e. in more than half the plots).

Habitat: Hot (mean temperature at 10 cm depth 44 °C) ground on geothermal sites.

Distribution: Waimangu.

Threat status: Not threatened. Despite its apparently restricted occurrence, this association is not threatened because of its occurrence on hot ground in a protected natural area.

GEOg1: *Axonopus fissifolius* grassland (*Axonopus* grassland)

Structure and composition: Short (mean 0.5 m, range 0.3–0.7 m) grassland, dominated by adventive *Axonopus fissifolius* (narrow-leaved carpet grass), with adventive *Agrostis capillaris* and the moss *Campylopus introflexus* also consistently present.

Habitat: Warm (26 °C) ground on the margins of geothermal sites.

Distribution: Tikitere (Papakiore Springs), Rotorua (Arawa Park Racecourse), Wairakei (Te Rautehuia Stream).

Threat status: Not applicable.

GEOfe1: *Hypolepis ambigua* fernland

Structure and composition: Tall (mean 2.1 m, range 1.4–6 m) fernland, dominated almost entirely by *Hypolepis ambigua.* No other species are consistently present, although *Histiopteris incisa* (water fern) and *Pteridium esculentum* (bracken) occur commonly.

Habitat: Warm (21 °C) ground on the margins of geothermal sites.

Distribution: Tikitere (Otutara Springs, Parengarenga Springs), Te Kopia.

Threat status: Despite its occurrence in at least one protected natural area, potentially threatened because of its occurrence on only warm ground.

GEOfe2: *Hypolepis distans* fernland

Structure and composition: Tall (mean 2.8 m, range 1–9 m) fernland, dominated almost entirely by *Hypolepis distans. Histiopteris incisa* (water fern) and *Pteridium esculentum* (bracken) are also consistently present.

Habitat: Warm (21 °C) ground on the margins of geothermal sites.

Distribution: Taheke, Tikitere (Parengarenga Springs), Rotorua (Cemetery Reserve, Whakarewarewa).

Threat status: Potentially threatened because of its occurrence on only warm ground and absence from formally protected natural areas.

GEOfe3: *Kunzea ericoides* var. *microflora*/*Lycopodiella cernua* fernland (*Kunzea*/*Lycopodiella* fernland)

Composition: Short (mean 0.6 m, range 0.2–1.3 m) fernland, dominated by *Lycopodiella cernua* (arching clubmoss), with scattered *Kunzea ericoides* var. *microflora* (prostrate kānuka) above it. No other species are consistently present. Threatened *Cyclosorus interruptus* occurs in this association at Spa/Otumuheke Stream.

Habitat: Very hot (68 °C) ground on geothermal sites.

Distribution: Wairakei (Karapiti/Craters of the Moon), Tauhara (Spa/Otumuheke Stream).

Threat status: Not threatened. Despite its apparently restricted occurrence, this association is not threatened because of its occurrence on very hot ground and in at least one protected natural area.

a: S1: *Leptospermum scoparium* successional shrubland (*Leptospermum* successional shrubland)

Structure and composition: Moderately tall (mean 3 m, range 0.3–6 m) shrubland, dominated by *Leptospermum scoparium* (mānuka). *Kunzea ericoides* var. *microflora* (prostrate kānuka), *Leucopogon fasciculatus* (mingimingi) and *Histiopteris incisa* (water fern) are consistently present.

Habitat: Warm (24 °C) ground on the margins of geothermal sites.

Distribution: Rotorua (Arawa Park Racecourse, Whakarewarewa), Waiotapu (Waiotapu North).

Nationally, this association has an estimated extent of 15 100 ha and has been recorded in scattered locations in both main islands. Sites range from flat to steeply sloping (50°). Altitudes range from just above sea level to 1020 m. On average, stands are 3 m tall, but may be up to 6 m tall. These shrublands have moderate numbers of species, with on average 18 species, but as few as 6 and as many as 57, recorded on a plot. Of these 9% are adventive, on average. See http://www.landcareresearch.co.nz/publications/factsheets/woody-types/shrublands/lepsco-shrubland/lepsco-successional-shrubland.

Threat status: Potentially threatened at geothermal sites because of its occurrence on only warm ground and absence from formally protected natural areas.

GEOsh1: *Leptospermum scoparium–Leucopogon fasciculatus–Kunzea ericoides* var. *microflora/Pteridium esculentum Dianella nigra–Paesia scaberula* shrubland (*Leptospermum–Leucopogon–Kunzea/Pteridium–Dianella–Paesia* shrubland)

Structure and composition: Tall (mean 9 m, range 6–19 m) shrubland, dominated by *Leptospermum scoparium* (mānuka), *Leucopogon fasciculatus* (mingimingi), *Kunzea ericoides* var. *microflora* (prostrate kānuka) and *Pteridium esculentum* (bracken), over a ground layer dominated by *Dianella nigra* (inkberry/turutu) and *Paesia scaberula* (ring fern). The adventive nitrogen fixing shrub *Cytisus scoparius* (broom) is consistently present.

Habitat: Slightly heated (17 °C) ground on the margins of geothermal sites.

Distribution: Waiotapu (Waiotapu Thermal Wonderland). Burns (1997) recorded a similar association at Te Kopia.

Threat status: Threatened, because it occurs on only slightly heated ground and is clearly susceptible to weed invasion.

GEOsh2: *Kunzea ericoides* var. *microflora–Leucopogon fasciculatus* shrubland (*Kunzea–Leucopogon* shrubland)

Composition: A variable association of widely varying height (mean 5 m, range 1–12 m) and structure (mostly shrubland, with some scrub, forest and treeland), dominated by *Kunzea ericoides* var. *microflora* (prostrate kānuka) and *Leucopogon fasciculatus* (mingimingi). *Dianella nigra* (inkberry/turutu) is consistently present in the ground layer.

Habitat: Warm (25 °C) ground on the margins of geothermal sites.

Distribution: Kawerau (Parimahana Scenic Reserve), Taheke, Tikitere (Hell's Gate), Rotorua (Ngapuna, Sulphur Point, Whakarewarewa), Waiotapu (Waiotapu North, Waiotapu Thermal Wonderland), Te Kopia. Also recorded at Te Kopia by Burns (1997).

Threat status: Not threatened. Despite its occurrence on only warm ground, this association is not threatened because of its occurrence in several protected natural areas and apparent resistance to weed invasion.

GEOsh3: *Kunzea ericoides* var. *microflora*/*Campylopus pyriformis* shrubland (*Kunzea/Campylopus* shrubland)

Structure and composition: Short (mean 0.4 m, range 0.2–1 m) shrubland, dominated by *Kunzea ericoides* var. *microflora* (prostrate kānuka) with a *Campylopus pyriformis* ground layer. No other species are consistently present, although *Lycopodiella cernua* (arching clubmoss) is moderately widespread in the ground layer.

Habitat: Hot (50 °C) ground on geothermal sites.

Distribution: Recorded only from Karapiti/Craters of the Moon.

Threat status: Not threatened. Despite its occurrence at only one geothermal field, it is protected from weed invasion by hot soil temperatures.

GEOsc1: *Kunzea ericoides* var. *microflora* scrub (*Kunzea* scrub)

Composition: Short (mean 1 m, range 0.6–2.3 m) scrub, dominated almost entirely by *Kunzea ericoides* var. *microflora* (prostrate kānuka). No other species are consistently present, although a range of bryophytes (*Chiloscyphus novae-zelandiae*, *Telaranea praenitens*, *Isopterygium* species) commonly occur. Threatened *Nephrolepis flexuosa* (thermal ladder fern) occurs in this association at Waimangu and Karapiti, and threatened *Dicranopteris linearis* at Crown Road.

Habitat: Hot (39 °C) ground on geothermal sites.

Distribution: Kawerau (Parimahana Extension), Waiotapu (Waiotapu Thermal Wonderland), Waimangu, Orakei-Korako, Rotokawa (Rotokawa North), Wairakei (Karapiti/Craters of the Moon, Wairoa Hill), Tauhara (Broadlands Road, Crown Road). Also recorded at Karapiti/Craters of the Moon by Given (1980) and at Te Kopia by Burns (1997).

Threat status: Not threatened because of its wide occurrence and on hot ground.

GEOsc2: *Leucopogon fasciculatus* scrub (*Leucopogon* scrub)

Composition: Moderately tall (mean 3 m, range 1–10 m) scrub and shrubland, dominated by *Leucopogon fasciculatus* (mingimingi). No other species are consistently present.

Habitat: Slightly heated (17 °C) ground on the margins of geothermal sites.

Distribution: Taheke, Tikitere (Hell's Gate, Papakiore Springs), Rotorua (Ngapuna, Kuirau Park, Whakarewarewa), Waiotapu (Waiotapu North), Reporoa (Longview Road).

Threat status: Not threatened. Despite its occurrence on only slightly heated ground close to weed sources at some sites, this association does not appear susceptible to weed invasion.

GEOsc3: *Leucopogon fasciculatus–Kunzea ericoides* var. *microflora/Dianella nigra* scrub (*Leucopogon–Kunzea/Dianella* scrub)

Composition: Tall (mean 5.5 m, range 2–9 m) scrub, dominated by *Leucopogon fasciculatus* (mingimingi) and *Kunzea ericoides* var. *microflora* (prostrate kānuka), with a ground layer dominated by *Dianella nigra* (inkberry/turutu). *Weinmannia racemosa* (kāmahi), *Myrsine australis* (māpou), and *Leptecophylla juniperina* (prickly heath) are also consistently present, along with bryophytes (*Chiloscyphus novae-zelandiae*, *Lepidozia* species, *Telaranea* species, and *Dicranoloma robustum*). Threatened *Dicranopteris linearis* occurs in this association at Te Kopia and Maungaongaonga, and threatened *Schizaea dichotoma* at Te Kopia and Rainbow Mountain.

Habitat: Warm (24 °C) ground on the margins of geothermal sites.

Distribution: Kawerau (Parimahana Scenic Reserve), Tikorangi (Tikorangi North), Waiotapu (Maungaongaonga, Rainbow Mountain/Maungakakaramea), Orakei-Korako, Te Kopia.

Threat status: Not threatened. Despite its occurrence on only warm ground, this association occurs mostly in locations remote from weed sources, some of them in protected natural areas.

GEOtf1: *Dicksonia squarrosa/Dianella nigra* treefernland (*Dicksonia/Dianella* treefernland)

Structure and composition: Short (mean 9 m, range 7–12 m) treefernland, dominated almost entirely by *Dicksonia squarrosa* (whekī), with a ground layer dominated by *Dianella nigra* (inkberry/turutu). *Weinmannia racemosa* (kāmahi), *Pseudopanax arboreus* (fivefinger), *Myrsine australis* (māpou) and *Leucopogon fasciculatus* (mingimingi) are also consistently present. Threatened *Dicranopteris linearis* occurs in this association at Orakei-Korako.

Habitat: Slightly heated (19 °C) ground on the margins of geothermal sites.

Distribution: Taheke, Waiotapu (Waiotapu North), Orakei-Korako.

Threat status: Not threatened. Despite its apparently restricted occurrence, this association is not threatened because of its occurrence in at least two protected natural areas and apparent resistance to weed invasion.

a: S5: *Kunzea ericoides/(Coprosma rhamnoides–Leucopogon fasciculatus–Leptecophylla juniperina)* treeland (*Kunzea/(Coprosma–Leucopogon–Leptecophylla*) treeland

Structure and composition: Short (mean 9 m, range 8–9 m) treeland, dominated by *Kunzea ericoides* (kānuka) with an understorey dominated by *Coprosma rhamnoides*, *Leucopogon fasciculatus* (mingimingi), and *Leptecophylla juniperina* (prickly heath). *Knightia excelsa* (rewarewa), *Myrsine australis* (māpou), *Coprosma lucida*, *Dianella nigra* (inkberry/turutu) and *Ptychomnion aciculare*, along with the adventive shrub *Cotoneaster glaucophyllus* (Khasia berry) and adventive tree *Prunus serrulata* (Japanese hill cherry), are consistently present.

Habitat: Warm (22 °C) ground on the margins of geothermal sites.

Distribution: Kawerau (Parimahana).

Nationally, this association – termed 'shrubland' in Wiser et al. (2013) – has an estimated extent of 68 000 ha and occurs in scattered locations in the northern half of the North Island and north of the Waitaki River in the South Island, mostly in the east or in Nelson–Marlborough. Altitudes range from 30 to 925 m. Sites can be flat or on slopes as steep as 60°. This shrubland association is, on average, 7 m tall but can range from 2 to 16 m. It tends to have moderate plant diversity with an average of 21 species on a plot but can reach 50. On average, 11% of species in this association are adventive. See http://www.landcareresearch.co.nz/publications/factsheets/woody-types/shrublands/kuneri-coprha-lepjun-shrubland/kuneri-coprha-leufas-lepjun-shrubland.

Threat status: Threatened at geothermal sites. Despite its wide occurrence beyond geothermal sites, it is significantly threatened by weed invasion at the one geothermal site where it has been recorded.

GEOf1: *Weinmannia racemosa/Leucopogon fasciculatus–Pteridium esculentum–Leptecophylla juniperina/Telaranea praenitens–Leucobryum javense* forest (*Weinmannia/Leucopogon–Pteridium–Leptecophylla/Telaranea–Leucobryum* forest)

Structure and composition: Short (mean 9 m, range 5–16 m) forest, dominated by *Weinmannia racemosa* (kāmahi), with an understorey dominated by *Leucopogon fasciculatus* (mingimingi), *Leptecophylla juniperina* (prickly heath) and *Pteridium esculentum* (bracken), and a ground layer dominated by bryophytes (especially *Telaranea praenitens* and *Leucobryum javense*). A range of other trees and shrubs – *Pseudopanax arboreus* (fivefinger), *Myrsine australis* (māpou), *Leptospermum scoparium* (mānuka), *Coprosma lucida*), megaherb (*Astelia solandri*), fern (Threatened *Dicranopteris linearis, Lycopodium deuterodensum*), and bryophyte (*Chiloscyphus novae-zelandiae, Ptychomnion aciculare*) species – are consistently present. Threatened *Schizaea dichotoma* also occurs in this type.

Habitat: Slightly heated (18 °C) ground on the margins of geothermal sites.

Distribution: Te Kopia. Also recorded at Te Kopia by Burns (1997).

Threat status: Not threatened. Despite its apparently restricted occurrence and on only slightly warm ground, this association is not threatened because of its occurrence in a protected natural area remote from weed seed sources.

Compositional outliers (unclassified plots) were distributed widely across the Kawerau (Parimahana Scenic Reserve), Tikorangi (Tikorangi South), Taheke, Tikitere (Parengarenga Springs), Rotorua (Old Government Gardens, Kuirau Park, Arikikapakapa Golf Course, Cemetery Reserve, Whakarewarewa), Waiotapu (Ngapouri, Rainbow Mountain/Maungakakaramea), Te Kopia, Orakei-Korako, Ngatamariki, Rotokawa (Lake Rotokawa), Tauhara (Spa/Otumuheke Stream), Wairakei (Wairoa Hill) and Waihi-Tokaanu (Tokaanu Thermal Park) geothermal fields.

The distributions listed for associations are not comprehensive, because we did not comprehensively sample any individual site. For example, Burns (1997) recorded two associations at Te Kopia in addition to those we recorded. Thus the absence of a geothermal field from a distribution list does not necessarily mean an actual absence, but it does mean that it is unlikely to be important there.

3.5 Relationships between vegetation and environment

The DCA ordination showed that compositional patterns largely reflect a single dominant vegetation gradient (Figs. 2, 3). This gradient is strongly related to a complex gradient reflecting changes in both soil temperature (Fig. 2, Table 8) and soil chemistry (Fig. 2, Table 8). Soil temperature, pH and base saturation decrease as one moves from left to right along the compositional gradient and aluminium, cation exchange capacity, total nitrogen and organic carbon increase. Litter cover is lower and boulders more prevalent on cooler soils as well. A secondary compositional gradient reflects the link between vegetation, soil temperature and litter cover. Species such as lichens, *Lycopodiella cernua*, *Campylopus pyriformis*, *Kunzea ericoides* var. *microflora* and *Campylopus introflexus* tend to occur at the warmer end of this gradient, whereas species such as *Pteridium esculentum*, *Histiopteris incisa*, *Dicksonia squarrosa*, *Pseudopanax arboreus*, *Rubus fruticosus*, *Coprosma lucida* and *Kunzea ericoides* tend to occur at the cooler end of this gradient (Fig. 2). Overlaying the association identities with the ordination shows how each association is restricted to a relatively small portion of this gradient (Fig. 3). The degree to which this reflects soil temperature is illustrated in Figure 4. Shorter associations dominated by mosses and by geothermal endemics (*Campylopus pyriformis*, *Kunzea ericoides* var. *microflora*) occur on the left side of the plot ordination (Fig. 3) and taller associations dominated by mesic species such as *Weinmannia racemosa* and *Dicksonia squarrosa* on the right side. The exceptions to this stature pattern are short fernland associations dominated by *Hypolepis ambigua* and *H. distans* on the right side of the ordination. Associations in which *Leucopogon fasciculatus* is prominent occur in the centre of the ordination.

Adventive species occur across the entire compositional gradient, but are most diverse on the end of the compositional gradient corresponding to cooler sites with higher total nitrogen and organic carbon (Figure 5). Threatened species also occur across the entire compositional gradient and, as a group, are not restricted to a small subset of the associations (Figure 6).

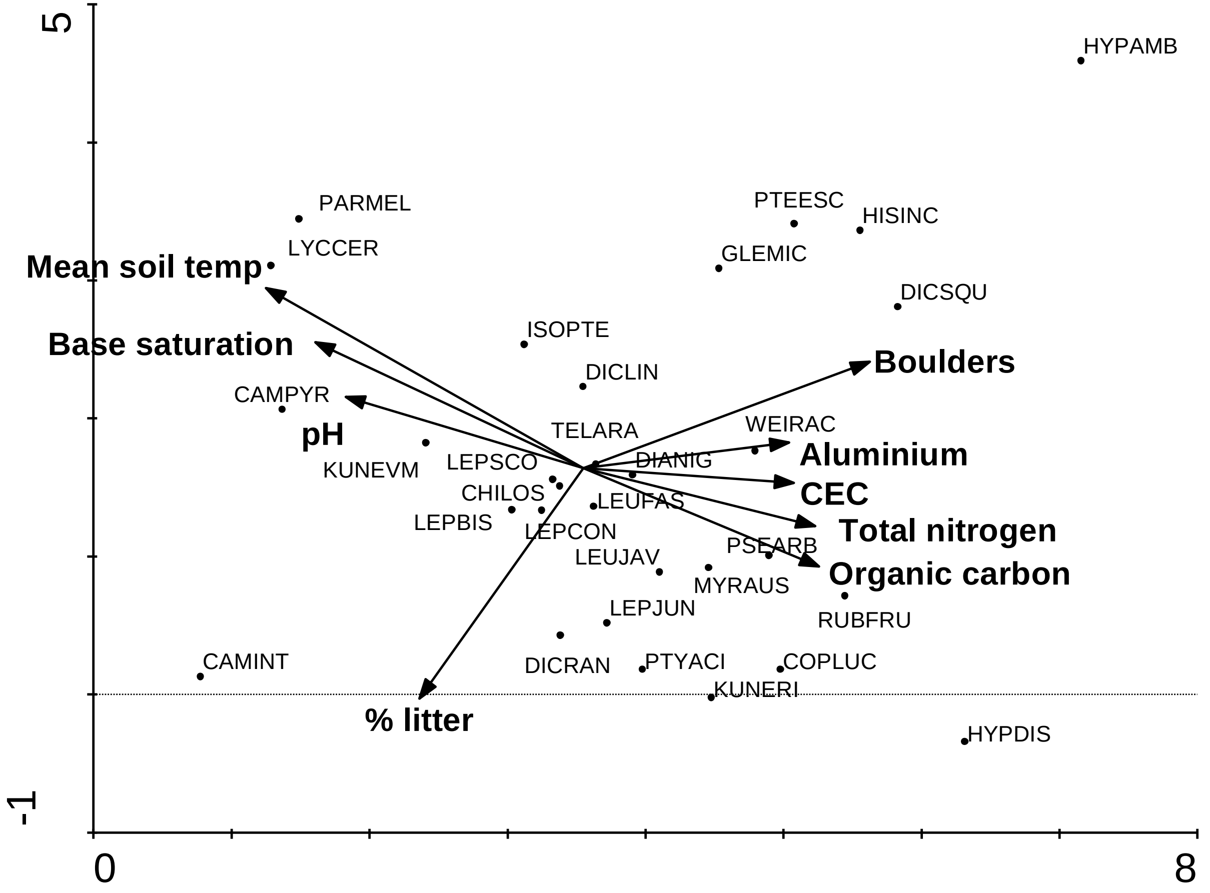


Figure 2 Species by environment biplot displaying results of DCA ordination of 155 plots with both vegetation and soil data in the Taupō Volcanic Zone. To simplify interpretation, only the most important species and environmental variables are displayed. For environmental variables, those having R^2 with one or more axes >0.18 are shown. For species, those 34 having a weight in the ordination >4 are displayed. Species codes are as in Appendix 5.

Table 8 Correlations of DCA axes with environmental parameters in geothermal vegetation associations of the Taupō Volcanic Zone. ** significant at $p < 0.01$

Parameter	Axis 1	Axis 2
Soil temperature	–0.6**	0.3**
pH	–0.4**	0.2
Base saturation	–0.4**	0.2
Aluminium	0.5**	–0.1
CEC	0.5**	0.01
Total nitrogen	0.6**	–0.1
Carbon	0.6**	–0.2
Boulders	0.7**	0.1
Litter cover	–0.6**	–0.3**

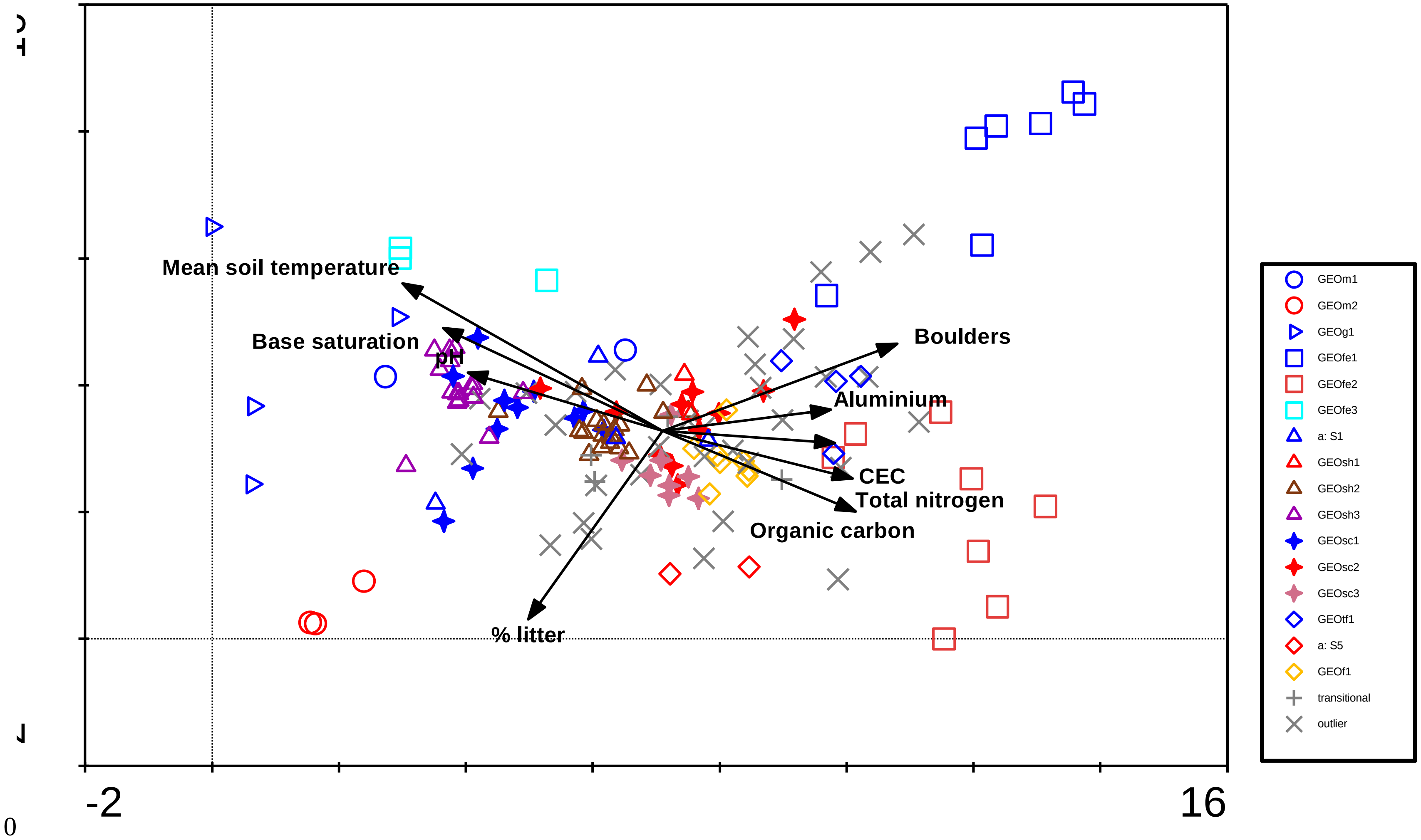


Figure 3 Plot by environment biplot displaying results of DCA ordination of 155 plots with both vegetation and soil data in the Taupō Volcanic Zone. To simplify interpretation, only the most important environmental variables are displayed, i.e. those having R^2 with one or more axes >0.18 are shown. Plots are coded by association with codes as in Table 6. The shapes of the association symbols reflect vegetation structure.

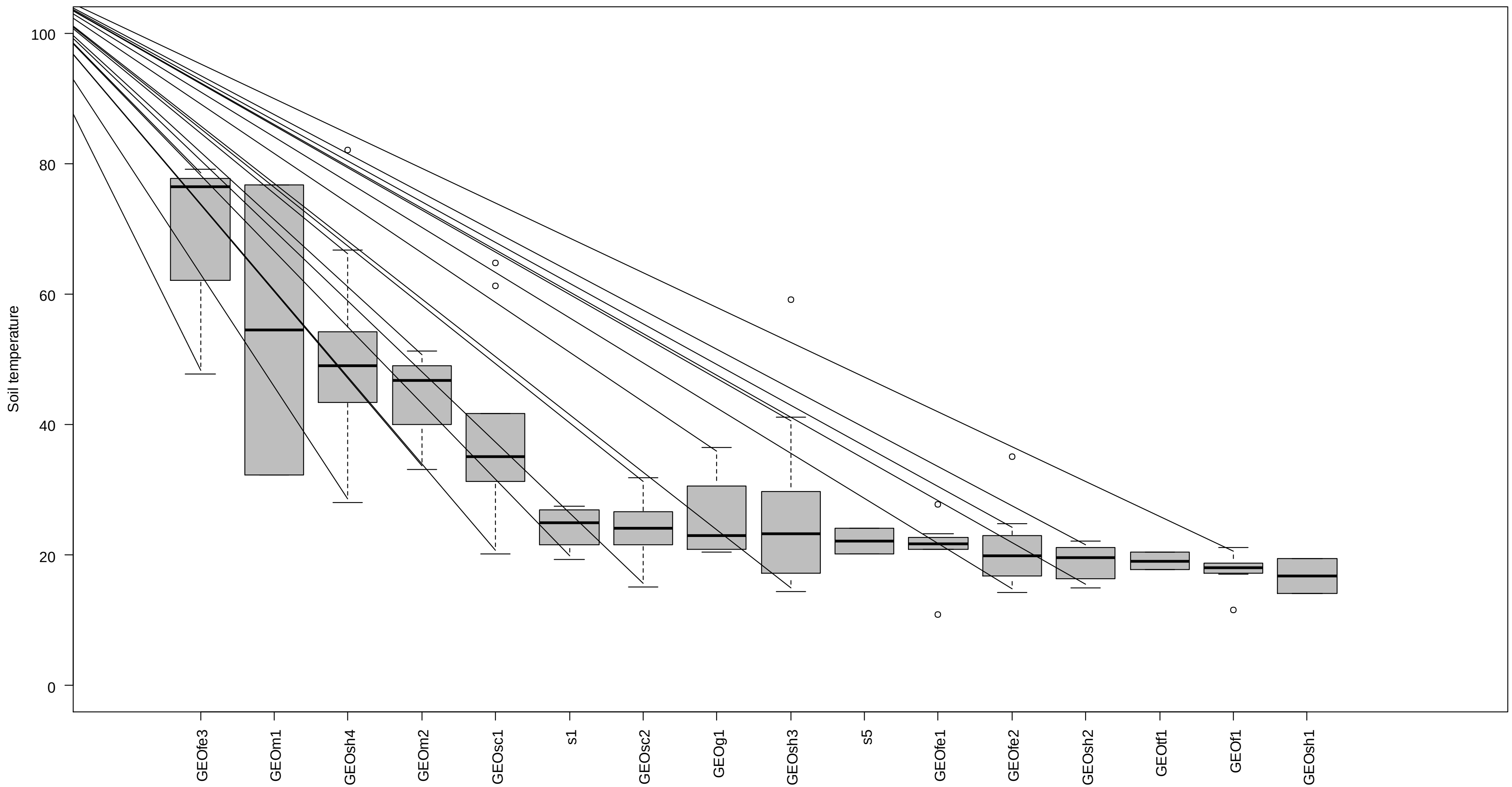


Figure 4 Box plot of soil temperature (10 cm depth) by vegetation association, ordered by descending median temperature, in the Taupō Volcanic Zone. Horizontal bars represent median temperature; the top and bottom of the boxes represent the 75th and 25th quartile respectively; the dashed vertical lines show the maximum and minimum values. Association codes as in Table 6.

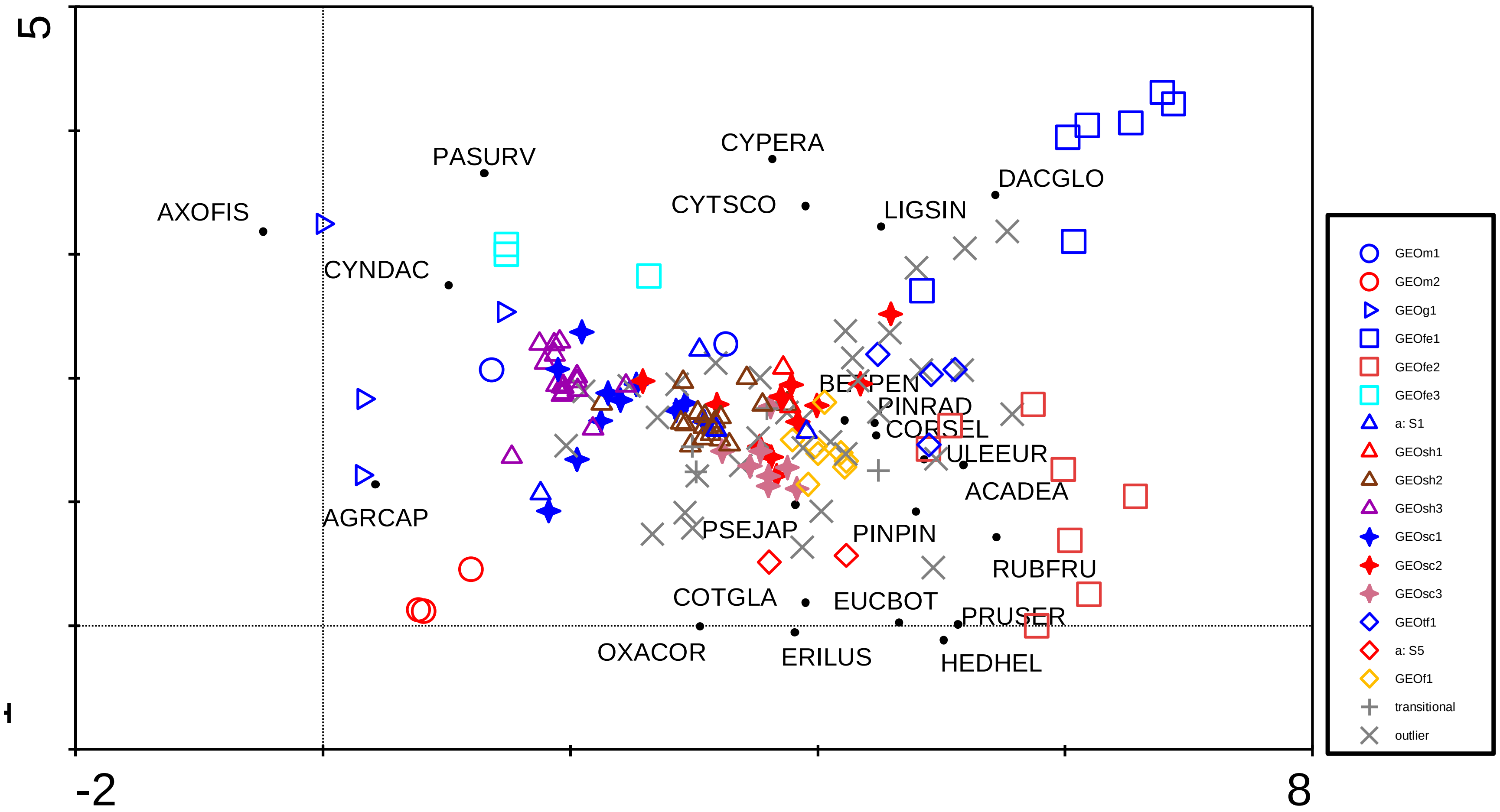


Figure 5 Species by plot biplot displaying results of DCA ordination of 155 plots with both vegetation and soil data in the Taupō Volcanic Zone. Adventive species occurring on 3 or more plots are shown. Plots are coded by association with codes as in Table 6. The shapes of the association symbols reflect vegetation structure. Species codes are as in Appendix 5.

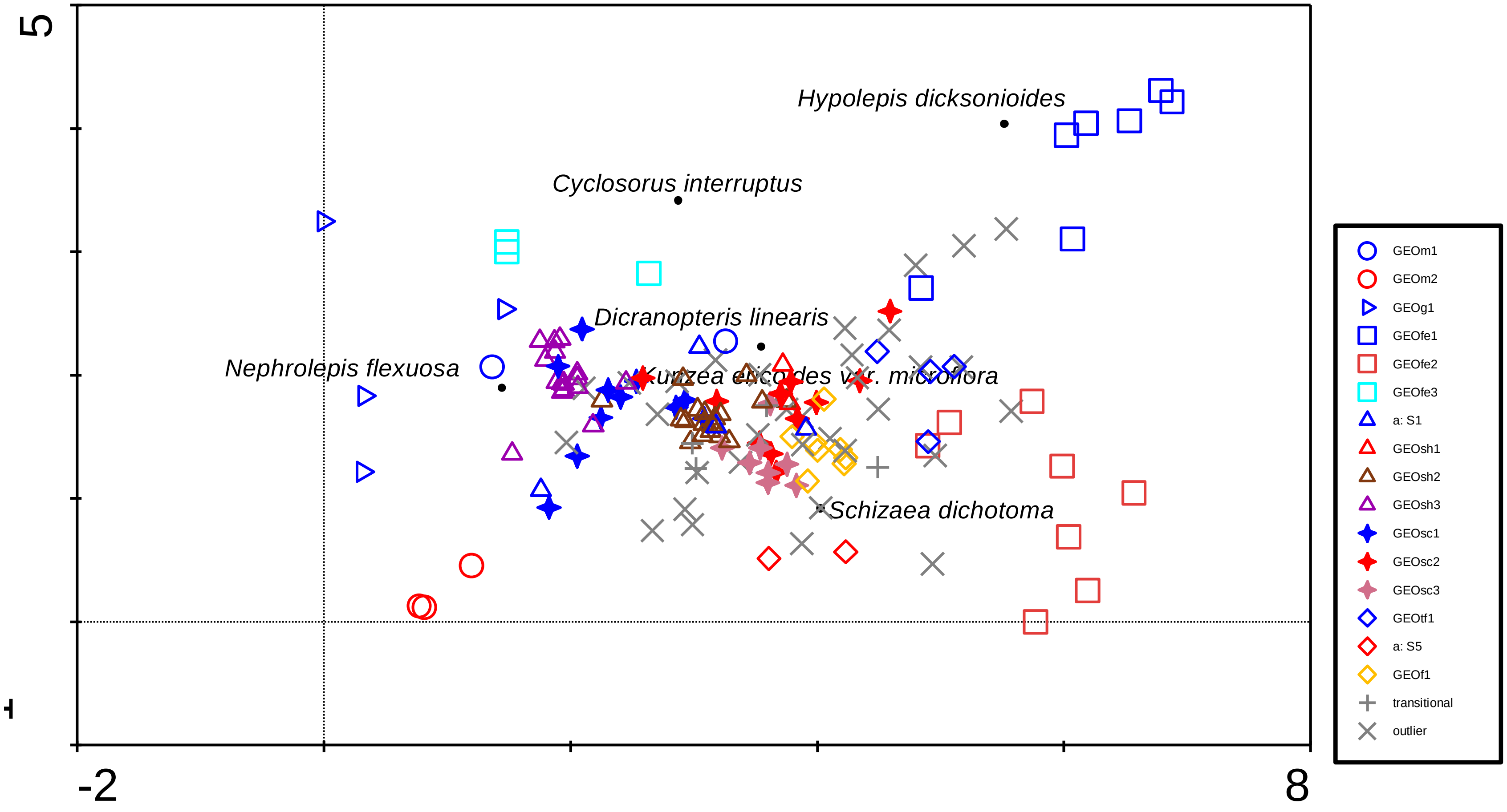


Figure 6 Species by plot biplot displaying results of DCA ordination of 155 plots with both vegetation and soil data in the Taupō Volcanic Zone. Threatened species are also shown. Plots are coded by association with codes as in Table 6. The shapes of the association symbols reflect vegetation structure.

3.6 Cross-reference with earlier classifications

Merrett & Clarkson (1999)

In a review of published and unpublished literature on geothermal vegetation, Merrett & Clarkson (1999) identified 16 vegetation types in seven structural classes. There is reasonable correlation between their six shrubland types and our seven shrubland and scrub ones (Appendix 8). Most of their other types are fernland (6) and weed-dominated (2) types that do not have exact or near-equivalents and are subsumed within broader types in our classification.

Fitzgerald & Smale (2010)

Most of the vegetation types listed for the Bay of Plenty Region by Fitzgerald and Smale (2010) do not have exact or near-equivalents and are subsumed within broader types in our classification (Appendix 9).

Wildland Consultants (2011)

Most of the vegetation types listed for the Waikato Region by Wildland Consultants (2011) do not have exact or near-equivalents and are subsumed within broader types in our classification (Appendix 10).

However, the types in both Bay of Plenty (Fitzgerald and Smale 2010) and Waikato (Wildland Consultants 2011) classifications that do have exact or near-equivalent types in our classification account for some 95% of the geothermal vegetation mapped across both regions. Thus, most subsumed types are of very minor extent and account only for a very small proportion of geothermal vegetation.

Almost all outlier plots and all transitional plots could be cross-referenced to Wildland Consultants (2011) types (Appendix 11).

4 Conclusions

Geothermal vegetation in the Taupō Volcanic Zone is floristically simple, dominated by a small suite of tree (kāmahi), shrub (prostrate kānuka, mānuka, mingimingi, prickly heath), liane (blackberry – adventive), herb (inkberry), grass (narrow-leaved carpet grass – adventive), fern (wheki̅, *Hypolepis distans*, *H. ambigua*, bracken), fern-ally (arching clubmoss), and bryophyte (*Campylopus pyriformis*, *C. introflexus*, *Leucobryum javense*, *Chiloscyphus novae-zelandiae*, *Telaranea praenitens*) species. Of these, only 7 native species (prostrate kānuka, mānuka, mingimingi, inkberry, bracken, *Campylopus pyriformis*, *Chiloscyphus novae-zelandiae*) and 1 adventive (blackberry) are at all widespread. Apart from two species endemic to geothermal sites (prostrate kānuka and *Campylopus pyriformis*), the dominant species are all widespread in other mesic habitats. A small number of other tree (fivefinger, māpou, rewarewa), shrub (*Coprosma lucida*), megaherb (*Astelia solandri*), and fern (water fern, *Dicranopteris linearis*, ring fern) species are consistently or commonly present in some associations, along with a very small suite of weedy adventives (narrow-leaved carpet grass, Japanese hill cherry, browntop, Khasia berry, broom). Although over one-third of the flora is adventive, at present very few species are widespread across geothermal fields or even within particular associations.

Geothermal vegetation in the Taupō Volcanic Zone is renowned amongst botanists for its unusual fern species, confined or almost confined in New Zealand to geothermal sites. Yet they occur very locally and contribute minimally to vegetation cover. Only one, *Dicranopteris linearis*, was at all widespread and then only at two sites, Te Kopia and Orakei-Korako. *Cyclosorus interruptus* and *Hypolepis dicksonioides* (giant hypolepis) were recorded only from Spa/Otumuheke Stream in Taupō, and *Nephrolepis flexuosa* (thermal ladder fern) from only one random plot at Karapiti/Craters of the Moon. *Christella* sp. aff. *dentata* was not recorded in any plots sampled.

This study generalises specific results from three sites on two geothermal fields in the Taupō Volcanic Zone: Karapiti/Craters of the Moon (Given 1980) and Wairoa Hill (van Manen & Reeves 2012) on the Wairakei field, and Te Kopia (Burns 1997). Geothermally-influenced vegetation and soils extend well beyond active geothermal features. A range of communities mostly unique to geothermal fields occurs across the spectrum of soil temperatures and chemistries present, 11 of them – including two that are widespread beyond them – on the extensive slightly heated soils surrounding geothermal features, with five on the smaller areas of markedly heated soils. Soil temperature is the main factor correlated with vegetation composition. Soil chemical fertility is generally low, with high acidity and high levels of sulphur and aluminium, the latter at levels that are normally toxic for plants. At Te Kopia, significant correlations between the principal ordination axis and sulphur, iron and copper content were observed.

There appear to be distinct regional patterns, with some associations – for example, *Leucopogon* scrub in the northern part of the zone – more common in or apparently restricted to part of the Taupō Volcanic Zone, and others – for example, *Kunzea*/*Campylopus* shrubland at Wairakei – apparently restricted to one geothermal field.

Geothermal vegetation presents particular difficulties for classification and mapping because of the highly dynamic nature of the environment in both space and time. This is reflected in the substantial amount of discord between mapped and actual structural classes at sampling locations, and in the relatively large number of samples that were so dissimilar from all other samples that they did not conform to any defined association. However, a higher proportion of unclassified (38 %) than classified (24 %) samples were in urban or peri-urban areas, and generally had higher proportions of adventive species, reflecting the greater weed 'pressure' on them (Timmins & Williams 1991) and the apparently unpredictable successional trajectories of the mixed communities of indigenous and adventive species that are becoming ever more common in New Zealand. Geothermal vegetation on slightly to warm ground appears to be particularly susceptible to weed invasion, particularly in urban and peri-urban areas where weed pressure is high.

The three dominant shrub species of geothermal shrubland – prostrate kānuka, mānuka, and mingimingi – are physiognomically similar species with narrow coriaceous leaves and may not be clearly distinguishable from aerial imagery. However, their relative dominance varies greatly among vegetation associations. Therefore, accurate mapping of the associations defined here – indeed, geothermal associations defined in any classification – may require an approach that integrates predictive modelling based on vegetation plot data and accurate spatial depiction of the primary correlate of vegetation pattern – soil temperature – by means of infrared sensing (e.g. Mongillo 1994), integrated with interpretation of aerial imagery.

5 Recommendations

- Because it is based on rigorous quantitative sampling, this classification should be used for all future assessment and monitoring of geothermal sites in the Taupō Volcanic Zone.
- Mapping this classification may require an approach that is more sophisticated than the straightforward interpretation of aerial imagery.
- Future plots in geothermal vegetation should be sampled in a manner consistent with the methods used here and assigned to the classes defined here. In cases where they cannot be assigned, then they could be analysed in concert with the existing 'outlier' plots to define as yet undescribed geothermal vegetation types. Ideally, plot size should not vary by more than 4-fold. Alternatively, nested designs – where progressively smaller plots are positioned within each other to accommodate progressively shorter vegetation – can be used.
- Distinctive geothermal vegetation occurs across a wide range of soil temperatures, so protection and management should ensure that the full gradients of composition and environment are protected and managed to prevent their degradation.
- Active weed control is necessary to maintain the integrity of geothermal vegetation on slightly warm to warm ground in urban or peri-urban areas where weed pressure is high. Ten sites on five geothermal fields have significant weed problems, six (Arawa Park Racecourse, Arikikapakapa Golf Course, Cemetery Reserve, Kuirau Park, Old Government Gardens, Whakarewarewa) of them in Rotorua City. The others are Parimahana Scenic Reserve (Kawerau), Karapiti (Wairakei), Tikorangi North (Tikorangi), and Waiotapu Thermal Wonderland (Waiotapu).

6 Acknowledgements

We thank Katherine Luketina (Waikato Regional Council) and Nancy Willems (Bay of Plenty Regional Council) for arranging the contract and for support and encouragement. Dr David and Susan Bergin (Tikitere) for accommodation, Michael Bergin (Tikitere), Christopher Floyd (Ohaupo), and Dr Bruce Burns (University of Auckland) for field assistance. Robbie Price (Landcare Research, Hamilton) for generating sampling points, Brian Daly and Ngaire Foster (Landcare Research, Palmerston North) for advice on and soil analysis, Dr Allan Fife and Dr David Glenny (Landcare Research Lincoln) for bryophyte identification, Kerry Ford (Landcare Research, Lincoln) for monocot identification, Dr Susan Wiser (Landcare Research, Lincoln) for analysing the data, and the individuals and organisations listed in Appendix 12 for access permission. Dr Susan Wiser and Dr Norman Mason (Landcare Research, Hamilton) commented on drafts.

7 References

Atkinson IAE 1985. Derivation of vegetation mapping units for an ecological survey of Tongariro National Park, North Island, New Zealand. New Zealand Journal of Botany 23(3): 361–378.

Blakemore LC, Searle PL, Daly BK 1987. Methods for chemical analyses of soils. NZ Soil Bureau Scientific Report 80. DSIR, Lower Hutt.

Burns BR 1997. Vegetation change along a geothermal stress gradient at the Te Kopia steamfield. Journal of the Royal Society of New Zealand 27(2): 279–293.

Burrows CJ, McQueen DR, Esler AE, Wardle P 1979. New Zealand heathlands. In: Specht RL ed. Heathlands and related shrublands: descriptive studies. Ecosystems of the World 9A, Elsevier, Amsterdam. Pp. 339–364.

De Cáceres M, Font X, Oliva F 2010. The management of numerical vegetation classification with fuzzy clustering methods. Journal of Vegetation Science 21(6): 1138–1151.

de Lange PJ 2014. A revision of the New Zealand *Kunzea ericoides* (Myrtaceae) complex. PhytoKeys 40: 1–185.

Fitzgerald NB, Smale MC 2010. An updated assessment of geothermal vegetation in the Bay of Plenty Region based on 2007 aerial photography. Landcare Research Contract Report LC1011/016.

Given DR 1980. Vegetation on heated soils at Karapiti, central North Island, New Zealand, and its relation to ground temperature. New Zealand Journal of Botany 18(1): 1–13.

Howell C 2008. Consolidated list of environmental weeds in New Zealand. DOC Research and Development Series 292.

Hoyt DB, Nyborg M 1972. Use of dilute calcium chloride for the extraction of plant available aluminium and manganese from acid soil. Canadian Journal of Soil Science 52: 163–167.

Hurst JM, Allen RB 2007. The Recce method for describing New Zealand vegetation – expanded manual. Version 4. Landcare Research Contract Report LC0708/029.

Merrett MF, Clarkson BR 1999. Definition, description and illustrations of geothermally influenced terrestrial and emergent wetland vegetation. Landcare Research Contract Report LC9900/022.

Mongillo MA 1994. Aerial thermal infrared mapping of the Waimangu-Waiotapu geothermal region, New Zealand. Geothermics 23(5–6): 511–526.

New Zealand Meteorological Service 1973. Summary of climatological observations to 1973. New Zealand Meteorological Service, Wellington.

Orlóci L 1967. An agglomerative method for classification of plant communities. Journal of Ecology 55(1): 193–206.

Timmins SM, Williams PA 1991. Weed numbers in New Zealand's forest and scrub reserves. New Zealand Journal of Ecology 15(2): 153–162.

van Manen SM, Reeves R 2012. An assessment of changes in *Kunzea ericoides* var. *microflora* and other hydrothermal vegetation at the Wairakei-Tauhara geothermal field, New Zealand. Environmental Management 50(4): 766–786.

Wildland Consultants Ltd 2005. Geothermal vegetation of the Bay of Plenty Region based on the 2003 digital aerial photographs. Wildland Consultants Ltd Contract Report No. 1072 prepared for Environment Bay of Plenty.

Wildland Consultants 2011. Geothermal vegetation of the Waikato Region. An update based on 2007 aerial photographs. Wildland Consultants Ltd Contract Report No. 2348.

Wiser SK, De Cáceres M 2013. Updating vegetation classifications: an example with New Zealand's woody vegetation. Journal of Vegetation Science 24(1): 80–93.

Wiser SK, Drake DR, Burrows LE, Sykes WR 2002. The potential for long-term persistence of forest fragments on Tongatapu, a large island in western Polynesia. Journal of Biogeography 29(5–6): 767–787.

Wiser SK, Hurst JM, Wright EF, Allen RB 2011. New Zealand's forest and shrubland communities: a classification based on a nationally representative plot network. Applied Vegetation Science 14(4): 506–523.

Appendix 1 – Common and scientific names of plants used in text

Common name	Scientific name	Origin
Arching clubmoss	*Lycopodiella cernua*	Native
Blackberry	*Rubus fruticosus*	Adventive
Bracken	*Pteridium esculentum*	Native
Browntop	*Agrostis capillaris*	Native
Fivefinger	*Pseudopanax arboreus*	Native
Giant hypolepis	*Hypolepis dicksonioides*	Native
Inkberry/turutu	*Dianella nigra*	Native
Japanese hill cherry	*Prunus serrulata*	Adventive
Kāmahi	*Weinmannia racemosa*	Native
Kānuka	*Kunzea ericoides*	Native
Khasia berry	*Cotoneaster glaucophyllus*	Adventive
Mānuka	*Leptospermum scoparium*	Native
Māpou	*Myrsine australis*	Native
Mingimingi	*Leucopogon fasciculatus*	Native
Narrow-leaved carpet grass	*Axonopus fissifolius*	Adventive
Prickly heath	*Leptecophylla juniperina*	Native
Prostrate kānuka	*Kunzea ericoides* var. *microflora*	Native
Rewarewa	*Knightia excelsa*	Native
Ring fern	*Paesia scaberula*	Native
Thermal ladder fern	*Nephrolepis flexuosa*	Native
Water fern	*Histiopteris incisa*	Native
Whekī	*Dicksonia squarrosa*	Native

Appendix 2 – Random plots by location and geothermal field in the Taupō Volcanic Zone

Site	Site code (Waikato Region only)	Geothermal field	Number of plots scheduled	Actual number of plots
Arawa Park Racecourse		Rotorua	4	4
Arikikapakapa Golf Course		Rotorua	2	2
Broadlands Road	THV04	Tauhara	1	1
Cemetery Reserve		Rotorua	2	2
Crown Road	THV06	Tauhara	3	3
Hell's Gate		Tikitere	4	4
Karapiti/Craters of the Moon	WKV10	Wairakei	25	24
Kuirau Park		Rotorua	6	6
Lake Rotokawa	RKV02	Rotokawa	6	6
Longview Road	RPV01	Reporoa	1	1
Maungaongaonga	WTV01	Waiotapu	1	1
Ngapouri	WTV02	Waiotapu	1	1
Ngapuna		Rotorua	4	4
Ngatamariki Springs	NMV02	Ngatamariki	1	1
Old Government Gardens		Rotorua	2	2
Orakei-Korako	OKV03	Orakei-Korako	6	6
Otutarara Springs		Tikitere	1	1
Papakiore Springs		Tikitere	2	2
Parengarenga Springs		Tikitere	9	9
Parimahana Scenic Reserve		Kawerau	6	6
Parimahana Extension		Kawerau	1	1
Rainbow Mountain/Maungakakaramea	WTV05	Waiotapu	2	2
Rotokawa North	RKV01	Rotokawa	2	2
Spa/Otumuheke Stream	THV01	Tauhara	4	4
Sulphur Point		Rotorua	1	1
Taheke		Taheke	12	12
Te Kopia	TKV01	Te Kopia	18	18
Te Rautehuia Stream	WKV02	Wairakei	1	1
Tikorangi Central		Tikorangi	4	4
Tikorangi North		Tikorangi	1	1
Tokaanu Thermal Park	TOV08	Waihi-Tokaanu	3	3
Upper Wairakei Stream/Geyser Valley	WKV03	Wairakei	1	1

Waikite Valley	WAV01	Waikite	12	0
Waimangu		Waimangu	1	0
Waiotapu North	WTV03	Waiotapu	7	7
Waiotapu Thermal Wonderland	WTV05	Waiotapu	8	8
Wairoa Hill/Te Kiri o Hine Kai Stream Catchment	WKV05	Wairakei	3	3
Whakarewarewa		Rotorua	12	12

Appendix 3 – Sites excluded from random plot generation

Site	Geothermal field	Reason
Whale Island (Moutohorā)	Moutohora	Inaccessibility
Tarawera Rift	Tarawera	Inaccessibility
Te Rata Bay (Hot Water Beach)	Tarawera	Inaccessibility
Hipaua	Tokaanu	Access restrictions
Tongariro (Red Crater, Emerald Lakes, Te Maari Craters, Ketetahi)	Tongariro	Inaccessibility
Mokoia Island	Rotorua	Inaccessibility, small size
Waitangi Soda Springs Hot Springs	Rotoma-Tikorangi	Wetland
Karapiti Forest	Wairakei	Small size
Pukaahu Springs (Awakeri)	Awakeri	Commercially developed
Waiaute Springs	Kawerau	Wetland
Upper Atiamuri West	Atiamuri	Inaccessibility
Manupirua Hot Springs	Tikitere	Commercially developed
Waipapa Stream	Mokai	Small size

Appendix 4 – Soil chemical analyses and mean soil temperatures (10 cm depth) of random plots in the Taupō Volcanic Zone

S = subjectively placed plot

Plot	Locality	pH	EC	Organic C	Total N	Olsen P	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	CEC	Base Sat.	$CaCl_2$ Extractable Al	Water Extractable S	% Soluble Salts	C/N	Mean soil temperature (10 cm)
47	Arawa Park Racecourse	3.92	0.12	12.95	0.70	93.56	0.82	0.42	0.66	0.14	26.53	7.32	103.92	68.19	4.15	18.52	19.3
175	Arawa Park Racecourse	4.15	0.13	10.62	0.71	138.47	0.40	0.19	0.35	0.42	22.17	6.11	92.61	122.55	4.38	14.94	21.2
178	Arawa Park Racecourse	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	23.1
179	Arawa Park Racecourse	4.45	0.09	3.74	0.16	19.85	0.78	0.09	0.39	0.06	11.53	11.50	77.67	110.60	3.07	23.44	20.5
73	Arikapakapa Golf Course	4.09	0.17	17.89	1.05	4.76	1.97	0.81	0.32	0.38	33.46	10.39	178.63	136.99	6.08	17.06	21.2
75	Arikapakapa Golf Course	4.30	0.20	15.75	0.96	4.55	3.66	1.03	0.41	0.30	30.93	17.48	109.93	304.76	7.11	16.48	17.4
125	Broadlands Rd	4.64	0.07	7.50	0.36	61.04	1.28	0.38	0.32	0.26	19.62	11.43	53.99	81.00	2.31	20.74	20.2
62	Cemetery Reserve	3.43	0.24	30.18	1.43	32.36	4.61	1.17	0.66	0.18	54.20	12.20	56.47	112.03	8.43	21.05	17
67	Cemetery Reserve	3.56	0.23	27.94	1.39	25.39	4.00	1.35	1.02	0.25	49.30	13.43	53.58	152.85	8.09	20.08	16.5
3	Crown Rd	2.19	3.23	0.52	0.04	6.62	0.23	0.11	0.18	0.16	13.21	5.11	382.14	4510.00	112.92	14.57	64.3
5	Crown Rd	2.70	0.88	0.14	0.02	7.99	0.01	0.02	0.02	0.02	3.91	1.71	71.95	1020.00	30.91	6.26	71.8

Plot	Locality	pH	EC	Organic C	Total N	Olsen P	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	CEC	Base Sat.	$CaCl_2$ Extractable Al	Water Extractable S	% Soluble Salts	C/N	Mean soil temperature (10 cm)
12	Crown Rd	3.68	0.33	17.69	1.10	101.72	2.13	0.42	0.57	0.40	29.07	12.09	131.54	463.47	11.44	16.14	29.1
2	Hell's Gate	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	Hell's Gate	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
64	Hell's Gate	3.19	0.40	7.03	0.33	63.61	0.55	0.34	0.57	0.15	22.45	7.15	96.20	383.09	13.89	21.15	14.9
121	Hell's Gate	2.94	0.60	5.29	0.18	30.43	0.81	0.21	0.28	0.11	27.16	5.59	33.64	440.58	20.96	28.89	14.4
44	Karapiti	6.67	0.04	1.71	0.10	5.17	31.29	4.06	0.79	0.28	38.63	93.06	0.16	10.33	1.52	17.55	62.9
128	Karapiti	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15.2
130	Karapiti	5.86	0.03	1.95	0.12	5.59	7.63	1.62	0.89	0.27	15.46	68.32	2.11	14.57	1.20	15.89	44.6
131	Karapiti	5.60	0.05	5.53	0.21	17.19	5.54	1.32	1.21	0.43	18.24	46.57	3.26	78.00	1.59	26.14	33.4
140	Karapiti	4.50	0.06	1.13	0.02	4.35	1.52	0.45	0.40	0.13	15.09	16.52	185.03	57.50	1.98	53.84	43.4
141	Karapiti	6.04	0.05	1.01	0.05	16.13	5.88	2.46	0.70	0.19	13.51	68.35	0.53	1.31	1.63	20.04	56.1
142	Karapiti	6.00	0.03	1.58	0.09	6.39	5.24	1.17	1.14	0.31	14.13	55.61	2.22	4.65	1.02	17.54	49.8
143	Karapiti	6.06	0.02	1.00	0.06	3.84	6.59	1.09	0.98	0.26	12.35	72.31	1.84	3.83	0.80	17.05	48
144	Karapiti	5.83	0.03	1.76	0.09	4.77	7.21	1.24	0.70	0.22	16.23	57.74	0.00	14.47	1.04	19.90	51.1
145	Karapiti	6.01	0.06	1.37	0.07	7.82	6.40	1.45	1.56	0.36	16.31	59.84	0.93	50.93	2.08	19.10	54.2
146	Karapiti	5.98	0.03	1.44	0.06	4.79	6.97	1.24	1.02	0.30	13.84	68.87	2.57	5.27	0.96	22.19	45.3
147	Karapiti	5.84	0.03	0.66	0.04	3.06	3.40	0.73	0.79	0.31	7.83	66.82	5.84	8.20	0.94	18.62	39
148	Karapiti	5.53	0.04	1.63	0.08	4.42	4.15	1.11	0.64	0.46	12.33	51.58	13.04	8.55	1.31	20.25	31
149	Karapiti	5.78	0.06	1.56	0.11	8.73	5.89	1.43	0.90	0.33	16.85	50.68	4.66	22.63	2.18	13.81	52.8

Plot	Locality	pH	EC	Organic C	Total N	Olsen P	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	CEC	Base Sat.	$CaCl_2$ Extractable Al	Water Extractable S	% Soluble Salts	C/N	Mean soil temperature (10 cm)
150	Karapiti	4.87	0.14	1.12	0.07	14.29	2.52	0.74	0.41	0.23	15.01	26.01	38.92	226.90	4.88	15.28	62.8
151	Karapiti	5.59	0.03	1.30	0.06	5.83	3.84	1.00	0.74	0.37	10.62	56.00	9.95	7.37	1.12	22.04	33.3
152	Karapiti	5.92	0.03	1.17	0.05	5.26	4.34	1.05	0.74	0.30	9.03	71.36	1.93	5.18	1.10	24.77	35.1
153	Karapiti	6.14	0.05	0.82	0.05	3.45	11.45	1.03	0.93	0.36	17.21	80.20	0.76	2.44	1.73	15.14	51.2
154	Karapiti	6.29	0.04	0.73	0.06	5.74	9.48	2.13	1.21	0.31	17.35	76.99	0.43	26.87	1.53	11.76	66.7
155	Karapiti	6.32	0.03	0.98	0.05	5.93	15.53	2.55	0.80	0.27	24.46	80.31	0.62	4.52	1.04	19.12	51.5
156	Karapiti	5.89	0.03	0.83	0.04	3.61	3.91	0.92	0.76	0.37	9.35	63.61	5.25	5.77	0.98	20.75	34.8
157	Karapiti	5.57	0.03	0.97	0.04	5.54	3.15	0.73	0.66	0.46	9.27	54.45	16.61	6.87	1.02	23.08	28
158	Karapiti	5.99	0.03	1.08	0.06	5.25	4.82	1.11	1.18	0.26	11.54	63.25	4.32	11.18	1.06	17.98	42.8
159	Karapiti	6.33	0.02	1.20	0.06	3.04	6.06	1.38	1.15	0.26	13.01	67.50	1.11	6.03	0.81	21.33	48.3
160	Karapiti	5.64	0.06	0.45	0.05	9.89	6.94	1.52	1.07	0.29	14.16	69.59	4.64	58.75	2.04	9.47	82.1
S11	Karapiti	5.73	0.04	0.32	0.03	3.37	5.11	0.69	0.32	0.08	7.61	81.38	0.38	80.00	1.38	10.34	76.4
S12	Karapiti	5.57	0.04	0.48	0.04	1.79	1.86	0.34	0.23	0.03	3.91	63.32	5.59	78.00	1.26	11.34	79.1
S13	Karapiti	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	70.2
S14	Karapiti	6.26	0.02	0.47	0.05	5.49	9.83	1.40	1.63	0.46	15.12	88.03	1.58	81.00	0.87	10.06	76.7
65	Kuirau Park	3.76	0.30	24.84	0.91	21.65	3.11	0.89	1.21	0.76	40.90	14.59	229.79	261.50	10.61	27.32	22.1
68	Kuirau Park	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	19.8
70	Kuirau Park	3.80	0.23	28.41	0.90	41.30	5.15	1.31	1.05	0.29	49.50	15.74	124.65	113.13	7.94	31.45	20.7
72	Kuirau Park	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	20.9

Plot	Locality	pH	EC	Organic C	Total N	Olsen P	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	CEC	Base Sat.	$CaCl_2$ Extractable Al	Water Extractable S	% Soluble Salts	C/N	Mean soil temperature (10 cm)
74	Kuirau Park	4.00	0.20	10.06	0.41	9.28	0.86	0.16	0.25	0.40	19.16	8.72	134.64	244.51	6.83	24.57	19.4
162	Kuirau Park	5.24	0.08	4.24	0.29	14.54	2.21	0.65	0.40	0.10	11.14	29.94	12.24	27.36	2.85	14.60	18
10	Lake Rotokawa	3.43	0.20	0.55	0.04	70.25	0.18	0.02	0.16	0.17	3.93	13.63	26.84	252.70	7.00	15.01	38.2
46	Lake Rotokawa	4.13	0.08	4.64	0.14	9.36	0.37	0.12	0.28	0.13	10.69	8.35	56.14	126.29	2.89	34.26	9.8
126	Lake Rotokawa	3.88	0.13	13.82	0.46	38.40	0.53	0.50	0.61	0.16	21.84	8.27	74.38	76.71	4.52	29.77	8.1
18	Longview Rd	2.48	1.65	11.22	0.37	21.59	1.21	0.09	0.22	0.53	33.20	6.18	96.03	2220.00	57.71	30.58	21.6
11	Maungaongaonga	3.62	0.16	10.28	0.26	2.76	0.57	0.38	0.32	0.17	27.27	5.30	201.87	128.11	5.61	39.11	25.8
132	Ngapouri	4.76	0.15	6.46	0.43	28.82	3.58	0.88	0.53	0.15	16.40	31.35	38.37	71.79	5.28	14.93	13.8
135	Ngapouri	4.19	0.14	12.97	0.64	39.17	2.28	0.79	0.74	0.28	30.99	13.20	121.88	195.40	5.06	20.24	29.5
23	Ngapuna	3.08	0.46	10.42	0.43	43.85	0.54	0.23	0.25	0.11	22.57	4.99	97.28	400.77	16.09	24.14	15.6
24	Ngapuna	2.74	0.98	9.12	0.38	88.37	0.29	0.13	0.20	0.14	23.14	3.32	120.44	875.32	34.13	23.91	23.4
31	Ngapuna	3.46	0.30	17.01	0.86	167.98	3.02	0.46	0.44	0.17	35.60	11.48	85.71	225.28	10.37	19.89	17.3
129	Ngapuna	2.09	3.85	5.24	0.24	15.06	0.69	0.11	0.25	0.13	27.79	4.23	167.18	3590.00	134.83	21.60	15.8
34	Ngatamariki Springs	4.60	0.07	12.14	0.42	19.27	4.17	1.41	0.46	0.15	25.56	24.21	35.51	79.00	2.47	28.94	19.5
25	Old Government Gardens	3.36	0.31	22.50	1.13	56.96	3.29	0.92	0.52	0.12	45.80	10.58	31.21	84.11	10.83	19.89	16.8
38	Old Government Gardens	3.57	0.24	17.35	0.91	115.85	3.33	0.46	0.37	0.24	41.20	10.68	53.11	110.39	8.23	19.11	18.7
15	Orakei-Korako	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Plot	Locality	pH	EC	Organic C	Total N	Olsen P	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	CEC	Base Sat.	$CaCl_2$ Extractable Al	Water Extractable S	% Soluble Salts	C/N	Mean soil temperature (10 cm)
20	Orakei-Korako	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
45	Orakei-Korako	5.49	0.05	5.50	0.25	2.79	1.69	0.71	0.47	0.25	15.10	20.53	10.89	36.66	1.59	21.66	41.7
138	Orakei-Korako	4.44	0.06	9.80	0.43	6.50	0.67	0.41	0.43	0.16	24.05	6.92	202.41	2.05	2.18	22.74	17.7
161	Orakei-Korako	3.92	0.18	11.95	0.45	8.60	2.32	1.34	0.78	0.53	28.57	18.15	26.63	73.95	6.18	26.40	21.1
174	Orakei-Korako	4.27	0.05	2.90	0.12	13.82	0.45	0.26	0.21	0.11	13.85	6.92	81.21	22.92	1.75	23.74	28.9
98	Otutarara Springs	4.22	0.12	11.93	0.70	205.56	1.90	0.61	0.43	0.19	28.46	11.01	111.23	59.29	4.06	17.10	21.7
6	Papakiore Springs	3.83	0.08	2.29	0.09	4.95	0.30	0.09	0.18	0.08	8.74	7.35	11.89	183.21	2.69	25.95	20.6
164	Papakiore Springs	6.33	0.02	1.20	0.06	3.04	6.06	1.38	1.15	0.26	13.01	67.50	1.11	6.03	0.81	21.33	36.5
102	Parengarenga Springs	4.17	0.51	10.50	0.48	71.32	5.08	0.86	0.47	0.99	29.73	24.88	76.02	1170.00	17.73	21.65	23.2
105	Parengarenga Springs	4.10	0.11	7.31	0.36	38.86	0.80	0.30	0.27	0.32	19.02	8.89	123.45	124.03	4.00	20.11	20.8
106	Parengarenga Springs	4.28	0.10	7.91	0.38	117.34	2.11	0.88	0.55	0.28	26.05	14.61	99.93	67.29	3.65	20.96	22.1
109	Parengarenga Springs	4.47	0.13	9.12	0.47	49.51	3.19	0.75	0.19	0.30	24.33	18.15	52.91	179.62	4.64	19.32	20.9
112	Parengarenga Springs	4.51	0.08	8.09	0.43	72.77	1.72	0.48	0.27	0.24	21.08	12.87	88.67	84.45	2.75	18.72	20.6
113	Parengarenga Springs	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16.4

Plot	Locality	pH	EC	Organic C	Total N	Olsen P	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	CEC	Base Sat.	$CaCl_2$ Extractable Al	Water Extractable S	% Soluble Salts	C/N	Mean soil temperature (10 cm)
114	Parengarenga Springs	4.10	0.13	8.83	0.39	62.76	1.94	0.55	0.29	0.30	24.21	12.75	105.53	130.08	4.42	22.72	19.2
115	Parengarenga Springs	3.69	0.51	15.14	0.72	22.43	1.68	0.60	0.62	0.94	32.38	11.84	248.20	821.06	17.94	20.88	23.8
119	Parengarenga Springs	3.80	0.74	19.30	0.95	61.44	4.32	0.58	0.44	1.17	45.60	14.59	180.04	1490.00	25.95	20.32	20.9
26	Parimahana Scenic Reserve	4.93	0.04	2.83	0.19	10.11	1.34	0.40	0.20	0.24	10.87	20.07	25.74	15.45	1.34	14.76	44.8
27	Parimahana Scenic Reserve	5.28	0.05	3.55	0.20	2.61	2.63	1.30	0.30	0.24	9.91	45.08	10.57	16.48	1.84	17.76	20.1
28	Parimahana Scenic Reserve	4.90	0.08	8.72	0.36	2.93	2.56	1.83	0.41	0.30	15.20	33.57	16.16	23.88	2.87	24.29	25.9
37	Parimahana Scenic Reserve	5.01	0.06	5.74	0.26	4.22	4.22	1.56	0.29	0.34	17.46	36.72	13.63	21.70	2.01	22.16	22.5
40	Parimahana Scenic Reserve	4.73	0.09	9.74	0.32	8.67	2.70	1.25	0.38	0.30	15.27	30.36	25.46	27.39	3.02	30.52	24.1
134	Parimahana Scenic Reserve	3.90	0.15	1.84	0.07	4.93	0.59	0.09	0.08	0.08	6.35	13.18	99.06	235.44	5.30	26.26	31.3
32	Parimahana Extension	5.48	0.04	2.83	0.17	2.60	3.26	0.73	0.24	0.24	9.46	47.19	6.03	17.68	1.50	16.60	41.7
49	Rainbow Mountain	3.72	0.15	15.29	0.47	6.33	1.76	1.03	0.44	0.20	32.98	10.09	126.64	48.05	5.13	32.28	21.9
43	Rainbow Mountain	3.82	0.13	8.09	0.27	10.09	1.22	0.42	0.27	0.15	19.43	10.48	88.27	67.90	4.64	30.06	19

Plot	Locality	pH	EC	Organic C	Total N	Olsen P	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	CEC	Base Sat.	$CaCl_2$ Extractable Al	Water Extractable S	% Soluble Salts	C/N	Mean soil temperature (10 cm)
41	Rotokawa North	3.51	0.26	13.57	0.46	106.47	1.45	0.40	0.64	0.17	30.02	8.83	91.87	269.02	9.11	29.55	10.4
55	Rotokawa North	4.05	0.12	8.60	0.25	2.95	0.31	0.14	0.25	0.27	14.32	6.76	104.68	162.35	4.30	33.99	24.8
59	Rotokawa North	3.99	0.15	5.86	0.16	5.48	0.48	0.18	0.35	0.14	15.59	7.33	83.13	207.42	5.12	36.05	11.4
81	Spa Stream	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	29.5
84	Spa Stream	3.78	0.39	1.03	0.07	5.18	3.35	0.86	0.92	1.86	6.89	101.51	0.31	884.80	13.77	14.79	59.6
89	Spa Stream	4.26	0.36	2.12	0.12	10.77	5.32	1.34	1.18	2.09	11.00	90.36	0.41	702.99	12.51	17.73	31.2
99	Spa Stream	5.44	0.49	2.69	0.15	9.53	3.26	0.93	0.95	1.90	10.09	69.70	0.54	1150.00	17.14	18.28	47.7
137	Sulphur Point	3.44	0.21	6.06	0.28	37.68	1.50	0.16	0.61	0.14	24.69	9.78	30.41	128.62	7.48	21.28	17.5
36	Taheke	3.89	0.11	6.18	0.26	2.49	0.67	0.28	0.25	0.07	15.96	7.95	103.37	68.93	3.78	23.80	14
101	Taheke	3.86	0.21	2.24	0.06	35.49	6.42	0.07	0.04	0.09	0.03	8.84		2.23	158.01	401.35	32.2
103	Taheke	4.22	0.09	2.83	0.09	45.40	0.11	0.06	0.18	0.13	9.21	5.16	98.08	133.84	2.98	29.90	24.8
104	Taheke	3.89	0.13	4.53	0.15	51.52	0.42	0.19	0.35	0.14	14.80	7.41	151.56	160.42	4.68	29.26	14.2
107	Taheke	3.72	0.12	3.81	0.13	67.93	0.17	0.17	0.15	0.14	13.69	4.25	106.36	104.49	4.28	29.41	21.5
108	Taheke	3.80	0.12	2.50	0.08	47.75	0.00	0.04	0.13	0.15	7.54	3.15	79.36	158.03	4.13	31.68	35.1
110	Taheke	3.77	0.16	2.64	0.08	37.72	0.12	0.16	0.19	0.07	10.03	5.04	121.83	199.49	5.63	33.24	22.1
111	Taheke	4.57	0.07	1.53	0.07	32.56	0.65	0.05	0.20	0.24	5.40	21.03	39.15	109.82	2.34	22.53	43
116	Taheke	3.84	0.12	6.09	0.23	89.45	0.78	0.21	0.26	0.09	17.58	7.62	111.19	99.26	4.20	26.68	21.1
117	Taheke	3.46	0.20	6.42	0.19	40.62	0.54	0.43	0.24	0.09	19.06	6.77	63.44	151.99	6.99	33.19	16
118	Taheke	3.82	0.23	6.56	0.25	10.18	1.45	0.42	0.50	0.29	21.63	12.48	151.29	326.00	7.99	26.60	17.7

Plot	Locality	pH	EC	Organic C	Total N	Olsen P	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	CEC	Base Sat.	$CaCl_2$ Extractable Al	Water Extractable S	% Soluble Salts	C/N	Mean soil temperature (10 cm)
120	Taheke	3.31	0.30	7.42	0.21	28.94	0.41	0.46	0.33	0.12	20.44	7.11	55.96	233.46	10.49	35.63	18.6
17	Te Kopia	3.19	0.37	8.25	0.18	5.67	0.09	0.12	0.16	0.16	20.23	2.61	219.85	458.24	13.01	45.90	33.4
50	Te Kopia	4.76	0.05	8.86	0.39	11.68	0.99	0.52	0.44	0.33	20.69	10.86	69.63	54.15	1.75	22.70	31.8
51	Te Kopia	3.76	0.14	8.46	0.43	11.06	0.66	0.17	0.27	0.14	26.29	4.74	183.27	150.55	5.04	19.77	27.7
82	Te Kopia	4.28	0.12	1.78	0.07	23.42	0.35	0.11	0.17	0.04	9.94	6.81	106.96	198.72	4.37	26.11	41.1
83	Te Kopia	6.07	0.12	4.28	0.26	12.36	1.26	0.46	0.53	0.05	15.43	14.86	73.13	77.00	4.32	16.49	10.9
85	Te Kopia	3.72	0.11	15.29	0.48	6.98	0.73	0.40	0.35	0.17	30.00	5.48	150.52	77.00	3.99	31.96	17.1
86	Te Kopia	4.07	0.13	3.15	0.13	4.56	0.67	0.24	0.36	0.03	12.93	10.04	107.41	129.99	4.61	23.53	18.6
88	Te Kopia	6.26	0.07	6.70	0.25	8.73	1.38	0.56	0.34	0.06	19.80	11.83	72.89	77.00	2.61	27.26	11.6
90	Te Kopia	3.81	0.06	7.98	0.26	2.64	0.94	0.47	0.21	0.07	18.61	9.08	90.26	79.00	2.17	31.25	26.6
91	Te Kopia	2.24	0.08	5.77	0.19	3.46	0.46	0.17	0.18	0.09	14.56	6.19	57.90	78.00	2.88	30.61	17.2
92	Te Kopia	4.32	0.09	16.84	0.60	3.79	1.03	0.56	0.36	0.32	29.62	7.69	147.91	78.00	3.18	27.88	21.1
94	Te Kopia	4.99	0.03	0.76	0.04	0.38	2.39	1.44	0.29	0.12	7.37	57.60	23.26	80.00	1.14	18.84	12.9
95	Te Kopia	3.92	0.10	10.97	0.36	5.29	0.89	0.56	0.30	0.12	23.92	7.81	108.98	78.00	3.44	30.40	18.9
96	Te Kopia	4.19	0.08	9.16	0.32	3.25	0.26	0.48	0.33	0.19	19.93	6.31	136.86	80.00	2.64	28.45	17.3
97	Te Kopia	3.73	0.14	13.56	0.42	5.57	0.72	0.88	0.45	0.25	29.85	7.71	78.96	81.00	4.82	32.63	18.7
100	Te Kopia	3.69	0.13	9.95	0.31	3.99	0.22	0.36	0.36	0.20	24.31	4.66	109.19	78.00	4.60	32.62	18.7
58	Te Kopia S3	4.08	0.05	2.77	0.10	2.36	0.10	0.15	0.09	0.06	9.15	4.37	57.58	80.00	1.77	27.72	26.7
14	Te Kopia S4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	83.6

Plot	Locality	pH	EC	Organic C	Total N	Olsen P	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	CEC	Base Sat.	$CaCl_2$ Extractable Al	Water Extractable S	% Soluble Salts	C/N	Mean soil temperature (10 cm)
177	Te Rautehuia Stream	4.99	0.08	4.56	0.35	69.95	0.57	0.21	0.79	0.06	14.75	10.99	43.20	36.68	2.72	13.14	24.7
63	Tikorangi Central	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	8.8
66	Tikorangi Central	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	8.2
78	Tikorangi Central	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	7.6
124	Tikorangi North	4.12	0.10	8.50	0.38	22.83	0.89	0.64	0.29	0.27	20.01	10.43	87.23	99.26	3.58	22.31	15.1
S1	Tikorangi South	4.72	0.05	3.98	0.12	8.85	0.27	0.10	0.24	0.25	7.76	11.03	40.21	79.00	1.60	31.91	8.6
S2	Tikorangi South	4.25	0.06	11.26	0.36	18.92	0.47	0.41	0.33	0.19	20.07	6.97	131.35	88.47	2.14	31.68	9
29	Tokaanu Thermal Park	4.68	0.05	4.35	0.20	2.22	1.42	0.51	0.45	0.20	10.00	25.76	25.70	77.00	1.92	21.56	12.1
30	Tokaanu Thermal Park	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	30
35	Tokaanu Thermal Park	4.49	0.93	9.97	0.43	5.67	3.50	0.58	1.05	5.34	23.92	43.78	12.82	112.84	32.41	23.00	26.7
13	Upper Wairakei Stream	5.09	0.05	1.37	0.03	7.35	2.67	1.26	0.54	0.16	9.70	47.70	23.58	60.97	1.71	44.84	45
21	Waimangu	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
S5	Waimangu	5.48	0.02	0.73	0.05	4.10	3.80	1.09	0.66	0.27	9.27	62.76	1.07	78.00	0.75	14.23	46.8
S6	Waimangu	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	35.4
S7	Waimangu	6.17	0.02	1.18	0.07	6.48	0.94	0.19	0.21	0.42	2.78	63.14	1.71	81.00	0.85	17.18	33.1

Plot	Locality	pH	EC	Organic C	Total N	Olsen P	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	CEC	Base Sat.	$CaCl_2$ Extractable Al	Water Extractable S	% Soluble Salts	C/N	Mean soil temperature (10 cm)
S8	Waimangu	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	22
S9	Waimangu	6.19	0.04	0.46	0.05	4.26	9.39	3.19	1.03	0.61	14.87	95.61	0.00	78.00	1.52	9.25	64.7
S10	Waimangu	5.74	0.03	0.76	0.05	4.30	2.37	0.45	0.59	0.31	5.91	62.93	2.10	80.00	1.07	14.71	51.2
7	Waiotapu Thermal Wonderland	2.94	0.61	6.17	0.19	15.39	0.37	0.09	0.22	0.23	25.29	3.56	88.03	509.11	21.26	32.30	22.1
48	Waiotapu Thermal Wonderland	4.65	0.11	6.50	0.40	5.46	0.61	0.25	0.85	0.17	14.54	12.72	85.57	130.49	3.90	16.10	14.1
52	Waiotapu Thermal Wonderland	3.60	0.17	4.29	0.23	34.27	0.17	0.11	0.37	0.11	13.87	5.46	116.83	150.31	6.02	18.89	15.3
53	Waiotapu Thermal Wonderland	3.09	0.47	6.21	0.20	8.48	0.00	0.05	0.16	0.14	16.76	2.10	215.11	627.35	16.38	31.15	38.6
54	Waiotapu Thermal Wonderland	2.96	0.45	16.06	0.56	12.49	0.52	0.20	0.49	0.07	38.50	3.35	177.80	238.89	15.68	28.78	15.1
56	Waiotapu Thermal Wonderland	3.82	0.14	10.21	0.37	30.79	0.77	0.27	0.37	0.20	24.87	6.44	175.26	179.19	4.90	27.74	19.4
60	Waiotapu Thermal Wonderland	3.04	0.37	27.24	0.97	16.28	0.80	0.28	0.65	0.25	52.40	3.76	122.52	199.71	12.89	28.11	15.9
133	Waiotapu Thermal Wonderland	3.68	0.15	5.87	0.19	7.96	0.74	0.17	0.95	0.19	18.90	10.89	151.57	127.86	5.08	31.21	17.2
4	Waiotapu North	3.48	0.42	5.84	0.21	4.88	0.97	0.15	0.32	0.50	19.29	10.08	84.51	628.29	14.63	28.25	20.4
8	Waiotapu North	3.27	0.33	2.41	0.07	1.61	0.18	0.04	0.08	0.04	7.19	4.65	68.94	318.84	11.56	36.08	29.7

Plot	Locality	pH	EC	Organic C	Total N	Olsen P	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	CEC	Base Sat.	$CaCl_2$ Extractable Al	Water Extractable S	% Soluble Salts	C/N	Mean soil temperature (10 cm)
122	Waiotapu North	3.90	0.14	6.48	0.32	53.88	0.83	0.19	0.44	0.24	21.57	8.08	116.82	175.57	4.80	20.11	23.7
123	Waiotapu North	3.50	0.47	17.14	0.67	31.89	1.59	0.29	0.47	1.20	38.10	9.34	201.32	531.84	16.58	25.65	20.4
127	Waiotapu North	3.38	0.75	9.58	0.32	15.27	2.46	0.16	0.47	1.74	29.16	16.60	109.13	987.61	26.10	29.88	23.7
139	Waiotapu North	3.47	0.17	16.38	0.54	12.16	3.57	0.35	0.31	0.15	48.10	9.13	40.17	70.45	6.12	30.46	16.8
9	Wairoa Hill	3.42	0.23	1.14	0.01	2.70	0.06	0.03	0.04	0.02	6.51	2.31	93.52	288.28	7.91	153.25	61.2
22	Wairoa Hill	4.41	0.08	9.11	0.40	3.38	0.85	0.23	0.22	0.21	20.24	7.49	130.73	41.76	2.68	22.57	18.5
39	Wairoa Hill	4.81	0.06	4.45	0.15	4.29	1.16	0.33	0.30	0.21	12.00	16.59	46.03	30.15	2.17	28.81	18.5
19	Whakarewarewa	3.73	0.25	9.03	0.25	6.00	1.30	0.21	0.40	1.00	24.45	11.94	38.25	17.43	8.66	35.78	27.4
33	Whakarewarewa	3.75	0.14	11.59	0.50	4.27	0.84	0.38	0.21	0.18	29.33	5.48	200.61	66.56	4.77	22.98	20
42	Whakarewarewa	3.21	0.39	25.97	0.80	19.13	1.37	0.52	0.42	0.27	41.60	6.19	252.32	306.12	13.72	32.60	26.4
61	Whakarewarewa	3.41	0.19	11.23	0.39	8.46	0.71	0.21	0.34	0.45	32.60	5.25	117.02	76.16	6.53	29.00	16.9
69	Whakarewarewa	3.67	0.16	9.70	0.36	30.12	1.05	0.21	0.18	0.16	25.99	6.19	130.81	171.34	5.76	27.32	20.5
71	Whakarewarewa	3.26	0.32	3.91	0.17	27.31	0.77	0.13	0.14	0.15	13.71	8.67	76.44	268.71	11.05	22.88	23
76	Whakarewarewa	3.09	0.58	2.95	0.10	87.07	0.69	0.10	0.19	0.52	11.12	13.39	66.63	601.16	20.21	30.57	26.3
77	Whakarewarewa	3.35	0.50	6.14	0.21	194.70	0.79	0.13	0.16	0.26	18.76	7.15	93.47	801.47	17.48	29.52	29.3
79	Whakarewarewa	3.69	0.21	9.18	0.30	35.58	1.78	0.40	0.36	0.27	26.62	10.57	122.78	234.61	7.19	30.26	18.7
80	Whakarewarewa	3.80	0.18	0.56	0.01	8.97	0.97	0.06	0.06	0.04	6.18	18.32	76.48	251.36	6.39	45.18	59.2
87	Whakarewarewa	4.74	0.14	9.01	0.40	6.38	2.82	0.65	0.62	0.04	22.97	17.98	59.74	61.89	4.86	22.36	16.6
93	Whakarewarewa	4.62	0.15	10.03	0.42	7.35	3.88	0.82	0.85	0.07	27.36	20.53	57.94	47.96	5.29	23.66	16.1

Appendix 5 – Vascular plant species recorded during geothermal vegetation sampling in the Taupō Volcanic Zone. Adventive species are marked with an asterisk

Species	Code	Frequency of occurrence (% of vegetated plots)
**Acacia dealbata*	ACADEA	2.4
**Achillea millefolium*		0.6
**Actinidia chinensis*		0.6
**Agrostis capillaris*	AGRCAP	6.2
Apodasmia similis		1.8
**Ailanthus altissima*		0.6
Asplenium flaccidum		1.8
Asplenium polyodon		7.1
Astelia solandri		5.3
**Aster subulatus*		
Astelia trinervia		0.6
Austroderia fulvida		0.6
**Axonopus fissifolius*	AXOFIS	6.5
**Banksia integrifolia*		0.6
**Betula pendula*	BETPEN	2.4
Blechnum novaezealandiae		4.1
Calystegia sepium		1.2
Carex geminata		1.8
Carex virgata		0.6
**Conyza sumatrensis*		1.2
Coprosma lucida	COPLUC	12.4
Coprosma rhamnoides		1.2
Coprosma robusta		2.4
Corokia buddleoides		0.6
**Cortaderia selloana*	CORSEL	1.8
**Cotoneaster glaucophyllus*	COTGLA	3
Cyathea dealbata		3.6
Cyathea medullaris		0.6
Cyclosorus interruptus		2.4
**Cynodon dactylon*	CYNDAC	3.0
**Cyperus eragrostis*	CYPERA	1.8
Cyperus ustulatus		1.8
**Cytisus scoparius*	CYTSCO	2.4

Species	Code	Frequency of occurrence (% of vegetated plots)
**Dactylis glomerata*	DACGLO	1.8
Deyeuxia avenoides		0.6
Dianella nigra	DIANIG	39.1
Dicksonia fibrosa		1.8
Dicksonia squarrosa	DICSQU	11.8
Dicranopteris linearis		12.3
**Digitalis purpurea*		1.2
**Digitaria sanguinalis*		1.2
Dracophyllum strictum		0.6
Dracophyllum subulatum		5.3
Elaeocarpus dentatus		0.6
**Eragrostis brownii*		1.2
**Erica lusitanica*	ERILUS	3
**Eucalyptus botryoides*	EUCBOT	2.6
**Eurhynchium praelongum*		0.6
Festuca rubra		1.2
Gahnia setifolia		3
Gaultheria antipoda		4.7
Gaultheria paniculata		0.6
**Genista monspessulana*		1.2
**Gladiolus undulatifolius*		0.6
Gleichenia dicarpa		0.6
Gleichenia microphylla	GLEMIC	7.1
Gonocarpus micranthus		1.8
**Hakea salicifolia*		0.6
**Hedera helix*	HEDHEL	1.8
Histiopteris incisa	HISINC	15.4
**Holcus lanatus*		2.4
Hydrocotyle microphylla		0.6
Hymenophyllum revolutum		0.6
Hymenophyllum sanguinolentum		0.6
Hypericum pusillum		0.6
**Hypochaeris radicata*		1.8
Hypolepis ambigua	HYPAMB	5.9
Hypolepis dicksonioides		1.2
Hypolepis distans	HYPDIS	10.7

Species	Code	Frequency of occurrence (% of vegetated plots)
**Ilex aquifolium*		0.6
Isolepis distigmatosa		0.6
**Juncus effusus*		0.6
Juncus kraussii		1.2
Knightia excelsa		4.7
Kunzea ericoides	KUNERI	4.7
Kunzea ericoides var. *microflora*	KUNEVM	56.8
Leptecophylla juniperina	LEPJUN	17.2
Leptospermum scoparium	LEPSCO	25.4
**Leucanthemum vulgare*		0.6
Leucopogon fasciculatus	LEUFAS	51.5
**Leycesteria formosa*		1.2
**Ligustrum sinense*	LIGSIN	1.8
Litsea calicaris		1.8
Lobelia angulata		0.6
**Lonicera japonica*		1.2
**Lotus pedunculatus*		1.8
**Ludwigia palustris*		0.6
Lycopodiella cernua	LYCCER	12.4
Lycopodium deuterodensum		3
Lycopodium volubile		1.8
Machaerina rubiginosa		0.6
Machaerina tenax		1.2
Metrosideros excelsa		2.4
Microlaena stipoides		3
Microsorum pustulatum		5.9
**Modiola caroliniana*		0.6
Morelotia affinis		1.8
Muehlenbeckia australis		1.8
Myrsine australis	MYRAUS	12.4
Nephrolepis flexuosa		2.4
Olearia furfuracea		0.6
**Ornithopus perpusillus*		0.6
**Oxalis corniculatus*	OXACOR	1.8
Paesia scaberula		4.1
**Paspalum distichum*		0.6

Species	Code	Frequency of occurrence (% of vegetated plots)
**Paspalum urvillei*	PASURV	3.6
Persicaria decipiens		2.6
**Pinus nigra*		1.2
**Pinus pinaster*	PINPIN	4.7
**Pinus radiata*	PINRAD	1.8
**Pinus strobus*		1.2
**Pinus radiata*		1.8
**Pinus strobus*		1.2
Pittosporum tenuifolium		1.8
**Plantago lanceolata*		0.6
**Plantago major*		0.6
Podocarpus totara		0.6
**Prunus serrulata*	PRUSER	5.9
Pseudopanax arboreus	PSEARB	11.8
**Pseudosasa japonica*	PSEJAP	2.4
Pseudognaphalium luteo-album		2.6
Psilotum nudum		0.6
Pteridium esculentum	PTEESC	27.8
Pyrrosia eleagnifolia		4.1
**Quercus robur*		0.6
**Ranunculus sceleratus*		0.6
**Rubus fruticosus*	RUBFRU	13.6
Rubus schmidelioides		0.6
**Rumex acetosella*		1.2
**Rumex crispus*		0.6
Rytidosperma gracile		2.4
**Salix cinerea*		0.6
Schizaea dichotoma		2.4
Symphyotrichum subulatum		0.6
Toronia toru		0.6
**Ulex europaeus*		1.8
Uncinia sp.		0.6
Veronica stricta		0.6
Weinmannia racemosa		15.2
**Wisteria sinensis*		1.2

Appendix 6 – Bryophytes recorded during geothermal with vegetation sampling in the Taupō Volcanic Zone

Species	Code	Frequency of occurrence (% of plots)
Liverworts		
Bazzania adnexa		0.6
Chandonanthus squarrosus		0.6
Chiloscyphus novae-zelandiae	CHINOV	21.9
Chiloscyphus semiteres		1.8
Jamesoniella monodon		0.6
Lepidozia bisbifida	LEPBIS	11.8
Lepidozia concinna	LEPCON	7.7
Syzygiella tasmanica		0.6
Telaranea praenitens	TELARA	13.6
Telaranea tetradactyla		2.4
Mosses		
Bryum billardierei		0.6
Campyliadelphus polygamous		1.8
Campylopus introflexus	CAMINT	13
Campylopus pyriformis	CAMPYR	25.4
Dicranella vaginata var. *clathrata*		0.6
Dicranoloma billardieri		0.6
Dicranoloma plurisetum		0.6
Dicranoloma robustum	DICRAN	8.3
Hypnum cupressiforme		3
Isopterygium albescens	ISOPTE	5.9
Leucobryum javense	LEUJAV	11.8
Pohlia cf. *nutans*		5.9
Polytrichum juniperinum		3.6
Pseudoscleropodium purum		0.6
Ptychomnion aciculare	PTYACI	8.9
Rhaphidorrhynchium amoenum		3
Sphagnum cristatum		0.6
Thuidium furfurosum		3.6
Wijkia extenuata		1.2

Appendix 7 – Environmental weeds (Howell 2008) encountered at geothermal sites in the Taupō Volcanic Zone

Site	Weeds
Arawa Park Racecourse	*Agrostis capillaris, Axonopus fissifolius*
Arikikapakapa Golf Course	*Acacia dealbata, Actinida chinensis, Pinus pinaster, Prunus serrulata*
Cemetery Reserve	*Acacia dealbata, Betula pendula, Pinus pinaster, Prunus serrulata*
Crown Road	*Axonopus fissifolius, Cytisus scoparius*
Government Gardens	*Hedera helix*
Hell's Gate	*Betula pendula*
Karapiti/Craters of the Moon	*Agrostis capillaris, Axonopus fissifolius, Cytisus scoparius, Cotoneaster glaucophyllus, Erica lusitanica, Holcus lanatus, Lotus pedunculatus, Pinus pinaster*
Kuirau Park	*Agrostis capillaris, Axonopus fissifolius, Banksia integrifolia, Cytisus scoparius, Dactylis glomerata, Hedera helix, Ilex aquifolium, Juncus effusus, Holcus lanatus, Lotus pedunculatus, Paspalum distichum, Prunus serrulata*
Ngapouri	*Ligustrum sinense*
Ngapuna	*Betula pendula, Ligustrum sinense, Pseudosasa japonica, Salix cinerea*
Ngatamariki Springs	*Ligustrum sinense*
Old Government Gardens	*Hedera helix, Pinus pinaster, Prunus serrulata, Pseudosasa japonica, Wisteria sinensis*
Papakiore Springs	*Axonopus fissifolius*
Parimahana Scenic Reserve	*Cotoneaster glaucophyllus, Erica lusitanica, Ligustrum sinense, Prunus serrulata*
Parimahana Extension	*Cytisus scoparius*
Rotokawa North	*Betula pendula*
Spa/Otumuheke Stream	*Cynodon dactylon, Ludwigia palustris, Pinus pinaster*
Sulphur Point	*Pinus pinaster*
Taheke	*Ulex europaeus*
Te Kopia	*Erica lusitanica*
Te Rautehuia Stream	*Axonopus fissifolius, Cytisus scoparius*
Tikorangi North	*Agrostis capillaris, Dactylis glomerata, Holcus lanatus*
Tokaanu Thermal Park	*Cytisus scoparius*
Waiotapu Thermal Wonderland	*Cytisus scoparius, Pinus nigra, Pinus pinaster, Pinus radiata, Pinus strobus, Ulex europaeus*
Waiotapu North	*Dactylis glomerata, Pinus nigra*
Wairoa Hill/Te Kiri o Hine Kai Stream Catchment	*Holcus lanatus, Pinus radiata*
Whakarewarewa	*Acacia dealbata, Lonicera japonica, Pseudosasa japonica*

Appendix 8 – Cross-reference between Merrett & Clarkson (1999) and this classification

(Brackets indicate a different structural class)

Association	Name	This classification
1	*Campylopus pyriformis* mossfield	GEOm1
2	*Christella* sp. aff. *dentata* fernland	–
3	*Cyclosorus interruptus* fernland	–
4	*Dicranopteris linearis* fernland	–
5	*Nephrolepis flexuosa* fernland	–
6	*Gleichenia microphylla* fernland	–
7	Mixed fernland	–
8	*Cynodon dactylon* grassland	–
9	*Rubus fruticosus* vineland	–
10	*Kunzea ericoides* var. *microflora* shrubland	(GEOsc1)
11	*Leucopogon fasciculatus – Leptospermum scoparium* shrubland	GEOsh3
12	*Kunzea ericoides* var. *microflora* scrub	GEOsc1
13	*Kunzea ericoides* var. *microflora – Leucopogon fasciculatus* scrub	GEOsc3
14	*Leucopogon fasciculatus* scrub	GEOsc2
15	*Dracophyllum subulatum* scrub	–

Appendix 9 – Cross-reference between Fitzgerald & Smale (2010), excluding wetland types and bare ground, and this classification

(Brackets indicate a different structural class)

Association	Name	This classification
01 01	Pōhutukawa-dominant forest	–
01 02	Wattle forest	–
01 03	Treefern-dominant forest	GEOtf1
01 04	Kānuka-dominant forest	(a: S5)
01 05	Exotic pine forest	–
01 06	Willow-dominant forest	–
01 07	Kāmahi-dominant forest	GEOf1
01 08	Kahikatea-dominant forest	–
01 09	Alder-dominant forest	–
01 10	Prostrate kānuka-dominant forest	–
02 01	Wattle treeland	–
02 02	Radiata pine-dominant treeland	–
02 03	Pōhutukawa-dominant treeland	–
02 04	Tree fern-dominant treeland	GEOtf1
02 05	Mixed exotic treeland	–
02 06	Silver birch-dominant treeland	–
02 07	Eucalypt treeland	–
02 08	Kāmahi-dominant treeland	(GEOf1)
03 01	Japanese honeysuckle-dominant vineland	–
03 02	Blackberry-dominant vineland	–
04 01	Prostrate kānuka-dominant scrub	GEOsc1
04 02	Mingimingi-dominant scrub	GEOsc2
04 03	Mānuka-dominant scrub	(a: S1), *(unclassified plot)*
04 04	Kānuka-dominant scrub	–
04 05	Indigenous shrub-dominant communities	–
04 06	Gorse-dominant scrub	–
04 07	Exotic and indigenous plantings scrub	–
04 08	Blackberry-dominant scrub	–
04 09	Bamboo-dominant scrub	–
04 10	Buddleia-dominant scrub	–
04 11	Mixed indigenous-exotic scrub	–
05 01	Prostrate kānuka-dominant shrubland	GEOsh3, *(unclassified plots)*
05 02	Mingimingi-dominant shrubland	(GEOsc2)

05 03	Mānuka-dominant shrubland	GEOsh1, a: S1, *(unclassified plot)*
05 04	Kānuka-dominant shrubland	–
05 05	Pōhutukawa-dominant shrubland	–
05 06	Gorse-dominant shrubland	–
05 07	Planted indigenous shrubland	–
05 08	Mixed indigenous shrubland	–
05 09	Exotic planted shrubland	–
05 10	Mixed indigenous-exotic shrubland	–
05 11	Mixed exotic shrubland	–
05 12	Bamboo-dominant shrubland	–
05 13	Blackberry-dominant shrubland	–
05 14	Cabbage tree-dominant shrubland	–
06 01	Pampas tussockland	–
06 02	Mixed pampas tussockland	–
07 01	*Dicranopteris*-dominant fernland	–
07 02	*Hypolepis dicksonioides*-dominant fernland	–
07 03	Bracken-dominant fernland	–
07 04	Water fern-dominant fernland	–
07 05	Mixed fernland	–
07 06	*Christella* sp. 'thermal'-dominant fernland	–
07 07	*Lycopodiella*-dominant fernland	GEOfe3, *(unclassified plot)*
07 08	Thermal ladder fern-dominant fernland	–
07 09	*Hypolepis ambigua*-dominant fernland	GEOfe1
07 10	Ladder fern-dominant fernland	–
08 01	Yorkshire fog-dominant grassland	–
08 02	Narrow-leaved carpet grass-dominant grassland	GEOg1
08 03	Creeping bent grassland	–
08 04	Mercer grassland	–
08 05	Kikuyu grassland	–
08 06	Mixed grassland	–
13	Herbfield	–
14 01	Woolly moss mossfield	–
14 02	*Campylopus* mossfield	GEOm1, GEOm2
15	Lichenfield	–
23 01	Whekī-dominant treefernland	GEOtf1

Appendix 10 – Cross-reference between Wildland Consultants (2011), excluding wetland types and bare ground, and this classification

(Brackets indicate a different structural class)

Association	Name	This classification
01 01	Pōhutukawa-dominant forest	–
01 02	Wattle forest	–
01 03	Treefern-dominant forest	GEOtf1
01 04	Kānuka-dominant forest	(a: s5), *(unclassified plot)*
01 05	Exotic pine forest	*(unclassified plots)*
01 07	Kāmahi-dominant forest	GEOf1, *(unclassified plot)*
01 09	Plantation-mixed indigenous forest	–
02 01	Wattle treeland	–
02 02	Radiata pine-dominant treeland	*(unclassified plot)*
02 03	Pōhutukawa-dominant treeland	–
02 04	Tree fern-dominant treeland	GEOtf1
02 05	Mixed exotic treeland	*(unclassified plots)*
02 06	Silver birch-dominant treeland	*(unclassified plot)*
02 07	Eucalyptus treeland	–
03 01	Japanese honeysuckle-dominant vineland	–
03 02	Grape vine-dominant vineland	–
03 03	Mixed exotic vineland	–
04 01	Prostrate kānuka-dominant scrub	GEOsc1
04 02	Mingimingi-dominant scrub	GEOsc2
04 03	Mānuka-dominant scrub	(a: s1), *(unclassified plot)*
04 04	Kānuka-dominant scrub	*(unclassified plot)*
04 05	Indigenous mixed shrubs-dominant communities	*(unclassified plots)*
04 06	Gorse-dominant scrub	–
04 07	Exotic and indigenous plantings scrub	–
04 08	Blackberry-dominant scrub	–
04 09	Exotic-dominant scrub	–
04 10	Buddleia-dominant scrub	–
04 11	Chinese privet-dominant scrub	–
04 12	Monoao-dominant scrub	–
05 01	Prostrate kānuka-dominant shrubland	GEOsh3, *(unclassified plots)*
05 02	Mingimingi-dominant shrubland	(GEOsc2)
05 03	Mānuka-dominant shrubland	a: S1, *(unclassified plot)*
05 04	Kānuka-dominant shrubland	–
05 05	Pōhutukawa-dominant shrubland	–

05 06	Gorse-dominant shrubland	–
05 07	Planted indigenous shrubland	–
05 08	Mixed indigenous shrubland	–
05 09	Exotic planted shrubland	–
05 10	Mixed indigenous-exotic shrubland	*(unclassified plot)*
05 11	Mixed exotic shrubland	–
05 12	Monoao-dominant shrubland	–
05 13	Blackberry-dominant shrubland	–
05 14	Ti kouka-dominant shrubland	–
06 01	Pampas tussockland	–
06 02	Mixed pampas tussockland	–
07 01	*Dicranopteris*-dominant fernland	*(unclassified plot)*
07 02	*Hypolepis dicksonioides*-dominant fernland	–
07 03	Bracken-dominant fernland	*(unclassified plot)*
07 04	*Histiopteris incisa*-dominant fernland	*(unclassified plots)*
07 05	Mixed fernland	GEOfe1, GEOfe2
07 06	*Christella* aff. *dentata*-dominant fernland	–
07 07	*Lycopodiella*-dominant fernland	GEOfe3, *(unclassified plot)*
07 08	*Nephrolepis flexuosa*-dominant fernland	–
07 09	*Hypolepis ambigua*-dominant fernland	GEOfe1
07 10	*Nephrolepis cordifolia*-dominant fernland	–
07 11	*Paesia scaberula*-dominant fernland	–
07 12	*Deparia*-dominant fernland	–
07 13	*Cheilanthes*-dominant fernland	–
07 14	*Cyclosorus*-dominant fernland	*(unclassified plot)*
08 01	Yorkshire fog-dominant grassland	–
08 02	Narrow-leaved carpet grass-dominant grassland	GEOg1
08 03	Creeping bent grassland	–
08 04	Mercer grass-dominant grassland	–
08 05	Kikuyu grassland	*(unclassified plot)*
08 06	Mixed exotic-dominant grassland	*(unclassified plot)*
08 07	Indian doab-dominated grassland	–
13	Herbfield	–
14 01	*Racomitrium*-dominant mossfield	–
14 02	*Campylopus*-dominant mossfield	GEOm1, GEOm2
15	Lichenfield	–
23	Whekī-dominant treefernland	GEOtf1, *(unclassified plots)*
30	Bamboo-dominant bambooland	–

Appendix 11 – Cross-reference between outlier and transitional plots and Wildland Consultants (2011) associations

Plot	Association	Name
Outliers		
Arikakapakapa Golf Course 73	08 06	Mixed exotic-dominant grassland
Arikakapakapa Golf Course 75	01 05	Exotic pine forest
Cemetery Reserve 67	02 05	Mixed exotic treeland
Kuirau Park 74	08 06	Mixed exotic-dominant grassland
Kuirau Park 162	08 05	Kikuyu grassland
Lake Rotokawa 46	04 05	Mixed indigenous shrubland
Lake Rotokawa 126	04 05	Mixed indigenous shrubland
Ngapuna 135	04 04	Kānuka-dominant scrub
Ngatimahinerua 34	05 10	Mixed exotic-indigenous shrubland
Old Govt. Gardens 25	02 05	Mixed exotic treeland
Old Govt. Gardens 38	–	
Orakei-Korako 174	07 01	*Dicranopteris*-dominant fernland
Parengarenga Springs 105	23	Whekī-dominant treefernland
Parengarenga Springs 115	23	Whekī-dominant treefernland
Parimahana 26	05 01	Prostrate kānuka-dominant shrubland
Parimahana 28	–	
Rainbow Mtn. 43	–	
Spa Stream 84	07 14	*Cyclosorus*-dominant fernland
Spa Stream 89	07 04	*Histiopteris*-dominant fernland
Taheke 36	01 07	Kāmahi-dominant forest
Taheke 110	04 03	Mānuka-dominant scrub
Taheke 111	07 07	*Lycopodiella*-dominant fernland
Te Kopia 86	07 04	*Histiopteris*-dominant fernland
Te Kopia 94	–	
Tikorangi South S1	04 05	Mixed indigenous shrubland
Tikorangi South S2	04 05	Mixed indigenous shrubland
Tokaanu 29	05 03	Mānuka-dominant shrubland
Waiotapu 132	–	
Wairakei 22	01 05	Exotic pine forest
Wairakei 39	02 02	Radiata pine-dominant treeland
Whakarewarewa 33	–	
Whakarewarewa 79	–	
Whakarewarewa 93	07 03	Bracken-dominant fernland

Transitional		
Lake Rotokawa 59	04 05	Mixed indigenous shrubland
Rotokawa North 41	02 06	Silver birch-dominant treeland
Taheke 117	01 04	Kānuka-dominant forest
Tokaanu 35	05 01	Prostrate kānuka-dominant shrubland

Appendix 12 – Individuals and organisations acknowledged for access permission

Site	Acknowledgment
Arawa Park Racecourse	D Thompson, Arawa Park Racecourse
Arikikapakapa Golf Course	The Manager, Arikikapakapa Golf Course
Broadlands Road	Dominic Bowden, Catherine Daniel, Contact Energy
Cemetery Reserve	Rotorua District Council
Crown Road	Dominic Bowden, Catherine Daniel, Contact Energy
Hell's Gate	Bryan Hughes, CEO, Hell's Gate
Karapiti/Craters of the Moon	Craters of the Moon Charitable Trust
Kuirau Park	Rotorua District Council
Lake Rotokawa	Richard Frankis, Mighty River Power
Longview Rd	Peter Molloy, Reporoa
Maungakakaramea/Rainbow Mountain	Leilani Fraser, Department of Conservation/Evelyn Forrest, Ngāti Tahu–Ngāti Whaoa Rūnanga Trust
Maungaongaonga	Leilani Fraser, Department of Conservation/Evelyn Forrest, Ngāti Tahu–Ngāti Whaoa Rūnanga Trust
Ngapouri	Charlotte Anderson, Timberlands Limited
Ngapuna	Rotorua District Council
Ngatamariki Springs	Dev Affleck, Mighty River Power/Gary Winslade, Wairakei Pastoral Ltd
Old Government Gardens	Rotorua District Council
Orakei-Korako	Orakei-Korako Ltd
Otutarara Springs	Barnett Vercoe/Ian Hulton, Hulton Patchell/Ross Larcombe, PF Olsen Group Limited
Papakiore Springs	Barnett Vercoe/Ian Hulton, Hulton Patchell/Ross Larcombe, PF Olsen Group Limited
Parengarenga Springs	Barnett Vercoe/Ian Hulton, Hulton Patchell/Ross Larcombe, PF Olsen Group Limited
Parimahana Scenic Reserve	Leilani Fraser, Department of Conservation/Department of Conservation/Elaine Savage, Ngāti Tūwharetoa ki Kawerau
Parimahana Extension	Gina Rintoul, Kawerau
Rotokawa North	Mark Thompson, Tauhara North No. 2 Trust
Spa/Otumuheke Stream	Spa Hotel, Taupō
Taheke	Sandra Eru, Taheke 8C Trust
Te Kopia Scenic Reserve	Leilani Fraser, Department of Conservation/Evelyn Forrest, Ngāti Tahu-Ngāti Whaoa Rūnanga Trust
Te Rautehuia Stream	Dominic Bowden, Catherine Daniel, Contact Energy
Tikorangi Central/South	Rotoma No. 1 Incorporation Trustees/Glenn Hawkins, Glenn Hawkins and Associates

Tikorangi North	Anthony Whata, Ben Parsons, Tautara Matawhaura Trust/Martin Kinder, Hulton Patchell
Tokaanu Thermal Park	Robyn Ellis, Department of Conservation/Tokaanu Marae Committee
Upper Wairakei Stream/Geyser Valley	Wairakei Thermal Valley
Waikite Valley	Mark Bowie, Landcorp
Waimangu Scenic Reserve	Harvey James, Waimangu Volcanic Valley Ltd/Leilani Fraser, Department of Conservation
Waiotapu Thermal Wonderland	Evelyn Forrest, Ngāti Tahu–Ngāti Whaoa Rūnanga Trust
Waiotapu North	Charlotte Anderson, Timberlands Limited
Wairoa Hill/Te Kiri o Hine Kai Stream Catchment	Dominic Bowden, Catherine Daniel, Contact Energy
Whakarewarewa	Taparoto Nicholson, Te Puia – New Zealand Māori Arts and Crafts Institute/Shannon Taua, Whakarewarewa Thermal Village