Can Geothermal Vegetation Monitoring be Standardised in Aotearoa New Zealand?

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ABSTRACT

Standardised monitoring protocols for measuring ecosystem integrity across Aotearoa New Zealand's diverse environments are under active development. However, no recommendations have been made for ecosystems considered dangerous to sample due to their intrinsic hazards, including geothermal ecosystems that contain heated and unstable ground. Waikato Regional Council commissioned a review of geothermal ecosystem monitoring, including consideration of options for implementing quantitative monitoring methods compatible with the national monitoring framework. Monitoring of geothermal ecosystems has occurred since the 1970s. Methods and data collected vary among studies and the most widely used method may not be fit for all purposes to which it is applied. Monitoring of geothermal vegetation presents a range of challenges: difficulty of access, high habitat diversity within sites, and habitats and species susceptible to trampling impacts. These challenges are discussed. Using our experience in survey and monitoring of geothermal systems, we designed a methodology and undertook monitoring using the standardised protocols at a number of sites in the Waikato Region. This paper discusses the challenges and advantages of using a national approach for this monitoring.

1. INTRODUCTION

Aotearoa New Zealand has a national-scale biodiversity monitoring programme in the form of the Department of Conservation's Biodiversity Monitoring and Reporting System (Tier 1). This programme covers terrestrial biodiversity across Aotearoa New Zealand's public lands, which comprise 32% of the land area, with monitoring occurring on an 8 × 8 km grid. This grid network does not capture geothermal sites within the Taupō Volcanic Zone due to their scale (geothermal vegetation in the Waikato Region only covers 0.04% of the land area, Wildland Consultants (2023b)) (https://www.doc.govt.nz/our-work/monitoring-reporting/plot-level-report/).

Outside of land administered by the Department of Conservation, monitoring is the responsibility of regional and unitary authorities, but there is not yet a coordinated approach to monitoring. Methods proposed for ground-based monitoring of ecological integrity (Bellingham et al. 2021) addressed the current lack of a national framework for monitoring of biodiversity and ecological integrity in ecosystem types outside of Aotearoa New Zealand's conservation estate, i.e., those areas largely falling under the responsibility of Regional Councils (with some also on LINZ and transport agency land, defence land, etc). These methods have largely been adopted by most Regional Councils.

The Bellingham et al. (2021) monitoring framework for Regional Councils, alongside the established Tier 1 Biodiversity Monitoring Framework for public conservation land, provides a national context for the measurement of ecosystem integrity. These national frameworks encourage consistency in monitoring among councils. Statistical and other mathematical methods can then be used to assess the effectiveness of management actions. However, the benefits of these national frameworks are limited in rare ecosystems which are of restricted occurrence, including geothermal ecosystems, which are not captured within either framework. Geothermal ecosystems may also be dangerous to sample, which further complicates monitoring of them.

No single monitoring method can be usefully applied to all the terrestrial ecosystems in Aotearoa New Zealand, though consistent methods have been developed for use across shrubland, grassland, and wetland ecosystems (e.g., Wildland Consultants 2018). Bellingham et al. (2021) therefore devised a set of six methods, each tailored to a different broad ecosystem type but based on the same principles and collecting the same kinds of data, all of which flows into a national monitoring framework. No recommendations were provided by Bellingham et al. (2021) as to how ecosystems deemed dangerous to sample should be measured, including geothermal ecosystems. Geothermal ecosystems are challenging. They are dangerous, at least in part, due to the presence of geothermal heat, unstable soils, and proximity to hot water features. They are also diverse due to the wide variation in soil temperatures within a site, the kind of geothermal activity that is present, the dynamic nature of geothermal activity, and the landscape settings in which they occur.

2. OVERVIEW OF GEOTHERMAL ECOSYSTEMS

For the purposes of this paper, geothermal ecosystems are defined as all geothermal habitat that includes vegetation dominated by vascular plants, non-vascular plants, geothermally-influenced bare ground (referred to in many studies as 'nonvegetated raw-soilfield' and which often contain scattered patches of non-vascular and vascular plants), and emergent wetland vegetation. It does not include open geothermal water. This definition of geothermal vegetation is consistent with the definition of Merrett and Clarkson (1999). Geothermal ecosystems occupy less than 0.01% of the total area of Te Ika-a-Māui/North Island.

There are two fundamental challenges for monitoring design associated with geothermal ecosystems. The first is the existence of sharp environmental gradients over small spatial scales, in the order of metres, which have profound effects on vegetation structure and composition (Burns 1997). Geothermal habitats also have a diverse range of vegetation types and conditions, and this presents the second challenge for monitoring. The varied nature of geothermal surface manifestations produces rare and unusual habitats for plants due to varying combinations of soil temperature, soil chemistry, hydrology, and localised protection from frosts. Vegetation types (as per Atkinson 1985) present at geothermal sites include lichenfield, mossfield, herbfield, fernland, scrub, shrubland, rushland, sedgeland, reedland, forest, wetland, open water and geothermally-influenced bare ground. Many geothermal sites are dynamic and unstable, and changes in surface geothermal activity are reflected in relatively rapid changes in the extent and composition of geothermal vegetation over time. Within the Waikato Region, geothermal sites occur from near sea level, e.g., Kāwhia and Otua/Hot Water Beach to the subalpine zone on Mt Tongariro. Vegetation and habitats are widely variable and include geothermally heated ground, steamy habitats alongside streams, hot springs, ponds and mudpools, forest, non-vegetated open areas, wetlands with emergent vegetation (e.g., sedgeland and reedland), mossfield, and lichenfield. The vegetation pattern is often complex, and the locations of natural surface features can vary through time. Care needs to be taken when interpreting changes revealed by monitoring at geothermal sites due to the degree of natural variation.

3. EXISTING MONITORING AT GEOTHERMAL SITES IN THE TAUPŌ VOLCANIC ZONE

Monitoring (broadly defined) of geothermal ecosystems within the Waikato and Bay of Plenty Regions has been undertaken regularly to some degree for many years, and geothermal ecosystems are possibly the most comprehensively monitored of all of Aotearoa New Zealand's rare ecosystem types.

In general, long-term geothermal vegetation monitoring comprises a network of permanent monitoring plots and photopoints, almost all associated with resource consenting requirements associated with geothermal drawdown for energy generation. It can be difficult to isolate a cause of change through this monitoring because geothermal habitats are naturally dynamic and the robustness of monitoring data can be limited by the frequency of monitoring and modifications to the methods over time. Long-term monitoring data from geothermal areas that are not exploited for energy may provide a valuable reference for determining changes to vegetation due to exploitation.

4. A MONITORING APPROACH

We reviewed monitoring methods described in 51 reports and publications between 1978 and 2021, and scored each for the presence of different monitoring methods associated with mapping the aerial extent of sites, describing and quantifying vegetation pattern, and surveying for threatened plant and animal species (Wildland Consultants 2023a).

We then held a workshop with relevant stakeholders from Iwi Māori, Regional Councils, Department of Conservation, Industry, and the Research sector to discuss the objectives of monitoring, and how those may be achieved with respect to the Biodiversity Monitoring Framework in geothermal areas. Input from participants was incorporated into the formulation of recommendations.

Various monitoring options were then discussed, including goals of monitoring, what should be done on the ground, where (including elements such as replication), sampling methodology (such as plot size), and sampling strategy (such as randomisation) (Wildland Consultants 2023a).

A mātauranga Māori perspective was also considered in the approach, and further discussion with relevant iwi is required to achieve this. Monitoring should include measures that have direct relevance to cultural values. Some geothermal features within particular sites are wāhi tapu and hold special significance to Māori. Monitoring within these features must be either avoided or adhere to strict cultural protocols, potentially affecting randomisation of plot placement.

Existing monitoring was acknowledged and it was concluded that there is value in continuing this monitoring, as it provides detailed, often spatially explicit, accounts of vegetation change through time. However, there is also scope to align this monitoring more closely to a national framework, thereby achieving multiple goals. Monitoring as a function of consent conditions is not always undertaken in a coordinated way, varying slightly between sites.

Monitoring frequency was discussed in detail. A key constraint for monitoring frequency is the susceptibility of geothermal sites to trampling impacts associated with monitoring (Burns et al. 2013).

Unmanned Aerial Vehicles (UAVs or drones) technology was identified as a significant innovation that could allow dangerous sites to be sampled remotely. Imaging and digital technologies now linked to UAVs means that high resolution (8-15 mm) orthorectified images of survey sites can be obtained.

Recommendations from the monitoring review were therefore to adopt, as closely as possible, the methods of Bellingham et al. (2021). Methods were adapted with modification of plot sizes so that plot size was appropriate to the vegetation stature.

For terrestrial geothermal vegetation, the use of plots where size scales with vegetation stature was recommended:

- Forest, tall (>2 m) scrub, and tall shrubland: 10 × 10 m
- Short (<2 m) scrub and short shrubland: 2 × 2 m
- Mossfield and lichenfield:1 × 1 m
- Raw soil field:1 × 1 m

It was recommended that plots be located in a stratified random manner, with the overall site being subdivided by habitat and vegetation type. The basis for this subdivision could be a standard vegetation classification system, however, the subdivision used must include rare and uncommon vegetation and habitat types that are found in geothermal ecosystems, to ensure that they are included within the sample of plots.

UAVs were recommended to extend sampling into dangerous areas. Many dangerous areas are hot, so are covered by sparse, short-stature vegetation, which can be measured using 1 m^2 plots located using high-resolution, orthorectified images. However, the plot sizes should be based on vegetation stature, as per the recommended plot sizes above. Data on species diversity and cover abundances can be obtained from images. A recommendation was made to undertake a comparison of data captured from aerial images and ground-based measurement for a selection of plots measured using both methods, to establish expected error margins.

5. BIODIVERSITY MONITORING

Following the review, we established biodiversity monitoring within Protected, Limited Development, and Research Geothermal Systems in the Waikato Region (as defined by Waikato Regional Council: https://www.waikatoregion.govt.nz/environment/geothermal/classifying-geothermal-systems/). Protected Systems contain vulnerable geothermal features valued for their cultural and scientific characteristics. Underground geothermal water cannot be extracted, and surface features are protected from unsustainable land uses. In Limited Development systems, extraction that will not damage surface features is allowed, and Research Systems only allow small scale extraction along with takes for scientific research.

5.1 Methods

We used the methods of Bellingham et al. (2021), adapted as per our review for plot size.

At a desktop level, plots were located in a stratified random manner, with each geothermal site being subdivided by vegetation and habitat type, 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 GIS 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 select thirty random points per site, and generate a GPX file of plot locations. Points located on the margin of vegetation types were then excluded. The randomised waypoints were prioritised for measurement based on accessibility (e.g., plots located on cliffs were excluded) and site knowledge of hazards.

The common occurrence of hazards in geothermal areas meant that it was unsafe to establish plots at many of the random locations in practice. Therefore plots were established as close to the random waypoints as it was safe to do so. If the entire area surrounding each randomised point was deemed unsafe, then the location was rejected and a different location was sought. Existing protocols around movement of plots were deemed impractical in the geothermal context.

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 10 × 10 metres was adopted for all ground-based plots containing woody vegetation, rather than varied plot sizes based on vegetation stature, as geothermal sites are highly dynamic and vegetation stature may change significantly in the future. This size is practical to measure in geothermal sites as any larger can increase exposure to hazards, while any smaller will increase the bias in sampling. Our observations of geothermal sites over the years have also shown that changes to major vegetation types can occur within relatively short time intervals, therefore measuring at a smaller scale is unlikely to provide long-term information on a site relative to monitoring effort.

2. The length of the animal transect (as per Bellingham et al. 2021) was reduced to 20 metres to account for the frequency of hazardous ground in geothermal sites.

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

4. 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).

A UAV was used to capture aerial images of 16 pre-established 10 × 10 metre plots. High resolution (8-15 mm) imagery was also captured of 11 additional randomly generated sites which were not safe to measure on the ground.

All data was provided to the Waikato Regional Council for entry into the National Vegetation Survey Database (https://nvs.landcareresearch.co.nz/) and for consideration within their regional biodiversity monitoring programme (https://www.waikatoregion.govt.nz/environment/biodiversity/biodiversity-strategy/).

6. MONITORING RESULTS

Fifteen permanent biodiversity monitoring plots were established in Protected Geothermal Systems, with a further plot established in a Limited Development System and one plot in a Research Development System.

The primary geothermal ecosystem habitat measured in plots was 'heated ground (dry)' which often comprised geothermally-heated ground dominated by geothermal kānuka (Kunzea tenuicaulis) and other woody species. This ecosystem type is one of the most widespread habitat types in these geothermal fields. Also, most other habitats are dangerous to access. Many plots had surface temperatures close to ambient, that are likely to have been subject to geothermal influence in the past (hydrothermally-heated ground now cool) and these parts of the plot often had vegetation that was taller than on the more active sites. Fumaroles were present on the margins of some plots and steam from these was often present in plots. Geothermal streamside and geothermal wetland habitat types were represented in two 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. Many plots are dominated by shrubs, particularly geothermal kānuka, but also occasional mingimingi (Leucopogon fasciculatus), mānuka (Leptospermum scoparium), monoao (Dracophyllum subulatum), 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 geothermal characteristics in much of the understorey. Hot soils were devoid of vegetation, and patches of bryophytes were present as the temperature reduced. Where vegetation is present, short stature geothermal kānuka was most prevalent on the soils with the warmest temperatures, and some species that can tolerate warmer temperatures, such as Palhinhaea cernua, were present. At cooler ground temperatures, other shrub species and ferns became more abundant, and the height of geothermal kānuka typically increased.

There were large variations in the soil temperature(s) recorded within each plot (even within one metre).

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

In a small number of cases, the animal transect lines were either not measured across the full 20 metres or not established at all due to impassable geothermal hazards. Introduced mammal presence was recorded in 16 (of 17) permanent plots. The most detected species was brushtail possum (Trichosurus vulpecula), recorded in 15 plots. Possum pellets were in 26% of pellet counts (present in 63 out of a total of 244 pellet counts completed) and possum chew was present on 8% 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.

6.1 UAV monitoring

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

The dominant canopy species (generally geothermal kānuka or occasional mingimingi or mānuka) was able to be identified in UAV-based images, and the relative canopy cover was assessed. Wilding pines (Pinus sp.) were also readily identifiable, even in very low numbers.

The number of vascular species (lichens and bryophytes were excluded from the data set) detected by UAV-based imagery was consistently lower than that recorded in ground-based methods, with the exception of three plots that only contained geothermal kānuka of relatively short stature, which was easily identified in the aerial imagery. No indication of species obscured by the canopy was possible from UAV images. Therefore, for plots that had much of their species richness within understorey and ground cover tiers, there was low correlation to the species richness obtained from UAV images.

Overall, the detection rate using aerial imagery ranged from 9.1% to 100%, with an average rate of species detection across all 16 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. Rare and pest plant species may be missed by this method.

The advantages of a UAV-based approach are that plots can be placed truly randomly, and measurement of sites that are inaccessible or too dangerous to measure on the ground can be undertaken.

Eleven plots were established using a UAV alone in randomised locations that were unsafe to access. 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 useful complementary approach to ground-based monitoring in dangerous environments, but should not be used in isolation.

6.2 Trampling impacts

Each plot was measured by a team of four people, working together in pairs for health and safety. Approximately one month after plot measurements were undertaken, an additional site visit was undertaken to a sub-sample of the plots to determine whether any trampling damage was visible. Trampling impacts assessed included soil disturbance, woody vegetation crushing, and trampling of non-vascular species. Each plot was assigned to one of five damage classes (none, negligible, minor, moderate, or high) based on the extent of visible damage.

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

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

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

7. DISCUSSION AND FINDINGS

Seventeen permanent monitoring plots and 11 unmarked UAV plots were established in geothermal areas in the Waikato Region. These plots complement the extent and condition monitoring undertaken through the ongoing region-wide inventory ecological studies of geothermal sites. They also complement the ongoing monitoring within Development 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 geothermal sites.

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.

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

Depending on the ultimate uses of the monitoring data obtained, UAVs can be used to capture information in a greater range of habitats than ground-based methods, particularly if their use is also supplemented with some form of fauna monitoring.

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