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Ecological indicators for geothermal vegetation and habitats in the Waikato region

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ECOLOGICAL INDICATORS FOR GEOTHERMAL VEGETATION AND HABITATS IN THE WAIKATO REGION

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ECOLOGICAL INDICATORS FOR GEOTHERMAL VEGETATION AND HABITATS IN THE WAIKATO REGION

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1. INTRODUCTION

Waikato Regional Council wishes to develop simple and accurate indicators for assessment of the extent, condition, and protection level of geothermal vegetation and habitats in the Region. Geothermal ecosystems are some of the most threatened in the Region, having undergone significant reductions in extent and condition.

The Council considers that good indicators should meet the following criteria (c.f. http://www.conservationmeasures.org,):

- Measureable: able to be recorded and analysed in quantitative or qualitative terms.
- Precise: defined in the same way by all stakeholders.
- Consistent: not changing over time so that comparable measurements are always available.
- Sensitive: changing proportionately in response to actual changes in the condition or item being measured.

Ideally, the indicators should have ranking categories such as Very Good, Good, Fair, and Poor.

This report addresses the above requirements and provides a set of indicators suitable for application to geothermal vegetation and habitats across the Region.

2. METHODS

Relevant information on monitoring indicators was reviewed, along with information on geothermal vegetation and habitats held in Wildland Consultants' databases. A geothermal indicators framework was then developed.

Potential indicators could include the extent of geothermal habitats and vegetation types, number and area of identified significant natural areas (SNA), and the extent of legal protection status, such as reserves and covenants, that cover geothermal habitats. The condition of geothermal vegetation and habitats is more difficult to assess in a simple yet quantitative manner, but options for indicators could include attributes such as the presence, abundance, and distribution of Threatened and At Risk species that rely on geothermal habitats, presence and abundance of invasive weeds, and the extent of bare soil, open water, and geothermal vegetation, which may indicate changes in geothermal hydrology.

We suggest that the following indicators could be used in a geothermal indicator framework:

- Extent
  - Area of identified geothermal SNA
  - Area of legally protected geothermal SNA
  - Scale

- Condition
  - Diversity of geothermal habitats
  - Indigenous dominance
  - Vegetation and habitat structure and composition
  - Characteristic species and diversity
  - Threatened and uncommon species
  - Direct human activity
  - Pest plants
  - Pest animals

Landscape context could also be assessed within an indicators framework, as site context can be a determinant of relative ecological value of geothermal sites, e.g. diverse sites set in a wider matrix of indigenous vegetation tend to be of higher relative value.

- Landscape context
  - Connectivity to other indigenous ecosystems and SNA.
  - State of hydrological regime.
  - Landscape pattern.
  - Human activity (already addressed in the Condition indicator above).

Each of these potential indicators is addressed in separate sections below, with an explanation, methods, and issues provided for each.

3. EXTENT

3.1 Area of identified geothermal SNAs

Explanation

The current area of geothermal SNAs provides a benchmark against which loss can be measured. Loss may occur due to land development pressures such as vegetation removal to enable agricultural or horticultural use, or urban expansion and road construction. Loss can also occur due to indirect effects such as geothermal fluid extraction and wetland drainage. In most instances, vegetation removal would result in habitat destruction, or decline in habitat quality, which has adverse impacts on indigenous biota, and physical processes (such as maintenance of water quality or erosion prevention), in addition to adverse effects on vegetation and flora.

Method

The extent of geothermal vegetation and habitats can be mapped for each site (with location of boundaries confirmed by field survey, and the number and area of sites would be calculated using digital mapping in a GIS.

Issues

- The resolution and quality of aerial imagery varies, which could result in changes to geothermal area boundaries that are not reflected in changes on the ground,

however this can be identified when measuring this indicator through knowledge of the site and comparison of aerial photographs of different ages.

- Boundaries between geothermal and non-geothermal habitats may be somewhat arbitrary as there is often a gradual decrease in geothermal influence, which can make the resulting transition zone difficult to map. Some major types are more clearly evident on recent photography (post-2011) such as prostrate kanuka scrub <2 m tall, but other types are more difficult to assess using aerial photographs. For wetlands it can be difficult to assess which parts of a wetland are subject to a geothermal influence, and what parts are not, e.g. the geothermal mānuka wetland at Waiotapu South. This is often also not easily rectified by field survey, as often these areas can be physically difficult and dangerous to walk through.

- Extent of an SNA can be somewhat arbitrary. For example, Waiotapu South and Waiotapu North could arguably be amalgamated (also Rotokawa and Rotokawa North). If sites have been amalgamated or split this should be reflected in application of the ratings.

Indicator Ratings

A potential framework for rating elements of this indicator is set out below. The three elements are related, but measure different attributes. It is important for interpretation that any changes detected are real changes, and not caused by mapping resolution differences.

- Individual geothermal SNA extent[1]:
  - Very good: No loss in area of any geothermal SNA.
  - Good: 1-2 individual SNAs have declined slightly in area.
  - Moderate: 3-5 geothermal SNAs have been reduced slightly in extent.
  - Low: 5-10 geothermal SNAs have declined in extent.
  - Very Low: More than 10 geothermal SNAs have declined in extent.

- Total geothermal SNA extent:
  - Very good: Total geothermal SNA extent has increased.
  - Good: Total geothermal SNA extent is stable.
  - Moderate: Total geothermal SNA extent has reduced by <1%.
  - Low: Total geothermal SNA extent has reduced by 1-5%.
  - Very Low: Total geothermal SNA extent has reduced by >5%

- Number[2] of geothermal SNAs:
  - Very good: Number of geothermal SNAs has increased[1].
  - Good: Number of geothermal SNAs is stable.
  - Moderate: Number of geothermal SNAs has reduced by <1%.
  - Low: Number of geothermal SNAs has reduced by 1-5%.
  - Very Low: Number of geothermal SNAs has reduced by >5%.

[1] Assessment to be based on the current grouping of geothermal habitat in the SNAs.

[2] Would require definition of what would be defined as a "new" SNA, e.g. new areas of geothermal habitat that are greater than 100 m from existing areas identified in geothermal SNAs.

3.2 Area of legally protected geothermal SNA

Explanation

The area (ha) of legally protected geothermal SNA is a measure of community (and political) attitudes to the value of these natural areas. Legal protection is important because it is a strong mechanism to prevent a site from being destroyed, and helps to ensure long-term security of sites.

Method

The extent of legally protected natural areas can be derived using a GIS and relevant digital data. Comparisons can be made, between years, of the total extent of legally-protected geothermal SNA.

Protection status could include reserves (Council, Department of Conservation) or covenants (QEII, Department of Conservation, Nga Whenua Rahui). Note that some areas are managed by Councils for recreational use, rather than the protection of ecological values. These need to be recognised separately in any assessment, and they may also have ecological values.

Issues

- Legal protection doesn't prevent sites from being destroyed or degraded by fire, pest animals, pest plants, subsurface extraction of geothermal fluid, and other direct and indirect human impacts. Protection from such threats may require other types of protection, such as protective resource conditions or active management to address threats.

3.3 Scale

Extent and legal protection can be summarised by altitudinal range, bioclimatic zone, extent of each vegetation class or key geothermal types, land tenure, geothermal field, council boundary, and/or by level of relative ecological significance. This would provide a more nuanced evaluation of changes in extent or legal protection.

Indicator Ratings

- Total area of legally protected geothermal SNA extent:
  - Very good: Area of protected geothermal SNA extent has increased.
  - Good: Area of protected geothermal SNA extent is stable.
  - Moderate: Area of protected geothermal SNA extent has reduced by <1%.
  - Low: Area of protected geothermal SNA extent has reduced by 1-5%.
  - Very Low: Area of protected geothermal SNA extent has reduced by >5%.

- Number of legally protected geothermal SNAs[1]:
  - Very good: Number of legally protected geothermal SNAs has increased.
  - Good: Number of legally protected geothermal SNAs is stable.

[1] Assessment to be based on the current grouping of geothermal habitat in the SNAs.

- Moderate: Number of legally protected geothermal SNAs has reduced by <1%.
- Low: Number of legally protected geothermal SNAs has reduced by 1-5%.
- Very Low: Number of legally protected geothermal SNAs has reduced by >5%.

4. CONDITION

4.1 Diversity of geothermal habitats

Explanation

Habitat-diverse geothermal sites are likely to be more representative of natural geothermal vegetation and habitats, and provide habitat for characteristic geothermal species. The presence of geothermal habitats is also related to pressures such as extraction of geothermal fluid or drainage. Geothermal sites with a good diversity of habitat types are also likely to contain a good diversity of characteristic species.

Methods

Small and/or localised types of some geothermal habitats, such as fumaroles, geothermal stream-sides, heated ground, hydrothermally-altered ground, and geothermal wetlands, may not necessarily be mapped at all sites, but could be assessed on a presence/absence basis, using existing information. Geothermal habitats present at each site should be listed on site assessment forms, and those present should be circled/ticked.

Issues

- Geothermal habitats may be defined in different ways by different people.
- Not all habitat types will have been mapped.
- Habitat mapping may be at different scales.

Indicator Ratings

Geothermal habitats can be listed, for each site or groups of sites, and they can be scored on a presence/absence basis.

- Number of geothermal habitats present:
  - Very good: Five or more habitat types.
  - Good: Four habitat types.
  - Moderate: Three habitat types
  - Low: Two habitat types.
  - Very low: One habitat type.

4.2 Indigenous dominance

Explanation

Indigenous structural dominance can be assessed for each vegetation type at a site. For most vegetation types, assessment of indigenous versus exotic structural dominance should be relatively straightforward.

The ratio of indigenous to exotic plant species within geothermal vegetation can be used to indicate indigenous floristic dominance.

Vegetation pattern has been mapped at almost all geothermal sites in the North Island. Detailed digital vegetation type maps are available of all sites in the Waikato Region, and these types have been grouped into classes, which have also been classed as indigenous or exotic (Table 1).

Table 1: Geothermal vegetation and habitat classes in the Waikato Region.

Overview	Vegetation/Habitat Class
Indigenous-dominant vegetation	Indigenous forest and treeland
	Prostrate kānuka-dominant vegetation
	Mingimingi/mānuka/monoao/kānuka dominant scrub and shrubland
	Fernland
	Wetland vegetation
	Mossfield*
	Bare ground**
	Geothermal water
Exotic-dominant vegetation	Exotic forest and treeland
	Exotic vineland
	Exotic species-dominant scrub and shrubland
	Exotic grassland
	Exotic sedgeland
	Herbfield
Mixed indigenous-exotic woody vegetation	Mixed exotic-indigenous species forest
	Mixed exotic-indigenous species scrub
	Mixed indigenous-exotic shrubland

* Including *Campylopus* and other mosses, and indigenous liverworts.
** Including loamfield, sinter, boulderfield, and sandfield.

At individual sites, each of the broad classes in Table 1 has also been mapped in more detail, at a vegetation and habitat type level, e.g. Figure 1.

Method

Classify vegetation and habitat classes (and/or types) as being either predominantly indigenous or exotic. Sum the areas of indigenous vegetation cover for each geothermal area. The current extent of these classes/types can be used as a broad benchmark against which the loss or increase of key classes/types can be measured.

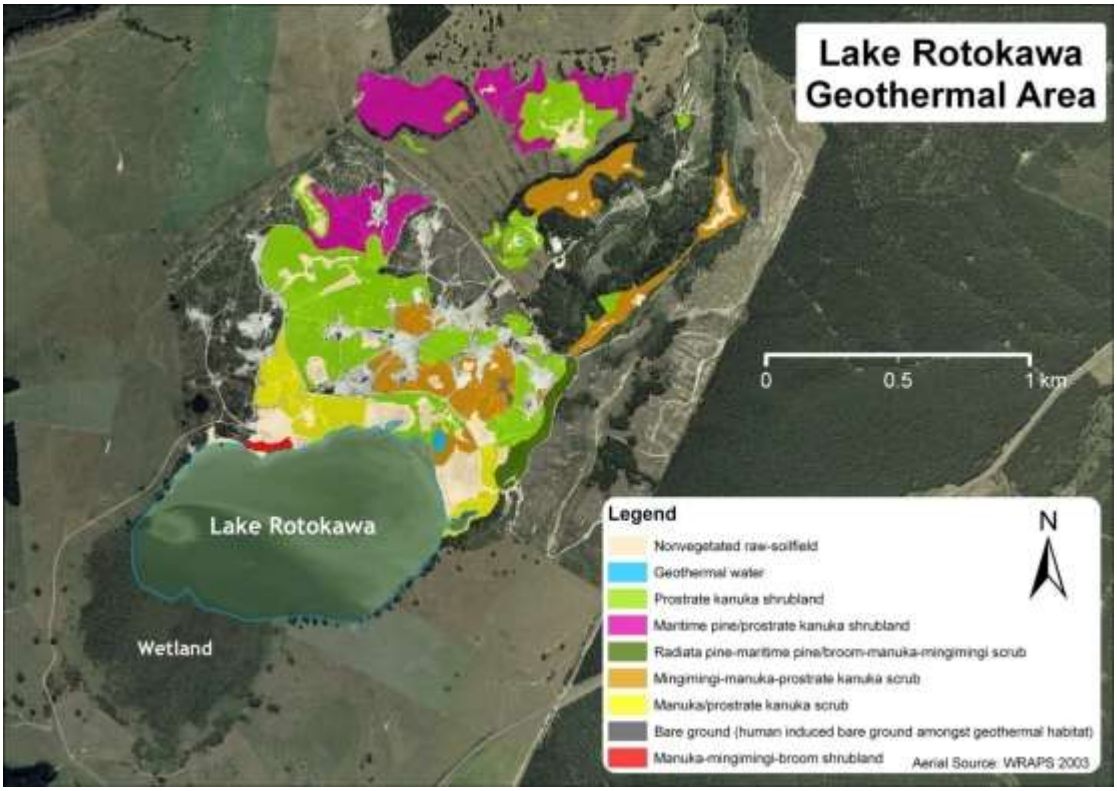

Figure 1: An example of vegetation type mapping of a geothermal area which could be used as a basis to assess the extent of indigenous cover.

Create a list of indigenous and exotic plant species for each geothermal area (based on existing information or field survey) and calculate the number of each (i.e. indigenous and exotic), and assess indigenous species richness and the proportion of indigenous species.

Issues

- Some vegetation classes/types may be difficult to assign to indigenous vs exotic status.
- The number of indigenous and exotic plant species detected will depend on observer skill and effort.

Indicator Ratings

Proportion of indigenous vegetation cover can be assessed within individual geothermal sites, and also as a total across all geothermal sites. The assessment of floristic indigenous dominance only makes sense within individual geothermal sites.

- Proportion of indigenous vegetation cover[1]:
  - Very good: Proportion of indigenous geothermal cover has increased.
  - Good: Proportion of indigenous geothermal cover is stable.

[1] Indigenous cover is vegetation with more than 50% cover of indigenous species.

- Moderate: Proportion of indigenous geothermal cover has reduced by <1%.
- Low: Proportion of indigenous geothermal cover has reduced by 1-5%.
- Very Low: Proportion of indigenous geothermal cover has reduced by >5%

- Indigenous floristic dominance:
  - Very good: No exotic plant species are present within geothermal vegetation.
  - Good: At least 90% of the plant species present are indigenous.
  - Moderate: Between 75% and 90% of the plant species present are indigenous.
  - Low: Between 50% and 75% of the plant species present are indigenous.
  - Very Low: Less than 50% of the plant species present are indigenous.

4.3 Vegetation and habitat structure and composition

Explanation

Where vegetation plots have been measured at a site, summaries of the variables measured can be calculated and assessed over time. Canopy cover and ground cover variables (vascular and non-vascular plant species cover, bare soil, rock/gravel, litter, geothermal water, lichen cover, bryophyte cover) are often good indicators of changes that may relate to substrate temperature (a key environmental factor for geothermal vegetation), soil/water chemistry, or human-induced or natural changes to geothermal hydrology.

Height-frequency data can be used to show changes in vegetation structure over time in communities that are less than 2 m tall.

Method

Change can be evaluated over time for vegetation composition and canopy cover and ground cover. Broad comparisons of changes in cover across different geothermal sites could also provide evidence of wider changes in the environment.

Maximum heights of species in particular plant groups (e.g. shrub/tree) can also be assessed over time. This might also indicate changes in soil temperature or geothermal hydrology. This should only be compared within the same vegetation type, as different vegetation types often differ in height. Height-frequency data can be used graphically to show changes in the structure of vegetation (Figure 2).

As it can be either dangerous (e.g. unstable crust) for human personnel, or potentially damaging to the vegetation (e.g. effects of human trampling around monitoring plots) it may not be appropriate to establish sample plots in some vegetation types at geothermal sites. An alternative approach is to use permanent photopoints. If photographs are taken of representative geothermal vegetation using an equivalent lens focal length, and are matched in the field to ensure that they cover the same field of view, then they can be used to evaluate changes in vegetation structure and composition over time. Changes can be assessed visually, say using a grid on the photographs, and software is available to assess vegetation change in photographs.

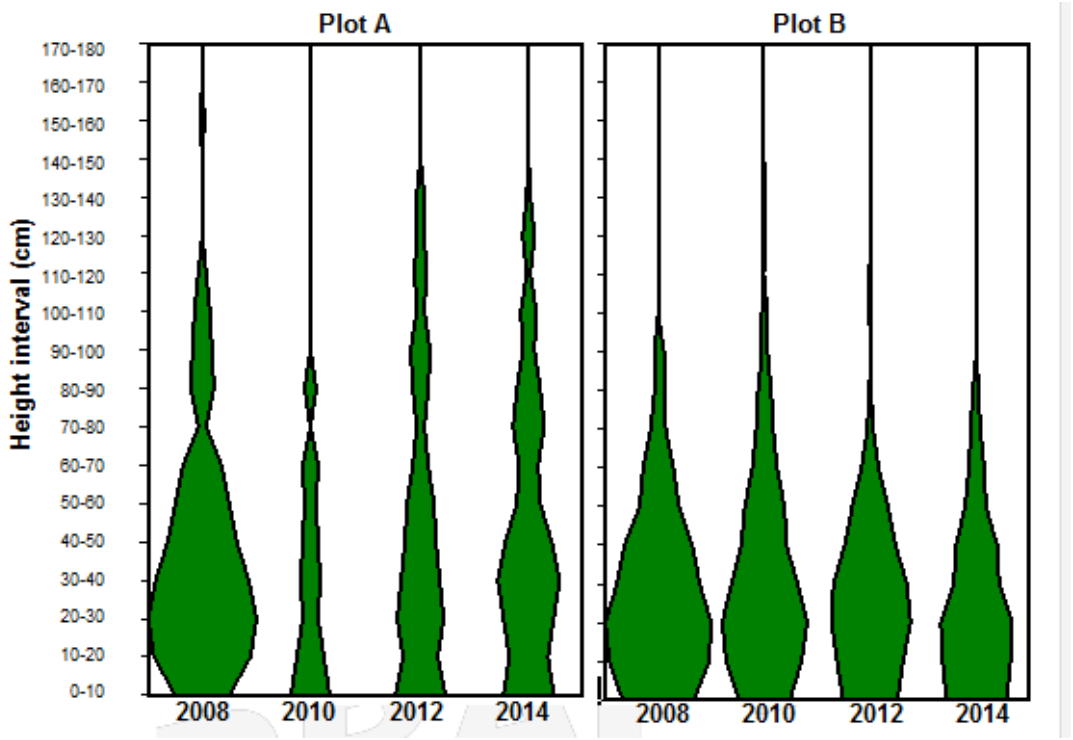

Figure 2: Example of height frequency changes for prostrate kānuka.

Issues

- Distinguishing between changes due to natural (e.g. variation in geothermal activity) or other processes (e.g. subsurface extraction of geothermal fluid for power generation) can be difficult.
- Monitoring can unintentionally alter the vegetation and habitats present by physically modifying the habitat through trampling damage and compression of substrate.

Indicator Ratings

A wide range of indicators are available from plot-based measurement. These could each be measured according to the degree of change between sampling intervals. For some indicators, an optimal level may need to be specified, with degree of change from the optimum level assessed.

- Degree of indicator change:
  - Very good: Increase or movement towards optimum level.
  - Good: Stable or no change in optimum level.
  - Moderate: Slight (<5%) decline from baseline level.
  - Low: Sizeable (6-10%) decline from baseline level..
  - Very Low: Significant decline from baseline level

4.4 Characteristic species and diversity

Explanation

Sites that support a high proportion of geothermal plant species are likely to be more intact.

Methods

Lists of vascular plant species are routinely collected during ecological surveys, and if entered into a site-specific database, can be easily summarised. If species are classified according to geothermal specificity (obligate vs facultative) the numbers of species in each of these categories can also be calculated, along with the proportion of geothermal species.

Characteristic plant species can also be documented.

Issues

- The number of species recorded at a site is related to the amount of search effort (and botanical skill levels and experience), so differences in species richness may result from differences in effort, rather than actual differences.
- Classification of indigenous species according to the degree of geothermal specificity may be problematic, or there may be too few geothermal obligates at particular sites to make this exercise useful.

Indicator Ratings

Classification of geothermal specificity has not been done, so the rating for this indicator would have a qualitative basis, based on the presence/absence of target geothermally-characteristic plant species[1]. The rating could be applied to an entire geothermal site, or to individual vegetation/habitat types within a geothermal site.

- Number of target 'geothermal' plant species:
  - Very good: Relatively large number of target 'geothermal' species are present.
  - Good: Large number of target 'geothermal' species are present.
  - Moderate: Moderate number of target 'geothermal' species are present.
  - Low: Few target 'geothermal' species are present.
  - Very Low: No target 'geothermal' species are present.

[1] Prostrate kānuka, *Korthalsella salicornioides*, *Christella* aff. *dentata* (b) (AK126902 "thermal"), *Cyclosorus interruptus*, *Hypolepis dicksonioides*, *Nephrolepis flexuosa*, *Dicranopteris linearis* var. *linearis*, *Thelypteris confluens*, *Schizaea dichotoma*, *Psilotum nudum*, *Fimbristylis velata*, *Calochilus paludosus*, *Calochilus robertsonii*, *Caladenia alata*, *Caleana minor* (only recorded from the Bay of Plenty Region in New Zealand), *Cheilanthes sieberi* var. *sieberi*, *Schizaea bifida*, *Corunastylis pumila*, *Stegostyla atradenia*, *Lycopodiella cernua*, *Isolepis cernua* var. *cernua*, *Triglochin striata*, turutu (*Dianella nigra*), monoao (*Dracophyllum subulatum*), mingimingi (*Leucopogon fasciculatus*), and mānuka (*Leptospermum scoparium* var. *scoparium*).

4.5 Threatened and uncommon species

Explanation

The presence of threatened or uncommon species at a site can potentially, but not always, indicate that a site is less degraded than other similar habitats. Also, an increase in the size or extent of a population of a threatened species may indicate an improvement in the state of the environment at that site (reflecting a lower level of threat from a threatening agent or process).

Information on the presence/absence of threatened plant species is generally available. If present, rare plants and fauna have been recorded at geothermal sites during field surveys. In some cases (e.g. geothermal ferns), individual plants (or clumps of plants) have been counted.

Plants:

Threatened and uncommon plant species recorded in geothermal areas in the Waikato Region include prostrate kānuka (*Kunzea tenuicaulis*), dwarf mistletoe *Korthalsella salicornioides*; the ferns *Christella* aff. *dentata* (b) (AK126902 "thermal"), *Cyclosorus interruptus*, *Hypolepis dicksonioides*, *Nephrolepis flexuosa*, *Dicranopteris linearis* var. *linearis*, *Thelypteris confluens*, and *Schizaea dichotoma*; the fern ally *Psilotum nudum*; the sedge *Fimbristylis velata*; and the orchids *Calochilus paludosus*, *Calochilus robertsonii*, *Caladenia alata*, *Cheilanthes sieberi* var. *sieberi*, *Corunastylis pumila*, *Stegostyla atradenia*, *Lycopodiella cernua*, *Isolepis cernua* var. *cernua*, and *Triglochin striata*,.

Fauna:

A number of Threatened and At Risk indigenous fauna are known to utilise geothermal habitats, including North Island fernbird (*Bowdleria punctate vealeae* - At Risk-Declining), spotless crake (*Porzana tabuensis tabuensis* - At Risk-Relict), bittern (*Botaurus poiciloptilus* - Threatened-Nationally Endangered), banded dotterel (*Charadrius bicinctus bicinctus* - Threatened-Nationally Vulnerable), New Zealand dabchick (*Poliocephalus rufopectus* - Threatened-Nationally Vulnerable), and black-billed gull (*Larus bulleri* - Threatened-Nationally Critical).

Methods

Threatened, uncommon, and characteristic species attributes that can be assessed over time include:

- Number of geothermal areas at which these species are present.
- Number of geothermal areas occupied by particular species.
- Changes in population size, where species populations have been measured or counted. This needs to take account of seasonal fluctuations in population sizes.
- Height-frequency changes can be compared graphically (Figure 2) and statistically.

Issues

- It is difficult to identify individuals in populations of some plants, e,g. clumps of ferns such as *Christella* aff. *dentata* (b) (AK126902 "thermal") and *Cyclosorus interruptus*.
- Different methods have been used in other fern surveys to calculate population size (e.g. counting fronds as plants, and not differentiating between mature and juvenile plants).
- Population sizes of some fern species and orchid species can vary markedly from year-to-year, as well as showing seasonal fluctuations.
- The apparent absence of fern populations at some sites during some years does not always indicate that they are extinct at those sites.
- 'Density' of prostrate kānuka foliage (i.e. the sum of occurrences at each sample point) may not be related to soil temperature.
- Orchids can only be surveyed at certain times of the year, depending on the particular species.
- No bird species are characteristic of geothermal habitats in New Zealand, but there are likely to be invertebrate species that are restricted to geothermal habitats (e.g. the leech species known to occur at Lake Rotokawa).

Indicator Ratings

A mix of qualitative indicators, such as the number of geothermal sites at which key 'target' species (this includes threatened, at risk, uncommon, and characteristic species) are present, and quantitative indicators such as changes in the population sizes of target species, can be used. 'Target' species are listed in Section 4.4 above, excluding prostrate kānuka and *Lycopodiella cernua*. A list of potential indicators is set out below.

- Number of sites at which 'target' geothermal species are present:
  - Very good: A very large number of sites have 'target' geothermal species present (>50).
  - Good: A large number of sites have 'target' geothermal species present (40-50).
  - Moderate: A moderate number of sites have 'target' geothermal species present (20-40).
  - Low: Few sites have 'target' geothermal species present (4-20).
  - Very Low: Very few or no sites have 'target' geothermal species present (<5).
- Population change in target geothermal species within sites:
  - Very good: Target species population size is at or near carrying capacity in the site.
  - Good: Target species population size is below carrying capacity and increasing by at least 5% annually.

- Moderate: Target species population size is below carrying capacity and stable.
- Low: Target species population size is declining at less than 5% annually.
- Very Low: Target species population size is declining at more than 5% annually.

4.6 Direct human activity

Explanation

Human activity - such as dumping of rubbish, and other land use activities - can affect geothermal vegetation and can be monitored as a potential indicator of geothermal site damage. Modification of the hydrological regime through drainage or subsurface draw-off is covered in a specific indicator below.

Methods

The presence of rubbish, infilling, uncontrolled tourism and recreation use, mining, road works, fire, urbanisation, and surrounding land use activities has been recorded, and adverse effects have generally been described during site surveys.

If the effects of human activity were to be scored, say on a 1-5 qualitative scale, then indicators such as the levels of human impact across sites, or the number of geothermal sites where a certain level of human impacts had been recorded, could be calculated.

Issues

- Quantitative data on adverse effects has not been collected previously apart from the number of sites where particular types of impacts were recorded.

- Subjective assessments of damage levels and associated observer variation.
- It will be necessary to assess whether human impact damage is historic, recent, or is occurring naturally.

Indicator Ratings

Subjective assessment can be made more rigorous if clear terms are used in definitions.

- Damage from human activities to specific geothermal sites:
  - Very good: No damage from human activities.
  - Good: Minor damage from human activities.
  - Moderate: Significant damage from human activities in parts of the site.
  - Low: Significant damage from human activities across most of the site.
  - Very low: Significant irreparable damage across most of the site.

- Number of geothermal sites affected by damage from human activities:
  - Very good: No sites affected by damage from human activities.
  - Good: No more than minor damage at any site caused by human activities.

- Moderate: Significant damage from human activities at <5% of sites.
- Low: Significant damage from human activities at 5%-25% of sites.
- Very low: More than 25% of geothermal sites affected by significant damage from human activities.

4.7 Pest plants

Explanation

Pest plants have the potential to displace indigenous species through competition, e.g. weeds that out-compete indigenous species at disturbed sites. The distribution and abundance of pest plants can be used as an indicator of the weed pressure being experienced by a site. Recording of the pest plant species at a site, and their relative abundance and/or extent, can be used as an indicator of the degree of site modification.

Methods

Pest plant presence and/or an estimate of abundance have been recorded during rapid surveys of many geothermal sites, and could be used to calculate the proportion of sites invaded by particular weeds, and the average abundance of weeds within or across sites.

The cover of pest plant species has been estimated within mapped units (e.g. Wildland Consultants 2010) and thus could be used as a cover attribute to assess changes over time.

Photopoints can be used to monitor change in the cover of pest plants, particularly wilding pines.

Issues

- Observer variation in the subjective assessment of weed abundance.
- Weeds need to be documented consistently across sites.
- Some pest plants have greater impacts on indigenous biodiversity than others.

Indicator Ratings

The indicators below require a list to be prepared of significant ecological pest plants in geothermal sites.

- Number of recognised pest plant species in individual geothermal sites
  - Very good: No recognised pest plant species are present.
  - Good: A single recognised pest plant species is present.
  - Moderate: 2-3 recognised pest plant species are present.
  - Low: 4-5 recognised pest plant species are present.
  - Very low: More than five recognised pest plant species are present.

- Number of geothermal sites at which individual recognised pest plants are established:
  - Very good: No geothermal sites colonised by pest plants.
  - Good: Less than 5% of geothermal sites colonised by pest plants.
  - Moderate: 5%-25% of geothermal sites colonised by pest plants.
  - Low: 26%-50% of geothermal sites colonised by pest plants.
  - Very low: More than 50% of geothermal sites colonised by pest plants.

- Cover of recognised pest plants:

  This indicator could be applied at the scale of an individual vegetation/habitat type, a single geothermal site, or across all geothermal sites.

  - Very good: Recognised pest plant species absent.
  - Good: Less than 1% cover of recognised pest plant species.
  - Moderate: 1%-5% cover of recognised pest plant species.
  - Low: 5%-20% cover of recognised pest plant species.
  - Very low: More than 20% cover of recognised pest plant species.

4.8 Pest animals

Explanation

Pest animals can adversely affect indigenous fauna at geothermal sites, and herbivory and trampling (e.g. deer, domestic stock) and rooting damage (e.g. feral pigs) can affect geothermal plant species. Other adverse effects can arise from possums (*Trichosurus vulpecula*) (herbivory and predation) and other predators, e.g. cat and mustelid predation of indigenous birds.

Methods

Presence of pest animals or their sign has been recorded during surveys of many geothermal sites, and could be used to assess the number of geothermal sites at which pest animal sign was recorded. This can also be documented for each species. Categories of observation type and abundance, such as seen, heard, or sign observed, and present versus common, could also be used to provide a more refined indication of pest animal occurrence. Tracking tunnel, wax tag, and chew card indices are techniques available for assessment of the activity levels of rodents (*Rattus* spp.), hedgehogs (*Erinaceus europaeus*), possums, and mustelids (*Mustela* spp.).

Potential indicator ratings could include:

- Presence/absence of pest animal species.
- Relative abundance (e.g. high, moderate, low) of selected pest animal species.
- Effects (e.g. damage: high, moderate, low, not evident) of selected pest animal species, e.g. possums, pigs, cattle, rabbits, hares.

Issues

- Some pest animals (e.g. rodents) may not be detected, at least not easily during single site visits.
- Seasonal variation in pest animal observability.
- Consistent data need to be collected.
- Pest animal indices need to be evaluated using standard protocols if the results are to be comparable between different sites or projects.
- Observer experience and skill levels.

Indicator Ratings

As with pest plants, a list of pest animal species will need to be developed for the indicators below. It may be necessary to limit the list to groups of animals such as ungulates, pigs, possums, and lagomorphs (hares and rabbits), that can be reliably detected by sign or observation during the day.

- Presence of pest animal species across all geothermal sites:
  - Very good: Pest animal sign present in less than 5% of geothermal sites.
  - Good: Pest animal sign present in 6%-25% of geothermal sites.
  - Moderate: Pest animal sign present in 26%-50% of geothermal sites.
  - Low: Pest animal sign present in 51%-75% of geothermal sites.
  - Very low: Pest animal sign present in more than 75% of geothermal sites.

- Abundance of pest animal species:
  - Very good: No sign or observation of pest animals.
  - Good: Sign or observation of pest animals recorded sparsely.
  - Moderate: Sign or frequent observation of pest animals.
  - Low: Sign or observation of dense pest animal activity in various parts of the site.
  - Very low: Pest animal activity abundant across the site.

- Adverse effects of pest animal species:
  - Very good: No adverse effects of pest animals evident.
  - Good: Less than minor effects of pest animals evident.
  - Moderate: Minor effects of pest animals evident.
  - Low: Significant effects of pest animals in parts of the site.
  - Very low: Significant effects of pest animals across most of the site.

5. LANDSCAPE CONTEXT

5.1 Connectivity and buffering

Explanation

Geothermal sites that are connected to other indigenous ecosystems and SNA or are part of a wider matrix of indigenous vegetation and habitats may have higher ecological value, and can, potentially, be better buffered from some external influences.

Methods

Wider context can be mapped and overall extent of contiguous indigenous vegetation can be determined.

Issues

- Geothermal sites are often present within a wider matrix of mixed indigenous and exotic vegetation.
- Refer to the issues outlined above under Section 3 Extent.

Indicator Ratings

- Extent of buffering:
  - Very good: Geothermal site completely surrounded by other indigenous habitat
  - Good: At least 75% of geothermal site margin is buffered by surrounding indigenous habitat.
  - Moderate: 25%-75% of geothermal site margin is buffered by surrounding indigenous habitat.
  - Low: Less than 25% of geothermal site margin is buffered by surrounding indigenous habitat.
  - Very low: No indigenous habitat surrounds the site.

5.2 Landscape pattern

Explanation

As discussed in the section above, the character of the landscape adjacent to and surrounding a geothermal site can be an important determinant of relative ecological value.

Methods

Landscape pattern adjacent to a geothermal site can be determined using vegetation and habitat mapping.

Issues

- Refer to the issues outlined in Section 5.1 above.

Indicator Ratings

- Surrounding landscape pattern:

  The area of different habitats can be determined at either a catchment scale, or within an arbitrary radius (for example 1km) around the geothermal site.

  - Very good: Indigenous habitats occupy the entire surrounding landscape.
  - Good: At least 75% of the surrounding landscape covered by indigenous habitat.
  - Moderate: 51%-75% of the surrounding landscape occupied by indigenous habitat.
  - Low: 20%-50% of the surrounding landscape occupied by indigenous habitat.
  - Very low: Less than 20% of the surrounding landscape occupied by indigenous habitat.

5.3 State of hydrological regime

Explanation

Many geothermal sites contain springs, lakes, and active water features. Lack of modification of hydrological regimes, by either surface or sub-surface draw-off, can be an important determinant of the relative naturalness of a site or key parts of a site.

Methods

The presence of surface or sub-surface draw-offs or waterway modification can be assessed relatively easily, although enquiries may be necessary to determine whether sub-surface draw-off is occurring (associated infrastructure may be located some distance from a geothermal site).

Potential indicator ratings include:

- Surface draw-off.
- Surface modification of drainage channels.
- Surface modification of springs or ponds/lakes.
- Sub-surface draw-off, without reinjection of geothermal fluid.
- Sub-surface draw-off, with reinjection of geothermal fluid.

Issues

- Surface effects of sub-surface draw-offs can be very hard to determine.
- Old surface modification of waterways may not be readily evident.

Indicator Ratings

- Hydrological modification:
  - Very good: No evidence of hydrological modification of the site.
  - Good: Hydrological modification is having only minor effects on geothermal habitats.
  - Moderate: Hydrological modification is having moderate effects on geothermal habitats at the site. More than 10% of the site has been affected by hydrological modifications.
  - Low: Hydrological modification is having significant effects in part of the site. Most of the site has been affected by hydrological modifications.
  - Very low: Hydrological modification is significantly affecting geothermal habitats across most of the site. Key values have been damaged or lost for all or most of the site.

6. DATA CAPTURE AND QUALITY

It is important that consistent data are captured for all indicators. This can be promoted by designing standard site assessment forms that have fields for all variables to be assessed. Standard forms should be designed for field use, to promote consistent capture of data. Qualitative categories can be listed on the form, with the appropriate option to be circled or ticked when identified in the field. Named blank cells should be used where data or unrestricted text need to be entered.

It is important that the data collected are able to be aggregated and analysed at various scales, to provide a basis for timely and meaningful reporting.

7. INDICATOR SET

A summary of potential geothermal indicators is provided in Table 4.

Table 4: Potential geothermal indicators for application in the Waikato Region.

Indicator Type	Indicator	Survey Type	Notes
Extent	Number and area of geothermal SNA	GIS plus ground-truthing	Could be summarised within ecological districts, council boundaries, or land environments, and by level of significance.
	Area and number of geothermal SNA protected	GIS	
Condition	Habitat diversity	Rapid field survey, GIS	Tick or circle habitats present on a pre-determined list.
	Indigenous dominance	Rapid field survey, GIS	Changes in indigenous cover in broad classes.
	Vegetation and habitat structure and composition	Intensive field assessment	Quantitative data from monitoring plots.
	Characteristic species and diversity[1]	Rapid field survey	Presence/abundance of significant geothermal plant species.

[1] See section 4.4

Indicator Type	Indicator	Survey Type	Notes
	Status of rare species populations (threatened and uncommon species)	Intensive field assessment	Demographic assessment.
	Human activity	Rapid field survey	Significance of land development, tracking, drainage, rubbish etc.
	Pest plants	Rapid field survey Vegetation plots Photopoints	Pest plant presence and/or abundance
	Pest animals	Various field survey methods	Pest animal presence and/or indices of relative abundance.
Landscape Context	Connectivity and buffering	GIS	Could be assessed relatively easily using existing data.
	Landscape pattern	GIS	Could be assessed relatively easily using existing data.
	State of hydrological regime	Rapid field survey	Assess physical modification.
		Inquiries via resource consent records	Determine whether consents are held for fluid use.

There are 13 potential indicators listed above, within three broad categories. Evaluation of all indicators for all sites would entail a reasonable amount of effort, and it may be appropriate to use selected indicators.

8. ASSESSMENT FREQUENCY

We suggest that the extent-based indicators, landscape context indicators, and rapidly-assessed condition indicators should be routinely assessed, with more intensive monitoring (for example demographic assessment of rare plant populations) to be undertaken where site values or pressures justify increased effort.

'Routine' assessments could be undertaken two- to five-yearly, or more frequently if required.

9. CONCLUSION

Geothermal ecosystems are one of the most threatened and sensitive ecosystem types in New Zealand and the Waikato Region. Simple and robust indicators are required, to provide relevant and timely information on changes over time. A comprehensive set of indicators has been developed, based on extent, condition, and landscape context. Each indicator is associated with a five-point scale by which the status of each indicator can be assessed. Indicator rating thresholds should be reviewed once monitoring has been implemented to ensure they are relevant and meaningful. The indicators can be assessed as part of an ongoing monitoring programme, which can be implemented at various levels of intensity, and frequency.

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