Waikato Regional Council Technical Report 2024/26R

Establishment of biodiversity monitoring plots within geothermal habitats, Waikato Region, 2024-2025

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The Establishment of biodiversity monitoring plots within geothermal habitats, Waikato Region, 2024 **report was revised in August 2025** **and this document** (*document number 32918277*) **supersedes the earlier version dated August 2024** (*document number 30458241)*.

Twelve permanent biodiversity monitoring plots were established in five geothermal sites in 2024 within three Protected Geothermal Systems (Orākei Kōrako, Te Kopia and Waikite-Waiotapu-Waimangu). In late 2024, the Department of Conservation granted a formal permit (Authorisation Number 101975- Flo, variation, 18 October 2024) for work allowing for the establishment of additional permanent plots on all land administered by DOC and including permission to fly a UAV (unmanned aerial vehicle/drone). In 2025, a further five plots were established within one Protected Geothermal System (Waikite-Waiotapu-Waimangu), one Limited Development Geothermal System (Atiamuri), and one Research Geothermal System (Reporoa). This revised document reports on all biodiversity monitoring plots within geothermal habitats established in 2024 and 2025.

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Disclaimer

Establishment of biodiversity monitoring plots within geothermal habitats, Waikato Region, 2024–2025

Contract Report No. 3330e-i

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Establishment of biodiversity monitoring plots within geothermal habitats, Waikato Region, 2024–2025

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June 2025

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Contents

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 UAVs/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 within the five Protected Geothermal Systems within the Waikato Region (Wildland Consultants 2023b). Prior to 2024, there was no established standardised and ongoing monitoring of geothermal vegetation within Protected Geothermal Systems in the Waikato Region. Monitoring within Development Geothermal Systems however, 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). In 2025, Waikato Regional Council commissioned Wildland Consultants to establish a further five plots within one Protected Geothermal System (Waikite-Waiotapu-Waimangu), one Limited Development Geothermal System (Atiamuri), and one Research Geothermal System (Reporoa).

[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 Accessed June 2025.

2.0 Prioritisation of Biodiversity Monitoring

2.1 Access permission

2024 Field Work

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 Ngāti Tahu Ngāti 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 plots to be established and monitored on land administered by DOC, with a formal permit still pending (Authorisation Number: 101975-Flo, 1 May 2024). To simplify the permit process, the one-off permit was limited to Te Kopia Scenic Reserve, Maunga Kākaramea Scenic Reserve and Maungaongaonga Scenic Reserve. Meetings were held with managers at Waiotapu Thermal Wonderland and Orakei Korako 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. Relevant permission to access plots via private land was obtained where this was required.

2025 Field Work

In late 2024, the Department of Conservation granted a formal permit (Authorisation Number 101975-Flo, variation, 18 October 2024) for the work allowing for the establishment of additional permanent plots on all land administered by DOC, and including permission to fly a UAV (unmanned aerial vehicle/drone). Relevant permission to access plots via private land was obtained where this was required.

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 be 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 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 working in geothermal areas.

Geothermal Hazard
Thin ground surface crust or potentially thin crust, with high sub-surface temperatures where accidents could potentially occur causing serious burn injuries.
Unstable ground surface above areas with high sub-surface temperatures where accidents could potentially occur causing serious burn injuries.
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, and/or 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, CH_4, CO).

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 the waypoints of potential 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 waypoints as it was safe to do so. If the entire area surrounding the randomised waypoint was deemed unsafe, then the location was rejected and a different location was sought.

3.0 Plot Measurements

3.1 Overview

Ground-based 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 size of 0.001 hectares with a layout of 10 × 10 metres (or in one case 5 × 20 metres[1]) 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

[1] This shape was adopted for one plot at one site (Waikite Valley) to allow a geothermal spring and stream on sinter to be measured while ensuring the plot was entirely within geothermal vegetation types. The alternative layout of 5 × 20 metres is useful in long and narrow habitats that extend over a short space well beyond the boundary of geothermal sites, such as vegetation alongside geothermal streams, mudpools and springs.

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.

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

3. The length of the fauna (animal) transects (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. Eleven of the 68 fauna transect lines were either not measured to the full 20 metres or not established due to safety.

4. Soil temperature measurements were taken at each plot corner and each understorey plot at 10 cm and 40 cm 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. This cannot be considered to be an effective lizard survey as tracking tunnels are normally left out for many consecutive nights, placed strategically within potential habitat rather than randomly. Additional methods are also generally used to survey for lizards and other herpetofauna (e.g. spotlighting for arboreal lizards at night).

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 the randomly generated potential plot locations 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 the plot).
- The entire plot contained geothermal vegetation.

Corner D was then marked with a fibreglass pole, and a GPS waypoint was created. Each plot was assigned a unique "plot identifier" (i.e. Plot Name). Plot locations are shown in Figures 1-9 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

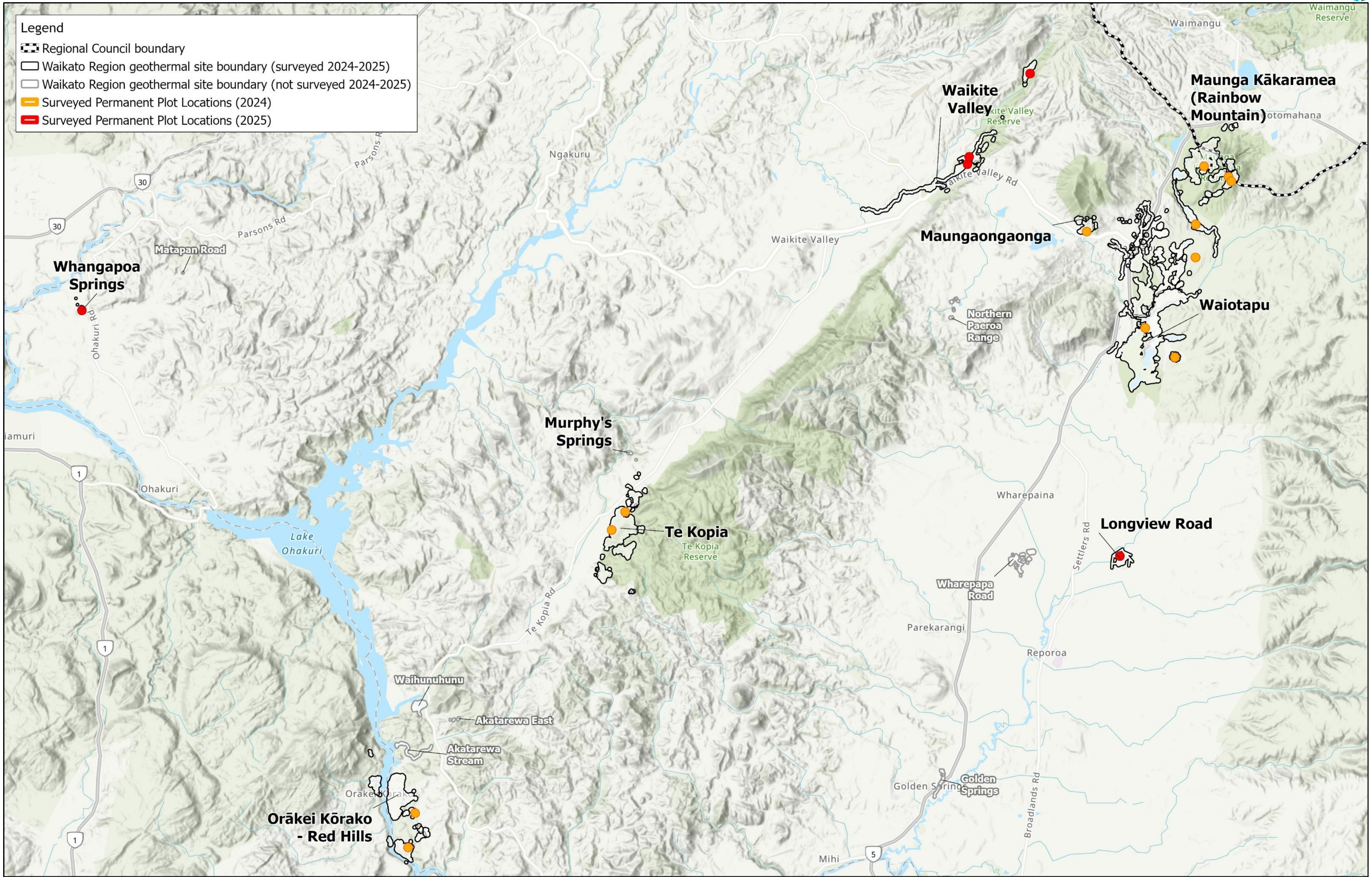

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Figure 1. Locations of permanent biodiversity monitoring plots in geothermal habitat within the Waikato Region, 2024-2025

0 2.5 5 Kilometers

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Scale: 1:90,000
Date: 6/08/2025
Cartographer: LW
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Figure 2. Location of permanent biodiversity monitoring plots and UAV imagery at Longview Road geothermal site, Reporoa Geothermal System

0 50 100 m

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Scale: 1:2,200
Date: 7/08/2025
Cartographer: LW
Format: A3

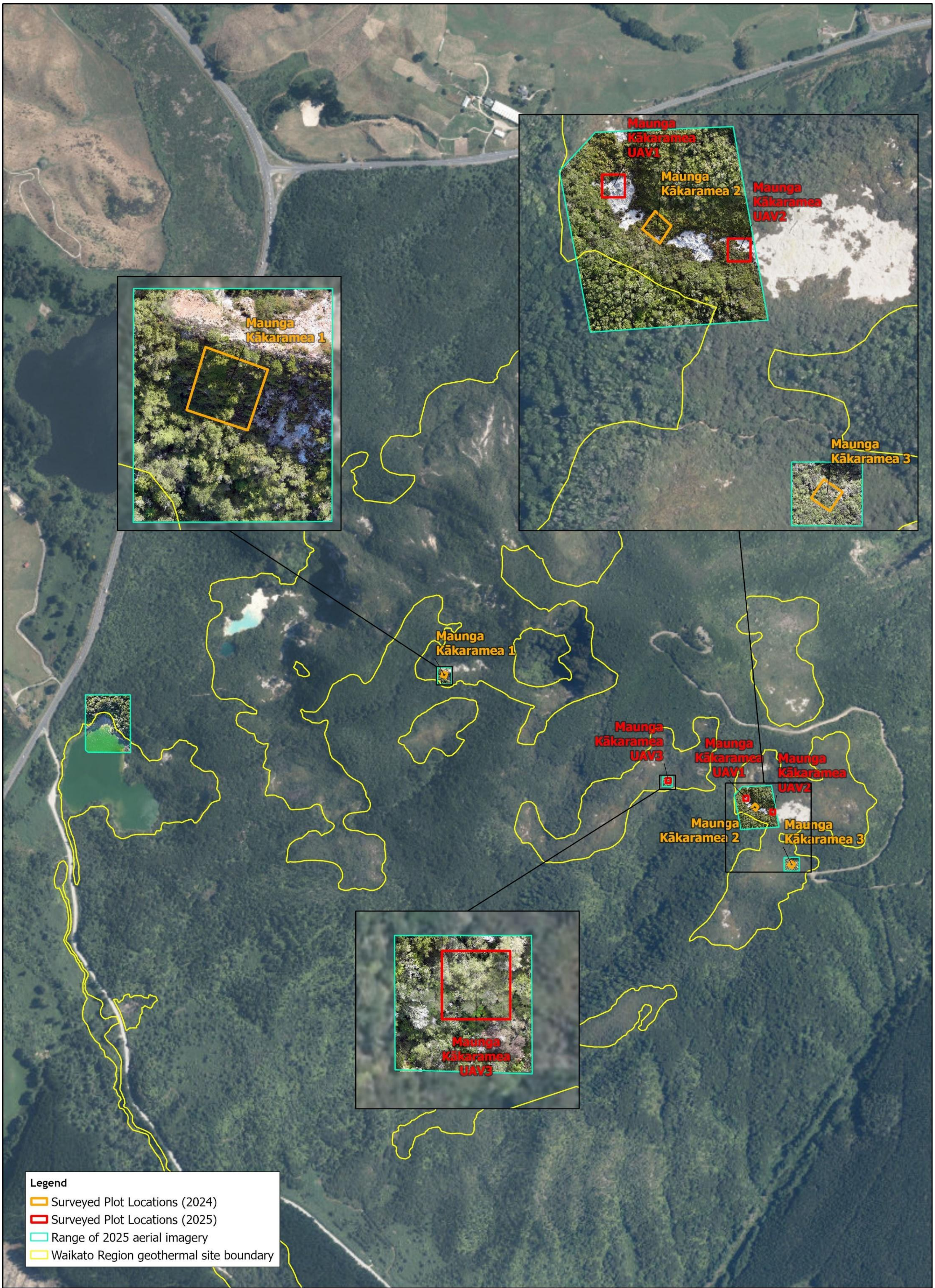

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Figure 3. Location of permanent biodiversity monitoring plots and UAV aerial imagery at Maunga Kākaramea/Rainbow Mountain geothermal site, Waikite-Waiotapu-Waimangu Geothermal System

0 250 500 m

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Scale: 1:7,000
Date: 7/08/2025
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Format: A3

Figure 4. Location of permanent biodiversity monitoring plot and UAV aerial imagery at Maungaongonga geothermal site, Waikite-Waiotapu-Waimangu Geothermal System

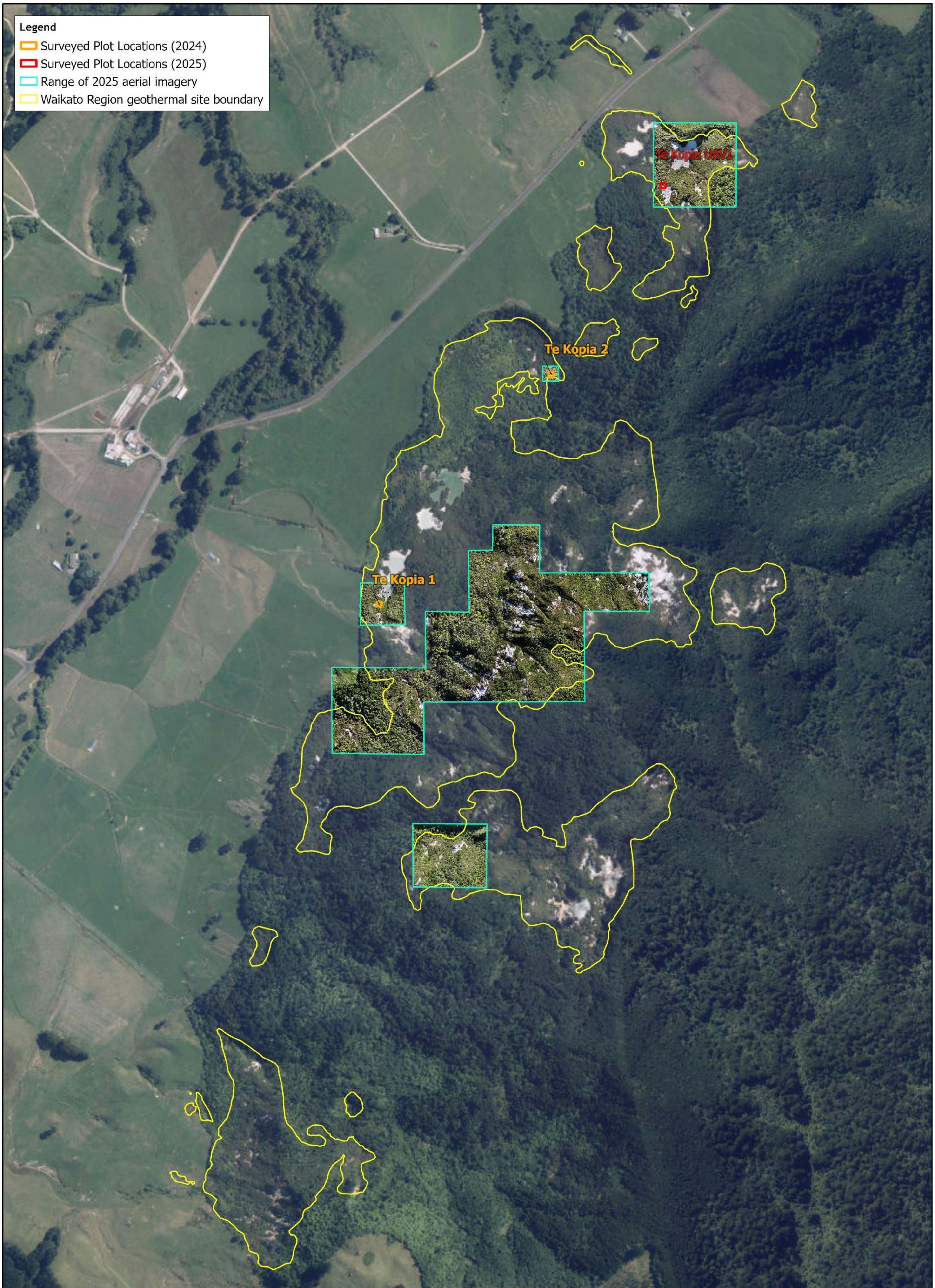

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Figure 5. Location of permanent biodiversity monitoring plot and UAV aerial imagery at Te Kopia geothermal sites, Te Kopia Geothermal System

0 250 500 m

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Scale: 1:7,000
Date: 7/08/2025
Cartographer: LW
Format: A3

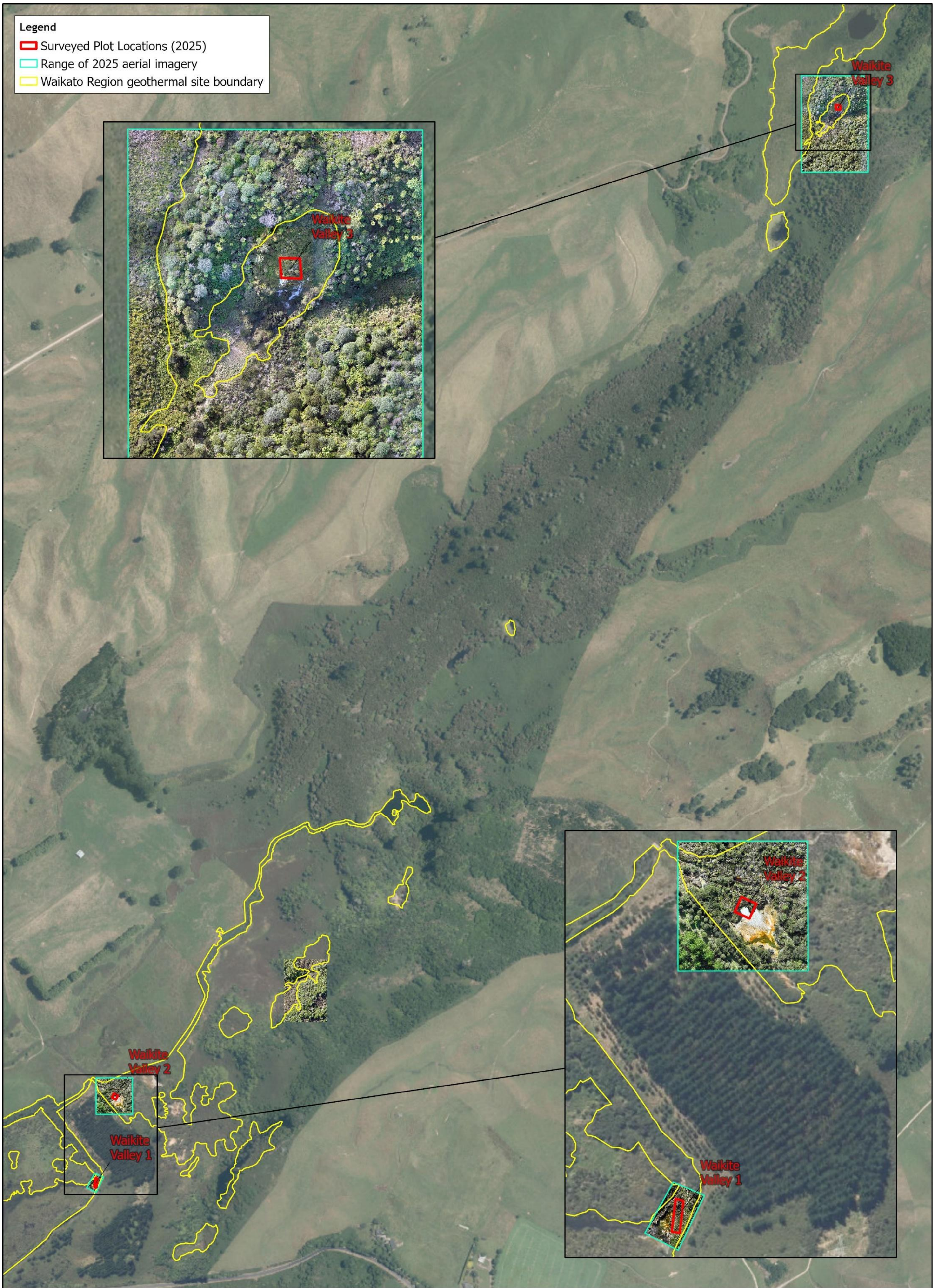

Figure 6. Location of permanent biodiversity monitoring plots and UAV aerial imagery at Waikite Valley geothermal site, Waikite-Waiotapu-Waimangu Geothermal System

0 250 500 m

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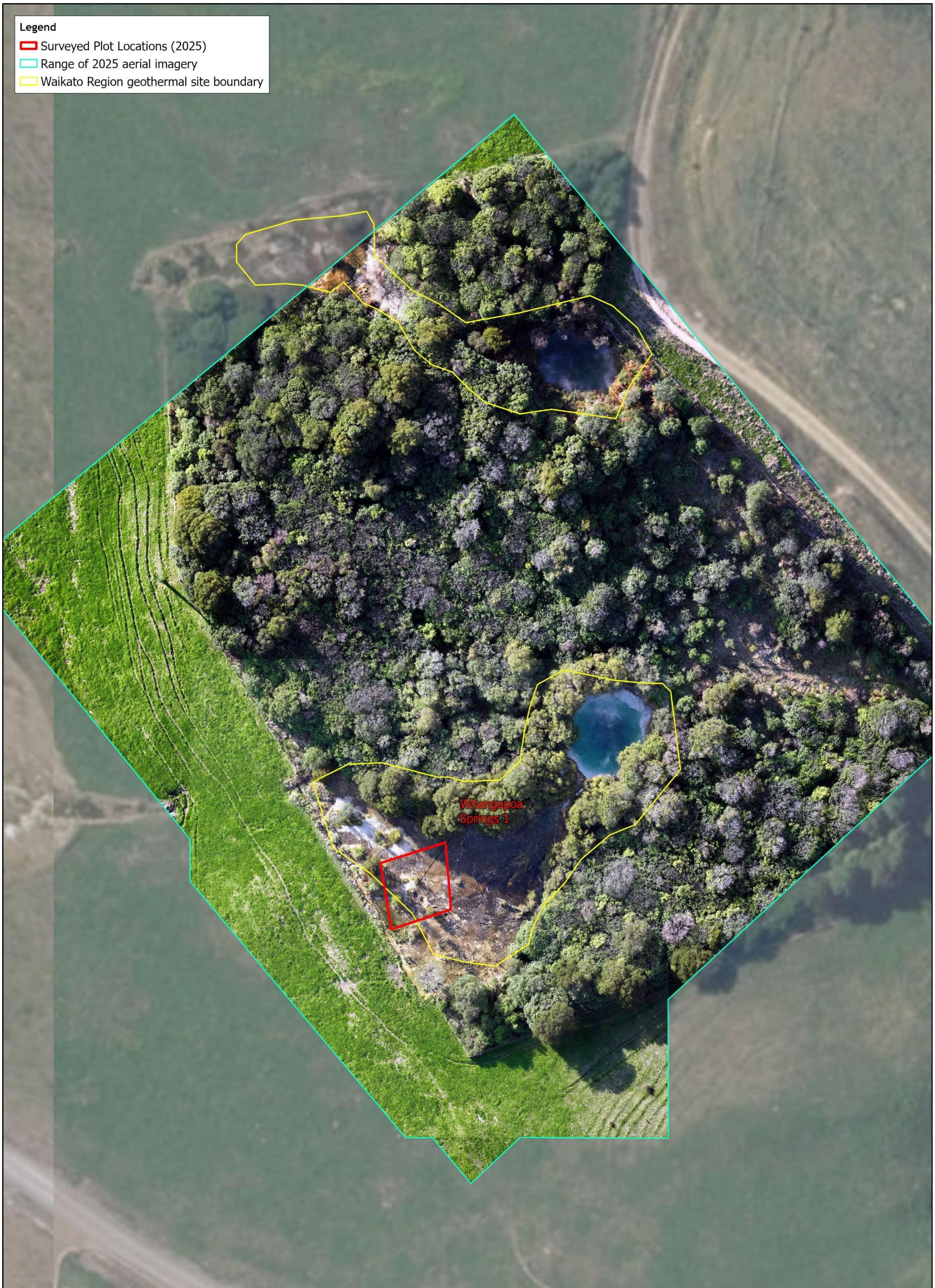

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Figure 7. Location of permanent biodiversity monitoring plot and UAV aerial imagery at Whangapoa Springs geothermal site, Atiamuri Geothermal System

0 25 50 m

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Figure 8. Location of permanent biodiversity monitoring plots at Waiotapu geothermal site, Waikite-Waiotapu-Waimangu Geothermal System

0 250 500 m

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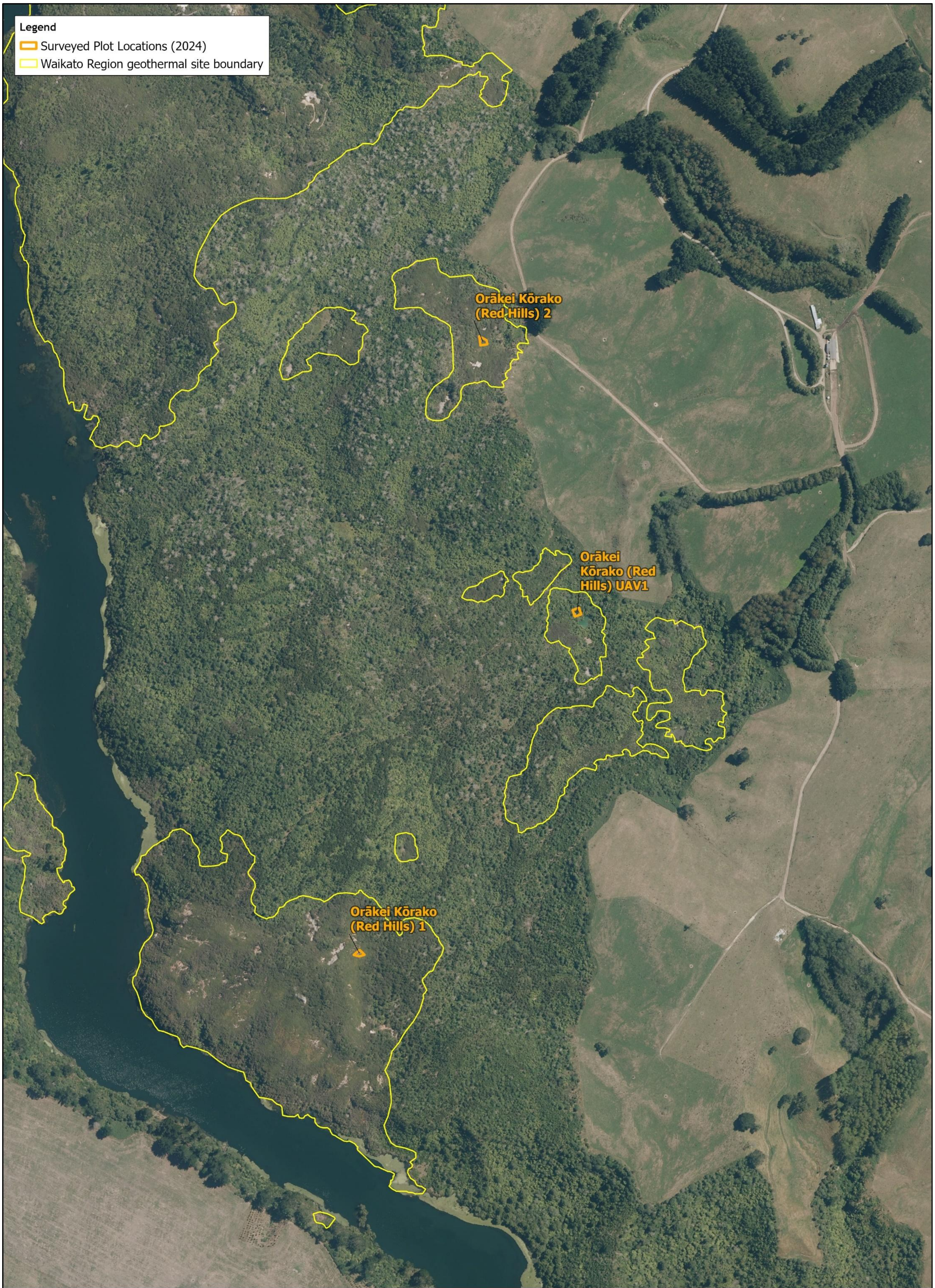

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Figure 9. Location of permanent biodiversity monitoring plots at Orākei Kōrako and Red Hills geothermal site, Orākei Kōrako Geothermal System

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Cartographer: LW
Format: A3

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 × 10 metre square. All tapes followed the ground surface where possible to do so.

Each 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 10.

A modified layout was adopted for one plot at one site (Waikite Valley 1) on a geothermal streamside. Plot establishment followed the method described above however the plot boundary lengths were changed to form a 5 × 20 rectangle along the edge of the habitat type. The D-A and C-B boundaries measured five metres in length. The A-B and C-D boundaries ran perpendicular, with 20-metre lengths. Internal tapes were lain at five metre intervals along the A-B boundary, dividing the plot into four 5 × 5 metre subplots. This method was developed specifically to include steamy streamside habitats, while minimising health and safety risks to field staff.

3.4 Vegetation measurement

Measurements undertaken within each plot largely followed the protocols of Bellingham *et al*. (2021) and Wildland Consultants (2023a) with some adjustments. 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 (<30 cm, 0.3-2 m, 2-5 m, 5-12 m, 12-25 m, >25 m) 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 0.1 cm 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 0.75 m^2) located at 2.5 m, 5 m, and 7.5 m along each internal tape were completed. All plant species <15 cm tall were recorded by presence (not counted), and each woody plant species >15 cm tall was counted in four height tiers (16-45 cm, 46-75 cm, 76-105 cm, 106-135 cm). Non-woody species and lianes >15 cm 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.

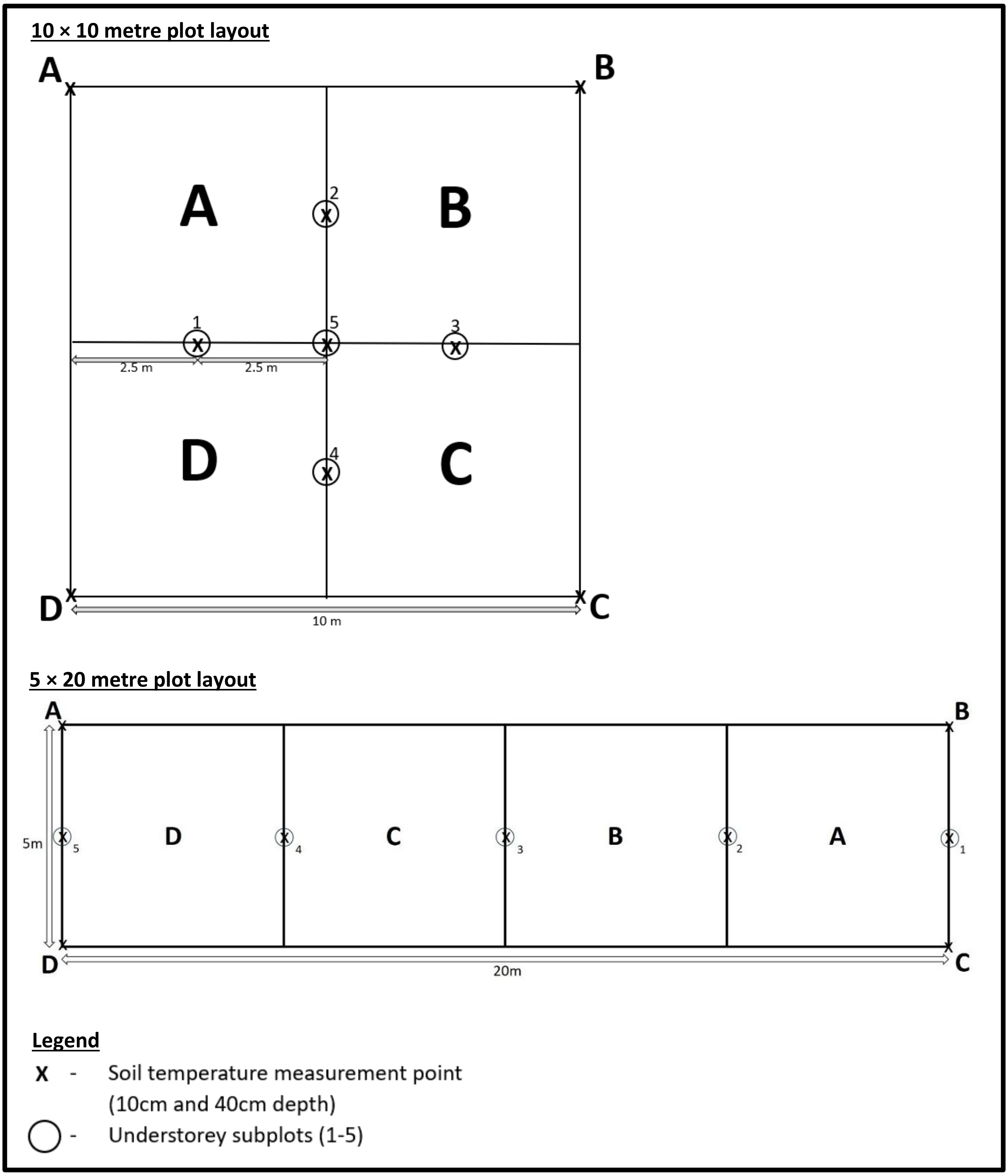

Figure 10. 10 × 10 metre (above) and 5 × 20 metre (below) permanent vegetation plot layout showing Corners A, B, C, D, Understorey subplots 1-5, and nine soil temperature measurement points. Markers for the understorey subplots (excluding the central marker), were placed on the centre lines halfway between the outer line and the centre point maker (as indicated by the 2.5 metres in shown in the diagram for understorey subplot peg 1).

3.5 Soil temperature measurements

Soil temperatures were measured at nine points within each plot: at each plot corner (A-D) and each understorey subplot (1-5) (Figure 10). Temperatures were taken at 10 cm and 40 cm depths. It was sometimes impossible to get the deeper (40 cm) soil temperature measurement in very hard substrates such as sinter without damaging the thermometer or the geothermal feature itself. In these cases, the depth of the maximum temperature was recorded.

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 survey for lizards

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

3.8 Fauna transect establishment

Fauna transect lines extended 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 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 five-metre interval faecal pellet plot (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 plot 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.

[1] https://www.doc.govt.nz/globalassets/documents/our-work/predator-free-2050/a-short-guide-to-identifying-footprints-on-tracking-tunnel-papers.pdf Accessed 20 May 2024 and Agnew 2009.

- 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 plot 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 plot measurement point), a GPS waypoint was created.

If fauna transects were unable to be established at a vegetation plot due to geothermal hazards, each vegetation subplot was systematically searched for faecal pellets.

3.9 Fauna transect measurement

The following methods were undertaken to detect introduced mammals.

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

A corflute chew card baited with an aniseed-flavoured paste was labelled with the plot identifier and transect, and placed at the terminus of each fauna transect. Chew cards were preferentially nailed 30 cm above the ground to a tree or shrub within three metres of the transect terminus. If no suitable trees or shrubs were available, the chew card was placed on a 40 cm long metal stake, 30 cm 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 (e.g. presence or absence of bite marks, initial identification of animal species) and confirmed by later inspection and comparison to the Landcare Research guide[2].

3.10 Unmanned aerial vehicle photographs

3.10.1 2024 Unmanned Aerial Vehicle monitoring

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 which were not safe to measure on the ground. The UAV plots were 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

[1] 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 one metre radius plot and lagomorph pellets are counted within the 0.18 m radius subplot and recorded if present in the one 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.

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

characteristics were obtained from the images. Locations of UAV plots established in 2024 are presented in Appendix 3 and plot photographs are presented in Appendix 4.

The UAV used was a DJI Mavic Pro II, which is equipped with a Hasselblad L1D-20c camera and 35 mm format equivalent: 28 mm 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 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 the number of vascular species able to be identified in each plot was recorded. A comparison of data captured from the UAV-based aerial images and ground-based measurements was undertaken for the five plots measured using both methods.

3.10.2 2025 Unmanned Aerial Vehicle monitoring

In 2025, aerial photography was undertaken with a DJI Mavic 3 Enterprise, equipped with a mechanical shutter, calibrated lens and RTK GPS. The photography runs were undertaken at heights between 20 metres and 50 metres above ground level, with the flying height being determined by height of vegetation at the sites.

The images were processed photogrammetrically with Agisoft Metashape to produce high resolution point clouds, which then provided orthorectified and georeferenced images. Estimated positional accuracy of the orthoimages is +/- 0.10 metres for plots at Maunga Kākaramea/Rainbow Mountain, Maungaongaonga, Longview Road, and Whangapoa Springs. For Waikite Valley and Te Kopia orthoimages, the estimated accuracy is +/- 1.0 metres absolute accuracy, as there was a delay in LINZ processing the base station data, required to accurately determine the base position. Relative accuracy of these sites is estimated at +/- 0.05 metres.

UAV photographs were taken in May 2025 of plots established in 2024 at Maunga Kākaramea Scenic Reserve (3 plots), Maungaongaonga Scenic Reserve (1 plot), and Te Kopia Scenic Reserve (2 plots), along with plots established in 2025: Waikite Valley Scenic Reserve (2 plots), Waikite Wildlife Management Reserve (1 plot), Whangapoa Springs Scenic Reserve (1 plot), Longview Road (1 plot). UAV photographs of the permanent vegetation plots and unmarked UAV plots established in 2025 are presented in Appendix 4.

Identification of visible vascular plant species richness from UAV photographs and comparison of data captured from the UAV-based aerial images and ground-based measurement follows the same method as 2024 (outlined above).

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

4.1 Summary of plots established

Fifteen biodiversity monitoring plots within Protected Geothermal Systems were established and measured between 14 May 2024 and 30 June 2025 (Figures 3-6, 8, and 9). One plot was established in a Limited Development System (Figure 7) and one plot was established in a Research System (Figure 2) in 2025, meaning that a total of 17 permanent plots were established and measured on the ground. The geothermal system classification, site name (per Wildland Consultants 2023b), and permanent plot names are presented in Table 2. All permanent plots (excluding one at Waiotapu) were also all photographed using a UAV. Eleven other plots with no permanent markers in areas unsafe to measure on the ground, were measured by UAV alone. This gives a total of 28 plots within Protected, Limited Development, and Research Geothermal Systems in the Waikato Region.

All permanent plots were established in either forest, scrub, shrubland, grassland, or sedgeland habitats. No permanent plots were established in areas comprising 100% cover of mossfield, lichenfield, rockland, open water, mudpools, or bare ground, but these types were included to some degree within some of the permanent plots. Several of the UAV-based plots contained non-vegetated areas such as geothermally-influenced bare ground and water.

4.2 Geothermal ecosystem types

The primary geothermal ecosystem habitat type measured in plots was 'heated ground (dry)' which often comprised geothermally heated ground dominated by geothermal kānuka (*Kunzea tenuicaulis*) (Table 2). Locally, some other woody species were present including mingimingi (*Leucopogon fasciculatus*), mānuka (*Leptospermum scoparium*), and monoao (*Dracophyllum subulatum*). Geothermal ferns were often present within plots. Introduced pines (*Pinus* sp.) formed the canopy at one site (Waiotapu 1). Geothermally heated ground with extensive areas of geothermal kānuka scrub and shrubland is the one of the most widespread habitat types of these geothermal fields, with many 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 (including occasional indigenous hardwood species) than areas of hotter ground. Fumaroles were represented by being within and on the margins of some plots (e.g. Red Hills 1, Maunga Kākaramea 1, Maungaongaonga 1, and Waikite 3), and the steam from these was often present in plots. Geothermal stream and spring margin habitat were present at three sites (Whangapoa Springs 1, Waikite Valley 1 and Waiotapu 4) and geothermal wetland habitat was present at two plots[1] (Waikite Valley 2, and Whangapoa Springs 1). Sinter was present at Whangapoa Springs 1 and Waikite Valley 1.

[1] Localised areas of geothermal wetland vegetation are also present at Waikite Plot 1, however the dominant vegetation type within the plot is exotic grassland (terrestrial).

Table 2 – Location of biodiversity monitoring plots established within Protected, Limited Development, and Research Geothermal Systems in the Waikato Region in 2024 and 2025.

Geothermal System Classification for Resource Use	Geothermal System	Geothermal Field	Site Name (Wildland Consultants 2023b)	Number of Permanent 10 × 10 m Plots	Number of Unmarked UAV Plots[1]	Permanent Plot Name	Date Established	Key Habitats and Vegetation Types on Plots
Limited Development	Atiamuri	Atiamuri	Whangapoa Springs	1	0	Whangapoa Springs 1	2025	Sinter wetland, herbfield, scrub
Protected	Orākei Kōrako	Orākei Kōrako	Orākei Kōrako and Red Hills	2	1	Red Hills 1	2024	Scrub, shrubland, mossfield, bare ground, fumaroles
						Red Hills 2	2024	Scrub, bare ground
Research	Reporoa	Reporoa	Longview Road	1	3	Longview Road 1	2025	Scrub
Protected	Te Kopia	Te Kopia	Te Kopia	2	1	Te Kopia 1	2024	Shrubland, mossfield, bare ground
						Te Kopia 2	2024	Scrub
Protected	Waikite-Waiotapu-Waimangu	Waikite	Waikite Valley	3	0	Waikite Valley 1	2025	Grassland, sinter, wetland
						Waikite Valley 2	2025	Wetland, rushland, bare ground
						Waikite Valley 3	2025	Shrubland
		Waiotapu	Maunga Kākaramea (Rainbow Mountain)	3	3	Maunga Kākaramea 1	2024	Shrubland, mossfield, fumaroles
						Maunga Kākaramea 2	2024	Shrubland
						Maunga Kākaramea 3	2024	Scrub
			Maungaongaonga	1	0	Maungaongaonga 1	2024	Shrubland, mossfield
			Waiotapu	4	3	Waiotapu 1	2024	Forest
						Waiotapu 2	2024	Shrubland
						Waiotapu 3	2024	Scrub, shrubland, bare ground
						Waiotapu 4	2024	Scrub
Total				**17**	**11**			

1. Note, all the permanent plots were also measured by UAV (Unmanned Aerial Vehicle).

4.3 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 were dominated by shrubs, particularly geothermal kānuka, but also occasional mingimingi, mānuka, monoao, prickly mingimingi (*Leptecophylla juniperina* var. *juniperina*) and ferns. One plot had a high cover of radiata pine (*Pinus radiata*) in the canopy, but this plot had characteristic geothermal species in much of the understorey.

The warmest temperature soils were devoid of vegetation. Patches of bryophytes (i.e. non-vascular plants, including mosses, liverworts, and hornworts) became present as the temperatures reduced. Short stature geothermal kānuka was the most prevalent vascular plant on soils with warm temperatures. Some vascular plant species that can tolerate warmer soil temperatures than geothermal kānuka were present, such as *Palhinhaea cernua*[1]. At cooler temperatures, other indigenous shrub species and ferns became more abundant, and the height of geothermal kānuka typically increased.

Several plots were 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 17 permanent biodiversity monitoring plots within geothermal habitats in the Waikato Region, May-June 2024 and March-April 2025. Average vegetation top heights are obtained from the Recce 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* species)	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 and shrubland	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) shrubland and scrub	0.3
Maunga Kākaramea 2	Geothermal kānuka/*Dicranoloma* species-(*Cladonia* species) scrub and shrubland	0.4
Maunga Kākaramea 3	Geothermal kānuka scrub	2.5
Maungaongaonga 1	Geothermal kānuka/*Dicranoloma* species.-*Campylopus* species-bare ground scrub and shrubland	1.0
Waiotapu 1	Radiata pine-geothermal kānuka/*Astelia solandri* forest	6.0
Waiotapu 2	(Radiata pine)/geothermal kānuka-mingimingi-(monoao) shrubland	1.0
Waiotapu 3	Geothermal kānuka/*Thuidiopsis furfurosa*-*Cladonia* species-bare ground shrubland	1.0
Waiotapu 4	Geothermal kānuka/geothermal kānuka-mingimingi-turutu scrub	2.0
Longview Road 1	Mānuka/mingimingi scrub	4.5
Waikite Valley 1	Kāpūngāwhā-mānuka-harakeke sedgeland, Indian doab grassland, open water, and sinter.	0.3

[1] Referred to as *Lycopodiella cernua* by some botanists.

Plot Name	Broad Vegetation Type	Average Vegetation Top Height (m)
Waikite Valley 2	(Mānuka)/*Machaerina juncea* sedgeland and bare ground	0.8
Waikite Valley 3	Geothermal kānuka scrub and shrubland	0.5
Whangapoa Springs 1	(Mānuka)/arrow grass herbfield and bare ground (sinter)	0.0

4.4 Soil temperature

Average soil temperatures measured at 10 centimetre and 40 centimetre depths in each of the biodiversity monitoring plots are presented in Table 4. The relationship between average soil temperature at 40 cm depths and the average vegetation top height is shown in Figure 11. Vegetation top heights were obtained from the Recce data sheets for each plot. Mean soil temperatures recorded at 40 cm depths for each plot were used for this analysis because 40 cm temperature measurements are less susceptible to short term fluctuations caused by external influences (such as air temperature, precipitation, and solar radiation) than soil temperatures at 10 cm depth. Three plots were excluded from the analysis as the ground was too hard to measure soil temperature at 40 cm depth at most locations within these plots.

Table 4 – Mean soil temperatures °C, at 10 cm and 40 cm depths and 95% confidence intervals on the estimate of the mean, in 17 permanent biodiversity monitoring plots, Waikato Region, 2024-2025. N = 9, unless otherwise stated.

Plot Name	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
Longview Road 1	25.4	22.5-28.3	19.7-31.3	31.6	29.3-33.9	27.4-36.0
Waikite Valley 1[1]	36.5	31.1-41.9	27.3-45.5	-	-	-
Waikite Valley 2[2]	19.0	17.1-20.9	16.9-23.6	-	-	-
Waikite Valley 3[3]	53.7	49.1-58.3	46.4-66.7	78.0	69.3-86.7	63.9-94.4
Whangapoa Springs 1[4]	17.8	15.3-20.3	14.8-23.6	-	-	-

[1] Soil temperatures (°C) at 10 cm, N=7. Temperature at 40cm depth (°C) not measured at most locations due to hard ground.
[2] Soil temperatures (°C) at 10 cm, N=8. Temperature at 40cm depth (°C) not measured at most locations due to hard ground.
[3] Soil temperatures (°C) at 40 cm, N=8
[4] Soil temperatures (°C) at 10 cm, N=8. Temperature at 40cm depth (°C) not measured at most locations due to hard ground.

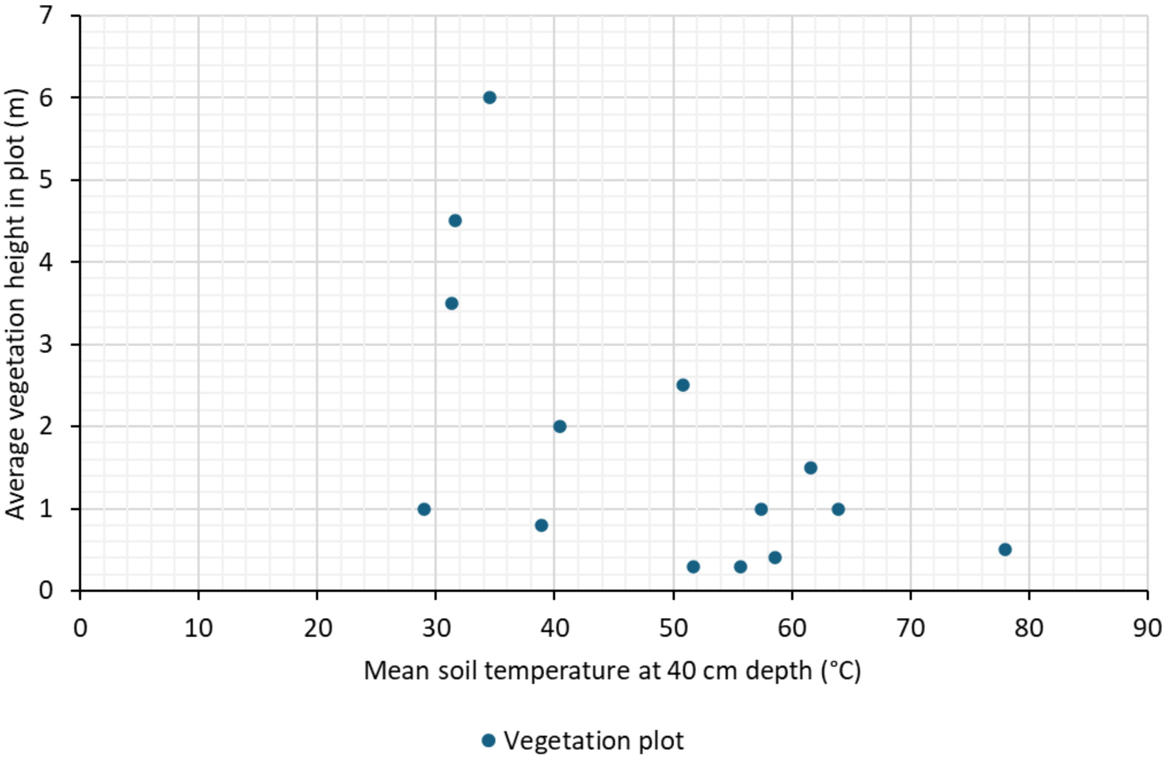

Figure 11. Comparison of the mean soil temperature at 40 cm depths (N=9, 13 plots. N=8, 1 plot) and the average vegetation top height recorded in biodiversity monitoring plots, 2024-2025, Waikato Region.

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 trend of decreasing average vegetation top height as mean soil temperature at 40 cm depth increases (Figure 11). There are large variations in the soil temperature measurements recorded within each plot (Table 4) and subsequently, the mean values do not capture these finer scale temperature variations within each 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 and geothermally-influenced bare ground.

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.

4.5 Flora

A list of vascular plant species recorded within the permanent geothermal monitoring plots is provided in Appendix 5. A total of 38 indigenous and eight introduced vascular plant species were recorded across all of the 17 permanent plots. Five of the indigenous species have a threat ranking in de Lange *et al.* 2024:

- *Cyclosorus interruptus* (At Risk-Declining).
- *Dicranopteris linearis* (Threatened-Nationally Endangered).
- Dwarf mistletoe (*Korthalsella salicornioides*; At Risk-Declining).

- Geothermal kānuka (At Risk-Naturally Uncommon).
- *Schizaea dichotoma* (At Risk-Naturally Uncommon).

Geothermal kānuka was present within 14 of the 17 permanent vegetation plots. Eleven dwarf mistletoe (*Korthalsella salicornioides*) plants were recorded growing on one geothermal kānuka shrub within one plot in Te Kopia Geothermal Field (Te Kopia 1). *Dicranopteris linearis* was present in two plots, Te Kopia 2 (cover of 6%) and Red Hills 2 (cover of 2%), within geothermal kānuka scrub on geothermally heated ground. *Schizaea dichotoma* was also present in two plots (Maunga Kākaramea 3 and Te Kopia 2). *Cyclosorus interruptus* was present alongside a geothermal stream at Waikite Valley 1, with a cover of 1% in the permanent plot.

Other plant species typical of geothermal habitat that were present in the plots include the clubmoss *Palhinhaea cernua*, which was recorded in two plots (Te Kopia 2 and Maunga Kākaramea 1); and *Schizaea bifida* which was observed near two plots (Waikite Valley 3 and Waiotapu 2). This is the first record of this *Schizaea* species at Waiotapu. *Psilotum nudum* was observed near one plot (Waikite Valley 3) under a canopy of geothermal kānuka.

Twenty-seven non-vascular plant 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 *P. pinaster*).

4.6 Avifauna

The five-minute bird count surveys identified 16 indigenous and 11 exotic bird species (Table 5) across all of the 17 permanent plots. Three indigenous bird species recorded are classified as At Risk-Declining in Robertson *et al.* (2021): koroātito/North Island fernbird (*Poodytes punctatus vealeae*), pīhoihoi/New Zealand pipit (*Anthus novaeseelandiae novaeseelandiae*), and toutouwai/North Island robin (*Petroica longipes*).

4.7 Herpetofauna

Sixteen of the permanent plot locations were surveyed, using a tracking tunnel, in an opportunistic effort to detect ground-dwelling lizards. No lizard species were detected. Three non-target detections were recorded including insect tracks (Red Hills 1, Waiotapu 1) and a mouse (Red Hills 2). One tracking tunnel was not set (Waikite Valley 3) due to unsuitable overnight weather conditions.

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 put in place for a minimum of two weeks. The time of year was also less than ideal for lizard detection, with the survey being undertaken in winter with overnight temperatures at freezing levels on most days.

4.8 Introduced mammals

Introduced mammal presence was recorded at 16 out of 17 permanent plots (Table 6). No introduced mammal species were detected at plot Longview Road 1 on chew cards or in faecal pellet counts. However, old game trails were noted in the faecal pellet plots and possum pellets were observed in low frequency within the general area surrounding the vegetation plot.

Table 5 – Indigenous and exotic bird species recorded during five-minute bird counts at 17 permanent geothermal monitoring plots, 2024 and 2025, Waikato Region. Common names, species names, and threat classifications are from Robertson *et al.* (2021).

Common Name	Scientific Name	Threat Classification 2021	Presence Detected					
			Atiamuri	Reporoa	Te Kopia	Orākei Kōrako	Waikite	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	✓					✓
Warou/welcome swallow	*Hirundo neoxena neoxena*	Not Threatened					✓	
Introduced								
Australian magpie	*Gymnorhina tibicen*	Introduced and Naturalised	✓	✓	✓	✓	✓	✓
Chaffinch	*Fringilla coelebs*	Introduced and Naturalised	✓				✓	✓
Dunnock	*Prunella modularis*	Introduced and Naturalised					✓	
Eastern rosella	*Platycercus eximius*	Introduced and Naturalised						✓
Eurasian Blackbird	*Turdus merula*	Introduced and Naturalised		✓	✓		✓	✓
European goldfinch	*Carduelis carduelis*	Introduced and Naturalised	✓	✓		✓	✓	✓
European greenfinch	*Carduelis chloris*	Introduced and Naturalised			✓			✓
House sparrow	*Passer domesticus*	Introduced and Naturalised	✓				✓	
Mallard	*Anas platyrhynchos*	Introduced and Naturalised			✓		✓	
Myna	*Acridotheres tristis*	Introduced and Naturalised	✓	✓			✓	
Song thrush	*Turdus philomelos clarkei*	Introduced and Naturalised			✓			

The most commonly detected species was brushtail possum (*Trichosurus vulpecula*) and possum sign (pellets or chew card detection) was recorded in 15 plots. Possum pellets were in 25.8% of pellet counts (present in 63 out of a total of 244 pellet counts completed) and possum chew was present on 8.2% of chew cards deployed. Three non-target species, rats (*Rattus* sp.), mice (*Mus musculus*), and rabbit (*Oryctolagus cuniculus cuniculus*) were detected on 14.8%, 32.8% and 1.6% of chew cards deployed, respectively.

Ungulate observations included both feral pig (*Sus scrofa*) and deer (likely red deer, *Cervus elaphus*[1]). Deer pellets were detected in faecal pellet counts at two plots: Te Kopia 2 and Waiotapu 3. Feral pig scat was recorded at Te Kopia 2, Red Hills 2, and Waikite Valley 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 this plot.

Wallaby pellets (*Notamacropus* sp.[2]) were recorded in faecal pellet counts at all three plots established in Waikite Geothermal System, and at two plots (Waiotapu 2 and Waiotapu 3) in Waiotapu Geothermal System. Wallaby pellet counts were detected in 11 out of a total of 244 pellet counts completed (4.5%).

Lagomorph pellets were recorded in one faecal pellet count at plot Waiotapu 2 and one faecal pellet count at plot Waikite Valley 1.

A complete list of introduced mammal species detected, and detection type is presented in Appendix 7. A total of 244 faecal pellet plots were measured and 61 chew cards deployed. Five fauna transects were shortened due to safety (Te Kopia 2, Transects C and D; Red Hills 1, Transect B; Maungaongaonga 1, Transect B; and Waikite Valley 3, Transect C). Two transects were not measured. Transect D at Waiotapu 4 was not measured due to unsafe geothermal terrain. Transect C at Whangapoa Springs 1 was not established as the plot corner was located on a boundary fence with exotic pasture (non-geothermal habitat).

A modified faecal pellet count method was adopted for plot Waikite Valley 1. Faecal pellet transects were unable to be established at Waikite Valley 1 due to unsafe geothermal ground and proximity to non-geothermally influenced habitats. For this plot, faecal pellet searches were undertaken within each subplot (5 × 5 metres).

One chew card at Longview Road 1 was not set as the location was within 20 metres of another chew card due to transect deviations. Two chew cards were not set at Waikite Valley 1 because the animal transects were not established due to dangerous geothermal ground. No chew cards were set at Waikite Valley 3 due to an unsuitable weather forecast.

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

Aerial images of 16 of the 17 permanent plots established were obtained. Vascular species richness was then determined from UAV-based aerial images and compared to ground-based vegetation plot measurements (Figure 12).

The dominant canopy species (generally geothermal kānuka, or occasionally mingimingi or mānuka) was able to be identified in UAV-based images, and the relative canopy cover was assessed. Wilding

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

[2] 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 since been shown to be present in the central North Island, dama wallaby and parma wallaby (*N. parma*) (Biosecurity New Zealand 2023, Veale 2023).

pines (*Pinus* sp.) were also readily identifiable, even in very low numbers. From UAV imagery alone it was not always possible to distinguish between similar looking canopy species such as geothermal kānuka, mānuka, mingimingi, and kānuka. Therefore, canopy species diversity is likely to be underrepresented where there are multiple of these species occurring within a plot. Species recorded using the ground-based method that were relatively uncommon in the canopy, were generally not able to be distinguished in the aerial imagery. For example, monoao was recorded in plots Red Hills 1, Waiotapu 2, and Te Kopia 1, with a percentage cover of 2%, 4%, and 1% respectively, but this species was not identified in the aerial imagery for any of these plots.

The number of vascular plant species (lichens and bryophytes were excluded from the data set) detected by UAV-based imagery was consistently lower than that recorded by ground-based methods, with the exception of three plots (Maunga Kākaramea 2, Maungaongaonga 1, and Waiotapu 3) that only contained geothermal kānuka of relatively short stature, which was easily identified in the aerial imagery (Figure 12). Species not present in the canopy could not be identified from UAV images, therefore for plots which had much of their species richness within understorey and ground cover tiers, there was low correlation of the ground-based measurements to the species richness obtained from UAV images.

Overall, the detection rate from aerial imagery ranged from 9.1% to 100%, with an average rate of species detection across all sixteen plots of 47%. 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 understorey and ground cover species. On average only around 50% of vascular plant species present were detected using UAV imagery, and it is likely that species missed will include rare and pest plant species.

Lower vascular plant species richness was recorded from UAV-based images (relative to ground-based measurements) at 13 of the 16 plots compared, with considerably lower vascular species richness recorded at plots Te Kopia 2, Maunga Kākaramea 3, Whangapoa Springs 1, and Red Hills 2. Both Te Kopia 2 and Maunga Kākaramea 3 are characterised by a relatively tall average canopy height (2.5-3.5 m), a canopy dominated by a single species (geothermal kānuka), and greater vascular plant species richness (in comparison to the other permanent plots). Most of the vascular plant species diversity within these two plots was recorded from the understorey and ground cover tiers, which are obscured by the canopy in the aerial image. Whangapoa Springs Plot 1 had relatively high species richness, but unlike the previous two plots, it had very low canopy cover (3%) and comprised mostly of groundcover species or sinter terraces (average top height of 0 metres). The plot contained many grasses and exotic herb species (such as Yorkshire fog (*Holcus lanatus*), *Lachnagrostis filiformis*, lotus (*Lotus pedunculatus*), and foxglove (*Digitalis purpurea*)), which could not be identified from the UAV aerial photographs. In addition, the aerial imagery was not of a sufficient resolution to identify larger stature species with low percentage covers within this plot, such as blackberry (1%), rārahu (*Pteridium esculentum*; 1%), and tūrutu (*Dianella nigra*; 1%). At a further six plots, only one vascular plant species was detected in the aerial images (the dominant canopy species), whereas a range of three to nine vascular plant species were recorded by the ground-based vegetation monitoring methods.

4.10 UAV-based monitoring for unsafe sites

Eleven plots were established by UAV alone in randomised locations that were unsafe to access on the ground. Six of the UAV plots sampled were very hot and contained predominantly bare ground and sparse, short stature vegetation. At these sites, measurement via UAV is likely to be comparable to ground-based methods. UAV monitoring is therefore a good complementary approach to ground-based monitoring in dangerous environments, but should not be used in isolation. The UAV plot name, date of measurement, and an assessment of the visible species richness and cover abundance of vegetation, bare ground, and water are presented in Table 7.

Table 6 – Introduced mammal species detected in faecal pellet counts or chew cards at 17 permanent geothermal monitoring plots, 2024-2025, Waikato Region.

Geothermal Field	Plot Name	Species Detected (chew cards or faecal pellet counts)					
		Ungulate	Possum	Wallaby	Lagomorph	Rat	Mouse
Atiamuri Geothermal Field	Whangapoa Springs 1	X	✓	X	X	X	X
Orākei Kōrako Geothermal Field	Red Hills 1	X	✓	X	X	X	✓
	Red Hills 2	✓	✓	X	X	✓	✓
Reporoa	Longview Road 1	X	X	X	X	X	X
Te Kopia Geothermal Field	Te Kopia 1	X	✓	X	X	X	X
	Te Kopia 2	✓	X	X	X	X	X
Waikite Geothermal Field	Waikite Valley 1	X	✓	✓	✓	X	X
	Waikite Valley 2	✓	✓	✓	✓	X	✓
	Waikite Valley 3[1]	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

[1] Chew cards were not deployed at this plot due to unsuitable weather.

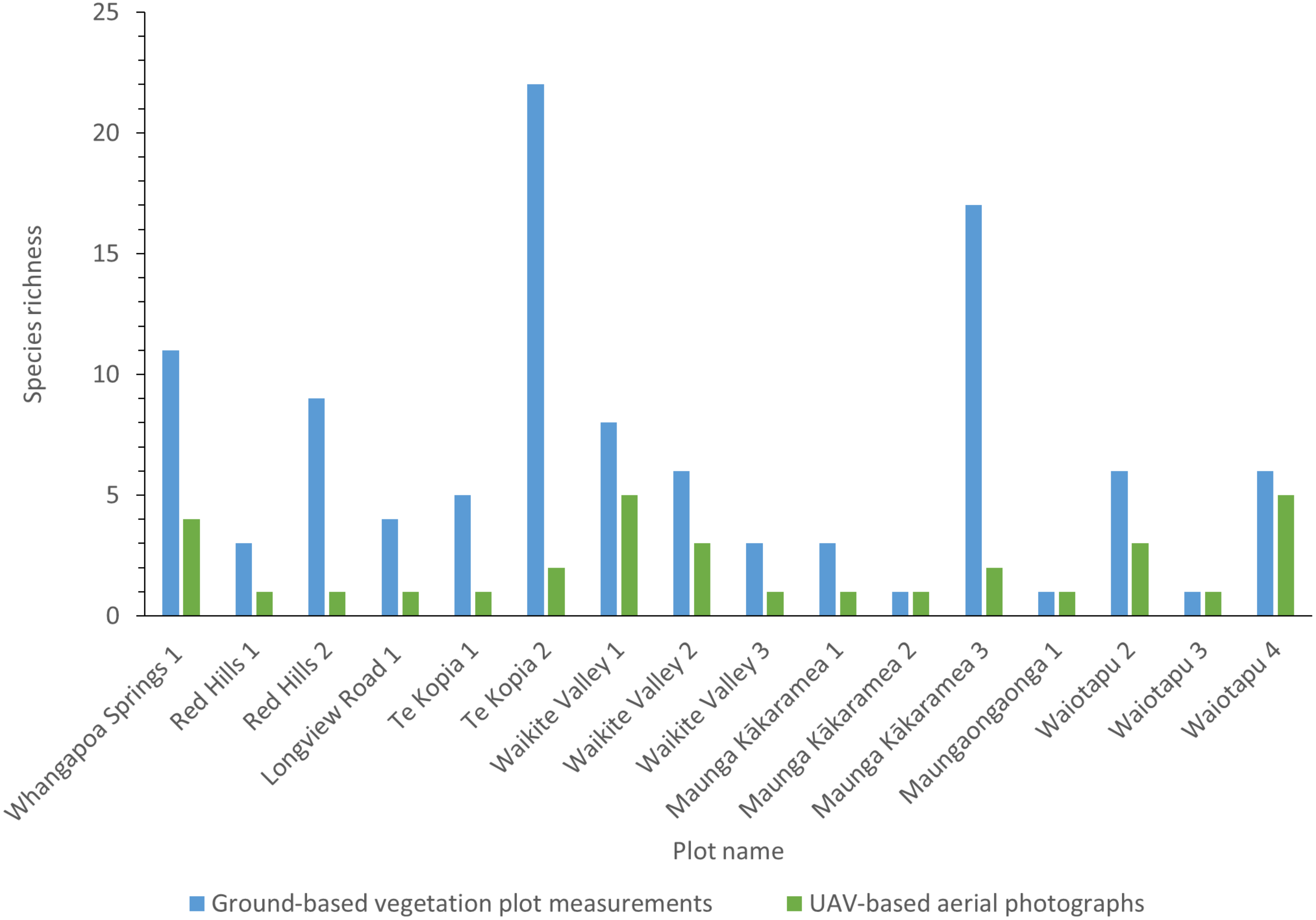

Figure 12. Comparison of the total number of vascular plant species recorded (species richness) in sixteen vegetation plots using ground-based measurements and UAV-based aerial photographs.

Table 7 – Estimated visible vascular plant species richness and cover abundance data obtained from UAV-based photographs of 11 plots located in geothermal areas that were unsafe to access on the ground, 2024 and 2025, Waikato Region.

Plot Name	Geothermal Field	Year of UAV Aerial Imagery	Plot Size (m)	Vegetation Stature	Relative Cover[1] (%)			Visible Species Richness
					Vegetation	Bare Ground	Open Water	
Red Hills UAV1	Orākei Kōrako	2024	10 × 10	Scrub (>2 m)	85	0	15	6
Longview Road UAV1	Reporoa	2025	10 × 10	Geothermal open water, geothermal mud, and geothermally-influenced bare ground	0	75	25	0
Longview Road UAV2	Reporoa	2025	10 × 10	Scrub (>2 m)	5	3	2	2
Longview Road UAV3	Reporoa	2025	10 × 10	Geothermal open water and geothermally-influenced bare ground	20	5	75	2
Te Kopia UAV1	Te Kopia	2025	10 × 10	Geothermally-influenced bare ground	40	60	0	1
Maunga Kākaramea UAV1	Waiotapu	2025	10 × 10	Geothermally-influenced bare ground	25	75	0	1
Maunga Kākaramea UAV2	Waiotapu	2025	10 × 10	Scrub (<2 m)	65	35	0	1
Maunga Kākaramea UAV3	Waiotapu	2025	10 × 10	Scrub (>2 m)	99	1	0	4
Waiotapu UAV1	Waiotapu	2024	2 × 2	Scrub (<2 m)	50 (live), 40 (dead)	10	0	1
Waiotapu UAV2	Waiotapu	2024	1 × 1	Geothermally-influenced bare ground	15	85	0	1
Waiotapu UAV3	Waiotapu	2024	1 × 1	Geothermally-influenced bare ground	0	100	0	0

[1] 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 the ground-based vegetation method in which both canopy cover (% cover of vegetation >1.35 m tall) and ground cover characteristics (% cover of vegetation <1.35 m, non-vascular, litter, bare ground, and rock, multiple layers will usually overlap summing to >100%) are recorded.

Advantages of a UAV-based approach include that plots can be placed truly randomly, and measurement of sites that are inaccessible or too dangerous to measure on the ground can occur. Capture of information by UAV is also significantly faster than by ground-based field methods, and depending on spacing of plots, photographs of many plots can be captured in one field day.

The size of the UAV plots established in 2024 was dependant on the vegetation structure and followed the methods described by Bellingham *et al*. (2021) (forest and scrub 10 × 10 m, short (<2 m) scrub and shrubland 2 × 2 m, and geothermally-influenced bare ground 1 × 1 m). All UAV plots established in 2025 were 10 × 10 m, irrespective of the vegetation type present. This larger plot size may provide a better scale for measuring long term change because geothermal sites are highly dynamic and vegetation stature may change significantly in the future. It also provides consistency with the size of the ground-based permanent plots.

Due to the hazardous nature of vegetation monitoring in close proximity to geothermal features such as heated pools, geothermal mud, or hot potentially unstable bare ground at these sites, 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.

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 Recce ground cover vegetation scores (provided vegetation height is <1.35 metres tall). A major 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 indicates that this method is not a comparable alternative to ground-based vegetation measures.

Vegetation height data was captured during the 2025 UAV monitoring, using high resolution point clouds (Figure 13). This will enable vegetation height to be included in future UAV monitoring, providing further useful monitoring information[1].

[1] Analysis of this vegetation height data was not undertaken at this time due to software requirements. In future, such analysis would need to be incorporated into the UAV subcontract.

Figure 13. Example of point cloud cross view of the vegetation at Longview Road Plot 1. This type of information can be used to infer vegetation heights within a plot.

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".

In 2024-2025, each plot was measured by a team of four people, working together in pairs for health and safety reasons. Approximately one month after plot measurements were undertaken, an additional site visit was undertaken to a sub-sample of the plots (15 plots) to note whether any trampling damage was visible (Table 8).

Table 8 – Permanent biodiversity monitoring plots revisited after monitoring and the extent of visible trampling damage (none to high) present, 2024-2025, Waikato Region.

Plot Name	Extent of Trampling Damage*	Comment
Longview Road 1	Negligible	• Minor trampling of non-vascular plant species. • Minor crushing of woody vegetation
Te Kopia 1	Minor	• Trampling damage in the plot is largely from existing animal tracks. • Minor trampling of non-vascular plant species. • Minor crushing of woody vegetation
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 non-vascular plant species (mosses) from workers slipping when walking around the plot.

Plot Name	Extent of Trampling Damage*	Comment
		• Minor damage to geothermal kānuka bark.
Maunga Kākaramea 1	Minor to moderate	• Minor soil damage, although largely unnoticeable (soils at this site are very suspectable to trampling). • Minor trampling of non-vascular plant species.
Maunga Kākaramea 2	Minor	• Minor trampling of non-vascular plant species. • Minor soil damage.
Maunga Kākaramea 3	Minor	• Minor trampling of non-vascular plant species. • Minor soil damage.
Maungaongaonga 1	Minor	• Evidence of foot traffic on non-vascular plant cover, and minor soil disturbance. • Minor vegetation crushing.
Red Hills 1	Minor to moderate	• Minor soil damage, although largely unnoticeable (soils at this site are very suspectable to trampling). • Minor trampling of non-vascular plant species.
Red Hills 2	Minor	• Minor trampling of non-vascular plant species. • Minor soil damage.
Waiotapu 1	Minor	• Minor soil damage, although largely unnoticeable
Waiotapu 2	Minor	• Trampling damage in the plot is largely from existing animal tracks. • Minor trampling of non-vascular plant species. • Minor crushing of woody vegetation.
Waiotapu 3	Minor	• Trampling damage in the plot is largely from existing animal tracks. • Minor trampling of non-vascular plant species. • Minor crushing of woody vegetation.
Waiotapu 4	Minor	• Trampling damage in the plot is largely from existing animal tracks. • Minor trampling of non-vascular plant species. • Minor crushing of woody vegetation.
Whangapoa Springs 1	Minor	• Soft sediments trampled. Not noticeable when visited a few weeks later.
Waikite Valley 1	Negligible	• No noticeable impacts when visited a few weeks later.

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

Trampling impacts assessed included soil disturbance, woody vegetation crushing, and trampling of non-vascular plant 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 of 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 plant 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 within and outside of the selected plot boundaries was minimal and vegetation is likely to fully recover within five years.

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 plant ground cover, caused by field teams walking though the plot. 6 August 2024.

Plate 3 – Maungaongaonga 1. Evidence of foot traffic on non-vascular plant ground 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.

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, in most cases, minimal and we expect that vegetation is likely to fully recover within five years.

Plots within Development Geothermal Systems are measured as frequently as annually in some cases for an initial period (e.g. for five years), with some plots measured two-yearly, four-yearly and five-yearly depending on consent condition.

For the Waikato Region geothermal biodiversity monitoring, 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 is likely to be a lot more extensive if the site is slippery after rain (as well as being more dangerous for workers). When the ground is wet, monitoring activities can cause considerable damage to the vegetation and substrate of the plot, especially on steep terrain or vulnerable geothermal ground.

To minimise the damage to the permanent plots caused by measurement activities in 2024-2025, plot measurement was undertaken on fine days and not following a period of significant rainfall. This monitoring round had particularly favourable conditions for the time of year (May-June in 2024, and March to May in 2025), however future monitoring rounds would benefit from being undertaken in late summer to mid-autumn 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, Limited Development, and Research Geothermal Systems in the Waikato Region 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, and allows for truly randomised plots to be established at sites where it is too dangerous to otherwise fully randomise plot locations.

Twelve permanent monitoring plots were established within the Orākei Kōrako, Te Kopia, and Waikite-Waiotapu-Waimangu Geothermal Systems in 2024. Five permanent monitoring plots were established within the Atiamuri, Reporoa, and Waikite-Waiotapu-Waimangu Geothermal Systems in 2025. A further 11 unmarked plots were established at these sites in 2024-2025 for measurement by UAV. These 28 plots will provide an important context for evaluation of vegetation changes in Protected, Limited Development, and Research Geothermal Systems in the Waikato Region. The plots complement the extent and condition monitoring that is undertaken through the region-wide inventory studies of geothermal sites (Wildland Consultants 2023b). The plots also complement the ongoing monitoring within Development Geothermal Systems which is undertaken for Resource

Consenting purposes, and which should continue (albeit often with a different methodology) as this provides a long-term data set on specific geothermal sites.

Geothermal sites are dynamic and can change significantly with regards to safe access within a short space of time. Future monitoring teams will need to reassess all hazards associated with the measurement of each plot and some plots may need to be abandoned in the future if they become 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 in a greater range of habitats than ground-based methods, particularly if they are also supplemented with fauna monitoring in some capacity.

The plots should be remeasured in 2029 and 2030 (for those established in 2024 and 2025 respectively). Alternatively, all plots could be remeasured in either 2029 or 2030. Permits and permission (including iwi consultation and UAV flying on DOC land) to undertake the measurements should be sought up to one year in advance of the monitoring to ensure permissions are obtained. 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 ground within the plots will dry out more quickly between periods of rain.

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Appendix 1

GPS coordinates (NZTM) of permanent geothermal vegetation plot locations established in 2024 and 2025, Waikato Region

Geothermal Field	Plot Name	Year Established	GPS Coordinates (Corner D)		Altitude (m)
			NZTM Easting	NZTM Northing	
Atiamuri Geothermal Field	Whangapoa Springs 1	2025	1866449	5749489	280
Orākei Kōrako Geothermal Field	Red Hills 1	2024	1874954	5735489	350
	Red Hills 2	2024	1875141	5736384	360
Reporoa	Longview Road 1	2025	1893492	5743080	280
Te Kopia Geothermal Field	Te Kopia 1	2024	1880260	5743771	410
	Te Kopia 2	2024	1880605	5744237	420
Waikite Geothermal Field	Waikite Valley 1	2025	1889530	5753312	370
	Waikite Valley 2	2025	1889575	5753482	378
	Waikite Valley 3	2025	1891156	5755659	465
Waiotapu Geothermal Field	Maunga Kākaramea 1	2024	1895688	5753235	570
	Maunga Kākaramea 2	2024	1896322	5752969	605
	Maunga Kākaramea 3	2024	1896404	5752847	600
	Maungaongaonga 1	2024	1892634	5751536	485
	Waiotapu 1	2024	1895468	5751733	380
	Waiotapu 2	2024	1894926	5748265	350
	Waiotapu 3	2024	1894155	5749034	350
	Waiotapu 4	2024	1895468	5750862	375

Appendix 2

Plot corner photographs

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

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

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

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

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

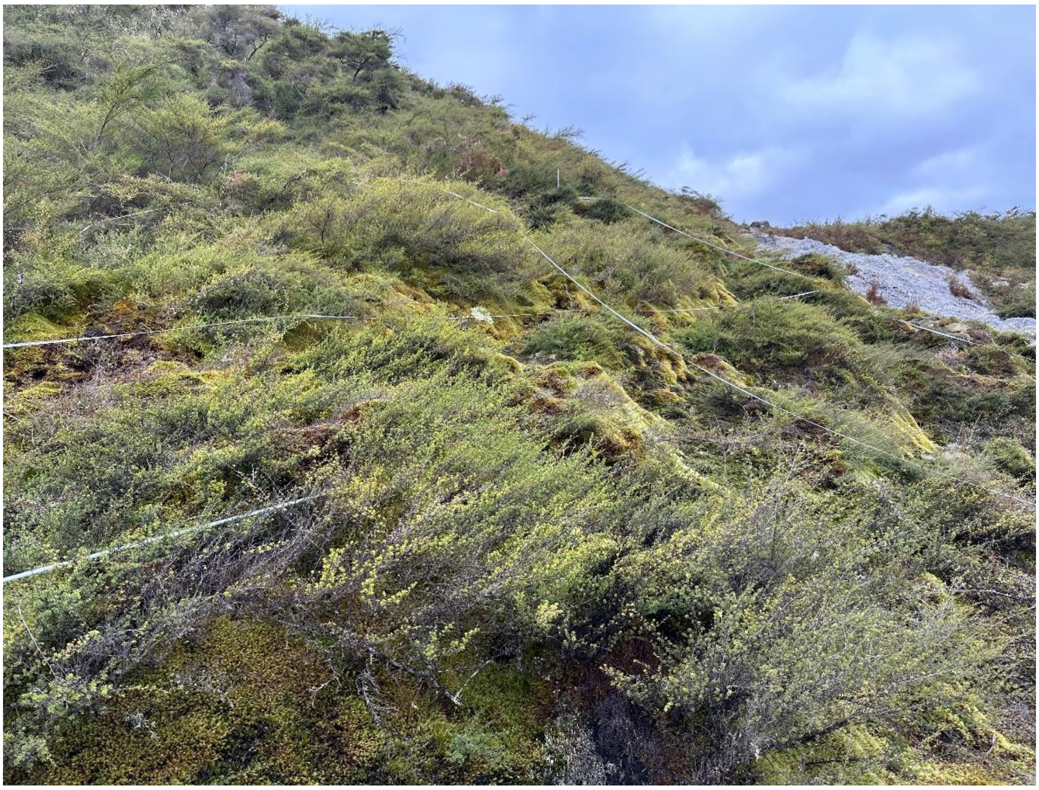

Plate A2-6 – Maunga Kākaramea Plot 2, Corner D. Waikite-Waiotapu-Waimangu Geothermal System. 6 June 2024.

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

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

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

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

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

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

Plate A2-13 – Whangapoa Springs Plot 1, Corner A. Atiamuri Geothermal System. 13 March 2025.

Plate A2-14 – Longview Road Plot 1, Corner B. Reporoa Geothermal System. 12 March 2025.

Plate A2-15 – Waikite Valley Plot 1, Corner A. Waikite-Waiotapu-Waimangu Geothermal System. 15 April 2025.

Plate A2-16 – Waikite Valley Plot 2, Corner A. Waikite-Waiotapu-Waimangu Geothermal System. 15 April 2025.

Plate A2-17 – Waikite Valley Plot 3, Corner A. Waikite-Waiotapu-Waimangu Geothermal System. 16 April 2025.

Appendix 3

Location of UAV photographs taken and photographic information

Plot Name	Year Established	Year of UAV Aerial Imagery	Location of UAV Photograph (NZTM)	Date Taken
Permanent Biodiversity Monitoring Plots				
Whangapoa Springs 1	2025	2025		6 May 2025
Red Hills 1	2024	2024	E1874950 N5735494	3 July 2024
Red Hills 2	2024	2024	E1875135 N5736393	3 July 2024
Longview 1	2025	2025	E1893500 N5743085	6 May 2025
Te Kopia 1	2024	2025	E1880256 N5743766	12 May 2025
Te Kopia 2	2025	2025	E1880608 N5744236	12 May 2025
Waikite Valley 1	2025	2025	E1889530 N5753300	12 May 2025
Waikite Valley 2	2025	2025	E1889572 N5753489	12 May 2025
Waikite Valley 3	2025	2025	E1891159 N5755660	12 May 2025
Maunga Kākaramea 1	2024	2025	E1895692 N5753241	6 May 2025
Maunga Kākaramea 2	2024	2025	E1896329 N5752969	6 May 2025
Maunga Kākaramea 3	2024	2025	E1896404 N5752852	6 May 2025
Maungaongaonga 1	2024	2025	E1892634 N5751540	6 May 2025
Waiotapu 2	2024	2024	E1894932 N5748265	3 July 2024
Waiotapu 3	2024	2024	E1894158 N5749025	3 July 2024
Waiotapu 4	2024	2024	E1895471 N5750867	3 July 2024
UAV-based Plots (in areas unsafe to access)				
Red Hills UAV1	2024	2024	E1875273 N5735992	3 July 2024
Longview Road UAV1	2025	2025	E1893542 N5743023	6 May 2025
Longview Road UAV2	2025	2025	E1893598 N5742994	6 May 2025
Longview Road UAV3	2025	2025	E1893536 N5742914	6 May 2025
Te Kopia UAV1	2025	2025	E1880838 N5744624	12 May 2025
Maunga Kākaramea UAV1	2025	2025	E1896310 N5752988	6 May 2025
Maunga Kākaramea UAV2	2025	2025	E1896365 N5752959	6 May 2025
Maunga Kākaramea UAV3	2025	2025	E1896151 N5753024	6 May 2025
Waiotapu UAV1	2024	2024	E1895495 N5751039	3 July 2024
Waiotapu UAV2	2024	2024	E1894382 N5749281	3 July 2024
Waiotapu UAV3	2024	2024	E1894361 N5749356	3 July 2024

Appendix 4

UAV photographs of plots

UAV photographs of permanent 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.

Plate A4-6 – Whangapoa Springs Plot 1. Atiamuri Geothermal System Red line indicates plot boundaries. 6 May 2025.

Plate A4-7 – Longview Road Plot 1. Reporoa Geothermal System. Red line indicates plot boundaries. 6 May 2025.

Plate A4-8 – Te Kopia Plot 1. Te Kopia Geothermal System. Red line indicates plot boundaries. 12 May 2025.

Plate A4-9 – Te Kopia Plot 2. Te Kopia Geothermal System. Red line indicates plot boundaries. 12 May 2025.

Plate A4-10 – Waikite Valley Plot 1. Waikite-Waiotapu-Waimangu Geothermal System. Red line indicates plot boundaries. A modified plot layout was adopted for this plot due to the presence of geothermal streamside habitat. The plot boundary lengths were changed to form a 5 × 20 rectangle. 12 May 2025.

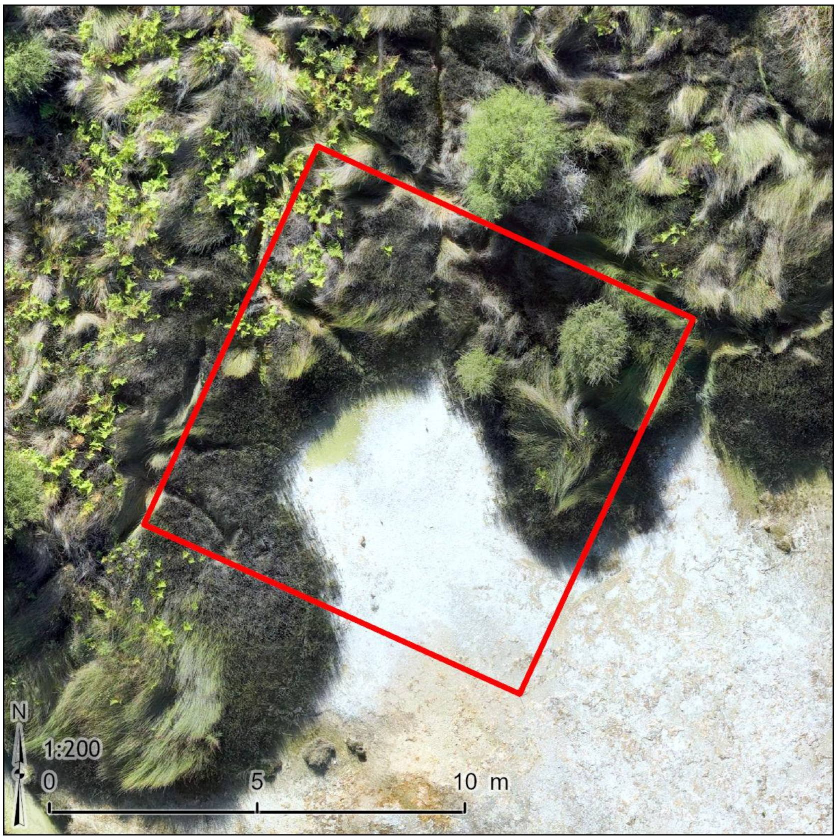

Plate A4-11 – Waikite Valley Plot 2. Waikite-Waiotapu-Waimangu Geothermal System. Red line indicates plot boundaries. 12 May 2025.

Plate A4-12 – Waikite Valley Plot 3. Waikite-Waiotapu-Waimangu Geothermal System. Red line indicates plot boundaries. 12 May 2025.

Plate A4-13 – Maunga Kākaramea Plot 1. Waikite-Waiotapu-Waimangu Geothermal System. Orange line indicates plot boundaries. The permanent plot was established in 2024 and photographed the following year. 6 May 2025.

Plate A4-14 – Maunga Kākaramea Plot 2. Waikite-Waiotapu-Waimangu Geothermal System. Orange line indicates plot boundaries. The permanent plot was established in 2024 and photographed the following year. 6 May 2025.

Plate A4-15 – Maunga Kākaramea Plot 3. Waikite-Waiotapu-Waimangu Geothermal System. Orange line indicates plot boundaries. The permanent plot was established in 2024 and photographed the following year. 6 May 2025.

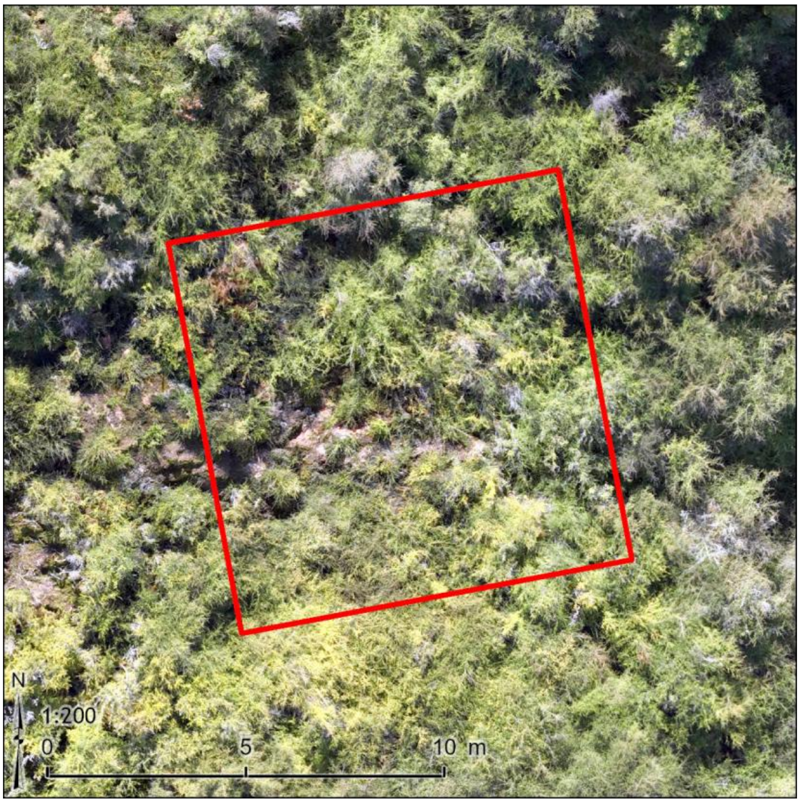

Plate A4-16 – Maungaongaonga Plot 1. Waikite-Waiotapu-Waimangu Geothermal System. Red line indicates plot boundaries. The permanent plot was established in 2024 and photographed the following year. 6 May 2025.

UAV-based unmarked plots

Plate A4-17 – Red Hills UAV1. 10 × 10 m 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 A4-18 – Waiotapu UAV1. 2 × 2 m 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 A4-19 – Waiotapu UAV2. 1 × 1 m 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 A4-20 – Waiotapu UAV3. 1 × 1 m 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 A4-21 – Te Kopia UAV1. 10 × 10m vegetation plot. The red line delineates the plot boundaries. Te Kopia Geothermal System. 12 May 2025.

Plate A4-22 – Maunga Kākaramea UAV1. 10 × 10 m vegetation plot. The red line delineates the plot boundaries. Waikite-Waiotapu-Waimangu Geothermal System. 6 May 2025.

Plate A4-23 – Maunga Kākaramea UAV2. 10 × 10 m vegetation plot. The red line delineates the plot boundaries. Waikite-Waiotapu-Waimangu Geothermal System. 6 May 2025.

Plate A4-24 – Maunga Kākaramea UAV3. 10 × 10 m vegetation plot. The red line delineates the plot boundaries. Waikite-Waiotapu-Waimangu Geothermal System. 6 May 2025.

Plate A4-25 – Longview Road UAV1. 10 × 10 m vegetation plot. The red line delineates the plot boundaries. Reporoa Geothermal System. 6 May 2025.

Plate A4-26 – Longview Road UAV2. 10 × 10 m vegetation plot. The red line delineates the plot boundaries. Reporoa Geothermal System. 6 May 2025.

Plate A4-27 – Longview Road UAV3. 10 × 10 m vegetation plot. The red line delineates the plot boundaries. Reporoa Geothermal System. 6 May 2025.

Appendix 5

Vascular plant species recorded at permanent geothermal monitoring plots in the Atiamuri Geothermal System, Waikato Region, March 2025

Scientific Name	Common Name	Whangapoa Springs 1
Indigenous Species		
Dicot. trees and shrubs		
Kunzea tenuicaulis	Geothermal kānuka	✓
Leptospermum scoparium	Mānuka	✓
Ferns		
Pteridium esculentum subsp. *esculentum*	Rārahu, bracken	✓
Grasses		
Lachnagrostis filiformis		✓
Sedges		
Carex virgata	Pūrei	✓
Monocot. herbs (other than orchids, grasses, sedges, and rushes)		
Dianella nigra	Tūrutu	✓
Triglochin striata	Arrow grass	✓
Naturalised and Exotic Species		
Dicot. trees and shrubs		
Rubus sp. (*R. fruticosus* agg.)	Blackberry	✓
Grasses		
Holcus lanatus	Yorkshire fog	✓
Dicot. herbs (other than composites)		
Digitalis purpurea	Foxglove	✓
Lotus pedunculatus	Lotus	✓

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 Reporoa Geothermal System, Waikato Region, March 2025

Scientific Name	Common Name	Longview Road 1
Indigenous Species		
Dicot. trees and shrubs		
Leptospermum scoparium	Mānuka	✓
Leucopogon fasciculatus	Mingimingi	✓
Monocot. herbs (other than orchids, grasses, sedges, and rushes)		
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 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 and April 2025

Scientific Name	Common Name	Maunga Kākaramea 1	Maunga Kākaramea 2	Maunga Kākaramea 3	Maungaongaonga 1	Waiotapu 1	Waiotapu 2	Waiotapu 3	Waiotapu 4	Waikite Valley 1	Waikite Valley 2	Waikite Valley 3
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			✓		✓						
Leptospermum scoparium	Mānuka									✓	✓	
Leucopogon fasciculatus	Mingimingi			✓		✓	✓		✓			✓
Myrsine australis	Māpou, matipou, māpau			✓								
Pterophylla racemosa	Kāmahi			✓								
Dicot. lianes												
Calystegia sepium	Pōhue									✓		
Lycopods and psilopsids												
Palhinhaea cernua	Mātukutuku	✓										✓
Ferns (excludes psilopsids)												
Asplenium flaccidum subsp. *flaccidum*	Makawe, ngā makawe o raukatauri, drooping spleenwort			✓								
Cyclosorus interruptus										✓		
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			✓								
Hypolepis ambigua											✓	
Lecanopteris pustulata subsp. *pustulata*	Kōwaowao, pāraharaha, hound's tongue fern			✓								

Scientific Name	Common Name	Maunga Kākaramea 1	Maunga Kākaramea 2	Maunga Kākaramea 3	Maungaongaonga 1	Waiotapu 1	Waiotapu 2	Waiotapu 3	Waiotapu 4	Waikite Valley 1	Waikite Valley 2	Waikite Valley 3
Parablechnum novae-zelandiae	Kiokio, horokio										✓	
Pteridium esculentum subsp. *esculentum*	Rārahu, bracken								✓			
Pyrrosia elaeagnifolia	Leather-leaf fern			✓								
Schizaea dichotoma				✓								
Orchids												
Thelymitra sp.						✓						
Grasses												
Lachnagrostis sp.											✓	
Sedges												
Machaerina juncea											✓	
Schoenoplectus tabernaemontani	Kāpūngāwhā									✓		
Monocot. Herbs (other than orchids, grasses, sedges, and rushes)												
Astelia solandri	Kōwharawhara			✓		✓						
Dianella nigra	Tūrutu			✓		✓	✓		✓			
Phormium tenax	Harakeke									✓		
Triglochin striata	Arrow grass										✓	
Naturalised and Exotic Species												
Gymnosperms												
Pinus pinaster	Maritime pine						✓		✓			
Pinus radiata	Radiata pine					✓	✓		✓			
Grasses												
Cynodon dactylon	Indian doab									✓		
Paspalum dilatatum	Paspalum									✓		
Dicot. Herbs (other than composites)												
Lotus pedunculatus	Lotus									✓		

Appendix 6

Non-vascular plant species, algae and fungi recorded at 17 permanent geothermal monitoring plots within the Waikato Region, May-June 2024 and March-April 2025

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 detected at geothermal plots, May-June 2024 and March-April 2025

Scientific Name	Common Name	Name of Plots Detected At	Detection Method/s
Cervus elaphus[1]	Deer	Te Kopia 2 Waiotapu 3	Faecal pellet count Faecal pellet count
Notamacropus species	Wallaby	Waiotapu 2 Waiotapu 3 Waikite Valley 1 Waikite Valley 2 Waikite Valley 3	Faecal pellet count Faecal pellet count Faecal pellet count 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 Waikite Valley 2	Chew card 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 Waikite Valley 1 Waikite Valley 2	Faecal pellet count Faecal pellet count Faecal pellet count Faecal pellet count Chew card
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 Waikite Valley 2	Faecal pellet count 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	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

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

Scientific Name	Common Name	Name of Plots Detected At	Detection Method/s
		Waiotapu 2	Faecal pellet count
		Waiotapu 3	Faecal pellet count
		Waiotapu 4	Faecal pellet count
		Waikite Valley 1	Faecal pellet count
		Waikite Valley 2	Chew card, faecal pellet count
		Waikite Valley 3	Faecal pellet count
		Whangapoa Springs 1	Faecal pellet count
	Ungulate (no further ID)	Waiotapu 3	Faecal pellet count
	Lagomorph (no further ID)	Waiotapu 2	Faecal pellet count

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