Waikato Regional Council Technical Report 2013/32

Invertebrate macro-fauna in geothermal soils under native vegetation in the Waikato region

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

Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato

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June 2013

Document #: 2785531

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Approved for release by:
Dr Jonathan Caldwell Date August 2013

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WRC contract RIG 391
June 2013

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Executive summary

A survey was designed to provide baseline descriptive information of soil macro-fauna under native vegetation in geothermal soils in the Waikato region. A ranking system was also explored to rate the quality and disturbance (human induced) at individual geothermal sites.

Descriptors including vegetation and soil macro-fauna did not correlate with soil temperatures. Habitat threats particularly from human activities were identified as significant. Structural and functional relationships within the geothermal soil environment are identified as fragile and little-studied in the context of New Zealand geothermal systems.

Site uniqueness with respect to vegetation and soil macro-fauna indicates that individual site plans to facilitate connectivity and design buffers to increase resilience of ecosystem services is necessary.

1 Introduction

Ecological data to form a baseline for soil fauna in geothermal areas is singularly lacking for the Waikato region. Soil temperature surveys undertaken by Thompson (1965) indicate a wide range of influences in terms of extent and intensity from geothermal features. Recording the range of endemic flora and surface dwelling fauna in close proximity to geothermal features by Boothroyd and Browne (2006) creates baseline data for this environment, but other than a soil macro-fauna survey of 12 geothermal features by Willoughby (2012) there is little specific information available about soil fauna in geothermal areas of the Waikato region. That survey was restricted to soils under pasture to simplify the interpretation of the data by reducing dietary induced complexities of soil fauna introduced by complex vegetative cover. Individual site characteristics were so variable to preclude any standardised soil macro-fauna interpretation, either spatially or temporally, within a geothermal environment.

The Waikato Regional Council (WRC) has, through the process of identifying Significant Natural Areas (SNAs), created an inventory of natural habitat in the Waikato region. Geothermal vegetation is mapped into three broad categories; non-vegetated raw soil field; emergent wet land; and terrestrial vegetation (Bycroft *et al* 2007). A process towards a better understanding of the functionality is required with a view to achieving better management and understanding the linkages required to sustain what at present comprises a mosaic of unconnected geothermal habitats.

We report on a survey that was designed to provide baseline descriptive information of soil macro-fauna under native vegetation in geothermal soils in the Waikato region. A ranking system was also explored to rate the quality and disturbance (human induced) at individual geothermal sites.

2 Methods

Twenty-one geothermal sites were sampled for soil macro-fauna between 3rd December and 7th December 2012. A total of 105 samples were assessed; five samples at each site; each consisting of a single spade divot (15 cm x 15 cm x 15 cm depth) from which the litter characteristics and soil profile were described, and any soil macro-fauna were recorded. A soil temperature recording was also taken at the base of each divot. A GPS position was recorded at each location site.

An assessment of invertebrate species present in canopy foliage at each sample site was also undertaken by beating canopy foliage above a 40 cm diameter circular tray for 30 seconds and identifying all the species that fell into the tray.

Sites were selected based on the presence of representative flora associated with geothermal features, following the classification of vegetation groupings recognised in Wildlands (2011). Eight vegetation classes were sampled:

- Prostrate kanuka/mingimingi-manuka scrub
- Prostrate kanuka/mingimingi scrub
- Prostrate kanuka shrubland
- Kanuka/mingimingi-manuka forest
- Manuka/mingimingi scrub
- Manuka shrubland
- Whauwhaupaku-kanuka/mingimingi scrub
- Mingimingi-kanuka-manuka-karamu/bracken scrub

The vegetation and habitat quality was evaluated at each site against a ranking classification (developed for the purposes of this study) that offered a comparison between sample sites as to the nature and amount of human-induced disturbance (either direct or indirect) to which the site had been subjected (Table 1).

Table 1: **Sample site quality ranking**

Quality ranking	description
5	Site undisturbed (no animal tracks or signs of trampling or browse), no weedy species present, landscape unmodified, site legally protected as park or reserve land.
4	Site relatively undisturbed (few or no animal tracks or signs of trampling or browse), few or no weedy species present, landscape unmodified, site legally protected as park or reserve land
3	Some animal disturbance evident (browse/tracking), weedy species present but not dominant, site legally protected as park or reserve land.
2	Animal disturbance evident but not heavy, landscape modified, weedy species present but not dominant, site not legally protected.
1	Signs of obvious disturbance (animal tracks, browse), weedy species prominent, highly modified landscape, site not legally protected.

3 Results

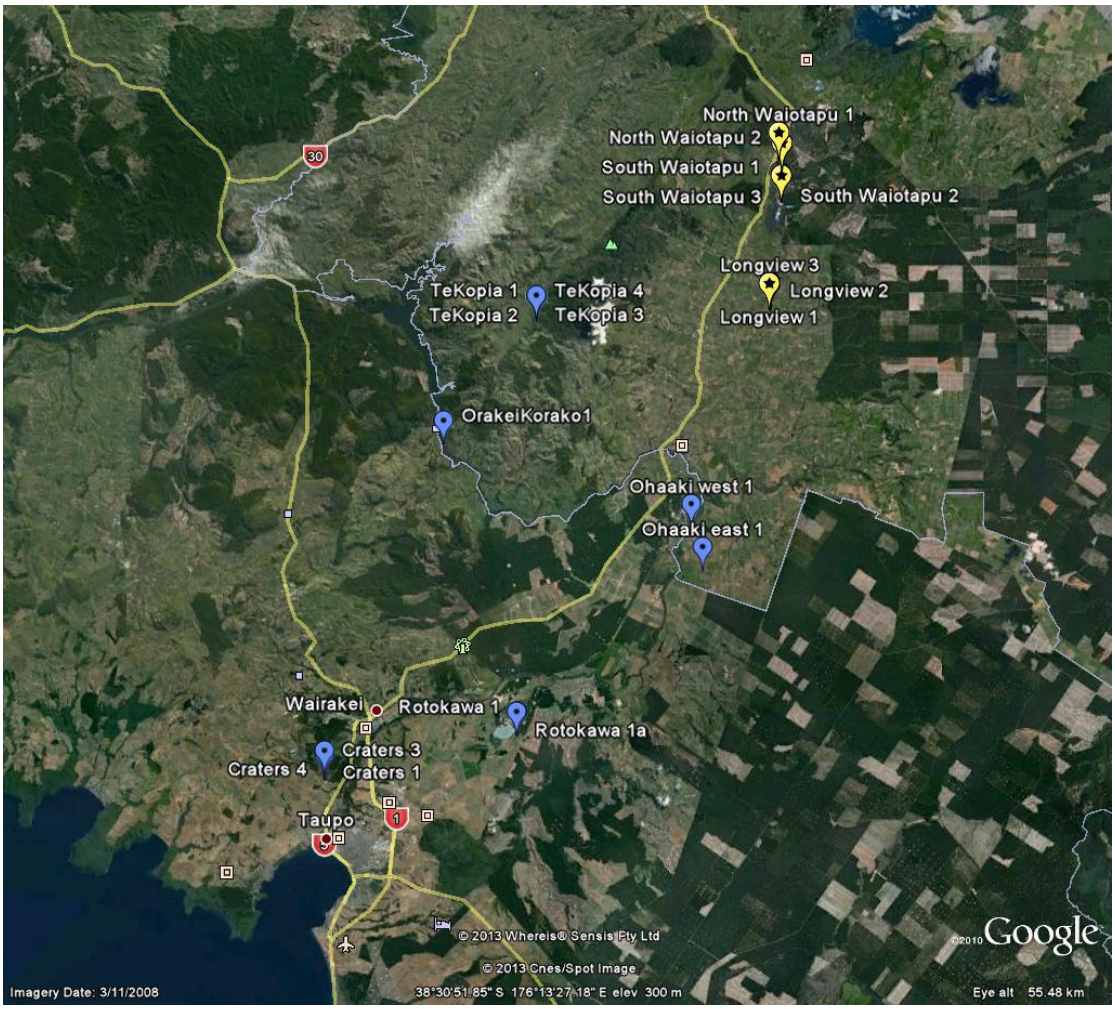

Figure 1: Location of sites sampled (Google Earth images)

Table 2: Results summary showing presence across all sample sites of macro-fauna and mycorrhizal fungi at the ground surface, in litter or root mat, within a 15 cm soil profile sample or (macro-fauna only) in the canopy vegetation. Key to species codes is given below the table.

Sample site (WRC Site code)	Sample number	temp (°C)	canopy	surface	litter/ root mat	soil
North Waiotapu 1	1-1	28.60	0	A	MF	MF
(WTV03)	1-2	27.50	0	0	0	0
	1-3	27.00	0	0	Pa	0
	1-4	27.20	0	0	0	0
	1-5	27.30	0	0	0	0
North Waiotapu 2	2-1	24.60	0	0	RLM	0
(WTV03)	2-2	24.90	0	0	0	0
	2-3	23.60	0	0	0	0
	2-4	25.30	0	0	0	0
	2-5	25.10	0	0	0	0

Sample site (WRC Site code)	Sample number	temp (°C)	canopy	surface	litter/ root mat	soil
South Waiotapu 1	3-1	34.70	0	0	0	0
(WTV05)	3-2	33.80	0	0	MF	0
	3-3	36.40	0	0	0	0
	3-4	34.80	0	0	0	0
	3-5	34.90	0	A	0	0
South Waiotapu 2	4-1	30.90	0	A	MF	0
(WTV05)	4-2	28.00	0	0	0	0
	4-3	26.60	NB	0	MF	0
	4-4	24.10	0	0	0	0
	4-5	24.00	0	0	0	NB
South Waiotapu 3	5-1	23.30	0	0	MBa, Cp, Cl	Cp, Cl
(WTV05)	5-2	22.90	0	0	0	0
	5-3	-	0	0	0	0
	5-4	-	0	0	0	0
	5-5	-	0	0	0	0
Longview 1	6-1	20.80	0	0	0	0
(RPV01)	6-2	22.30	0	0	RLM, NB	0
	6-3	22.50	0	0	NB	0
	6-4	22.30	0	0	0	0
	6-5	22.80	0	0	NB	0
Longview 2	7-1	23.50	0	0	0	SM
(RPV01)	7-2	22.50	0	0	0	0
	7-3	22.60	BB	BB	0	0
	7-4	-	0	0	0	0
	7-5	-	0	0	0	0
Longview 3	8-1	23.50	0	0	MF	BB, MF
(RPV01)	8-2	23.00	0	0	CBl, MF	MF
	8-3	26.30	0	0	0	0
	8-4	24.70	0	0	MF	MF, BB
	8-5	24.60	0	0	MF	MF
Te Kopia 1	9-1	33.80	0	0	MBa, MF	MF
(TKV01)	9-2	35.90	0	0	0	0
	9-3	35.30	0	0	0	0
	9-4	37.00	0	0	BB, MF	MF
	9-5	36.30	0	0	MF	MF
Te Kopia 2	10-1	37.80	0	0	0	0
(TKV01)	10-2	34.70	0	0	BB, egg mass	0
	10-3	29.70	0	0	MBa	0
	10-4	33.10	0	0	MF	0
	10-5	32.90	MBa	0	MBa,BB, MF	0
Te Kopia 3	11-1	32.10	0	0	BB	0
(TKV01)	11-2	31.70	0	0	MBa	0
	11-3	34.90	0	0	0	0
	11-4	35.60	0	0	MBa	0
	11-5	43.60	0	0	BB	0

Sample site (WRC Site code)	Sample number	temp (°C)	canopy	surface	litter/ root mat	soil
Te Kopia 4	12-1	33.10	0	0	MBa	0
(TKV01)	12-2	38.70	MBa	0	0	0
	12-3	40.30	MBa	0	0	0
	12-4	45.70	0	0	0	0
	12-5	37.90	0	0	MBa	0
Orakei Korako	13-1	26.70	0	0	CBa, MF	0
(OKV03)	13-2	28.90	0	0	BB	0
	13-3	34.90	MBa	0	MF	0
	13-4	33.50	0	0	0	0
	13-5	36.70	0	0	S, MF	0
Ohaaki East	14-1	44.70	0	0	MF	0
(OHV02)	14-2	48.90	0	0	MF	0
	14-3	38.70	0	0	MBa, MF	0
	14-4	40.90	0	0	0	0
	14-5	43.70	0	0	T	0
Ohaaki West	15-1	25.70	MBa	0	0	0
(OHV01)	15-2	24.20	0	0	0	0
	15-3	24.30	0	0	MBl	0
	15-4	-	0	0	MBa,MBl, egg mass	0
	15-5	22.30	0	0	0	0
Rotokawa 1	16-1	18.50	0	0	GG	0
(RKV02)	16-2	17.30	BB,MBa	GG, P	MBl	0
	16-3	18.20	BB	0	MBa	0
	16-4	19.10	BB,MBa	0	0	0
	16-5	19.30	NB,BB, MBa, BUB, HB	0	0	0
Rotokawa 2	17-1	24.60	BB	0	MF	0
(RKV02)	17-2	23.20	BB,MBa	0	MF	MBp
	17-3	37.50	BB	0	MF	0
	17-4	35.10	BB	0	MF	0
	17-5	31.70	0	0	GG, MF	0
Craters 1	18-1	18.40	0	0	0	0
(WKV10)	18-2	18.60	0	0	MF	0
	18-3	17.70	0	0	MF	0
	18-4	18.90	MBa	0	MBa, MF	0
	18-5	18.80	MBa	0	0	0
Craters 2	19-1	38.50	0	0	0	0
(WKV10)	19-2	33.70	MBa	0	0	0
	19-3	33.40	MBa	0	0	0
	19-4	28.70	0	0	0	0
	19-5	34.60	0	0	0	0
Craters 3	20-1	19.50	0	0	BB,MBa,MF	0
(WKV10)	20-2	18.80	0	0	0	0
	20-3	18.20	0	0	0	0
	20-4	17.80	0	0	0	0

Sample site (WRC Site code)	Sample number	temp (°C)	canopy	surface	litter/ root mat	soil
	20-5	17.80	0	0	0	Cl
Craters 4	21-1	17.50	0	NB	0	0
(WKV10)	21-2	15.90	0	0	0	0
	21-3	15.20	0	0	0	0
	21-4	15.80	0	0	MF	MBa
	21-5	15.90	0	0	0	0

Key to species codes in Table 1

A	ants (Family: Formicidae)	**MBa**	manuka beetle adult (*Pyronota* sp.)
BUB	bumble bee (*Bombus* sp.)	**MBl**	manuka beetle larva *(Pyronota* sp.*)*
HB	honey bee (*Apis mellifera*)	**MBp**	manuka beetle pupa (*Pyronota* sp.)
NB	native bees *(Leioproctus* sp.)	**Pa**	porina adult (*Wiseana* sp.)
CBa	click beetle - adult (*Conoderus exsul*)	**Pl**	porina larva (*Wiseana* sp.)
CBl	click beetle - larva (*Conoderus exsul*)	**MF**	mycorrihizal fungus *(Pisolithus* sp.*)*
Cp	cicada - pupa (*Notosalta* sp.)	**RLM**	red-legged mite (*Halotydeus destructor*)
GG	grass grub (*Costelytra zealandica*)	**SM**	soil mite (Sub Order: Oribatidae)
Cl	cicada - larva *(Notosalta* sp.)	**BB**	bronze beetle (*Eucolaspis* sp.)
		T	thrips (*Thysanoptera*)

3.1 Waiotapu Geothermal Field

3.1.1 SITE 1: North Waiotapu 1 - Tourist Loop

30° 20’ 31S 176° 22’ 13E ± 5 m
Altitude: 311 m

Figure 2: Location of sample site 1 - Tourist Loop (Waiotapu Geothermal Field)

Vegetation type: Kanuka/mingimingi-manuka forest

Site quality ranking: 4.
Few weeds present and little/no site disturbance evident.

Canopy:

Kanuka (*Kunzea ericoides)* dominant (up to 7 m tall) with occasional tall mingimingi (*Leucopogon fasciculatus*), sparse manuka (*Leptospermum scoparium*) and prostrate kanuka (*Kunzea ericoides* var. *microflora*). Kanuka and manuka both flowering profusely at time of visit.

Understorey:

Mainly kanuka with occasional mingimingi, water fern (*Histiopteris incisa*) and turutu (*Dianella nigra*).

Ground cover (0- 50 cm):

Dense litter (mainly leaves and dead branches of kanuka) with seedlings/small shrubs of mingimingi,turutu, sickle spleenwort (*Asplenium polydon*), and hanging spleenwort (*Asplenium flaccidum*). Litter layer is approximately 10 cm deep (comprising predominantly kanuka and wood fragments). The main litter layer is dry and variable and often "perched" with gaps beneath the layer. Signs of mud splatter present in the litter.

General description of sample area:
Located approximately 20 m south of active mud pools. Small active vents scattered throughout the site. Samples were positioned at random 5 m spacing approximately 8 m from (and parallel to) a mud feature. If a perched litter layer was present, the sample divot was taken beneath it in order to sample a full soil profile.

Sample 1-1: Temperature 28.6 ^{o}C.
Litter layer 10 cm. Strong sulphurous (H_2S) smell in soil.

Numerous large ants present on surface - possibly native. Mycorrhizal fungal hyphae abundant in upper layers.

Sample 1-2: Temperature 27.5 ^{o}C.
Litter layer 10 cm, very fibrous, gas smell.

No macro-fauna observed in litter or soil.

Sample 1-3: Temperature 27.0 ^{o}C.
Litter layer 10 cm, also very dry.
Unidentified moth pupa (possibly *Porina* sp.) present in litter
Soil layer is a coarse ash - smelt strongly of H_2S.

No macro-fauna observed in litter or soil.

Sample 1-4: Temperature 27.2 ^{o}C.
Litter layer 10 cm, very fibrous. No smell of H_2S.
Soil layer is a coarse ash with organic smell.

No macro-fauna observed in litter or soil.

Sample 1-5: Temperature 27.3 ^{o}C.
Litter layer 10 cm.
Soil layer is a coarse pumice with strong smell of H_2S.

No macro-fauna observed in litter or soil.

3.1.2 SITE 2: North Waiotapu 2

Berry's Farm (Scenic Reserve - Department of Conservation)_
38° 20' 12S 176° 22' 06E ± 5 m
Altitude: 386 m

Figure 3: Location of sample site 2, Berry's Farm (Waiotapu Geothermal Field).

Vegetation type: Prostrate kanuka/mingimingi scrub

Site quality ranking: 3
Some animal disturbance evident; mainly tracking (pigs). Very few weeds present. Site fenced and otherwise relatively undisturbed

Canopy:
Very dense cover of prostrate kanuka (maximum height c. 4 m) and occasional mingimingi. *Trentepohlia* alga obvious on tree branches. Kanuka in flower at the time of visit.

Understorey:
Prostrate kanuka, mingimingi and dead branches.

Ground cover (0 – 50 cm):
Dense dry litter (mainly from prostrate kanuka/mingimingi). Seedlings of prostrate kanuka present along with mosses and bracken (*Pteridium esculentum*), some turutu (*Dianella nigra*), foxglove (*Digitalis purpurea*) and very occasional fivefinger (*Pseudopanax arboreus*) High litter levels indicative of very poor soil fauna.

General description of sample area:
Samples were collected approximately 20 m distant from an active geothermal feature (a small lake with active mud pools) and 30 m from the edge of pine forest/tall scrub to the east of the site. A very moist environment due to steam from the lake.

Sample 2-1: Temperature 24.6 ^{o}C.
Litter layer 3 cm. Fine ash soil; very mixed with patches of organic matter interspersed.

Red legged mite (*Halotydeus destructor*) present in litter layer

Sample 2-2: Temperature 24.9 ^{o}C.
Litter layer 5 cm, moist and very friable with moss cover. Fine ash soil, but not so mixed as in Sample 2-1.

No macro-fauna present in the litter or soil layers.

Sample 2-3: Temperature 23.6 ^{o}C.
Litter layer 3 cm, moist, and very friable with moss cover.
Fine ash soil (mixed with slightly coarser pumice medium than previous samples).

No macro-fauna present in the litter or soil layers.

Sample 2-4: Temperature 25.3 ^{o}C.
Litter layer 3 cm, moist, and very friable with moss cover.
Pumice/ash mixed soil.

No macro-fauna present in the litter or soil layers.

Sample 2-5: Temperature 25.1 ^{o}C.
Litter layer 5 cm, moist, and very friable with moss cover.
Predominantly coarse pumice soil.

No macro-fauna present in the litter or soil layers.

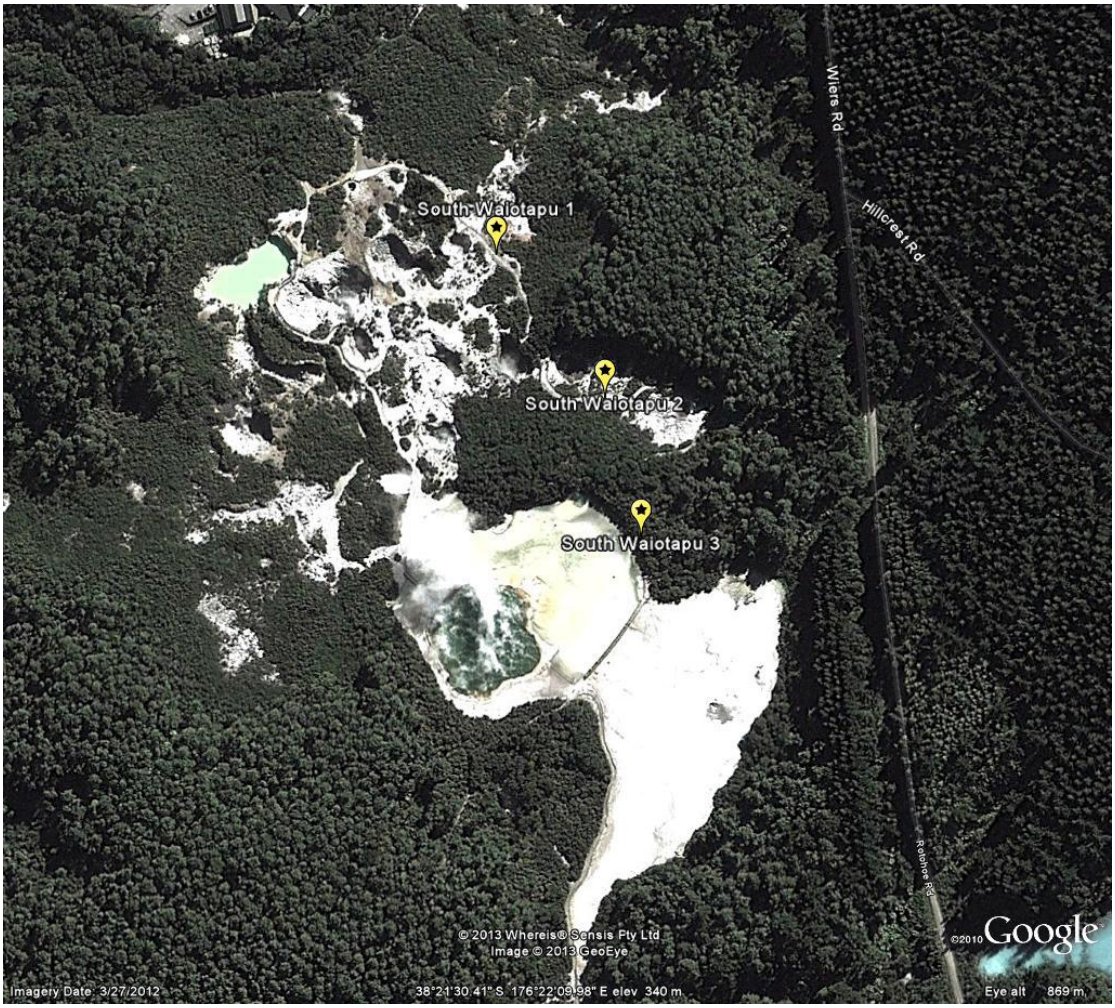

Figure 4: Location of sample sites 3 – 5 at South Waiotapu (Waiotapu Geothermal Field).

3.1.3 SITE 3: South Waiotapu 1

38^{o} 21' 434S 176^{o} 22' 152E ± 5 m
Altitude: 335 m

Vegetation type: Prostrate kanuka/mingimingi scrub

Site quality ranking: 4

Located within the park reserve; well protected, no sign of animal disturbance, tourist tracks nearby. Few weeds.

Canopy:

An even mix of prostrate kanuka and mingimingi approximately 1 - 2 m tall. Very dense growth branching to near ground level.

Understory:

Not distinct – layer composed mainly of canopy tree branches.

Ground cover (0 – 50 cm)

Very sparse cover of *Cladonia* lichens and mosses (*Campylopus* sp.), some *Trentepohlia* alga in amongst lower and fallen branches.

General description of sample area:

Site bounded by bare soil field on both sides. Prostrate kanuka in flower at the time of visit, but no bees observed (likely soil is too hot to burrow here).

Sample 3-1: Temperature 34.7 ^{o}C.

Litter layer 1 – 2 cm, overlaying a coarse pumice ash. Roots confined to top 4 cm only. Soil moist.

No macro-fauna present in litter or soil.

Sample 3-2: Temperature 33.8 °C.
Litter layer 1 cm with some *Cladonia* sp. lichens present on surface. Pumiceous ash below litter layer. Roots penetrate only to base of litter layer.

Mycorrhizal fungal hyphae abundant in litter layer only.

Sample 3-3: Temperature 36.4 °C.
Litter layer 1 cm overlaying 10 cm of fine ash. Roots penetrate through to the bottom of the fine ash layer, but most of the root mass is in the top 4 cm. Coarse pumice/sand at base.
No macro-fauna present in litter or soil.

Sample 3-4: Temperature 34.8 °C.
Litter layer 2.5 – 3 cm overlaying a very dense and fibrous root mat which reaches a depth of 5 cm. Slightly more moisture in lower part of divot.

No macro-fauna present in litter or soil.

Sample 3-5: Temperature 34.9 °C.
Litter layer sparse with less than 0.5 cm depth overlaying very coarse pumice with bands of sulphur deposit through it.

Ants (likely native) present on surface, otherwise no soil macro-fauna present.

3.1.4 SITE 4: South Waiotapu 2

38° 21' 479S 176° 22' 183E ± 5 m
Altitude: 328 m

Vegetation type: Prostrate kanuka/mingimingi scrub.

Site quality ranking: 4
Protected site, no animal disturbance or weeds evident. Tourist tracks nearby.

Canopy:
Low cover of prostrate kanuka and mingimingi with very occasional monoao (*Dracophyllum subulatum*). Canopy height between 1.5 – 2 m. Prostrate kanuka fully in flower at time of visit.

Understorey:
Not distinct – layer composed mainly of canopy tree branches.

Ground cover (0 – 50 cm):
Sparse cover of lichens and mosses where the canopy is fairly open (also in and around the bases of shrubs). Ground cover is otherwise absent – mainly bare sinter cobbles on the surface.

General description of sample area:
Site is approximately 5 m distant from a public walking track and around 10 m distant from an active feature. Sampling line follows a small ridge, with ground temperature decreasing in the uphill direction.

Sample 4-1: Temperature 30.9 °C.
Litter layer of 1 cm overlaying a 3 cm root mat. Base material is very coarse pumice.

Mycorrhizal fungal hyphae present in the organic layers. Abundant ants present on surface.

Sample 4-2: Temperature 28.0 ^{o}C.

Litter layer of 3 cm covered by a dry algal mat. Very dense root mat layer (1 cm) beneath litter. Base material a fine raw pumice. No roots below 4 cm.

No macro-fauna present in litter or soil.

Sample 4-3: Temperature 26.6 ^{o}C.

Dense surface cover of lichens (*Cladonia* sp. and *Cladia* sp.) growing on a minimal layer (< 0.5 cm) of loose litter. Material beneath comprises 4 cm of dense undecomposed dry compacted litter (texture of coconut fibre matting) and roots (some large). Base material includes 3 cm pumice sitting over 1 cm of buried topsoil. Coarse ash layer from 15 cm.

Mycorrhizal fungal hyphae abundant through the organic matter.
Note: Native bees (*Leioproctus* sp.) working the kanuka flowers.

Sample 4-4: Temperature 24.1 ^{o}C.

Very dense canopy. Surface cover comprising 20% lichens sitting on 2 cm undecomposed leaf litter. Litter underlain by 2 cm layer of densely packed fibrous root material. A 1 cm layer of buried soil occurs in the profile. Base is coarse pumice.

No macro-fauna present in litter or soil.

Sample 4-5: Temperature 24.0 ^{o}C.

Lichen species occupy approximately 10% of sample surface area. Leaf litter (fresh looking) of 3 cm depth. Layer beneath litter is dry clay infused with sulphur (possibly an artefact from a no-longer-active feature). Base material is a multi-coloured (yellow/pink/grey/white) clay. Live root material confined entirely to litter layer.

One native bee (*Leioproctus* sp.) present in a soil tunnel. 4 other (unoccupied) tunnels observed.

3.1.5 SITE 5: South Waiotapu 3

38° 21' 510S 176° 22' 193E ± 5 m
Altitude: 354 m

Vegetation type: prostrate kanuka/mingimingi scrub

Site quality ranking: 4
Some disturbance evident (from nearby track and maintenance work); no weeds present

Canopy:
Tall mingimingi and prostrate kanuka (up to 4 -5 m tall)

Understory:
Shrubby mingimingi and kanuka saplings with abundant dead fallen branches/stems.

Ground cover (0 – 50 cm):
Extensive patches of lichens, mosses and liverworts (very dry). Scattered individuals of turutu and patches of bracken. Abundant *Trentephohlia* on branches.

General description of sample area:
The sample area was located within 10 m of large lake/spring and next to a tourist walking track. Vegetation cover fairly open and around 4-5 m tall.

Sample 5-1: Temperature 23.3 °C.
Coarse litter layer of branches/slash on surface overlaying 6 cm depth of undecomposed and densely packed leaf litter. Base material is mottled grey/black fine clay.

Macro-fauna comprised one Manuka beetle (*Pyronota* sp.) adult and three Cicada pupal cocoons in the litter layer. One Cicada pupa and two Cicada larvae were present in the underlying clay material. Based on the cicada calls in the vicinity, the species is likely to be *Notosalta sericea*.

Sample 5-2: Temperature 22.9 °C.
Surface cover of mosses and liverwort overlaying 6 cm of dense litter above mottled grey and black fine clay.

No macro-fauna observed in litter or base layer

Sample 5-3: Temperature not recorded.
Surface cover 100% moss/liverwort overlaying 15 cm of compact litter.
Base material a heavy clay.

No macro-fauna observed in litter or base layer

Sample 5- 4: Temperature not recorded.
Dense surface cover of *Cladonia* lichen and liverwort/moss over >15 cm of compact litter.

No macro-fauna observed in litter or base layer.

Sample 5-5: Temperature not recorded.
Surface moss covered over litter down to 15 cm. Abundant *Trentepohlia*-covered branches
Base material (at bottom of sample hole) a black buried soil

No macro-fauna observed in litter or base layer

3.2 Reporoa Geothermal Field

Figure 5: Location of sites 6 -8 sampled at Longview Road (Reporoa Geothermal Field)

3.2.1 Site 6: Longview Road 1

38^{o} 24’ 845S 176^{o} 21’ 726E ± 5 m
Altitude: 307 m

Vegetation type: Manuka/mingimingi scrub

Site quality ranking: 4
Natural disturbance on site due to active feature
No weeds or animal disturbance observed
Entire site well protected, but under threat from perimeter drainage

Photo 1: manuka-mingimingi scrub at Longview Road sample site

Canopy:

Very dense manuka-mingimingi; approximately 3 m tall. *Trentephohlia* alga abundant on lower branches.

Understorey:

Not distinct; some bracken present, but mainly consisting of branches and dense growth of canopy manuka and mingimingi.

Ground cover (0 – 50 cm):

Lichens (*Cladonia* spp.) present on mounds of pumice.

General description of sample area:

Sample sites located in an area of low dense scrub on the eastern side of a small lake at the south end of the reserve (Figure), approximately 10 m from the perimeter drain. The area is active with bare soil-field and pools close to the sampling site. Sampling line was along the slightly raised vegetated margin of the lake/soil field. Manuka was in full flower at the time of this visit and native bees were prolific – abundant presence over all the plants.

Trentephohlia alga abundant on lower branches of the canopy trees.

Sample 6-1: Temperature 20.8 ^{o}C

Litter layer virtually non-existent (despite dense canopy cover). Root mat penetrating 2 cm from surface. No sign of any insect feeding on roots. Soil is very raw pumice interspersed with bits of baked mud. Petrified vegetative matter present down to 150 mm.

No macro-fauna observed in litter or soil.

Sample 6-2: Temperature 22.3 ^{o}C

Virtually no litter present. Canopy semi-open. Root mat approximately 1 cm deep. Raw pumice soil below interspersed with bits of baked mud and some sinter.

Macro-fauna included one red-legged earth mite (*Halotydeus destructor*) and four *Leioproctus* sp. (native bees) in well formed tunnels.

Sample 6-3: Temperature 22.5 ^{o}C

Virtually no litter present (despite sample site being under a completely enclosed and dense canopy). Raw pumice soil interspersed with large chunks of baked mud. No evidence of any insect root feeding.

Macro-fauna included two native bees in tunnels within 1 cm of surface amongst the root layer.

Sample 6-4: Temperature 22.3 ^{o}C

No litter (despite sample site being under a completely enclosed and dense canopy). 2 cm of fine pumice at surface, beneath which is a 5 cm layer of buried litter. No evidence of geothermal heating. Profile relatively moist throughout. Sub-soil a fine pumice.

No macro-fauna observed in litter or soil.

Sample 6-5: Temperature 22.8 ^{o}C

No litter. Canopy open – surface exposed. No root mass present in the upper layer of the sample, but growing roots present at 15 cm depth. Entire profile is raw pumice.

Native bee tunnels present in upper profile, but no bees observed in the sample.

3.2.2 SITE 7: Longview Road 2

38^{o} 24' 50S 176^{o} 21' 46E ± 5 m
Altitude: 281 m

Vegetation type: manuka shrubland

Site quality ranking 5

No signs of animal disturbance, no tracking, few weeds,
Some natural disturbance from nearby active features.

Canopy:

Manuka dominant with shrubs/small trees ranging from 3 to 6 m tall. Edge trees estimated at <10 yrs old.

Understorey:

Dense manuka; mostly branching of canopy trees.

Ground cover (0 – 50 cm):

Light cover of manuka litter with patchy *Cladonia* lichens and mosses..

General description of sample area:

Sampling sites located approximately 5 m west of the reserve perimeter drain. Flat topography. Bare soil field approximately 3 m distant in a south-westerly direction.

Sample 7-1: Temperature 23.5 ^{o}C.

Semi –open manuka canopy. Litter layer negligible. A few lichens – *Cladonia* sp. - present on surface. Fine ash soil with no discernible A horizon. Upper layer is a fine ash with very little organic matter present (other than live roots penetrating through all layers). About 5 cm of heavy clay sits beneath the ash layer (this appeards to be water-deposited). Lower layer to 150 mm includes a buried soil rich in organic matter. High moisture levels.

Soil macro-fauna comprised one black mite (approx 2 mm long) present in the buried soil layer.

Sample 7-2: Temperature 22.5 ^{o}C.

Closed manuka canopy. Litter layer of 0.5 cm depth comprising manuka leaves. *Cladonia* sp. lichens and mosses present on surface. Soil includes a

fine ash layer which contains the main root mass. This sits over a layer of massive clay structure which in turn is underlain by a buried soil. Roots present through all levels.

No macro-fauna observed in litter or soil.
No evidence of root feeding.

Sample 7-3: Temperature 22.6 ^{o}C.

Closed manuka canopy. Litter layer 0.5 cm depth comprising manuka leaves. Friable ash soil approximately 12 cm depth). Soil was moist to the base of the sample hole and full of root material. Heavy clay present at the base of sample (roots did not penetrate this layer).

No macro-fauna observed in litter or soil.
No evidence of root feeding.
Note: three scarab adults collected from surface most likely disturbed out of the canopy.

Sample 7-4: Temperature not recorded.

Very dense closed canopy of manuka – Leaf litter covers entire surface. Entire divot sample was composed of litter with dense root material throughout. A coarse ash layer was present at the base of the sample hole.

No macro-fauna observed in litter or soil.
No evidence of root feeding.

Sample 7-5: Temperature not recorded.

Closed manuka canopy. Litter layer of 2 cm depth with a very dense root mat below to a depth of 4 cm. Remainder of sample comprised undecomposed litter. Ash layer present at the base of sample.

No macro-fauna observed in litter or soil.

3.2.3 SITE 8: Longview Road 3

38^{o} 24' 50S 176^{o} 21' 45E ±5 m
Altitude: 284 m

Site quality ranking: 4

Stable site, with little to no obvious influence from exotic species (although deer are possibly present within the area).

Vegetation type: Mingimingi/manuka shrubland

Canopy:

Dense low canopy approximately 0.5 to 1.5 m tall, dominated by mingimingi. Some taller manuka scattered throughout.

Understorey:

Not distinct – high density of branches to ground level

Ground cover (0 – 50 cm):

Sparse – mainly litter

General description of sample area:

Sample site was immediately adjacent to a bare soil-field in which there are a couple of deep active vents. *Trentepohlia* alga abundant on lower branches.

Sample 8-1: Temperature 23.5 ^{o}C.

Profile included a top litter layer of 2 cm depth overlaying a 0.5 cm layer of charcoal/fire burnt material and a dense fibrous root mat of 3 cm. The remaining 9.5 cm had a high content of organic matter. Base of the profile was massive clay structure. The entire profile was very moist with evidence of soil

processes occurring. Organic material appeared dissolved with evidence of movement into the clay layer. Clay layer was also very wet.

Soil macro-fauna comprised a single large bronze beetle (*Eucolaspis* sp.) specimen and additional elytra present at 10 cm depth. Mycorrhizal fungal hyphae were abundant in the 10 cm organic layer.

Sample 8-2: Temperature 23.0 ^{o}C.

Very thin litter layer overlaying 0.5 cm of organic material and a root mat of 10 cm depth. Remaining profile made up of a massive clay (quite wet).

Soil macro-fauna comprised a click beetle larva *Conoderus exsul* at 1 cm depth.
No soil macro-fauna were observed below 1 cm depth.
Mycorrhizal fungal hyphae were abundant in upper 10 cm.

Sample 8-3: Temperature 26.3 ^{o}C.

Litter layer of approximately 1 cm depth overlaying 3 cm of very dark organic matter. A massive structure (impervious) formed at approximately 4 cm depth to the bottom of the profile. This appeared to be alluvial in nature. No root material present. Pronounced H_2S smell from sample.

No macro-fauna observed in litter or soil.

Sample 8-4: Temperature 24.7 ^{o}C.

Litter layer of 2 cm depth overlaying a further 2 cm of organic matter that appeared alluvial in origin. Plant roots were present throughout the entire profile. Base of sample was a massively structured clay.

Six bronze beetle elytra were present within the 2 cm organic layer amongst roots.

No soil macro-fauna were observed below the organic layer.
Mycorrhizal fungal hyphae abundant in upper 2 cm.

Sample 8-5: Temperature 24.6 ^{o}C.

Litter layer of 3 cm depth overlaying an organic layer of 1 cm depth. The remaining profile comprised a layer of clay. Roots did not penetrate further than the 4 cm depth.

No macro-fauna observed in litter or soil.
Mycorrhizal fungal hyphae abundant in upper 4 cm.

3.3 Te Kopia Geothermal Field

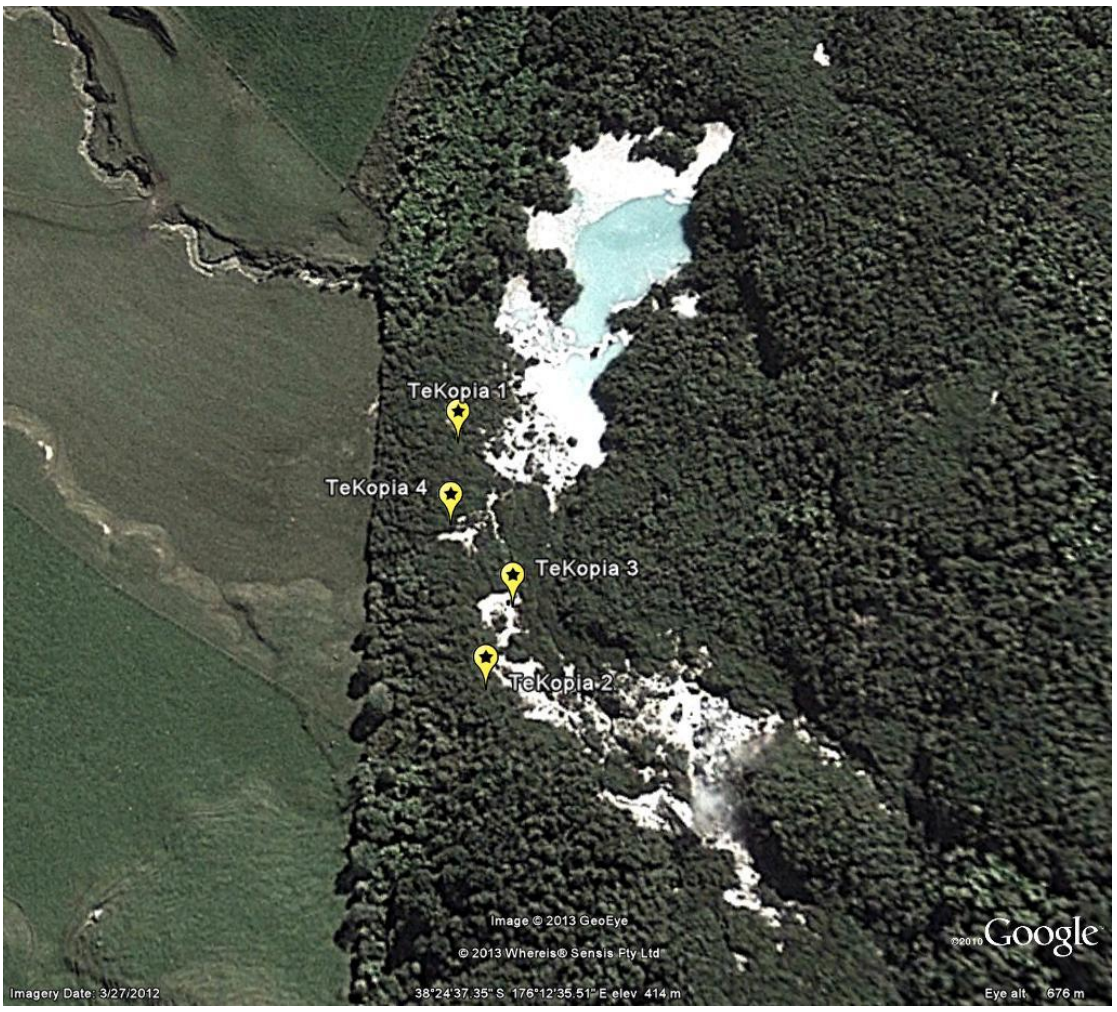

Figure 6: location of sample sites at Te Kopia Reserve (Te Kopia Geothermal Field)

3.3.1 SITE 9: Te Kopia 1

38^{o} 24’ 619S 176^{o} 12’ 556E ± 5 m
Altitude: 410 m

Site quality ranking: 4
Site protected and relatively intact, but deer tracking extensive in places

Vegetation Type:
Prostrate kanuka/mingimingi scrub

Canopy:
Dense cover of prostrate kanuka 1-2 m tall. Abundant lichen growth on shrubs (moist site with a lot of steam from active features). Quite a bit of standing-dead debris. Some mingimingi in canopy. *Korthalsella* present

Understorey:
Underlayer mainly prostrate kanuka, with *Dianella nigra*, *Pyrrosia elaeagnifolia*, and mingimingi.

Ground cover (0 – 50 cm):
Abundant mosses, liverworts and lichens.

General description of sample area:
Sample sites were all located at the foot of a steep scarp. Samples were taken along each transect in the direction from the edge nearest farmland towards the scarp (generally eastward). Prostrate kanuka in full flower - no bees observed in sample area.

Photo 2: prostrate kanuka-mingimingi scrub at Te Kopia reserve (sample site 1)

Photo 3: typical sample within sample area 9 showing moss/liverwort layer and dense root mat overlaying clay

Sample 9-1: Temperature 33.8 ^{o}C.
Fairly open canopy.
Dense surface layer of mosses and liverworts (not much litter). Root mat depth >3 cm, under which is a subsoil of a massively structured white/grey clay.
One Manuka beetle sp. (adult – dead) present in the root mat.
Mycorrhizal fungal hyphae abundant in upper layers.

Sample 9-2: Temperature 35.9 ^{o}C. (34.1 ^{o}C just beneath surface)
Dense canopy. A thick layer of moss/liverwort on the surface and not much litter. Over 3 cm depth of dense root mat beneath surface under which the subsoil is a massively structured white/grey clay.
No macro-fauna observed in litter or soil.

Sample 9-3: Temperature 35.3 ^{o}C.
Dense canopy. Soil surface covered in moss, liverwort and lichen (*Ramalina* sp.) growing on small sticks which also comprises a portion of the litter. 5 cm of dense root mat beneath litter grades into a subsoil of grey/white fine clay.
No macro-fauna observed in litter or soil.

Sample 9-4: Temperature 37.0 ^{o}C.

Dense canopy. Ground surface covered in mosses and liverworts beneath which is a 3 cm litter layer. Soil beneath is a grey/white fine clay.

Soil maco fauna were confined to the root mat (1 cm depth) and included bronze beetle elytra (approximately 10 mm in length).

Mycorrhizal fungal hyphae patchy in the organic layer.

Sample 9-5: Temperature 36.3 ^{o}C.

Semi-open canopy. Ground surface covered in 2 cm of moss/liverwort over 2 cm of tightly packed litter containing all the root material. Soil beneath is a grey clay with massive structure

No macro-fauna observed in litter or soil.

Mycorrhizal fungal hyphae abundant in upper layers

3.3.2 SITE 10: Te Kopia 2

38^{o} 24' 634S 176^{o} 12' 567E ± 5 m
Altitude: 418 m

Site quality ranking: 4
Site protected and relatively intact, but deer tracking extensive in places

Vegetation type:
Kanuka/mingimingi-manuka scrub

Canopy:

Variable, ranging from completely closed canopy to open patches. Canopy dominated by tall kanuka (4-5 m) with mixed with mingimingi, manuka and mapou.

Understorey:

Fairly open dominated by kanuka, and an even mix of mingimingi, mapou, manuka and prickly mingimingi.

Ground cover (0 – 50 cm):

Dense cover of mosses/liverworts, ferns (*Asplenium polyodon, Pyrrosia elaeagnifolia*), *Dianella nigra* and seedlings of canopy species. Localised steaming vents nearby with *Dicranopteris linearis* growing in the steam zone.

General description of sample area:
Sample sites were all located at the foot of a steep scarp. Samples were taken along each transect in the direction from the edge nearest farmland towards the scarp (generally eastward). Prostrate kanuka in full flower. Native bees scarce, but abundant adult *Pyrenota* beetles were present in the kanuka. Deer sign present.

Sample 10-1: Temperature 37.8 ^{o}C (Temperature on bare soil 35.5 ^{o}C)

Sample taken in an open patch of scrub forest.

Moss/liverwort covered surface to a depth of approximately1 cm. Root mat beneath to depths of 0.5-2 cm. Base is a white clay subsoil.

No macro-fauna observed in litter or soil.

Sample 10-2: Temperature 34.7 ^{o}C.

Closed canopy.

Surface fully covered in mosses/liverworts over 5 cm of litter/root mat. Upper layer slightly elevated above the white clay subsoil beneath.

Macro-fauna present within the root mat included bronze beetle (elytra only) and egg mass

Sample 10-3: Temperature 29.7 ^{o}C.

Closed canopy

Soil surface cover moss to 1 cm deep over 5 cm of litter/root mat. Base material a white clay.

Macro-fauna present: Manuka beetle sp. (elytra only) at a depth of approximately 2 cm within the litter/root layer

Sample 10-4: Temperature 33.1 ^{o}C.

Closed canopy

Soil surface cover 1 cm of moss over 4 cm of root mat/litter. Remainder is a white clay.

No macro-fauna observed in litter or soil.

Mycorrhizal fungal hyphae patchy throughout the root mat layer.

Sample 10-5: Temperature 32.9 ^{o}C.

Closed canopy (with abundant adult Manuka beetle present).

Soil surface fully covered with moss/liverwort to a depth of approximately 1 cm deep, over 2 cm root mat/litter on a base of white clay.

Elytra of both Manuka beetle and bronze beetle observed at the base of the moss layer (at approximately 1 cm depth).

Mycorrhizal fungal hyphae patchy throughout the root mat layer.

3.3.3 SITE 11: Te Kopia 3

38^{o} 24' 634S 176^{o} 12' 577E ± 6 m

Altitude: 423 m

Site quality ranking: 4

Site protected and relatively intact, but deer tracking extensive in places

Vegetation type:

Prostrate kanuka shrubland

Canopy:

Low prostrate kanuka (height approximately 50 cm-1 m) interspersed with occasional mingimingi.

Understorey:

Not well defined - mainly branches and debris of the canopy species.

Ground cover (0 – 50 cm):

Variable cover of mosses and lichens.

Photo 4: prostrate kanuka cover (foreground) at Te Kopia

General description of sample area:
Site is located approximately 40 m distant from a hot lake. Prostrate kanuka dominates the immediate area of around 0.5ha. The dense vegetation cover is interspersed by bare soil field and ephemeral flow paths. *Trentepohlia* covers low branches nearest ground. Manuka beetle adults abundant in the canopy. Deer tracks present and there are many obvious pathways through low scrub and soil field.

Sample 11-1: Temperature 32.1 ^{o}C (Temperature on bare soil 35.5 ^{o}C)
Prostrate kanuka canopy, approximately 80% cover. Dense soil surface cover of *Dicranoloma* sp. and other mosses (2-3 cm) over a root mat between 2-4 cm thick. Base material a light coloured massively structured clay.

Soil macro-fauna: bronze beetle (elytra only) in root mat.

Sample 11-2: Temperature 31.7 ^{o}C.
Prostrate kanuka canopy. Fine surface cover of mosses (~1 cm) over 2 cm of root mat with a light coloured clay base.

Soil macro-fauna: manuka beetle (elytra only) in root mat. No evidence of root feeding.

Sample 11-3: Temperature 34.9 ^{o}C.
Prostrate kanuka canopy. Soil surface 30% varied cover of *Cladonia* sp. lichens, *Campylopus* sp. and *Dicranoloma* sp. mosses and litter to a height of 2 cm over 3-4 cm depth of root mat. Base material light coloured clay.

No macro-fauna observed in litter or soil.

Sample 11-4: Temperature 35.6 ^{o}C.
Prostrate kanuka canopy with adult manuka beetle present in the foliage.
Soil surface 100% cover of mosses (~1 cm) over a 3-4 cm root matt.
Base material light coloured clay.

Soil macro-fauna: manuka beetle (elytra only) present in the root mat. No evidence of root feeding.

Sample 11-5: Temperature 43.6 ^{o}C.
Prostrate kanuka canopy – very stunted (approximately10 cm tall)
Soil surface cover of mosses around 2-3 cm in height over a root mat 3-4 cm deep. Base material -- light coloured clay.

Soil macro-fauna: bronze beetle (dead adult) present in the root mat.

3.4 SITE 12: Te Kopia 4

38^{o} 24' 625S 176^{o} 12' 562E ± 6 m
Altitude: 414 m

Site quality ranking: 3
Site is protected and relatively intact, but deer tracking is extensive and dung/trampling abundant in places.

Vegetation type:
Prostrate kanuka shrubland
Canopy:
Prostrate kanuka (<1 m height)
Understorey:
Not clearly defined – mainly branches of canopy shrubs
Ground cover (0 – 50 cm):
Either none, or a variable cover of mosses (*Campylopus* sp.) and lichens (*Cladonia* spp.).

Photo 5: prostrate kanuka shrubland at Site 12 – Te Kopia Reserve

Site quality ranking: 3
Site protected and relatively intact, but deer tracking is extensive in places and signs of browse and dung present.

General description of sample area:
An area of prostrate kanuka (<1 m height) adjacent to small hot lake - interspersed with patches of bare soil field and patches of *Campylopus* moss and *Cladonia* lichens. Deer sign (prints and dung) present. Abundant manuka beetle present in the canopy.

Sample 12-1: Temperature 33.1 ^{o}C
Canopy cover 100% prostrate kanuka with dense undergrowth

Litter layer 1 cm thick over a root mat of 1 cm. Base material a light coloured clay.

Soil macro-fauna comprised a single manuka beetle adult in the root mat.

Sample 12-2: Temperature 38.7 ^{o}C.

Canopy is dense low prostrate kanuka with manuka beetle adults abundant in foliage.
Soil surface cover very sparse *Campylopus* sp. moss over 1 cm root mat/litter layer and the remaining sample a light coloured clay.

No macro-fauna observed in litter or soil.
Note manuka beetle was most abundant in the foliage where ground temperatures were lowest.

Sample 12-3: Temperature 40.3 ^{o}C.

Canopy of dense prostrate kanuka with adult manuka beetles present in foliage.
Litter layer of 0.5 cm over 1 cm depth of root mat. Mosses absent on surface.

No macro-fauna observed in litter or soil.

Sample 12-4: Temperature 45.7 ^{o}C.

100% cover of prostrate kanuka. Ground surface also supports full cover of mosses approximately 1 cm in height (includes *Campylopus* sp.). Depth of root mat is around 2 cm and remaining profile is clay.

No macro-fauna observed in litter or soil.

Sample 12-5: Temperature 37.9 ^{o}C.

Prostrate kanuka canopy (100% cover); soil surface with around 20% cover of mosses including *Campylopus* sp.; underlaying root mat formed to a depth of 1 cm thick; remaining profile is light coloured clay.

Soil macro-fauna: manuka beetle elytra present in the root mat.

3.5 Orakeikorako Geothermal Field

Figure 7: Location of Orakeikorako sample site 13 (Orakeikorako Geothermal Field)

3.5.1 SITE 13: Orakei-Korako

38^{o} 28' 444S 176^{o} 08' 904E ± 6 m
Altitude: 295 m

Site quality ranking: 3
Site protected, but modified (tourist track construction and maintenance, weeds present)

Vegetation type:
Prostrate kanuka-mingimingi scrub

Canopy:
Prostrate kanuka approximately up to 4 m tall with scattered mingimingi

Understorey:
Diverse mixture of prostrate kanuka, mingimingi, and fivefinger

Ground cover (0 – 50 cm):
Tangle fern (*Dicranopteris linearis* var.*linearis*), inkberry/turuturu (*Dianella nigra)*, arching clubmoss (*Lycopodiella cernua*), whisk fern (*Psilotum nudum*), mosses (*Campylopus* sp.) and lichens (*Cladonia* spp.). Leaf litter and fallen branches prominent.

General description of sample area:
Site located alongside a well-formed tourist track. Presence of buried topsoil indicates site has been subject to disturbance in the near past (localised geothermal activity or possibly also alteration during construction of track).

Sample 13-1: Temperature 26.7 ^{o}C
Prostrate kanuka canopy around 2 m tall. Soil surface cover 0.5 cm tall *Cladonia* sp. lichens. Underlaying root mat extends to a depth of 2-3 cm. A

well-formed B horizon is present between 3-4 cm and remaining profile is a yellow ash sub-soil. Plant roots extend into the subsoil layer.

Soil macro-fauna: a single *Conoderus exsul* (click beetle) adult. Mycorrhizal fungal hyphae abundant in upper layers.

Sample 13-2: Temperature 28.9 ^{o}C.

Prostrate kanuka canopy around 2 m tall. Soil surface clear with no living matter. This is underlain by a 5 cm root mat. A well formed B horizon beneath that sits over a base of yellow ash.

Soil macro-fauna: elytra of bronze beetle present in root mat.

Sample 13-3: Temperature 34.9 ^{o}C.

Prostrate kanuka canopy around 4 m tall with adult manuka beetles present. on the foliage. Soil surface has a sparse cover of litter and moss overlaying 3-4 cm of root mat. Base of sample is an apricot coloured clay.

Mycorrhizal fungal hyphae abundant in root mat.

Sample 13-4: Temperature 33.5 ^{o}C.

Prostrate kanuka canopy around 4 m tall. Approximately 1 cm depth of litter and root mat overlaying a subsoil of yellow ash.

No macro-fauna observed in litter or soil.

Sample 13-5: Temperature 36.7 ^{o}C.

Prostrate kanuka canopy around 3.5 m tall. Mosses dominate surface cover and overlay 2-4 cm depth of root mat. B horizon (1 cm thick). Base is a yellow ash.

Soil macro-fauna: bronze beetle elytra in root mat. Abundant Mycorrhizal fungi also present.

3.6 Ohaaki Geothermal Field

Figure 8: Location of Ohaaki East (sample site 14).

3.6.1 SITE 14: Ohaaki East 1

38^{o} 32’ 365S 176^{o} 19’111E ± 5 m
Altitude: 321 m

Site quality ranking: 3
Site is infested with weeds (pine, broom and introduced grasses) and has had a history of mechanical disturbance.

Vegetation type:
Prostrate kanuka shrubland
Canopy:
Short prostrate kanuka (average height around 0.5 m). Vegetation cover very dense in the area sampled.
Understorey:
Undefined due to low height of canopy – dense branch cover to ground level.
Ground cover (0 – 50 cm):
Mosses (mainly *Campylopus* sp.) abundant within canopy gaps and open edges. *Trentepohlia* alga present on low branches throughout.

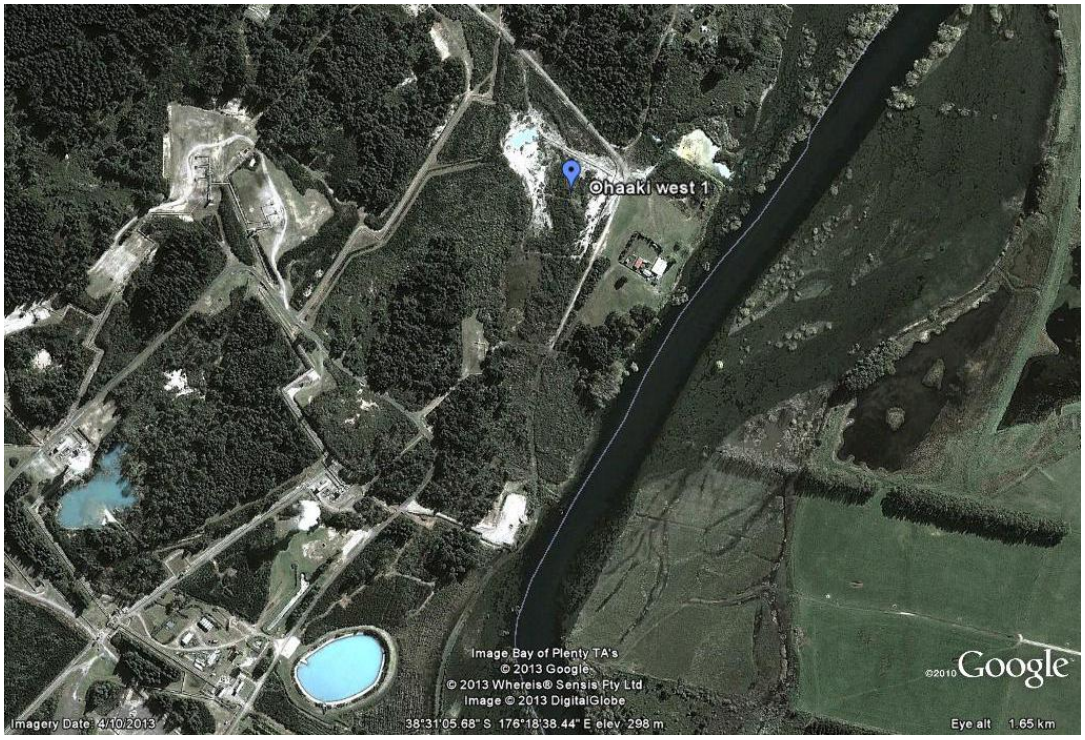

Figure 9: Location of Ohaaki West (sample site 15).

General description of sample area:
Site is on gently sloping ground with prostrate kanuka and mosses dominating the cover and patches of raw soil field throughout. Active features are nearby (within 10 m of the sample site). Prostrate kanuka was in full flower at the time of visit and abundant native bees and honey bees were working the flowers. Manuka beetle were also abundant in the vegetation.

Photo 6: Ohaaki East site looking north-east over prostrate kanuka.

Sample 14-1: Temperature 44.7 ^{o}C

Prostrate kanuka canopy cover 100%. Moss cover at 1 cm height sits over a very dense 2 cm thick layer of litter and root mat. Base of sample is a yellow ash (with some organic material towards its top end)

Mycorrhizal fungi abundant through root mat layer.
No macro-fauna observed in litter or soil.

Sample 14-2: Temperature 48.9 °C.

Prostrate kanuka canopy cover 100%. Moss cover at 0.5 cm height sits over a very dense 2-3 cm thick layer of litter and root mat. Remaining profile is a yellow ash (very hot).

Mycorrhizal fungi abundant through root mat layer.
No macro-fauna observed in litter or soil.

Sample 14-3: Temperature 38.7 °C.

Prostrate kanuka canopy cover 100%. Moss cover at 0.5 cm height sits over a very dense 2-3 cm thick layer of litter and root mat. Remaining profile is a yellow ash.

Soil macro-fauna: manuka beetle elytra in root mat layer.

Sample 14-4: Temperature 40.9 °C.

Prostrate kanuka canopy 100%. Sparse cover of moss (0.5 cm height) sits over a very dense 2-3 cm thick layer of litter and root mat. Remainder of profile is a brownish ash.

No macro-fauna observed in litter or soil.

Sample 14-5: Temperature 43.7 °C.

Kanuka canopy 100%. Mosses cover approximately 10% of surface. This is underlain by a dense 2-3 cm root mat. Remaining profile is a brownish ash.

Soil macrofauna: Adult Thrips
Mycorrhizal fungi abundant through root mat layer.

3.7 SITE 15: Ohaaki West

38° 31' 042S 176°18' 659E ± 5 m
Altitude: 306 m

Site quality ranking: 2
Very degraded site - many weeds present, tracks (vehicle) and clearance areas and modified drainage (channel). Signs of pest animals (rabbit).

Vegetation type:
Manuka shrubland

Canopy:

Open canopy of manuka (3-4 m tall) with scattered prickly mingimingi (*Leptecophylla juniperina* subsp.*juniperina*), maritime pine *(Pinus pinaster*), pampas and Spanish heath (*Erica lusitanica*).

Understorey:

Manuka, prickly mingimingi, blackberry (Rubus fruticosus agg.),pampas, *Cotoneaster glaucophyllus*, Spanish heath and maritime pine

Ground cover (0 – 50 cm):

Seedlings of manuka, prickly mingimingi, Spanish heath and *Cotoneaster*. Sundew (*Drosera auriculata*) also abundant with mosses (*Campylopus* sp.) and lichens (*Cladonia* sp., *Cladina leptoclada*).

General description of sample area:
The sample area sits on an extensive sinter terrace near (within 30 m) an active boiling pool. The site supports a high density of weed species and has been subject to extensive modification in recent times (tracks, vegetation clearance, hydrological changes). Manuka (the dominant native species here) was in flower at the time of the

site visit. Manuka beetle were abundant. Outlet of geothermal spring: pH 8.7, Temperature 60°C.

Sample 15-1: Temperature 25.7 °C

Canopy of sparse manuka. Mosses and lichens occupy surface to a height of 2-3 cm. Hard sinter pan and coarse pumice beneath.

No macro-fauna observed in litter or soil. Manuka beetles (adults) abundant in the canopy foliage.

Sample 15-2: Temperature 24.2 °C.

Sample coincides with an open gap in the canopy. Sparse cover of mosses and organic material on the ground surface (0.25-0.5 cm layer) overlaying a coarse pumice (sinter layer > 15 cm)

No macro-fauna observed in litter or soil.

Sample 15-3: Temperature 24.3 °C.

Manuka canopy cover around 50%. Very sparse cover of mosses on the ground surface overlaying 0.5 cm of organic matter and 10 cm coarse pumice. Sinter layer presents at 10 cm depth (plant roots do not penetrate through sinter layer).

Macro-fauna: a single manuka beetle larva (3rd instar) at approximately 5 cm depth (voucher specimen collected).

Sample 15-4: Temperature not given.

Manuka canopy cover around 50%. Very sparse cover of mosses on the ground surface overlaying 0.5 cm of organic matter and 10 cm coarse pumice. Sinter layer presents at 10 cm depth (plant roots do not penetrate through sinter layer).

Macro-fauna comprised two manuka beetle (1 larva and 1 adult female) in the coarse pumice layer. The adult female was laying eggs.

Sample 15-5: Temperature 22.3 °C.

Manuka canopy around 70% cover. Mosses and manuka seedlings on the surface sit above 1 cm organic matter and 7 cm coarse pumice. Impenetrable sinter layer presents at 8 cm.

No macro-fauna observed in litter or soil.

3.8 Rotokawa Geothermal Field

Figure 10: Location of sample sites 16 and 17 within the Rotokawa geothermal field.

3.8.1 SITE 16: Rotokawa 1

38^{o} 37' 450S 176^{o}11' 795E ± 5 m
Altitude: 332 m

Site quality ranking:2
Extensively modified with vehicle tracks/bulldozed areas, vegetation clearance and a high proportion of weedy species present.
Vegetation type: Mingimingi-manuka-prostrate kanuka scrub

Canopy:

Mingimingi, manuka and prostrate kanuka mix up to approximately 4 m tall. Cover varies between 50 – 100%.

Understorey:

Dense cover of manuka, prostrate kanuka and snowberry (*Gaultheria antipoda*) growing in and around piles of pine slash.

Ground cover (0 – 50 cm):

Pine slash abundant. Live plant component includes snowberry, mingimingi/manuka/prostrate kanuka seedlings, bracken (*Pteridium esculentum*), prickly mingimingi, inkberry, lichens (Cladonia sp., Cladia aggregata) and mosses (Campylopus sp.)

General description of sample area:
Patches of dense regrowth - low vegetation occur in amongst extensive areas of bare soil field (these being either cleared or naturally bare). Felled pine debris is present throughout the area (pines have been targeted in recent weed control operations).

Indigenous vegetation is in the process of re-establishing. Bronze beetle and manuka beetle were both abundant in the manuka.

Sample 16-1: Temperature 18.5 ^{o}C

Canopy approximately 2 m tall with cover of around 100%. Approximately 2-3 cm depth of leaf litter overlays an ash base. No organic layer present in the soil. Plant roots extended to bottom of sample (15 cm).

Macro-fauna: elytra of grass grub (*Costelytra zealandica*) present at the top of the litter layer

Sample 16-2: Temperature 17.3 ^{o}C.

Canopy approximately 2 m tall with cover of around 50%. Surface lichens (*Cladonia* sp., *Cladia aggregata*) sit atop a litter layer of 0.5 cm depth. Remaining profile is coarse pumice.

Adults of both bronze beetle and manuka beetle were present in the canopy foliage. Manuka beetle and grass grub adult forms were also present on the ground surface. Pre-pupal form of manuka beetle was present in the root mat.

Sample 16-3: Temperature 18.2 ^{o}C.

Canopy approximately 2 m tall with cover of around 50%.
Soil surface cover 25% of lichens (*Cladonia*, *Cladia* agg) and moss (*Campylopus*) over a root mat 0.5-4 cm on coarse pumice

Macro-fauna: Large numbers of bronze beetle present in the canopy foliage. Manuka beetle elytra present in the root mat.

Sample 16-4: Temperature 19.1 ^{o}C.

Canopy cover 70% (prostrate kanuka). 10% cover of vegetation at the soil surface. Moss (*Campylopus* sp.) and lichens (*Cladonia* sp. and *Baeomyces* sp.) overlay 0.5 cm of litter. Remaining profile depth is a pumice mineral soil (plant roots penetrate to 15 cm).

Macro-fauna: Large numbers of manuka beetle and bronze beetle adults present in the canopy foliage, but no macro-fauna observed in litter or soil.

Sample 16-5: Temperature 19.3 ^{o}C.

Canopy cover around 80% comprising 3 m tall prostrate kanuka. Scattered mosses present on the ground beneath. An 0.5 cm litter layer comprising loose leaf material overlays a root mat of 1-3 cm depth. Remaining profile depth is a coarse pumice soil with plant roots penetrating through 15 cm.

Macro-fauna: abundant manuka beetle and bronze beetle adults present in the canopy foliage, along with active native and honey bees and bumble bees. No macro-fauna observed in litter or soil.

3.8.2 SITE 17: Rotokawa 2

38º 37' 30" S 176º 11' 53" E ± 5 m
Altitude: 335 m

Photo 7: prostrate kanuka shrubland at sample site 17 (Rotokawa).

Site quality ranking:

Vegetation type: Prostrate kanuka shrubland

Canopy:

Prostrate kanuka of varying height (30 cm – 1 m) dominates. Mingimingi and monoao (*Dracophyllum subulatum*) present but uncommon in the immediate area.

Understorey:

Not well defined – similar composition as the low canopy.

Ground cover (0 – 50 cm):

Variable cover of mosses (*Campylopus* sp.) and lichens (*Cladonia* sp)

General description of sample area:

Prostrate kanuka dominates the low canopy. Cover is variable with patches of bare soil occurring throughout. The site is located within 10 m of an active feature and is part of an area that has been extensively modified in recent times (tracks, re-contouring and vegetation clearance). Bronze beetle and manuka beetle were both abundant in the prostrate kanuka on the day of the site visit.

Sample 17-1: Temperature 24.6 ^{o}C

Prostrate kanuka canopy cover at 100%. Mosses and lichens (height 0.5 cm) cover approximately 30% of ground surface with the remainder occupied by a thin layer of leaf litter. Profile formed entirely of a coarse, pinkish coloured pumice soil.

Adult manuka beetle and bronze beetle abundant in the foliage. Mycorrhizal fungal hyphae present just below ground surface.

Sample 17-2: Temperature 23.2 ^{o}C.

Canopy cover around 100%. Surface cover 50:50 lichens/moss: leaf litter. Shallow organic layer (<0.5 cm) overlays clay and pumice soil.

Macro-fauna: manuka beetle and bronze beetle adults present in the foliage. Manuka beetle pupae (dead – attacked by fungus) were present in the pumice layer. Mycorrhizal fungal hyphae present at the interface between organic layer and pumice.

Sample 17-3: Temperature 37.5 ^{o}C.

Very stunted dense (100% cover) canopy of prostrate kanuka (approximate height 30 cm). Soil surface (emitting steam) comprised a thin litter layer with root material overlaying a pumice/clay subsoil.

Macro-fauna: bronze beetle present in the canopy foliage. Mycorrhizal fungal hyphae present in the litter/root mat.

Sample 17-4: Temperature 35.1 ^{o}C.

Dense (100% cover) stunted canopy of prostrate kanuka (approximate height 50 cm). 100% cover of lichens and moss on surface overlays a 4 cm thickness of litter and root mat. Remaining profile is a coarse pumice (multi-coloured: yellow/orange/red/pink).

Macro-fauna: bronze beetle present in the canopy foliage. Mycorrhizal fungal hyphae present in the litter/root mat.

Sample 17-5: Temperature 31.7 ^{o}C.

Dense (100% cover) stunted canopy of prostrate kanuka and mingimingi. 80% cover of lichens (up to 1 cm tall) and mosses overlay a 1 cm thickness of litter and root matt. Base material is a coarse yellow pumice.

Macro-fauna: grass grub elytra present in the root mat. Mycorrhizal fungal hyphae also present in the litter/root mat.

3.9 Wairakei Geothermal Field

Figure 11: Location of sample sites 18 – 21 at Craters of the Moon - Karapiti (Wairakei geothermal field).

3.9.1 SITE 18: Craters of the Moon 1

38^{o} 38’717S 176^{o}04’ 190E ± 5 m
Altitude:451 m

Site quality ranking: 4
Extensive tracking (old and current) throughout, some weed issues in places (wilding pines, pampas, broom, buffalo grass). Pest animals present (possum, hares, rabbits). Entire area is vulnerable to changes driven by management of the Wairakei geothermal power plants.

Vegetation type:
Mingimingi-kanuka-manuka-karamu/bracken scrub

Canopy:
Dense canopy of kanuka, mingimingi and karamu (*Coprosma robusta*) mix approximately 2 – 3 m in height. Montpelier broom also present.

Understorey:
Similar composition as the canopy.

Ground cover (0 – 50 cm):
Abundant dead branches covered with *Usnea* lichens. Otherwise sparse cover of canopy species seedlings with bracken and Spanish heath. Hanging spleenwort (*Asplenium flaccidum*) and onion orchid (*Microtis uniflora*) also present.

General description of sample area:
Site is located near the main entrance track to the reserve but otherwise is relatively undisturbed. Some weedy species present.

Photo 8: Manuka beetle (*Pyronota* sp) in prostrate kanuka, Craters of the Moon/Karapiti.

Sample 18-1: Temperature 18.4 ^{o}C
Canopy cover of 2 m tall kanuka-mingimingi. Soil surface cover of mosses (1 cm height) over 4 cm depth of litter/root mat overlaying an ash soil. Buried topsoil at 7 cm depth. Roots penetrate through the entire 150 mm.

No macro-fauna observed in litter or soil.

Sample 18-2: Temperature 18.6 ^{o}C.
Open canopy cover <50% of kanuka. Soil surface cover of mosses (1 cm height) over 3 cm depth of litter/root mat overlaying an ash soil. Roots penetrate through the entire 15 cm profile.

No macro-fauna observed in litter or soil.
Mycorrhizal fungal hyphae abundant through litter/root mat.

Sample 18-3: Temperature 17.7 ^{o}C.
Kanuka canopy cover. Soil surface has 100% cover of moss and lichen (1 cm height) overlaying 3 cm depth of decomposing litter/root mat. Remaining depth of profile is an ash soil.

No macro-fauna observed in litter or soil.
Mycorrhizal fungal hyphae abundant through litter/root mat.

Sample 18-4: Temperature 18.9 ^{o}C.
Kanuka/mingimingi canopy. Soil surface has 100% cover of moss/lichen overlaying 4 cm depth of root mat/litter. Remaining depth of profile is an ash soil. Roots penetrate through the entire 15 cm profile.

Macro-fauna: abundant manuka beetle adults in the canopy foliage and elytra present in the root mat.
Mycorrhizal fungal hyphae abundant through litter/root mat.

Sample 18-5: Temperature 18.8 °C.
Canopy cover of mingimingi/kanuka. 2 cm moss/lichen on surface overlaying 2 cm depth of litter/root mat. Remaining depth of profile is an ash soil. Roots penetrate through the entire 15 cm profile.

Macro-fauna: abundant manuka beetle adults in the canopy foliage.

3.9.2 SITE 19: Craters of the Moon 2

38° 33' 781S 176°04'197E ± 5 m
Altitude: 448 m

Photo 9: prostrate kanuka shrubland at sample site 19 (Craters of the Moon – Karapiti)

Site quality ranking: 4
Extensive tracking (old and current) throughout, some weed issues in places (buffalo grass). Pest animals present (possum, hares, rabbits). Entire area is vulnerable to changes driven by management of the Wairakei geothermal power plants.

Vegetation type:
Prostrate kanuka shrubland

Canopy:
Low prostrate kanuka 30-50 cm tall.
Understorey:
Indistinct – mainly branches of prostrate kanuka.
Ground cover (0 – 50 cm):
Patchy *Campylopus capillaceus* moss. Occasional patches of lichens (*Cladina leptoclada, Cladonia* spp.) and arching clubmoss.

General description of sample area:
Dense low vegetation on a flat/ gently sloping site. Active features and patches of bare soil scattered throughout. Tourist tracks confined to a nearby boardwalk.

Sample 19-1: Temperature 38.5 °C
Prostrate kanuka cover of 100%. Mosses to heights of 2-3 cm cover the ground surface. Beneath lies 2-3 cm of root mat which ends abruptly in a light ash soil.

No macro-fauna observed in litter or soil.

Sample 19-2: Temperature 33.7 °C.

Prostrate kanuka cover of 100%. Ground surface cover includes 2-3 cm of moss and some lichens. Beneath lies 2-3 cm of root mat which ends abruptly in a light ash soil.

Manuka beetle adults abundant in foliage but no macro-fauna observed in litter or soil.

Sample 19-3: Temperature 33.4 °C.

Prostrate kanuka cover of 100%. Ground surface cover includes 0.5-1 cm of moss overlaying a 5 cm root mat. Light ash soil beneath.

Manuka beetle adults abundant in foliage but no macro-fauna observed in litter or soil.

Sample 19-4: Temperature 28.7 °C.

Prostrate kanuka cover of 100%. Ground surface 25% cover; includes lichen of heights 0.5-1 cm (*Cladia aggregata*). Litter virtually non-existent. Root mat of 0.5 cm thickness perched above a light ash soil.

No macro-fauna observed in litter or soil.

Sample 19-5: Temperature 34.6 °C.

Prostrate kanuka cover of 100%. Ground surface 25% cover; includes lichen (*Cladia aggregata*) and mosses (*Campylopus capillaceus*) of heights 0.5-1 cm. Litter virtually non-existent. Root mat of 2-3 cm thickness perched above a light ash soil.

No macro-fauna observed in litter or soil.

3.9.3 SITE 20: Craters of the Moon 3

38° 38' 751S 176°04'170E ± 5 m
Altitude: 451 m

Site quality ranking: 4
Extensive tracking (old and current) throughout, some weed issues in places (wilding pines, pampas, broom, buffalo grass). Pest animals present (possum, hares, rabbits). Entire area is vulnerable to changes driven by management of the Wairakei geothermal power plants.

Vegetation type:
Whauwhaupaku-kanuka/mingimingi scrub

Canopy:

Dense mix of 3-5 m tall five-finger-Whauwhaupaku (*Pseudopanax arboreus*), mingimingi and kanuka.

Understorey:

Diverse mixture including five-finger, mingimingi and kanuka saplings with prickly mingimingi, karamu, mapou (Myrsine australis) and bracken also present.

Ground cover (0 – 50 cm):

Seedlings of canopy and understorey species with a mix of ferns (bracken, hound's tongue, spleenwort) and inkberry/turuturu.

General description of sample area:
An island of taller vegetation between areas of prostrate kanuka shrubland. Tourist tracks pass close by site. Old (cut) pine tree stumps present within the site. Blackberry prominent.

Sample 20-1: Temperature 19.5 ^{o}C

Canopy cover 100%. Soil surface cover of leaf litter (0.5-1.5 cm depth) overlays a root mat thickness of 3-4 cm. Base of profile is an ash soil. Plant roots penetrate through to the base of the sample.

Macro-fauna: elytra of manuka beetle and bronze beetle present in litter and root mat only.
Mycorrhizal fungal hyphae abundant through litter/root mat.

Sample 20-2: Temperature 18.8 ^{o}C.

Canopy cover 100%. Leaf litter layer 0.5-1 cm overlaying a light ash soil. Roots penetrating to base of sample.

No macro-fauna observed in litter or soil.

Sample 20-3: Temperature 18.2 ^{o}C.

Canopy cover 100%, with some blackberry present in the mix, and evidence this was once a more open site (fern roots). Soil surface includes 1 cm litter layer, with a mixed litter and fern roots down to 15 cm.

No macro-fauna observed in litter or soil.

Sample 20-4: Temperature 17.8 ^{o}C.

Open canopy under kanuka with bracken and Spanish heath in the gap.
Soil surface cover includes 2-3 cm moss over a 2-3 cm root mat with an abrupt transition into an ash soil layer.

No macro-fauna observed in litter or soil.

Sample 20-5: Temperature 17.8 ^{o}C.

Canopy cover 100%, with 0.5 cm moss/lichen on the soil surface. Standard soil/ash subsoil occupies the remaining sample profile.

Macro-fauna: Cicada (larval stage) at 150 mm.

3.9.4 SITE 21: Craters of the Moon 4

38° 38'624S 176°04'178E ± 5 m
Altitude: 470 m

Photo 10: prostrate kanuka merging into whauwhaupaku scrub on a hillslope at Craters of the Moon – Karapiti

Site quality ranking: 3
Extensive tracking (old and current) throughout, some weed issues in places (wilding pines, broom,). Pest animals present (possum, hares, rabbits). Entire area is vulnerable to changes driven by management of the Wairakei geothermal power plants.

Vegetation type:
Whauwhaupaku-kanuka/mingimingi scrub

Canopy:
Dense mix of five-finger, mingimingi and kanuka

Understorey:
Dense mix of canopy species with Montpelier broom, karamu, prickly mingimingi, bracken and blackberry.

Ground cover (0 – 50 cm):
Abundant litter and branches with a variety of lichens (Usnea, Parmelia sp., Cladina leptoclada), ferns (bracken, hanging spleenwort, *Dicranopteris linearis, Gleichenia dicarpa*).

General description of sample area:
Located on a steep slope uphill from tourist tracks. Some active features nearby and evidence of previously active areas. Hillslope area has many weeds present.

Sample 21-1: Temperature 17.5 °C
Canopy cover 100%, Soil surface cover of moss/lichen to approximately 0.5 cm height overlaying a 3-4 cm root mat. Yellow/grey ash soil forms the base of the sample. Plant roots penetrated the full depth to 15 cm. Evidence that the sample site was an old fumarole, but this is now well grown over.

A single native bee was observed in the canopy but no macro-fauna were present in the litter or soil.

Sample 21-2: Temperature 15.9 ^{o}C.
Canopy cover 100%. Soil surface cover comprised a loose layer of litter with a lot of dead bracken material sitting on top. A root mat of 3-4 cm depth overlaid the ash soil forming the base of the sample. Plant roots penetrated the full sample depth of 15 cm.

No macro-fauna observed in litter or soil.

Sample 21-3: Temperature 15.2 ^{o}C.
Canopy cover 100%. Sparse cover of lichens on top of a thin layer of litter.
A root mat of 8-10 cm depth overlaid the ash soil forming the base of the sample.

No macro-fauna observed in litter or soil.

Sample 21-4: Temperature 15.8 ^{o}C.
Canopy cover 100%. Soil surface with a thin litter layer. A root mat of 8-10 cm depth root mat overlaid the ash soil forming the base of the sample.

Macro-fauna: one live female manuka beetle adult at 10 cm depth in the ash soil.
Mycorrhizal fungal hyphae present in the root mat.

Sample 21-5: Temperature 15.9 ^{o}C.
Canopy cover 100%. 0.5 cm litter layer above a root mat of 3-5 cm depth. Base of the sample an ash soil.

No macro-fauna observed in litter or soil.

4 Discussion

The vegetation types chosen for sampling were generally a good fit to the geothermal vegetation classes recognised by Wildlands (2011) and with recent work by Landcare Research (WRC report in preparation 2013) which describes sixteen vegetation associations for the Taupo Volcanic Zone. Seven vegetation types were sampled in the current study. Whilst these represent only a small proportion of the many vegetation classes recognised by Wildlands, and around one-third of those recognised by Landcare, the sampled range is well aligned with the broad structural classes of woody vegetation associated with geothermal areas in the Waikato Region. Results of the present pilot study indicate that further investigations of soil macro-fauna in a greater range of geothermal vegetation classes are warranted, specifically to help better inform management actions around maintenance of environmental services and habitat.

The five-category site-quality ranking developed for this study classifies the sites relative to disturbance (human related activity; direct and indirect), including physical disturbance to the site and the ingress of weedy plants and pest animals, with these criteria ranging from not present to active incursion. These factors may be judged from a visual inspection with little or no site disturbance required. The tool simplifies the assessment of priorities put forward by Bycroft et *al.* (2011).

Whilst Bycroft et *al.* (2011) identifies priorities for pest control and fencing on a site-by-site basis, it does not adequately recognise the inherent fragility of the vegetation (including the root mat structure and how this might be protected), the special nature of the soils, soil processes and soil macro-fauna in each system, nor does it assess each site in the context of the surrounding landscape and land-use pressures. We don't

question the role of animal pest control or the protective role of fencing, but do question whether the weed pests become a problem because the geothermal habitats are inherently fragile/susceptible to invasion, or that the weeds are so aggressive that they invade anyway. We suggest that all this information be integrated within a decision tool to form a strategy for managing geothermal biodiversity, with a view to prioritising management objectives that provide best value for resource investment.

While not the role of this report, the implications in terms of buffering to protect fragile geothermal habitats from perturbations and addressing connectivity between systems to enhance resilience raise more questions than answers. From a biodiversity manager's point of view, recognising this fragility and understanding the implications of disturbance on these systems would be a first step in devising a management plan, along with commissioning research to address knowledge gaps about the role of the kanuka root mat, nutrient cycling and soil macro-fauna habitat.

Initially this could target the role and dimensions of buffers to increase the resilience of what are currently many island geothermal ecosystems. Currently adjoining areas may be pasture, exotic forestry or native vegetation. Ranking the quality of individual sites with respect to adjoining land-use could be a good start point and a project that could be scoped up based on either geo-photo analysis and/or field assessment.

This information would lead to identifying sustaining linkages between both geothermal and non-geothermal plant and animal communities. Pollination is a service that comes to mind for consideration. Some sites will have to be managed for native bee habitat while others may offer opportunities for managed honey bee hives for the commercial harvest of manuka honey. For the latter licensing might be considered to ensure hives were installed annually. Increasing farming intensity, particularly dairying, has lead to broad acre use of insecticides to control pasture pests. Misuse may have severe impacts on bee populations, both native and honey bee.

A significant physical feature of the root substrate at the majority of the sites sampled was the presence of undecomposed litter within which the roots, both alive and dead, were confined in the form of a mat. In some instances this root mat was elevated above the mineral soil by 2 – 4 cm and in most instances the roots did not penetrate the mineral soil. In browntop (*Agrostis capillaris*) pasture soils a root mat usually indicates the absence of soil macro-fauna that feed on and process live and dead root material as part of a nutrient cycling process (B. Willoughby personal observation). Tropical soils developed at high temperature exhibit root mats that result from fluctuating water tables depositing Ca, Mg and Al in toxic concentrations (Kingsbury and Kellman 1997). This may be an explanation where geothermal waters reach near the soil surface. The absence of soil macro-fauna at the sites sampled in the course of this survey may be a result of toxicity and/or temperature. As earthworms are primary agents for nutrient cycling and mineral soil formation the fact that none were detected in the course of this survey begs the question as to how nutrients are cycled in geothermal soils under native vegetation. The absence of predatory insects (e.g. from the families Staphylinidae and Carabidae) and their prey (e.g. Order Collembola) in the root mat and litter is also significant, indicating that the nutrient cycling processes in soils developed over geothermal heating do not resemble what might be seen as a 'normal' soil process.

In considering how the flora of geothermal areas might best be managed the apparently unique 'soil' environment must be considered. There are processes important to the maintenance of the flora in terms of nutrient cycling that are yet to be elucidated,particularly with respect to the role of the ectomycorrhiza *Pisolithus* sp. This fungal genus has been shown as effective in improving plant growth in dry soils with high soil temperatures (Garbaye et al 1988, Marx et al 1977) and is restricted in New Zealand to geothermal areas (Moyersoen 2004). The fungi may be implicated in the ability of prostrate kanuka to survive in geothermal sites and as such a better understanding of its role and implications for re-establishing prostrate kanuka would be

valuable. *Pisolithus* sp. was observed to be widespread in our (2012) survey, but no associations with land-use were undertaken as the survey was not designed to provide that detail. A better understanding of its role in nutrient uptake for kanuka in geothermal areas would be useful and could be assessed by site quality, adjacent land-use and presence. The association would be by implication but still useful from a biodiversity management point of view.

Immediate questions arise as to the supporting role of surrounding mineral soils developed under ambient rather than geothermal temperatures. Willoughby (2012) demonstrated that once removed from the influence of geothermal heating, soil macro-fauna, and one assumes the nutrient cycling processes, exhibited expected diversity.

Manuka beetle and bronze beetle adults were observed in large numbers on the foliage of manuka and kanuka at some of the sites. Eggs in the soil might be expected at this time of the year. However, despite close inspection few were detected and an absence of root pruning as evidence of the presence of the larvae was also not seen. Wing-cases (elytra) of manuka beetles and bronze beetles were noted in the root mat but these may have originated from adults that had died naturally on the soil surface. The question this elicits is where are the eggs of the beetles laid and where do the larvae develop in geothermal habitat mosaics?

Implications of the raised root mat implies a very fragile system that if disturbed may require a number of essential components for restoration. For example what might be the role of the litter in terms of propensity to break down under the geothermal conditions? Why does prostrate kanuka dominate these systems? The fact that ectomycorrhiza may play a vital role in the survival of prostrate kanuka may have implications for restoring or managing geothermal sites. In the apparent absence of mechanisms for effective nutrient cycling these sites may be more dependent on managed buffers to ensure nutrients are available to the resident plant species.

Buffers and linkages may have an important role in terms of the maintaining habitat mosaics and sustaining both the soil macro-fauna and flora. Field observations of plant death indicated that plant populations are vulnerable to 'wandering' areas of high soil temperatures. The presence of a suitable soil environment (temperature) to sustain insect populations is also important for pollination. This is particularly important since the introduction of the varroa mite (*Varroa destructor*) in 2000 has decimated feral honey bee colonies (Kraus 1995) that in many cases supplanted the native bee's role in pollination of native plant species. For example beetles and native bees will forage in the areas of high soil temperatures but in the example of manuka beetle must have survivable soil temperatures to complete life cycle. In the example of native bees, which live in burrows but forage into the areas of high temperature, there must be suitable conditions (soil) to enable their survival.

5 Recommendations

It is recommended that a site quality ranking be developed in conjunction with the criteria set out in Bycroft (2011) to categorise geothermal sites as to vulnerability, particularly with respect to ecosystem services.

Potential loss of function in terms of ecological services has been identified in this report with examples of pollination, the significance of the absence of soil macro-fauna that act in a role as decomposers and the role of mycorrihizal fungi. Measures of ecosystem resilience of geothermal systems are lacking. These measures need to be identified to manage ecosystem resilience. Taking as an example the soil root mat; understanding how it is formed, what is its role in isolating root systems from high temperatures and how nutrient cycling is affected? Better understanding of the features of this system would allow the identification of suitable buffers and linkages to sustain ecosystem function and resilience.

For effective management better understanding of the environmental services provided by geothermal features is needed. The role of functional groups in relation to biodiversity priorities is not well understood in geothermal terrestrial ecosystems. The implication of the loss, or part loss, of functionality is currently unknown. Examples may include the role of pollinators in sustaining populations of geothermal vegetation but also in protecting the habitat of the pollinators themselves. It is recommended that functional groups be identified and prioritised at a site level.

The three areas of threats (weeds, pest animal and domestic stock) to geothermal terrestrial vegetation as defined by Bycroft et al (2011) go partway to defining system vulnerability. Weeds may be symptomatic of a system fragility/susceptibility or reflect invasion aggression. Factoring in the role of functional systems such as the health of soil macro-fauna (and micro flora) by identifying and managing risk for that functionality is essential for effective ecosystem management.

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