Invertebrates of geothermally influenced aquatic and terrestrial ecosystems:
Longitudinal and lateral linkages

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INVERTEBRATES OF GEOTHERMALLY INFLUENCED AQUATIC AND TERRESTRIAL ECOSYSTEMS: LONGITUDINAL AND LATERAL LINKAGES

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SUMMARY – The landscape and water bodies overlying geothermal areas are characterised by zones of high temperature, high ion concentrations, unusual pH conditions, and the influence of geothermal activity on these waters is also often highly variable between and within each system. The biodiversity of geothermally influenced aquatic is typically low but little is known of the fauna of associated terrestrial ecosystems. As part of studies investigating the food web linkages between geothermally influenced aquatic and terrestrial ecosystems, the longitudinal distribution of invertebrates in two geothermal streams has been quantified. Species counts varied little downstream but abundance varied. Studies of ground-dwelling invertebrates at a single geothermal site showed a variety of species transient within the geothermally influenced zones alongside streams and varied with distance from the waterway. Most invertebrates found were commonly-occurring types.

1. INTRODUCTION

Increasing use of geothermal resources for human activities will increase pressure on these ecosystems. Cleaner energy production, tourism, and human health and well-being are amongst the uses for geothermal systems. Research is increasingly being directed at obtaining a better understanding of currently producing geothermal fields in New Zealand, and of deep geothermal systems which might have potential for future resource development (Graham *et al.* 2000).

The chemical and physical environments of geothermal systems are being investigated (e.g., mechanical and petrological properties of rocks in shallow aquifers, changes in surface heat flows, carbon dioxide flux). Until recently, little attention has been given to the biotic and bio-physical components of these geothermal systems.

Despite the significance of geothermal areas within New Zealand, the ecology 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 geothermal characteristics.

The aquatic biota is better documented with a number of published accounts which have been largely descriptive in nature (Vincent & Forsyth 1987, Boothroyd 2000). Much less has been documented of the terrestrial invertebrate biota that exists in association with geothermal systems.

The associations of terrestrial and aquatic biota with geothermal resources are 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). 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.

As part of a first step to understanding the fate of these contaminants, an understanding of the diversity and types of invertebrates associated with different geothermal systems is required. This paper presents the results of studies of aquatic and terrestrial invertebrates in contrasting geothermal ecosystems.

2. STUDY SITES AND METHODS

Studies of aquatic and terrestrial invertebrates were carried out in different geothermal ecosystems respectively. Longitudinal studies on the aquatic biota were carried out in the Waioutapu and Waimangu geothermal systems, and lateral studies on the terrestrial biota were carried out at the Rotokawa geothermal field.

For the aquatic fauna, five sites from the Hot Stream at the Waimangu geothermal system and one site on the Haumi Stream were sampled. At Waiotapu four sites were sampled. Sites were selected to follow a longitudinal or downstream sequence (i.e., Site 1 = upper catchment etc.). At each site, ten samples of invertebrates and algae were taken. Invertebrates were identified to species where possible.

For the terrestrial fauna, six transects were established alongside the Parariki Stream (outlet stream from Lake Rotokawa). At each transect, ground-dwelling invertebrates were collected using pitfall traps at three nodes along each transect (six pitfall traps were clustered at each sampling node). Transects weer placed within upper and lower sinter terracing (USB and SB respectively); within bush (Site B) and a bush clearing (Site BC); and proximal to two large geothermal springs (Sites Basin and FS). The pitfall traps were deployed for a four week period during May 2005.

3. RESULTS

3.1 Terrestrial Invertebrates

The terrestrial invertebrate fauna was dominated by insects (78%) followed by Arachnida (29%). A total of 1,290 invertebrates were collected in the pitfall traps during March 2005. The invertebrates belonged to 34 identified family groups.

Over half of the total numbers of individuals were flies comprising Sciaridae (black fungus gnats, 51%). Following the Diptera, the next most abundant orders were Araneae (spiders, 11%) and ants (Formicidae, 8%). Other groups represented were Orthoptera (grasshopper and crickets), beetles (weevils and staphylinids), Collembola (springtails) and Hymenoptera (bees and wasps). At least 29 invertebrate family groups were recorded across all sites.

The largest numbers of invertebrates were recorded furthest away from the Parariki Stream (448 individuals, mean = 75 per trap) and lowest numbers on the sinter surface (36 individuals, mean = 6 per trap) closest to the Parariki Stream.

With the exception of the bush site, the invertebrate communities at all sites were dominated by Diptera; Bush site was dominated by spiders (Table 1). Ants were also more common at the bush site.

The sinter bank exhibited the lowest number of major groups; only Diptera (Families Lauxaniidae, Ephydridae, Sciaridae and Phoridae), hymenoptera (Formicidae) and spiders (Family Linyphiidae). The Upper Sinter Bank was also inhabited by Coleoptera (weevils and ground-dwelling carabids), Hemiptera, Trichoptera and Acarina. Invertebrates from eight major groups were recorded at Sites BC and Bush as well as the Basin site.

3.2 Aquatic invertebrates

As for the terrestrial fauna, the aquatic fauna was dominated by insects. A total of 5165 invertebrates were collected from the benthos of the two geothermally influenced streams. With the exception of Site WM6, all sites were dominated by Diptera (Chironomidae).

Mean taxa number varied little in the longitudinal sequence downstream at Waiotapu (range 1-1.9) or Waimangu (range = 0.8-3.9) (Table 2). At Waiotapu the invetebrate fauna was dominated by *Chironomus novae-zelandiae* (Chironomidae) but with the mosquito larva, *Culex rotoruae* present from site WT2, and the dance fly larva, *Ephydrella thermarum*, present from Site WT3 downstream.

Diversity of aquatic invertebrates was greater at the Waimangu geothermal area with *Ephydrella thermarum* present at WM1 (at the outlet from the main crater), and an undescribed chironomid species (*Tanytarsus* sp.) at the lower site.

Mean abundance was significantly higher at site at Waimangu geothermal area than Waiotapu (Table 2). Greatest mean abundance was recorded at Site WT3 (13,195 m^{-2}) at Waiotapu and the lowest mean abundance at the most downstream site (WT4, 2,093 m^{-2}). At Waimangu, greatest mean abundance was recorded at the most downstream site (WM5, 133,713 m^{-2}) and the lowest at Site WM2 in the upper catchment (1,820 m^{-2}).

4. DISCUSSION

Terrestrial invertebrates associated with geothermal areas exhibited a moderate to high diversity. Fewer invertebrates occurred in close proximity to springs and geothermal resources, in part probably resulting from the lack of diverse habitat on the sinter terraces. A large proportion of foraging taxa were collected from the sinter terraces (e.g., Lauxaniidae, Formicidae), which appear to ‘raid’ the carcasses of other invertebrates that have been killed in closer proximity to the hot springs and the outlet stream. It is not clear how many of the invertebrates reside in the sinter terrace area. Elsewhere, the invertebrate fauna was more diverse and probably included resident taxa as well as those transiting the respective areas.

The aquatic fauna was highly restricted and exhibited a low diversity characteristic of aquatic geothermal ecosystems (Boothroyd 2000). At least two taxa are obligate thermophiles and are only found in high temperature (*Ephydrella thermarum*) or other characteristics (*Tanytarsus* sp.) (Boothroyd 2002). Other taxa (e.g., *Chironomus novae-zelandiae*) are common in a variety of warm and cold stream and spring environments). The lack of diverse communities of invertebrates also means no competition for existing food resources and space. Diptera are often the most common insect group in geothermally influenced streams and at times their larvae are extremely abundant (Boothroyd 2002).

Our studies have shown that geothermal ecosystems exhibit low diversity but characteristic communities of aquatic invertebrates. The terrestrial invertebrate fauna associated with geothermal ecosystems is more diverse with

Table 1. Total numbers of major groups of terrestrial invertebrate recorded from pitfall traps, Parariki Stream, Rotokawa, March 2005. Number in parentheses represents percent (%) of total for each site.

Taxon	Site						
	USB	S	BC	Bush	Basin	FS	TOTAL
Arachnida							
Acarina	1 (1)	0	6 (2)	29 (16)	3 (1)	1 (1)	40
Araneae	10 (7)	6 (17)	11 (4)	46 (25)	16 (7)	161 (36)	250
Insecta							
Collembola	0	0	10 (4)	5 (3)	2 (1)	0	17
Coleoptera	6 (4)	0	25 (10)	2 (1)	17 (8)	4 (1)	54
Diptera	107 (76)	29 (81)	177 (69)	34 (18)	169 (78)	237 (53)	753
Hemiptera	1 (1)	0	1 (1)	1 (1)	3 (1)	9 (2)	15
Hymenoptera	15 (11)	1 (1)	20 (8)	69 (37)	4 (2)	29 (7)	138
Orthoptera	0	0	7 (3)	0	0	0	7
Trichoptera	1 (1)	0	0	1 (1)	4 (2)	5 (1)	11
Total numbers	141	36	257	187	218	446	1285
Taxon number	7	3	8	8	8	7	9

Table 2. Mean taxa number and total abundance of aquatic invertebrates recorded from Waiotapu geothermal area (WT), and Hot Stream, Waimangu geothermal area (WM), March 2004. Number in parentheses represents range.

	Geothermal Area									
	Waiotapu				Waimangu					
Site	WT1	WT2	WT3	WT4	WM1	WM2	WM3	WM4	WM5	WM6
Mean taxa number	1.0 (1)	1.9 (1-2)	1.9 (1-3)	1.5 (0-3)	1.5 (1-2)	0.8 (0-2)	1.4 (0-3)	1.9 (1-2)	1.8 (1-3)	3.9 (1-5)
Mean total numbers (m^{-2})	4,493 (910-8,190)	8,702 (2,275-1,2740)	13,195 (4,550-2,1840)	2,093 (0-7,280)	12,228 (1,365-34,850)	1,820 (0-10,465)	2,900 (0-10,010)	117,219 (48,685-217,035)	133,713 (67,795-268,905)	13,593 (3,640-44,135)

changes in community related to habitats occurring in the vicinity of the geothermal resource.

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