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Update on Sustainable Management of Geothermal Vegetation in the Waikato Region, New Zealand

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ABSTRACT

Geothermal vegetation - influenced by surface expressions of heat from the Earth's interior - is naturally rare in New Zealand, and internationally. The varied nature of geothermal manifestations, due to varying combinations of temperature, chemistry, hydrology, and localised protection from frosts, results in rare and unusual habitats for plants. These naturally uncommon ecosystems are classed as threatened and critically endangered, and include habitats for species occurring outside 'normal' latitudinal and altitudinal ranges. The varied nature of geothermal vegetation, one of the most threatened ecosystems in New Zealand, has important implications for management, including retention of existing areas and the maintenance and enhancement of ecological values. Most geothermal vegetation in New Zealand occurs in the Central North Island in the Taupo Volcanic Zone, with *c.*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. Inventories of geothermal vegetation and identifications of management priorities have been undertaken regularly in the Waikato Region since 2000. The latest inventory, undertaken in 2014, covered over 863 ha of geothermal habitat at *c.*64 sites within 15 geothermal systems. Energy production (thermal and hydro-electricity, heating, and industrial uses), land use changes such as mining, farming, forestry, urban development, tourism, and fire has resulted in the loss of significant geothermal areas in the past, and such activities continue to threaten geothermal vegetation. Invasion of pest plants, particularly introduced conifers and other woody plant species, continues to be a major threat at many sites. Threat mechanisms operating at each site, vulnerability to those threats, actions required to address them, and the benefits and priorities of ecological management have been identified. Pest plant control programmes are being implemented at many sites, however pest plant control remains a High priority at *c.*16 sites. Pest animal management is a High priority at one site, whilst exclusion of domestic stock is an Immediate priority at one site and a High priority at four sites. For sites where management requirements have been ranked as being Immediate or High priorities, action should be instigated as soon as practicable. In most cases, holistic management of sites is recommended. Active restoration management is being undertaken by the Department of Conservation, tangata whenua, regional and local government, private landowners, and forestry companies. There are considerable opportunities for further restoration initiatives, at other sites and where work has already been undertaken. New threats have also been recognised, showing the importance of regular monitoring and inventory assessments. Continued monitoring and appropriate planning is a key requirement to improve management of this nationally rare ecosystem. Monitoring, protection, and restoration, where possible, are essential requirements to halt the decline of these fragile and unique ecosystems.

1. INTRODUCTION

Geothermal vegetation, which 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), and habitats are naturally rare in New Zealand (Williams *et al*. 2007) and internationally. In New Zealand, four types of geothermal ecosystems have been ranked as Critically Endangered (fumaroles, geothermal stream sides, geothermal heated ground, and geothermal hydrothermally altered ground) (Holdaway *et al*. 2012). Most geothermal vegetation in New Zealand occurs in the central North Island, in the Taupō Volcanic Zone (see Figure 1), 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. 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 2011b), chemistry, hydrology, and localised protection from frosts, produces rare and unusual habitats for plants. These include plants 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, and local 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 are reflected in relatively rapid changes in the extent and composition of geothermal vegetation. Geothermal vegetation includes populations of several plant species which have a national threat ranking in New Zealand.

2. METHODS

The Waikato Regional Council has been undertaking inventory studies of geothermal vegetation in the Waikato Region since 2000 with regular updates during this period. In 2014, a further update was undertaken, using 2012 colour digital aerial photographs as the base map. This study mapped, described, assessed, and ranked 64 sites (including four areas newly identified in 2014) supporting geothermal vegetation covering *c.*750 ha (including nonvegetated raw-soilfield). An additional *c.*113 ha is mapped as geothermal water, where it is an integral part of a site containing geothermal vegetation.

The grouping of individual examples of geothermal habitats as 'sites' can be somewhat arbitrary, however groupings were generally based on areas of geothermal surface manifestations that were located adjacent to each other, and were easy to assess in

the field as a single unit. Vegetation type boundaries were digitized and the extent of each type was calculated. Topographical maps and vegetation maps were prepared for each site. In addition, a geophysical assessment of 19 sites was carried out in 2010. At each site, the vegetation was described and classified using predefined vegetation structural classes and a protocol for assigning vegetation type names based on the dominant plant species. Site condition, current threats, modifications and vulnerability were assessed, and management requirements were identified. Each site was assessed for significance and assigned a relative significance level of International, National, Regional, or Local. Significance and relative significance were assessed using criteria in the Waikato Regional Policy Statement.

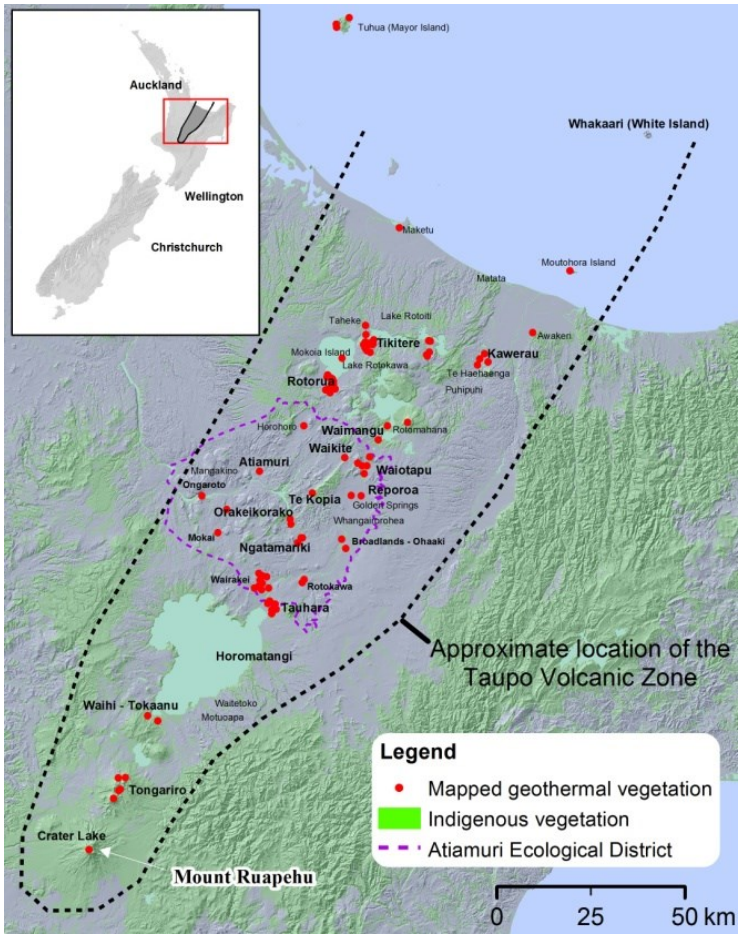

Figure 1: Location of geothermal vegetation in the Taupō Volcanic Zone.

Geothermal vegetation was assessed in the geothermal systems within which it occurred. A geothermal system is an individual body of geothermal energy (including geothermal water) not believed to have any other connection in the upper few kilometers of the earth crust (Luketina, 2012). The geothermal system boundaries of all known high temperature systems have been mapped previously in the Waikato Regional Plan. There are 15 known high temperature, and approximately 31 low temperature, geothermal systems in the Waikato Region (Luketina, 2012). Some of these have surface expressions of geothermal energy that provide habitat for geothermal vegetation, while others do not.

The above information was then used to assess priorities for control of pest plants and animals, and fencing. An Excel spreadsheet was populated, including fields containing information on threats at each site. Relative vulnerability of each site to each threat mechanism was evaluated as lower to high, as defined in Table 1:

Table 1: Definitions and ranks of relative vulnerability.

Rank	Definition
High	The indigenous plant community or geothermal feature is likely to undergo a significant decline in quality within the next five years if no measures are undertaken to control the threat.
Medium	The indigenous plant community or geothermal feature is likely to undergo a significant decline in quality in the next five to ten years if no measures are undertaken to control the threat.
Lower	The indigenous plant community is likely to undergo minor degradation due to the threat in the next ten years or so, or significant decline in quality over a longer period.

Furthermore, ecological benefit of controlling the threat(s) at each site was assessed as low to high, as defined in Table 2:

Table 2: Ranking levels for assessment of the ecological benefit of controlling the threat(s) at each site.

Rank	Assessment of Ecological Benefit
High	Likely to significantly improve the viability of the indigenous geothermal vegetation and geothermal features at the site within the next five years.
Medium	Management of the threat is likely to significantly improve the viability and quality of the site within the next five to ten years.
Lower	Management of the threat in any site category is likely to improve or maintain the viability of the site over a timeframe beyond the next ten years.
Not Applicable	There is no perceived threat and/or no management action is required or recommended.

Finally, priorities for managing each threat at each site were assessed, as defined in Table 3:

Table 3: Definitions of relative priority levels for managing each threat at each site, immediate to low or not applicable.

Rank	Priority
Immediate	Highest priority sites for active management. These are generally of international or national significance, or are large regionally significant sites. Includes sites where a relatively small investment in the short term may deal cost-effectively with a management problem or threat and avoid potentially more significant problems.
High	Generally sites of high ecological value (e.g. large regionally significant sites, nationally significant sites or better) where threats do not immediately threaten the site, but management will significantly improve the viability of key ecological features.
Medium	Sites of regional significance or better where management will significantly improve the long-term viability of ecological features at the site, or sites of local significance where the management action has the potential to improve the site so that it may, in future, meet the criteria for regional significance.
Low	Either sites of local significance where management will improve the viability of ecological values or geothermal features or sites ranked higher where management will improve ecological viability but will require the allocation of significant resources.
Not Applicable	No obvious threats or no action required.

3. VEGETATION

Vegetation assemblages at geothermal sites include lichenfield, mossfield, herbfield, fernland, scrub, shrubland, rushland, sedgeland, reedland, forest, wetland, open water habitats, and geothermally-influenced bare ground. Vegetation composition is highly variable, reflecting soil temperatures, the presence/absence of permanent water and ephemeral wetlands, acidity and other chemical aspects of soil and water, altitude, and the age of the geothermal activity at a particular site. Sites occur over a wide range of altitudes, from sea level to the summits of the central North Island volcanoes. Soil chemistry and temperature (environmental gradients) strongly influence vegetation at geothermal sites (c.f. Given 1980 and Burns and Leathwick 1995).

The 750.3 ha of geothermal vegetation and habitats were mapped in three broad categories: nonvegetated raw-soilfield (*c.*89.8 ha), terrestrial vegetation (*c.*574.7 ha) and emergent wetland (*c.*85.8 ha). Terrestrial vegetation is all vegetation that was not mapped as geothermal wetland and nonvegetated raw-soilfield and includes (but is not limited to) forest, scrub, shrubland, fernland, and mossfield.

The largest single area of geothermal vegetation (*c.*221 ha) occurs in the Waiotapu Geothermal System, three systems (Horohoro, Atiamuri, and Whangairorohea) have less than 1 ha of geothermal vegetation (see Table 4), and two systems (Mangakino and Horomatangi) have no known geothermal vegetation.

Most geothermal vegetation in the Waikato Region occurs in Atiamuri Ecological District (*c.*81%), while Taupō and Tongariro Ecological Districts contain *c.*13% and *c.*7% respectively. Geothermal vegetation is distributed relatively evenly between two local authorities: Rotorua District (*c.*51%) and Taupō District (*c.*49%).

3.1 Changes in Extent of Geothermal Sites Over Time

In 2012 historical (1940s) photographs of 37 sites held by the Waikato Regional Council were compared with 2007 aerial photographs. Using a combination of historical photographs and existing literature, we determined that the extent of geothermal vegetation has decreased at 23 of these sites. At six sites, the extent of geothermal vegetation has increased, and eight sites had no discernible change. Causes of a reduction in geothermal vegetation cover include an increase in ground temperature beyond the capacity to support vegetation, vegetation clearance (e.g. for roading, pasture), and weed encroachment.

Many historical photographs showed large light-coloured patches, often not present in 2007 aerials. These light-coloured patches may be bare ground, but could also be short-statured vegetation, or open water. Bare ground can indicate heated soils, resulting in less vegetation cover. It is possible that one or more sites may have cooled over the last 60 years as a result of geothermal extraction, resulting in a corresponding increase in vegetation cover.

Table 4: Areas of geothermal vegetation and habitats by geothermal system and ecological significance ranking of sites in the Waikato Region. Key I = International; N = National; R = Regional; L = Local. [1] Includes geothermal water (113 ha) where it is an integral part of a site with geothermal vegetation.

Geothermal System	Area (ha) Within Each Geothermal System at Each Level of Significance and Total Area (ha)				Total
	I	N	R	L	
Horohoro				<0.1	<0.1
Waikite		20.7		0.3	21.0
Waiotapu	126.8	63.8	51.2	8.0	249.8
Mokai			0.9	2.7	3.5
Atiamuri				0.1	0.1
Te Kopia	65.1		0.2	0.8	66.1
Orakeikorako		65.5	1.4	0.1	66.9
Ngatamariki			1.6		1.6
Whangairorohea				0.1	0.1
Reporoa			10.0	0.6	10.6
Ohaaki			18.1		18.1
Wairakei-Tauhara		40.0	101.7	3.4	145.1
Rotokawa		145.4	40.7		186.2
Tokaanu-Waihi-Hipaua		42.3	20.2	1.4	64.0
Tongariro	22.4	8.2			30.6
Grand Total	214.4	386.0	245.9	17.5	863.8[1]

Sites where real changes to the extent and quality of vegetation were anticipated since the last field visit (between 2006-2010) were re-visited in the field where possible. Reasons for changes to the extent of geothermal vegetation at each site were identified. There has been a net gain (*c.*16 ha or 2%) in mapped area of geothermal vegetation across all sites in the Waikato Region between 2012 and 2014 with a total of *c.*750 ha of geothermal vegetation mapped in 2014 compared with *c.*734 ha mapped in (2012). When comparing changes to the extent of geothermal vegetation (based on digital aerial photographs) at sites, most showed little real change, i.e. most differences in mapped extent related to better quality aerial photographs and/or knowledge of the site. For example, changes in extent of mapped geothermal vegetation at Orakeikorako, Rotokawa North, and Te Kopia were largely as a result of better quality aerial photographs, and improved site knowledge.

There was, however, a real increase in geothermal vegetation at two sites (Wairakei Borefield and Te Maari Craters), and a real decline at two others (Ohaaki Steamfield East and Broadlands Road). The eruption of Te Maari Craters in 2012 has increased the extent of this site by *c.*3.5 ha, and geothermal vegetation at Wairakei Borefield has increased by 36% since 2007. At Broadlands Road, two very small areas of geothermal vegetation (<0.1 ha total) were destroyed by development for industrial use and recreational use. At Ohaaki Steamfield East extensive earthworks in the northwest of the site are evident, and new roads are also present both of which are likely to account for the *c.*0.4 ha reduction in geothermal vegetation extent.

Many geothermal sites are very active and dynamic, and their habitats are therefore somewhat unstable. Changes in surface activity tend to be reflected in changes in the extent and composition of geothermal vegetation. Local increases in heat, steam production, and eruptions of mud and hot water often damage or kill surrounding vegetation, or cooling ground may lead to increased weed invasion and the decline of heat-tolerant species. These changes are an integral part of the natural dynamics of geothermal sites. For example, the Te Maari Craters erupted in 2012 which has almost doubled the extent of this site.

4. FLORA

4.1 Species Representations

The varied nature of geothermal surface manifestations, due to varying combinations of temperature, chemistry, hydrology, and localised protection from frosts, combines to form rare and unusual habitats. Species present in geothermal habitats can be divided into three groups:

(i) Relatively common indigenous plant species able to tolerate conditions within geothermal habitats, and which may also occur in neighbouring non-geothermal vegetation. Examples of such species include mānuka (*Leptospermum scoparium*), mingimingi (*Leucopogon fasciculatus*), monoao (*Dracophyllum subulatum*), and tūrutu (*Dianella nigra*).

(ii) Relatively uncommon plant species, either at other sites in New Zealand or outside of New Zealand. Geothermal sites mimic aspects of these species usual habitats (Given 1995), for example outside their normal latitudinal and/or altitudinal range. These include species that occur in warmer climates outside New Zealand, but within New Zealand only occur at geothermal sites. Examples are the ferns *Nephrolepis flexuosa*, *Dicranopteris linearis*, and *Christella* aff. *dentata* ("thermal"). Other species occur at higher altitudes in geothermal areas than in their normal range, including the ferns *Thelypteris confluens* and *Cyclosorus interruptus*, and the fern allies *Lycopodiella cernua* and *Psilotum nudum.* Many of these species are frost-intolerant and conditions such as steam and heated soils protect them from these cold events.

(iii) Species endemic to New Zealand geothermal habitats. One of the most interesting is the shrub, prostrate kānuka (Kunzea ericoides var. microflora; Recent revision to Kunzea taxonomy (see de Lange 2014) was not adopted in this iteration of the extent and composition of geothermal vegetation in the Waikato Region because field work was completed prior to the publication of the revision paper, and fieldwork focused on kanuka identification would be required at each site in order to accurately determine the species composition of the "kānuka" and "prostrate kānuka" populations at each site according to the de Lange 2014 paper.), which is endemic to New Zealand and only occurs in geothermal habitats. Its form varies in relation to soil temperatures, becoming shorter as soil temperatures increase. Prostrate kānuka has an ectomycorrhizal association with the fungus Pisolithus (Moyersoen & Beever 2004).

4.2 Threatened and at Risk Vascular Plants

Seventeen nationally threatened or at risk vascular plant species (as per de Lange et al. 2013) are known from geothermal sites in New Zealand, as listed in Table 5. Fifteen of these occur in geothermal habitats in the Waikato Region, including the largest populations of prostrate kānuka in New Zealand, and key populations of six other at risk species. These species are a key indicator of the current health and previous management of geothermal sites, for example *Cyclosorus interruptus* is thought to have become extinct at four geothermal sites in the last 40 years, and *Christella* aff. *dentata* ("thermal") is now presumed extinct at four sites in the Waikato Region for which historic records are available.

Table 5: Nationally Threatened and At Risk vascular plant species (as per de Lange *et al*. 2013) of geothermal habitats in New Zealand. * Present in the Waikato Region. + Key populations i.e. these populations are the most important populations in the Waikato Region and/or New Zealand and thus survival of these populations is very important for conservation of the species.

Plant Species
Threatened - Nationally Critical
Paracaleana minor
Threatened - Nationally Vulnerable
Machaerina complanata
At Risk - Declining
*Cyclosorus interruptus**+, *Nephrolepis flexuosa**+
At Risk - Naturally Uncommon
*Calochilus paludosus**, *Calochilus robertsonii**+, *Christella* aff.*dentata* ("thermal")*+, *Dicranopteris linearis* var. *linearis*+, *Fimbristylis velata**, *Hypolepis dicksonioides**+, *Korthalsella salicornioides**, *Kunzea ericoides* var. *microflora**+, *Caladenia alata**, *Schizaea dichotoma**+, *Thelypteris confluens**, *Stegostyla atradenia, Corunastylis pumila*.

Seven sites (listed in Table 6) contain over 20 ha of prostrate kānuka scrub and shrubland. In total there is *c.* 426 ha of prostrate kānuka-dominant vegetation in the Waikato Region. This number is higher than the area identified in the 2011 report. This increase is a combination of improved mapping accuracy and additional areas mapped because of better quality aerial photographs and pine control works.

Table 6: Location and size of the seven largest areas of prostrate kānuka scrub and shrubland in the Waikato Region.

Site	Area (ha)
Waiotapu South	*c.*70.8
Te Kopia	*c.*47.2
Maungakakaramea/Rainbow Mountain	*c.*44.6
Waiotapu North	*c.*37.3
Lake Rotokawa	*c.*35.8
Rotokawa North	*c.*34.8

Key populations for seven other threatened species also occur in geothermal areas in the Region, with large populations of *Schizaea dichotoma* at Te Kopia, *Dicranopteris linearis* var. *linearis* (Orakeikorako, Te Kopia, Te Kiri O Hine Kai Stream Catchment/Wairoa Hill, Red Hills), *Cyclosorus interruptus* (Otumuheke, Waikite Valley), *Hypolepis dicksonioides* (Waikite Valley), *Christella* aff. *dentata* ("thermal") (Waipapa Stream, Waikite Valley, Red Hills, Waihunuhunu), and *Calochilus robertsonii* (Lake Rotokawa, Maungakakaramea (Rainbow Mountain)).

5. ECOLOGICAL SIGNIFICANCE

Each of the 64 sites mapped and described meets one or more of the criteria for ecological significance in the Waikato Regional Policy Statement, and were ranked as being of International, National, Regional, or Local significance. Four sites of international significance (and part of one site) contain c.214 ha or 25% of the geothermal habitat in the Waikato Region. Eleven sites of national significance (and one part site) contain c.386 ha or 45% of geothermal habitat in the Region. Internationally and nationally significant sites are listed in Table 7.

Table 7: Sites of international and national significance.

International	Total geothermal habitat (ha)	National	Total geothermal habitat (ha)
Te Kopia	*c.*65.1	Waikite Valley	20.7
Te Maari Craters, Emerald Lakes, Red Crater	*c.*22.4	Maungaongaonga	8.7
Waiotapu South	*c.*126.8	Maungakakaramea (Rainbow Mountain)	55.1
		Waihunuhunu	5.4
		Orakeikorako	46.8
		Red Hills	13.3
		Craters of the Moon	38.1
		Lake Rotokawa	145.4
		Tokaanu Lake Shore Wetland	42.3
		Ketetahi	8.2
		Otumuheke Stream	1.9
		Waipapa Stream (part)	0.9
Total	214.4	Total	386.0

Twenty-one sites (and part of five other sites) were identified as being of Regional significance. In total, *c.*246 ha or 29% of geothermal habitat in the Region was identified as being Regionally significant. Other sites (22) were identified as being of Local significance (*c.*18 ha or *c.*2% of geothermal habitat). Ecological significance rankings (extent in ha) within each geothermal system are given in Table 4 above.

6. HUMAN DISTURBANCE, THREATS, AND MANAGEMENT ISSUES

Human disturbance and associated threats include the following:

Exploitation for Energy Production: This is one of the greatest threats to the viability and sustainability of geothermal vegetation and habitats. Exploitation can cause changes to underground geothermal systems, with potential to change both the character of sites and the distribution of species within them. Exploitation can result in increases in surface temperatures (e.g. Karapiti), or decreases in temperature, 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 has resulted in a lowering of the water table and consequent loss of hot springs and geysers. Past collections of plant specimens indicate that Geyser Valley at Wairakei supported populations of nearly all the tropical ferns and fern allies associated with thermal areas in New Zealand (Given 1989). Most of these species are now either completely absent or much reduced in abundance and distribution at this site. Cooler ground has also allowed the invasion of adventive weeds. However, at nearby Karapiti, a ten-fold increase in heat output has occurred following development of the Wairakei field (Huser 1989), habitat for some species has been increased and enhanced, with considerable development of geothermal vegetation and large populations of plants characteristic of geothermal sites (Given 1989), including At Risk species. However, this does not include habitat for all the species that have been lost from Geyser Valley (e.g. *Christella* aff. *dentata* ("thermal").

Large-scale energy development has been undertaken, or is being developed, in the following systems: Wairakei-Tauhara, Mokai, Ohaaki, Ngatamariki, and Rotokawa; these systems are classified as Development Geothermal Systems by Waikato Regional Council (http://www.waikatoregion.govt.nz/Environment/Natural-resources/Geothermal-resources/Geothermal-systems-map) Large-scale uses are allowed as long as they are undertaken in a sustainable and environmentally responsible manner. Horohoro and Mangakino Geothermal Systems are also classified as Development Geothermal Systems, but no large scale developments have been undertaken there. A total of *c.*354.5 ha of geothermal habitat was mapped within Development Systems, comprising *c.*41% of geothermal habitats mapped in the Waikato Region.

Two geothermal systems (Atiamuri and Tokaanu-Waihi-Hipaua) are classified as Limited Development Geothermal Systems, and in these systems Waikato Regional Council allows takes that will not damage surface features. A total of *c.*64.1 ha of geothermal habitat was mapped, comprising *c.*7% of geothermal habitat in the Region.

Reporoa Geothermal System is classified as a Research Geothermal System, because the Regional Council considers that not enough is known to classify it as either Development, Limited Development, or Protected. In these systems, only small takes and those undertaken for scientific research are allowed. A total of 10.6 ha of geothermal habitat was mapped in this Geothermal System, which represents *c.*1% of geothermal habitat in the Region.

Six geothermal systems are protected from development and are classified as Protected: Horomatangi, Orakeikorako, Te Kopia, Tongariro, Waikite, and Waiotapu. These systems contain vulnerable geothermal features, and are valued for their cultural and scientific characteristics. A protected status ensures that underground geothermal water sources cannot be extracted and that surface features are not damaged by unsuitable land uses. A total of *c.*385.6 ha of geothermal habitat was mapped in Protected Geothermal Systems, representing *c.*45% of geothermal habitat in the Region.

Tourism and Recreation: Damage can result from construction of facilities such as tracks, roads, and buildings, and from the combined effects of large numbers of visitors, especially to popular tourist sites such as Waiotapu, Wairakei, Maungakakaramea (Rainbow Mountain), Craters of the Moon, Upper Wairakei Stream (Geyser Valley), and Orakeikorako. Some sites, such as Craters of the Moon, have developed a plan to reduce the impacts of tourists, by discouraging visitors from walking off formed tracks. This plan is currently being successfully implemented, although it will take some time for vegetation to recover where there is soil compaction. Geothermal sites are particularly vulnerable to trampling damage, particularly threatened ferns and prostrate kānuka-dominant vegetation.

Attempts to 'tidy' or otherwise 'enhance' areas for tourism and recreation can also degrade geothermal vegetation. Mowing or slashing of geothermal vegetation, indiscriminate use of herbicides for weed control, replacement of 'scruffy' geothermal vegetation with exotic grasses or other introduced plants, and the application of fertilizer to promote growth of non-thermal vegetation all threaten the viability of geothermal vegetation. Some geothermal vegetation and geothermal features at Crown Road have been destroyed for motocross tracks.

Dumping of Rubbish: Dumping of garden refuse can lead to the establishment of garden escapes and other weeds. Dumping of other rubbish is a problem at some sites, e.g. Wharepapa Road, Crown Park, Otumuheke, and Ngapouri, where it threatens the viability of geothermal vegetation, as well as being unsightly.

Pest Plants: Invasive exotic plants, particularly blackberry and wilding pines, are the most obvious threat to most sites. The scale of the problem is large; in 2008 we calculated that within 125 ha (or 17% of all geothermal vegetation), pest plants covered greater than 25% of the area and, furthermore, that pest plants covered between 5-25% of a further *c.*272 ha or 37% of geothermal vegetation. More than 118 pest plant species have been recorded from geothermal habitats in the Region. While weeds will generally not survive on hotter sites, species such as blackberry, wilding pines, silver birch (*Betula pendula*), Montpellier broom (*Teline monspessulana*), tree lucerne (*Chamaecytisus palmensis*), Himalayan honeysuckle (*Leycesteria formosa*), broom (*Cytisus scoparius*), Spanish heath, *Cotoneaster glaucophyllus*, and pampas (mainly *Cortaderia selloana*) readily invade cooler ground on the margins of heated sites, e.g. Maungakakaramea (Rainbow Mountain), Te Kopia, Lake Rotokawa, and Waiotapu. Wilding pines are the most common weeds; seven species of wilding conifers are known from Maungakakaramea (Rainbow Mountain), and earlier reports noted them covering 6-20% of the geothermal vegetation. However considerable pine control work has been undertaken at this site by the Department of Conservation, with a dramatic improvement in vegetation condition. Pine control has also taken place at Waiotapu, Te Kopia, Orakeikorako, and several sites near Wairakei.

Wilding conifers, particularly maritime pine (*Pinus pinaster*) and radiata pine (*Pinus radiata*), and also lodgepole pine (*Pinus contorta*), black pine (*Pinus nigra*), bishop pine (*Pinus muricata*), ponderosa pine (*Pinus ponderosa*), strobus pine (*Pinus strobus*), Douglas fir (*Pseudotsuga menziesii*), and European larch (*Larix decidua*), are a threat to many sites. Other pest trees present within geothermal habitats include flowering cherry (*Prunus* sp.), Chinese privet (*Ligustrum sinense*), cotoneaster (*Cotoneaster simonsii*, *Cotoneaster glaucophyllus*), false acacia (*Robinia pseudoacacia*), eucalyptus (*Eucalyptus* sp.), Tasmanian blackwood (*Acacia melanoxylon*), silver birch, crack willow (*Salix fragilis*), grey willow (*Salix cinerea*), and tree lucerne.

Blackberry (*Rubus fruticosus* agg.), broom (*Cytisus scoparius*), buddleia (*Buddleja davidii*), Himalayan honeysuckle (*Leycesteria formosa*), gorse (*Ulex europaeus*), Spanish heath (*Erica lusitanica*), and exotic grasses are common on cooler geothermal soils and on the margins of sites, but are difficult to manage in most situations. Where they are present in low abundance, they should be controlled to prevent them from spreading or, if possible, they should be eradicated.

Some pest plant species are site-specific and require urgent management, for example *Cyperus involucratus* and ivy (*Hedera helix*) are a significant threat to *Nephrolepis flexuosa* and geothermal vegetation at Waikite. Weed control methods need to avoid or minimise risk to geothermal vegetation. Protection of threatened species is important, e.g. *Christella* aff. *dentata* ("thermal") at Waikite Valley. Pampas (*Cortaderia selloana*) is scattered through many geothermal sites and is a high priority for control.

When undertaking pest plant control it is important to avoid damaging indigenous geothermal vegetation. For example, removal of pest plants may make geothermal ferns more susceptible to damage during frosts if the canopy providing shelter is removed. Pest plant control can also threaten 'At Risk' ferns alongside stream margins by making stream banks more vulnerable to erosion. A plan should be developed to control and monitor pest plants at each site (apart from those in Tongariro National Park which are currently not threatened by pest plants).

Domestic Livestock: Where livestock have access to geothermal vegetation they are a major threat to its viability, and stock-proof fencing is a high priority. Livestock cause damage to geothermal vegetation and habitats by grazing, trampling and pugging of the ground surface and open up sites for weed invasion. Stock can cause considerable damage to sites by congregating within warm areas during cold weather. An area of Golden Springs has been fenced since it was last surveyed in 2007, and the condition of the vegetation at this site had improved considerably when inspected in 2014, however pest plant control will be required. Fences need to be regularly maintained at all fenced sites to ensure livestock are kept out and unfenced sites located within or adjacent to farmland should be fenced. We found that the ecological values of 22 sites would be enhanced by exclusion of domestic stock. At another 42 sites, fencing is not currently required given the current surrounding land use (e.g. forestry and conservation land).

Plantation Forestry and Shelterbelts: Wilding pines have invaded geothermal habitats at many sites in the past, and continue to invade these habitats. However, over the last few years control of wilding pines has been undertaken successfully at several geothermal sites. Ongoing control and vigilance is required to ensure that pines do not reinvade these areas. Where geothermal areas adjoin plantations, management and harvesting operations need to be undertaken with care to avoid damaging the geothermal vegetation or associated buffers. Such damage can allow weed invasion and wind access, and threaten the viability of geothermal vegetation. The adverse effects of plantation forestry need to be addressed, including the establishment of buffer zones of indigenous vegetation between geothermal vegetation and plantation forests, few of which currently exist. For example, a protection buffer was not established around the relevant geothermal habitats at Karapiti Forest when plantation pines were recently replaced. Some sites (e.g. Northern Paeroa Range) are surrounded by shelter belts. These should be managed to ensure that trees are not felled, or do not fall, into geothermal sites.

Introduced Pest Animals: Pest animals such as possums, deer (red deer and sambar), wallaby, and pigs can threaten the viability of indigenous vegetation associated with geothermal sites. Deer have caused considerable damage in some areas of prostrate kānuka shrubland through trampling. Significant damage by pigs was noted at Waiotapu South in Orutu Wetland. Other pest animals present in geothermal areas include goats, rabbits and hares, cats, hedgehogs, rodents, and mustelids. Waiotapu South has been identified as high priority for pest animal control because pigs are having significant adverse effects on geothermal wetlands. Feral pigs are a medium priority for control at Waiotapu North and pigs, deer, and possums require monitoring and management at Te Kopia, Maungaongaonga, Maungakakaramea, Red Hills, and Waikite Valley. Five sites that are currently grazed by stock are not considered a priority for pest animal management until fencing of geothermal habitat has been undertaken: Horohoro, Northern Paeroa Range, Matapan Road, Mangamingi Station, and Akatarewa East. An additional 13 sites were considered too small for pest animal control to be practicable, unless pest control of the wider area was being undertaken.

Fire: Geothermal vegetation is frequently dominated by flammable species such as prostrate kānuka and monoao, and great care needs to be taken with fire. Fires have occurred at several sites in the Waikato Region, including Crown Road. A fire in late 2012 at the Upper Wairakei Stream (Geyser Valley) (started as a result of a discarded cigarette butt) has resulted in degradation of the site through significant weed invasion of the burnt area. Smoking should be discouraged at all geothermal sites.

Genetic Pollution: The planting of indigenous species around geothermal areas using plants sourced from other parts of New Zealand can result in genetic mixing of different ecotypes (c.f. Simpson 1992). Only species currently present at a site should be planted. Moreover, only locally-sourced indigenous plant stock, suitable to the individual planting site, in proportions similar to that at which they occur at similar microsites within the site, should be used for all planting in and around geothermal areas.

Wetland Infilling and Drainage: Some geothermal activity is associated with freshwater wetlands, and these sites are vulnerable to infilling and drainage, which are common threats to wetlands. Geothermal wetlands have been much reduced in extent in the Region, and remaining wetlands deserve a high level of protection. Restoration work at Waikite Valley has resulted in an increase in wetland area.

Industrial/Residential/Roading Development/Mining: Geothermal habitat near urban areas has been destroyed by industrial, residential, and roading developments. For example, the new State Highway 1 Bypass around Taupō traverses the Crown Road site,

and areas to the south of this site have recently been converted to industrial land use. Approximately 50 ha (6%) of geothermal vegetation in the Taupō Volcanic Zone has been affected by industrial or mining operations.

7. GENERAL MANAGEMENT OPTIONS

Regulatory Controls: All areas of geothermal vegetation in New Zealand are significant and are worthy of formal protection and management to protect them from threats discussed above. Some sites may improve in condition over time if protected, and could warrant a higher significance ranking in the future.

Buffers and Connections: Protective buffers enhance the viability of natural areas and are a key management issue. Buffers protect sensitive ecosystems from external modifying influences such as wind and weed invasion. Most geothermal habitats were previously surrounded by extensive areas of non-geothermal indigenous vegetation, which also previously provided connective links or corridors to other geothermal sites. Connections need to be protected or enhanced wherever possible. Many geothermal sites are relatively small and currently have inadequate protective buffers. Geothermal surface activity can fluctuate at a particular location and across the landscape therefore a good-sized buffer is desirable around many geothermal sites, to allow for this natural variability. Te Kopia is an example of a site with an effective protective buffer.

Land Status, Protection and Landowner Engagement: Many sites containing significant geothermal vegetation are located on private land and formal legal protection (e.g. using covenants) is warranted. Current management of some privately-owned sites is ecologically unsustainable, and land management agencies need to consider opportunities to promote and fund physical protection and restoration works (e.g. fencing) for geothermal features in private ownership. Better engagement with private landowners/managers is warranted as management issues at some sites have changed little since the last survey several years previously, indicating that key messages are not being taken up.

Some legally-protected sites (e.g. reserves administered by District Councils or the Department of Conservation) require physical protection works, e.g. control of wilding pines. Some reserves (or parts of them) may also warrant upgraded protective classifications, to reflect their relative significance for nature conservation. Change of management and/or ownership of some Department of Conservation land to Iwi may be an opportunity for new restoration initiatives.

Ecological Restoration: Ecological restoration of degraded geothermal sites will enhance the conservation values and viability of many areas, particularly smaller sites. Restoration works have been undertaken in at least 18 sites in the Waikato Region: Waikite Valley, Maungakakaramea (Rainbow Mountain), Waiotapu South, Waiotapu North, Waipapa Stream, Whangapoa Springs, Te Kopia, Orakeikorako, Red Hills, Orakonui, Craters of the Moon, Otumuheke Stream, Broadlands Road, Crown Road, Crown Park, Waipahihi, Rotokawa North, and Lake Rotokawa.

Successful restoration requires a sound ecological basis and an achievable vision. Examples of restoration works being undertaken include weed control at several sites, including radiata pine control at Orakeikorako, radiata pine and pampas control at Otumuheke Stream, control of pampas and planting of “closed” informal tracks to restore vegetation cover at Craters of the Moon, and local removal of fill previously placed on geothermal features (Crown Road).

8. CONCLUSIONS

Field survey has been undertaken of all geothermal sites containing geothermal vegetation in the Waikato Region in the last ten years, with 37 sites resurveyed in 2014. Management requirements have also been assessed for all sites.

In Atiamuri Ecological District there has been a significant decline in extent, estimated to be approximately 30%, since European settlement. However, there has been a gain of approximately 4% in the Taupō Ecological District. In the Tongariro Ecological District there has been no change as a result of human activity, although some minor natural change will have occurred. Overall decline in geothermal vegetation is the result of a number of factors, including energy and hot water draw-off, damming of the Waikato River to form Lake Ohakuri, clearance and burning of vegetation, weed invasion, grazing, modification of water tables, dumping of rubbish, and other activities associated with forestry, farming, tourism, and recreation. Geothermal vegetation is subject to ongoing threats from pest plants and animals, and from human activity, especially on private land. Monitoring, protection, and restoration are essential to halt the decline of these fragile and unique ecosystems.

This project has identified threat mechanisms operating at each site, vulnerability to those threats, actions required to address them, and the benefits and priorities of ecological management. Pest plant control is required at many sites, with wilding pines, blackberry, and pampas being the most common pest species. Pest animal control is also required at some sites, although in many cases, fencing to exclude domestic stock is more urgent than pest animal control.

For sites where management requirements have been ranked as being of Immediate or High priority, action should be instigated as soon as practicable. In most cases, holistic management of sites is recommended. For example, if management of one factor, e.g. pest plants, pest animals, or fencing, is to be undertaken at a particular site because it has been identified as an Immediate or High priority, then it may be cost-effective and desirable to undertake other management actions at that site at the same time.

Active restoration management is being undertaken by the Department of Conservation, tangata whenua, regional and local government, private landowners, and forestry companies. There are considerable opportunities for further restoration initiatives, at other sites and where work has already been undertaken. New threats have been recognised, showing the importance of regular monitoring and inventory assessments. The recent eruption of the Te Maari Craters is a timely reminder of the dynamic nature of geothermal ecosystems and thus continued monitoring and appropriate planning is a key requirement to improve management of these nationally rare ecosystems.

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