SUSTAINING GEOTHERMAL ECOSYSTEMS: GEOCHEMICAL INFLUENCE AND RESTORATION OF GEOTHERMAL ECOSYSTEMS

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ABSTRACT

New Zealand has a range of geothermally-influenced ecosystems with distinctive ecological features and biotic communities. Despite the significance of geothermal areas within New Zealand and the investment and interest in the use of geothermal resources to generate energy, studies of the ecology and functioning of these extreme environments have been sporadic. Recent studies of geothermal ecosystems in New Zealand have determined the diversity and characteristics of aquatic geothermal ecosystems. In this paper we examine the geochemical influence on the biota associated with geothermal ecosystems, by looking at the uptake of potential contaminants by plants in the vicinity of the geothermal fluids. We discuss the implications of these results for potential new developments and potential new sources of these contaminants to the earth's surface. In addition we consider the implications of the geochemical influence on the potential to restore geothermal ecosystems and their features on the earth's surface.

1. INTRODUCTION

Geothermal resources of New Zealand and worldwide are coming under increasing interest particularly as a renewable source of energy, but also for other sustainable energy and business initiatives. Despite the potential usage of geothermal areas within New Zealand, the ecology and function of geothermal areas has been little studied. Published works have generally described the flora and fauna, with some attempts to relate distributions to temperature and other geochemical characteristics (Burns 1999; Boothroyd 2009). Studies of geothermal biota elsewhere have typically focussed on single elements, and are often focussed more upon the techniques used to measure these elements than the ecological implications (e.g., Koch et al. 1999).

Wherever geochemical fluids are released onto the earth's surface there is the potential for contaminants in high concentrations to be available to geothermal and downstream ecosystems. The relationship and function of the aquatic and the terrestrial geochemical and biological environments is highly relevant to contaminant fate on the surface of the earth but paradoxically is little understood. This is of particular interest to the development of deep geothermal resources and the potential of increasing geothermal fluids on the earth's surface (excepting where reinjection occurs) as opposed to natural springs and seepages of geothermal fluids. Because geothermal fluids contain a high content of potential contaminants (e.g., arsenic, boron) it is beneficial to understand the fate of these contaminants in geothermal ecosystems.

The sustainability geothermal resources for renewable energy is also dependent on the ability to avoid, remedy or mitigate effects on the environment. As part of a programme of understanding the resilience and sustainability of geothermal ecosystems, an understanding of the biodiversity and communities of biota associated with different geothermal systems has been studied (Boothroyd and Browne 2006). In the present paper we report on the uptake of potential contaminants by plants in the vicinity of the geothermal fluids and discuss the potential for restoration of geothermal systems.

2. STUDY SITES AND METHODS

Instream and riparian plant communities were identified and sampled for selected geothermally-derived chemicals within Waimangu and Wai-O-Tapu geothermal systems. At Waimangu, three sites were selected along Hot Stream and within a local tributary (Haumi Stream) to act as a reference site. At Wai-O-Tapu, the sampling sites consisted of two sites on the margin of Champagne, two along the drainage from Champagne Pool towards Lake Ngakaro and one along Waiotapu Stream, at a site immediately northwest of the geothermal tourist park.

Collections of vegetation (leaves only) and soil were taken from four sampling locations along a transect running from the stream margin (0-1 m, 1-5 m, 5-10 m and 10-20 m) within a 30 m reach at each site. Collections were made by hand and kept cool prior to processing in the laboratory. In the laboratory samples of vegetation were washed and frozen and before freeze drying; samples were then stored at -20ºC. Soil samples were dried at 50ºC and then sieved to <0.5 mm. Vegetation samples were digested in HNO_3:H_2O_2: soils were digested in aqua-regia. Samples were then analysed by ICP-MS for a suite of trace elements, aluminium, arsenic, boron, copper, iron, lithium, molybdenum, lead, antimony and selenium.

3. RESULTS

3.1 Chemical composition

Soils at all sites were acidic (pH <4). Soil temperatures ranged from near boiling (92ºC on Warbrick Terrace, Waimangu), to near freezing (3.0ºC) at Haumi Stream. Soils typically contained about 0.7 ± 0.2 % aluminium and 1.0 ± 0.3% iron. Compared to data for the greater Waikato Region, measured lead and copper concentrations were lower than observed in Waikato pasture (Taylor, 2011). Arsenic concentrations in Wai-O-Tapu and Waimangu soils were higher than typical Waikato pastoral soils, but arsenic concentrations were unexceptional compared to results for other geothermal samples collected from the TVZ (Robinson et al. 2006). Elemental concentrations were at least as variable between transect sites as they were between site locations: for example there was no evidence to suggest the chemistry of soils collected alongside Hotwater Stream were different from those collected at the Haumi Stream location.

A summary of data for the vegetation by plant group is presented in Table 1. Trace element concentrations were normalised using soil data to eliminate the effect of contamination, particularly in mosses, lichens etc. The data presented in Table 1 are thus presented as enrichment factors (plant concentrations/soil concentrations).

Table 1 Mean enrichment factors by plant group for bioaccumulated elements. Significant enrichment factors >1 (i.e., indicative of bioaccumulation with 95% confidence) are marked in bold. For the purposes of clarity, confidence interval data are not presented.

Group	n	Li	Mo	Se
Fern	16-22	0.53	**9.91**	**21.3**
Green Algae	3-9	1.04	0.92	**8.42**
Herb	3-7	0.22	2.25	**7.49**
Lichen	11-14	0.12	0.51	**21.2**
Liverwort	11-12	0.64	1.72	**22.7**
Moss	13-15	0.28	3.04	**19.9**
Sedge	5	1.48	**21.7**	11.5
Shrub	21-32	**5.03**	**4.15**	**15.5**
Tree	34-40	1.62	**3.90**	**13.1**

Enrichment factors <1 indicate plants are taking up less of an element than is available, and therefore bioaccumulation is not occurring. When analysed on a plant group basis, evidence of bioaccumulation was only observed for three elements: lithium, molybdenum and selenium (Table 1). Bioaccumulation of selenium was observed in all plant groups, while molybdenum uptake was enriched in higher plant species (ferns, sedges, shrubs and trees). Lithium bioaccumulation was only observed in shrubs.

When the data were further analysed, as presented in Table 2, the observed bioaccumulation of lithium was restricted to a single shrub species, the thermophilic species *Kunzea ericoides var. microflora* (prostrate kanuka). Unlike other shrub species, and more similar to its non-thermophilic relative *Kunzea ericoides* (the tree species Kanuka), there was no evidence for bioaccumulation of molybdenum in prostrate kanuka.

Aquatic algae from Hotwater Stream (Waimangu) contained exponentially higher arsenic concentrations than were observed in terrestrial plant species (Figure 1). Elevated concentrations of antimony, a metalloid with broadly similar behaviour to arsenic, were not observed. These elevated arsenic concentrations correlated with aluminium and iron concentrations (Figure 1b).

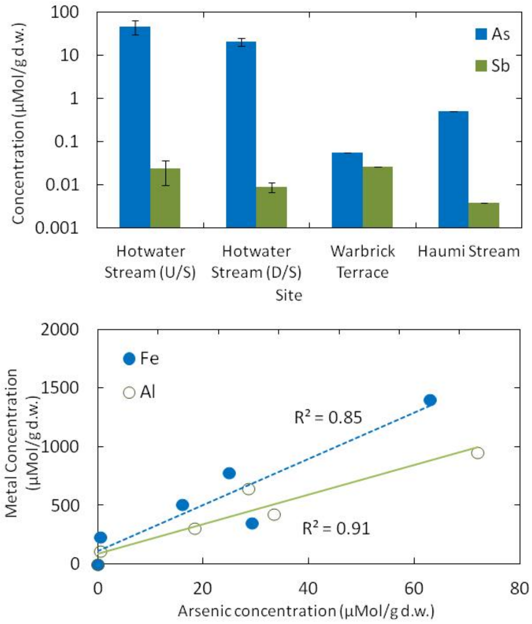

Figure 1 Arsenic concentrations in aquatic algae collected from Waimangu compared to a) antimony, and b) aluminium and iron.

4. DISCUSSION

The results of the survey indicate that terrestrial native plant species are unlikely to be a source of so-called geothermal contaminants such as arsenic, antimony, copper or lead. The uptake of arsenic and antimony may be restricted because the acidic pH of the soil favours metalloid immobility (Wilson et al. 2004). However the absence of metal uptake (copper, lead, iron and aluminium) was unexpected as these metals are considered to be mobile in acidic pH conditions (Spycher and Reed, 1989).

Molybdenum is a micronutrient, and is a co-factor in nitrogenise functioning (Downs et al. 2008). However, the uptake of molybdenum by higher plants growing on geothermal soils has implications for the management of stock on geothermally affected pasture, because high concentrations of molybdenum can cause copper deficiencies in grazing mammals (Smith et al. 2006). Copper deficiencies occur because of the formation of stable copper-molybdenum complexes within the gut, which cannot be digested. In this context, the uptake of molybdenum may therefore be considered to be an accumulation of a potential geothermal contaminant.

Table 2 Mean enrichment factors for kanuka species compared to other shrub species. Errors are 95% confidence intervals.

Species	n	Li	Mo	Se
Kunzea ericoides var. microflora	7-11	8.94 ± 6.69	4.43 ± 4.43	14.2 ± 7.4
K. ericoides (tree)	18-23	2.19 ± 1.36	2.83 ± 2.30	16.6 ± 7.5
All other shrub species	14-21	3.25 ± 2.82	10.4 ± 3.2	23.7 ± 8.0

In contrast to molybdenum, the uptake of selenium is probably beneficial to ecosystems. New Zealand soils are typically selenium deficient (Lee et al. 1999), but soils sampled from Wai-O-Tapu and Waimangu contain near-seleniferous (>0.5 mg/kg; (KS Dhillon and SK Dhillon, 2003)) concentrations (mean Se in sampled soils was 0.46 mg/kg). The subsequent enrichment of selenium in the leaves of higher plants suggest that there is the potential for transport of selenium form within a selenium rich environment into selenium poor environments, and thus native geothermal ecosystems may have a beneficial effect on agriculture and horticulture in neighbouring catchments. We are unaware of any data for selenium uptake in native New Zealand plants outside geothermal systems, so it is not yet possible to comment further on whether the observed bioaccumulation is specific to the sampled plants. Nonetheless, the use of selenium bioaccumulators to transport selenium from high-selenium soils to low-selenium soils has been reported elsewhere (Barceló and Poschenrieder, 2010).

The uptake of lithium by prostrate kanuka does not appear to be an effect of temperature; no correlation was evident between either lithium concentrations or lithium enrichment factors and soil temperatures. Whether the observed bioaccumulation of lithium in prostrate kanuka is a response to growth in higher temperature soils or instead coincidental is unclear and further research is required. The absence of molybdenum accumulation in prostrate kanuka was also observed in the non-geothermal "normal" kanuka species, so is unlikely to be related to changes in behaviour with respect to lithium.

The high concentrations of arsenic measured in the algae growing in Hotwater Stream indicate that, rather than terrestrial transport mechanisms, aquatic processes are the principal mechanism for transporting arsenic. The end point for any arsenic accumulated in Hotwater Stream is Lake Rotomahana, a lake with already naturally elevated concentrations of the metalloid (Wilson, 2009). However, if such algae were allowed to grow in the discharges from other systems, for example the discharge from Wairakei Power Station, then it is possible the dislodgement of such algae may contribute pulses of the metalloid downstream.

5. CONCLUSIONS

Plant and soil samples were collected from a series of sites in the Wai-O-Tapu and Waimangu geothermal systems to gain a better understanding of the resilience of native plant communities and their uptake of geothermally elevated elements.

The results of chemical digests and analyses presented indicate native New Zealand plants are a potential pathway for the transport of molybdenum and selenium from geothermal systems into non-geothermal systems. There was no evidence for the terrestrial uptake of arsenic, but aquatic algae appear to be a hyper accumulator of the potentially toxic metalloid.

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