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Establishment of biodiversity monitoring plots within geothermal habitats, Waikato Region, 2024

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Establishment of biodiversity monitoring plots within geothermal habitats, Waikato Region, 2024

Contract Report No. 3330e

Providing outstanding ecological services to sustain and improve our environments

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August 2024

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1.0 Introduction

In 2023, Wildland Consultants reviewed the standardised monitoring protocols for measuring ecosystem integrity across New Zealand's diverse environments, with specific consideration on geothermal ecosystem monitoring (Wildland Consultants 2023a). Geothermal habitats present a range of challenges for monitoring biodiversity which are not sufficiently accounted for by the current national monitoring framework methodology described in Bellingham *et al*. 2021 and Hurst *et al.* 2022. Monitoring geothermal vegetation presents a range of challenges: difficulty of access, high habitat diversity within sites, and habitats and species susceptible to trampling impacts. There are also many safety issues associated with heated and unstable ground, dangerous features such as mudpools, hot springs, geysers, hidden geothermal holes, dangerous geothermal streamsides, and toxic gases.

In 2023 geothermal ecosystem monitoring was reviewed, including consideration of options for implementing quantitative monitoring methods compatible with the national monitoring framework (Wildland Consultants 2023a). Previous monitoring was reviewed and challenges workshopped. Three recommendations with regard to monitoring geothermal ecosystems were made. First, methods to quantitatively measure geothermal ecosystem integrity should be added to the suite of indicators currently being monitored. Second, quantitative assessment of the integrity of geothermal habitats should be achieved by applying the methods for wetland ecosystems proposed by Bellingham *et al.* (2021) for geothermal wetlands; and a modification of methods proposed by Bellingham *et al.* (2021) for other geothermal habitats that are not dangerous. Third, a new approach to measuring vegetation structure and cover abundance using drones and 1 m^2 plots could be explored to extend measurement of ecosystem integrity into areas unsafe to access on foot.

Following the 2023 review, Waikato Regional Council commissioned Wildland Consultants to prioritise and establish biodiversity monitoring of geothermal ecosystems within Protected Geothermal Systems[1] and develop procedures to identify monitoring frequencies. There are 15 geothermal sites (Wildland Consultants 2023b) within the five Protected Geothermal Systems. Monitoring within Development Geothermal Systems is generally well-established through resource consent processes, although methodologies differ across sites. This report presents the process undertaken to establish monitoring within Protected Geothermal Systems, results of the monitoring and key findings, and recommendations on future monitoring including frequency. Twelve permanent monitoring plots were established within the budget and timeframe available (May – June 2024) within five sites within three Protected Geothermal Systems (Orākei Kōrako, Te Kopia and Waikite-Waiotapu-Waimangu).

2.0 Prioritisation of biodiversity monitoring

2.1 Access permission

Permission to access sites and undertake monitoring was the main factor in selection of sites to locate plots, and the process to obtain permission was started in January 2024. Permission was received early in the project from Ngati Tahu-Ngati-Whaoa Runanga Trust to undertake monitoring of land within their rohe, which allowed for monitoring at Red Hills- Orākei Kōrako and Waiotapu. Other geothermal sites within Protected Geothermal Systems required the permission of the Department of Conservation (DOC). In mid-May 2024, the DOC Rotorua office authorised a one-off permit to allow

[1] https://www.waikatoregion.govt.nz/environment/geothermal/classifying-geothermal-systems/#:~:text=Protected%20geothermal%20systems,-System&text=Sinter%2Ddepositing%20springs%20on%20the,tubes%20and%20associated%20specialised%20ecosystems.&text=New%20Zealand's%20largest%20concentration%20of,to%20highly%20vulnerable%20geothermal%20features.

plots to be established and monitored on land administered by DOC, with a formal permit still pending. To simplify the permit process, the one-off permit was limited to Te Kopia Scenic Reserve, Maunga Kakaramea Scenic Reserve and Maungaongaonga Scenic Reserve. Meetings were held with managers at Waiotapu Thermal Wonderland and Orākei Kōrako tourist operations to discuss access to these sites. Permission was granted to establish plots at Waiotapu Thermal Wonderland, however Orakei Korako management held concerns over safety of work being undertaken "off path" and did not grant permission for monitoring to proceed. Permission was also obtained to establish plots in areas of Waiotapu managed by Timberlands.

Sites available for monitoring therefore, were reduced to five (from a potential 15 sites located within Protected Geothermal Systems in the Waikato).

Permission to fly a UAV (unmanned aerial vehicle/drone) was obtained for:

- Sites at Waiotapu managed by Timberlands (separate permits from Timberlands were required for this).
- Waiotapu Thermal Wonderland.
- Red Hills.

Permission was not sought to fly a UAV over DOC land.

2.2 Health and safety

Working in geothermal areas involves multiple hazards which include, but are not limited to:

- Geothermal gases such as hydrogen sulphide and carbon dioxide.
- Unstable ground and thin crust with high sub-surface temperatures.
- Hot water and boiling mud pools.
- Steam clouds.
- Potential eruptions.

As such, random plot locations need to checked to ensure that they can be safely established (see Table 1 for an excerpt from Wildlands Site Specific Safety Plan for geothermal work for hazards that need to be considered). There are areas within all of the geothermal sites surveyed that were inaccessible because they are too hot, the ground surface is too unstable, there was a risk of burns from falling into a feature, and/or a risk of suffocation from the accumulation of hydrogen sulphide and carbon monoxide in hollows and low-lying areas. In addition, the heightened danger of particular habitat types (e.g., dangerous ground alongside springs, geysers, and geothermal streams) affected whether all vegetation types and habitats could be included in the monitoring.

Table 1 – List of potential hazards for geothermal areas.

Geothermal Hazard
Working on or around thin crust or potentially thin crust with high sub-surface temperatures where accidents could potentially occur causing serious burn injuries.
Working on or around unstable ground surface above areas with high sub-surface temperatures where accidents could potentially occur causing serious burn injuries.
Working around hot water pools and springs, boiling mud, geothermal holes and depressions where accidents could potentially occur causing serious burn injuries.
Potential serious burns/harm injuries associated with eruptions of gas, hot water, mud, hard materials.
Potential serious harm injuries associated with steam clouds obscuring vision.
Potential serious harm injuries associated with harmful gases (e.g. H_2S, CO_2).

2.3 Plot locations

Plots were located in a stratified random manner, with each geothermal site being subdivided by habitat and vegetation type. The subdivision was based on vegetation and habitat types mapped in 2023 (Wildland Consultants 2023b). Areas of geothermal habitat (excluding the habitat types geothermal water, mud pools, geothermal spring, geothermal stream, and sinter) were identified, and Esri ArcPro was used to generate a grid of potential plot locations within each habitat type present, with a minimum of 10 metre spacing between each point. Esri ArcPro was then used to selected thirty random points per site, and generate a GPX file of plot locations. Points located on the margin of vegetation types were then excluded. The randomised waypoints were prioritised for measurement based on accessibility (e.g. plots located on cliffs were excluded) and local site knowledge of hazards.

The high frequency of hazards in geothermal areas meant that it was unsafe to establish plots at many of the random locations. Plots were established as close to the random way points as it was safe to do so. If the entire area surrounding the randomised point was deemed unsafe, then the location was rejected and a different location was sought.

3.0 Plot measurements

3.1 Overview

Plot establishment and measurement followed the methods described by Bellingham *et al.* (2021), Hurst *et al.* (2022) and Wildland Consultants (2023a) with the following major modifications:

1. A plot sized of 10 × 10 metres was adopted for all ground-based plots containing woody vegetation, rather than varied plot sizes based on vegetation stature, as geothermal sites are highly dynamic and vegetation stature may change significantly in the future. This size is very practicable to measure in geothermal sites as any larger can increase the danger in working in geothermal sites, while any smaller will increase the bias in sampling. Our observations of geothermal sites over the years have also shown that changes to major vegetation types can occur within relatively short time scales and therefore measuring at a smaller scale is unlikely to provide long-term information on a site relative to monitoring effort. A smaller size on unstable substrate would increase the risk to field teams and damage to geothermal sites by increasing movement through sites.

2. An initial attempt was made to use the randomly generated points to locate plots. However, most areas contained numerous areas that were too dangerous to place a monitoring plot. Therefore, plots were placed as closely as possible to a random location, where it was safe to access. Protocols around movement of plots were deemed impractical in the geothermal context.

3. The length of the animal transect (as per Bellingham *et al*. 2021) was reduced to 20 metres in length to account for the high frequency of hazards found in geothermal sites. In five of the 48 animal transect lines measured, they were not measured to the full 20 metres due to safety.

4. Soil temperature measurements were taken at each plot corner and each understorey plot at 10cm and 40cm depths as soil temperature is major influence on geothermal vegetation height and composition (Burns 1997).

5. Taking advantage of the field teams being on site for more than one day at a time, a tracking tunnel was left overnight in each plot, baited with pear, to survey for lizards that may be present in the site. This cannot be considered to be an effective lizard survey as tracking tunnels are normally be

left out for many consecutive nights, placed strategically within potential habitat rather than randomly.

In addition, minor additional changes to standard methodology are outlined within the specific methodologies provided below.

3.2 Plot locations

A hand-held Garmin GPSmap64sx unit was used to locate potential waypoints in the field. Plots were then established as close as safely possible to the selected waypoint. Corner D of the vegetation plot was then placed such that the plot location would meet the following criteria:

- Safe (the area of the plot was carefully inspected to check that it was safe to establish and measure a plot).
- The entire plot contained geothermal vegetation.

Corner D was then marked with a fibreglass pole, and a GPS waypoint was created. Plot locations are shown in Figures 1-3 and GPS coordinates are presented in Appendix 1.

3.3 Plot establishment and layout

The three remaining corners of the vegetation plot were located as follows. If the site was flat (slope <5°), a sighting compass was used to set the D-C boundary so that Corner C was North of Corner D (bearing 000°, magnetic North). If the site was sloping, the D-C boundary was established along the predominant contour of the slope, a 10 metre tape was laid out along this contour and was marked as corner C. The bearing along the D-C line was then determined by using a sighting compass. Ninety degrees was added to this bearing to determine the compass bearings of the D-A and C-B boundaries at right angles. Corner A was located 10 metres at a right angle (generally upslope) of Corner D, Corner B was located by placing tape measures out at approximately right angles from each of Corner A and Corner C. Corner B was marked at the meeting point of both tape measures, to form a 10 m × 10 m square. All tapes followed the ground surface where possible to do so.

The plot was subdivided into four 5 × 5 metre subplots by laying out two internal tapes at five metre intervals. The corners of each plot were marked using fibreglass poles (0.5 or 1 metre length, 0.8 cm width depending on vegetation height) and labelled using Permolat or Dymo labels marked A, B, C, and D, and also written on the fibreglass poles using a cattle tag pen. Five understorey plots were established along the internal tapes and marked permanently using a (270mm × 4mm) aluminium peg, with permolat labels numbered 1-5. A plot layout diagram is presented in Figure 4.

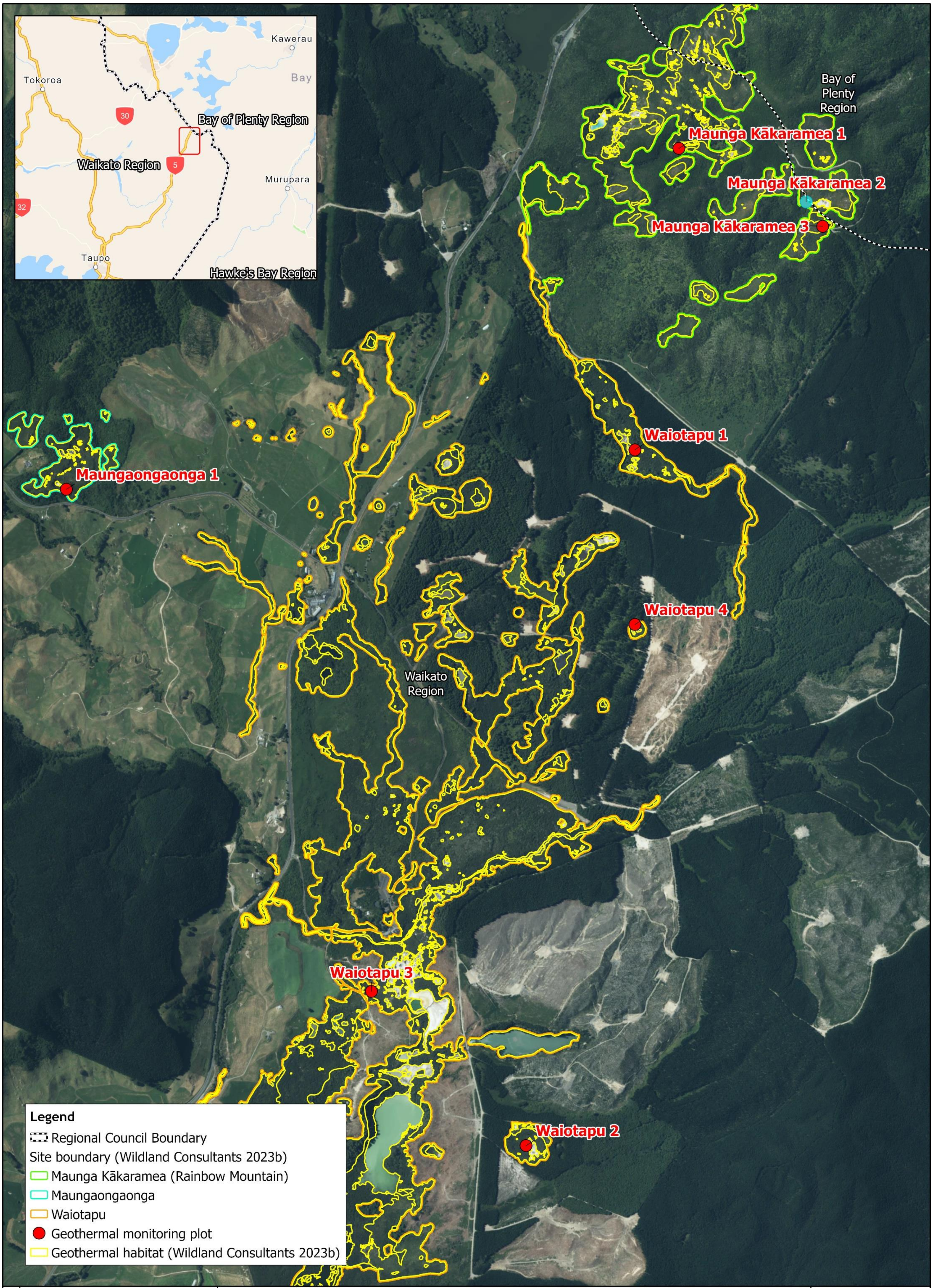

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Figure 1. Locations of permanent biodiversity monitoring plots within geothermal habitats in three geothermal sites, Waikite-Waiotapu-Waimangu Geothermal System, Waikato Region

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Scale: 1:17,000
Date: 9/08/2024
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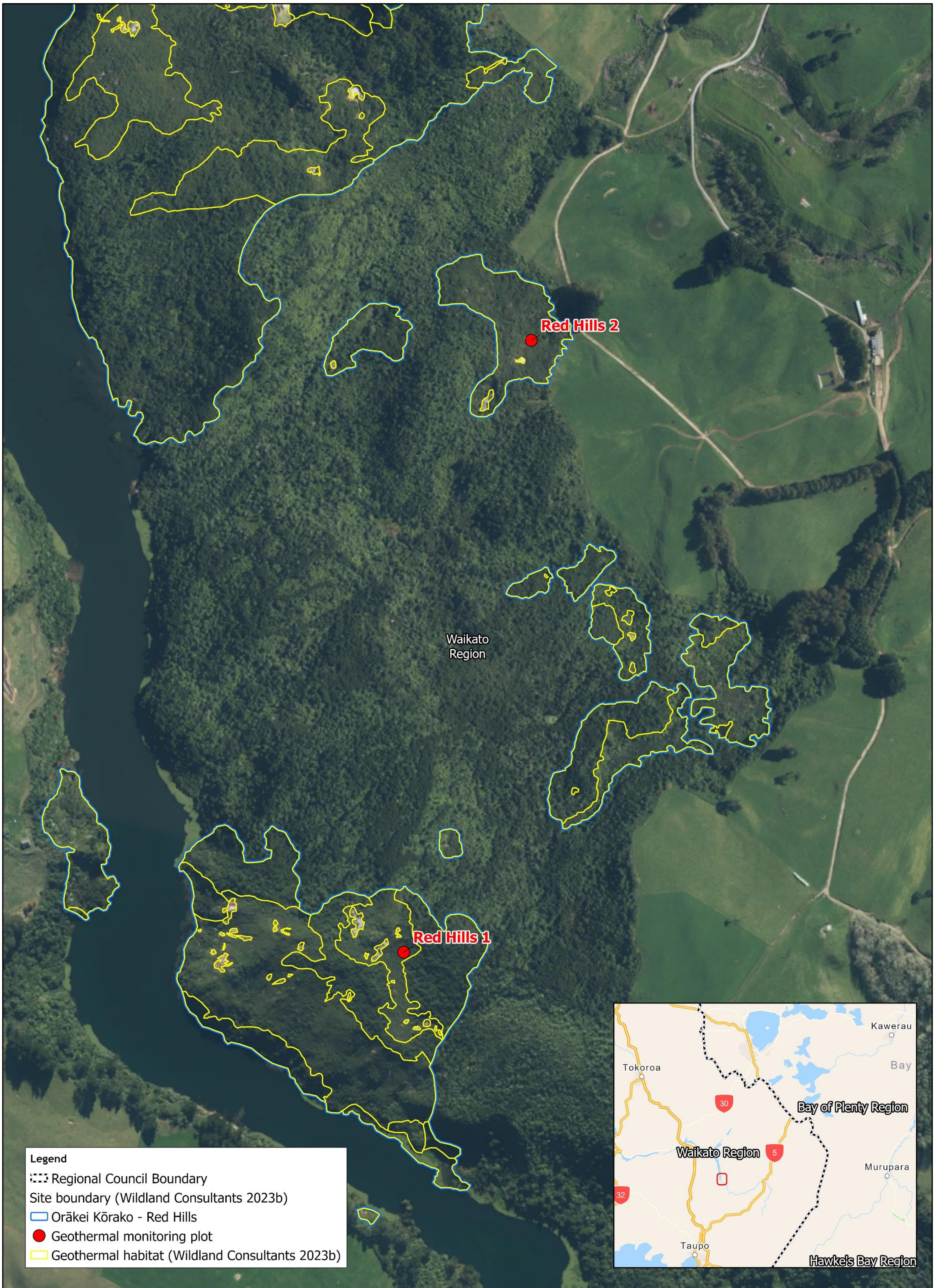

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Figure 2. Locations of permanent biodiversity monitoring plots within geothermal habitats at the Orākei Kōrako and Red Hills site, Orākei Korako Geothermal System, Waikato Region

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Scale: 1:5,000
Date: 9/08/2024
Cartographer: LW
Format: A3

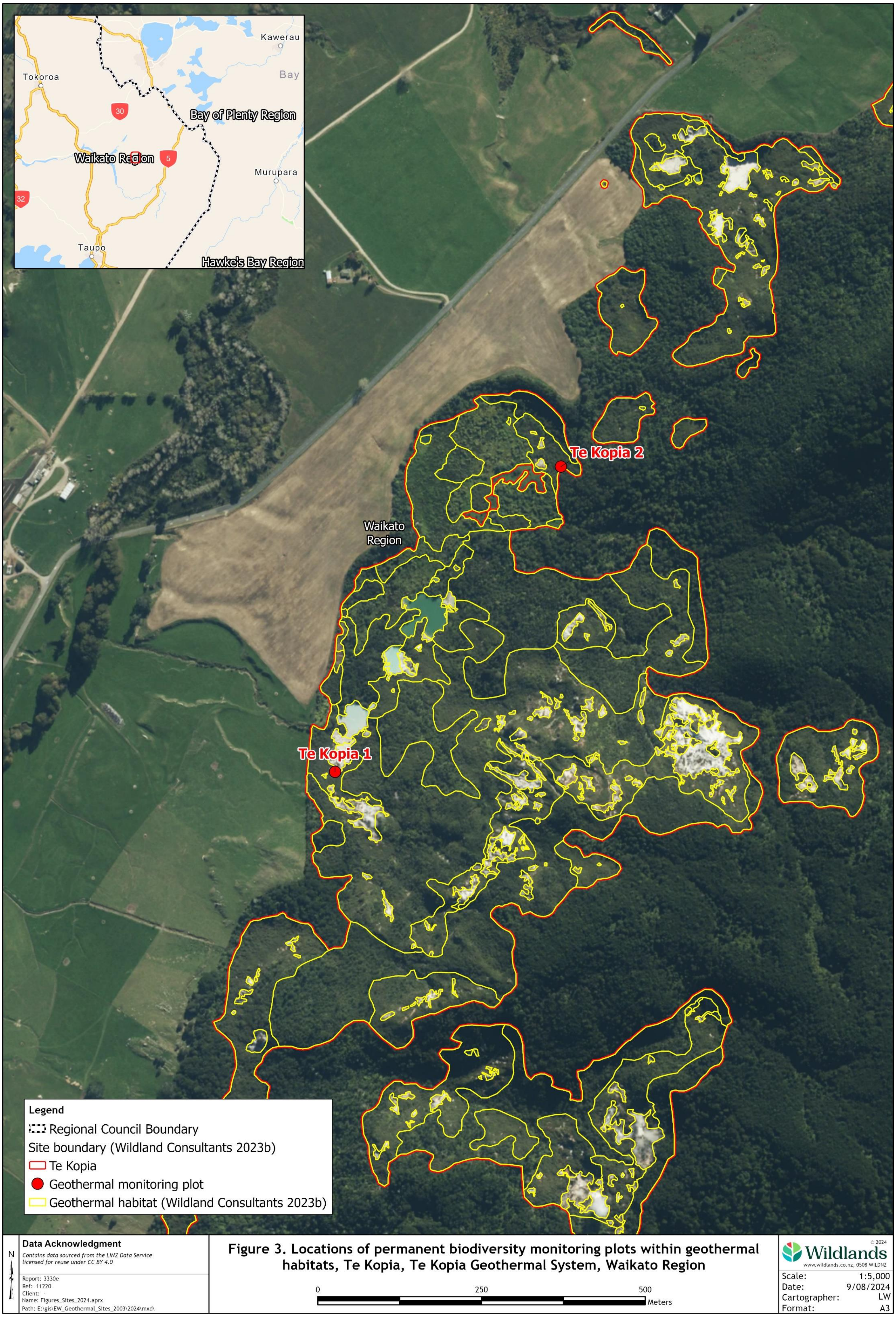

Figure 3. Locations of permanent biodiversity monitoring plots within geothermal habitats, Te Kopia, Te Kopia Geothermal System, Waikato Region

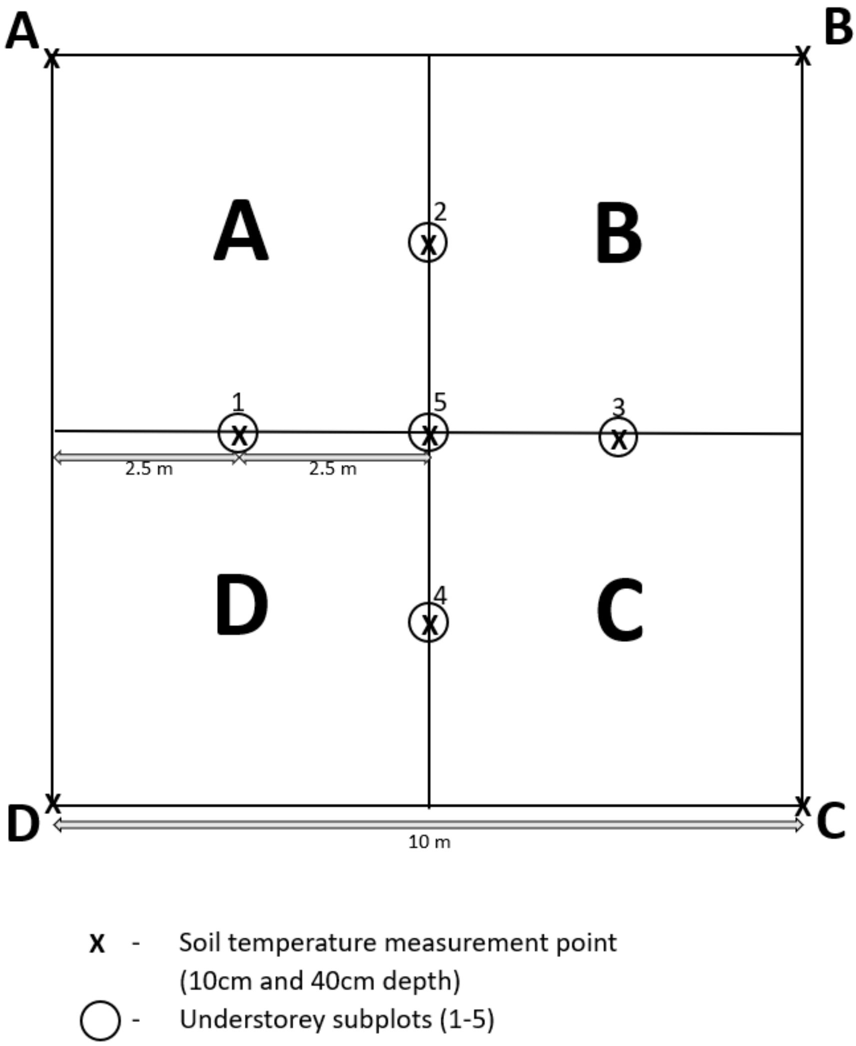

Figure 4. 10 × 10 metre geothermal vegetation plot layout showing Corners A, B, C, D, understorey subplots 1-5, and 9 soil temperature measurement points. The seedling markers for the understorey subplots (excluding the central marker) on the centre lines, were placed halfway between the outer line and the centre point maker, the 2.5 metres in shown in the diagram for understorey subplot peg 1 is just an example.

3.4 Vegetation measurement

Plot measurement largely followed the protocols of Bellingham *et al*. (2021) and Wildland Consultants (2023a) with some adjustments. The modified vegetation methods are summarised below.

A standard National Vegetation Survey (NVS) permanent plot reconnaissance (Recce) plot sheet was completed for each plot, with modifications to account for the difference in plot size. Plot characteristics were recorded including slope, aspect, drainage, approach, and a diagram of the area. Groundcover variables, fauna, vegetation browse, and relative abundance of each plant species present in seven vegetation tiers (<30cm, 0.3-2m, 2-5m, 5-12m, 12-25m, >25m) were also recorded.

Stem diameter and sapling NVS plot sheets were also completed for each plot if these components were present. The plot was divided into the four 5 × 5 metre subplots. In each subplot, each stem >2.5 diameter at breast height (dbh, 1.35 metres) was identified to species level, tagged using a numbered tree tag, and dbh to the nearest 0.1cm was measured. The number of saplings (woody species >1.35 metres tall and <2.5 cm dbh) of each species in each subplot was also counted. Trees and shrubs were only measured/counted if their bases were either wholly located within the plot, or if, for larger trees, at least half of the tree base (at ground level) occurred within the plot.

Understorey subplot sheets for five circular subplots (each 0.75m^2) located at 2.5m, 5m, and 7.5m along each internal tape were completed. All plant species <15cm tall were recorded by presence (not counted), and each woody plant species >15cm tall was counted in four height tiers (16-45cm, 46-75cm, 76-105cm, 106-135cm). Non-woody species and lianes >15cm tall were recorded by presence (not counted) in the height tier in which they occurred.

Vascular and non-vascular plant species recorded at each plot are listed in Appendix 5 and 6. For any plants that were unable to be identified in the field a sample was collected, ideally including flowering, fruiting, or otherwise fertile material.

Two photographs were taken at each plot corner, facing in towards the centre of the plot, and out along the fauna transect bearing. A representative photograph from each plot is presented in Appendix 2.

3.5 Temperature measurements

Nine soil temperature measurements were taken: at each plot corner (A-D) and each understorey plot (1-5) (Figure 4). Temperatures were taken at 10cm and 40cm depths.

3.6 Bird counts

Two five-minute bird counts were completed at each plot, one at the beginning of plot measurement, and one at the end of plot measurement with a minimum of one hour between counts. The count methodology followed Dawson and Bull (1975) and Hartley and Greene (2012). The observer stood quietly and recorded all birds seen and heard within three distance categories (>25 m, 26-100 m, >100 m) over a five-minute period. No individual bird was knowingly counted more than once. All five-minute bird counts were completed during daylight, i.e. between 1.5 hours after sunrise and 1.5 hours before sunset.

3.7 Tracking tunnel

One tracking tunnel was deployed per plot for one clear night (<1mm rain in the first 4 hours after sunset), and collected the following day, located at a strategic location within 1 metre of the plot. One pre-inked Black Trakka tracking card was baited with pear-based baby food and placed in the tracking tunnel. Deployment location was recorded and upon collection, initial observations noted (presence or absence of tracks, initial identification). Cards were re-inspected and checked against the Department of Conservation guide[2].

3.8 Fauna transect establishment

Fauna transect lines extend from each of the vegetation plot corners at 45° angles away from each plot edge. The bearing for Transect A was calculated by subtracting 45° from the D-A boundary bearing. For example, if the bearing for the D-A edge of the vegetation plot was 170°, the Transect A bearing was 125°. A 20-metre tape was laid out along this bearing using a sighting compass. Transect B was established by adding 90 degrees to the bearing for Transect A, and running a measuring tape

[2] https://www.doc.govt.nz/globalassets/documents/our-work/predator-free-2050/a-short-guide-to-identifying-footprints-on-tracking-tunnel-papers.pdf. Accessed 24 May 2024.

20 metres from Corner B along this bearing using a sighting compass. Transects C and D were established in the same way by adding 90 degrees to the previous transect bearing.

Where a fauna transect met an obstacle (e.g. unstable geothermal ground), one of the following approaches was utilised:

- If the obstacle was able to be walked around safely and only affected one 5-metre interval faecal pellet measurement point (e.g. a small geothermal vent or small patch of unstable ground <1m^2), the transect was continued across the obstacle while walking around the unsafe area, using a safety pole to test the ground. If a faecal pellet measurement point fell within the unsafe area and the ground was bare, the measurement point was viewed from a safe distance. If the ground was not bare in the unsafe area, the below approach was utilised.

- If the obstacle was impassable i.e. large, vegetated, and/or unable to walked around safely, the transect was turned 90 degrees at the last safe faecal pellet measurement point in whichever direction provided the safest route. If a second impassable object was encountered on the transect, the transect was terminated at the last safe faecal pellet measurement point.

At the terminus of each fauna transect (either 20 metres or the last safe faecal pellet measurement point), a GPS waypoint was created.

3.9 Fauna transect measurement

Faecal pellet searches were completed at 5 metre intervals along each animal transect (at 5, 10, 15, and 20 metres). Faecal pellets were recorded as either present or absent within the faecal pellet plot and individual pellets were not counted[3]. At each measurement point, presence or absence of ungulate, possum, and wallaby pellets within a 1 metre radius subplot was recorded. Presence or absence of lagomorph (rabbit or hare) pellets within a 0.18m radius subplot was also recorded, nested within the centre of the 1 metre radius subplot. When searching each faecal pellet plot, vegetation was pushed aside (where possible) to ensure that the entire plot surface was searched. Each plot was searched in a systematic manner.

A corflute chew card baited with an aniseed-flavoured paste was labelled with the plot identifier and transect, and installed at the terminus of each fauna transect. Chew cards were preferentially nailed 30cm above the ground to a tree or shrub within 3 metres of the transect terminus. If no suitable trees or shrubs were available, the chew card was installed on a 40cm long metal stake, 30cm above the ground and adjacent to existing vegetation. Chew cards were deployed for one clear night and collected the following day. Initial observations were recorded upon collection (presence or absence of bite marks, initial identification) and confirmed by later inspection and comparison to the Landcare Research guide[4].

3.10 Unmanned Aerial Vehicle Photographs

An Unmanned Aerial Vehicle (UAV) was used to capture aerial images of five pre-established 10 × 10 metre plots on 3 July 2024. High resolution imagery was also captured of four additional randomly generated sites (UAV Plots 1-4) which were not safe to measure on the ground. UAV Plots 1-4 were

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3 Faecal pellet searches follow the method provided in Bellingham *et al*. (2021). This method differs from the DOC field protocols for Tier 1 monitoring in which ungulate pellets are counted within the 1 metre radius plot and lagomorph pellets are counted within 0.18m radius subplot and recorded if present in the 1 metre radius plot. https://www.doc.govt.nz/globalassets/documents/our-work/monitoring/field-protocols-tier-1-monitoring-recce-surveys.pdf. Accessed 16 September 2024.

4 https://www.landcareresearch.co.nz/assets/Discover-Our-Research/Biodiversity/vertebrate-pests/Chewcard_interpretation.pdf. Accessed 24 May 2024.

chosen based on their proximity to a randomly generated waypoint that would not be safe to undertake ground-based monitoring, and whether they were representative of the vegetation type and stature of the random waypoint (viewed on Google Earth). Plot boundaries were then located onto and measured from the resulting orthorectified images, centred on a randomly selected point. The size of the plot established followed the vegetation stature (forest and scrub 10 × 10 m, short (<2 m) scrub and shrubland 2 × 2 m, and geothermally-influenced bare ground 1 × 1 m). Data on species richness and surface characteristics were obtained from the images. UAV Plots 1-4 are presented in Appendix 4.

The UAV used was a DJI Mavic Pro II, which is equipped with a Hasselblad L1D-20c camera and 35mm format equivalent: 28mm lens, and is capable of capturing images of up to 5472×3648 resolution. Photographs taken with the UAV include GPS location in the image metadata.

The DJI Go 4 application was used to pilot the UAV and collect aerial data. Relevant landowner permissions, permits and pre-flight checks (including restricted airspace areas) were sought before flying, with flights also logged through the Airshare application to inform other aerial operators at each location.

At each plot pre-established 10 × 10 metre plot, the UAV was flown directly above the centre of the plot at an altitude that ensured full capture of the plot boundary in its entirety, which was at around 20 metres above the plot. UAV plot photographs are presented in Appendix 4.

The plot boundaries were later delineated on the images. The plot photographs were reviewed and number of vascular species able to be identified in each plot were recorded. A comparison of data capture from the UAV-based aerial images and ground-based measurement was undertaken for the five plots measured using both methods.

3.11 Data management

All field data sheets were scanned and saved to the Wildlands server.

All samples of plants and faecal pellets collected in the field were identified by experts, and chew cards and tracking tunnel cards were checked. Updated information was noted on plot data sheets, re-scanned, labelled as ‘final’, and entered in the relevant spreadsheet.

Raw data from the vegetation plots, soil temperature, five-minute bird count, and fauna transect measurements was entered to a Microsoft Excel workbook. Mean values were calculated for soil temperature data. Summary data were provided for vegetation plots, fauna transects and five-minute bird counts, and a brief discussion was prepared.

A Microsoft Excel workbook containing the raw data, GPS waypoints, and site photographs were saved to the Wildlands server and provided to Waikato Regional Council.

4.0 Monitoring Results

Sixteen biodiversity monitoring plots were established within three Protected Geothermal Systems (Table 2) established and measured between 14 May and 30 June 2024 (Figures 1-3). Twelve of these plots were permanent, and measured on the ground. Five of these plots were also photographed using a UAV on 3 July 2024 for comparison of data collection. Four other plots with no permanent markers in areas unsafe to measure on the ground, were measured by UAV alone. All permanent plots were established in either forest, scrub, or shrubland habitats. No permanent plots were established in areas comprising 100% cover of mossfield, lichenfield, rockland, or bare ground, but these types were included within the 10 × 10 plots.

Table 2 – Location of biodiversity monitoring plots established within Protected Geothermal Systems in the Waikato Region.

<table>
<tr><th>Geothermal System</th><th>Geothermal Field</th><th>Site Name (Wildland Consultants 2023b)</th><th>Number of Permanent 10 × 10m Plots</th><th>Number of Unmarked UAV Plots</th><th>Total Number of Plots</th></tr>
<tr><td>Orākei Kōrako</td><td>Orākei Kōrako</td><td>Orākei Kōrako and Red Hills</td><td>2</td><td>1</td><td>3</td></tr>
<tr><td>Te Kopia</td><td>Te Kopia</td><td>Te Kopia</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td rowspan="3">Waikite-Waiotapu-Waimangu</td><td rowspan="3">Waiotapu</td><td>Maunga Kākaramea (Rainbow Mountain)</td><td>3</td><td>0</td><td>3</td></tr>
<tr><td>Maungaongaonga</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>Waiotapu</td><td>4</td><td>3</td><td>7</td></tr>
<tr><td colspan="3">Total</td><td>12</td><td>4</td><td>16</td></tr>
</table>

4.1 Geothermal ecosystem type

The primary geothermal ecosystem habitat measured in plots was ‘heated ground (dry)’ which often comprised geothermally heated ground dominated by geothermal kānuka and other woody species. This ecosystem type is the one of the most widespread habitat types these geothermal fields, with most other habitats being dangerous to access. Parts of many plots contained areas of relatively ambient surface temperatures, that are likely to have had geothermal influence in the past (hydrothermally heated ground now cool) and these parts of the plot often had taller vegetation than the more active soils (such as parts of Red Hills 2). Fumaroles were represented by being on the margins of some plots (e.g. Red Hills 1, Maunga Kākāramea 1 and Maungaongaonga), and the steam from these was often present in plots.

4.2 Vegetation cover in plots

In general, vegetation cover in most plots comprised geothermal kānuka dominant scrub, shrubland or forest with local areas of fernland, mossfield, and bare ground (Table 3). Many plots are dominated by shrubs, particularly geothermal kānuka, but also occasional mingimingi, mānuka, monoao, prickly mingimingi and ferns. One plot had a high cover of radiata pine in the canopy, but this plot had geothermal characteristics in much of the understorey. The warmest temperature soils were devoid of vegetation, and patches of bryophytes were present as the temperature reduced. Where vegetation occurs, short stature geothermal kānuka was most prevalent on the soils with the warmest temperatures, and some species that can tolerate warmer temperatures such as *Palhinhaea cernua* (referred to as *Lycopodiella cernua* by some botanists) were present. As temperatures cooled, other shrub species and ferns became more abundant, and the height of geothermal kānuka typically increased.

Several plots are located in taller geothermal kānuka scrub or forest, with an increased prevalence of exotic species, such as wilding pines.

Table 3 – Vegetation types present in twelve permanent vegetation monitoring plots within the Waikato Region, May-June 2024. Average vegetation top heights are obtained from the REECE plot sheets. Notation follows Atkinson (1985).

Plot Name	Broad Vegetation Type	Average Vegetation Top Height (m)
Te Kopia 1	Geothermal kānuka scrub with local bare ground and mossfield (e.g. *Dicranoloma*)	0.8
Te Kopia 2	Geothermal kānuka-kāmahi/geothermal kānuka-mingimingi-*Dicranopteris linearis* scrub	3.5
Red Hills 1	Geothermal kānuka-(monoao)-(mingimingi)/*Dicranoloma* species-*Campylopus* species-bare ground scrub	0.3
Red Hills 2	Geothermal kānuka scrub with local shrubland and bare ground	1.5
Maunga Kākaramea 1	Geothermal kānuka/*Dicranoloma* species-*Campylopus* species-(*Cladonia* species)-(bare ground)	0.3
Maunga Kākaramea 2	Geothermal kānuka/*Dicranoloma* species-(*Cladonia* species) shrubland	0.4
Maunga Kākaramea 3	Geothermal kānuka scrub	2.5
Maungaongaonga 1	Geothermal kānuka/*Dicranoloma* species-*Campylopus* species-bare ground scrub	1.0
Waiotapu 1	Radiata pine-geothermal kānuka/ kōwharawhara forest	6.0
Waiotapu 2	(Radiata pine)/geothermal kānuka-mingimingi-(monoao) shrubland	1.0
Waiotapu 3	Geothermal kānuka/*Thuidiopsis furfurosa*-*Cladonia*-bare ground shrubland	1.0
Waiotapu 4	Geothermal kānuka/geothermal kānuka-mingimingi-turutu scrub	2

4.3 Temperature

Average soil temperature measured at 10 centimetre and 40 centimetre depths are presented in Table 4 below. The relationship between average soil temperature at 40 cm depths and the average vegetation top height is shown in Figure 5. Vegetation top heights were obtained from the REECE data sheets for each plot. Mean soil temperatures recorded at 40 cm depths for each plot were used for this analysis as 40 cm temperature measurements are less susceptible to short term fluctuations caused by external influences, such as air temperature, precipitation, and solar radiation.

The overall pattern of vegetation height in relation to soil temperature is highly variable and there are large differences in average vegetation top height for plots with similar mean soil temperatures. However, in general there is a decreasing trend in average vegetation top height as mean soil temperature at 40 cm depth increases (Figure 5). There are large variations in the soil temperature measurement recorded within each plot (Table 4) and subsequently, the mean values do no capture these finer scale temperature variations within the plot (e.g. locations of hot spots) and the average values are likely skewed by hot spots. Likewise, the average top height recorded cannot accurately reflect the finer changes to vegetation height within a plot, such as locally shorter vegetation in areas of higher ground temperatures, or the spatial relationships between the relative cover of vegetation to geothermally-influenced bare ground.

Table 4 – Mean soil temperatures °C, at 10 cm and 40 cm depths and 95% confidence intervals on the estimate of the mean, in 12 permanent biodiversity monitoring plots, Waikato Region 2024. N=9 in each plot.

Plot	10 cm depth			40 cm depth		
	Mean	95% CI	Range	Mean	95% CI	Range
Te Kopia 1	31.0	25.5-36.5	24.3-47.9	38.9	33.7-44.1	32.3-52.1
Te Kopia 2	25.1	21.9-28.3	19.5-33.3	31.3	25.0-37.6	24.9-51.6
Red Hills 1	42.2	38.1-46.3	31.7-47.3	55.7	49.3-62.1	48.4-75.9
Red Hills 2	47.9	36.7-59.1	30.8-69.6	61.6	48.6-74.6	40.5-88.8
Maunga Kākaramea 1	40.4	33.8-47.0	31.7-53.0	51.7	40.3-63.1	38.8-84.5
Maunga Kākaramea 2	45.3	40.2-50.4	30.2-53.6	58.6	54.7-62.2	50.3-65.2
Maunga Kākaramea 3	35.1	29.5-40.7	18.0-41.9	50.8	41.0-60.6	22.1-64.1
Maungaongaonga 1	49.8	37.5-62.1	32.0-77.2	63.9	52.4-75.4	44.3-90.5
Waiotapu 1	23.6	19.3-27.9	19.1-37.5	34.5	30.3-38.7	29.7-48.1
Waiotapu 2	21.1	15.7-26.5	15.2-38.4	29.0	22.0-36.0	19.5-49.8
Waiotapu 3	40.8	36.1-45.5	33.1-51.3	57.4	50.2-64.6	46.0-75.1
Waiotapu 4	28.9	21.5-36.3	15.6-43.0	40.4	31.4-49.4	25.2-57.5

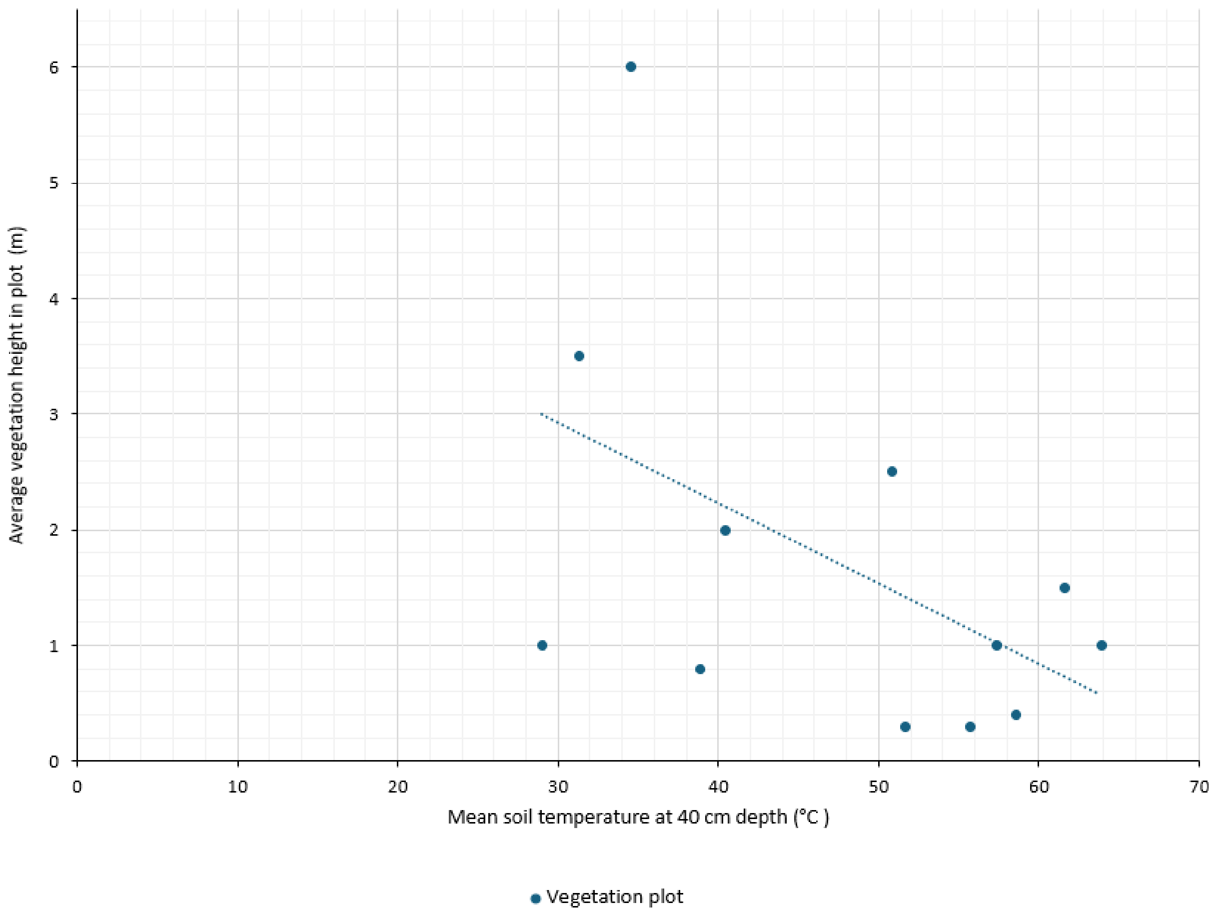

Figure 5: Comparison of the mean soil temperature at 40 cm depths (N=9 in each plot) and the average vegetation top height recorded in 12 10 × 10 m vegetation plots.

Future remeasurements could include an increased frequency of soil temperature measurements within each vegetation plot. This would allow the production of soil temperature heat map figures to explore the overall distribution and pattern of soil temperatures within each permanent monitoring plot and identify hot spot locations. Heatmap figures could then be compared to UAV-based imagery to further explore the relationship between soil temperature and vegetation height and coverage.

4.4 Flora

A list of vascular plant species recorded within the permanent geothermal monitoring plots is provided in Appendix 5. A total of 27 indigenous and three introduced vascular plant species were recorded from all 12 plots. Of which, four species have a threat ranking in de Lange *et al.* 2018:

- Dwarf mistletoe; *Korthalsella salicornioides* (Threatened-Nationally Critical)
- Geothermal kānuka; *Kunzea tenuicaulis* (Threatened-Nationally Endangered)
- *Dicranopteris linearis* (Threatened-Nationally Endangered)
- *Schizaea dichotoma* (At Risk-Naturally Uncommon)

Geothermal kānuka was present within all 12 permanent vegetation plots. Eleven dwarf mistletoe plants were recorded growing on one geothermal kānuka shrub within one plot in the Te Kopia Geothermal Field (Te Kopia 1) (there are probably more plants present at this site, as this is a cryptic species) and *Dicranopteris linearis* was present in two plots, Te Kopia 2 and Red Hills 2. *D. linearis* had a cover of 6% in Te Kopia and 2% in Red Hills and was observed growing within geothermal kānuka scrub on geothermally heated ground. *Schizaea dichotoma* was present in plots Maunga Kākaramea 3 and Te Kopia 2. The largest known population of *Schizaea dichotoma* in geothermal habitat occurs at Maunga Kākaramea (Rainbow Mountain).

Other plant species typical of geothermal habitat present in the plots include the clubmoss *Palhinhaea cernua*, which was recorded in two plots (Te Kopia 2 and Maunga Kākaramea 1), *Schizaea bifida* which was observed near plot Waiotapu 2; this is the first record of this species at Waiotapu.

Twenty-six non-vascular species were recorded from the permanent plots and these are listed in Appendix 6.

Pest plant species present in geothermal plots include blackberry (*Rubus fruticosus* agg.) and wilding pines (*Pinus radiata* and *Pinus pinaster*).

4.5 Avifauna

The five-minute bird count surveys identified fifteen indigenous and eight exotic bird species (Table 5) across all permanent plots. Three indigenous bird species recorded in the five-minute bird counts are classified as At Risk-Declining in Robertson *et al.* (2021): koroātito/North Island fernbird (*Poodytes punctata vealeae*), pīhoihoi/New Zealand pipit (*Anthus novaeseelandiae novaeseelandiae*), and toutouwai/North Island robin (*Petroica longipes*).

4.6 Herpetofauna

Twelve locations were surveyed, using a tracking tunnel baited with pear baby food in an opportunistic effort to detect ground-dwelling lizards. No lizard species were detected in the twelve tracking tunnels deployed. Three non-target detections were recorded including insect tracks (Red Hills 1, Waiotapu 1) and one mouse detection at plot Red Hills 2.

Table 5 – Indigenous and exotic bird species recorded during five-minute bird counts at 12 permanent geothermal monitoring plots, Waikato Region. Common names, species names, and threat classifications are from Robertson *et al.* (2021).

Common Name	Scientific Name	Threat Classification 2021	Presence Detected		
			Te Kopia	Orākei Kōrako	Waiotapu
Indigenous					
Kāhu/swamp harrier	*Circus approximans*	Not Threatened	✓		
Karoro/southern black-backed gull	*Larus dominicanus dominicanus*	Not Threatened			✓
Korimako/bellbird	*Anthornis melanura melanura*	Not Threatened	✓	✓	✓
Koroātito/North Island fernbird	*Poodytes punctatus vealeae*	At Risk - Declining	✓		
Miromiro/North Island tomtit	*Petroica macrocephala toitoi*	Not Threatened			✓
Pīhoihoi/New Zealand pipit	*Anthus novaeseelandiae novaeseelandiae*	At Risk - Declining			✓
Pīwakawaka/North Island fantail	*Rhipidura fuliginosa placabilis*	Not Threatened	✓	✓	✓
Pōpokotea; whitehead	*Mohoua albicilla*	Not Threatened	✓		✓
Pūkeko	*Porphyrio melanotus melanotus*	Not Threatened	✓		
Pūtangitangi/paradise shelduck	*Tadorna variegata*	Not Threatened	✓		✓
Riroriro/grey warbler	*Gerygone igata*	Not Threatened	✓	✓	✓
Spur-winged plover/masked lapwing	*Vanellus miles novaehollandiae*	Not Threatened	✓	✓	✓
Tauhou/silvereye	*Zosterops lateralis lateralis*	Not Threatened	✓		✓
Toutouwai/North Island robin	*Petroica longipes*	At Risk - Declining			✓
Tūī	*Prosthemadera novaeseelandiae novaeseelandiae*	Not Threatened			✓
Introduced					
Australian magpie	*Gymnorhina tibicen*	Introduced and Naturalised	✓	✓	✓
Eurasian Blackbird	*Turdus merula*	Introduced and Naturalised	✓		✓
Chaffinch	*Fringilla coelebs*	Introduced and Naturalised			✓
Eastern rosella	*Platycercus eximius*	Introduced and Naturalised			✓
European goldfinch	*Carduelis carduelis*	Introduced and Naturalised		✓	✓
European greenfinch	*Carduelis chloris*	Introduced and Naturalised	✓		✓
Mallard	*Anas platyrhynchos*	Introduced and Naturalised	✓		
Song thrush	*Turdus philomelos clarkei*	Introduced and Naturalised	✓		

Tracking tunnels were placed within or immediately adjacent to the monitoring plot, rather than targeted within areas considered to represent potential high quality lizard habitat. Due to the time constraints of the survey, tracking tunnels were deployed for one fine night. Preferably, tracking tunnels targeting ground dwelling lizards are installed for a minimum of two weeks. The time of year of sampling was also less than ideal for lizard detection, with the monitoring being undertaken in winter with overnight temperatures at freezing levels on most days.

4.7 Introduced mammals

Introduced mammal presence was recorded at all 12 permanent plots (Table 6). The most commonly detected species was brushtail possum (*Trichosurus vulpecula*), recorded in 11 plots. Possum pellets were in 24.0% of pellet counts (present in 44 out of a total of 183 pellet counts completed) and possum chew was present on 6.3% of chew cards deployed. Two non-target species, rats (*Rattus* sp.) and mice (*Mus musculus*) were detected on 18.6% and 39.6% of chew cards deployed, respectively.

Ungulate observations include both feral pig (*Sus scrofa*) and deer. Deer pellets were detected in faecal pellet transects at two plots; Te Kopia 2 and Waiotapu 3. Feral pig scat was recorded at Te Kopia 2 and Red Hills 2. Feral pig sign, such as rooting and scat, was frequently observed in the wider habitat surrounding plot Red Hills 2. Large family groups of feral pigs (up to 10 individuals) were observed while walking to plot.

Wallaby pellets (*Notamacropus* sp.[5]) were recorded in faecal pellet counts at two plots in the Waiotapu Geothermal System. Lagomorph pellets were recorded in one faecal pellet count at plot Waiotapu 2.

A complete list of fauna species detected and detection type is presented in Appendix 7. All 48 chew cards were deployed. Four fauna transects were shortened due to safety (Te Kopia 2 transects C and D, Red Hills 1 Transect B, and Maungaongaonga 1 Transect B) and one transect was not measured (Waiotapu 4 Transect D) due to unsafe geothermal terrain. Therefore, nine pellet counts were not completed.

4.8 Comparison of UAV-based aerial imagery and ground-based vegetation measurements

A comparison of data capture from UAV-based aerial images and ground-based vegetation plot measurements was undertaken for five 10 × 10m plots in the Orākei Kōrako and Waikite-Waiotapu-Waimangu geothermal systems. Species richness was obtained from the aerial images and compared to vegetation plot measurements (Figure 6).

The number of vascular species detected on the UAV-based imagery was consistently lower than that recorded in the ground-based methods. The one exception, plot Waiotapu 3, contained only one vascular species, geothermal kānuka (up to *c.*70% cover), which was easily identified in the aerial imagery. Non-vascular species, including bryophyte ground cover species, were not included in the data capture comparison. Non-vascular species identification is not possible from the aerial images and it is not possible to get an accurate measure of their cover. Ground cover species were only visible in canopy gaps, but non-vascular species were often a dominant groundcover under the canopy.

[5] Until recently it was thought that all wallabies in the Rotorua and Central North Island were dama wallabies (*Notamacropus. eugenii*). Two species of wallaby have recently been shown to be present in the central North Island, dama wallaby and parma wallaby (*N. parma*) (Biosecurity New Zealand 2023, Veale 2023)

Table 6 – Introduced mammal species detected at 12 permanent geothermal monitoring plots, Waikato Region.

Geothermal Field	Plot Name	Species Detected (chew cards or faecal pellet counts)					
		Ungulate	Possum	Wallaby	Lagomorph	Rat	Mouse
Orākei Kōrako Geothermal Field	Red Hills 1	X	✓	X	X	X	✓
	Red Hills 2	✓	✓	X	X	✓	✓
Te Kopia Geothermal Field	Te Kopia 1	X	✓	X	X	X	X
	Te Kopia 2	✓	X	X	X	X	X
Waiotapu Geothermal Field	Maunga Kākaramea 1	X	✓	X	X	✓	✓
	Maunga Kākaramea 2	X	✓	X	X	X	X
	Maunga Kākaramea 3	X	✓	X	X	✓	✓
	Maungaongaonga 1	X	✓	X	X	✓	✓
	Waiotapu 1	X	✓	X	X	✓	✓
	Waiotapu 2	X	✓	✓	✓	X	✓
	Waiotapu 3	✓	✓	✓	X	X	✓
	Waiotapu 4	X	✓	X	X	X	X

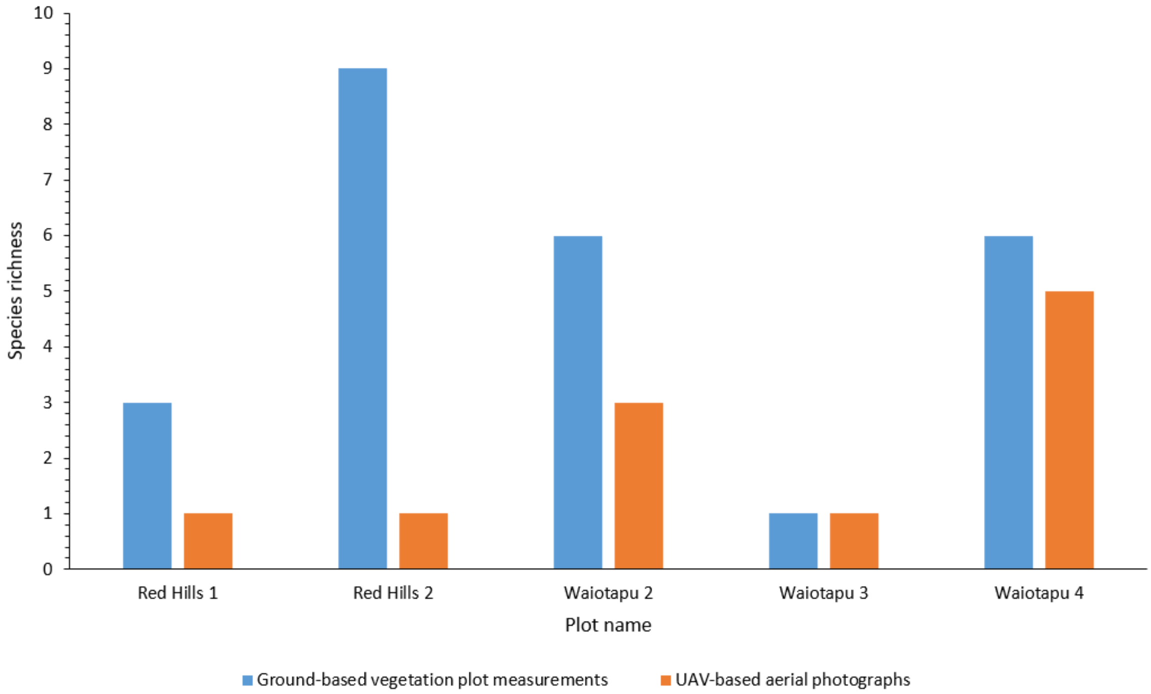

Figure 6: Comparison of the total number of vascular plant species recorded in five 10 × 10 m vegetation plots using ground-based vegetation plot measurements and UAV-based aerial photographs.

In all plots, the dominant canopy species (generally geothermal kānuka and occasional mingimingi) were easily identified and the relative canopy cover established from studying the UAV imagery. Species recorded using the ground based method with a relatively low canopy cover, were generally not able to be distinguished in the aerial imagery. For example, monoao was recorded in plots Red Hills 1 and Waiotapu 2 with 2% and 4% cover respectively, but not identified in the aerial image for either plot. Wilding pines, however, were easily identified in aerial images despite relatively low covers (ranging from *c.*<1%-3%).

The UAV-based photographs give no indication of the species obscured by the canopy, therefore it is not a replacement for ground based monitoring. Lower species richness was recorded from UAV-based images at four of the five plots compared, with considerably lower species richness recorded at plots Red Hills 1, Red Hills 2, and Waiotapu 2 (Figure 6). Red Hills 2 comprised geothermal kānuka scrub with an average top height of 1.5 metres. One vascular species (geothermal kānuka) was detected in the aerial image, compared to nine vascular species recorded in the ground-based vegetation methods (detection rate 11%). This implies that there can be large errors in the detections from aerial images particularly in taller scrub habitat types where the canopy cover obscures understory and ground cover species.

UAV-based aerial imagery provides a spatial overview of the relative extent of vegetation to bare ground, which is not captured in the recce method, and captures a permanent record of the vegetation observed at the time of survey. The spatial overview of vegetation within a plot allows for the relationship between vegetation cover and soil temperature measurements recorded in the plot to be further explored, and is useful for comparing change in geothermalness through time, i.e. if the soil temperature of the plot cools, establishment of vegetation on areas which were previously bare ground may become visible. In short stature vegetation, the relative vegetation cover captured by UAV imagery may be compared to REECE ground cover vegetation scores (provided vegetation height is <1.35 metres tall). A further benefit of UAV-based imagery is the ability to extend sampling into sites that are unsafe to be measured by a field team. However, the high degree of error in detected species richness indicate this method is not a comparable alternative to ground-based vegetation measures.

Vegetation height data was not captured in the current UAV monitoring, however, further investigation with a specialist aerial surveyor has since revealed that technology exists to use a surface model to calculate the height of vegetation to reasonable accuracy above the ground (provided there is accurate LiDAR data of the ground surface). This would allow vegetation height to be included in UAV monitoring, providing further useful monitoring information. Capture of information by UAV is also significantly faster than ground based field methods, and depending on spacing of plots, images of many plots can be captured in one field day.

4.9 UAV-based sampling for unsafe sites

Four UAV-based photographs of sites that were unsafe to access on the ground were assessed visually for species richness and cover abundance of vegetation, bare ground, and water (Table 7). Cover abundance data comprises the relative cover (%) of each variable from a birds-eye view of the plot.

Two of the unsafe areas sampled were very hot and contained sparse short stature vegetation or bare ground. This reduced the problem of assessing ground layers obscured by above-ground vegetation. Vascular plant species richness was very low at these sites; geothermal kānuka, was the only species identified in UAV Plots 2 and 3, and no vegetation was recorded in UAV Plot 4. In dangerous sites that contain short stature vegetation or geothermally-influenced bare ground, UAV-imagery provides an alternative method to capture monitoring information, i.e. measure changes to the relative cover of defined variables (vegetation, bare ground, open water) through time, and obtain data in habitats that would be otherwise unsafe to measure.

One 10 × 10 metre plot containing scrub >2 metres tall was assessed by UAV alone (UAV Plot 1). Six species were identified from the UAV photographs. Understorey and ground cover species are obscured by the canopy, therefore it is very unlikely that all species present within the delineated boundaries of UAV Plot 1 were detected.

Due to the hazardous nature of vegetation monitoring in close proximity to geothermal features such as the heated pools in Red Hills or hot potentially unstable bare ground at Waiotapu, overflying a UAV to obtain high-quality georeferenced aerial imagery provides a safe way to monitor basic parameters such as canopy species and relative cover, and enables areas unsafe to access to be included within the Biodiversity Monitoring Framework. UAV-based photographs should be taken as close to the plot surface as possible to gain the highest quality image possible.

5.0 Trampling impacts

The 2023 monitoring study (Wildland Consultants 2023a) identified that “because of the extreme variability in geothermal sites, safety issues and inherent fragility, it is likely that the level of sampling, including replication, and sampling strategy will need to be tailored on a site-by-site basis. A study of the rate of recovery of geothermal vegetation types following disturbances associated with plot-measurement, or simulated disturbance regimes, should be undertaken to establish the minimum return time for plot remeasurement”.

Table 7 – Species richness and cover abundance data obtained from UAV-based photographs of four plots located in geothermal areas unsafe to access.

Plot Name	Geothermal site	Plot size (m)	Vegetation Stature	Relative Cover[6] (%)			Species Richness
				Vegetation	Bare Ground	Open water	
UAV Plot 1	Red Hills	10 × 10	Scrub (>2 m)	85	0	15	6
UAV Plot 2	Waiotapu	2 × 2	Scrub (<2 m)	50 (live), 40 (dead)	10	0	1
UAV Plot 3	Waiotapu	1 × 1	Geothermally-influenced bare ground	15	85	0	1
UAV Plot 4	Waiotapu	1 × 1	Geothermally-influenced bare ground	0	100	0	0

[6] Refers to the relative area (%) of the plot covered by selected variables, when looking from a birds-eye view of the plot, and must sum to 100%. Bare ground and rock are only recorded when there is no vegetation above them This differs from ground-based vegetation method in which both canopy cover (% cover of vegetation >1.35m tall) and ground cover characteristics (% cover of vegetation <1.35m, non-vascular, litter, bare ground, and rock, multiple layers will usually overlap summing to >100%) are recorded.

Given the short timeframe available to undertake the current monitoring round once permission was granted, a full analysis on the rate of recovery of geothermal vegetation types after monitoring was not possible. Each plot was measured by a team of four people, working together in pairs for health and safety. Approximately one month after plot measurements were undertaken, an additional site visit was undertaken to a sub-sample of the plots to note whether or not any trampling damage was visible (Table 8).

Table 8 – Plots revisited after monitoring and the extent of visible trampling damage (none to high)

Plot Name	Extent of Trampling Damage	Comment
Te Kopia 1	Negligible	
Te Kopia 2	Minor	• Crushing of woody vegetation and ferns, particularly along the plot boundaries. This was unavoidable but it is expected that the vegetation will recover quickly. • Some damage to mosses from workers slipping when walking around the plot. • Minor damage to geothermal kānuka bark.
Maunga Kākaramea 1	Minor	• Minor soil damage, although largely unnoticeable. • Minor trampling of non-vascular species in plot.
Maunga Kākaramea 2	Minor	• Minor trampling of non-vascular species in plot. • Light soil disturbance.
Maunga Kākaramea 3	Negligible	
Maungaongaonga 1	Minor	• The thermal ground within this plot is particularly vulnerable to trampling effects. • Evidence of foot traffic on non-vascular cover, and minor soil disturbance. • Minor vegetation crushing.
Waiotapu 1	Negligible	
Waiotapu 3	Minor	• Trampling damage within the plot is largely from existing animal tracks. • Minor trampling of non-vascular species. • Minor crushing of woody vegetation.

*Damage classes: none, negligible, minor, moderate, and high

Trampling impacts assessed included soil disturbance, woody vegetation crushing, and trampling of non-vascular species. Each plot was then assigned one of five damage classes (none, negligible, minor, moderate or high) based on the extent of visible damage.

Crushing of woody vegetation was largely confined to just outside the plot boundaries. Care was taken when establishing and measuring plots to reduce the number of times the plot was walked through (i.e. where possible when moving around the plot a route was taken outside of the plot boundaries). Minor damage to non-vascular species was noted including compression and detachment, caused by field teams walking through the plot.

Plots with negligible to minor trampling damage are expected to recover. Overall, trampling damage observed at the selected plots was minimal and vegetation is likely to fully recover within five years. Trampling damage should be assessed during the next monitoring round.

Plate 1 – Te Kopia 2. Trampling damage to woody vegetation and ferns along the A-B plot boundary. Red arrow indicates plot corner marker (Corner A) 6 August 2024.

Plate 2 — Maunga Kākaramea 2. Red arrows indicate areas of crushing and disturbance to non-vascular ground cover caused by walking though the plot. 6 August 2024.

Plate 3 — Maungaongaonga 1. Evidence of foot traffic on non-vascular cover. 6 August 2024.

Plate 4 — Te Kopia 1. Minor vegetation crushing on fauna transect line A (outside of plot). The decrease in vegetation height where crushing has occurred is indicated by the red arrows. 6 August 2024.

To minimise the damage to the permanent plots caused by measurement activities, plot measurement was undertaken on fine days and not following a period of significant rainfall. When the ground is wet, measurement activities can cause considerable damage to the vegetation and substrate on the plot, especially on steep terrain or vulnerable thermal ground. This monitoring round had particularly favourable conditions for the time of year (May-June), however future monitoring rounds would benefit from being undertaken in late summer when the ground generally dries fully between periods of rain.

6.0 Recommendations on Monitoring Frequency

Although the 2023 monitoring report (Wildland Consultants 2023a) noted that "because of the extreme variability in geothermal sites, safety issues and inherent fragility, it is likely that the level of sampling, including replication, and sampling strategy will need to be tailored on a site-by-site basis", it was found that trampling impacts were minimal and we expect that vegetation is likely to fully recover within five years.

Plots within development systems are measured as frequently as annually in some cases for a short period of time, with some plots measured two-yearly, four-yearly and five-yearly depending on consent condition.

We recommend that all plots are remeasured on a five-yearly cycle consistent with other biodiversity monitoring across the Region. Within five years, even sensitive plots with some trampling damage are likely to have recovered from monitoring, although this should be assessed during the next monitoring round (i.e. if evidence from previous monitoring is noted, then that plot should be moved to a 10-year rotation). Plots should only be measured in fine weather, and not immediately after heavy rainfall. Trampling damage (through slipping damage) would presumably be a lot more extensive if the site is slippery after rain (as well as being more dangerous for workers).

To minimise the damage to the permanent plots caused by measurement activities, plot measurement was undertaken on fine days and not following a period of significant rainfall. When the ground is wet, measurement activities can cause considerable damage to the vegetation and substrate on the plot, especially on steep terrain or vulnerable thermal ground. This monitoring round had particularly favourable conditions for the time of year (May-June), however future monitoring rounds would benefit from being undertaken in late summer when the ground generally dries fully between periods of rain.

7.0 Discussion and findings

This study established biodiversity monitoring of geothermal ecosystems within sites in Protected Geothermal Systems and identified monitoring frequencies. The standard national monitoring framework methodology (Bellingham *et al*. 2021, Hurst *et al.* 2022) was able to be implemented in most cases with fairly minor modifications in spite of the range of challenges presented by monitoring in dangerous habitats. UAVs provide a useful tool to expand the monitoring (in a more limited capacity) into areas that are unsafe to access on foot, particularly in habitats containing low stature vegetation or bare ground.

Twelve permanent monitoring plots were established within the Orākei Kōrako , Te Kopia and Waikite-Waiotapu-Waimangu Geothermal Systems. These permanent plots will provide an important context for evaluation of vegetation changes in development systems. The plots also complement the extent and condition monitoring undertaken through the region-wide inventory studies of geothermal sites (Wildland Consultants 2023b).

The plots should be remeasured in 2029. Permits and permission to undertake the measurements should be sought up to one year in advance of the monitoring to ensure permissions are obtained, and should include permission for UAV flying on DOC land. Ideally, plot monitoring should be undertaken at a similar time of year as previous monitoring in order to avoid seasonal biases such as seedling emergence. However, in this case, we recommend that the next monitoring round is undertaken in late summer when day length is longer and weather is generally more settled. Consideration could be given to expanding the plot network to other sites that were excluded from this study due to lack of access permission.

Geothermal sites are dynamic and can change significantly with regards to safe access within a short space of time. Future monitoring teams need to reassess all hazards associated with the measurement of each plot and some plots may be abandoned if unsafe to measure. In this case, a UAV could be used to capture monitoring information.

Depending on the ultimate uses of the monitoring data obtained, UAVs could be used to capture information more efficiently than ground-based methods, particularly if they are also supplemented with fauna monitoring in some capacity.

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Paul Dutton, Waikato Regional Council, initiated this project. Elizabeth Overdyck (Waikato Regional Council) provided advice on data collection and data entry to ensure consistency with Waikato Regional biodiversity monitoring. Paul Cashmore, Department of Conservation, facilitated a permit to allow plots to be installed on DOC land. Michelle Phillips, Ngati Tahu - Ngati Whaoa Runanga Trust, granted permits to allow plot installation on Runanga land and facilitated land access with key stakeholders. Nathan Maynard allowed plots to be installed within the Wai-o-tapu Thermal Wonderland. Timberlands Ltd allowed plots to be installed on land managed by Timberlands Ltd. Alec Salt allowed access across his farm for plot installation at Red Hills.

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Appendix 1

GPS coordinates (NZTM) of 2024 permanent geothermal vegetation plot locations, Waikato Region

Geothermal Field	Plot Name	GPS Coordinates (Corner D)		Altitude (m)
		NZTM Easting	NZTM Northing	
Orākei Kōrako Geothermal Field	Red Hills 1	1874954	5735489	350
	Red Hills 2	1875141	5736384	360
Te Kopia Geothermal Field	Te Kopia 1	1880260	5743771	410
	Te Kopia 2	1880605	5744237	420
Waiotapu Geothermal Field	Maunga Kākaramea 1	1895688	5753235	570
	Maunga Kākaramea 2	1896322	5752969	605
	Maunga Kākaramea 3	1896404	5752847	600
	Maungaongaonga 1	1892634	5751536	485
	Waiotapu 1	1895468	5751733	380
	Waiotapu 2	1894926	5748265	350
	Waiotapu 3	1894155	5749034	350
	Waiotapu 4	1895468	5750862	375

Appendix 2

Plot corner photographs

Plate A2-1 – Red Hills Plot 1, D corner. Orākei Kōrako Geothermal System. 28 May 2024.

Plate A2-2 – Red Hills Plot 2, A corner. Orākei Kōrako Geothermal System. 28 May 2024.

Plate A2-3 – Te Kopia Plot 1, D corner. Te Kopia Geothermal System. 29 May 2024.

Plate A2-4 – Te Kopia Plot 2, D corner. Te Kopia Geothermal System. 19 June 2024.

Plate A2-5 – Maunga Kākaramea Plot 1, B corner. Waikite-Waiotapu-Waimangu Geothermal System. 6 June 2024.

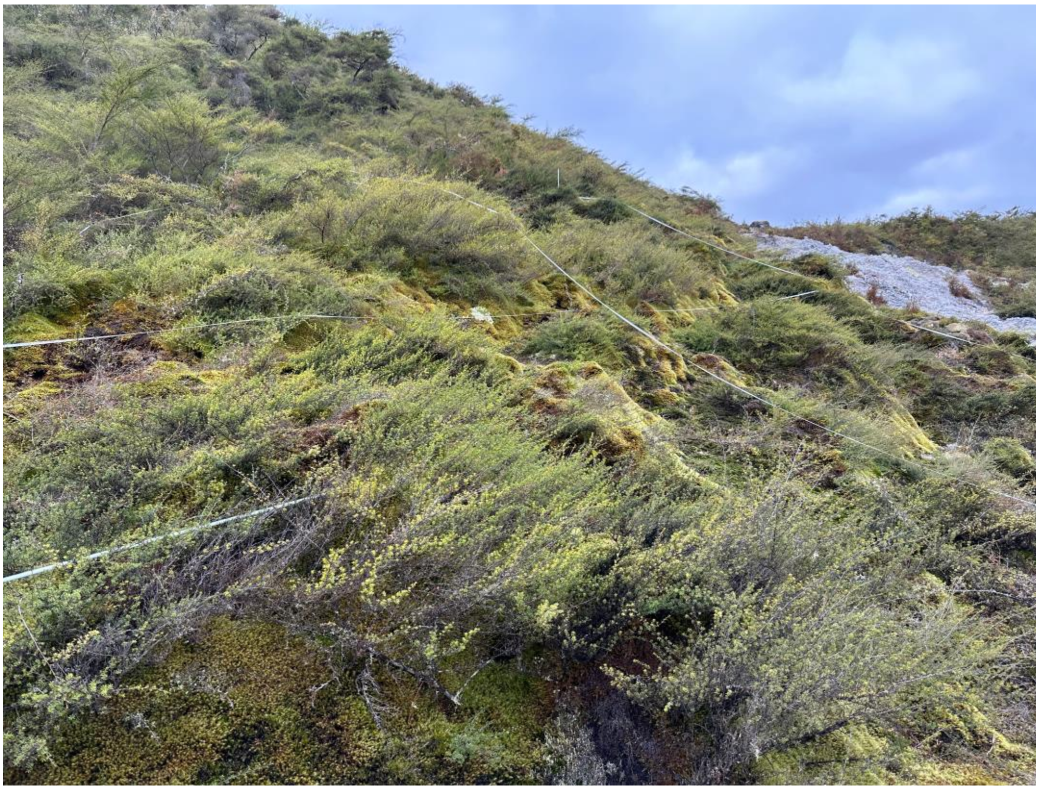

Plate A2-6 – Maunga Kākaramea Plot 2, D corner. Waikite-Waiotapu-Waimangu Geothermal System. 6 June 2024.

Plate A2-7 – Maunga Kākaramea Plot 3, D corner. Waikite-Waiotapu-Waimangu Geothermal System. 18 June 2024.

Plate A2-8 – Maungaongaonga Plot 1, D corner. Waikite-Waiotapu-Waimangu Geothermal System. 5 June 2024.

Plate A2-9 – Waiotapu Plot 1, C corner. Waikite-Waiotapu-Waimangu Geothermal System. 14 May 2024.

Plate A2-10 – Waiotapu Plot 2, B corner. Waikite-Waiotapu-Waimangu Geothermal System. 22 May 2024.

Plate A2-11 – Waiotapu Plot 3, C corner. Waikite-Waiotapu-Waimangu Geothermal System. 23 May 2024.

Plate A2-12 – Waiotapu Plot 4, D corner. Waikite-Waiotapu-Waimangu Geothermal System. 20 June 2024.

Appendix 3

Location of UAV photographs taken in 2024 and photographic information[7]

Plot Name	Location of UAV Photograph (NZTM)	Elevation (metres)	Date Taken
Permanent biodiversity monitoring plots			
Red Hills 1	E1874950 N5735494	383	3 July 2024
Red Hills 2	E1875135 N5736393	382	3 July 2024
Waiotapu 2	E1894932 N5748265	375	3 July 2024
Waiotapu 3	E1894158 N5749025	368	3 July 2024
Waiotapu 4	E1895471 N5750867	398	3 July 2024
UAV-based plots (in areas unsafe to access)			
UAV Plot 1	E1875313 N5736166	422	3 July 2024
UAV Plot 2	E1895495 N5751039	404	3 July 2024
UAV Plot 3	E1894382 N5749281	365	3 July 2024
UAV Plot 4	E1894361 N5749356	366	3 July 2024

[7] No permission sought to photograph geothermal plots using a UAV on DOC land at Te Kopia, Maunga Kākaramea, and Maungaongaonga. Plot Waiotapu 1 was not photographed due to a pine canopy which obscured geothermal vegetation beneath the canopy.

Appendix 4

UAV photographs of plots

Plate A4-1 – Red Hills plot 1. Orākei Kōrako Geothermal System. Red line indicates plot boundaries. 3 July 2024.

Plate A4-2 – Red Hills plot 2. Orākei Kōrako Geothermal System. Red line indicates plot boundaries. 3 July 2024.

Plate A4-3 – Waiotapu plot 2. Waikite-Waiotapu-Waimangu Geothermal System. Red line indicates plot boundaries. 3 July 2024.

Plate A4-4 – Waiotapu plot 3. Waikite-Waiotapu-Waimangu Geothermal System. Red line indicates plot boundaries.3 July 2024.

Plate A4-5 – Waiotapu plot 4. Waikite-Waiotapu-Waimangu Geothermal System. Red line indicates plot boundaries. 3 July 2024.

UAV plots

Plate A4-6 – UAV Plot 1. 10 × 10m vegetation plot located within a geothermal area unable to be accessed on foot at the Red Hills site. Close up of plot vegetation (top) and overview of the geothermal area (below), the yellow line delineates the plot boundaries. Orākei Kōrako Geothermal System. 3 July 2024.

Plate A4-7 – UAV Plot 2. 2 × 2m vegetation plot located within a geothermal area unable to be accessed on foot at the Waiotapu site. Close up of plot vegetation (top) and overview of the geothermal area (below), the yellow line delineates the plot boundaries. Waikite-Waiotapu-Waimangu Geothermal System. 3 July 2024.

Plate A4-8 – UAV Plot 3. 1 × 1m vegetation plot located within a geothermal area unable to be accessed on foot at the Waiotapu site. Close up of plot vegetation (top) and overview of the geothermal area (below), the yellow line delineates the plot boundaries. Waikite-Waiotapu-Waimangu Geothermal System. 3 July 2024.

Plate A4-9 – UAV Plot 4. 1 × 1m vegetation plot located within a geothermal area unable to be accessed on foot at the Waiotapu site. Close up of plot vegetation (top) and overview of the geothermal area (below), the yellow line delineates the plot boundaries. Waikite-Waiotapu-Waimangu Geothermal System. 3 July 2024.

Appendix 5

Vascular plant species recorded at permanent geothermal monitoring plots in the Orākei Kōrako Geothermal System, Waikato Region, May-June 2024

Scientific Name	Common Name	Red Hills 1	Red Hills 2
Indigenous Species			
Dicot. trees and shrubs			
Coprosma lucida	karamū, kāramuramu, glossy karamū		✓
Dracophyllum subulatum	monoao	✓	
Kunzea tenuicaulis	geothermal kānuka	✓	✓
Leptecophylla juniperina var. *juniperina*	prickly mingimingi		✓
Leucopogon fasciculatus	mingimingi	✓	✓
Pseudopanax arboreus	whauwhaupaku, puahou, five finger		✓
Ferns (excludes psilopsids)			
Asplenium polyodon	petako, paratao, sickle spleenwort		✓
Dicranopteris linearis			✓
Pyrrosia elaeagnifolia	leather-leaf fern		✓
Monocot. herbs (other than orchids, grasses, sedges, and rushes)			
Dianella nigra	tūrutu		✓

Vascular plant species recorded at permanent geothermal monitoring plots in the Te Kopia Geothermal System, Waikato Region, May-June 2024

Scientific Name	Common Name	Te Kopia 1	Te Kopia 2
Indigenous Species			
Dicot. trees and shrubs			
Coprosma lucida	karamū, kāramuramu, glossy karamū		✓
Dracophyllum subulatum	monoao	✓	
Knightia excelsa	rewarewa		✓
Korthalsella salicornioides	dwarf mistletoe	✓	
Kunzea tenuicaulis	geothermal kānuka	✓	✓
Leptecophylla juniperina var. *juniperina*	prickly mingimingi		✓
Leptospermum scoparium	mānuka		✓
Leucopogon fasciculatus	mingimingi	✓	✓
Myrsine australis	māpou, matipou, māpau		✓
Pseudopanax arboreus	whauwhaupaku, puahou, five finger		✓
Pterophylla racemosa	kāmahi		✓
Lycopods and psilopsids			
Palhinhaea cernua	mātukutuku		✓
Ferns			
Alsophila dealbata	ponga, silver fern		✓
Asplenium flaccidum subsp. *flaccidum*	makawe, ngā makawe o raukatauri, drooping spleenwort		✓
Asplenium polyodon	petako, paratao, sickle spleenwort		✓
Dicranopteris linearis			✓
Histiopteris incisa	mātātā, water fern		✓
Hymenophyllum sanguinolentum	piripiri, filmy fern		✓
Pteridium esculentum subsp. *esculentum*	rārahu, bracken		✓
Pyrrosia elaeagnifolia	leather-leaf fern		✓
Schizaea dichotoma			✓
Monocot. herbs (other than orchids, grasses, sedges, and rushes)			
Astelia solandri	kōwharawhara		✓
Dianella nigra	tūrutu	✓	✓
Naturalised and Exotic Species			
Dicot. trees and shrubs			
Rubus sp. (*R. fruticosus* agg.)	blackberry		✓

Vascular plant species recorded at permanent geothermal monitoring plots in the Waikite-Waiotapu-Waimangu Geothermal System, Waikato Region, May-June 2024

Scientific Name	Common Name	Maunga Kakaramea 1	Maunga Kakaramea 2	Maunga Kakaramea 3	Maungaongaonga 1	Waiotapu 1	Waiotapu 2	Waiotapu 3	Waiotapu 4
Indigenous Species									
Dicot. trees and shrubs									
Coprosma lucida	karamū, kāramuramu, glossy karamū			✓					
Dracophyllum subulatum	monoao						✓		
Knightia excelsa	rewarewa			✓					
Kunzea tenuicaulis	geothermal kānuka	✓	✓	✓	✓	✓	✓	✓	✓
Leptecophylla juniperina var. *juniperina*	prickly mingimingi			✓		✓			
Leucopogon fasciculatus	mingimingi			✓		✓	✓		✓
Myrsine australis	māpou, matipou, māpau			✓					
Pterophylla racemosa	kāmahi			✓					
Lycopods and psilopsids									
Palhinhaea cernua	mātukutuku	✓							
Ferns (excludes psilopsids)									
Asplenium flaccidum subsp. *flaccidum*	makawe, ngā makawe o raukatauri, drooping spleenwort			✓					
Hymenophyllum multifidum	mauku, much-divided filmy fern	✓		✓					
Hymenophyllum nephrophyllum	kidney fern, konehu raurenga, kopakopa			✓					
Hymenophyllum sanguinolentum	piripiri, filmy fern			✓					
Hymenophyllum scabrum	mauku, rough filmy fern			✓					
Lecanopteris pustulata subsp. *pustulata*	kōwaowao, pāraharaha, hound's tongue fern			✓					
Pteridium esculentum subsp. *esculentum*	rārahu, bracken								✓
Pyrrosia elaeagnifolia	leather-leaf fern			✓					
Schizaea dichotoma				✓					
Orchids									
Thelymitra sp.						✓			
Monocot. herbs (other than orchids, grasses, sedges, and rushes)									
Astelia solandri	kōwharawhara			✓		✓			
Dianella nigra	tūrutu			✓		✓	✓		✓
Naturalised and Exotic Species									
Gymnosperms									
Pinus pinaster	maritime pine						✓		✓
Pinus radiata	radiata pine					✓	✓		✓

Appendix 6

Non-vascular plant species, algae and fungi recorded at twelve permanent geothermal monitoring plots within the Waikato region, May-June 2024

Mosses

Campylopus introflexus
Campylopus pallidus
Campylopus sp.
Dicranella vaginata
Dicranoloma billardierei
Dicranoloma robustum
Dicranoloma sp.
Leucobryum javense
Ptychomnion aciculare
Sphagnum cristatum
Sphagnum sp.
Thuidiopsis furfurosa
Wijkia extenuata

Lichens

Cladia aggregata
Cladia retipora
Cladonia confusa
Cladonia sp.
Dibaeis arcuata
Hypogymnia sp.
Usnea rubicunda
Usnea sp.

Liverworts

Chandonanthus squarrosus
Chiloscyphus (*Lophocolea*) *semiteres*
Lepidozia sp. (includes *L. bisbifida*)
Neolepidozia sp.
Neolepidozia praenitens
Neolepidozia tetrapila

Algae

Trentepohlia sp.

Fungi

Pisolithus sp.

Appendix 7

Introduced mammal species recorded at geothermal plots, May-June 2024

Scientific Name	Common Name	Plots Detected	Detection Method/s
Cervus elaphus[8]	Deer	Te Kopia 2 Waiotapu 3	Faecal pellet count Faecal pellet count
Notamacropus species	Wallaby	Waiotapu 2 Waiotapu 3	Faecal pellet count Faecal pellet count
Mus musculus	Mouse	Red Hills 1 Red Hills 2 Te Kopia 2 Maunga Kākaramea 1 Maunga Kākaramea 3 Maungaongaonga 1 Waiotapu 1 Waiotapu 2 Waiotapu 3	Chew card Chew card Chew card Chew card Chew card Chew card Chew card Chew card Chew card
Oryctolagus cuniculus cuniculus	Rabbit	Te Kopia 2 Maunga Kākaramea 3 Maungaongaonga 1	Faecal pellet count Faecal pellet count Faecal pellet count
Rattus species	Rat	Red Hills 2 Maunga Kākaramea 1 Maunga Kākaramea 3 Maungaongaonga 1 Waiotapu 1 Waiotapu 2	Chew card Chew card Chew card Chew card Chew card Faecal pellet count
Sus scrofa	Feral Pig	Te Kopia 2 Red Hills 1	Faecal pellet count Faecal pellet count
Trichosurus vulpecula	Brushtail possum	Red Hills 1 Red Hills 2 Te Kopia 1 Maunga Kākaramea 1 Maunga Kākaramea 2 Maunga Kākaramea 3 Maungaongaonga 1 Waiotapu 1 Waiotapu 2 Waiotapu 3 Waiotapu 4	Faecal pellet count Chew card, faecal pellet count Faecal pellet count Faecal pellet count Faecal pellet count Faecal pellet count Chew card Chew card, faecal pellet count Faecal pellet count Faecal pellet count Faecal pellet count
	Ungulate (no further ID)	Waiotapu 3	Faecal pellet count
	Lagomorph (no further ID)	Waiotapu 2	Faecal pellet count

[8] Red deer (*Cervus elaphus*) are the most likely species recorded, however sambar (*Rusa unicolor*) or other deer species may be present at Waiotapu.

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