Vegetation, Ecology and Management of the Waimangu Rotomahana geothermal site

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ABSTRACT

The Waimangu-Rotomahana geothermal area is part of the Waikite-Waiotapu-Waimangu Geothermal System (WWWGS) which is located in the Taupō Volcanic Zone, which extends across the Bay of Plenty and Waikato Regions. WWWGS is a protected geothermal system. The Waimangu-Rotomahana geothermal area includes the Waimangu Geothermal Valley, and the margins and cliffs of Lake Rotomahana. The Waimangu Geothermal Valley is considered to be one of the youngest geothermal areas in Aotearoa New Zealand, and all current geothermal vegetation has developed since the Tarawera eruption in 1886. Despite its young age, the area contains some of the most important populations of the special plants and habitats present within the geothermal areas of the Taupō Volcanic Zone. Geothermal vegetation is of high ecological significance, and almost all the geothermal vegetation within the area is in good condition. However, there are ongoing pressures from pest plants and pest animals which threaten ecological integrity. This paper presents information on important plants and fauna at the Waimangu-Rotomahana geothermal field (including Threatened and At Risk species), endangered ecosystem types, ecological pressures, and management requirements. A brief ecological history and a summary of geothermal vegetation and habitats present at other sites in this geothermal field is presented.

1. INTRODUCTION

1.1 Study aims

This study of the Waimangu-Rotomahana geothermal area, undertaken for Bay of Plenty Regional Council (BOPRC), is the first of a series of ecological inventory surveys which are planned for all geothermal sites in the Bay of Plenty Region. The surveys will provide information on the current distribution, extent, and character of geothermal vegetation, along with ecological pressures and threats to geothermal sites.

1.2 Cultural Context

Waimangu Geothermal Valley was returned to two iwi organisations in 2020: Te Mana o Ngāti Rangitihi Trust (Te Mana) and Tūhourangi Tribal Authority (TTA). Prior to this settlement, the land was leased from the Department of Conservation and managed as an ecotourism business. Both Tūhourangi and Ngāti Rangitihi lived within the geothermal areas and the lakes of Waimangu-Rotomahana-Tarawera prior to the 1886 eruption, including many who were killed or displaced by it. The sites are of deep significance to the iwi and remain a vital part of their history and culture.

1.3 Waimangu-Rotomahana geothermal site and environment

The Waimangu-Rotomahana geothermal field is located within the Taupō Volcanic Zone (TVZ), across the south-western margin of the Ōkataina Volcanic Centre. The site is c.20 kilometres southeast of Rotorua City in the southwestern part of the Bay of Plenty Region, Te Ika-a-Māui/North Island, Aotearoa New Zealand (Figure 1). The area assessed in this study includes the Waimangu Geothermal Valley, and margins and cliffs of Lake Rotomahana. Waimangu-Rotomahana is part of the Waikite-Waiotapu-Waimangu Geothermal System (Waikato Regional Council 2011) and is within the Waimangu-Tarawera-Rotomahana Geothermal Field (WTRGF). The Waikite-Waiotapu-Waimangu Geothermal System (WWWGS, including the Waiotapu and Waikite Geothermal Fields) contains the largest area of geothermal habitat at any geothermal system in the TVZ and extends across the boundary between the Bay of Plenty (all the WTRGF) and Waikato Regions (including most of Waiotapu and all the Waikite Geothermal Fields).

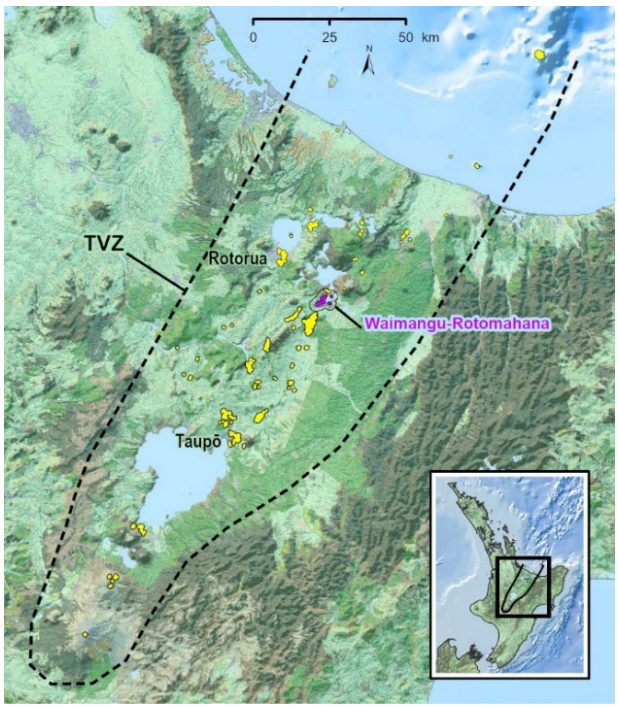

Figure 1: Location of geothermal vegetation in the Waimangu-Rotomahana geothermal site (purple) and other geothermal sites (yellow) within the approximate boundary of the TVZ. TVZ = Taupō Volcanic Zone.

On a related note, Bay of Plenty Regional Council refers to Waimangu-Rotomahana-Tarawera as its own system in planning documents (e.g. Zuquim et al. 2023, BOPRC 2014,

GNS Science and BOPRC, 2021) and has been reviewing the boundaries of the extent of 17 recognised systems in the Bay of Plenty Region.

Geothermal habitats at Waimangu, Rotomahana, and Tarawera - along with two other sites in the Bay of Plenty Region - are listed as Management Group 1, a Protected geothermal system, with the complete preservation of the outstanding natural, intrinsic, scenic, cultural, heritage, and ecological values (BOPRC 2014). The Waikite-Waiotapu-Waimangu Geothermal System has also been identified as a protected system by both the Waikato and Bay of Plenty Regional Councils. For the Bay of Plenty Region, this means no existing extractive use or potential for extractive use, e.g. energy production.

The soil, water, and unusual atmospheric chemistry of geothermal areas can be important determinants of the plant species present and their relative abundance at different geothermal sites. One important factor can be the variation in acidity between sites. Simmons et al. (1993) measured the pH levels of many springs at Waimangu-Rotomahana, with most springs at the steaming cliffs beside Lake Rotomahana being in the range of pH 7.3-9.1 and similarly most features in the Waimangu Geothermal Valley ranging from pH 7.4 to 8.5, but the lake at Inferno Crater was very acidic at pH 2.5.

1.4 Vegetation and habitat changes due to the 1886 eruption

The volcanic eruption of the Tarawera Rift on 10 June 1886 modified the character of the geothermal activity in the vicinity of the pre-eruption Lake Rotomahana (Kissing *et al.* 2022). Of note, was the loss of what would have been areas of significant geothermal vegetation and habitat surrounding Te Tarata (White Terrace) and Otukapuarangi (Pink Terrace) (Keam 2016). Furthermore, there are likely to have been other areas of geothermal vegetation and habitats surrounding the two lakes (Lake Rotomahana (pre-1886) and Lake Rotomakariri), where Lake Rotomahana currently lies.

While no detailed vegetation assessments to map the extent and quality of the geothermal habitats present prior to the eruption are known, pre-eruption photographs, paintings and descriptions show extensive areas of typical geothermal vegetation and habitats near the terraces and margins of the lakes, including what is almost certainly geothermal kānuka (Kunzea tenuicaulis) scrub and shrubland, and geothermal wetlands, e.g. 1885 photographs of G.D. Valentine, pages 42 and 47 in Hall 2004. Hochstetter and Petermann (1864) published a map indicating the area of hot ground, rocks composed into many-coloured clays, and emitting jets of steam (page 97: Johnston and Nolden 2011). Watercolour paintings of the areas surrounding the terraces (such as the painting by Charles Heaphy, page 100: Johnston and Nolden 2011) show extensive geothermal vegetation, particularly expansive areas of geothermal kānuka scrub.

Geothermal vegetation and habitats lost during the 1886 eruption would have been a considerable portion of the geothermal vegetation present at that time, at a regional level, and probably at a national level. Based on many years of field research, and mapping and describing vegetation at geothermal sites throughout the TVZ, it has become increasingly evident to the authors that short field surveys of larger geothermal sites can miss many areas of geothermal habitat. Even with high-quality aerial photography, many geothermal features are hidden by vegetation or landforms. Therefore, any estimates based on partial information would likely be an underestimate. This does not undermine the importance of the early information collected in difficult conditions during the pre- and post- eruption visits to the area by scientists, such as Hochstetter, artists, and photographers, as without the information they collected, much less would be known about these sites today.

Devastation created by the 1886 eruption was so intense that it is believed that all current geothermal vegetation and habitats in Waimangu Geothermal Valley, and on the margins of Lake Rotomahana, have established since the eruption. This makes it the youngest area of geothermal vegetation and habitats of this size in Aotearoa New Zealand. Similarly, there was also an increase in extent of geothermal vegetation and habitats surrounding Te Maari Crater at Tongariro, following the Te Maari Crater eruptions of 2012 (Wildland Consultants 2023), although at this site it was not a complete loss of geothermal habitats. Photographs in the vicinity of the Waimangu-Rotomahana geothermal site taken after the eruption by G.D. Valentine in 1886 (pages 76-77: Hall 2004) show complete devastation and no vegetation, only bare ground and rocks. This confirms that all the vegetation currently present in Waimangu Geothermal Valley and on the margins of Lake Rotomahana has established since the eruption. Devastation of the vegetation was subsequently also reported by Turner (1928), who also noted the colonisation of 'pioneer' vegetation on the margins of Lake Rotomahana and near Waimangu Geyser following visits to the area in 1900. Nicholls (1959) summarises the effects of the eruption on surrounding forests and concludes that there would have been complete destruction of any vegetation within 3-4 miles (5-6 km) of the main fissures; this certainly would have encompassed any pre-eruption Waimangu-Rotomahana geothermal vegetation. Geothermal vegetation is likely to have developed slowly following the eruption, along with the natural succession of other non-geothermal habitats. Simmons et al. (1993) stated that it took several years for hot springs to develop along the 1886 craters southwest of Lake Rotomahana. The diverse geothermal features currently present at the Waimangu-Rotomahana geothermal site occur in an area where no features were known prior to the 1886 eruption (Simmons et al 1993, Stucker et al. 2016).

1.5 Other geothermal sites in the Waimangu-Tarawera Rotomahana Geothermal Field

Locations of terrestrial and wetland geothermal habitats in the WTRGF have been mapped and described at four geothermal sites (Figure 2; Wildland Consultants 2020). Most of the geothermal vegetation in the WTRGF currently occurs within the Waimangu-Rotomahana geothermal site, which is the focus of the current study. A brief description of the other three areas of geothermal surface activity with terrestrial geothermal vegetation and habitats present in the wider WTRGF, is provided here.

- Tarawera Rift. In the central craters of the summit of Mt Tarawera there is a small area of geothermally-heated ground habitat with fumaroles. This geothermal site was most recently assessed in 2005, covering an area of c.0.2 hectares at c.960 metres elevation. Species representative of geothermal habitats that are present include geothermal kānuka and the clubmoss Palhinhaea cernua.

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- Waimangu North. This small area (c.0.3 hectares) of geothermally-heated habitat occurs between Lake Rotomahana and Lake Tarawera, and is referred to as Waimangu North (Fitzgerald and Smale 2010). This site contains geothermal kānuka scrub, and small populations of the geothermal ferns Nephrolepis flexuosa and Psilotum nudum, but the ecology and values present are poorly known compared to other sites in this geothermal field.

- Te Rātā (Hot Water Beach). The geothermal site is located near the southern end of Lake Tarawera, centred around Te Rātā Bay/Hot Water Beach and the lower Wairua Stream Valley (Wildland Consultants 2005, 2020). Approximately three hectares of terrestrial and emergent wetland geothermal vegetation is mapped at this site, comprising kānuka (Kunzea robusta) scrub, geothermal kānuka scrub, mixed indigenous-exotic grassland and geothermal wetlands. Te Rātā geothermal site has populations of the geothermal fern species, Cyclosorus interruptus, Nephrolepis flexuosa, and Christella aff. dentata ("thermal"). Also of botanical interest are hybrid populations of pōhutukawa (Metrosideros excelsa) with northern rātā (Metrosideros robusta) near the lake shoreline.

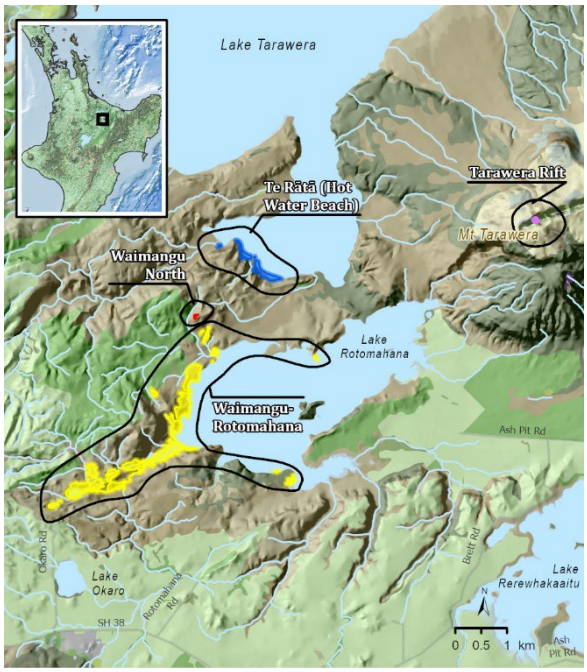

Figure 2: Location of geothermal sites in the Waimangu-Rotomahana-Tarawera Geothermal Field.

There are extensive geothermal features on the beds of Lakes Tarawera (e.g. Caratori Tontini et al. 2023) and Rotomahana (e.g. de Ronde et al. 2016), although these habitats and their connections to the various geothermal systems are beyond the scope of this paper.

2. METHODS

2.1 Background and preparation

Geothermal sites in the TVZ have been visited and assessed in ecological surveys undertaken on many occasions (e.g. Wildland Consultants 2005). Background information for the 2023-24 project was collated on the Waimangu-Rotomahana geothermal site, including aerial photographs and previous reports.

2.2 Field surveys and post-field work assessment

The Waimangu Geothermal Valley was surveyed on 15 December 2023. Most of the site was visited on-foot or viewed from a safe distance. Lake Rotomahana and its Steaming Cliffs were surveyed on 21 March 2024 by boat and on foot. Geothermal vegetation and habitat type boundaries were updated in the field. Some areas that could not be accessed by walk-through surveys, as they were either too dangerous or remote, were assessed using aerial photographs.

The following information was collected in the field:

- A list of vascular plant species seen during the survey was prepared. Species not seen during the current survey but recorded in published works were also included and referenced.

- Within each Vegetation and Habitat Type, the distribution and abundance of pest species (including species listed in the Regional Pest Management Plan (BOPRC 2022) were identified. Where possible, GPS co-ordinates were recorded of pest plant species that were less common at the site.

- For species of conservation concern (listed as Threatened and At Risk species in de Lange et al. 2024, except geothermal kānuka), GPS co-ordinates of all individuals/ populations found were recorded. Note this often had to be estimated from a safe viewing distance due to the dangerous nature of the site.

- Incidental fauna observations and "notable" plant species observed during field surveys were recorded.

- Any pest animal sign or observed presence was recorded.

Following field work, boundaries were finalised using 2021 aerial photographs, with reference to oblique photographs provided by Bay of Plenty Regional Council, especially for areas that could not be visited safely.

An updated inventory site sheet for the Waimangu-Rotomahana geothermal site was prepared to capture the new information collected in the field, i.e. vegetation maps, vegetation and habitat descriptions, and a condition assessment.

The following were calculated:

- The extent of each pest plant species (% cover) in each vegetation type within the site. These were later used to prepare management units to prioritise pest plant control.

- Changes in the extent of geothermal vegetation and habitats since 2016 (Wildland Consultants 2020 and earlier inventories), including assessment of how much of the change could be considered real change or artefact change, i.e. based on higher-quality imagery and better site information.

Management requirements, including priorities for the control of pest plants and pest animals, were identified based on the updated site information.

3. GEOTHERMAL HABITATS AND PLANTS

Geothermal ecosystems and vegetation are naturally rare in Aotearoa New Zealand (Williams et al. 2007) and internationally. Four types of geothermal ecosystems (fumaroles, geothermal stream sides, geothermally heated (dry) ground, and geothermal hydrothermally-altered ground (now cool)) have been classified as Critically Endangered in Aotearoa New Zealand (Holdaway et al. 2012, Wiser et al. 2013). Emergent geothermal wetlands were not included in the assessment of Holdaway et al. (2012) or Wiser et al. (2013) but these do provide habitat for Threatened and At Risk plant and fauna species and are greatly reduced in extent due to land use change and drainage. There are high-quality examples of all these ecosystem types at the Waimangu-Rotomahana geothermal site.

A total of c.54 hectares of terrestrial and emergent wetland geothermal habitat were mapped at Waimangu-Rotomahana, as per Figure 3. This site contains the largest area of geothermal habitat in the Bay of Plenty Region (outside of Whakaari/White Island). A wide diversity of habitats dominated by indigenous species are present, and more than half of the site is dominated by the geothermal endemic species geothermal kānuka (c.34 hectares) as scrub, shrubland, and occasional forest habitats. Other habitats present include kānuka (Kunzea robusta and K. tenuicaulis) forest, small pockets of pōhutukawa forest, fernland, c.3 hectares of geothermal wetland, and c.4 hectares of geothermally-influenced bare ground. Emergent wetlands are most notable in size in the lower Waimangu Geothermal Valley and on the margins of Lake Rotomahana.

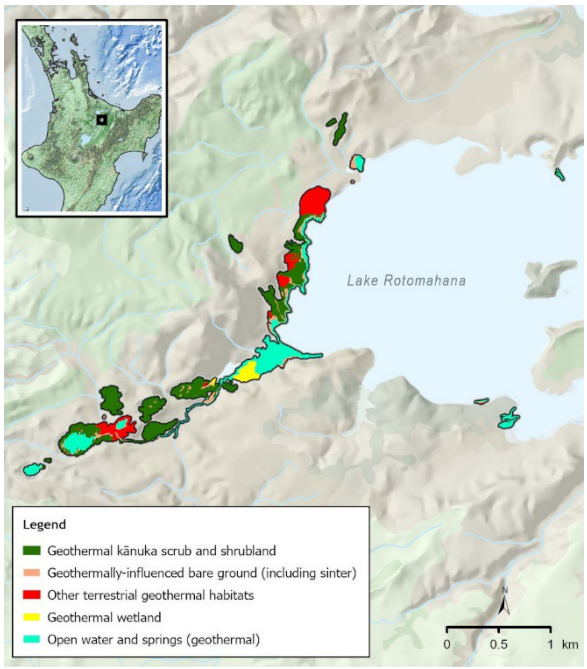

Figure 3: Broad scale mapping of geothermal vegetation and habitat types identified during field surveys in 2023-2024 at the Waimangu-Rotomahana geothermal site.

Botanical surveys at Waimangu-Rotomahana have been undertaken since at least the early 1970s (Given 1971, Atkinson 1972). During the 2023-2024 surveys an updated vascular plant species list (i.e. plants except mosses, liverworts and algae) was compiled for the site. Species were also included (and referenced) if they were recorded in previous published species lists compiled between 1985 and 2009 (Bellingham 1985, Clarkson and Watt 1986, Clarkson et al. 1989, Ecroyd et al. 1990, Ecroyd 1999, Howard-Williams and Ecroyd 1991, and Hobbs 2009) but were not recorded in the current survey. In total, 171 indigenous and 143 introduced species have been recorded at the Waimangu-Rotomahana geothermal site over this time. The high number of indigenous species reflects the diversity of habitats present at Waimangu-Rotomahana compared with other geothermal areas. For instance, the Tauhara Geothermal Field has 91 indigenous species in c.66 hectares, and Wairākei Geothermal Field has 110 indigenous species in c.98 hectares (Bycroft et al. 2023), despite both sites being considerably being considerably larger than Waimangu-Rotomahana.

Six nationally Threatened or At Risk plant species were observed at the Waimangu-Rotomahana geothermal site during the 2023-2024 surveys, as per the most recent assessment of the conservation status of indigenous plants (de Lange et al. 2024). While important populations for the conservation of many of these species occur at Waimangu-Rotomahana, none of the six are endemic to this geothermal system and all are also known to occur at other locations in the Bay of Plenty Region. These species are listed below with their threat status and plant type:

Threatened-Nationally Endangered	
Christella aff. dentata (“thermal”)	Fern
Dicranopteris linearis	Fern
At Risk-Declining	
Cyclosorus interruptus	Fern
At Risk-Naturally Uncommon	
Geothermal kānuka	Shrub or tree
Hypolepis dicksonioides	Fern
Nephrolepis flexuosa	Fern

Waimangu-Rotomahana contains some of the best quality geothermal vegetation and habitat types and is in the best overall condition of any of the larger geothermal sites in Te Ika-a-Māui/North Island . It contains the largest and best quality area of geothermal kānuka-dominant vegetation in the Bay of Plenty Region. Although the Wairākei-Tauhara Geothermal System, in the Waikato Region, has more geothermal kānuka habitat, it is not in as good condition, i.e. pest plants are more common, and there is degradation by other human activities. Additionally, parts of this system are subject to declining geothermally-heated ground (Bycroft et al. 2023). Waimangu-Rotomahana also has the largest populations in Te Ika-a-Māui/North Island of Nephrolepis flexuosa and Christella aff. dentata (“thermal”), and one of the largest populations of Dicranopteris linearis. The site forms part of an uninterrupted ecological sequence of indigenous vegetation extending from Lake Rotomahana and Lake Tarawera, up to the summits of the Tarawera, Ruawāhia, and Wahanga Domes, with regenerating indigenous forest surrounding the lakes following the 1886 eruption.

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4. AVIFAUNA

Forest, wetland and open water habitats at Waimangu-Rotomahana provide important habitat for indigenous birds. Of particular importance is the geothermal margins and open water of Lake Rotomahana, and its associated shoreline and wetlands that provide important habitat for water birds. The following Threatened and At Risk bird species (as per Robertson et al. 2021) were seen or heard at the site during the 2023-2024 survey: weweia/New Zealand dabchick (Poliocephalus rufopectus, Threatened-Nationally Increasing), kawaupaka/little shag (Microcarbo melanoleucos, At Risk-Relict), māpanga/black shag (Phalacrocorax carbo, At Risk-Relict), kawau-tūī/little black shag (Phalacrocorax sulcirostris, At Risk-Naturally Uncommon), kōtuku ngutupapa/royal spoonbill (Platalea regia, At Risk-Naturally Uncommon), Australasian coot (Fulica atra, At Risk-Naturally Uncommon), and toutouwai/North Island robin (Petroica longipes, At Risk-Declining). Pārera/grey duck (Anas superciliosa, Threatened-Nationally Vulnerable) have previously been recorded at the site (Wildland Consultants 2005). Staff at Waimangu Volcanic Valley reported that a North Island weka (Gallirallus australis greyi, At Risk-Relict) was present in 2023 but has since died (Martin Pearce pers comm.). Wetlands in the lower Waimangu Geothermal Valley are likely to support pūweto/spotless crake (Zapornia tabuensis tabuensis) and koroāito/North Island fernbird (Poodytes punctatus vealeae) (both classed as At Risk-Declining), as they have been observed by the authors in nearby wetlands, although neither of these species have been confirmed at Waimangu-Rotomahana during surveys to date. Koekoeā/ long-tailed cuckoo (Eudynamys taitensis, Threatened-Nationally Vulnerable) were also present in 2023-2024.

5. CHANGES IN VEGETATION WITHIN AND AROUND SIGNIFICANT GEOTHERMAL FEATURES

No real change in the extent of the Waimangu-Rotomahana geothermal site has been identified since it was first mapped in 1996 (Beadel et al. 1996, Wildland Consultants 2005). Likewise, there have also been no notable changes in extent of the major geothermal vegetation and habitat types between surveys. The mapped extent of geothermal vegetation has increased over time, a result of the discovery of more areas of existing geothermal habitat becoming visible on aerial photography.

6. THREATS AND MODIFICATION TO GEOTHERMAL HABITATS, AND FUTURE MANAGEMENT

6.1 Overview

Vegetation at the Waimangu-Rotomahana geothermal site has remained in relatively good ecological condition. There have been relatively minor impacts due to road and track construction, and local impacts from human visitors trampling vegetation. The main ongoing threats are pest plants and pest animals.

6.2 Pest plants

Pest plants are generally less common in the main Waimangu Geothermal Valley than on the hillslopes and cliffs above Lake Rotomahana to the north of the valley. These hillslopes and cliffs have a higher cover of pampas (Cortaderia selloana) and wilding pines, mostly radiata pine (Pinus radiata). Pampas is a significant threat in open habitats. All pampas and wilding conifers should be controlled throughout the site. A small population of willow-leaved hakea (Hakea salicifolia) is also present on the cliffs.

The main pest plant threats are summarised below:

- Wilding conifers have spread throughout the site (mostly radiata pine, but some Douglas fir (Pseudotsuga menziesi) are present in the central part of Waimangu Geothermal Valley.
- Pampas has a cover of <1 % in Waimangu Geothermal Valley.
- Franchet's cotoneaster (Cotoneaster franchetii) currently has a relatively low cover at the site, but is readily spread by birds. It is scattered in Waimangu Geothermal Valley and occasional along the lake edge. Without control, it is likely to increase in cover.
- Male fern (Dryopteris species[1]) is spreading markedly. It is now probably too extensive to eradicate as many plants are hidden under the forest canopy and are inaccessible. However, the site managers should be encouraged to control it when seen.
- Pteris cretica is occasionally present alongside stream margins and could potentially still be eradicated from the site.
- A small population of orange firethorn (Pyracantha angustifolia) is present to the north of Echo Crater.
- Shrubs and trees of barberry (Berberis glaucocarpa) are present in geothermal habitats, mainly east of Echo Crater. Chinese privet (Ligustrum sinense) is also present in this area and is likely to increase in cover in the understorey, particularly where the geothermal influence is less marked.
- A few exotic grasses have established locally on sinter, most notably Indian doab (Cynodon dactylon), narrow-leaved carpet grass (Axonopus fissifolius), and beard grass (Polypogon monspeliensis).

The biostatus of the fern Pteris vittata requires further work. This species is spreading widely at Waimangu-Rotomahana and it is unclear whether it is indigenous, introduced and naturalised, or exotic (c.f. Brownsey and Perrie 2012; Ecroyd and Miller 2012, de Lange 2025). If exotic, it poses a threat to other indigenous geothermal species that occupy similar habitats such as Nephrolepis flexuosa, Dicranopteris linearis, and Christella aff. dentata ("thermal"). Pteris vittata is abundant in geothermal areas in both Waimangu Geothermal Valley and on the hillslopes and cliffs above Lake Rotomahana to the north of the valley. If it is determined to be exotic, then control may be necessary if it threatens the cover of other special plants of geothermal habitats.

A wide range of other weedy woody pest plant species are widespread at Waimangu-Rotomahana, but are largely absent from the most active geothermal sites. These species

[1] Possibly both Dryopteris filix-mas and Dryopteris affinis.

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should be controlled where they are unsightly or clearly spreading into undisturbed indigenous habitats, including blackberry (Rubus fruticosus. agg.), Spanish heath (Erica lusitanica), broom (Cytisus scoparius), and buddleia (Buddleja davidii).

A priority order for pest plant control (of target species and habitats) at Waimangu-Rotomahana was developed based on feasibility of control and the impact control would have on the geothermal character of the site. Species with the highest priority for control (Priority 1) occur in relatively low abundance, and control is necessary before they become widespread at the site. Examples include orange firethorn and willow-leaved hakea. Any new pest plant species found at the site in the future could be added to this priority category if they are readily controllable. Priority 2 includes species that are relatively feasible to control and can change the character of geothermal sites if not controlled but will require ongoing effort. Wilding conifers and pampas are in this category. Priority 3 encompasses pest plant species which threaten the highest quality parts of geothermal sites or are unsightly. These species are unlikely to be easily eradicated but can feasibly be controlled in geothermal habitats, particularly site margins. Examples include blackberry, Franchet's cotoneaster, and narrow-leaved carpet grass.

6.2 Pest animals

Incidental observations of wallabies (Notomarcropus sp.), deer (Cervus sp.), brushtail possums (Trichosurus vulpecula), and European rabbits (Oryctolagus cuniculus) were recorded during the 2023-2024 field surveys at Waimangu-Rotomahana geothermal site. Other pest animals likely to be present include European hares (Lepus europaeus), European hedgehogs (Erinaceus europaeus), and predators such as cats (Felis catus), ship rats (Rattus rattus), Norway rats (Rattus norvegicus), mice (Mus musulus), and mustelids such as stoats (Mustela erminea) and weasels (Mustela nivalis).

Pest animal control at Waimangu-Rotomahana would enhance the condition of the vegetation and habitats present. Emphasis should be placed on controlling wallabies, deer, possums, and lagomorphs, which have significant impacts on understorey vegetation and may affect geothermal vegetation by trampling. Possums are likely to be browsing on pōhutukawa and can cause severe damage to the canopy, resulting in dieback, if their numbers are not controlled.

Geothermal parts of Lake Rotomahana, particularly wetlands near the outlet of Waimangu Stream, are used by a wide range of water birds (as discussed above). Introduced predators have detrimental impacts on a range of indigenous fauna, including wetland bird species (O'Donnell et al. 2015). Predator control would help to protect avifauna populations, provide protection of breeding habitat for water birds such as weweia/New Zealand dabchick (Threatened-Nationally Increasing) and pāpango/New Zealand scaup (Aythya novaeseelandiae), and enhance other indigenous fauna populations.

6.3 Tourism

The Waimangu-Rotomahana geothermal site has been very well managed to keep tourists on tracks, and disturbance of significant vegetation and habitats has been minimal over the last few decades due to tracks being maintained to a high standard, and habitats being protected by not damaging vegetation.

7. MONITORING

Little formal permanent plot-based monitoring of geothermal vegetation and habitats has been undertaken at Waimangu-Rotomahana. Due to the importance of the site, it would be worthwhile to establish formal monitoring of geothermal vegetation. At a minimum this should include vegetation plots in geothermal kānuka habitats, a network of photopoints, and monitoring of the impacts of Pteris vittata on other geothermal fern species.

8. CONCLUSION

Botanical information has been collected from the Waimangu-Rotomahana geothermal site since at least the 1970s, with regular inventories being undertaken since 1996. Waimangu-Rotomahana contains some of the best geothermal vegetation and habitat types, and is in the best overall condition of any of the larger geothermal sites in Te Ika-a-Māui/North Island of Aotearoa New Zealand. The site is of high botanical and ecological interest for several reasons: it is the only relatively large geothermal site in Aotearoa New Zealand where it is known that the vegetation has developed following a volcanic eruption, and its maximum age is known (all vegetation is <140 years old). Despite the young age of the site, it also supports a high proportion of the diversity of the special vascular plants of geothermal sites, including some of the largest populations of some of these species. Key threats to the Waimangu-Rotomahana geothermal site are the ongoing impacts of pest plants and pest animals. Ongoing appropriate management of tourism operations is also crucial. Implementation of the pest plant management advice provided above is an opportunity to improve the ecological values of this internationally significant geothermal site.

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REFERENCES

Atkinson, I.A.E., (1972). *Report on Waimangu Reserve.* Unpublished report. Botany Division, Department of Scientific and Industrial Research. 8 pp.

Bay of Plenty Regional Council, (2014). *Bay of Plenty Regional Policy Statement 2014 (amended). Part 3.* Bay of Plenty Regional Council/Toi Moana (boprc.govt.nz).

Bay of Plenty Regional Council, (2022). *2023 Operational plant for the Bay of Plenty Regional Pest Management Plan 2020-2030:* Strategic Policy Publication 2022/03. Bay of Plenty Regional Council/Toi Moana (boprc.govt.nz).

Beadel S.M., MacKinnon S.M., and Shaw W.B. (1996). *Geothermal vegetation of the Bay of Plenty Region.* Wildland Consultants Ltd Contract Report No. 155. Prepared for Environment Bay of Plenty. 234 pp.

Bellingham, P. (1985). *Waimangu Thermal Valley Scenic Reserve 5/8/1985*. Unpublished report. Department of Lands and Survey. 3 pp.

Brownsey, P., Perrie, L., (2012). The biostatus of *Pteris vittata* in New Zealand. *New Zealand Botanical Society Newsletter No. 108:* 19-21.

Bycroft, C., McQueen J., Beadel, S., McQuillan, A., Shaw, W.S, (2023). Vegetation of Wairākei-Tauhara Geothermal System: History and Future Options. *Proceedings 45th New Zealand Geothermal Workshop. 15-17 November 2023, Auckland, New Zealand.* 6 pp.

Caratori Tontini F., de Ronde, C.E.J., Black, V.K., Stucker, S.L., Walker, S.L., (2023). The geology and geophysics of Lake Tarawera: Implications for sublacustrine geothermal activity. *Journal of Volcanology and Geothermal Research 433:* 107731.

Clarkson, B.D., Watt V.J., (1986). *Waimangu Scenic Reserve.* Unpublished report to Department of Lands and Survey, Hamilton. Botany Division, Department of Scientific and Industrial Research, Rotorua. Copy held on Department of Conservation File RSC-043. 7 pp.

Clarkson, B.D., Smith-Dodsworth, J., Beadel, S.M., (1989). *Waimangu Scenic Reserve.* Unpublished report to Department of Lands and Survey, Hamilton. Botany Division, Department of Scientific and Industrial Research, Rotorua. Copy held on Department of Conservation File RSC-043. 7 pp.

de Lange, P.J. (2025): Pteris vittata Fact Sheet (content continuously updated). New Zealand Plant Conservation Network. https://www.nzpcn.org.nz/flora/species/pteris-vittata/ (2 July 2025).

de Lange, P.J., Gosden, J. Courtney, S.P., Fergus, A.J., Barkla, J.W., Beadel, S.M., Champion, P.D., Hindmarsh-Walls, R., Makam, T., Michel, P., (2024). Conservation status of vascular plants in Aotearoa New Zealand, 2023. *New Zealand Threat Classification Series 43*. Department of Conservation, Wellington. 105 pp.

de Ronde, C.E.J., Walker, S.L., Le Blanc, C., Davy, V.W., Fornari, D.J., Caratori Tontini, F., Scott, B.J., Sebeck, H., Stewart, T.J., Mozat, A., Nicol, A., Tivey, M.A., (2016). Reconstruction of the geology and structure of Lake Rotomahana and its hydrothermal systems from high resolution multibeam mapping and seismic surveys: Effects of the 1886 Tarawera Rift eruption. *Journal of Volcanology and Geothermal Research 314*: 57-83.

Ecroyd, C.E., (1991). *Vegetation of Thermal Areas.* In: Clarkson B.D., Smale M.C., and Ecroyd C.E. (compilers) *Botany of Rotorua,* 65-72. Forest Research Institute, Rotorua, New Zealand.

Ecroyd, C.E., (1999). *Waimangu Scenic Reserve, 1 March 1999*. Unpublished list. Forest Research Institute Rotorua. 5 pp.

Ecroyd C., Clarkson, B. D., Wilcox, M., (1990). *Annotated list of vascular plants in the Rotorua Lakes Ecological District.* Rotorua Botanical Society Newsletter Special Issue No. 1. 69 pp.

Ecroyd, C., Miller, E., (2012). The biostatus of *Pteris vittata* in New Zealand: Response to Brownsey & Perrie. *New Zealand Botanical Society Newsletter No. 109:* 12-14.

Given, D.R., (1971). *Notes on some ferns and allies of fumarole areas at Waimangu.* Unpublished report. Botany Division, Department of Scientific and Industrial Research, Rotorua. 3 pp.

GNS Science and Bay of Plenty Regional Council, (2021): *Ngā punaha ngāwhā o Te Moana-ā-Toitehuatahi. Bay of Plenty Geothermal Systems: The Science Story.* Prepared by Brad Scott and Paul Scholes. Environment Summary Report – September 2021. 58 pp.

Fitzgerald, N., Smale, M., (2010): An updated assessment of the geothermal vegetation in the Bay of Plenty Region based on 2007 aerial photography. *Landcare Research Contract Report LC0016.* Prepared for Environment Bay of Plenty. 163 pp.

Hall K. (2004). George D. Valentine. A 19th Century photographer in New Zealand. Craig Potton Publishing. 132 pp.

Hobbs J., (2009). *Plant list for Waimangu Scenic Reserve.* Rotorua Botanical Society Newsletter 52: 10-16.

Hochstetter, F. von, Petermann A., (1864) *Geological and Topographical Atlas of New Zealand. Six maps of the Provinces of Auckland and Nelson.* Auckland.

Holdaway R.J., Wiser S.K., Williams P.K., (2012). *Status assessment of New Zealand's naturally uncommon ecosystems.* Conservation Biology 26(4): 619-629. DOI:10.1111/j.1523-1739.2012.01868.x

Howard-Williams C., Ecroyd C., (1991). *Lake Rotomahana Field Trip: 24 February 1991.* Rotorua Botanical Society Newsletter 22: 10-14.

Johnston, M., Nolden, S., (2011). *Travels of Hochstetter and Haast in New Zealand 1858-60.* Nikau Press. 336 pp.

Keam, R.F., (2016). The Tarawera eruption, Lake Rotomahana, and the origin of the Pink and White Terraces. *Journal of Volcanology and Geothermal Research 314:*10-38.

Kissing, W.M., Pearson-Grant, S.C., de Ronde, C.E.J., (2002). Fluid and heat flow at Lake Rotomahana prior to the 1886 Tarawera Rift eruption, Taupo Volcanic Zone, New Zealand. *Journal of Volcanology and Geothermal Research 431: DOI: 10.1016/j.jvolgeores.2015.07.002*.

Nicholls, J. L. (1959). The volcanic eruptions of Mt Tarawera and Lake Rotomahana and effects on surrounding forests. *New Zealand Journal of Forestry 8 (1):* 133-42.

O'Donnell, C.F.J., Clapperton, B.K., Monks, J.M. (2015). *Impacts of mammalian predators on indigenous birds*

of freshwater wetland in New Zealand. New Zealand Journal of Ecology 39: 15-33.

Robertson, H.A., Baird, K. A., Elliott, G. P., Hitchmough, R. A., McArthur, N. J., Makan, T. D., Miskelly, C. M., O'Donnell, C. F. J., Sagar, P. M., Scofield, P. R., Taylor, G. A., Michel P., (2021). *Conservation status of birds in Aotearoa New Zealand, 2021.* New Zealand Threat Classification Series 36. Department of Conservation, Wellington. 43 pp.

Simmons, S.F., Keywood, M., Scott B.J., Keam R.F., (1993). Irreversible change of the Rotomahana-Waimangu hydrothermal system (New Zealand) as a consequence of a volcanic eruption. *Geology 21 (7)*: 643-646.

Stucker, V.K., de Ronde, C.E.J., Scott, B.J., Wilson, N.J., Walker, S.L., Lupton J.E., (2016). Subaerial and sublacustrine hydrothermal activity at Lake Rotomahana. *Journal of Volcanology and Geothermal Research 314*: 156-158.

Turner, E. P. 1928: A brief account of the re-establishment of vegetation on Tarawera Mountain since the eruption of 1886. *Transactions and proceedings of the New Zealand Institute 59 (1):* 60-6.

Waikato Regional Council 2011. Waikato Regional Plan: (Reprinted December 2011 – incorporating Variations No.2, No.5 and No.7) ed, Waikato Regional Council.

Wildland Consultants, (2005). *Geothermal Vegetation of the Bay of Plenty Region based on 2003 digital aerial photographs.* Wildland Consultants Ltd Contract Report No. 1072. Prepared for Environment Bay of Plenty. 266 pp.

Wildland Consultants, (2020). An assessment of gain and loss of geothermal vegetation and habitats in the Bay of Plenty Region based on recent aerial photographs since 2016. *Wildland Consultants Ltd Contract Report No. 5404.* Prepared for Bay of Plenty Regional Council. 283 pp.

Wildland Consultants, (2023). *Geothermal Vegetation of the Waikato Region.* Wildland Consultants Ltd Contract Report No. 3330d. Prepared for Waikato Regional Council. 588 pp.

Wildland Consultants, (2024). *Extent and condition of geothermal vegetation and habitats at the Waimangu-Rotomahana site.* Wildland Consultants Contract Report No. 7067a. Prepared for Bay of Plenty Regional Council. 67 pp.

Williams, P.A, Wiser, S., Clarkson, B., and Stanley, M.C. (2007). New Zealand's historically rare terrestrial ecosystems set in a physical and physiognomic framework. *New Zealand Journal of Ecology 31(2)*: 119-128.

Wiser, S.K., Buxton, R.P., Clarkson, B.R., Hoare, R.J.B., Holdaway, R.J., Richardson, S.J., Smale, M.C., West, C., Williams, P.A. (2013). *New Zealand's naturally uncommon ecosystems.* In: Dymond J.R. (ed.). *Ecosystem services in New Zealand – conditions and trends,* 49-61. Manaaki Whenua Press, Lincoln, New Zealand.

Zuquim, M, Box, C. Camburb, F. (2023). Geothermal Systems of the Bay of Plenty Region, Aotearoa New Zealand -Inventory and Systems Extent. Proc. 45th New Zealand Geothermal Workshop, Auckland, New Zealand.

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