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Soil macro-fauna in geothermal heated soils in the Waikato region

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Abstract

Geothermal ecosystems are among the most rare and vulnerable in New Zealand (Townsend *et al.,* 2008) and the world. While some geothermal ecosystems such as terrestrial vegetation are well-studied, 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. However, significant areas of geothermal heated soils are these days covered in pasture with associated threats in the form of insect pest habitat outside of normal thermal range and opportunities to breed beneficial species such as earthworms. These biosecurity threats and biodiversity opportunities have the potential to be important to the regional economy.

This report presents the results of a trial designed to determine the spatial distribution of soil macro fauna under pasture in relation to geothermal induced changes in soil temperature and pH, focusing on Oligochaeta species as major components of most terrestrial systems. A survey of soil macro-fauna within geothermal soils was undertaken at eleven sites (geothermal features) in the Waikato Region in the late spring of 2011.

By sampling soil macro fauna within the context of the spatial distribution and range of soil temperatures close to geothermal features a record of the presence and population density of both beneficial and threatening soil macro fauna was established. Restricting the sampling to soils under pasture simplified the interpretation of the data by reducing dietary induced complexities of soil fauna (particularly but not exclusively earthworms) introduced by complex vegetative cover.

No spatial pattern was observed with respect to either earthworms or other soil macro-fauna between geothermal features sampled.

No earthworm species were found in soils above 24.8 °C. However, sub-tropical soil macro-fauna and soil litter dwellers were discovered in soils to 38.2 °C. Some of these species may expand their range to pose a pest threat to horticulture, agriculture, viticulture or forestry should suitable soil temperature conditions become more extensive (e.g. as a response to climate warming or an increase in the area of heated ground).

Evidence was recorded of the dynamic nature of the soil environment, particularly soil temperatures, near geothermal features regardless of type (e.g. bare soil, fumarole, hot spring). Because the survey was conducted at one point in time, a limitation is that there can be no temporal extrapolations, so while it provides vital base information, repeat surveys over time would give important temporal trends.

Environment conditions because of human activity at the eleven sites ranged from one where the ground cover had been removed by earth-moving machinery to sites with stable grass cover with all having been modified at some stage. As active geothermal ecosystems are represented by just 1000 ha or ca. 0.004% of New Zealand's land area this extent and degree of modification may be of concern.

A soil macro-fauna and flora assessment should be undertaken at each site to determine the nature and extent of soil macrofauna biodiversity, with a view to managing human activity where there may be an impact on environmental conditions to ensure that these rare ecosystems are not damaged or reduced further and to reduce establishment and incursion of pest organisms.

1 Introduction

The Waikato region includes the major part of the Taupo Volcanic Zone (TVZ), and within that, New Zealand's most abundant and diverse geothermal habitats.

The Resource Management Act 1991 S6(c) identifies the protection of significant habitats of indigenous fauna as a matter of national importance. One of the Waikato Regional Council's statutory requirements under RMA S35 is to describe the state of the regional environment. In conformity with that requirement, this study has been designed to provide a preliminary assessment of the habitat characteristics of geothermal soil macrofauna within a limited ecosystem sub-type.

The operative Waikato Regional Policy Statement (RPS) Appendix 3 lists geothermal habitat as a Significant Habitat of Indigenous Fauna. Appendix 5 identifies the geothermal habitat of indigenous species as a Significant Geothermal Feature type.

Section 3.7.3 Policy One requires the protection of Significant Geothermal Features from surface activities. However, Section 3.7.2.1 Policy Five allows for adverse effect on Significant Geothermal Features from the take, use and discharge of geothermal energy and water.

The New Zealand Biodiversity Strategy (2000) does not identify geothermal habitats specifically but does emphasise the commitment under the Rio Earth summit in 1992 to stem the tide of biodiversity decline in New Zealand. Under Objectives 9.1 and 9.2 within the NZ Biodiversity Strategy (2000), there is an obligation to research and map indigenous biodiversity at ecosystem scales.

Active geothermal ecosystems are represented by just 1000 ha or ca. 0.004% of New Zealand's land area (Wildlands 2004). This rarity presents the possibility of the presence of highly specialized, if not locally endemic, biota.

Government policies to develop sustainable energy resources have seen in recent years a focus on the geothermal resource, which the Resource Management Act 1991 defines as a sustainable energy resource. Commercial development of the energy resource and the land overlying it in and around unique and spatially limited geothermal environments behoves the need for a better understanding of what might be lost to adverse effects of energy extraction, and from land use activities that do not comply with RPS S3.7.2.1 Policy Five. The Assessment of Environmental Effects (AEE) required for resource consent applications serves this purpose but as Burns (2007) implies in such a report for the development of the Rotokawa Geothermal Development: '*Species that occupy geothermal areas are tolerant of combinations of high temperatures and stressful environmental chemistry. Because they tolerate these extreme conditions, there is scientific interest in these organisms and they often have unusual and potentially valuable properties*', there is a need to know what actually lives in these environments.

A soil macro-fauna survey was undertaken late spring 2011 of eleven geothermal features in the Waikato Region. The objective of the survey was to determine whether or not there was a consistent pattern to the presence and diversity of soil fauna at differing temperature and pH in geothermal heated soils. The survey was primarily confined to soils under grassland to reduce the effect of differing vegetative cover influencing soil fauna.

Methods

Geothermal features in the Waikato region were selected based on their proximity to grassland. To ensure a range of potential habitats, altitude and spatial distribution was taken into consideration during site selection. Low lying and high-altitude sites were

selected, as were sites in the northern, eastern, western and southern parts of the TVZ extent within the Waikato Region. See Map 1 for the site locations.

At each site temperature and pH were measured using a pHep ® model HI 98127 hand held meter at sample points along predefined transects across or down slope from the geothermal feature. Soil sample points consisted of divots (150 mm x 150 mm) taken to a depth of 150 mm at a range of distances along a linear transect from the geothermal feature to a point at which ambient soil temperatures were recorded. Between 10 and 30 divots were taken at each site. Soil temperatures and pH were measured at a depth of 150 mm at the base of the divot hole. The divot was then hand-sorted in the field and the soil macro-fauna recorded.

Unless otherwise mentioned a single transect was sampled at each site. Where the topography was flat the transect was directed towards the most representative pasture. Where the geothermal feature was on a slope the transect was run parallel to the slope from the midpoint of the feature.

Site locations and descriptions

Site 1: Paerata Road (WRC Site No. MKV04)

Three transects were undertaken at the Paerata Road geothermal feature:

The Paerata Road site is within the Mokai geothermal area, which displays only a few superficial manifestations as steaming ground or hot springs yet contains some of the hottest geothermal wells in New Zealand ranging 300-330 °C. The active features were fenced and recently planted with a mixture of exotic (*Pinus radiata*) and native (kanuka) seedlings. The site was within an area of pastoral farming (dairy and dry stock). The geothermal feature included eight pools and small hot seeps with temperatures 24-45 °C and pH range 2.3-4.6, near zero flow and calm ebullitions of murky grey-brown mud with black scum (Figure 1). Adjacent sites had hot seeps up to 77 °C and a small gas discharge without visible liquid at 93 °C.

Figure 1: Site 1. Paerata Road feature "P4". Photo courtesy J. Newson (Newson, 2010: Fig.5-11).

Wildlands (2011a) note that Paerata Rd.: "*A small population of prostrate kanuka, an 'At Risk – Declining' (Townsend et al 2008) species is present. It is the largest population of this species in the Mokai Geothermal Field.*" The only weeds or pests they identified were blackberry and rabbits.

Site 2: Mangamingi Station (WRC Site No. TKV06)

Location geothermal feature: S 38°5.535 E 176°12.996

The site is located on an extensive sheep and beef property. The site itself lies at the head of an east-facing valley for the most part vegetated with 30+ year old browntop dominated pasture. The pasture is considered of low productivity and grazed infrequently with both sheep and cattle. The site is currently the subject of study by Auckland University (C. Campbell and D. Downs). Present on site was a weather station managed by NIWA.

A total of three transects were sampled from three separate geothermal features.

Figure 2: Site 2. Mangamingi Station

Site 3: Arataki Honey (WRC Site No. WTV02 Ngapouri)

Location geothermal feature: S 38°20.447 E 176°21.654

The site is located behind the Arataki Apiaries retail and packing buildings off SH 5 within a paddock showing evidence of draining and profiling. The geothermal features comprising small (<1 ha) hot water ponds had been fenced and were steep sided precluding sampling of water temperature. The pasture was comprised 30% grasses (perennial ryegrass, brown top, rats tail, sweet vernal, Yorkshire fog), legumes 40% (*Lotus pedunculatus*), weeds 30% (predominantly buttercup).

Site 4: Ohaaki East (WRC Site No. OHV02)

Location geothermal feature: S 38˚32.437 E 176˚19.128
The site is located to the south of Ohaaki Thermal Kilns Ltd and accessible from Ohaaki Road some 500 m west of the intersection with Broadlands Road. The paddock containing the geothermal features was perennial ryegrass/white clover dominant and managed by Landcorp as part of Rotomahana Farm Deep Creek Block as a runoff for dairy stock.

Figure 3: Site 4. Ohaaki East

Site 5: Oruanui Block (WRC Site No. WKV01 Te Rautehuia)

Location geothermal feature 1: S 38˚36.390 E 176˚03.650
Location geothermal feature 2: S 38˚36.437 E 176˚03.603

The site lies on the Landcorp Oruanui Block accessed off Link Road 5 km north of Wairakei. The first geothermal feature sampled lay within a paddock that at the time was being reseeded following cultivation. During this latter process the feature had been obliterated. The second feature was within a deer enclosure facing east on a 30 degree pasture covered slope. Pasture, set stocked with deer and visited by wild pigs, was dominated by browntop/sweet vernal and *Lotus pedunculatus*.

Figure 4: Site 5. Oruanui Block. Geo feature 1.

Figure 5: Site 5. Oruanui Block. Geo feature 2.

Site 6: Maxwell (WRC Site No. RPV02 Wharepapa)

Location geothermal feature 1: S 38˚24.756 E 176˚20.071
Location geothermal feature 2: S 38˚24.957 E 176˚19.869

Three geothermal features were sampled each with a single transect.
Geothermal feature 1 is located on a privately owned 1.6 ha farmlet. The feature had been fenced and comprised a crust of heated mud that apparently was flooded at times covering an area 100 m^2 and surrounded by prostrate kanuka.

Geothermal feature 2 comprising a fenced hot spring (temperature 96.8 ˚C, pH 7.7) is located on a dairy property. The hot spring is in a 0.5 ha paddock of pasture dominated by perennial ryegrass (30%) with Yorkshire fog, paspalum and weeds (40% mostly buttercup). An outflow from

Figure 6: Site 6. Maxwell. Geo feature 2.

the hot spring flowed in a shallow drain along the southern boundary of the paddock. Fifty metres along this drain the water temperature was 67˚C and pH 8.2.

Geothermal feature 3 comprised an unfenced fumarole in an adjacent paddock. The vent was diameter 4.0 metres with boiling water at the base.

Site 7: Berry property (WRC Site No. WTV02)

Location geothermal feature S 38˚20.201 E 176˚22.089

The geothermal feature is a small hot water lake within the Waiotapu Scenic Reserve discharging through a style property. Temperature of the stream within the property was 33.9 ˚C with pH 2.6. The property ran cattle and sheep with the paddock where the sampling took place comprised grasses 80% predominantly perennial ryegrass, cocksfoot and twitch with a balance of clover 10% and weeds 10% (dock and sorrel). Changes in soil structure and composition combined with observations of recent changes in vegetation indicated changes in the geothermal heating of the soil.

Site 8: Taupo Golf Course (WRC Site No. THV04 Broadlands Rd)

Location geothermal feature 1: S 38˚40.659 E 176˚06.713
Location geothermal feature 2: S 38˚40.587 E 176˚06.730

Feature 1 is a bare soil field within an area of prostrate kanuka with a temperature at the soil surface of 56.8˚C and pH 5.0

Feature 2 is a bare soil field with steam discharging from a vent with a surface temperature of 51˚C and ph 4.9

Changes in soil structure and composition combined with observations of recent changes in vegetation indicated changes in the geothermal heating of the soil.

Figure 7: Site 8. Taupo Golf Course

Site 9: Tauhara Road (WRC Site No. THV04 Broadlands Rd)

Location geothermal feature 1: S 38˚41.018 E 176˚07.234
Location geothermal feature 2: S 38˚41.012 E 176˚07.176

Feature 1 is a bare soil field at the base of a north facing grassed slope of approximately 30˚ with the temperature at the geothermal feature of 59 ˚C and pH 4.8

Feature 2 is a bare soil field within pasture on flat topography with the temperature at the geothermal feature of 69 ˚C and pH 4.3.

Changes in soil structure and composition combined with observations of recent changes in vegetation indicated changes in the geothermal heating of the soil.

Figure 8: Site 9. Tauhara Road.

Site 10: Crown Rd MotoX (WRC Site No. THV06 Crown Rd)

Location geothermal feature 1: S 38˚41.168 E 176˚06.626

The geothermal feature is a bare soil field of approximately 0.25 ha including a fringe of prostrate kanuka. The area was fenced with a single electric wire that was not live at the time. The geothermal feature had a surface temperature of 58.9 ˚C and pH 5.6 The surrounding area was pasture comprising a range of grass and weed species on a west facing slope of approximately 15˚. Changes in soil structure and composition combined with observations of recent changes in vegetation indicated changes in the geothermal heating of the soil.

Figure 9: Site 10. Crown Park MotoX

Site 11: Tauhara Middle (WRC Site No. THV06 Crown Rd)

Location geothermal feature 1: S 38˚41.258 E 176˚06.883

The area locally known as Tauhara Middle lies adjacent to and on the east side of the East Taupo Arterial (ETA). An area of approximately 2 ha comprising prostrate kanuka and pasture dotted with small geothermal features including small (<2 m^2) bare soil fields and small vents has been excluded from grazing for a couple of years (N. Hughes pers comm.).

The transect was initiated in prostrate kanuka with a soil cover comprising *Campylopus* sp. moss. Soil temperature was 47.9 ˚C and pH 5.9. Changes in soil structure and composition combined with observations of recent changes in vegetation indicated changes in the geothermal heating of the soil.

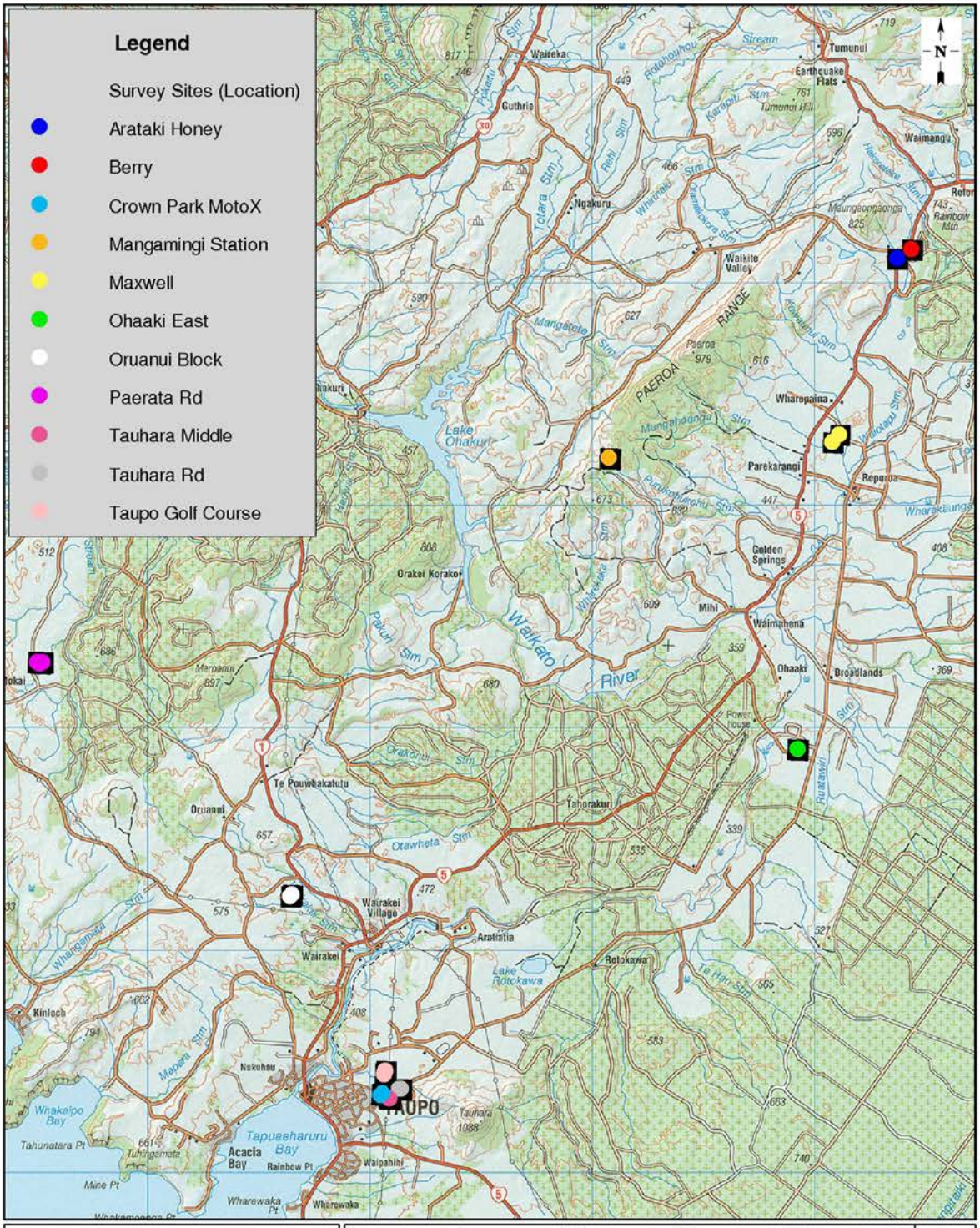
Figure 10: Site 11. Tauhara Middle.

2 Results

A total of 21 transects were sampled across 11 sites totalling 145 samples. As the study was designed to detect presence or absence of soil macrofauna at prescribed points from an active geothermal feature the data for individual species is not presented as a population density (nos/m^2).

Table 1: Location (address and GPS) of geothermal features sampled for soil macro-fauna on the Volcanic Plateau in November 2011

Site/ Transect	Location	GPS	Altitude (m)
1/1	Paerata Rd	S38,30.946 E175,55.545	517.0
1/2	Paerata Rd	S38,30.968 E175,55.617	508.9
1/3	Paerata Rd	S38,30.943 E175,55.705	507.8
2/1	Mangamingi Station	S38,25.535 E176,12.996	613.6
2/2	Mangamingi Station	Adjacent to feature	613.6
2/3	Mangamingi Station	Adjacent to feature	613.6
3/1	Arataki Honey	S38,20.447 E176,21.654	399.0
4/1	Ohaaki East	S38,32.437 E176,19.128	320.6
5/1	Oruanui Block	S38,36.390 E176,03.650	514.8
5/2	Oruanui Block	S38,36.437 E176,03.603	537.7
6/1	Maxwell	S38,24.756 E176,20.071	310.0
6/2	Maxwell	S38,24.957 E176,19.869	311.0
6/3	Maxwell	S38,24.957 E176,19.869	311.0
7/1	Berry	S38,20.201 E176,22.089	404.8
8/1	Taupo Golf Course	S38,40.659 E176,06.713	442.0
8/2	Taupo Golf Course	S38,40.587 E176,06.730	448.1
9/1	Tauhara Rd	S38,41.018 E176,07.234	468.8
9/2	Tauhara Rd	S38,41.012 E176,07.176	467.6
10/1	Crown Park MotoX	S38,41.168 E176,06.626	459.0
10/2	Crown Park MotoX	S38,41.134 E176,06.665	456.0
11/1	Tauhara Middle	S38,41.258 E176,06.883	467.3



Elevation of the geothermal features ranged from 310 m to 613 m with the topography ranging from flat (slope 0 degrees) to moderate (slope >10 degrees and <20 degrees) (Table 2).

Table 2: Sample data for each location including the temperature and pH at the geothermal feature, the distance (m) at which soil macro-fauna (SMF) was first detected and the species and number of individuals present at the first detected sample point (see comment)

Site/ Transect	Location	Feature Temp (pH)	SMF Dist (m)	SMF Temp (pH)	SMF Species
1/1	Paerata Rd	13.1 (5.8)	0	13.1 (5.8)	5 A.caliginosa
1/2	Paerata Rd	18.8 (2.9)	3	13.6 (4.8)	7 A.caliginosa (plus some L.rubellus)
1/3	Paerata Rd	22.5 (4.5)	10	15.0 (5.7)	9 A.caliginosa (plus some L.rubellus and O.cyaneum)
2/1	Mangamingi Station	53.8 (4.5)	20	17.1 (6.3)	2 I.rubriceps (larvae) 1 Wiseana sp. (larvae)
2/2	Mangamingi Station	76.3 (5.4)	15	17.0 (6.1)	4 I.rubriceps (larvae 2 mature, 2 immature) 1 worm cacoon 1 1 C. exsul
2/3	Mangamingi Station	80.8 (5.7)	5	26.0 (5.4)	1 C.exsul (larvae)
3/1	Arataki Honey	30.0 (nr)	10	22.0 (5.3)	2 I.rubriceps (immature larvae) 3 native worms (tails only) 1 Asian worm (immature)
4/1	Ohaaki East	90.0 (3.3)	10	27.2 (3.6)	1 N.leucoloma (larvae)
5/1	Oruanui Block	95.0 (6.0)	25	16.1 (5.8)	2 N.leucoloma (larvae) 1 I.rubriceps (larvae) 1 S. lepidus (larvae)
5/2	Oruanui Block	92.9 (4.8)	15	28.2 (4.7)	Onthophagus sp. (14 larvae, 5 pupae, 4 adult)
6/1	Maxwell	22.0 (4.0)	10	19.5 (4.1)	1 A. calliginosa (immature) 1 C..exsul (larvae)
6/2	Maxwell	96.8 (7.7)	1	26.6 (6.7)	1 A. caliginosa 1 C.exsul (larvae) 1 N.leucoloma (larvae)
6/3	Maxwell	52.6 (6.2)	30	24.8 (5.6)	3 L.rubellus
7/1	Berry	33.9 (2.6)	100	23.8 (5.4)	2 A. caliginosa (1 mature 1 immature)
8/1	Taupo Golf Course	56.8 (5.0)	15	22.9 (5.4)	1 C. exsul (immature)
8/2	Taupo Golf Course	51.0 (4.9)	5	23.4 (5.7)	nil at 5m, 10 m, 15m.
9/1	Tauhara Rd	59.0 (4.8)	5	32.1 (5.5)	1 Creophilus oculatus
9/2	Tauhara Rd	69.0 (4.3)	5	36.4 (5.1)	H.destructor (numerous)
10/1	Crown Park MotoX	58.9 (5.6)	30	32.8 (7.0)	nil at 30 m
10/2	Crown Park MotoX	64.5 (6.4)	30	23.1 (6.4)	3 L.rubellus (1 mature 2 juvenile) 2 A.caliginosa 1 L.terrestris (mature) 1 Wiseana sp. (larvae) 1 centipede
11/1	Tauhara Middle	47.9 (5.9)	15	30.2 (7.2)	2 C. exsul (larvae)

Key to soil macrofauna reported

Species	Species common name
Earthworms	
Species unidentified	Asian worm
Aporrectodea caliginosa	
Aporrectodea trapezoides	
Lumbricus rubellus	
Lumbricus terrestris	
Octolasion cyaneum	
Others	
Aphodius tasmaniae	Tasmanian grass grub
Aploneura lentisci	root aphid
Bobilla sp.	small field cricket
Conoderus exsul	wireworm
Costelytra zealandica	grass grub
Creophilus oculatus	Devil's coachhorse
Halotydeus destructor	redlegged earth mite
Heteronychus arator	black beetle
Inopus rubriceps	soldier fly
Naupactus leucoloma	whitefringed wWeevil
Onthophagus sp.	Australian dung beetle
Porcellio scaber Latreille	slater
Pyronota sp.	manuka beetle
Sitona lepidus	clover root weevil
Teleogryllus commodus	black field cricket
Wiseana sp.	porina

Over all 11 sites there was no obvious relationship between temperature at the geothermal feature and soil temperature distal from the feature. Geothermal feature temperature ranged from 13.1 ˚C to 95.0 ˚C, generally reducing to ambient temperatures within 20 m.

The pH at the geothermal features sampled ranged from pH 2.6 to pH 6.7. No obvious relationship was observed between either the species of soil macro fauna or temperature and pH.

As might have been anticipated there was no correlation between altitude and the temperature of a geothermal feature.

Site 1

The soil macro-fauna at Site 1 (Paerata Rd) featured dense populations of *Aporrectodea caliginosa* (indications were of populations >1,000/m^2) with the occasional specimen of *Lumbricus rubellus* and *Octolasion cyaneum*. These introduced Lumbricidae species are in general shallow burrowing and litter/dung feeding. They play an important role in pastures for nutrient cycling and soil formation.

Site 2

The main Site 2 (Mangamingi) geothermal feature covered approximately 0.3 ha. Two transects were sampled from the margins and a further transect extended from a nearby small geothermal feature (vent). *Inopus rubriceps* (Australian soldier fly) was present at this site. The Australian soldier fly, a recognised pest of improved pastures, is a tropical/subtropical insect surviving in soil temperatures from 15 – 25 ˚C (Wilcocks and Oliver 1976) and in New Zealand is confined above the 12.8 ˚C mean average soil temperature (Robertson 1985). This thermocline extends north of Hamilton and into the coastal regions of the Bay of Plenty and northern Taranaki.

Site 3

Site 3 (Arataki Honey) revealed Australian soldier fly outside of its normal range and examples of Megascolecidae earthworms. The latter were likely to be native species

that normally inhabit bush environments where they are less vulnerable to predators that could take advantage of their habits of moving through litter and not constructing permanent burrows. Extensive soil disturbance at this site indicated earthworks for both drainage purposes and topographical 'smoothing'. The pasture was dominated by sweet vernal (*Anthoxanthum odoratum*) and Yorkshire fog (*Holcus lanatus*) (40%) with *Lotus pedunculatus* and flatweeds (40%). The nature of the pasture (with a high percentage cover of flat weeds) and the proximity to undisturbed native scrub may have explained the presence of the of Megascolecidae earthworms.

Site 4

Site 4 (Ohaaki East) revealed a *Naupactus leucoloma* (white fringed weevil) larvae in soil at a temperature of 27.2 ˚C. White fringed weevil originating from South America is widespread in New Zealand and a pest in improved (high fertility) pasture and crops (particularly potato) (Hardwick and Prestige 1996, Perrot 1964). With phytosanitary issues for exports to Europe and few management options, White fringed weevil may be a threat to the economics of these enterprises. The single specimen of White Fringed Weevil found at this site was under a cover (70%) of weeds (predominantly sorrel *Rumex acetosella*) and *Lolium perenne* (perennial ryegrass) within a paddock dominated by *Paspalum dilatatum* (paspalum). Paspalum is common in the North Island but confined to areas not subject to heavy frosts. A total of twelve divots were sorted at this site down to ambient temperatures of 22.7 ˚C with no other soil macro-fauna discovered.

Site 5

Two geothermal features were sampled at Site 5 (Oruanui Block). The paddock containing the first feature sampled had been cultivated (discing followed by roto-tiller) two months earlier and in November 2011 was in the process of being drilled for a winter crop. The cultivation had obliterated details of the geothermal feature but had left a few patches of paspalum. These revealed no soil macro-fauna and the discovery of white fringed weevil, Australian soldier f and *Sitona lepidus* (clover root weevil) was made in bare (devoid of vegetation) ground. Vigorous cultivation had destroyed any soil structure and reduced the soil to dust in the top 5 cm.

The paddock containing the second geothermal feature sampled on the Oruanui Block comprised a pasture approximately 30 years old dominated by sweet vernal and *Axonopus affinis* (carpet grass). The paddock had been deer fenced in the 1980s and red deer (*Cervus elaphus*) the primary grazing stock although in areas there was evidence of pig (*Sus* sp.) rooting. The *Onthophagus* species found at this site near the soil surface at temperatures ranging from 31.9 ˚C to 38.2 ˚C was likely *O. posticus* based on Emberson and Mathews (1973). *O. posticus* originates from Australia with a natural range in South Australia.

Site 6

Three geothermal features were sampled at Site 6 (Maxwell property, Wharepapa). A transect was initiated from the margins of a fenced bare ground geothermal feature. (Feature 1) The soil was gleyed with massive structure containing un-decomposed organic matter arising from previous /kanuka vegetative cover. Soil macro-fauna, first detected at a soil temperature of 19.5 ˚C some 10 m from the geothermal feature, included an earthworm (*A.caliginosa*) and a *Conoderus exsul* (wireworm) larva. Despite evidence of soil pugging across the paddock in the form of a compaction layer at 3-4 cm depth the earthworm population included *L.rubellus* in ambient soil temperature around 18 ˚C.

A second geothermal feature (Feature 2) is an alkaline (pH 7.7) spring at 96.8 ˚C where 1 m from the margin the soil temperature was 26.6 ˚C and soil macro-fauna *A.caliginosa*, *C. exsul*, and *N.leucoloma* were present. Near the feature the ground cover was *Polycarpon tetraphyllum* (allseed) with paspalum present at 5 m beyond which perennial ryegrass became the dominant grass species. The pasture was dominated (20% - 40% by cover) by weeds; predominantly *Ranunculus repens* (creeping buttercup). Earthworms recovered included both *A.caliginosa* and *L.rubellus*

with most aestivating at a depth greater than 10cm. Interestingly, of five mature *A.caliginosa* recovered from a sample, three had re-generating tails. It was speculated that the presence of a pugging pan at 3 cm may have impeded the earthworms' ability to escape predating birds.

The third geothermal feature (Feature 3) sampled was a vent expelling steam at a temperature of 52.6 ˚C. Temperatures of 33.0, 27.2 and 26.8 were recorded at 5, 15 and 25 m respectively from the vent. At a distance from the vent of 30 m and a temperature of 23.8 (pH 5.6) three *L.rubellus* were recovered. Vegetative cover within 5 m of the vent was dominated by paspalum (40%) with weeds (60%) predominantly sheep sorrel and bare ground (40%) dominating to a distance where the vent was not having an effect on soil temperature.

Site 7

Site 7 (Berry) featured a hot (33.9 ˚C) stream with a low pH (2.6) discharging from a spring. The pH of the soil within the adjacent paddock averaged 5.3 (range 5.3 – 5.4) to a distance 100 m from the stream at which point there appeared to be no geothermal influence. Pasture at this point was dominated by *Lolium perenne* (perennial ryegrass) and *Holcus lanatus* (Yorkshire fog). Soil temperatures to 100 m from the stream averaged 26.7 ˚C (range 24.5 to 27.8) and the pasture variable with perennial ryegrass), *Axonopus affinis* (carpet grass) and bare ground alternately predominating (cover >40%).

Site 8

Two transects were completed at Site 8 (Taupo Golf course). The area sampled had been in pasture but was currently un-grazed and restoration planting with native species had recently been undertaken. Both geothermal features comprised a bare-soil field. The first coloniser from the feature was a moss, *Campylopus* sp. followed by *Kunzea ericiodes* var. *microflora* (prostrate kanuka) underlain with litter (80%), liverworts and lichen (*Usnea* sp.). Pasture comprised *Holcus lanatus* (Yorkshire fog) 80%, *Agrostis capillaris* (browntop), *Rumex acetocella* (sheep sorrel) and *Vicia* sp. (Vetch).

No soil macrofauna was identified under the native vegetation with soil temperature of 53.0 ˚C at the feature declining to 22.9 ˚C at 15 m where pasture dominated. At this point in the first transect evidence (frass) of *Aploneura lentisci* (root aphid) was recorded along with an immature *C. exsul* (wireworm) larva. Further samples at 5 m intervals to 40 m from the feature revealed extensive areas of frass, and the regular presence of *N. leucoloma* (white fringed weevil) larvae. No earthworms were recorded.

The second transect extended to 30 m from a small vent discharging steam at 51.0 ˚C. Native vegetation extended as above. However, there was evidence of soil temperature variations in the form of random patches of pasture dominated by bare ground and *Anthoxanthum odoratum* (sweet vernal); a grass species that favours dry soils. No soil macro-fauna was revealed on that transect.

Site 9

Transect 1 at Site 9 (Tauhara Road) was initiated within a bare soil field (temperature 59.0 ˚C and pH 4.8) transitioning at 2 m to mixed pasture comprising the C4 grasses *Axonopus affinis* (narrow-leaved carpet grass), *Cynodon dactylon* (Indian doab), *Paspalum dilatatum* (paspalum), *Digitaria sanguinalis* (summer grass), and the C3 grass *A. odoratum* (sweet vernal). Within 10 m from the vent the litter layer revealed a specimen of *Creophilus oculatus* (Devil's coachhorse) active in a soil temperature of 32.1 ˚C and an adult *C. exsul* (click beetle) in soil temperature of 31.9 ˚C. These litter dwelling predatory insects were unlikely to be exposed to the soil temperature measures at 15 cm. However, an adult female *Costelytra zealandica* (grass grub) revealed 15 m from the vent in soil with a temperature of 28.0 ˚C may represent some form of adaption. Grass grub lay their eggs in the soil at around 15 cm depth and while this may have been a recently arrived dispersing individual, for the most part grass grub lay their eggs where they existed as a larva. The soil temperature recorded was

near to the lethal temperature (32.5 ˚C) for grass grub larvae and well outside this insect's normal temperature range (East and Willoughby 1980). Twenty metres from the vent the soil temperature was 25.9 (pH 5.9) where a mature *N.leucoloma* (white fringed weevil) larva was recorded. Ambient temperatures (21 – 22 ˚C) were recorded at greater than 25 m from the vent at which point the pasture comprised the grasses *Anthoxanthum odoratum* (sweet vernal) and *Holcus lanatus* (Yorkshire fog) (40%) with the balance weeds; *Achillea millefolium* (yarrow), *Rumex acetosella* (sheep sorrel) and *Vicia* sp. (vetch) with some *Trifolium repens* (white clover). Soil macro-fauna included larvae and pupae of *Sitona lepidus* (clover root weevil), an immature *N.leucoloma* (white fringed weevil) larva and mature and immature *Lumbricus rubellus*. Evidence (frass) of *Aploneura lentisci* (root aphid) was recorded.

Transect 2 at Site 9 (Tauhara Road) was initiated from a bare soil field (temperature 69.0 ˚C, pH 4.3) with the first colonisers *Cynodon dactylon* (Indian Doab) and *Portulaca oleracea* (Common Purslane). The latter is a frost-tender herbaceous weed. Numerous *Halotydeus destructor* (red legged mite) were identified in a soil temperature of 36.4 ˚C some 12 m from the feature. *H.destructor* is usually inactive in dry summer conditions when soil conditions are less humid. In suitable soil conditions it may be a serious pest feeding on roots and foliage (Ridsdill-Smith 1997). An *Aphodius tasmaniae* (Tasmanian grass grub) larva was identified in soil temperature 23.2 ˚C some 20 m from the feature beyond which the soil temperatures began to rise.

Site 10

Two transects were sampled at Site 10 (Crown Rd MotoX). The geothermal feature was a bare soil field with a temperature of 58.9 ˚C and pH 5.6 with the initial vegetation colonisation dominated by *Axonopus affinis* (narrow leafed carpet grass) (60%) and *Cynodon dactylon* (Indian doab) (20%). There was evidence of soil disturbance either from nearby road construction and/or cultivation. The site was characterised by large fluctuations in soil temperature along the transect and no evidence of soil macro-fauna. However, the diversity of vegetation was considerable (Table 4).

The second transect at Site 10 traversed the slope as did the first transect to avoid any effects of heated water runoff. A temperature of 64.6 ˚C (pH 6.4) was measured at the bare soil field. At 5 m the soil temperature was 36.7 ˚C (pH 6.4) with some (<1%) *Kunzea ericiodes* var. *microflora* (Prostrate Kanuka) cover, with the balance comprising bare soil. A mature earthworm (*L.rubellus*) was recovered 27 m from the geothermal feature in soil temperature of 23.1 ˚C (pH 6.4). The vegetation cover was a range of weeds and C4 grasses (Table 4). No other examples of soil macro-fauna were recovered.

Site 11

The Site 11 (Tauhara Middle) transect was initiated in a bare soil field with a temperature of 47.9 ˚C (pH 5.9). Wire worm (*C.exsul*) larvae were recovered in soil at temperature 30.2 ˚C (pH 7.2) and dominated the soil macro-fauna to ambient soil temperatures (20.1 ˚C). At this point a slater (*Porcellio* sp.) and evidence of root aphid (*Aplonuera lentisci*) were recorded. Vegetation cover was dominated by sweet vernal (*Anthoxanthum odoratum*) and narrow-leaved carpet grass (*Axonopus affinis*) with a dense litter layer to 2 cm. The grass species were present 7 m from the feature in soil temperatures of 32 ˚C (pH7.2) with the occasional presence of Mercer grass (*Paspalum distichum*). The sweet vernal was characterised by a growth form that could be described as massive with individual plants having a base of diameter 200 mm and foliar height exceeding 400 mm. The soil profile contained evidence of past cultivation with organic matter mixed to 150 mm.

The detail of this transect is included (Table 3) to show the 'typical' composition of a pasture transect in geothermal heated soils.

Table 3: Vegetative cover at a given distance and temperature from the bare soil geothermal feature at Site 10 (Crown Rd MotoX)

Dist	Temp	pH	*Species* (cover)	Common Name
0	58.9	5.6	Bare soil (100%)	
2	36.7	5.8	*A.affinis* (60%)	narrow leafed carpet grass
			C.dactylon (20%)	Indian doab
			Litter/moss (20%)	
7	36.6	6.3	*C.dactylon* (50%)	Indian doab
			B.diandrus (10%)	ripgut brome
			L.pedunculatus (5%)	lotus
			Litter/moss (30%)	
12	36.6	5.8	*C.dactylon* (60%)	Indian doab
			P.distichum (20%)	Mercer grass
			Litter (20%)	
17	53.6	5.8	*C.dactylon* (60%)	Indian doab
			A.affinis (20%)	narrow leafed carpet grass
			P.distichum (10%)	Mercer grass
			Conyza albida (5%)	fleabane
			Litter (5%)	
27	37.2	6.2	*C.dactylon* (40%)	Indian doab
			A.affinis (20%)	narrow leafed carpet grass
			P.distichum (10%)	Mercer grass
			Lotus corniculatus	birdsfoot trefoil
			L. suaveolens	hairy birdsfoot trefoil
			Plantago lanceolata	plantain
			Silene gallica	catchfly
			Bare ground (10%)	
37	32.8	7.0	*C.dactylon* (60%)	Indian doab
			Bromus mollis (10%)	soft brome
			*P. vaginatum** (5%)	saltwater paspalum
			Litter (25%)	

*Patches of *Paspalum vaginatum* (Saltwater Paspalum) are present alongside the feature in warm ground.

3 Discussion

The survey of the 11 sites in the North Island central volcanic plateau volcanic area within the Waikato Region revealed no consistent pattern of soil macro-fauna across sites. The implications of this result from the point of view of the administration and management of these geothermal areas are that each must be treated as a unique configuration of physical parameters, vegetation and soil macro-fauna.

There was strong evidence in both the vegetation and soil macro-fauna that the bare field sites in particular exhibited varied geothermal activity both spatially and temporally. The evidence of temporal changes included newly dead vegetation at some sites, indicating a recent increase in temperature, and vegetation freshly encroaching into previously bare areas at some sites, indicating recent cooling. At two sites the presence of recently dead earthworms at the soil surface indicated that the changes had been too rapid for the earthworms to escape. In these instances the

vegetation appeared unaffected and there was no evidence of flooding implying that the earthworms had most likely been driven to the surface by increasing soil temperatures.

While quantitative population data was not an objective of the survey it was notable that earthworms, predominantly the introduced species *A. caliginosa*, were widespread at only one site (Site 1 – Paerata Road) and present at five of the eleven sites sampled.

Megascolecidae earthworms were recorded at one site characterised by undisturbed scrub-land adjacent to hot pools that did not appear to have any great impact on soil temperatures. The majority of the features sampled were initially dominated by native vegetation (predominantly mosses, lichens and prostrate kanuka) before soil temperature declined sufficiently to allow grasses to survive. No earthworm species (native or introduced) were detected under these conditions. It is inferred that no earthworm species had adapted to survive in soil temperatures greater than 24.8 ˚C.

There are no known reports of earthworms under geothermal system soils in New Zealand (B. Brown, University of Auckland, pers. comm. 14th Oct. 2011). Perhaps the most pertinent studies were nearly 60 years ago when Lee (1953: 49) noted temperature tolerance of the small (~23mm) endemic *Acanthodrilus kermadecensis* Lee (1953) collected from steaming soil, almost too hot to handle (perhaps 50-60°C?), at the mouth of a fumarole in the main crater on subtropical Raoul Island, Kermadecs. Recorded nearby was exotic *Eisenia fetida* (Tiger Worm, Manure Worm) that dominated forest litters on the island. This species, reported at a hot spring in Iceland by Backlund (1949), is widespread in New Zealand.

It is noteworthy that *Eisenia fetida* universally used in vermicomposting world wide, is the most common introduced species in the Himalayas, is found on or under snow in Scandinavia and on subarctic Spitsbergen yet has experimental temperatures ranging from -2 to +40°C (Lee, 1985: tab. 2). Such wide tolerance appears exceptional, but this species of northern Holarctic origin may be expected to tolerate both exothermic compost and cold ambient temperatures. Gates (1967) reports it in desert environments in the USA along with a few other exotic European lumbricids and Asiatic megascolecids, some from Hot Sulphur Springs (NB maybe place name rather than actual source).

Regarding distributions of earthworms in the Taupo Volcanic Zone, Lee (1959: 439) surveyed soils from geologically recent volcanic activity examining those formed of pumiceous material from Mt Tarawera and mud from Lake Rotomahana ejected during the 1886 eruption. In general he found native earthworms in the muds but excluded from the coarser and abrasive ash deposits. Further descriptions by Lee (1959) and Blakemore (2010b) are of native Megascolecidae well south of volcanic zone.

Amongst native earthworms previously described from Lake Taupo-Rotorua region are: Acanthodrilidae *Rhododrilus aduncocystis* (Lee 1959) and *R. similis* (Benham 1906) along the Waikato River, and Megascolecidae *Celeriella antarctica* (Baird 1871) in the form of its synonym *Diporochaeta shakespeari* (Benham 1904) at least, found by Lee (1952) in western coastal ranges of the Waikato and Taranaki districts. *Megascolides fuscus* (Lee 1952) is from "*topsoil and subsoil in Taupo sandy silt in areas of native rain forest and exotic forest (Pinus spp.) in the Rotorua district*" along with *Diporochaeta obtusa* (Lee 1952) that is particularly widespread elsewhere. *Notoscolex sapidus* (Benham 1904) was collected from Ruatahuna between Rotorua and Lake Waikaremoana; and *N. suteri* (Benham 1904) range extends from Auckland to Rotorua-Taupo where its common habitat is under rotten logs (Lee 1952, 1959). Previously described exotics (Lee 1959, Martin 1977; Blakemore 2010a, b) include *Dendrodrilus rubidus* sub-spp. and several other Lumbricidae of probable direct or indirect European origin. That none of these species were recorded in the present study likely reflects the nature of the 'improved pasture' habitat sampled.

On the volcanic plateau populations were found of sub-tropical insect species (e.g *Halotydeus destructor* (red legged mite), *Aphodius tasmaniae* (Tasmanian grass grub), *Heteronychus arator* (black beetle)) with potential for pest status. Their survival well outside their accepted (temperature) range has potential as infestation sources should increased global temperatures become a reality. The dung beetle *(Onthophagus* sp.) found in soil at a temperature of 38.2 ˚C is primarily a litter and surface dweller. However, the red legged earth Mite (*H. destructor*) sampled in large numbers in soil at a temperature of 36.4 ˚C may be well adapted to these conditions. Black beetle has good mechanisms (flight) for dispersal should suitable (annual soil thermocline >12.5 ˚C) environmental conditions become available. The survival (Site 5, geothermal feature1) of white fringed weevil, Australian soldier fly and clover root weevil two months after intensive cultivation and in the absence of living vegetation draws attention to the robust nature of these potential pasture pests.

The presence of frost tender plant species (e.g. *Portulaca oleracea* (common purslane, *Paspalum vaginatum* (saltwater paspalum)), with potential for weed status in the geothermal areas, on the volcanic plateau where 20 +/- 8 frost days might be expected per annum carries implications for weed management should environmental conditions change. It must be noted that the identification was unverified and given that this is superficially similar to *Paspalum distichum* (mercer grass) it could have been an odd morph of that species. However, *P.vaginatum* being a tropical species would thrive in the warm soil and is also tolerant of saline soils. While no reference to geothermal salinity could be found there are indications that the identification may be correct and certainly warrants following up.

Geothermal heating of the soil varied considerably from site to site. No consistencies were apparent in terms of temperature range at source (geothermal feature) and distal impact on soil temperatures. Transects were run across slope where applicable to avoid any influence of the movement of surface/ground water.

While the changes observed in vegetation around the geothermal features surveyed indicated both temporal and spatial changes in soil temperature by far the greatest impact was from human activity. Disturbances ranged from erasure of endemic vegetation by disking (Site 5), through stock damage both to the features and vegetation to minimal disturbance where efforts had been made to isolate the feature with fencing to exclude stock and in one instance (Site 8) plantings had been undertaken.

Changes in soil structure and composition combined with observations of recent changes in vegetation indicated changes in the geothermal heating of the soil. The growth stage of the vegetation indicated the timing of the change. As this varied from quite recent (i.e. the vegetation while still standing was dead) to vegetation re-growth months to years old, temporal variation was inferred. Pringle and Triska (1991) demonstrated that spatial and temporal variability of surface and groundwater chemistry was linked to geothermal activity and hydrogeochemical features regulating ecological processes in two tributaries to the Salto River in Costa Rica. Direction and rate of groundwater movement is dynamic. A numerical model of the shallow coastal hydrothermal system at Waiwera indicated that the hydraulic properties of the aquifer were not significantly affected by precipitation. Complex movement of groundwater, including seawater intrusion, contribute to the sustainability of this resource, which has been improved by reduced exploitation (Kuhn and Stofen 2005).

Given the national rarity of geothermal features and associated vegetation combined with the paucity of understanding of these systems attention to preservation of remaining systems is indicated.

4 Conclusions

No spatial pattern was observed with respect to either earthworms or other soil macro-fauna between geothermal features sampled. At each site, the geothermal feature demonstrated a unique pattern of effects on soil temperature and pH.

No earthworm species were found in soils above 24.8 ˚C. However, sub-tropical soil macro-fauna and soil litter dwellers were discovered in soils to 38.2˚C. Some of these species may expand their range to pose a pest threat should suitable soil temperature conditions become more extensive (e.g. as a response to climate warming).

Evidence was recorded of the dynamic nature both spatially and temporally of the soil environment, particularly soil temperatures, near geothermal features regardless of type (e.g. bare soil, fumerole, hot spring). These observed changes in the effects of geothermal heating of the soil may be because of changes in the levels and movement of groundwater the complexity of which implies direct management may be difficult. However, based on the observations made here the implications for the management of associated ecosystems may be less daunting with the planning of buffer areas to protect the flora and soil macro-fauna within geothermal features.

Environment conditions because of human activity at the eleven sites ranged from obliterated to protected with fencing from grazing and in one instance attempts to re-establish native vegetation. All sites exhibited evidence of having been modified by human activity at some stage. Active geothermal ecosystems are represented by just 1000 ha or ca. 0.004% of New Zealand's land area with a paucity of research and spatial mapping of these habitats.

5 Recommendations

In the light of the small and diminishing examples of geothermal habitat in the Waikato Region it is recommended that managing human activity where there may be an impact on environmental conditions in geothermal features should be undertaken within the context of a soil macro-fauna and flora assessment at each site.

Because the current survey was conducted at one point in time, a limitation is that there can be no temporal extrapolations. While the survey provides vital base information, repeat surveys over time would give important temporal trends.

It is also recommended that consideration be given to extend the survey to macrofauna in geothermal soils under native (endemic) vegetation.

An appropriate buffer range should be determined from the ecological evidence to protect the habitats of geothermal features, and if necessary, policy changed to ensure this buffer is implemented. While this survey gives an indication of spatial trends in relation to geothermally-influenced pasture, further analysis of soil-dwelling organisms under native geothermal vegetation would be needed to determine the appropriate buffer.

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Appendix: Soil macrofauna data

This appendix contains the soil macrofauna data obtained from eleven geothermal sites in the Waikato Region in a study undertaken in November 2011.

Key to soil macro fauna reported

SMF Species	Species common name
Earthworms	
Aporrectodea caliginosa	
Aporrectodea trapezoides	
Lumbricus rubellus	
Lumbricus terrestris	
Octolasion cyaneum	
Others	
Aphodius tasmaniae	Tasmanian grass grub
Aploneura lentisci	root aphid
Bobilla sp.	small field cricket
Conoderus exsul	wireworm
Costelytra zealandica	grass grub
Creophilus oculatus	Devil's coachhorse
Halotydeus destructor	redlegged earth mite
Heteronychus arator	black beetle
Inopus rubriceps	soldier fly
Naupactus leucoloma	whitefringed weevil
Onthophagus sp.	Australian dung beetle
Porcellio scaber Latreille	slater
Pyronota sp.	manuka beetle
Sitona lepidus	clover root weevil
Teleogryllus commodus	black field cricket
Wiseana sp.	porina

Table 1: Paerata Road (WRC Site No MKV04) Transect A data

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)
Ambient	**19.0**	**-**	**-**
Surface	**24.0**	**-**	**-**
1	13.10	5.8	A. cal.
20	12.9	6.2	A. trap, some A. cal (30)
30	12.90	7.3	A. trap, some A. cal, L. rub rare (37)
50	11.1	6.1	A. trap, some A. cal (11)
70	13.8	6.1	A. trap, some A. cal, O. cy rare (17)

Table 2: Paerata Road (WRC Site No MKV04) Transect B data

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)
Mud Pool	**18.8**	**2.9**	**-**
1	15.6		-
3	13.6	4.8	A. cal, L. rub rare (7)
20	16.7	5.0	A. trap, A. cal. (2)
40	15.2	5.3	A. cal, A. trap. L. rub (27)
60	13.4	5.7	A. cal (17)
80	10.4	5.7	A. cal (13)

*Many dead.

Table 3: Paerata Road (WRC Site No MKV04) Transect C data

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)
Stream	**15.1**	**6.3**	**-**
1	16-20	-	-
2	22.5	4.5	-
10	15.0	5.7	A. cal, some L. rub, O. cy (9)
30	16.2	5.9	A. cal, O. cy rare (21)
50	15.3	6.5	A. ca,l some A. trap (13)
70	17.4	6.7	A. cal, some A. trap (19)

Notes: Species identified at Mokai were primarily *Aporrectodea caliginosa* species-complex; however two superficial Mokai morphs were recognized as "*A. caliginosa*" and "*A.* cf. *trapezoides*", as detailed in Discussion. Other earthworms recovered infrequently were *Lumbricus rubellus* that inhabits organic rich soil and manure, and *Octolasion cyaneum* a geophage (mineral soil diet) often implicated as a first colonizer in disturbed sites or as a pioneer species. Only indication of species differences were that "*A.* cf. *trapezoides*" was more prevalent and numerous in the upper paddock (Transect A), while "*A. caliginosa*" appeared dominant in the lower paddock (Transect C) where *O. cyaneum* was also slightly more frequent. [Sample specimen sketches made]

Table 4: Mangamingi Station (WRC Site No. TKV06)

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)	Other SMF
Small Fumerole	**32.5**	**5.5**	**L. rub (5 alive, many dead)**	**-**
Fumerole #1	**90.0**	**4.3**	**-**	**-**
1	54.1	4.5	-	-
5	51.3	4.3	-	-
10	41.4	5.5	-	-
15	16.6	6.3	-	-
20	17.1	6.3	Lumbricids (2 immature)	2 I.rubriceps (larvae) 1 Wiseana sp. (larvae)
Dry pool	20.0	6.2	-	-
Fumerole #2	**76.3**	**5.6**	**-**	**-**
.5	56.6	4.7	-	-
5	27.3	5.4	-	-
10	19.6	6.1	-	-
15	17.0	6.1	L. rub (1 mature,1 subadult) L. ter (1 immature) D. rub (1 immature) 1 cocoon	4 I.rubriceps (larvae 2 mature, 2 immature), 1 C. exsul
20	22.5	5.7	-	-
Fumerole #3	**80.8**	**5.9**		**-**
1	51.0	5.9		-
5	26.0	5.4		1 C. exsul, 1 H. arator
10	17.5	5.7		2 C. exsul, 2 I. rubriceps, 1 Pyronota sp., 1 Encytraeid sp.
15	18.7	5.6	Lumbricids (2 immature)	4 Tipulidae larvae, 2 Encytraeid sp. 1 C. zealandica (adult)

Table 5: Arataki Honey (WRC Site No WTV0 Ngapouri)

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)	Other SMF
Pool	**29.1**	**4.0**	**-**	**-**
1	23.2	4.4	-	-
5	24.5	4.7		-
10	22.0	5.3	L. rub. (4 mature) *Amynthas* sp. ? L. castaneus Unidentified immature and bits of worm (6)	-

Table 6: Ohaaki East (WRC Site OHV02)

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)	Other SMF
Fumarole 1	**85.0**	**4.0**	**-**	**-**
Fumarole 2	**61.0**	**3.0**	**-**	**-**
Fumarole 3	**90.0**	**3.3**	**-**	**-**
1	72.0	2.3	-	-
5	43.5	3.0	-	-
10	27.2	3.6	-	1 N. leucoloma (larvae)
15	23.3	4.0	-	-
20	22.8	4.5	-	-
30	31.1	4.5	-	-
40	29.1	4.2	-	-
50	34.5	4.0	-	-
60	23.2	4.0	-	-
70	23.2	4.0	-	-
90	21.5	4.2	-	-
100	22.3	4.4	L. rub. (1 immature)	-
50	26.1	4.5	-	-

Table 7: Oruanui Block (WRC Site WKV01 Te Rautehuia)

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)	Other SMF
Fumarole 1	**94.5**	**6.0**	**-**	**-**
1	81.1	5.0	-	-
5	38.2	4.5	-	-
10	32.5	4.9	-	-
15	25.5	4.5	-	-
20	22.0	5.1	-	-
25	16.1	5.8	-	2 N. leucoloma (larvae) 1 I. rubriceps (larvae) 1 S. lepidus (larvae)
30	19.3	5.4	-	1 I. rubriceps (larvae)
Fumarole 2	**92.9**	**4.8**	**-**	**-**
1	57.4	3.5	-	-
5	39.9	3.6	-	-
10	38.2	3.9	-	-
15	28.0	4.7	-	Onthophagus sp. (14 larvae, 5 pupae, 4 adult)
20	28.9	4.7	Lumbricids (4,1 in diapause)	Onthophagus sp. (4 larvae), 1 C. exsul, 1 centipede
25	31.9	5.1	Lumbricids (2, 1 in diapause)	Onthophagus sp. (11 larvae, 3 adult)
30	42.7	4.8	-	-

Table 8: Maxwell (WRC Site RPV02 Wharepapa)

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)	Other SMF
Bare soil field	**22.0**	**4.2**	**-**	**-**
1	27.1	8.1	-	-
5	20.7	4.1	-	-
10	19.5	4.2	1 A. cal (1 immature)	1 C. exsul (larvae)
15	19.5	4.4	-	-
20	18.9	4.6	L. rub. (3 immature)	-
Hot pool	**96.8**	**7.7**	**-**	**-**
1	26.6	6.7	A. cal (1 immature)	1 C. exsul (larvae) 1 N. leucoloma (larvae)
5	24.5	5.3	-	-
10	23.8	5.2	-	-
15	24.8	4.9	A. cal. (7 sub-adult + immature + cocoon)	-
25	25.2	5.7	L. rub. (1 mature) A. cal. (5 mature and 4 immature)	-
100	67.0	8.2	Some unidentified dead worms	-
				-
Fumarole				**-**
3	52.6	6.1	-	-
8	33.0	5.5	-	-
13	27.0	5.8	-	-
30	24.8	5.6	L. rub. (3 mature)	-

Table 9: Berry property (WRC Site No WTV02)

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)	Other SMF
Hot spring	**96.8**	**7.7**	**-**	**-**
Spring outlet@20m *	**33.9**	**2.6**	**-**	**-**
1	24.5	4.9	-	-
10	26.5	5.2	-	-
20	27.5	5.4	-	-
30	26.7	5.3	-	-
100	23.8	5.4	1 A. cal, 1 unidentified	-

* Chironomidae larvae in stream; Staphylinid larvae on embankment.

Kerosene Creek at Waiotapu was visited. However, what had been a pastoral site was planted with pines (*Pinus radiata*).

A bare soil field adjacent to the primary school on Crown Road was visited and another adjacent to the road but the locations were either unsuitable through lack of pasture or had been modified by roadway development restricting access.

Table 10: Taupo Golf course (WRC Site No TH04 Broadlands Road)

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)	Other SMF
Bare soil field 1	**56.8**	**5.0**		
2	53.0	5.9	-	-
5	34.3	5.5	-	-
10	28.3	5.3	-	-
15	22.9	5.4	-	1 C. exsul, many A. lentisci
20	23.8	5.6	-	A. lentisci
25	23.1	5.3	-	A. lentisci
30	22.1	5.2	-	2 N. leucoloma (larvae)
35	21.4	5.4	-	1 N. leucoloma (mature larva)
40	22.2	5.5	-	A. lentisci frass
Bare soil field 2	**51.0**	**4.9**		
2	26.3	5.8	-	-
5	23.4	5.7	-	-
10	21.3	5.7	-	-
15	22.7	5.9	-	-

Note: The soil at the Taupo Golf Course site was a a disturbed coarse pumice with a dense root mat under the pasture. The latter indicative of little in the way of soil macro fauna present. Patches of *Anthoxanthum odoratum* (Sweet Vernal) and moss indicated patchy temperature changes.

Table 11: Tauhara Road (WRC Site No TH04 Broadlands Road)

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)	Other SMF
Bare soil field 1	**59.0**	**4.8**	**-**	**-**
2	31.0	5.6	-	
5	32.1	5.5	-	1 Staphylinid (C. oculatus)
10	31.9	5.9	-	
15	28.0	6.3	-	1 C. zealandica (adult female)
20	25.9	5.9	-	1 N. leucoloma (larva mature)
30	22.5	6.1	-	6 S. lepidus (5 pupae, 1 larva) A. lentiser frass
40*	21.2	6.3	2 L. rubellus (mature +immature)	1 N. leucoloma, 3 S. lepidus (larvae, 1 parasitized with nematodes)
Bare soil field 2	**69.0**	**4.3**		
2	44.2	4.7	-	-
5	36.4	5.1	-	H.destructor (numerous)
20	23.2	5.5	-	A. tasmaniae (larva mature)
30	27.8	5.7	-	-

* 40 m directly uphill from geothermal feature (bare soil field 1)

Table 12: Crown Park MotoX (WRC Site Th06 Crown Road)

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)	Other SMF
Bare soil field Transect 1	**58.9**	**5.6**		
2	36.7	5.8	-	-
5	36.6	6.3	-	-
10	36.6	5.8	-	-
15	53.7	5.3	-	-
25	37.2	6.2	-	-
35	32.8	7.0	-	-
Bare soil field Transect 2	**64.5**	**6.4**		
5	36.7	6.4	-	-
10	39.8	5.9	-	-
15	32.0	6.4	-	-
20	31.5	6.9	-	-
25	26.2	6.6	-	-
30	23.1	6.4	3 L. rubellus (1 mature, 2 immature), 1 L. terrestris, 2 A. caliginosa	1 Wiseana sp. (larva mature), 1 centipede

Table 13: Tauhara Middle (WRC Site Th06 Crown Road)

Dist. from Feature (m)	Temp °C	pH	Earthworm Spp (nos)	Other SMF
Small bare soil fields/vents	**47.9**	**5.9**		
2	46.6	5.8	-	-
5	32.4	7.1	-	-
10	28.6	7.2	-	-
15	30.2	7.2	-	2 C. exsul (larvae)
25	32.0	7.2	-	-
35	30.3	7.1	-	1 C. exsul (larva)
60	20.1	6.8	-	5 C. exsul (1 adult, 4 larvae), 1 Porcellio scaber, A. lentisci frass