Uniqueness and diversity of geothermally-influenced aquatic ecosystems

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UNIQUENESS AND DIVERSITY OF GEOTHERMALLY INFLUENCED AQUATIC ECOSYSTEMS

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SUMMARY – Geothermal systems and features are of economic, scientific and cultural importance both within New Zealand and internationally. The Taupo Volcanic Zone represents a highly significant geothermal resource on an international scale and is an important area in which to study aquatic geothermal biota, both for its intrinsic value and for its potential application to geothermal waters generally. The composition and value of biological communities within geothermal waters is poorly understood. As part of studies investigating the uniqueness and biodiversity of geothermal ecosystems, we studied the structural components of the biota associated with various levels of organisation; at the ecosystem, community and population levels. Overall, two broad but distinct types of geothermal ecosystem were identified, each with a characteristic associated biological community. Furthermore, genetic studies on a common geothermal inhabitant, *Chironomus novae-zelandiae* (Insecta: Diptera) suggest an apparent genetic distinction between larvae from geothermal and non-geothermal areas, but not within geothermal areas. Implications for the use of geothermal areas in the context of these finding will be discussed..

1. INTRODUCTION

Despite the significance of geothermal areas within the Taupo Volcanic Zone, and unlike the geochemical and geophysical components of these areas, the ecology of geothermal areas has been little studied. A shift in research focus occurred in the 1980's toward geothermal organisms with commercial potential, mostly microbiota. Consequently, although the macrofauna of thermal waters in New Zealand has been variously described by several authors (see Vincent & Forsyth 1987), most of the information available is descriptive, listing species present at certain temperature and pH (Duggan & Boothroyd 2001a,b).

Geothermally influenced waters typically contain an unusual and distinctive biota (Boothroyd 2000, Death et al. 2004). The species present have adapted to the generally hostile geothermal environment (Vincent & Forsyth, 1987). Several microbial groups especially, flourish in these conditions. However the trophic systems remain simple by comparison with other lakes, rivers and streams (Pritchard, 1990; Vincent & Forsyth, 1987).

Some knowledge of the full diversity of biota found in the geothermal systems is necessary if we are to understand the uniqueness of communities found in geothermal waters. Management and resource use may be restricted or advanced based on the uniqueness and diversity characteristics. To date, much of the attributes that have characterised classifications have been based on geo-physical and geochemical characteristics with much less focus on the living ecosystem.

In this paper we consider the uniqueness of the biota within and between geothermal ecosystems of the Taupo Volcanic Zone at three levels of organisation: molecular, population and community level. The primary objectives of this research were to assess the diversity and uniqueness of macroinvertebrate and algal communities in multiple geothermal streams, both within and between geothermal fields.

2. STUDY SITES

Three geothermal fields were selected for study: Waikite-Waimangu-Waiotapu (Otamakokore Stream), Waimangu (Hot Stream), Waiotapu (Waiotapu and Hakereteke Stream), Rotokawa (Parariki Stream) and Orakei-Korako (Fig. 1). For the population and community studies, 19 sites were sampled within six geothermal areas. Waimangu, Waikite, Waiotapu, Kerosene Creek, Rotokawa and Orakei Korako For the molecular study, nine sites were sampled within three geothermal areas: Waiotapu, Kerosene Creek and Rotokawa. An additional three sites were sampled within a non-geothermal control area at Lake Okaro. Site locations and codes are listed in Figure 2.

Sites were selected according to a number of criteria. Areas for sampling were selected primarily from those within the TVZ that were accessible for scientific research (many of these are administered by DoC and require permits). The areas selected had to contain at least one geothermal-fed stream, had to comprise a diverse range of known types of geothermal spring between them (e.g., alkali-chloride, acid-sulphate) and were preferably located at different distances from one another. Areas that have previously been the focus of scientific research were also favoured.

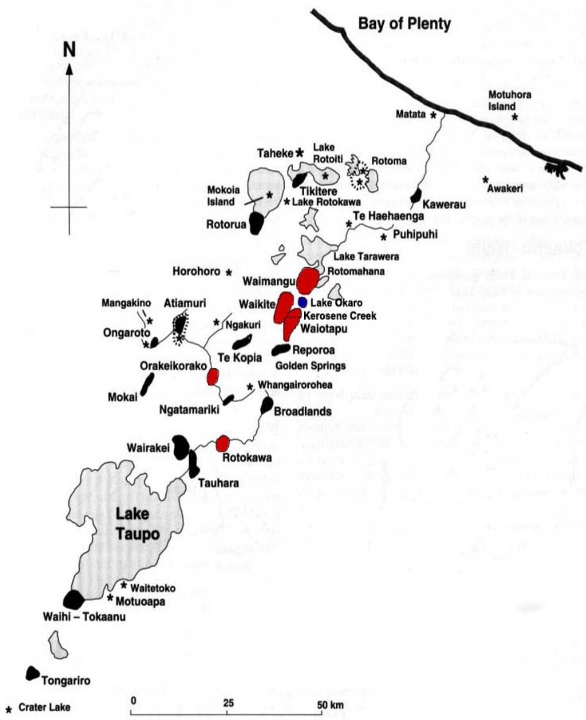


Figure 1. Location of sampling areas within the Taupo Volcanic Zone. Red indicates geothermal sampling areas (Waikite, Waimangu, Waiotapu, Kerosene Creek, Orakei Korako, Rotokawa). Non-geothermal control site is Lake Okaro.

METHODS

Macroinvertebrate samples were collected using a surber sampler (0.25 mm mesh, 0.0625 m^2 sample area). This was the maximum size specified for sensitive sampling sites in order not to cause excessive visual disturbance of the substrate. Samples were preserved in 70% ethanol. Macroinvertebrates were enumerated and identified in the laboratory using available literature and identification keys.

Ten individual algal samples were taken at five equally spaced points across each of two transects established at each site, and the ten samples were pooled togther. Samples were collected by either scraping a known surface area from loose rocks taken from the stream bed; or a modified plastic tube of the same diameter as above was placed on the substrate and algae disturbed and extracted using a syringe. All microalgae samples were transferred to opaque containers and stored. Algae were identified and ranked from 1 (rare) to 8 (abundant) in each sample.

Molecular analysis was carried out on a single species, the chironomids midge, *Chironomus novae-zelandiae*. Random amplified polymorphic DNA (RAPD) was selected as a method as RAPD has frequently been found to elucidate genetic variation at the sub-species level in a quick and reliable manner. RAPD techniques are able to be applied to any organism from which DNA can be extracted. For this study, Details of the methodology are described in Hay (2006), and with a stated aim of determining the potential utility of the (RAPD) technique for genotyping dipteran larvae, as well as obtaining some preliminary data on the diversity of *Chironomus novae-zealandiae* within and between geothermal and non-geothermal waters.

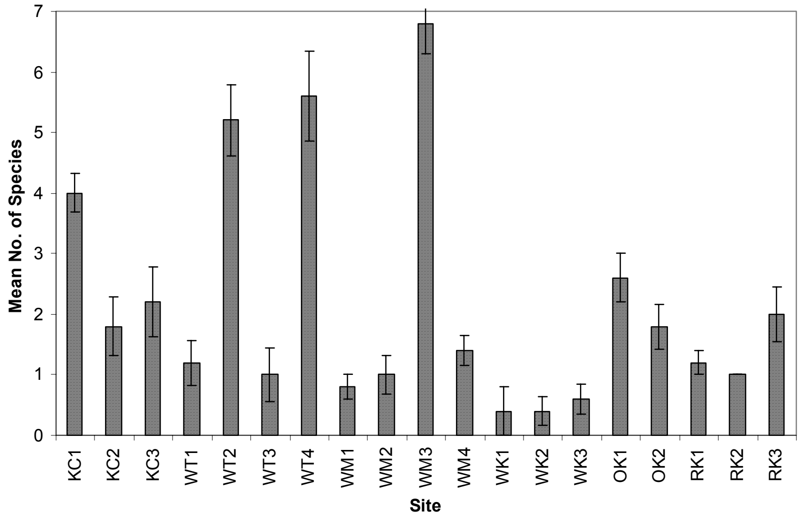
3. RESULTS

3.1 Macroinvertebrate diversity

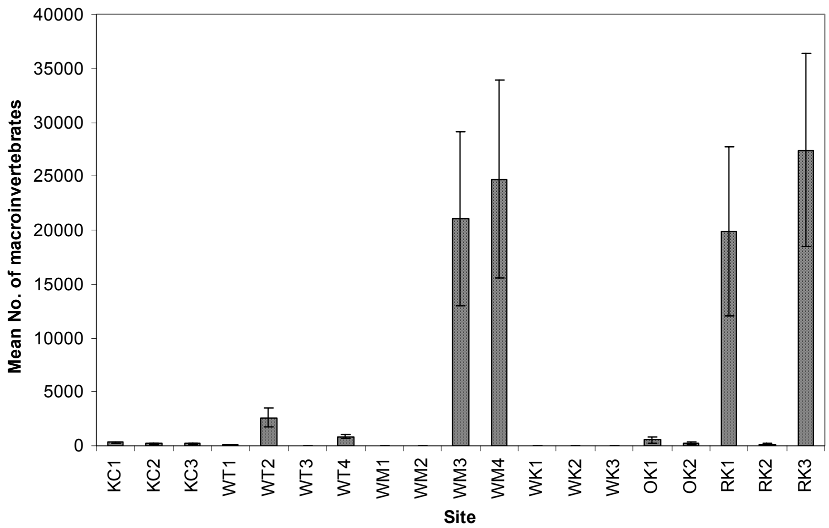
A total of 36 macroinvertebrate species representing at least 13 different orders were recorded within the six geothermal areas sampled. The macroinvertebrate fauna was dominated by insect species, particularly Diptera, but Coleoptera, Hemiptera, Odonata and Trichoptera all occurred at multiple sites. Every one of the 19 sites sampled had Diptera present. Three of the six areas also had non-arthropod species recorded. WM3 was the only site from which species belonging to the phyla Mollusca, Nemertea and Platyhelminthes were recorded.

Diversity of species (Fig. 2a) was variable, both between and within geothermal areas. Mean number of species at each site ranged from less than 1 to 7. Kerosene Creek, Waiotapu and Waimangu all had some sites with significantly more species than others within the same area (ANOVA, $P<0.05$). Differences in the number of species present was also significant between areas (ANOVA, $P<0.05$). Waikite has a different number of species to Kerosene Creek, Waimangu and Waiotapu; and Waiotapu has a different number to Rotokawa (Tukey test).

a)



b)



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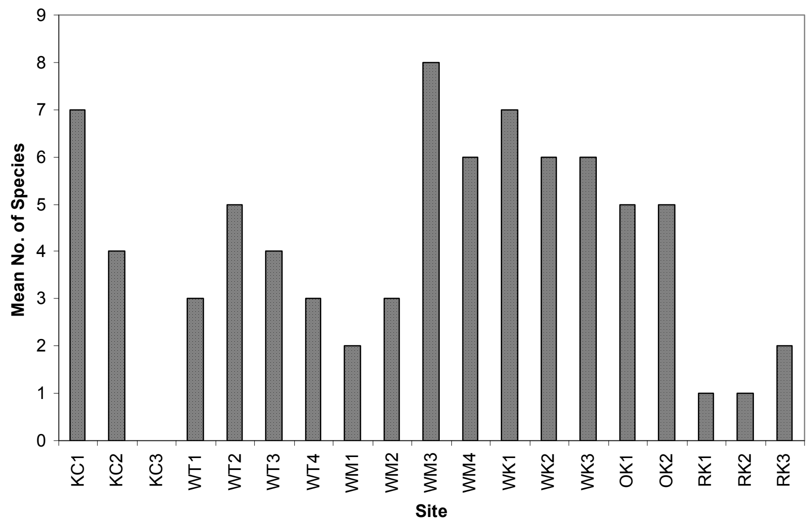

Figure 2. Diversity and abundance of macroinvertebrate species (a,b), and diversity of algal taxa from six geothermal areas. Error bars(a,b) = ±SE, n=5. c, n=10, pooled. Sites KC1-KC3 = Kerosene Creek; WT1-WT4 = Waiotapu; WM1-WM4 = Hot Stream, Waimangu; WK1-Wk3 = Waikite; OK1-OK2 = Orakei Korako; and RK1-RK3 = Rotokawa.

Mean abundance of individual macroinvertebrates was highly variable, both within and between geothermal areas (Fig. 2b, ANOVA, P<0.05). Sites WM3, WM4, RK1 and RK3 had a significantly greater mean abundance of macroinvertebrates when compared to all other sites (Tukey Test, P<0.05). Waikite geothermal area had a lower mean abundance compared to all other sites; and Waiotapu has a significantly lower number to Rotokawa geothermal area (ANOVA, P<0.05).

3.2 Algal diversity

Number of algal taxa recorded at each site varied between zero and eight (Fig. 2c). Except for Kerosene Creek and Waimangu, thegeothermal areas exhibited a similar diversity of algal taxa between sites (range ≤2). No algal taxa were recorded from KC3 (kerosend Creek. Only tow and three algal taxa respectively were recorded from WM1 and WM2 respectively, while 8 and 6 taxa were recorded from sites WM3 and WM4 (Hot Water Stream, Waimangu).

Cyanobacteria or Bacillariophyta (diatoms) were the most abundant groups at all sites sampled (Fig. 3). Seven sites were dominated by cyanobacteria, 11 sites by Bacillariophyta and one site had no algal taxa (Kerosene Creek site 3, KC3). All sites at Waikite and Orakei Korako were dominated by Cyanobacteria. All sites at Waiotapu, Rotokawa and Kerosene Creek were dominated by Bacillariophyta. At Waimangu, the dominant group varied between different sites, while Waiotapu, Kerosene Creek and Rotokawa all had at least one site containing solely Bacillariophyta. Waimangu had two sites with exclusive representation of Cyanobacteria. Four sites have Rhodophyta present (<15%). Chlorophyta occurred at only three sites (<10% of total algal taxa).

Macroinvertebrate Community

Multi-dimensional scaling analyses for macroinvertebrate communities show that the composition of macroinvertebrate communities from within each geothermal area were more similar to one another than communities from other geothermal areas (Fig. 4).

Sites from within each geothermal area were generally tightly grouped. The notable exceptions are those sites from within the Waimangu area whereby sites WM1 and WM2 group together, separately from WM3 and WM4 (which also group together).

Chironomid larvae were the invertebrate group contributing most to the differences observed between sites (ANOSIM). All 12 pairwise comparisons featured a Chironomid species as the macroinvertebrate contributing most to differences between the macroinvertebrate communities, explaining between 27% and 88% of variation. In 11 of 12 pairwise comparison, a Chironomid species most frequently explained the second and/or third order of variation. The thermophile ephydrid, *Ephydrella thermarum*, explained between 2% and 38% of variation for eight of the pair-wise comparisons.

3.3 Molecular study

Extensive optimisation and standardisation of PCR was required to obtain reproducible results. An optimised RAPD-PCR method was able to be developed that was relatively reliable and discriminatory. The RAPD technique is particularly applicable to unusual species such as those from geothermal waters for which DNA markers have not previously been identified.

Using this method, seven out of twenty primers screened were shown to produce polymorphic banding patterns for *Chironomus novae-zealandiae* from different populations. Two of these primers were used to assess diversity of *Chironomus novae-zealandiae* from both geothermal and non-geothermal populations within the Taupo Volcanic Zone. Results suggest that there is a difference at the molecular level between larvae from geothermal versus non-geothermal sites. A single band sized at approximately 915bp was potentially able to discriminate between geothermal and non-geothermal larvae. No difference was demonstrated between *Chironomus novae-zealandiae* larvae from isolated geothermal sites.

4. DISCUSSION

Geothermal systems and features are of economic, scientific and cultural importance both within New Zealand and internationally. The Taupo Volcanic Zone represents a highly significant geothermal resource on an international scale and is an important area in which to study aquatic geothermal biota, both for its intrinsic value and for its potential application to geothermal waters generally.

The composition and value of biological communities within geothermal waters is relatively poorly understood. The results of the present study provide an extension of the knowledge of diversity and uniqueness of biota at different geothermal sites.

At the molecular level, preliminary findings from the current study suggest that there is a difference at the genetic level between larvae from geothermal versus non-geothermal sites. However these results also indicated that there is no difference between larval populations at different

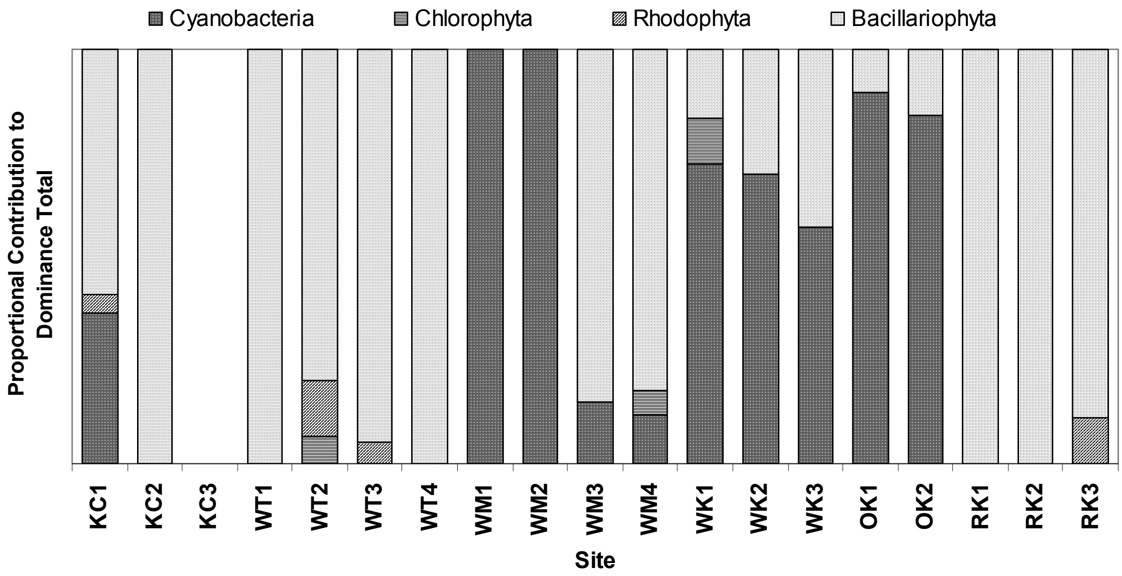

Figure 3. Relative Dominance of Algal Orders by Site. Dominance Total = sum of relative dominance values at each site.

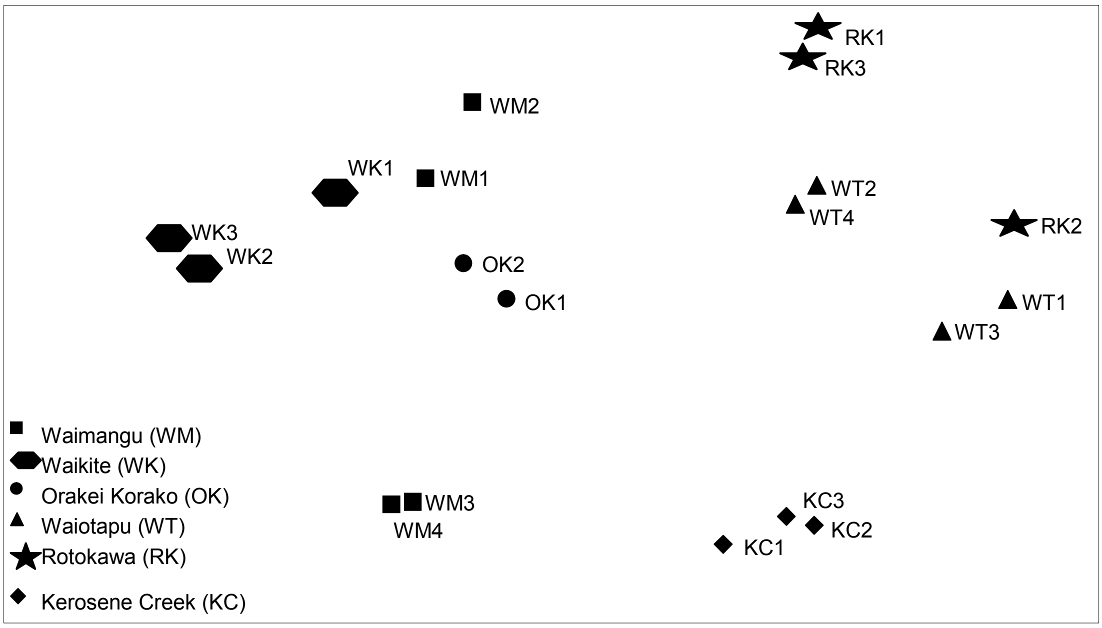

Figure 4. MDS Ordination for Macroinvertebrate Communities (abundance). Distance statistic = Bray-Curtis Similarity. Stress value: 0.04

spatial scales within the TVZ. Results might vary with different study species or spatial scales.

At the population level, both macroinvertebrate and algal populations were highly variable between the different systems and sites. Differences within individual streams were generally minimal compared with differences between streams from different geothermal areas.

At the ecosystem level, communities present primarily reflected the physico-chemical conditions of their particular stream environment. While factors such as temperature, pH, conductivity and dissolved oxygen influence biota in all streams, these appear to be major determinants of biological communities in geothermal streams. The influence of these factors in geothermal streams is most likely due to the acute levels of these stressors by comparison with non-geothermal streams, making these the limiting constraints for life in these environments. Composition of geothermal communities was comparable to findings of previous studies (Duggan and Boothroyd 2001a,b).

Low diversity in geothermal streams is likely to be compounded by the exacerbating effect of some stressors on others, e.g., the effect of high temperature on toxicant levels present (Vincent & Forsyth, 1987), or reduced solubility of oxygen in water of high temperature.

The influence of habitat factors such as land use, shading and substrate type appears to be of secondary, and lesser, importance in geothermal streams than in non-geothermal streams, although Duggan and Boothroyd (2001a) showed that habitat can also be a factor explaining differences in geothermal communities.

Overall, two broad but distinct types of geothermal ecosystem were identified, each with a characteristic associated biological community. Streams that have been identified as alkali-chloride and/or -bicarbonate (Hunt & Bibby, 1992) tended to have a distinctive community dominated by *Tanytarsus* sp., *Ephydrella thermarum* and Cyanobacteria at high biomass. Streams identified by Hunt and Bibby (1992) as acid-sulphate and/or –chloride tended to have communities dominated by *Chironomus* spp. along with various other diptera and diatoms.

5. ACKNOWLEDGEMENTS

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