ECOLOGICAL ASSESSMENT AND SUSTAINABLE MANAGEMENT OF GEOTHERMAL VEGETATION IN THE WAIKATO REGION, NEW ZEALAND

Sarah Beadel[1], William Shaw[1], Chris Bycroft[1], and Roger Bawden[1]

[1]Wildland Consultants Ltd, P.O. Box 7137, Te Ngae, Rotorua 3042, New Zealand

sarah.beadel@wildlands.co.nz

Keywords: *Vegetation, threatened plants, management priorities, ecosystems*

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, produces rare and unusual habitats for plants. These include habitats for threatened and naturally rare plant species, as well as 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. Inventories of geothermal vegetation were recently updated for the Waikato Regional Council, covering *c.*734 ha at 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 still threaten geothermal vegetation today. Invasion of pest plants, particularly introduced conifers and other woody plants, is a major threat at many sites. Monitoring, protection, and restoration where possible, are essential to halt the decline of these fragile and unique ecosystems.

1. INTRODUCTION

Geothermal vegetation[1] is naturally rare in New Zealand (Williams *et al*. 2007) and internationally, and four types of geothermal ecosystems have been ranked as Critically Endangered (fumaroles, geothermal stream sides, geothermal heated ground, 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 70% of the total extent of New Zealand's geothermal vegetation within the Waikato Region. 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 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.

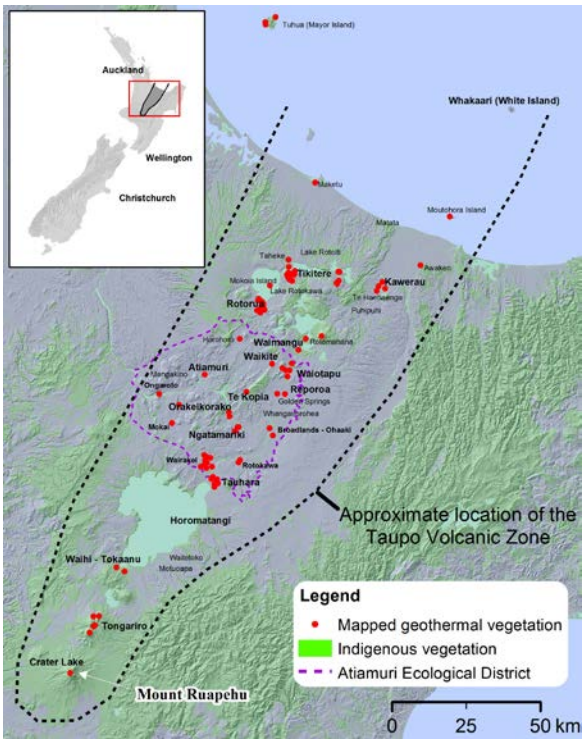

Figure 1: Location of geothermal vegetation in the Taupō Volcanic Zone.

2. METHODS

During 2010 and 2011 we undertook a study for the Waikato Regional Council to update and extend existing inventories of geothermal vegetation in the Region. The study identified, mapped, described, assessed, and ranked 64 sites supporting geothermal vegetation covering *c.*734 ha (including nonvegetated raw-soilfield). An additional *c.*106 ha was mapped as geothermal water, where it was 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 digitised and the extent calculated of each type. Topographical maps and vegetation maps were prepared for each site. For 19 sites, a geophysical assessment was also carried out. For each site, the vegetation was described and classified using predefined

[1] 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).

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 (refer to Table 1).

Geothermal vegetation was assessed in the geothermal systems within which it occured. A geothermal system is an individual body of geothermal energy (including geothermal water) not believed to have any other connection in the upper few kilometres 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 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 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 and open water habitats, and geothermally-influenced bare ground. Vegetation 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 *c.*734 ha of geothermal vegetation and habitats in the Waikato Region were mapped using three broad categories: nonvegetated raw-soilfield (*c.*92 ha), emergent wetland (*c.*81 ha), and terrestrial vegetation (*c.*561 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.*248 ha) was mapped in the Waiotapu Geothermal System, whilst two systems (Horohoro and Whangairorohea) have less than 0.1 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.*86%), while Taupō and Tongariro Ecological Districts contain *c.*9% and *c.*5% respectively. It is distributed relatively evenly between two local authorities; Rotorua District (51%) and Taupō District (*c.*49%).

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

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		25.8		0.3	26.1
Waiotapu	127.2	63.1	54.9	3.3	248.5
Mokai		0.8		2.6	3.4
Atiamuri				0.1	0.1
Te Kopia	59.9		0.2	0.8	60.9
Orakeikorako		59.2	1.4	<0.1	60.6
Ngatamariki			2.3		2.3
Whangairorohea				<0.1	
Reporoa			7.3	0.3	7.6
Ohaaki			18.6		18.6
Wairakei-Tauhara		46.4	102.7	2.0	151.1
Rotokawa		137.3	34.4		171.7
Tokaanu-Waihi-Hipaua		42.4	19.7	0.9	63
Tongariro	17.7	8.2			25.9
Grand Total	**205**	**382**	**242**	**11**	**840**[1]

1. Includes geothermal water (106 ha) where it is an integral part of a site with geothermal vegetation.

3.1 Changes in extent of geothermal sites 1940s to 2007

Historical photographs of 37 sites held by the Waikato Regional Council were studied. 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 cover include an increase in ground temperature beyond the capacity to support vegetation or vegetation clearance (e.g. for roading, pasture), and weed encroachment (refer to Table 5).

Table 5: Changes in the extent at 23 geothermal sites between the 1940s and 2007.

Decrease in Extent
Waikite Valley, Ngapouri, Waiotapu North, Maungakakaramea (Rainbow Mountain), Waiotapu South, Waihunuhunu, Akatarewa Stream, Orakeikorako, Red Hills, Longview Road, Wharepapa Road, Spa Thermal Park, Crown Park, Crown Road, Waipahihi Valley, Te Rautehuia, Te Rautehuia Stream, Upper Wairakei Stream (Geyser Valley), Te Kiri O Hine Kai Stream Catchment/ Wairoa Hill, Karapiti Forest, Lake Rotokawa, Tokaanu Thermal Park, Maunganamu East
Increase in Extent
Ngatamariki, Ohaaki Steamfield West, Ohaaki Steamfield East, Broadlands Road, Waipouwerawera Stream/Tukairangi, Craters of the Moon
No Change in Extent
Maungaongaonga, Te Kopia, Whangairorohea, Rotokawa North, Hipaua, Tokaanu Lakeshore Wetland, Tokaanu Tailrace Canal, Ketetahi

3.2 Changes in extent of geothermal sites 2002 to 2007

Sites where real changes to the extent and quality of vegetation were anticipated since the last field visit (in 2002-2007) were re-visited in the field where possible. When comparing changes to the extent of geothermal vegetation (based on 2002 and 2007 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 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 one site (Waikite Valley), while there was a real decline at another (Crown Road). Restoration works undertaken in at a geothermal wetland at Waikite Valley included increasing water table levels in this wetland and its surrounds (drains previously excavated through this wetland had lowered the water table). Recent restoration has resulted in a significant increase in the area of geothermal habitat at this site, which is now *c.*7 ha larger than in 2004. At Crown Road, *c.*1.5 ha of geothermal vegetation was destroyed by development for industrial use, and roading. Reasons were identified for changes to the extent of geothermal vegetation at each site.

3.3 Dynamics

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.

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 many sites have cooled over the last 60 years as a result of geothermal extraction, resulting in a corresponding increase in vegetation cover.

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 manuka (*Leptospermum scoparium*), mingimingi (*Leucopogon fasciculatus*), monoao (*Dracophyllum subulatum*), and turutu (*Dianella nigra*).

(ii) Relatively uncommon plant species, either at other sites in New Zealand or outside of New Zealand. Geothermal sites mimic aspects of their usual habitats (Given 1995), for example outside their normal latitudinal and/or altitudinal range. These include species which 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 kanuka (*Kunzea ericoides* subsp. *microphylla*), 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 kanuka has an ectomycorrhizal association with the fungus *Pisolithus* (Moyersoen & Beever 2004).

4.2 Threatened and At Risk vascular plants

Sixteen nationally threatened or at risk vascular plant species (as per de Lange *et al*. 2009) are known from geothermal sites in New Zealand, as listed in Table 6. Fourteen of these occur in geothermal habitats in the Waikato Region, which contains the largest populations of prostrate kanuka 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 6: Nationally Threatened and At Risk vascular plant species (as per de Lange *et al*. 2009) of geothermal habitats in New Zealand.

Plant Species
Threatened - Nationally Critical
Sullivania minor
Threatened - Nationally Vulnerable
Baumea complanata
At Risk - Declining
Christella aff.*dentata* ("thermal")*+, *Cyclosorus interruptus**+, *Dianella haematica, Nephrolepis flexuosa**+, *Thelypteris confluens**
At Risk - Naturally Uncommon
*Calochilus paludosus**, *Calochilus robertsonii**+, *Dicranopteris linearis* var. *linearis*+, *Fimbristylis velata**, *Hypolepis dicksonioides**+, *Korthalsella salicornioides**, *Kunzea ericoides* var. *microflora**+, *Petalochilus alatus**, *Schizaea dichotoma**+

***** Present in the Waikato Region.
\+ Key populations.

Seven sites (listed in Table 7) contain over 20 ha of prostrate kanuka scrub and shrubland. In total there is *c.*298 ha of prostrate kanuka-dominant vegetation in the Region.

Table 7: Location and size of the seven largest areas of prostrate kanuka scrub and shrubland in the Waikato Region.

Site	Area (ha)
Maungakakaramea/Rainbow Mountain	*c.*38.5
Craters of the Moon	*c.*31.9
Waiotapu North	*c.*30.6
Te Kiri O Hine Kai Stream Catchment/Wairoa Hill	*c.*29.6
Lake Rotokawa	*c.*27.9
Waiotapu South	*c.*26.5
Te Kopia	*c.*21.0

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* (Orakekorako, 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 was ranked as being of International, National, Regional, or Local significance. Three sites of international significance encompass *c.*205 ha or 24% of the geothermal vegetation in the Waikato Region. Eleven sites of national significance encompass *c.*382 ha or 46% of geothermal habitat in the Region. Internationally and nationally significant sites are listed in Table 8:

Table 8: Sites of international and national significance.

International	**(ha)**	**National**	**(ha)**
Te Kopia	*c.*60	Waikite Valley	25.8
Te Maari Craters, Emerald Lakes, Red Crater	*c.*18	Maungaongaonga	9.1
Waiotapu South	*c.*127	Maungakakaramea (Rainbow Mountain)	54.0
		Waihunuhunu	5.3
		Orakeikorako	42.4
		Red Hills	11.5
		Craters of the Moon	44.6
		Lake Rotokawa	137.3
		Tokaanu Lake Shore Wetland	42.4
		Ketetahi	8.2
		Waipapa Stream (part)	1.1
Total	**205**	**Total**	**382**

Twenty-three sites were identified as being of Regional significance, with an additional two sites being partly of Regional and Local significance. In total, *c.*242 ha or 29% of geothermal habitat in the Region was identified as being Regionally significant. Other sites (25) were identified as being of Local significance (*c.*11 ha or *c.*1% of geothermal habitat). Ecological significance rankings (extent in ha) within each geothermal system is given in Table 4 above.

6. HUMAN DISTURBANCE AND THREATS

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. Extraction of energy can alter underground geothermal systems, and can change both the quality of these systems and the distribution and composition of species in vegetation of surface geothermal manifestations. 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 indicate that Geyser Valley at Wairakei supported colonies of nearly all the tropical ferns and fern allies associated with thermal areas in New Zealand (Given 1989). Most are now either completely absent or much reduced in abundance and distribution. 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.

Large-scale energy development has been undertaken, or is being developed, in the following systems: Wairakei-Tauhara, Mokai, Ohaaki, Ngatamariki, and Rotokawa: being classified as Development Geothermal Systems by Waikato Regional Council[1]. 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.*277.7 ha of geothermal vegetation was mapped within Development Systems, comprising *c.*38% of geothermal habitats mapped in the Waikato Region.

Two geothermal systems (Atiamuri and Tokaanu-Waihi-Hipaua) are classified as Limited Development Geothermal Systems. Waikato Regional Council allows takes that will not damage surface features[1]. A total of *c.*59.6 ha of geothermal vegetation was mapped, comprising *c.*8% of geothermal vegetation 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[1]. A total of 7.3 ha of geothermal vegetation was mapped in this Geothermal System, which represents *c.*1% of geothermal vegetation in the Region.

Six geothermal systems are protected from development and classified as Protected: Horomatangi, Orakeikorako, Te Kopia, Tongariro, Waikite and Waiotapu. These systems contain vulnerable geothermal features, valued for their cultural and scientific characteristics. Protected status ensures that underground geothermal water source cannot be extracted and that surface features are not damaged by unsuitable land uses. A total of *c.*389.0 ha of geothermal vegetation was mapped in Protected Geothermal Systems, representing *c.*53% of geothermal vegetation 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, and Upper Wairakei Stream (Geyser Valley, and Orakeikorako). Some sites, such as Craters of the Moon, have a plan in place to reduce the impacts of tourists, by discouraging visitors from walking off formed tracks. Geothermal sites are particularly vulnerable to trampling damage, particularly threatened ferns and prostrate kanuka-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 fertiliser to promote growth of non-thermal vegetation all threaten the viability of geothermal vegetation.

Vegetation and geothermal features at Crown Road have been destroyed for motorcross tracks.

Dumping of Rubbish: Dumping of garden refuse leads 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. 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. For example seven species of wilding pines 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.

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. A plan should be developed to control and monitor pest plants at each site larger than 10 hectares (apart from those in Tongariro National Park which are currently not threatened by pest plants). 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.

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 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.

[1] http://www.waikatoregion.govt.nz/Environment/Natural-resources/Geothermal-resources/Geothermal-systems-map: Accessed 15 August 2012.

Plantation Forestry and Shelterbelts: A number of geothermal sites in the Region are adjacent to plantation forest and wilding pines are invading geothermal habitats. 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. Adverse effects of plantation forestry needs to be addressed, including the establishment of buffer zones of indigenous vegetation between geothermal vegetation and forests, of which currently few exist.

Some sites (e.g. Northern Paeroa Range) are surrounded by shelter belts. These should be managed to ensure that trees are not felled 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 by trampling some areas of prostrate kanuka shrubland. Significant damage by pigs was noted at Waiotapu South in Orutu Wetland. This is the best quality geothermal wetland in New Zealand, and control of pigs should be undertaken to reduce their impacts at this site. Other pest animals present in geothermal areas include goats, rabbits and hares, cats, hedgehogs, rodents, and mustelids.

Fire: Geothermal vegetation is frequently dominated by flammable species such as prostrate kanuka and monoao and great care needs to be taken with fire. Fire has been a problem at several sites in the Waikato Region, including Crown Road. 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 locally-sourced indigenous plant species, suitable to the individual site, in proportions similar to that at which they occur at that 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 the Region and remaining wetlands deserve a high level of protection.

Industrial/Residential/Roading Development/Mining: Sites near urban areas have been destroyed by industrial, residential, and roading developments. For example, the new State Highway 1 bypass around Taupō has passed through the Crown Road site, and areas to the south of the 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. MANAGEMENT REQUIREMENTS AND PRIORITIES

The vulnerability of each of the 64 sites to particular threats was assessed, along with the actions required and the benefits and priorities for ecological management. Sites that are of a high, medium, or lower priority for pest plant control, pest animal management, and/or exclusion of domestic stock were identified (Wildland Consultants 2011b).

7.1 Pest Plants

Six geothermal sites require immediate weed control. Ongoing control of wilding pines (*Pinus* sp.) and pampas (*Cortaderia selloana*) is required at Ohaaki Steamfield West and Orakeikorako, following initial large-scale control works at Orakeikorako. Wilding pines also require action at Waiotapu North and Waiotapu South. Ornamental trees and plantings at Tokaanu Thermal Park should be removed, whilst surveillance for pest plants (e.g. pampas) is the priority at Hipaua.

Wilding pines, 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 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 (*Betula pendula*), crack willow (*Salix fragilis*), grey willow (*Salix cinerea*), and tree lucerne (*Chamaecytisus palmensis*).

Pampas (*Cortaderia selloana*) is scattered through many geothermal sites and is a high priority for control. One species, *Cyperus involucratus*, was only recorded at one site (Waikite), from which it should be eradicated. It has the potential to spread further along stream banks at this site, threatening *Christella* aff. *dentata* ("thermal"). Ivy and Mexican daisy are also invading stream banks, threatening *Nephrolepis flexuosa*, and should be controlled. These species also have the potential to threaten other parts of this site if allowed to spread.

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.

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. Examples of management priorities are presented in Table 9.

Table 9: Management priorities for pest plants at six sites in the Waikato Region.

Site	Ranking	Area (ha)	Vulner-ability	Benefit	Relative Priority
Waikite	National	25	High	Immediate	Immediate
Waiotapu	International	113	High	High	Immediate
Wharepapa	Regional	3	Medium	Medium	Medium
Orakeikorako	National	5	No Threat	N/A	N/A
Paerata Road	Local	2	Medium	Medium	Lower

7.2 Pest Animals

Pest animal management requirements were assessed during the project. Waiotapu South has been identified as high priority for pest animal control because pigs are having significant adverse effects on geothermal wetlands there. 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. Six 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, Akatarewa East, and Golden Springs. An additional 13 sites were considered too small for pest animal control to be practicable, or where management of pests was considered to be unlikely to enhance values.

7.3 Exclusion of Domestic Stock

Ecological values of 22 sites would be enhanced by exclusion of domestic stock. At the other 42 sites, fencing is not currently required, given the current surrounding land use (e.g. forestry and conservation land).

7.4 Overall Priorities

Numbers of sites ranked as Immediate, High, Medium, or Lower priority for each management requirement are set out in Table 10.

Table 10: Geothermal sites in the Waikato Region where control of pest plants or animals, or exclusion of domestic stock is of Immediate, High, Medium, or Lower priority.

Management Requirements	**Relative Priority**				
	Immediate	**High**	**Medium**	**Lower**	**N/A**
Pest plant management	7	16	13	23	5
Pest animal management	0	1	18	31	14
Exclusion of domestic stock	1	4	7	10	42

7.5 Regulatory controls

All areas of geothermal vegetation 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 ranking in the future.

7.6 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. A good-sized buffer is desirable around many geothermal sites, to allow for this natural variability.

7.7 Land status and protection

7.7.1 Private land

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.

7.7.2 Protected sites

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 classifications, to reflect their relative significance for nature conservation.

7.8 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 16 sites in the Waikato Region: Waikite Valley, Maungakakaramea (Rainbow Mountain), Waiotapu South, Waiotapu North, Waipapa Stream, Whangapoa Springs, Te Kopia, Orakeikorako, Red Hills, Ngatamariki, Craters of the Moon, Otumuheke Stream, Broadlands Road, Crown Road, Crown Park, Waipahihi, 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 over about 39 ha at Orakeikorako, radiata pine and pampas control at Otumuheke Stream, control of pampas and planting of “closed” informal tracks to restore vegetation cover at Karapiti, and local removal of fill previously placed on geothermal features (Crown Road).

8. CONCLUSIONS

Inventories have been undertaken for most geothermal sites in the Waikato Region, along with assessment of management requirements.

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 the 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 an Immediate priority at seven sites and a High priority at 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. At the single site (Waiotapu South) which is of High priority for pest animal control, pest plant control is also ranked as an Immediate priority.

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 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. Continued monitoring and appropriate planning is a key requirement to improve management of this nationally rare ecosystem.

ACKNOWLEDGEMENTS

We gratefully acknowledge the assistance of the following people during the project: landowners for allowing access to study areas and providing useful information; Katherine Luketina (Waikato Regional Council) for organising the project, and providing aerial photography and logistical support; Paul Cashmore and Pete Corson (Department of Conservation, Rotorua) for providing background information on existing and new geothermal sites. Paul Cashmore, Brendon Christensen, and Johlene Kelly (Department of Conservation, Rotorua), and Angela Padget and Harry Keys (Department of Conservation, Turangi) provided assistance for permits to undertake this study; JoAnne Evelyn (Waikato Regional Council) for assistance with historical aerial photographs; and Jo McQueen (Wildland Consultants) for providing comments on a draft of this paper.

REFERENCES

Burns B.R.: Vegetation change along a geothermal stress gradient at the Te Kopia steamfield. *Journal of the Royal Society of New Zealand* 27: 279-294. (1997).

Burns B.R. and Leathwick J.: Geothermal Vegetation Dynamics. *Science for Conservation 18*. Department of Conservation, Wellington. 26 pp. (1995).

de Lange, P.J., Norton, D.A., Courtney, S.P., Heenan, P.B., Barkla, J.W., Cameron, E.K., Hitchmough, A.J.: Threatened and uncommon plants of New Zealand (2008 revision). *New Zealand Journal of Botany 47*: 61-96. (2009).

Given D.R.: Vegetation on heated soils at Karapiti, central North Island, New Zealand, and its relation to ground temperature. *New Zealand Journal of Botany 18*: 1-13. (1980).

Given D.R.: Botanical values on geothermal site - Taupō Volcanic Zone. Christchurch Botany Division, DSIR. (1989a).

Given D.R.: Geothermal Vegetation - an assessment of botanical values of selected geothermal sites in the Taupō Volcanic Zone. David Given and Associates, Christchurch. (1995).

Holdaway R.J., Wiser S.K., and Williams P.A.: Status assessment of New Zealand's naturally uncommon ecosystems. *Conservation Biology*. (2012).

Huser B.: Wairakei Geothermal Field: an assessment of natural features. Waikato Catchment Board: 1989/1. (1989).

Luketina K.: The Waikato regional geothermal resource. *Waikato Regional Council Technical Report 2012/10*. 28 pp. (2012).

Merrett M.F. and Clarkson B.R.: Definition, description and illustrations of geothermally influenced terrestrial and emergent wetland vegetation. *Landcare Research Contract Report: LC9900/022*. (1999).

Moyersoen B., Beever R.E.: Abundance and characteristics of *Pisolithus* ectomycorrhizas in New Zealand geothermal areas. *Mycologia 96*(6): pp. 1225-1232. (2004).

Simpson P.: Sustaining genetic integrity through restoration using local plant provenances. International Conference on Sustainable Land Management, Napier, New Zealand. November 18-22 1991. Proceedings pp. 336-342. Hawkes Bay Regional Council 1992. (1992).

Wildland Consultants: Priorities for pest plant control, pest animal control, and fencing at geothermal sites in the Waikato Region: 2011 Update. *Waikato Regional Council Technical Report 2011/28*. Waikato Regional Council. (2011a).

Wildland Consultants. Geothermal vegetation of the Waikato Region: an updated based on 2007 aerial photographs. *Waikato Regional Council Technical Report 2011/29*. Waikato Regional Council. (2011b).

Williams, P.A., Wiser, S., Clarkson, B., and Stanley M.C.: New Zealand's historically rare terrestrial ecosystems set in a physical and physiognomic framework. New Zealand Journal of Ecology 31:119-128. (2007).