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Monitoring of Geothermal Vegetation in New Zealand, and the Effects of Geothermal Energy Extraction

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ABSTRACT

In New Zealand, monitoring of natural geothermal vegetation is a requirement for all energy abstraction that occurs in geothermal fields where such vegetation occurs. Geothermal vegetation, influenced by surface expressions of heat from the Earth's interior, is naturally rare both in New Zealand and internationally. Rare and unusual habitats for plants arise due to varying combinations of temperature, chemistry, hydrology, and localised protection from frosts. In New Zealand, all geothermal ecosystems are classified as Critically Endangered. Exploitation for energy production has the potential to be a significant threat to the viability and sustainability of geothermal vegetation and habitats. Changes to underground systems have the potential to change both the above ground character of natural areas and the distribution of species within them. Changes can include both increases and decreases in above-ground temperatures, as well as alteration of water tables, which can lead to a loss of hot springs and geysers. Most geothermal vegetation in New Zealand occurs in the central North Island, in the Taupō Volcanic Zone. The authors have been involved in the long-term monitoring of many of the geothermal areas in New Zealand which are utilised for energy abstraction. In this paper, we examine the history, methods, and findings of current monitoring programmes, consider whether monitoring is achieving its desired purpose, and discuss what could be done differently.

1. INTRODUCTION

Geothermal vegetation is defined as "terrestrial and emergent wetland vegetation … communities that have compositional, structural, and/or growth rate characteristics determined by current and former inputs of geothermally-derived energy (heat) or material (solid, fluid, or gas)" (Merrett and Clarkson 1999). Geothermal vegetation and habitats are both naturally rare both in New Zealand (Williams et al. 2007) and internationally. In New Zealand, four types of geothermal habitat (fumaroles, geothermal stream sides, geothermal heated ground, and geothermal hydrothermally altered ground) have been classified as Critically Endangered (Holdaway et al. 2012). Most geothermal vegetation in New Zealand occurs in the central North Island, in the Taupō Volcanic Zone, with approximately 74% of the total extent of New Zealand's geothermal vegetation located within the Waikato Region, and the remaining 26% located within the Bay of Plenty Region (Figure 1). Although geothermal features are present elsewhere in New Zealand (in Northland, the Hauraki Gulf, and scattered hot springs in the North and South Islands), there is little to no associated geothermal vegetation at these localities. The varied nature of geothermal surface manifestations, due to varying combinations of temperature (Burns 1997, Given 1980 & 1989, Wildland Consultants 2011), chemistry, hydrology, and localised protection from frosts, produces rare and unusual habitats for plants. These include plant species capable of surviving high soil temperatures, disjunct populations found a considerable distance from other sites of the same species and which are usually confined to warmer climates, locally endemic species, and distinct genetic forms arising where ground temperatures are sufficiently stable (Given 1989). Many geothermal sites are dynamic and unstable, and changes in surface geothermal activity can be reflected in relatively rapid changes in the extent and composition of geothermal vegetation. For example, increased cover and height of geothermal kānuka (*Kunzea tenuicaulis*) may indicate that soil temperature has decreased. Geothermal vegetation includes populations of several plant species which have a national-level threat or at risk ranking in New Zealand.

Geothermal power is considered to be a sustainable and renewable form of energy (Rybach 2007). However, exploitation for energy production has the potential to be one of the greatest threats to the viability and sustainability of geothermal vegetation and habitats (Beadel et al. 2018a; Beadel et al. 2018b). Exploitation can cause changes to underground geothermal systems (Bromley 2005), with potential to change both the character of sites and the distribution of species within them. Exploitation can result in increases in surface temperatures at some sites, or decreases in temperature at others (e.g. Te Rautehuia) (Wildland Consultants 2017b), both of which can result in the disappearance of plant communities and/or species. For example, exploitation of the Wairakei-Tauhara Geothermal System for electricity generation resulted in lowering of the water table and consequent loss of hot springs and geysers (Given 1980). Past collections of plant specimens indicate that the Thermal Valley at Wairakei supported populations of nearly all the tropical ferns and fern allies associated with thermal areas in New Zealand (Given 1989). Some of these species are now either completely absent or much reduced in abundance and distribution at this site (Wildland Consultants 2007). Cooler ground also allowed the invasion of adventive weeds. However, at nearby Karapiti, a ten-fold increase in heat output occurred following development of the Wairakei field (Huser 1989). Habitat for some species has been increased and enhanced here, with considerable development of geothermal vegetation and large populations of plants characteristic of geothermal sites (Given 1989), including species classified as 'Threatened' or 'At Risk' in New Zealand[1]. However, this increase does not provide habitat suitable for all the species that have already been lost.

[1] Threat classifications for vascular plants are from de Lange et al. (2018).

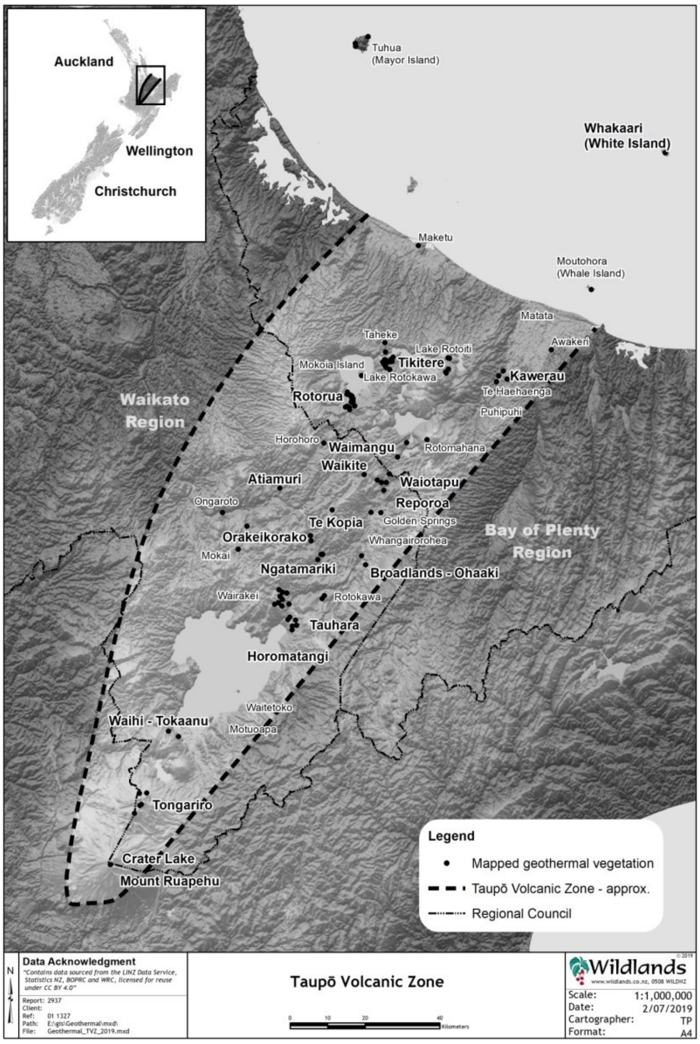

Figure 1: Location of geothermal vegetation in the Taupō Volcanic Zone, New Zealand.

Newer power stations utilise extraction and reinjection techniques that have been developed to minimise adverse effects (Bromley 2005). As such, newer power stations are predicted to have lesser effects on the surface features and geothermal groundwater of natural geothermal areas (Powell 2015) than existing stations. Therefore changes to geothermal vegetation and habitats within geothermal fields associated with new power stations are expected to be fewer and more difficult to detect. Despite this, ongoing monitoring of the effects of new power stations on geothermal vegetation is warranted as a precautionary approach to provide evidence that minimal or no change actually occurs.

The Waikato Region provides 90% of the primary geothermal energy extracted in New Zealand[2] and contains 863 hectares of geothermal habitat. Within the Waikato Region, geothermal systems have been classified into one of four management categories by Waikato Regional Council[3]. A total of *c.*354 ha or 41% of geothermal habitat has been mapped within Development Geothermal Systems within the Waikato Region; *c.*64 ha or 7% has been mapped in Limited Development Geothermal Systems; *c.*10 ha or 1% within Research Geothermal Systems and *c.*386 ha or 45% has been mapped in Protected Geothermal Systems (Wildland Consultants 2014b) (Table 1).

In total, *c.*300 ha (excluding geothermal habitats on Whakaari/White Island (*c.*325 ha) which have not been sufficiently surveyed to determine their accurate extent) of geothermal habitat have been described and mapped in the Bay of Plenty Region (Wildland Consultants 2019b). Within the Bay of Plenty Region, geothermal systems have been classified into similar management categories (as undertaken by the Waikato Region) by the Bay of Plenty Regional Council[4] (Table 1).

[2] https://www.waikatoregion.govt.nz/environment/natural-resources/geothermal/energy-and-extraction. Accessed 6 August 2018.
[3] https://www.waikatoregion.govt.nz/environment/natural-resources/geothermal/classifying-geothermal-systems/. Accessed 6 August 2018.
[4] https://www.boprc.govt.nz/our-region-and-environment/geothermal-resource/management-of-geothermal-systems/. Accessed 9 August 2018.

Table 1: Geothermal systems in the Taupō Volcanic Zone, management classification and extent of habitat present[5].

Geothermal System	Classification	Number of geothermal power plants present (large-scale extraction)	Extent of geothermal habitat[6] in Taupō Volcanic Zone (%)
Wairakei-Tauhara	Development (large-scale use allowed)	4	12.48
Mokai	Development (large-scale use allowed)	1	0.31
Ohaaki	Development (large-scale use allowed)	1	1.56
Ngatamariki	Development (large-scale use allowed)	1	0.14
Rotokawa	Development (large-scale use allowed)	2	16.01
Horohoro	Development (large-scale use allowed)	0	0.01
Mangakino	Development (large-scale use allowed)	0	0
Kawerau	Development (large-scale use allowed)	7	1.74
Rotoiti/Puhi Puhi	Development (large-scale use allowed)	0	1.09
Total within Development systems			**33.34%**
Atiamuri	Limited Development (extraction allowed that will not damage surface features)	0	0.01
Tokaanu-Waihi-Hipaua	Limited Development (extraction allowed that will not damage surface features)	0	5.50
Rotokawa/Mokoia	Conditional Development (extraction allowed that will not damage surface features)	0	0.0005
Taheke/Tikitere/Ruahine	Conditional Development (extraction allowed that will not damage surface features)	0	3.61
Rotoma/Tikorangi	Conditional Development (extraction allowed that will not damage surface features)	0	1.08
Total within Conditional Development systems			**10.20%**
Reporoa	Research	0	0.91
Total within Research systems			**0.91%**
Rotorua	Protected with extractive and non-extractive use	0	11.81
Horomatangi	Protected	0	0
Orakeikorako	Protected	0	5.75
Te Kopia	Protected	0	5.68
Tongariro	Protected	0	2.63
Waikite-Waiotapu-Waimangu	Protected	0	23.28
Waimangu/Rotomahana/Tarawera	Protected	0	5.34
Moutohora Island (Whale Island)/Raurima Island	Protected	0	1.00
Total within Protected systems			**55.49%**

[5] Excludes low temperature systems within the Bay of Plenty Region (for example the Tauranga low temperature system).

[6] Only includes terrestrial and emergent wetland geothermal habitats. Underwater geothermal habitats (e.g. Horomatangi which is on the bed of Lake Taupō) are excluded from this assessment.

In New Zealand, the Resource Management Act (1991) requires local councils to ensure that effects on the environment are managed sustainably, and this is managed through a consenting process. Resource consents are required prior to developing or expanding activities in geothermal areas. Significant adverse environmental effects must be avoided, remedied, or mitigated. Monitoring of potentially adverse effects is one of the requirements of all consent conditions associated with geothermal energy exploitation. We have undertaken the monitoring of geothermal vegetation at eight areas for three power generation companies(Wildland Consultants 2009, 2014a&c, 2015, 2016a&b, 2017a-c, 2018a-d, 2019a).

2. MONITORING OF GEOTHERMAL VEGETATION

2.1 History

Geothermal vegetation monitoring was initially developed as a cost-effective method to estimate the extent and heat loss of thermal ground (Dawson and Dickson 1970). However, geothermal vegetation is now recognised as being important in its own right and effects on geothermal vegetation are specifically considered in resource consent applications.

Geothermal vegetation monitoring began in earnest in 1996 (Burns et al. 1996), with the most recent monitoring round starting in 2014 (Wildland Consultants 2014c). Monitoring frequency has varied from annually to six-yearly. Monitoring methodology has differed among areas, and the consequences of this are discussed in more detail below. In general, long-term geothermal vegetation monitoring comprises a network of permanent monitoring grids and photopoints within the Development Geothermal Systems. Vegetation cover, ground temperature (at 10 cm depth) and a variety of other measures are made at regular intervals (generally every four years) in these areas. Any changes are analysed in comparison to data from previous years and potential causes of changes are identified where possible. It can be difficult to isolate a cause of change because geothermal habitats are naturally dynamic, and the robustness of monitoring data is 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 that are caused by exploitation. However, we are not aware of any consistent and comparable monitoring programmes within Protected Systems. The only similar monitoring which has been undertaken in a Protected System is a study by Burns (1997) at Te Kopia, which has not been repeated so cannot provide a reference for natural changes in geothermal vegetation.

2.2 Methods

Various methods are used to monitor geothermal vegetation, as described below and summarised in Table 2.

2.2.1 Photopoints

Photographs are taken from known locations (photopoints) over several years to provide a visual record of changes in vegetation over time. There are currently between seven and 21 photopoints at each monitoring area. Over time, some photopoints have become less relevant, unsafe, or difficult to access. In such situations, additional or replacement photopoints have been established.

2.2.2 Geothermal indicator plant species

At two monitoring areas, monitoring is undertaken for populations of geothermal indicator plant species, including *Cyclosorus interruptus* (At Risk-Declining), *Dicranopteris linearis* (Threatened-Nationally Endangered), dwarf mistletoe (*Korthalsella salicornioides*) (Threatened-Nationally Critical), geothermal kānuka (Threatened-Nationally Endangered), mātukutuku (*Lycopodiella cernua*) (Not Threatened), *Psilotum nudum* (Not Threatened), and arrow grass (*Triglochin striata*) (Not Threatened). These species have been selected for monitoring because they are characteristic features of geothermal habitats. For each population of each species, assessments are made of the health, population size, cover, age structure, fertility, key threats, and management requirements. Any new populations of geothermal indicator plant species are recorded, and reassessed in the following monitoring periods.

2.2.3 Vegetation mapping

Vegetation and habitats are mapped onto a hard copy of the most recent digital aerial photographs at scales of 1:1,000 to 1:4,000 for some of the monitoring areas. Mapping units are then digitised in ArcGIS. Vegetation types are described based on the dominance of plant species in individual vegetation tiers and are used to show broad changes in the extent of vegetation and habitats over time.

2.2.4 Lay-out of monitoring grids

Permanent monitoring grids have been established at all but one of the monitoring areas, with 2-7 monitoring grids at each area. Dimensions of the grids vary from 22 metres long × 4 metres wide to 10 metres long × 1 metre wide. Transects have been established within all but one of these grids, where a Recce method (Hurst and Allen 2007) was used instead. The length of transects varies from 10-50 metres long. Along each transect, subplots of either 1 × 1 metre, or 0.5 × 0.5 metre are established.

2.2.5 Measurements within monitoring grids

Soil temperature is recorded using a thermometer at 0-10 cm deep (depending on the hardness of the substrate), every 1 metre along each transect. Additional soil temperature readings at 40 cm depth (at 5 metre intervals) were recorded during the most recent monitoring surveys at four of the monitoring areas, in order to assess temperature change where it is less influenced by short term fluctuations (e.g. daily or hourly) in surface temperature and solar radiation. Correlation between ground temperature and above-ground vegetation has been noted since the 1960's (Dawson 1964, Hochstein & Dickinson 1970, Vucetich & Wells 1978) and was described most fully by Burns (1997) at Te Kopia where a strong relationship was found between vegetation and soil temperature at a depth of 15 cm. Various vegetation monitoring studies which have been undertaken since the late 1990s for consenting purposes have thus included temperature measurements at a depth of 15 cm or 10 cm as part of the suite of measurements being undertaken at the site. These temperature measurements are then compared to the vegetation present to determine if any trends can be noted. The temperature measurements are not designed to measure the ground temperature of the site *per se*.

Within each subplot of each transect, the percent cover of each vascular plant species (non-vascular plants are included in some cases) present within specified height tiers is visually estimated and recorded. In some cases, height tiers were not included in the original monitoring method, but were added at a later date. Measurement of plant species cover by this method has been used at five areas since their initial monitoring surveys, and at one additional area more recently.

The Scott height-frequency method has been used at three monitoring areas since their initial monitoring surveys and at one additional area during the most recent reassessment. A modified 2.5 metre Scott height-frequency pole (Scott 1965) is placed vertically at 1 metre intervals along each transect. The presence or absence of vascular plants is recorded within a 5 × 10 cm 'cylinder' at 10 cm height intervals. Non-vascular species presence is only recorded if present in the 1-10 cm height tier.

2.2.6 Data analysis

Comparisons are made of soil temperatures, vegetative, and non-vegetative cover (from the transects and Recce plots), and Scott height frequency data between monitoring grids and years. The number of taxa recorded in monitoring grids is also compared between years. The total occurrence of geothermal kānuka foliage in each height interval is presented as a kite diagram for each monitoring grid, and visual comparisons are made between years. The number of intercepts and the mean percentage cover of selected taxa and ground cover variables are summarised in tabular form and comparisons made between years.

At one area, the Scott height-frequency data is used to calculate five indicators of geothermal vegetation health. These indicators are “biomass” (the number of 10 cm vertical intervals occupied by vegetation), vegetation height, vascular plant species richness (the number of vascular plant species present), “nativeness” (the proportion of point occupancy comprised of indigenous species), and “geothermalness” (the proportion of point occupancy comprising “geothermal vegetation”, where “geothermal vegetation” is defined as cover of a suite of species indicative of geothermal habitat. Comparisons of these five indicators of geothermal vegetation health have been made between two years.

Table 2: Summary of methods used at eight sites for monitoring the effects of geothermal energy exploitation.

		Site							
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Method	Vegetation mapping	✓	✓	✓		✓			✓
	Geothermal indicator plant species	✓	✓						
	Number of photopoints	10	7	11	17	18	7	10	21
Layout of Monitoring Grids	Number of permanent monitoring grids	4	4	2	4	0	7	4	6
	Number of Recce plots	0	1	2	4	0	7	0	0
	Number of transects	4	3	8	20	0	0	4	6
Methods Used Within Transects	Soil temperature at 10 cm depth	✓	✓	✓	✓		✓	✓	✓
	Percent cover of each plant species	✓	✓	✓	✓			✓	✓
	Scott-height frequency			✓	✓		✓		✓
Data Analysis	Comparisons of data between years and monitoring grids	✓	✓	✓	✓		✓	✓	✓
	Comparisons of indicators of geothermal vegetation health						✓		
	Comparisons of number and identity of plant taxa recorded	✓	✓	✓	✓	✓	✓	✓	✓

2.3 Frequency of monitoring

Geothermal vegetation is extremely vulnerable to trampling, which influences the frequency of vegetation monitoring. Many of the vascular plant species in geothermal vegetation have shallow root systems and non-vascular plant species are also highly vulnerable to disturbance. Ongoing frequent trampling (such as within sites subject to high visitor use for tourism) may lead to loss of vegetation and removal of organic layers in the topsoil (if present). Subsoil may become compacted into an impervious pavement which impedes root development and is much less suitable for vegetation recolonisation than soil not subject to trampling pressures (Burns et al. 2013).

Monitoring of geothermal vegetation currently requires monitoring personnel to access areas that are otherwise infrequently visited by people. Routes used to access some of the monitoring areas are relatively well defined, which indicates that other users of the area may also be utilising the same paths, which is preferable to using multiple different paths for access. To reduce trampling impacts, care is taken to minimise the effects of walking to and throughout each area. This includes accessing parts of the area via non-geothermal vegetation where possible, and avoiding the most vulnerable slopes, features, and vegetation. Unmanned aerial vehicles (UAV or ‘drones’) have also been used for assessment of geothermal vegetation (Beadel et al. 2018a).

Frequency of monitoring should be minimised to reduce any impacts of trampling, although this needs to be balanced against the amount of data required for useful monitoring. For instance, during the early phase of monitoring, annual monitoring may be necessary to establish an understanding of baseline trends. Vegetation can change relatively quickly and it can be more difficult to determine a cause of change if monitoring is not frequent enough, e.g. vegetation death due to herbicide drift was detected because the area was visited soon after the event. Monitoring frequency may be reduced to two- or four-yearly after the collection of sufficient baseline data that shows consistent trends, with less damaging sampling methods such as photopoints being undertaken more frequently. It may be tempting to reduce the frequency of monitoring to reduce costs or trampling impacts. However, when moving to a longer monitoring cycle, consideration should be given to the fact that an event or change that occurs immediately after the monitoring round will not be surveyed for a significant time period. During this time, the processes which brought about that change will have been obscured and the cause and effect may not be able to be determined.

The preferred programme of monitoring is annually for about five years, and then reducing the frequency to two- or four-yearly monitoring. If monitoring grids are discontinued and replaced at any point during the monitoring programme, consideration should be given to reverting back to annual monitoring to collect new baseline data. If a replacement monitoring grid is only assessed every four years, the comparisons will be less robust. Monitoring that is of insufficient frequency has limited use for determining trends and causes of change because there are a limited number of time data points.

2.4 Changes in monitoring methods over time

Changes to monitoring locations (such as monitoring grids or photopoints) can occur if marker pegs cannot be relocated. Marker pegs often don't last particularly long in geothermal environments, or are removed by other users of an area, and without good records of location, transects can be difficult to relocate.

If a monitoring location becomes too dangerous to continue to access for monitoring it should be replaced in a safer location (if possible). At least two photopoints and one monitoring grid have been discontinued due to safety concerns. At the discontinued monitoring grid, soil temperature has cooled (to non-geothermal temperatures) and blackberry (*Rubus fruticosus* agg.) has invaded the area. Climbing through dense blackberry vines over a geothermal substrate to assess the monitoring grid is hazardous because monitoring personnel cannot see their footing. Two monitoring grids may be too unsafe to access during future monitoring because of high soil temperatures and unstable ground. The reasons for discontinuing photopoints or monitoring grids have been documented and assessed as part of the overall assessment of change. In some cases, it is possible to continue limited monitoring of an area by using photographs from a safe distance.

If a monitoring location changes, or cannot be replaced in almost exactly the same location, new data cannot be compared with that of previous years. This is because the small-scale heterogeneous nature of geothermal vegetation and habitats means that data from the new location is unlikely to be comparable with the original location. Changes to monitoring locations or discontinuation of monitoring locations should be avoided unless absolutely necessary because such changes will decrease in the robustness of comparisons and new baseline data will need to be collected.

2.5 Monitoring of geothermal indicator plant species

Monitoring of geothermal indicator plant species may provide evidence of a vegetation response to changes in geothermal activity. Such monitoring also provides a way to detect abnormal changes in the health of populations, and a chance to recognise when any action may be required to prevent loss of these species from the areas.

Geothermal kānuka occurs in all of the monitoring areas. The conservation status of geothermal kānuka (along with other Myrtaceae species, such as mānuka (*Leptospermum scoparium*)) was recently elevated as a precautionary measure based on the potential threat posed by myrtle rust (*Austropuccinia psidii*). Myrtle rust is a fungal disease which arrived in New Zealand in May 2017, and infects plants from the Myrtaceae family. It has potentially devastating effects and there is no known treatment. The general health of geothermal kānuka is assessed from the data currently collected at each of the monitoring areas. However, more detailed monitoring of geothermal kānuka is now of greater importance due to the risk posed by myrtle rust. An autecological study (the relationship of an individual species to the environment, in particular the demographics of individual plants over time) of geothermal kānuka has been initiated at two of the monitoring areas. Autecological studies (using the same methods) should be initiated at the other monitoring areas during the next monitoring periods. All monitoring of geothermal kānuka and other Myrtaceae species should adhere to the most-recent guidelines regarding myrtle rust, to reduce potential for spreading the disease.

The conservation status of dwarf mistletoe has also been elevated (from At Risk-Naturally Uncommon to Threatened-Nationally Critical) because it is hemiparasitic and most commonly found on mānuka and species in the *Kunzea* complex including on geothermal kānuka. Dwarf mistletoe is a cryptic species that can be challenging to find, but because of its conservation status, it should be searched for and monitored at as many of the areas as possible.

Monitoring of geothermal indicator plant species (using standardised methods) should be undertaken at the other monitoring areas where it has not been undertaken previously. Suitable populations of indicator and threatened species have already been found at each area and observational data has been recorded for some of these. Additional populations of these and other indicator and threatened species are likely to be discovered during monitoring and could be included in the monitoring. Detailed monitoring of the unusual and threatened plant species in these geothermal areas over time will provide valuable information that could be used to inform management of these species.

3. GENERAL FINDINGS AND DISCUSSION

Changes identified in these geothermal areas by vegetation mapping include: identification of additional geothermal areas, changes in the distribution and abundance of weed plant species, and local changes in cover of geothermal vegetation. A marked change occurred at one site when herbicide spray drift from a neighbouring land use killed susceptible plants (e.g. arrow grass) within several geothermal vegetation types. Recovery of vegetation was mapped in the following years. Artefactual changes commonly occur because the resolution and quality of aerial photographs available increases over time. Such changes are more likely to obscure real changes when the time period between aerial photography is longer.

In some areas, "geothermalness" has declined to a point where they are no longer considered to support geothermal vegetation. One monitoring grid has subsequently been discontinued due to the safety concerns of monitoring within dense blackberry, which has covered unstable ground. The discontinuation of monitoring grids or photopoints is considered as part of the assessment of overall change.

In general, the monitoring has provided useful information, including, for some areas, good baseline information on the threatened species that occur there. Weed invasions have been monitored, and results clearly indicate the adverse effect of weeds on geothermal areas. Conversely, the effect of good weed control has been shown to provide quantifiable benefits to geothermal vegetation. Monitoring may also identify new threats to vegetation such as myrtle rust.

Change in geothermal kānuka height has been recorded at multiple sites, but only attributed to ground temperature changes at one area. At many sites, geothermal kānuka has increased in height over the monitoring period, and this has been attributed to weed control, cessation of grazing and natural growth over time. At one site, geothermal kānuka height has decreased over time as weed species including wilding pines, gorse (*Ulex europaeus*), broom (*Cytisus scoparius*), Spanish heath (*Erica lusitanica*), and exotic grasses and herbs have increased in abundance. Geothermal kānuka is less vigorous when it is an understorey species.

Over 22 years of monitoring, the results of the monitoring programmes described here have not triggered any resource consent actions i.e. no thresholds within the consent documents have been reached. This is in spite of a general acceptance that energy extraction (at least using earlier technology) does alter geothermal habitats and features, and that changes in geothermal vegetation have been measured during monitoring. However, linking of changes in geothermal vegetation to energy extraction remains difficult. Confounding factors which can alter geothermal vegetation structure and composition include fire, land clearance, weed invasion, and herbicide spraying. In some instances, changes have been able to be attributed to a cause because the monitoring period was short enough to determine this, but where monitoring periods are longer it can be very difficult to attribute change to a particular cause.

4. CONCLUSION

Monitoring of geothermal vegetation in New Zealand is important because it may be used to determine whether geothermal extraction is causing adverse effects on geothermal vegetation, habitats, and associated threatened plant species. Results of monitoring can be used to inform power generation companies on ways to improve protection of these Critically Endangered land environments and Threatened and At Risk plants within geothermal areas. However, the usefulness of current monitoring regimes is somewhat limited, for several reasons. Linking causes and effects through a monitoring regime is limited by the frequency of monitoring period and the consistency of monitoring locations throughout this period. Some more recent monitoring regimes have involved annual monitoring for a five year period. In one case this enabled an event that caused plant deaths to be attributed to an actual cause. If monitoring had not occurred at this frequency, then vegetation change would have occurred with no apparent cause. However, it is necessary to balance the gathering of sufficient information and the potential to adversely affect an area due to the concentration of trampling that occurs at monitoring sites. Annual monitoring for three to five years followed by reassessments at two- to four-yearly intervals seems to be a good balance. One power generation company has also instigated yearly walk-through surveys during intervening years, when plot markers are replaced if required and general changes are recorded. This type of assessment is more cost-effective than a full monitoring round and will ensure that any major events which may influence vegetation change are captured (with probable cause more likely to be identified). In addition, plot locations will be more easily relocated (also saving time and money), while minimising trampling impacts and allowing the vegetation within monitoring areas to recover between monitoring periods. UAV (drones) are also a useful tool for low impact monitoring.

Most areas that are monitored do not yet have an adequate baseline condition established to allow for particularly meaningful comparison of results. Although monitoring has been ongoing for over 20 years, only four measurement cycles have been implemented at some sites. There is also no comparable monitoring being undertaken (that we are aware of) at any site which is within a Protected System. Therefore, although the vegetation responses to changes in temperature and other stressors have been well documented (Burns 1997), the 'normal' or 'expected' long-term changes in geothermal vegetation in a natural system have not been monitored and are not particularly well known.

Monitoring could be improved through a number of simple measures such as:

- Gathering of baseline data for all areas over a number of years of annual monitoring, to increase data levels for analysis.
- Reducing time periods between monitoring rounds and undertaking walk-through surveys and measuring photopoints on an annual basis, to record general changes without damaging vegetation.
- Undertaking comparable monitoring within several Protected Systems with similar geothermal features for comparison.
- Undertaking monitoring of geothermal indicator plant species, using standardised methods, at all monitoring areas, including those where such monitoring has not been undertaken previously.
- Aerial photography should be retaken prior to field work, to ensure that mapping of vegetation is up-to-date and accurate, and artefactual changes are minimised.

Finally, with approximately 33% of geothermal habitats in the Waikato and Bay of Plenty Regions located within Development Systems, it is important that monitoring is undertaken to ensure that potential adverse effects on vegetation are avoided or minimised. Geothermal systems are naturally in a state of flux, and ensuring that enough geothermal vegetation survives within geothermal areas is essential to allow buffering for in-site changes and dispersal to other areas.

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