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Aquatic Ecosystems of the Maniapoto Karst

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Executive Summary

The karst landscape of south-western Waikato (Maniapoto Karst), created through limestone dissolution, is one of the region's iconic landforms. The caves, springs and other features associated with this landform are valued for their association with Ngati Maniapoto culture, unique natural heritage attributes, utility for recreation and tourism, and their role in supply of water. Despite their regional significance, our knowledge of the structure and functioning of karst aquatic ecosystems is limited and this may constrain effective management of aquatic ecosystems in karst landscapes.

In this report, we summarise results of extensive surveys of aquatic invertebrates and water quality in cave and spring habitats of the Maniapoto karst area. The aims of this study were to relate biodiversity patterns and water quality to a range of potential environmental drivers, including water source (i.e., groundwater vs. surface water), land use and tourism activities. In addition, a comparison was made between springs draining the Maniapoto Karst with those found in a diverse range of lithologies to assess the distinctiveness of karst habitats. The final aim of the study was to provide recommendations on approaches to managing aquatic habitats in karst landscapes.

There are several distinct aquatic habitats associated with karst. We sampled spring, side passage and cave streamway habitats, but did not sample the epikarst (saturated zone between the surface and the cave, often containing aquatic fauna). Habitat type (spring, streamway or side passage) was an important driver of observed patterns in both physicochemical and biological data from aquatic ecosystems of the Maniapoto Karst. Temperature and conductivity/alkalinity provided useful indicators of the source of water, with observed patterns suggesting that autogenic (groundwater-dominated) habitats (i.e., side passages and some springs) can be characterised by lower temperatures and higher alkalinity. Differences in water source were also reflected in the fauna present in springs and side passage habitats. In particular, the stygobitic (groundwater) amphipod *Paraleptamphopus* sp. was an indicator of habitats dominated by groundwater sources. Very little is known of the life history or feeding ecology of this invertebrate. We suggest that future research into its population ecology would provide valuable information to assist the management of karst ecosystems dominated by groundwaters.

In contrast to water source, land use patterns seemed to have limited influence on biological patterns at sampled sites, although pasture-dominated land use was associated with elevated temperature and nitrate concentrations in each habitat type. In addition, our surveys showed no evidence of adverse effects of tourism activity on cave streamways. We suggest that the absence of strong land use effects on biological patterns may be the result of cool groundwater inflows acting as a buffer against elevated temperatures (compared to surface flowing streams) that might otherwise act as a major stressor on invertebrate communities.

Effects of tourism on cave streamways ecosystems are likely to be minor, due to low numbers of invertebrates in these systems and the relatively small proportion of habitat actually directly affected by human traffic. However, further research will assess indirect tourism impacts on native fish which are known to occur in underground cave systems in the area. The potential impacts on fish may be greater than for other ecosystem components, because some cave operators have installed physical barriers that might limit fish passage.

Spring invertebrate community structure in Waitomo was distinct from that in sites from a number of different lithologies around the Waikato (Kaimai ignimbrite, Waihou sedimentary sands/ashes, Kawhia sands, Lowland sedimentary), and waters from these systems tended to exhibit low temperature and high conductivity.

Despite the significance of karst landscapes to the Waikato Region there are no objectives in the Regional Plan that relate specifically to water-related issues in cave and karst environments. It is assumed that achieving general objectives related to water quality, aquatic ecosystems and water quantity will ensure that water in the Region’s karst areas is managed appropriately. Based on results of this study, we suggest that Environment Waikato’s Regional Plan is likely to be providing adequate implicit protection for most karst aquatic ecosystems from catchment land use activities, because objectives relating to erosion control, improved point source treatment and riparian management are all likely to benefit karst aquatic ecosystems. However, under Variation No. 6 (Water Allocation) of the Plan, water flowing in karst systems is considered to be surface water rather than groundwater. We suggest that this definition fails to recognise the presence of important groundwater habitats and the distinct communities associated with them. We recommend that identification of significant areas of autogenic karst and associated anthropogenic threats to natural heritage values should be a priority for future management-driven research within the Maniapoto Karst.

1. Introduction

Karst landscapes cover a relatively small area of New Zealand, but are regionally important landscapes in the Waikato, upper West Coast of the South Island and northwest Nelson (Williams 2004a). The karst landscape of south-western Waikato (Maniapoto Karst), created through limestone dissolution, is one of the region's iconic landforms. The caves, springs and other features associated with this landform are valued for their association with Ngati Maniapoto culture, unique natural heritage attributes, utility for recreation and tourism, and their role in supply of water (DoC 1998).

Despite their regional significance, our knowledge of the structure and functioning of karst aquatic ecosystems is limited, and this may constrain effective management of aquatic ecosystems in karst landscapes (Urich 2002). For example, in the Waikato Regional Plan (Chapter 3; September 2007), karst systems are recognised as an important aspect of the Region's water resources, but there are few objectives that explicitly relate to management of these systems (Objective 3.1.2 l refers to protecting the natural character of caves from inappropriate use and development). Management objectives tend to be broad in their nature, with the karst systems being covered by objectives common to any waterbody (Waikato Regional Plan 2007). It is therefore assumed that general objectives relating to water quality, aquatic ecosystems and water quantity will ensure that water in the Region's karst areas is managed appropriately. For this assumption to be valid, it must be assumed that karst aquatic ecosystems are either similar to other aquatic ecosystem types across the region, or respond to anthropogenic pressures in similar ways. As an initial test of this assumption this report provides a comparison of invertebrate community structure in karst springs with springs of other common lithologies in the region.

Another important feature of the Maniapoto Karst is the geological heterogeneity throughout the area. Within the catchment area of a given stream system there may be areas of karstified limestone overlain by a series of other sedimentary rock types (e.g., sandstones and mudstones). This geological heterogeneity plays an important role in the hydrological characteristics of freshwater habitats in the area, as these habitats may collect water draining from both karst (autogenic) and non-karst (allogenic) areas (Williams 2004b). In autogenic systems much of the water derives from percolation of rain through carbonate rocks, whereas water in allogenic systems is sourced from captured surface streams. We predict that different water sources will strongly influence hydrological characteristics, water chemistry and community composition in karst ecosystems.

As is the case with other aquatic ecosystems in the region, those draining karst areas are threatened by a range of human activities, including farming, forestry, quarrying and mining, urbanisation and waste disposal (Urich 2002). Other potential threats unique to karst areas include recreation and tourism activities in cave systems. Operators of recreational activities are required to monitor their effects on the systems they operate in and report on this as part of their operation licence. To date however, there has been no published assessment of the impacts of land use activities on karst aquatic ecosystems in the Waikato.

In the surveys of karst aquatic ecosystems presented in this report we have focussed on what are termed Groundwater Dependent Ecosystems (GDE; Hatton & Evans 1998). GDE are ecosystems which have their species composition and their natural ecological processes determined by groundwater properties. In relation to the Maniapoto Karst, we recognise three distinct GDE types. Within caves we recognise the main streamway and side passages, and where these passages emerge at the ground surface we find springs. Some of these springs flow from cave systems (i.e., underground passages accessible to humans) and are termed resurgences, whereas other springs emerge from smaller inaccessible passages. The largest springs in the area are resurgences of the Mangapu, Mangawhitikau, Mangakowhai and Waitomo cave systems. These springs have mean discharges in the range of 1-3 m^3/s (Williams 2004). For simplicity we term all groundwater re-emergence sites as springs.

In this report, we summarise results of extensive surveys of aquatic invertebrates and water quality in cave and spring habitats of the Maniapoto karst area, conducted between 2006-2007. Our objectives in this report are to:

i) Describe aquatic invertebrate biodiversity patterns and water quality in cave streams and springs of the Maniapoto Karst.

ii) Relate biodiversity patterns and water quality to a range of potential environmental drivers, including hydrogeology and land use.

iii) Compare community structure in springs draining the Maniapoto Karst with those found in a diverse range of lithologies including ignimbrite (Kaimai ranges), sand (Kawhia Harbour), lowland sedimentary ashes (Morrinsville), and sedimentary sand (Waihou valley) spring ecosystems.

iv) Provide some recommendations on approaches to managing aquatic habitats in karst landscapes.

2. Methods

2.1 Site description: The Maniapoto Karst

Karst is the term given to terrain underlain by carbonate rocks (usually limestone or marble) that has been significantly modified by dissolution creating sinkholes, caves, and underground drainage networks.

The Maniapoto Karst covers an area of approximately 1000 km^2 and is located along the Waikato Region's west coast between Kawhia Harbour in the north and the Mokau River in the south (Fig 1). The main karst host rocks are the Otorohanga and Orahiri limestones of the Te Kuiti Subgroup. The limestone beds of the Te Kuiti Subgroup extend from Northland to Taranaki, but are thickest in the central Maniapoto region. An important feature of the karst in the Maniapoto area is the very high density of pitting by enclosed depressions (dolines; Williams 2004a), forming the highest density polygonal karst landscape widely recognised throughout the world (DoC 1998). These dolines are an important part of the recharge system for karst groundwaters, acting as conduits for precipitation into the underlying drainage networks dissolved in the limestone, and associated sandstones of the area.

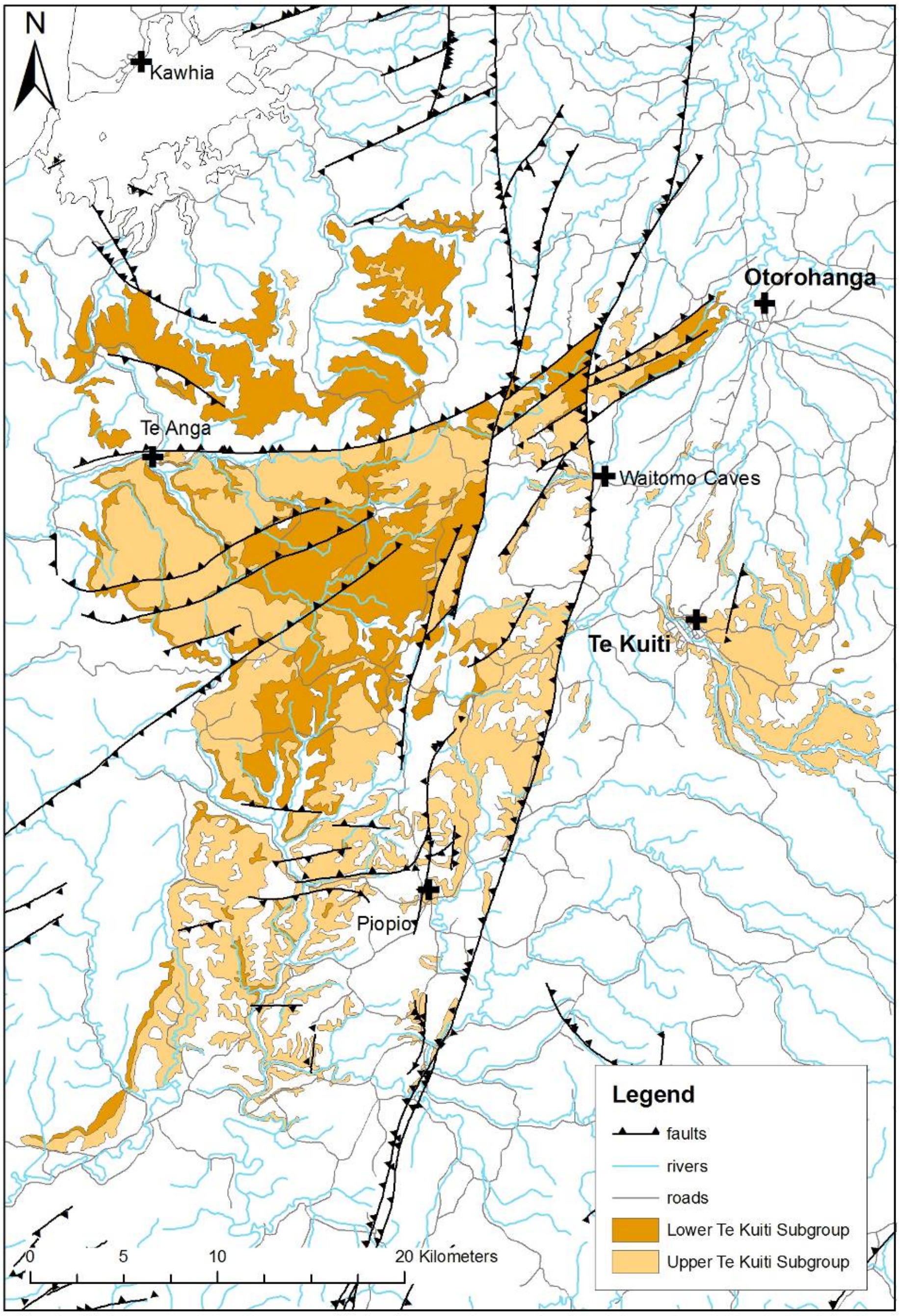


Figure 1: Location of the Maniapoto Karst. Geology layers sourced from Edbrooke (2005).

2.2 Sampling locations in Maniapoto Karst

We sampled extensively in several subcatchments of the Mangapu River (Waitomo, Mangawhitikau, Te Ana Roa (Fullerton Rd), and Upper Mangapu, and in one subcatchment of the Marakopa River (Mangapohue). Figure 2 shows the location of spring and cave sampling sites. Springs were sampled between 27th February and 9th

March 2006. Cave sites were sampled between 7th February and 9th March 2007. Cave sampling locations were obtained from spatially referenced cave maps. These cave maps vary in spatial resolution and accuracy, so cave sampling locations are approximate.

Determination of land use characteristics for sampling sites was complicated by uncertainty in drainage patterns upstream of the sites. As a result we classified sampling sites as "Native" or "Pasture" based on the dominant land cover surrounding sites (Fig. 2).

Within the cave systems we sampled two distinct habitats. These were the main streamway of the cave system and small side passages. The small side passages included those that could be accessed by humans, as well as inaccessible cracks discharging water to the cave. In the former, we sampled up the passage away from the main streamway, whereas the latter were sampled at source.

2.2.1 Physicochemical sampling

At each site a 1 l water sample was collected in a sterile container prior to any other activities. In the springs, sample collection was as close to the spring emergence point as possible. Samples were kept in the dark on ice for not more than 24 hours before analysis. Samples were analysed for nitrate/nitrite nitrogen (NO_x-N; mg/m^3; automated Cadmium reduction using Flow Injection Analyser), alkalinity (g $CaCO_3$/m^3; APHA 2320B) and total organic carbon (TOC, g/m^3; APHA 5310B) at NIWA's Hamilton Water Quality laboratory. Conductivity (µS/cm @ 25 °C) and pH were also measured in the lab. Water temperature was measured in the field with a hand held electronic thermometer.

2.2.2 Biological sampling

Invertebrate sampling was consistent across spring and cave sampling sites. We used a 0.25 mm mesh triangular hand net or sieve to collect a sample from approximately 1 m^2 area of substrate, with sampling time of 30 seconds. All samples were preserved in 70% isopropyl alcohol.

In the laboratory, samples were first rinsed through nested 2 mm and 0.25 mm sieves. Both fractions were sorted under a binocular microscope. All specimens were identified to genus or species, where possible, using the keys in Winterbourn & Gregson (1989), Winterbourn et al. (2000), Towns & Peters (1996), Winterbourn (1974) and various unpublished guides.

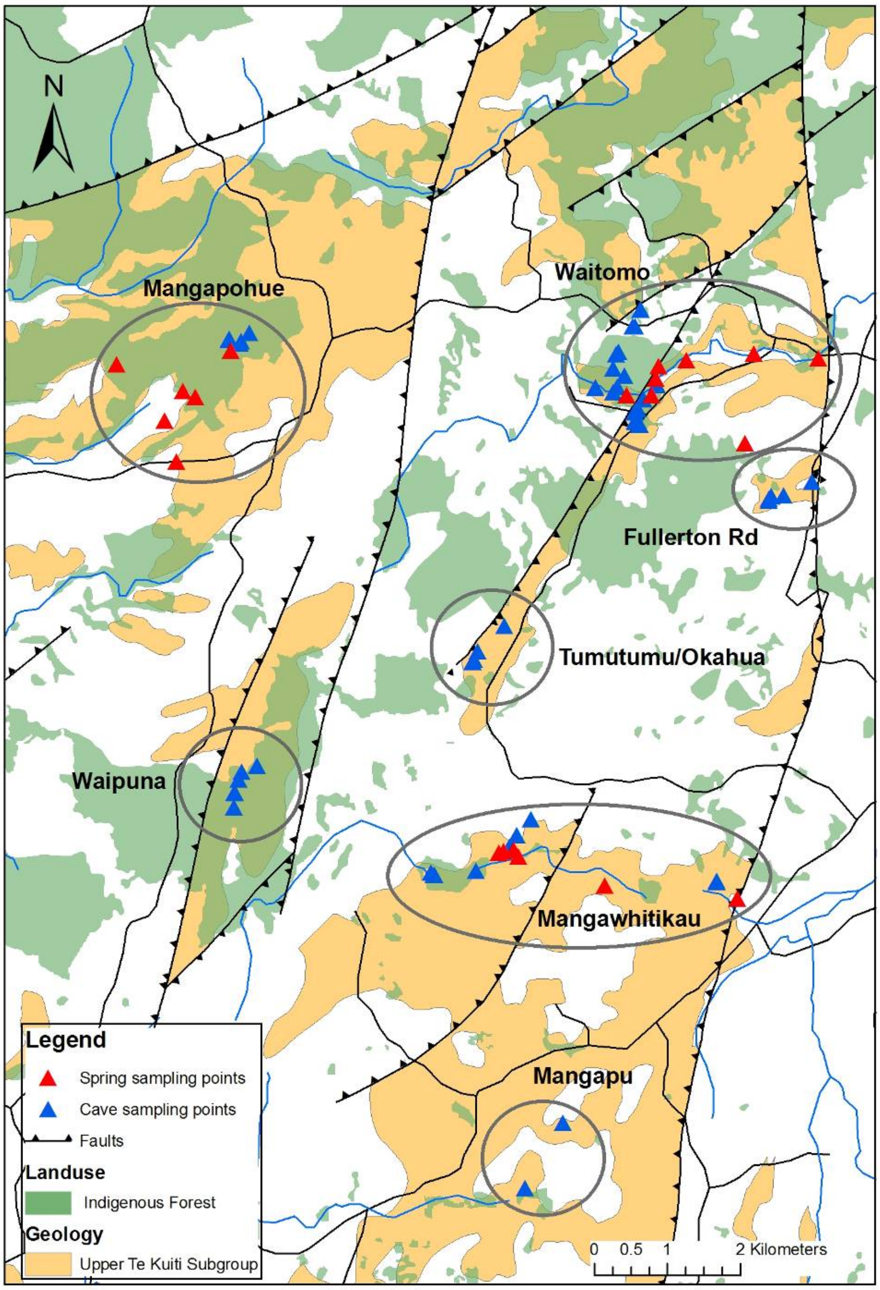


Figure 2: Map of sampling sites. Land use data was sourced from LCDB2. Geology data sourced from Edbrooke (2005). Note that the Waipuna and Tumutumu/Okahua sites flow northeast into the Waitomo system; the Mangapohue flows west; and the Fullerton Rd, Mangawhitikau and Mangapu sites flow east to the Mangapu River. Refer to Appendix 1 for site details. Non shaded white areas represent predominantly pasture landuse.

2.3 Study sites for comparison of biodiversity patterns in springs of differing geology

A total of 54 spring sites in five areas of the Waikato Region were sampled between January 2003 and August 2006 (Appendix 2). Figures 3a-d show the location of springs sampled in each region. Sampling of spring habitats focussed on springs draining a range of lithologies, but land use around the springs also varied. In addition to the springs from karst landscapes already described above, we used existing data from springs draining ignimbrite rocks of the Kaimai ranges (Scarsbrook et al. 2007), and sedimentary/ashes in lowlands southeast of Morrinsville (Scarsbrook & Haase 2003). Springs draining coastal sand aquifers around Kawhia Harbour were sampled in February 2006 as part of a project with a local iwi (Ngati Hikairo). Finally, a series of small springs draining sedimentary/sand lithology along the Waihou River were sampled in August 2006 as part of the current project.

2.3.1 Kaimai Ranges

The Kaimai ranges rise over 900 m, forming a mountainous barrier between the Waikato and Bay of Plenty regions. The dominant lithology is volcanic ignimbrite, that forms by deposition and consolidation of ash flows. Springs occur along the western base of the escarpment (Fig. 3a). Over a relatively narrow elevation range (100-500 m) the indigenous forest of the Kaimai - Mamaku Forest Park undergoes a sharp transition to intensive agriculture, as elevation drops, with dairying as the dominant land use. Further details on sampling sites and results for this group can be found in Scarsbrook et al. (2007).

2.3.2 Kawhia

Springs have always been highly valued by Maori, and this has been reflected in many legends and traditional practices (Frank Thorne, Ngati Hikairo, unpublished data). Recent work by NIWA with Tainui hapu around Kawhia Harbour has identified significant historical and cultural values assigned to springs by the local people. In pre-European times, springs provided the only reliable source of freshwater on the Kawhia peninsular, which is underlain by a series of small sand aquifers. From earliest settlement of the area the springs around Kawhia peninsula (Fig. 3b) have also provided significant food gathering sites (e.g., tuna and taro, and more recently watercress), and water sources for irrigation of kumara crops. Most of Kawhia peninsula is now heavily modified for urban, production forestry, and farming land uses. The springs sampled as part of the current work were all within an area of planted *Pinus radiata* forest, with cattle grazing within the forest.

2.3.3 Waihou springs

The headwaters of the Waihou River are largely spring fed, with the largest of these springs being Blue Spring near Putaruru. Water from Blue Spring is bottled for commercial sale. Springs reflect the alluvial sedimentary-sand lithology (volcanic ash and sand). Sampling sites (Fig. 3c) were all located along a walking track (the Te Waihou Walkway), which passes Blue Spring and areas of regenerating wetland and native forest plantings. However, dairying on pasture land near the river still impacts some springs in the area.

2.3.4 Waikato Lowlands

The Waikato Lowlands make up the central part of the Waikato region. Much of the land in this area has been drained for agriculture and natural habitats have been extensively modified. Dairying is now the dominant land use. This area includes extensive flat land and rolling hills, which have been formed by infilling with alluvial pumice and ash deposits. All sampled springs were small (<10 l/s) and in highly modified landscape settings (Fig. 3d). Scarsbrook & Haase (2003) provide further details of these sites and their comparison with springs in other dairying areas of New Zealand.

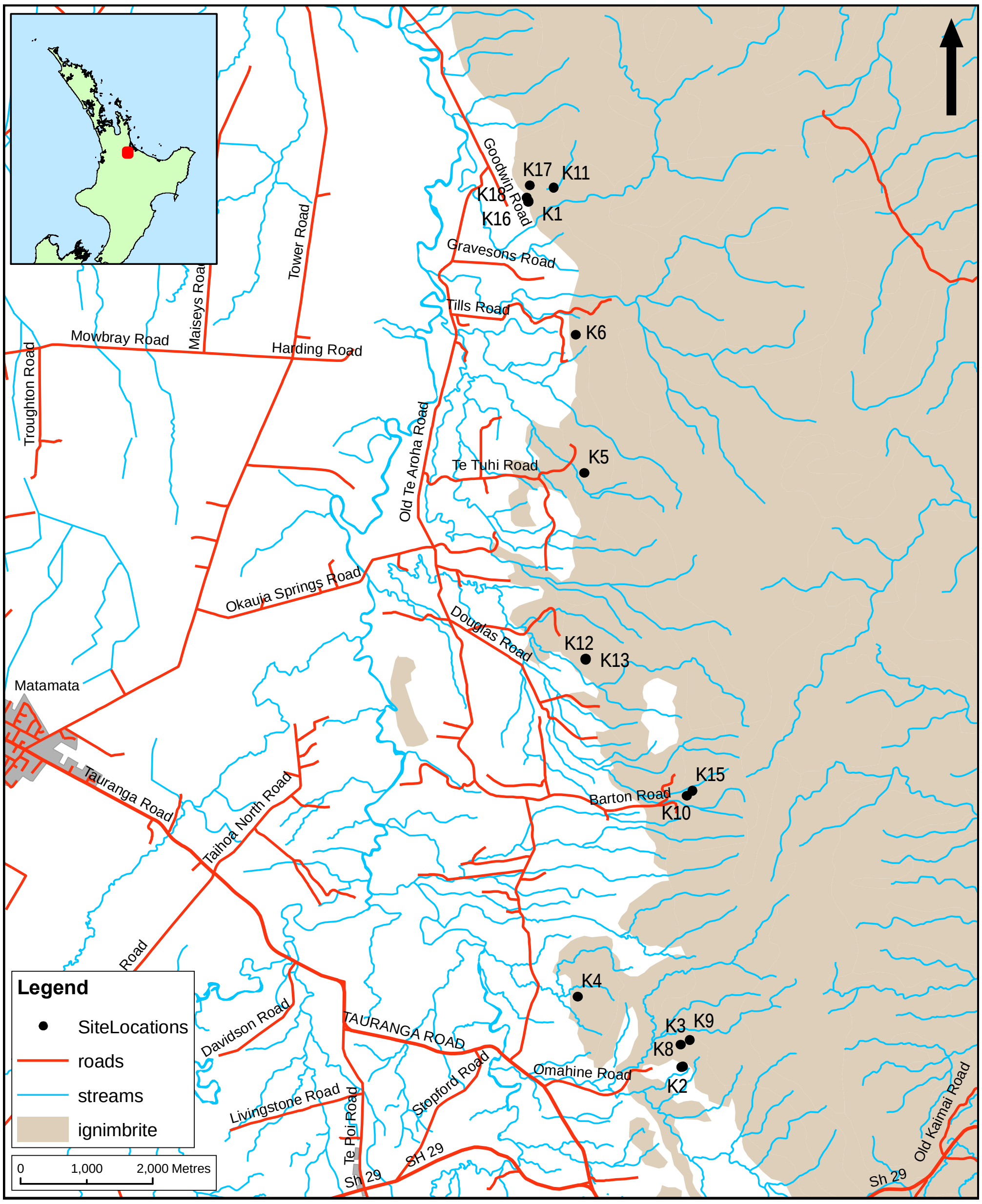


Figure 3a: Location of sampling sites along western edge of Kaimai ranges (ignimbrite). Refer to Appendix 2 for site details.

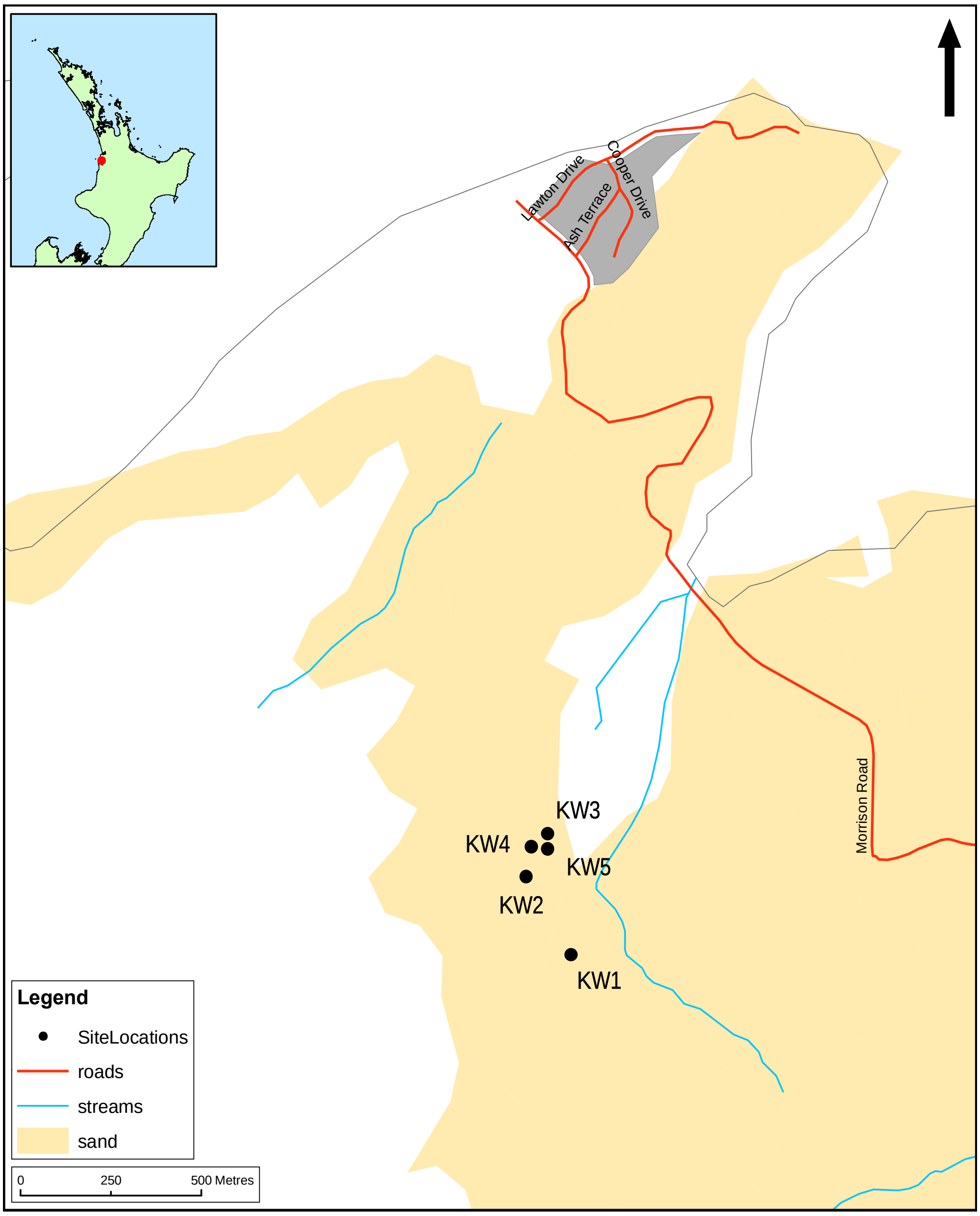


Figure 3b: Location of sampling sites near Kawhia (Aotea Harbour; sand lithology). Refer to Appendix 2 for site details.

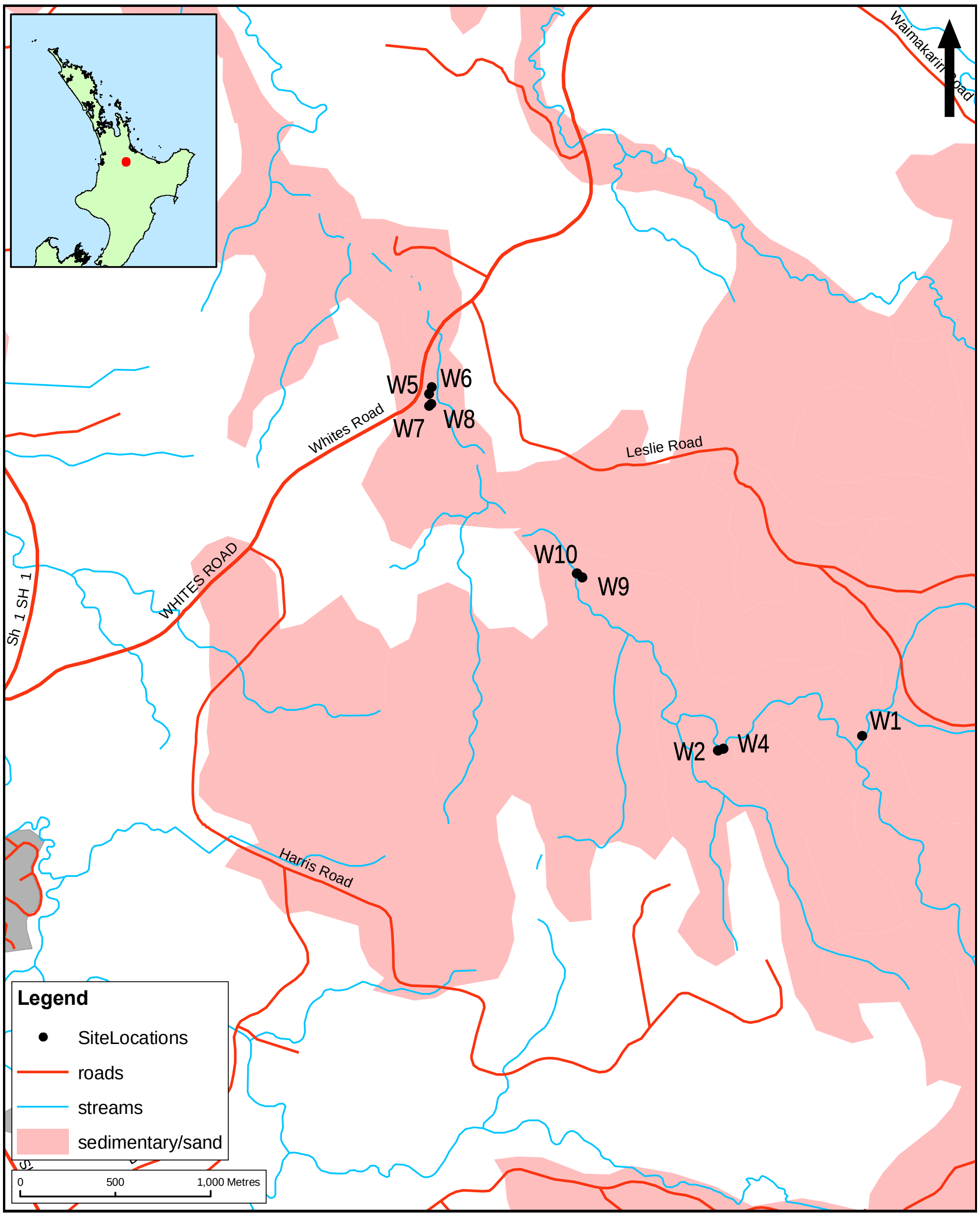


Figure 3c: Location of sampling sites along Waihou River (sedimentary/sand). Refer to Appendix 2 for site details.

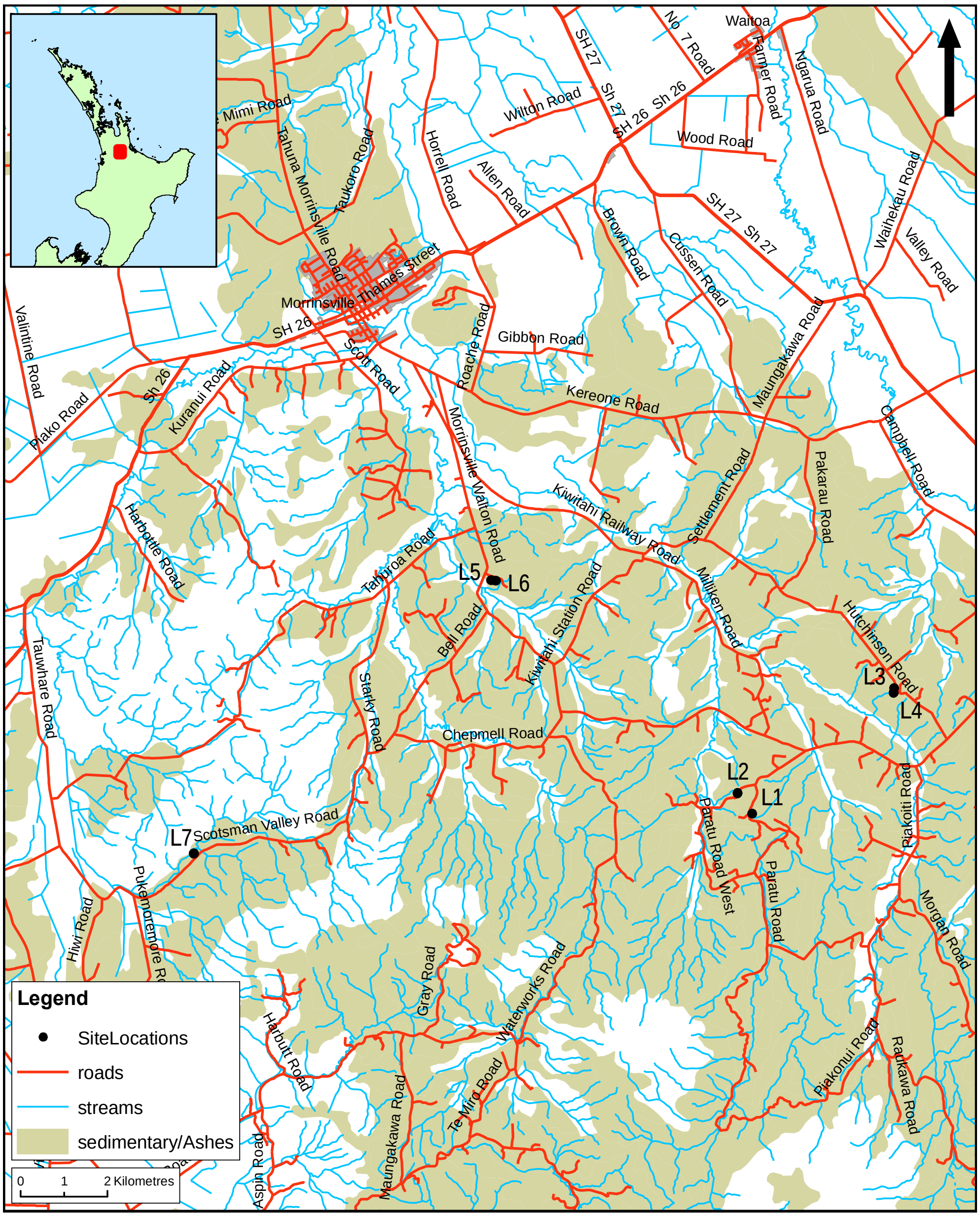


Figure 3d: Location of sampling sites in Morrinsville area (lowland sedimentary/ashes). Refer to Appendix 2 for site details.

2.4 Methods

Each springhead site was classified as 'impacted' or 'not impacted' in relation to the degree of habitat modification (land use). This was a qualitative assessment based primarily on the presence or absence of riparian canopy trees, intact fences, and the ease of access by stock (access was limited in some cases by steep banks, and dense vegetation).

All sampled springs were small, with discharges generally less than 10 l/s (estimated by eye). To allow for a fair comparison in relation to spring size we removed the larger resurgences (i.e., Waitomo Cave, Mangawhitikau Cave) from analyses.

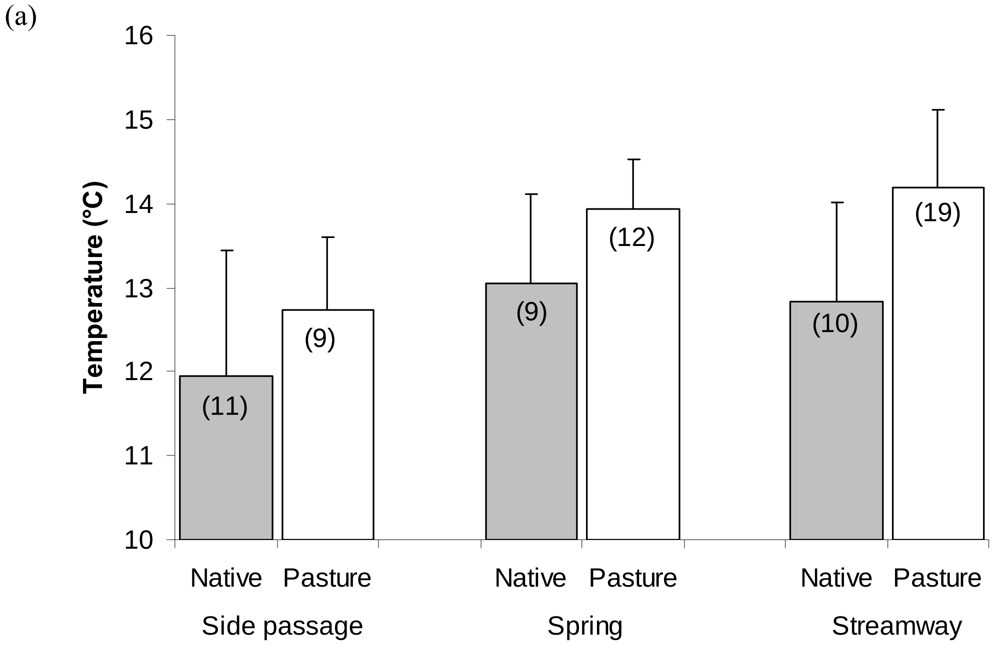
Water temperature and conductivity were measured at all locations using handheld field meters. Biological sampling was carried out in a manner similar to the Waitomo surveys.

3. Results

3.1 Physicochemical characteristics of Maniapoto karst habitats

Summer spot temperatures at 21 spring and 49 cave sites ranged from 10.2 (a side passage in Waipuna Cave) to 15.4 °C (Main streamway in Fullerton Rd system). Based on a two-way ANOVA, temperature varied significantly with land use ($F_{1,54}$ = 13.55; $P < 0.001$) and habitat type ($F_{2,54}$ = 8.06; $P < 0.001$). The interaction term was not significant. Spot temperatures in pasture-dominated sites were significantly higher than in native forest sites. Bonferonni post-hoc tests showed that temperatures in side passages were lower than in streamways, or springs ($P < 0.05$; Fig. 4a).

When log-transformed, concentrations of NO_x-N (N as nitrate/nitrite) varied significantly with land use ($F_{1,54}$ = 15.29; $P < 0.001$) but not by habitat type (P = 0.066). Differences between pasture and native forest were particularly marked in side passages and springs and less so in streamways (Fig. 4b).



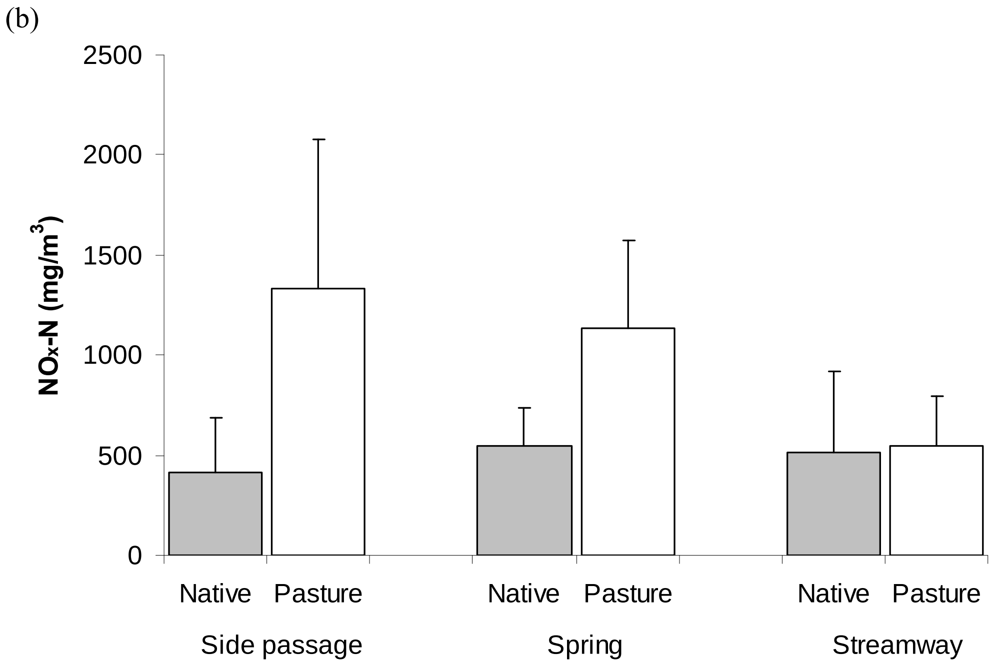


Figure 4: (a) Mean water temperature and (b) NO_x-N (Nitrate/nitrite) concentrations across different karst habitat types within a predominantly native forest or pasture landscape. Sample size is given in parentheses for temperature graph (sample size the same for NO_x-N). Error bars are 1SD.

Other physicochemical variables showed significant differences by habitat type, but not land use (Fig. 5). Conductivity varied significantly by habitat ($F_{2,54}$ = 3.53; P = 036), with side passages having significantly higher conductivity than streamways. For pH (Habitat: $F_{2,54}$ = 7.17; P = 0.002), springs had significantly higher values than either streamways or side passages. TOC varied significantly by habitat ($F_{2,54}$ = 8.82; P < 0.001), with streamways having significantly higher TOC than either springs or side passages. Finally, alkalinity ($F_{2,54}$ = 5.84; P = 0.005) was lower in streamways than either springs or side passages.

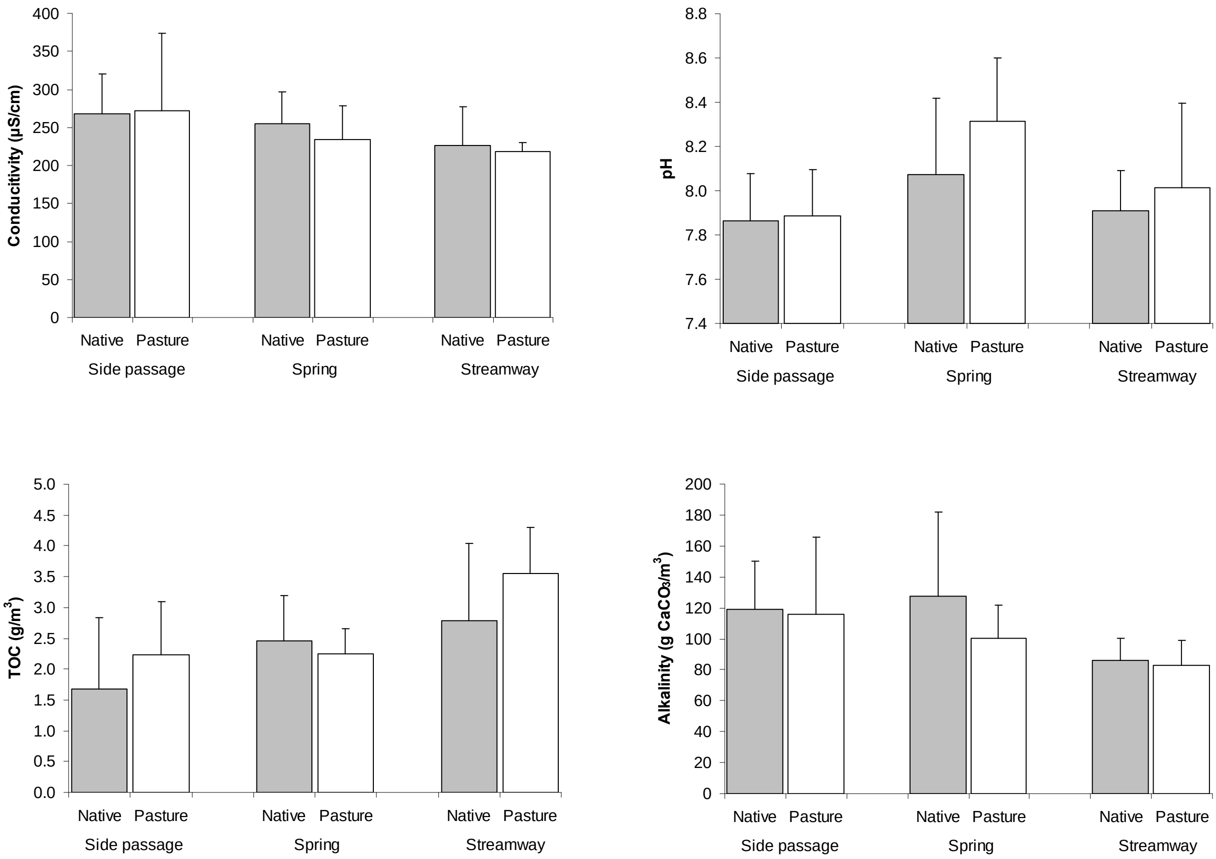


Figure 5: Comparison of mean (+1SD) conductivity, pH, total organic carbon (TOC) and alkalinity across karst habitat types within predominantly native forest or pasture land uses. Sample sizes are the same as in Fig. 4.

There were very highly significant correlations (Spearman rank correlation) between water temperature and conductivity, TOC and alkalinity (Table 1). TOC was also significantly correlated with conductivity and alkalinity. The correlation between conductivity and alkalinity was very high, suggesting that these two variables convey similar information.

Table 1: Spearman rank correlations between physicochemical variables. N = 60. Values given in red are very highly significant correlations ($P < 0.001$).

	Temperature	pH	EC	TOC	NO_x-N
pH	0.27				
EC	-0.44	-0.12			
TOC	0.54	0.01	-0.48		
NO_x-N	0.16	0.24	0.13	-0.11	
ALK	-0.49	-0.09	0.90	-0.52	0.14

In Figure 6 the correlations between temperature and TOC are broken down by habitat type. There was no significant correlation between temperature and TOC in spring habitats, whereas side passage and especially streamway habitats showed strong correlations between temperature and TOC. Figure 6 also suggests a linkage with water source and TOC such that groundwater-dominated sites (i.e., lower temperature) in streamways and side passages have reduced TOC.

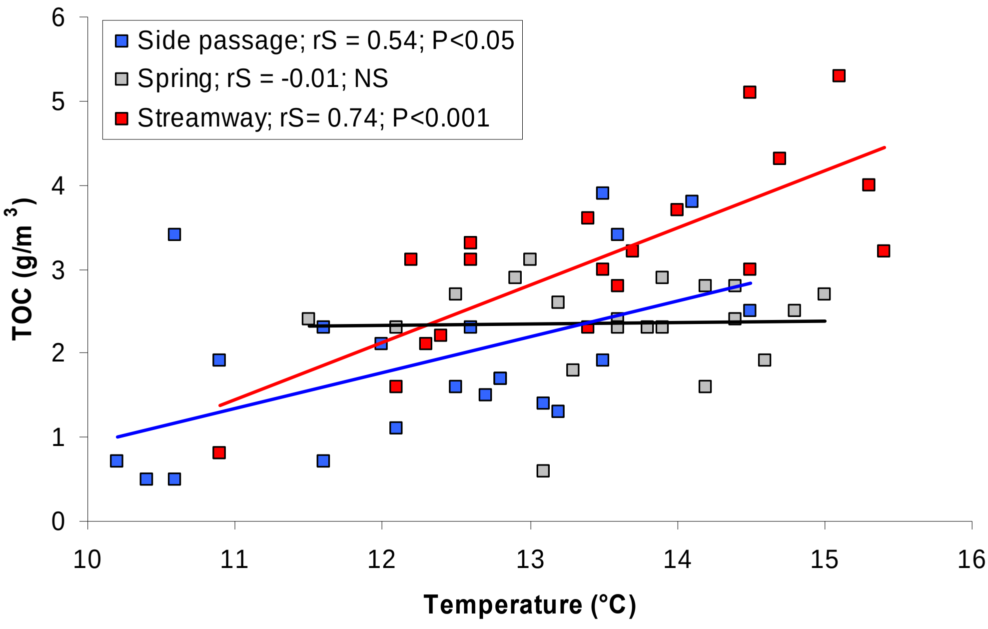


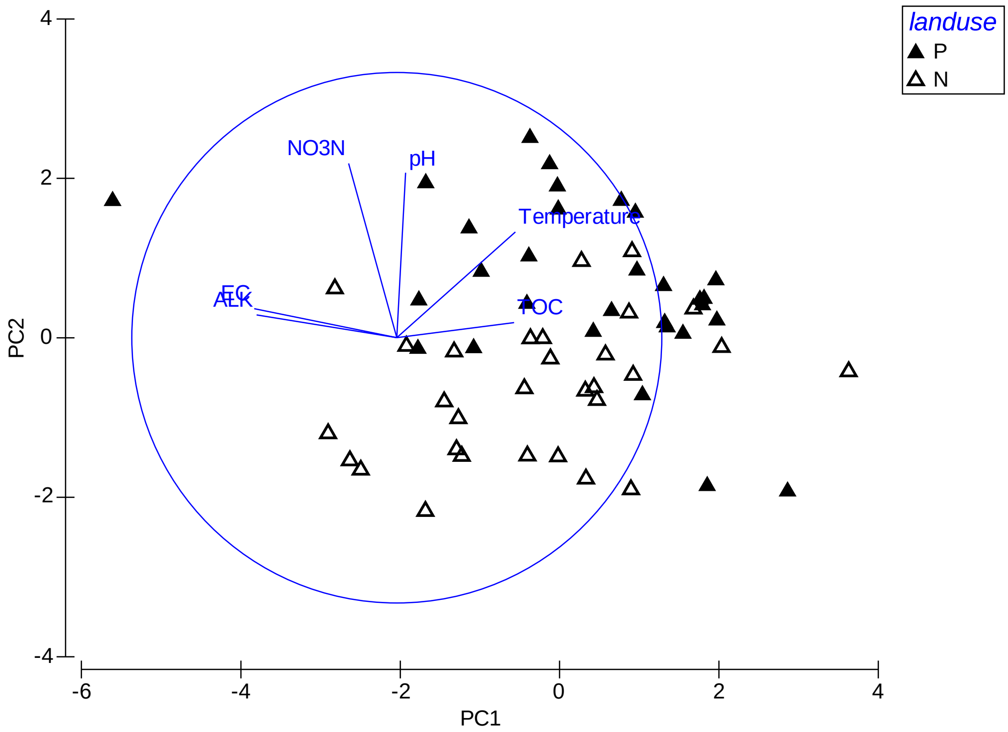
Figure 6: Relationships between temperature and TOC compared by habitat type.

A Principal Component Analysis (PCA) was carried out on normalised physicochemical data to provide a 2D representation of sites. Table 2 gives a summary of the PCA results. PC1 accounted for 43.1% of the variance in the physicochemical data, with conductivity and alkalinity being the main contributors. PC1 can be interpreted as the degree to which the sample reflects autogenic waters. That is, the interaction of water with limestone increases alkalinity and conductivity, so the higher the alkalinity, the greater is the influence of autogenic karst. PC2 accounted for a further 21.5% of variance and was most strongly associated with NO_x-N and pH. We interpret this as a land use axis. Sites in native and pasture land use categories separated relatively well along PC2 (Fig. 7a), but karst habitat types appear more poorly discriminated along PC1 (Fig. 7b). We suggest this is due to all three habitat types reflecting different proportions of allogenic and autogenic water (as reflected by levels of alkalinity). In later sections we deal with each habitat separately.

Table 2: PCA results (Eigenvectors and % variance explained) on physicochemical data from spring, streamway and side passage habitats within predominantly native forest or pasture land use (shown graphically in Fig. 7).

Variable	PC1	PC2	PC3
Temperature	0.445	-0.430	0.236
pH	0.067	-0.561	-0.690
Conductivity	-0.559	-0.151	0.268
Total Organic Carbon	0.407	-0.133	0.562
NO_x-N	-0.202	-0.668	0.222
Alkalinity	-0.527	-0.121	0.177
% variance explained	43.1	21.5	16.2

(a)



(b)

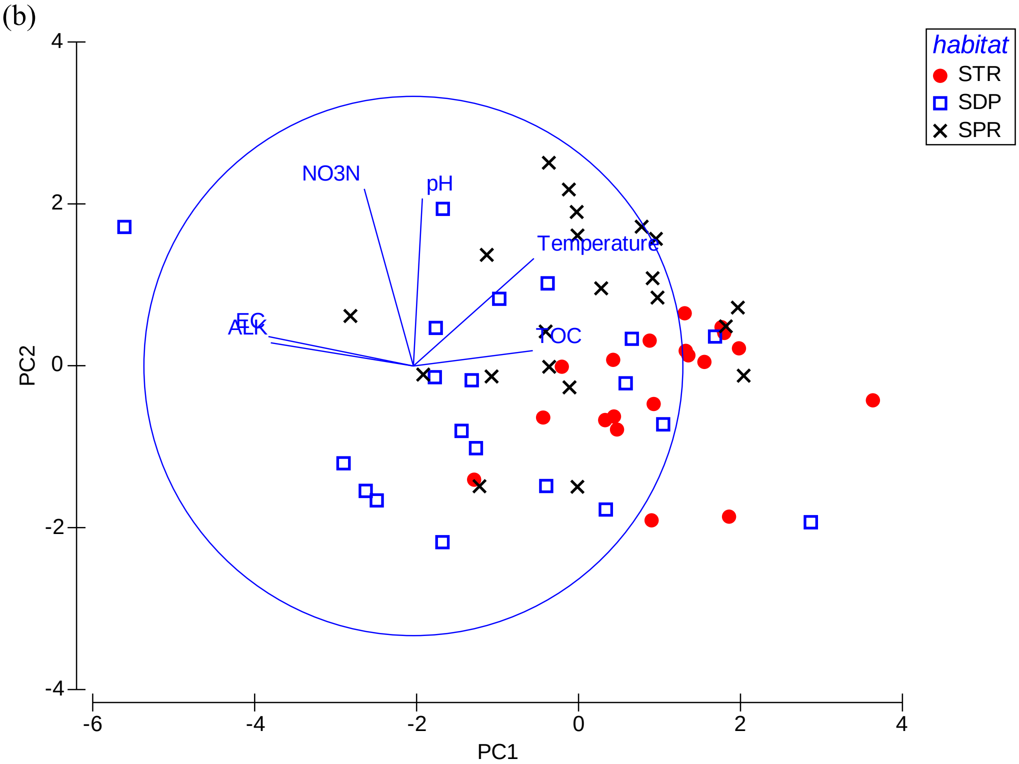


Figure 7: Principal components analysis of physicochemical data with (a) landuse and (b) habitat type superimposed (top and bottom graph, respectively). In upper panel, P = pasture, N = native forest; in lower panel, STR = streamway, SDP = side passage, SPR = spring.

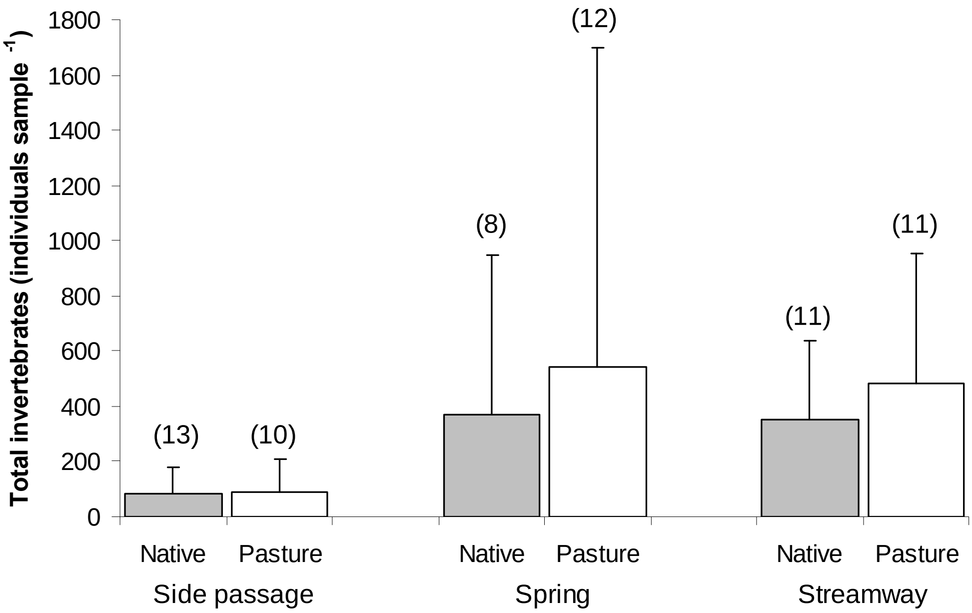
3.2 Invertebrate community patterns in karst habitats

A total of 81 taxa were collected from 65 locations (23 side passage; 20 spring; and 22 streamway sites). Numbers of invertebrates per sample varied from 2 individuals (both the amphipod *Paraleptamphopus* sp.) collected from a side passage in Mangapu Cave, to 4188 individuals (dominated by the snail *Potamopyrgus antipodarum* and *Paraleptamphopus* sp.) collected in an open pasture spring along the Mangawhitikau Stream.

The most frequently occurring taxa were Oligochaeta, *Deleatidium*, *Zephlebia*, *Potamopyrgus*, Orthocladiinae, *Coloburiscus*, Ostracoda, *Polypedilum*, *Paraleptamphopus* and *Austrosimulium* (Appendix 3). 17 rare taxa occurred at only 1 site each.

Total abundance (Fig. 8) varied significantly with habitat type (two-way ANOVA on rank-transformed data; $F_{2,59} = 13.46$; $P < 0.001$), but not land use ($F_{1,59} = 0.05$; $P = 0.816$). Side passages had significantly lower numbers of animals than streamway or spring sites (Bonferonni post-hoc tests; $P < 0.05$). The overall pattern in taxon richness was the same (habitat $F_{2,59} = 16.90$; $P < 0.001$; land use $F_{1,59} = 1.16$; $P = 0.286$), but all pairwise habitat comparisons were statistically significant (i.e., streamway > spring > side passage).

(a)



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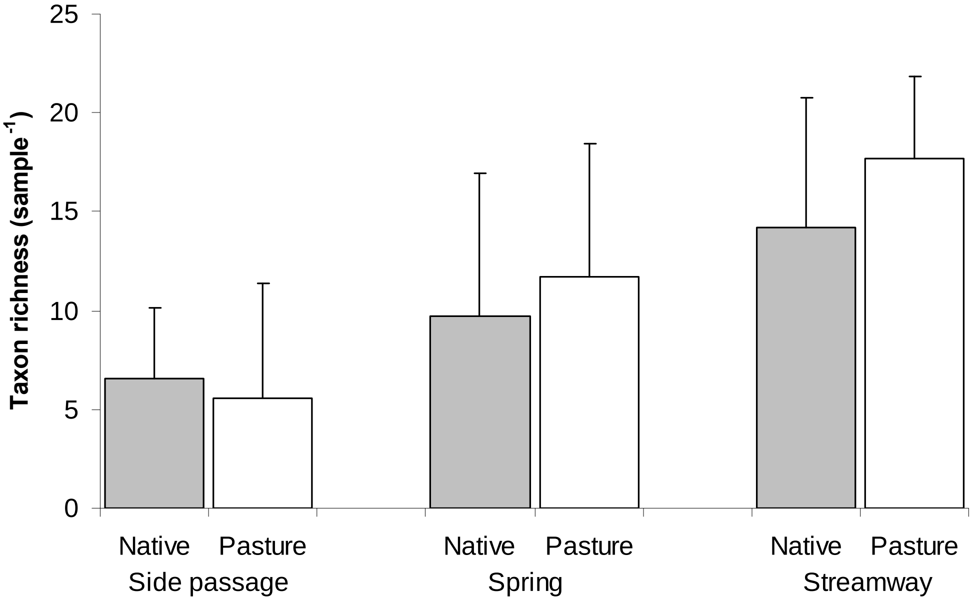


Figure 8: (a) Mean total invertebrate abundance and (b) taxon richness per sample (standardised by effort) across karst habitat types within a predominantly native forest or pasture landscape. Sample size is given in parentheses. Error bars are 1SD.

Community composition varied strongly across habitat types (Fig. 9). Overall, the most common groups were Ephemeroptera (35%), Oligochaeta (21%), Amphipoda (14%) and Mollusca (11%). The relative abundance of Ephemeroptera (NB: all relative abundance data were rank-transformed prior to analyses) varied significantly with habitat type ($F_{2,59}$ = 20.88; P < 0.001), but not with land use ($F_{1,59}$ = 3.07; P = 0.085). Mayfly relative abundance was significantly higher at streamway sites than at either spring or side passage sites (Bonferroni post-hoc test; P < 0.05). Amphipoda also varied significantly with habitat ($F_{2,59}$ = 4.04; P = 0.042), but not land use ($F_{1,59}$ = 0.12; P = 0.734). This group made up a significantly greater proportion of the community in side passages than streamways. Relative abundance of Oligochaeta was greatest in the side passages, intermediate in streamways and lowest in springs (all pair-wise comparison significant P < 0.05). Relative abundance of Mollusca varied significantly with both habitat ($F_{2,59}$ = 10.28; P < 0.001) and land use ($F_{1,59}$ = 4.44; P = 0.039). Pasture dominated sites had higher snail relative abundance, and springs had higher abundance than either side passages or streamways. Overall, for community composition, habitat factor was highly significant ($F_{2,59}$ = 34.63; P < 0.001), but land use was not ($F_{1,59}$ = 1.88; P = 0.176).

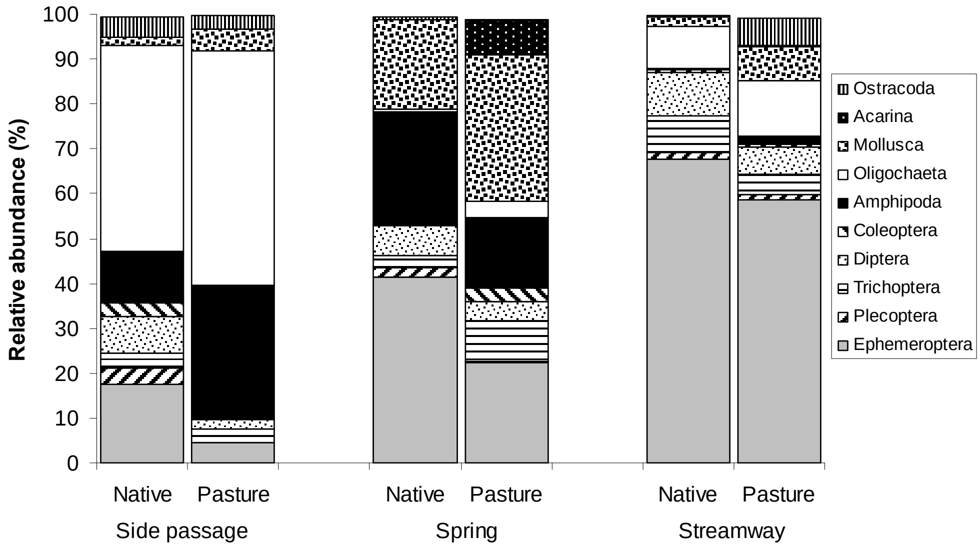


Figure 9: Relative abundance of key invertebrate groups across three karst habitats within predominantly native forest or pasture land use.

Another way of graphically representing invertebrate community patterns is through ordination techniques, such as non-metric Multi-Dimensional Scaling (MDS). This is an iterative multivariate ordination technique, whereby samples with greatest similarity in community composition, as measured by Bray-Curtis index, are placed close together, whereas dissimilar samples are placed farther apart (Clarke & Warwick 2001). The value of "2D stress" is a measure of the goodness of fit of the 2D solution to the underlying similarity matrix. 2D solutions with stress values < 0.2 are considered a useful representation of patterns in the data.

All invertebrate data were 4^{th} root-transformed (unlike the log transformation, power transformations preserve the ability to deal appropriately with zeros) to reduce the influence of highly abundant taxa. Figure 10 shows the output from the MDS using these data. The figure shows considerable overlap of samples from the three different habitat types, but the level of stress (0.2) is relatively high, so the degree of separation of different habitat types requires further testing. This was done using a two-way Analysis of Similarities (ANOSIM), a multivariate equivalent of ANOVA. Results from this analysis showed community composition varied significantly by habitat type (Global R = 0.381; P = 0.001), but not land use (Global R = 0.039, P = 0.153). All pair-wise comparisons by habitat type were very highly significant (P = 0.001).

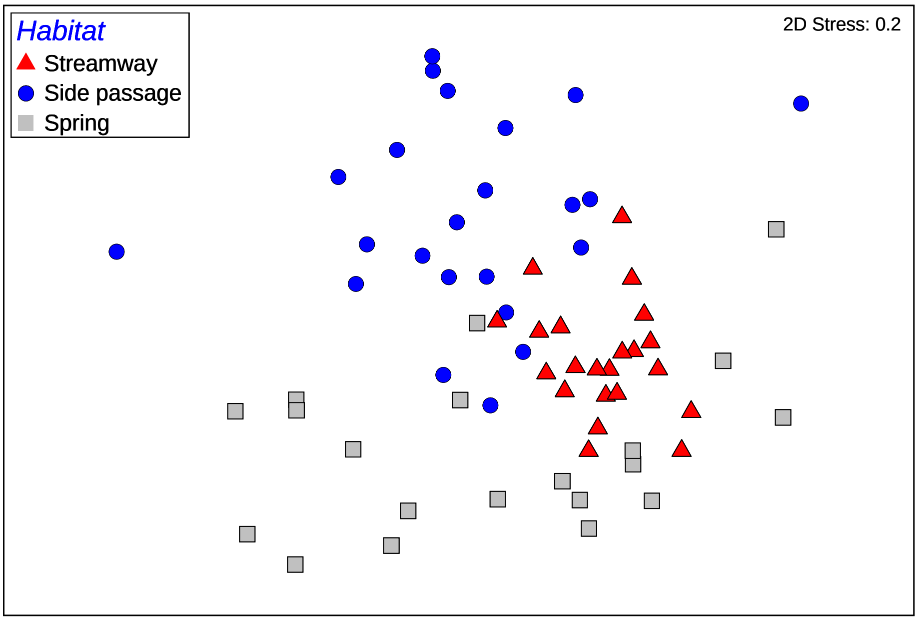


Figure 10: MDS plot of invertebrate abundance data (4th root-transformed) from three karst habitats.

The amphipod genus *Paraleptamphopus* is a major component of New Zealand's groundwater fauna (Scarsbrook et al. 2003) and its presence may provide a useful indicator of the source of water (i.e., surface or groundwater). Figure 11 shows a scatterplot of temperature and conductivity values for all Maniapoto sampling sites, overlaid with presence/absence data for *Paraleptamphopus* spp. Overall, sites where *Paraleptamphopus* spp. were present had significantly lower temperatures (2-sample t-test; $P < 0.001$) and higher conductivities ($P = 0.017$) than sites without. Also, there appears to be a temperature threshold (14 °C) above which *Paraleptamphopus* spp. is absent from all habitats.

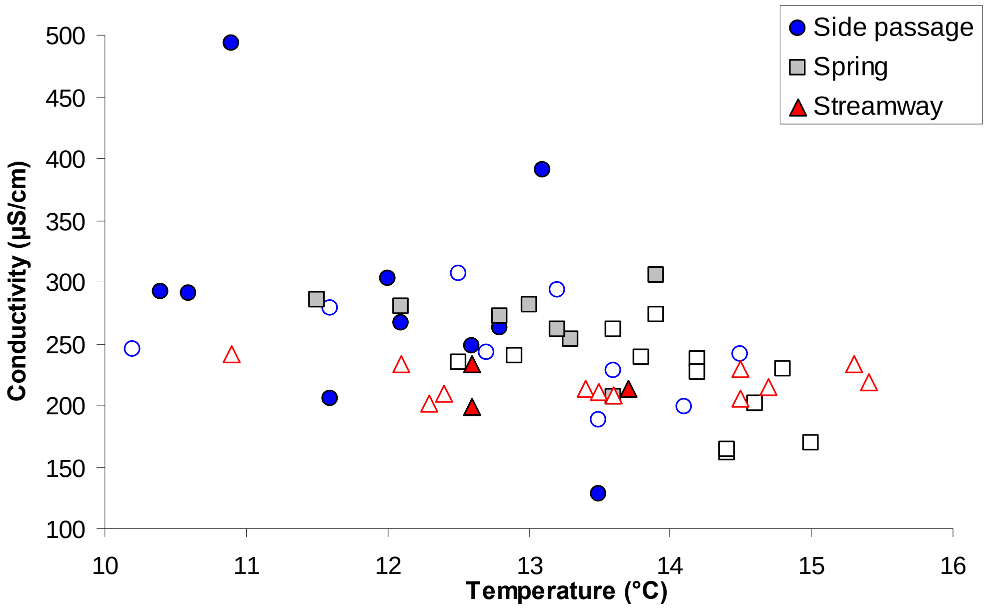


Figure 11: *Paraleptamphopus* spp. presence (shaded symbols) and absence (open symbols) in relation to temperature and conductivity across different karst habitats.

Given the separation by community composition across habitat types (Fig. 10) we decided to look in more detail at individual habitats, with the aim of linking patterns within habitats to measured physicochemical variables.

3.2.1 Side passages

Invertebrate communities of side passage habitats showed considerable variability within the same cave systems (Fig. 12, Appendix 4). Samples from different side passages within the same cave system were generally widely separated in the 2D MDS (e.g., samples from Lost World: LW3, LW4 and LW5). Key invertebrate groups in side passage habitats were Oligochaeta (49%), Amphipoda (19%; represented by a single taxon, the stygobitic *Paraleptamphopus* spp.), and Ephemeroptera (12%). These groups contributed over 75% of individuals. Overall, abundance of invertebrates tended to be low (range 2-268 individuals). 18 rare taxa occurred at only 1 site each.

There were relatively weak correlations between invertebrate community structure and measured physicochemical variables (Table 3). Temperature was the only variable showing a statistically significant correlation with community structure and was positively correlated with axis 2. Sites within the side passages that were dominated by Oligochaeta tended to be slightly warmer than sites with higher relative abundance of Amphipoda (Fig. 12).

Land use had a very weak influence on community structure in samples from side passages (one-way ANOSIM; Global R = 0.004; P = 0.422).

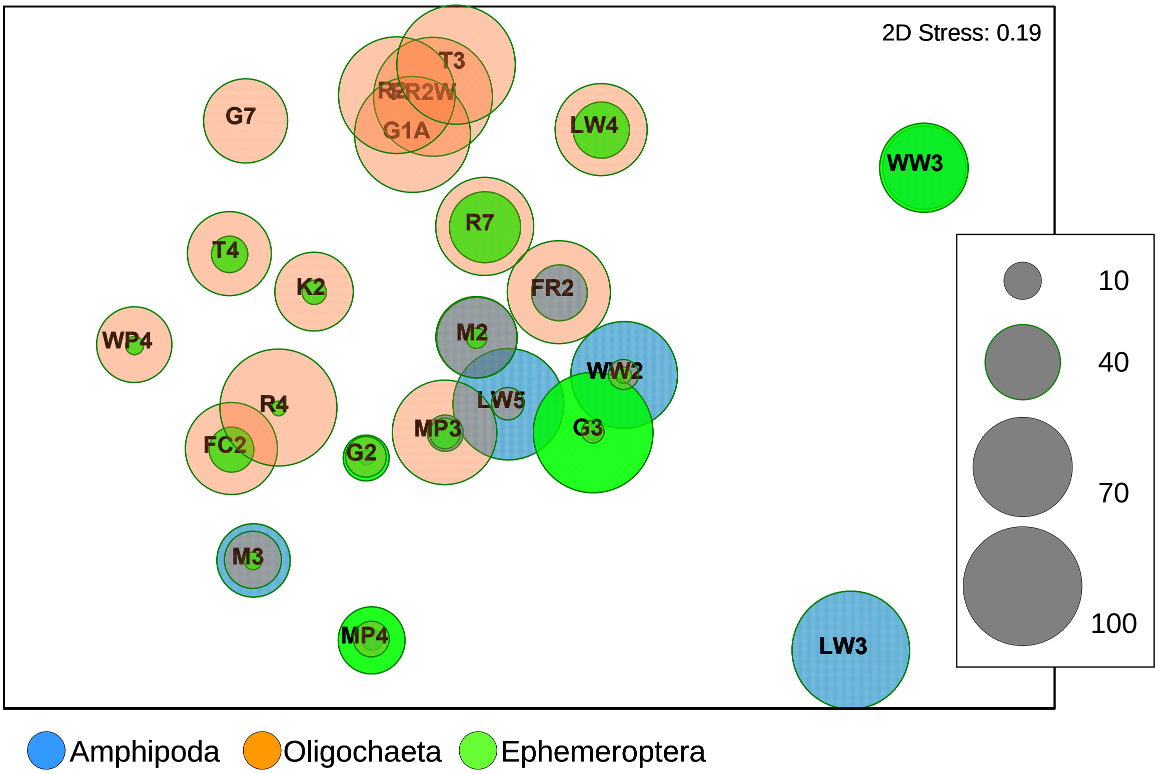


Figure 12: MDS ordination plot of invertebrate data from side passages. Data was 4th root-transformed. Bubble size is related to the relative abundance of the three most abundant invertebrate groups. See Appendix 1 for site codes.

Table 3: Spearman rank correlations between site scores from MDS (as they lie in Fig. 12) on side passage invertebrate data, and values of physicochemical variables measured at those sites. Correlation coefficients given in bold are statistically significant ($P < 0.05$; N = 19).

Variable	Axis1	Axis2
Temperature	-0.087	**0.551**
pH	-0.381	-0.044
Conductivity	-0.444	-0.347
Total Organic Carbon	0.233	0.023
NOx-N	-0.367	0.035
Alkalinity	-0.388	-0.373

3.2.2 Streamways

Samples from within individual cave systems tended to cluster together (Fig. 13). Six of the eight caves sampled at more than one point formed distinct groups. Koropupu (K3 and K4) and Tumutumu (T1, T2 and T5) did not form distinct clusters.

Land use had a relatively weak, but statistically significant effect on community structure (ANOSIM Global R = 0.111; P = 0.039), although this is difficult to discern from the 2D MDS (Fig. 13). Sampling did not include any sites where there were major changes in land use along a cave system, although these situations do occur frequently in the Maniapoto Karst area (e.g., Gardner's Gut).

Cave streamways are the habitat most likely to be directly impacted by cave tourism, particularly activities such as blackwater rafting. Within the group of caves sampled, several (Ruakuri, Fullerton Rd, Tumutumu/Okahua and Lost World) are used on a daily basis for tourism activities that include walking along the streamways. Other cave systems (Gardner's, Mangapohue, Waipuna) are used more occasionally by schools, or recreational caving groups. Figure 13 indicates some separation of caves into tourist caves (Lost World, Fullerton Rd and Ruakuri) and non-tourist caves (Mangapohue, Gardners and Waipuna), but this was not supported statistically by an ANOSIM (Global R = 0.171; P = 0.058). However, levels of Total Organic Carbon (TOC) were significantly higher in tourist than non-tourist caves (Mann-Whitney U test; $P < 0.05$) and the relative abundance of filter-feeders (mainly net-spinning caddis of the family Hydropsychidae) was also significantly higher in tourist caves (Mann-Whitney U test; $P < 0.01$).

Ephemeroptera was the dominant taxon within streamway habitats (average relative abundance = 63%). There were thirteen mayfly species identified in the original dataset (i.e., before collapsing to genera and above), with nine of these being Leptophlebiidae. The next most common groups were Oligochaeta (11%), Diptera (8%) and Trichoptera (6%). 16 rare taxa occurred at only 1 site each.

Correlations between axis scores for the invertebrate MDS and physicochemical variables were relatively weak, with the exception of temperature, which was positively correlated with Axis 2 scores.

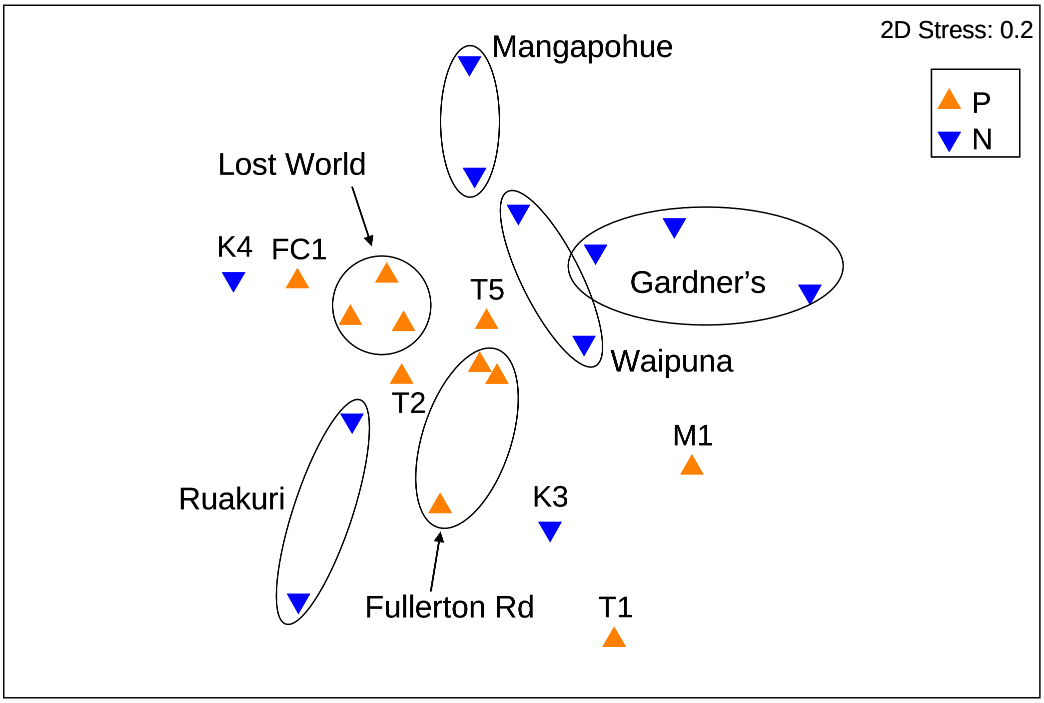


Figure 13: MDS ordination plot of invertebrate data (4th-transformed) from streamway sites classified by land use type. Cave names (see Appendix 1 for locations) and ellipses are given for some samples to show groupings. P = pasture, N = native. The Lost World, Ruakuri and Fullerton Rd caves are used for tourism on a daily basis, the others are used less frequently.

Table 4: Spearman rank correlations between site scores from MDS (Fig. 13) on streamway invertebrate data, and values of physicochemical variables measured at those sites. Correlation coefficients given in bold are statistically significant (*P* < 0.05; N = 15).

Variable	Axis1	Axis2
Temperature	-0.254	**0.780**
pH	0.384	0.303
Conductivity	-0.424	-0.059
Total Organic Carbon	-0.496	0.472
NOx-N	-0.189	-0.146
Alkalinity	-0.211	-0.111

3.2.3 Springs

Ephemeroptera (30%), Mollusca (27%) and Amphipoda (19%) were the dominant invertebrate groups within spring habitats. 25 rare taxa occurred at only 1 site each. Sites tended to cluster out quite distinctly by the relative abundance of these groups (Fig. 14).

Temperature, conductivity and alkalinity showed significant correlations with one, or both axes of the MDS (Table 5). Samples at the top left of the MDS were associated with high conductivity/alkalinity and low temperatures, and were dominated by Amphipoda (the stygobitic *Paraleptamphopus*). In contrast, sites in the bottom right of the ordination had low conductivity/alkalinity and higher temperatures, with high mayfly relative abundance. Amphipod relative abundance was also significantly correlated with temperature (r_S = - 0.55).

Land use had little effect on spring invertebrate community structure (Global R = 0.004, NS).

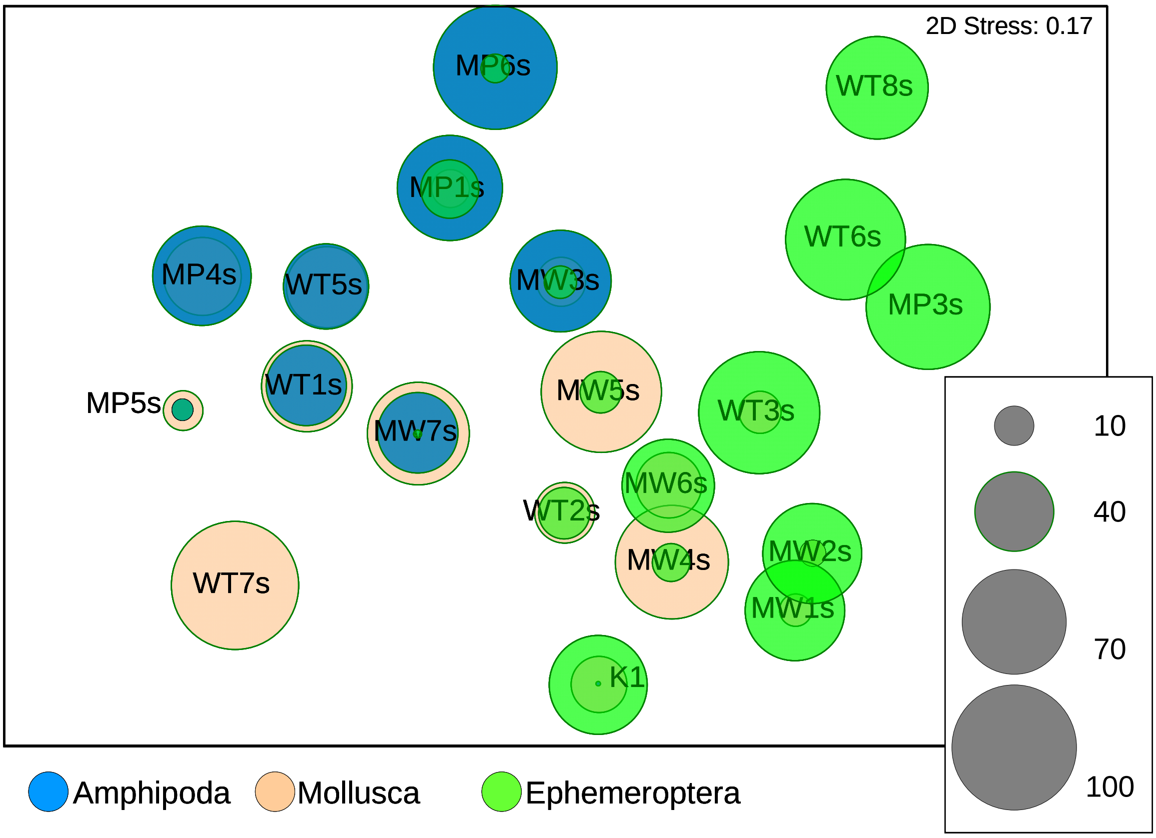


Figure 14: MDS ordination plot of invertebrate data (4[th] root-transformed) from springs**.** Bubble size is related to the relative abundance of the three most abundant invertebrate groups.

Table 5: Spearman rank correlations between site scores from MDS (Fig. 14) on spring invertebrate data, and values of physicochemical variables measured at those sites. Correlation coefficients given in bold are statistically significant ($P < 0.05$; N = 20).

Variable	**Axis1**	**Axis2**
Temperature	0.267	**-0.855**
pH	0.136	-0.036
Conductivity	**-0.588**	**0.567**
Total Organic Carbon	0.143	-0.150
NOx-N	0.085	-0.068
Alkalinity	**-0.599**	**0.567**

3.3 Comparison of Maniapoto karst springs with those in other geological types and geographical locations

3.3.1 Temperature and conductivity patterns

Temperature varied significantly with spring geology (Fig. 15), with differences confirmed by a one-way ANOVA on untransformed data ($F_{4,47}$ = 30.5; P < 0.001). Mean temperatures were highest at Lowland (17.6 °C) and Kawhia sites (16.4), intermediate at Kaimai sites (14.3), and lowest at Waihou (13.8) and Waitomo (13.1) sites (Bonferroni post-hoc test; Lowland = Kawhia > Kaimai = Waihou = Waitomo). Conductivity also varied significantly with geology (Fig. 15; $F_{4,47}$ = 108.2; P < 0.001). Waitomo sites had the highest average conductivity (254.8 µS/cm @ 25 °C), along with Kawhia sites (226.4), Lowland sites had intermediate conductivity (156.8), while Waihou (104.4) and Kaimai (76.6) sites had low conductivity (Bonferroni post-hoc test; Waitomo = Kawhia > Lowland > Waihou = Kaimai). Overall, Waitomo sites formed a distinct cluster exhibiting low temperature and high conductivity (Fig. 15).

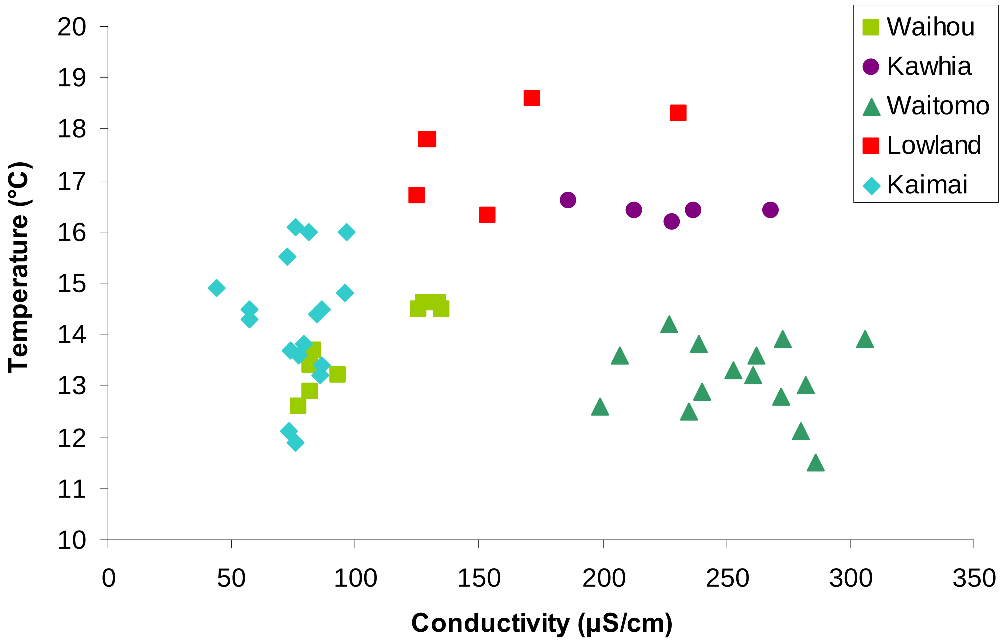


Figure 15: Scatterplot of spot measurements of temperature and conductivity at 52 Waikato spring sites.

3.3.2 Invertebrate patterns

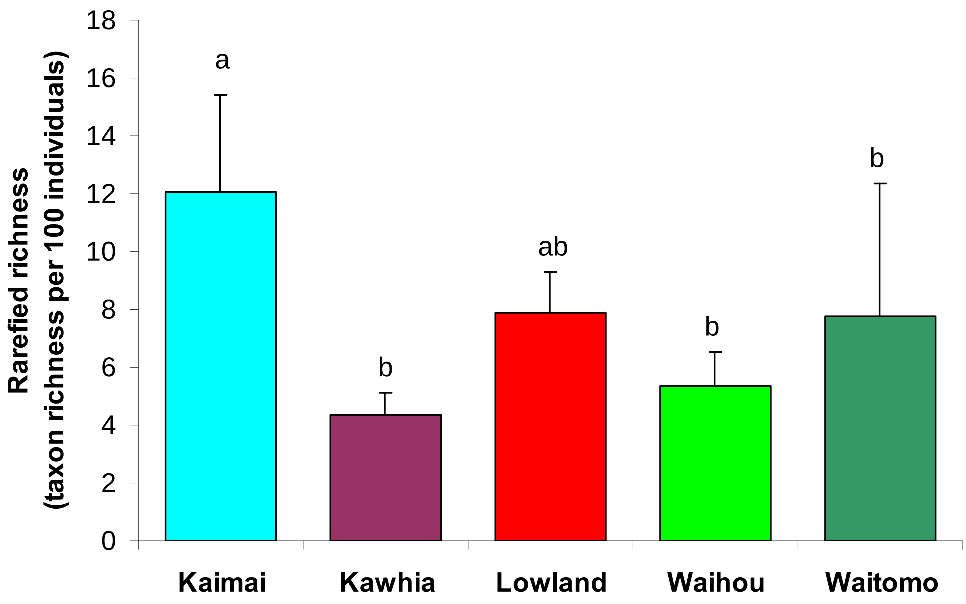
A composite dataset containing invertebrate data from 54 spring sites around the Waikato contained 95 taxa (Appendix 5), 25 of these occurring each at a single site. The most frequently occurring taxa were *Potamopyrgus* (40 sites), *Paraleptamphopus*

(36), *Zephlebia* (28 sites), Oligochaeta (27) and Acarina and *Polypedilum* (both 26). 10 taxa occurred at single sites within the Waihau area, 4 taxa occurred at a single sites within the Kawhia area, 21 in the Waitomo area, 13 in the Lowland area and 31 in the Kaimai area. Appendix 6 gives taxa lists and relative abundances for individual sites within each geology type.

Total invertebrate abundance ranged from 5 to 4187 individuals (both maximum and minimum abundance occurred in Waitomo samples). A one-way ANOVA on rank-transformed abundance data showed no significant difference in total abundance with geology type ($F_{4,49} = 1.29$; $P = 0.287$).

Given the significant range in sampling dates, and very different spring habitat types, species richness data were standardised by rarefaction in Primer 6.0 (i.e., species richness was calculated per 100 individuals). Standardised/rarefied taxon richness varied significantly with geology (one-way ANOVA; $F_{4,49} = 9.0$; $P < 0.001$), with richness highest at Kaimai and Lowland springs (Fig. 16).

%EPT_{taxa} (i.e., the percentage of taxa within the insect orders Ephemeroptera, Plecoptera and Trichoptera (including Hydroptilidae)) also varied significantly with geology (ANOVA on rank-transformed data; $F_{4,49} = 3.96$; $P = 0.007$). Post-hoc pair-wise comparisons showed that Waitomo samples had significantly higher %EPT_{taxa} than Lowland sites (Fig. 16).



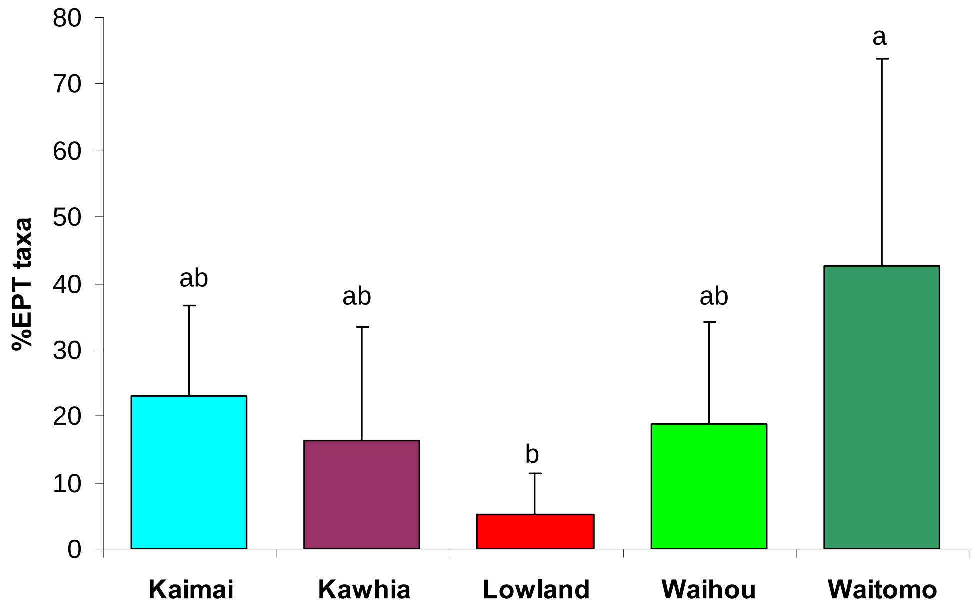


Figure 16: Total taxon richness (rarified to N = 100 individuals) and relative richness of mayflies, stoneflies and caddisflies (%EPT_{taxa}) in springs for each area. Letters above each bar refer to results of a Bonferroni post-hoc test – bars sharing the same letter are not significantly different.

Invertebrate community composition varied among springs from different geologies (Fig. 17). Relative abundance of Ephemeroptera varied significantly with geology (One-way ANOVA on rank-transformed data; $F_{4,49} = 3.01$; $P = 0.027$), as did relative abundance of Diptera ($F_{4,49} = 10.78$; $P < 0.001$), Crustacea ($F_{4,49} = 3.15$; $P = 0.022$) and Mollusca ($F_{4,49} = 3.60$; $P = 0.012$). Waitomo samples tended to be dominated by Ephemeroptera, Mollusca and Crustacea. Mollusca and Crustacea also dominated in Kawhia, Lowland and Waihou sites. Kaimai sites were dominated by Diptera and Crustacea.

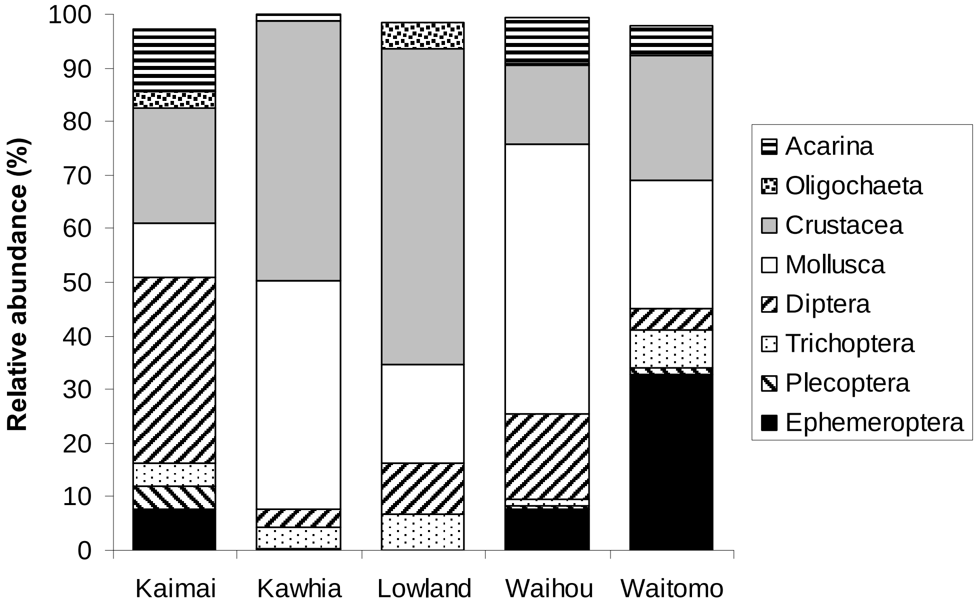


Figure 17: Relative abundance (%) of invertebrates in different taxonomic groups collected from springs of differing geology.

A MDS ordination on presence/absence data at each of the spring sites sampled within each geology is given below (Fig. 18). The 2D stress level (0.23) is relatively high indicating a weak representation of patterns in the data. However, the MDS plot does show distinct separations between some of the geological types and this was supported by a one-way ANOSIM on presence/absence data for the 54 sites (Global R = 0.347; $P < 0.001$). Pair-wise tests showed significant separation of Waitomo (karst) samples from Lowland and Kaimai samples, but community structure in Waitomo samples was more similar to Waihou and Kawhia.

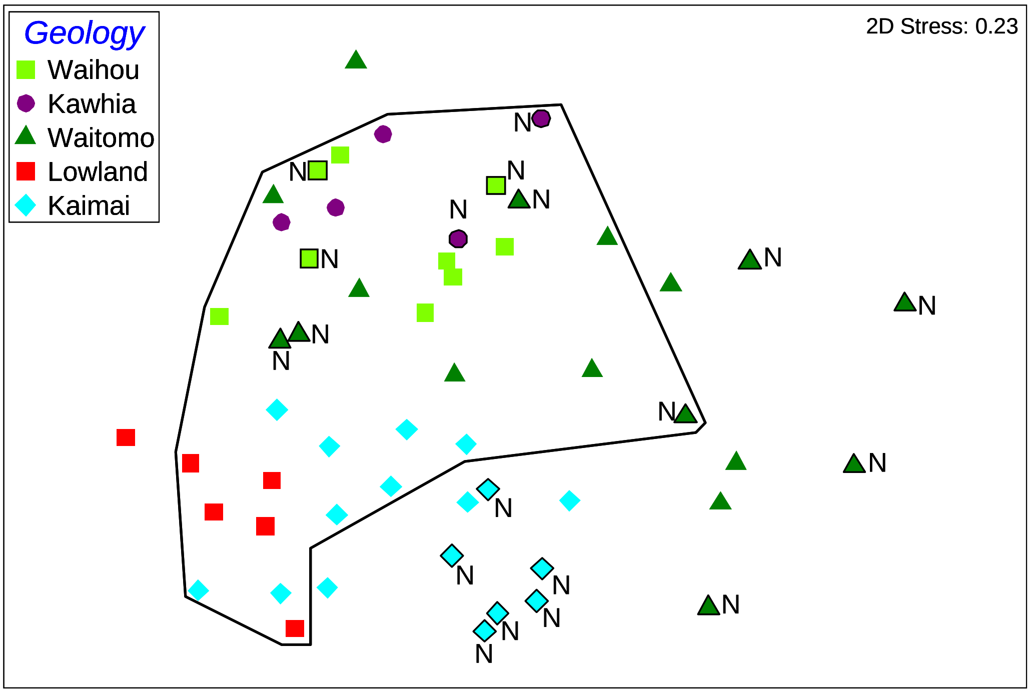


Figure 18: MDS plot of presence/absence data from 54 spring sites across different geological types. “N” = springs with intact native riparian vegetation, other sites had landscapes modified by human activity (predominantly farming). The polygon encloses all sites where *Paraleptamphopus* spp. was present.

The relative abundance of *Paraleptamphopus* spp. was significantly correlated with both axes of the MDS (Spearman rank correlation; $P < 0.01$). A SIMPER analysis indicated this taxon was a major component of the fauna in Kawhia and Waihou springs, also important in Waitomo and Lowland samples, but of limited importance in Kaimai springs (Table 6). The snail *Potamopyrgus* was the only taxon to be a major contributor to community structure across all geological types.

Kaimai samples provided some degree of separation between sites with intact native vegetation and those more impacted sites (Fig. 18). This is not surprising as these samples were collected in a study designed to assess effects of land use on spring community structure (Scarsbrook et al. 2007).

Table 6: Results of SIMPER analysis indicating the five most important taxa within each geological type. Values in parentheses are the % contribution made by that taxon to the group similarity.

Kaimai	Kawhia	Lowland	Waihou	Waitomo
Oligochaeta (13)	*Paraleptamphopus* (35)	Oligochaeta (19)	*Paraleptamphopus* (34)	*Potamopyrgus* (22)
Polypedilum (13)	*Paracalliope* (20)	*Potamopyrgus* (12)	*Potamopyrgus* (34)	*Zephlebia* (20)
Acarina (11)	*Potamopyrgus* (20)	Ostracoda (11)	*Zephlebia* (9)	*Paraleptamphopus* (12)
Potamopyrgus (5)	*Paradixa* (9)	*Paraleptamphopus* (11)	Acarina (9)	*Deleatidium* (10)
Orthocladiinae (5)	Acarina (4)	*Zelandotipula* (7)	Orthocladiinae (3)	Acarina (4)

4. Discussion

4.1 Environmental patterns in karst habitats

Habitat type (spring, streamway or side passage) was an important driver of observed patterns in both physicochemical and biological data from aquatic ecosystems of the Maniapoto Karst. Temperature and conductivity/alkalinity provided useful indicators of the source of water, with observed patterns suggesting that autogenic (groundwater-dominated) habitats (i.e., side passages and some springs) were characterised by lower temperatures and higher alkalinity. Levels of total organic carbon (TOC) were significantly correlated with water temperature in cave habitats, suggesting that carbon availability is likely to be influenced by water source. Cave streamways that have an allogenic hydrology (i.e., dominated by surface streams) had warmer temperatures and higher TOC concentrations than those fed by cooler groundwater. Gunn et al. (2000) also found temperature to have an important influence on invertebrate communities in Peak-Speedwell Cave in England.

Gunn et al. (2000) found that spatial patterns of invertebrate community structure within caves reflected differences in water source. Similarly, our results indicated that invertebrate community structure reflected differences in habitat type and water source. Our results showed that total invertebrate abundance and species richness was lowest in groundwater-dominated side passage sites, which we hypothesise may be a result of reduced food availability (TOC was lower in side passages than other habitat types, and reduced with distance into the cave). The principal source of organic debris is running water entering the cave from above-ground. This material may be fine humus which is easily utilised by cave biota, or coarser debris (twigs, leaves and branches) which must first be broken down by fungi and bacteria (Gillieson 1996). Sites with high amounts of organic matter are often associated with greater invertebrate richness whereas sites within caves that are rarely flooded may therefore be expected to have depauperate invertebrate faunas. Sites located along the main streamway with direct connection to the surface environment are likely to be richer in species and total numbers of organisms (Gillieson 1996). Water source (allogenic v. autogenic) also appears to be a major driver of community structure in karst springs. The presence of groundwater amphipods, notably *Paraleptamphopus* spp., appeared to be a good indicator of autogenic water, whereas high mayfly abundance more typically reflected an allogenic water source.

There were significant correlations between temperature and community structure for all three habitats types, with springs having the strongest correlation. Thermal variability is dependent on the mode of flow, and the duration that water is underground. Smith et al. (2003) investigated, the influence of habitat structure on invertebrate communities in karst spring systems in England and found that flow permanence, water temperature and input of leaf litter exerted a strong influence on invertebrate communities. Our results suggest that among the 3 habitat types, springs tended to most strongly reflect varying water source in their invertebrate communities.

In contrast to habitat type, land use had only a limited influence on biological patterns in our dataset. Landuse, and hence riparian structure around a karst water source may influence invertebrate community structure and abundance, with the input of leaf-litter from the surrounding vegetation potentially forming an important source of organic matter, particularly in habitats where autochthonous production is naturally low Gillieson 1996). Our results showed some land use effects on concentrations of NO_x-N, but little effect on invertebrate community composition in cave streamways, side passages or springs. Our measure of land use was relatively coarse, due in part to the difficulty of delineating contributing area for aquatic habitats in karst areas. It is very difficult to determine land use patterns in karst because the stream networks are poorly defined. However, concentrations of nitrate appear to be a good indicator of systems draining pasture.

Pasture streams are often characterised by elevated maximum temperatures in summer (e.g., Quinn 2000), and these elevated temperatures can be a key driver of aquatic invertebrate community structure (Quinn et al. 1997; Cox & Rutherford 2000). We suggest that the absence of strong land use effects on biological patterns may be the result of cool groundwater inflows acting as a buffer to moderate the elevated temperatures typically found in agriculturally impacted streams. Just as springs in porous aquifer landscapes have been suggested as potential refugia from elevated water temperatures (Death et al. 2004), so karstic stream ecosystems in open pasture may benefit from groundwater inflows. The highest water temperature observed during our extensive survey of karst habitats was 15.4 °C. This is considerably lower than any of the recorded LD_{50} levels for common stream invertebrates (Quinn et al. 1994). However, it is worth nothing that the stygobitic amphipod *Paraleptamphopus* spp. did not occur in any locations where water temperature exceeded 14 °C. This may reflect the relative contribution of surface and groundwater, but might still be driven by the (unknown) temperature tolerance of *Paraleptamphopus* spp.

4.2 Biodiversity values in karst aquatic ecosystems

The family Paraleptamphopiidae is thought to contain a large number of yet to be described species and is a group desperately requiring taxonomic research in New Zealand (Fenwick 2001). Stygobitic (i.e., blind, colourless) forms of

Paraleptamphopus spp. are found in Groundwater Dependent Ecosystems (e.g., springs, caves, aquifers, hyporheic zones) throughout New Zealand, and this group is arguably more ubiquitous than some of the more commonly known aquatic insect taxa (e.g., *Deleatidium*). *Paraleptamphopus* spp. is an important indicator organism in karst streams, yet very little is known of its life history, feeding ecology, or biological interactions with other taxa. We suggest that future research into its population ecology would provide valuable information to assist the management of karst ecosystems.

Another group of particular note in relation to karst ecosystems are the hydrobiid snails. Haase (2008) has identified 64 species of hydrobiids from New Zealand many of them having close associations with karst (Scarsbrook et al. 2007). However, the taxonomic resolution of sampling carried out for the present report was not sufficiently detailed to pick up any of these species. Indeed, identification of this highly diverse group is problematic, requiring highly specialised knowledge. Simplified identification tools are desperately needed if this group is to be included in ecological studies of karst systems in the future.

Another habitat type not covered in this report is the epikarst (partially saturated vadose zone overlying saturated karst). Some preliminary sampling of drips in Aranui and Ruakuri caves has turned up no invertebrates, but this ecosystem is likely to contain a distinct meiofauna, dominated by copepods (Pipan & Culver 2005). Similarly, rockface seepages around the entrance of caves were another habitat not covered in this report. Work by Collier and Smith (2005) in the Waikato suggests a diverse fauna occurs in these environments, including several new species and taxa found only in these habitats. Rimstone pools fed by epikarst drips are another potentially distinct habitat to investigate. Some preliminary collections by Dave Smith (DoC Te Kuiti) have shown that hydrobiid snails and *Paraleptamphopus* spp. are present in rimstone pool habitats. Investigations into both of these habitats will be hindered by taxonomic difficulties with both groups.

4.3 Comparison of Maniapoto karst springs with those in other geologies

Waitomo springs formed a distinct cluster with respect to temperature and conductivity values. Invertebrate community composition also varied significantly among springs from different geologies. In particular, Waitomo springs had the highest %EPTtaxa, and communities in karst springs were distinct from springs in Lowland sedimentary and Kaimai ignimbrite lithologies. *Paraleptamphopus* spp. was an important component of the invertebrate fauna in four of the five lithologies, with the exception being the Kaimai ignimbrite springs. It is interesting to speculate whether greater taxonomic resolution within this group might allow for better discrimination. Phylogeographical studies (the study of geographic distribution of individuals in light of the patterns associated with a gene genealogy) would be useful to identify the level of local endemism in this group.

4.4 Tourism and karst aquatic ecosystems

Tourism is a defining feature of the Waitomo area and has been for over 100 years. Some research has been undertaken to assess tourism effects on cave environments (De Freitas 1998) and glowworm (*Arachnocampa luminosa*) populations (Pugsley 1980), but there have been no studies on potential direct tourism impacts on stream faunas.

Based on results of extensive surveys, tourism activities appear to have little direct impact on invertebrate communities in cave streamways. Further work is planned to assess impacts on fish communities in these cave systems. We envisage the potential for greater impacts on fish communities from tourism operations, because some cave operators have installed physical barriers that might limit fish passage. For example, weirs are present in Ruakuri, Fullerton Rd and Managapohue caves to provide for blackwater rafting. The question is whether these barriers are limiting upstream fish passage, or whether they are simply additional to natural waterfalls that tend to be a feature of cave systems.

Direct effects of tourists on fish present in the caves are likely to be low. Preliminary electrofishing (EFM300) investigations in Ruakuri Cave (Scarsbrook unpublished data; 19/3/2005) identified a small population of torrentfish (*Cheimarrichthys fosteri*) in the first cascade up from the cave resurgence. Searches of the New Zealand Freshwater Fish Database found records of the same population present in 1985 before blackwater rafting operations began.

4.5 Management of karst aquatic ecosystems

Karst systems are best protected by maintaining the intact surface vegetation, soils and hydrological systems over the whole catchment affecting the area (DoC 1998). Unfortunately, protection of the entire catchments of karst systems is seldom practicable, and resource managers need to balance the risk of damage to these valued ecosystems against human activities in the catchment. Karst systems face a range of anthropogenic threats (Table 6), some of which are unique to karst ecosystems (e.g., tourism & recreational caving), while others (e.g., forestry and quarrying) may have proportionately greater potential impacts on karst systems than in other ecosystems

(Gunn et al. 2000). There is limited information on the impacts of primary activities, such as farming, forestry and mining, on karst ecosystems (Urich 2002).

Within the Waikato Regional Plan (Sept 2007), karst systems are recognised as an important landscape feature and a valued component of the Region's water resources. In particular, the caves and springs found throughout the Maniapoto Karst are of customary significance to Ngati Maniapoto and protection of these systems from further desecration or disruption of caves or karst formations by tourism, land excavations, pollution, quarrying or rubbish dumps is a key objective for Ngati Maniapoto.

Despite the significance of karst landscapes to the Waikato Region there no objectives in the Waikato Regional Plan (WRP) that relate specifically to water-related issues in cave and karst environments. It is assumed that achieving general objectives related to water quality, aquatic ecosystems and water quantity will ensure that water in the Region's karst areas is managed appropriately. For example, under the Plan's Chapter 4 "River and Lake Beds" section, cave passages that are either ephemeral or permanently flowing water bodies are considered to be a riverbed, and therefore they are given the same protection as other riverbeds. However, it could be argued that cave passages may not be adequately protected by general objectives and rules relating to river beds, as any alterations within these passages have the potential to affect cave formations.

Based on results of this study, we suggest that Environment Waikato's WRP is likely to be providing adequate *implicit* protection for most karst aquatic ecosystems from management objectives common to all waterbodies. The Waikato RRMP provides very clear objectives with respect to land use activities and the avoidance, remediation and mitigation of any adverse effects on aquatic ecosystems. For example, controls on sediment generation through erosion control and exclusion of stock from waterways, along with controls on point source discharges and strict riparian zone management should all provide adequate protection for karst aquatic ecosystems.

Our confidence in supporting the assumption that general water quality objectives will provide adequate protection for karst ecosystems is strengthened by the fact that our study provided little evidence of significant effects of agricultural land use on cave and spring habitats in these systems. The effects that were observed (i.e., elevated nitrate concentrations and temperatures), did not appear to have adverse effects on invertebrate community structure. In addition, activities that are unique to karst systems, such as tourism and recreational caving, did not appear to have significant effects on aquatic communities, and there tends to be tight controls on cave tourism activities in the District. For example, operations within Waitomo Glowworm Cave are tightly controlled by the Waitomo Glowworm Cave Environmental Management Plan (Waitomo Environmental Advisory Group, personal communication).

Under the proposed Variation No. 6 (Water allocation) to the WRP water flowing in karst systems is considered to be surface water rather than groundwater. However, results in this report show that some aquatic habitats within karst systems have physicochemical and biological characteristics that clearly associate them with groundwater rather than surface water. In addition, several springs sampled during our extensive surveys were being tapped into as sources of drinking water for stock and/or humans, because they reflected high quality groundwater, rather than relatively poor quality surface water. Many of these water source springs have been used as water supplies throughout the period of human habitation in the Waitomo District (Huia Davis, Ruapuha Uekaha Hapu, Waitomo), and as such they have huge significance for local iwi.

Definition of all karst waters as surface waters within Variation No. 6 ignores the presence of important groundwater habitats and the distinct communities associated with them. There are provisions within the Variation that take into account the link between groundwater and karst systems when allocating groundwater abstraction (e.g., Policy 2; Establish sustainable yields from groundwater, Policy 9; Consent application assessment criteria - groundwater). However, we suggest that management of water resources in karst ecosystems should recognise the separation of systems in autogenic (groundwater dominated) and allogenic (surface water dominated) components. Though the current report did not investigate epikarst ecosystems, we suggest that this might constitute a third distinct system for managers to consider. Identification of significant areas of autogenic karst and their associated fauna should be a priority for future management-driven research within the Maniapoto Karst.

Table 6: Threats to aquatic ecosystems in karst landscapes. Modified after Gunn et al. (2000).

Threat	Potential impact	Risk to aquatic ecosystems around Waitomo
Quarrying and mining	Habitat loss Siltation Altered hydrology	High – McDonalds Lime has a major quarrying operation in the Mangapu catchment. No monitoring of ecological effects?
Landfill/waste disposal	Chemical contamination Siltation Faecal contamination	High – dolines provide convenient sites for waste disposal
Agriculture	Physical habitat modification Chemical contamination Animal carcasses Faecal contamination	High – reduction of riparian vegetation reduces allochthonous inputs, nutrient enrichment from agricultural practices, increased sanitary bacteria, change in community structure and food chains.
Forestry	Siltation	High – forestry harvesting increases fine sediment habitats, siltation/loss of interstitial habitats, accumulation of organics.
Groundwater abstraction	Altered hydrology (dams and weirs)	Unknown (barriers to fish passage)
Tourism & caving activities	Physical habitat damage Altered hydrology (dams & weirs)	High – physical mobilisation of organics, siltation/loss of interstitial habitats, increase in fine sediment habitats, increase sanitary bacteria, changes community structure and food chains, block migration of fish through physical barriers.
Vandalism	Physical habitat damage Chemical contamination	High – there have been recent examples of vandalism in Waitomo Glowworm Cave

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7. Appendices

Appendix 1: Location of 65 karst sites sampled in three habitat types (STR = streamway, SDP = side passage, SPR = spring) and two landuse types (P = pasture, N = native) in the Maniopoto Karst. New Zealand Map Grid references given for 20 spring habitats (note that grid references were not obtainable from underground sites). Refer to Figure 2 for location map.

Site	Landuse	Habitat	Cave	Location	Easting	Northing
FC1	P	STR	Mangawhitikau	Flood Caverns		
FC2	P	SDP	Mangawhitikau	Flood Caverns		
FRS	P	STR	Footwhistle/Fullerton Rd	Main streamway, Base of stairs		
FR1	P	STR	Footwhistle/Fullerton Rd	Main streamway, Lichencamp		
FR2	P	SDP	Footwhistle/Fullerton Rd	TL trib		
FR2W	P	SDP	Footwhistle/Fullerton Rd	TR trib drip/wf pool		
FR4	P	STR	Footwhistle/Fullerton Rd	Main streamway		
G1	N	STR	Gardener's Gut	Lower Cave (above resurgence)		
G1A	N	SDP	Gardener's Gut	Lower Cave		
G2	N	SDP	Gardener's Gut	TR Trib <1L/s		
G3	N	SDP	Gardener's Gut	TR Trib <5L/s (The junction)		
G4	N	STR	Gardener's Gut	Main streamway under Vivienne's needle route		
G5	N	STR	Gardener's Gut	U/S waterfall passage		
G7	N	SDP	Gardener's Gut	Drip pool Exit 7		
K1	N	SPR	Koropupu	Koropupu resurgence ~100 m from opening		
K2	N	SDP	Koropupu	Small pool 1 m above stream level		
K3	N	STR	Koropupu	Cold Creek		
K4	N	STR	Koropupu	Cold Creek		
LW1	P	STR	Mangapu/Lost World	Base of abseil		
LW2	P	STR	Mangapu/Lost World	above lost world rockfall		
LW3	P	SDP	Mangapu/Lost World	above ladder climb/by waterfall		
LW4	P	SDP	Mangapu/Lost World	dead sheep creek TL trib		
LW5	P	SDP	Mangapu/Lost World	TR trib. Large passage		
LW6	P	STR	Mangapu/Lost World	Cave entrance (30 m d/s)		
M1	P	STR	Matthews	15m into cave		
M2	P	SDP	Matthews	small trib flowing into mainstem		
M3	P	SDP	Matthews	small trib flowing into mainstem - not too far from surface		
MP3	N	SDP	Mangapohue	Up Weir stream		
MP4	N	SDP	Mangapohue	TR trib From JP Cave		
MP5	N	STR	Mangapohue	Main stream below MP4 confluence		
R2	N	SDP	Ruakuri	TL Trib		
R3	N	STR	Ruakuri	Main streamway by Dam (US)		

Site	Landuse	Habitat	Cave	Location	Easting	Northing
R4	N	SDP	Ruakuri	Rebirthing Chamber		
R5	N	STR	Ruakuri	Cecil's Pool Huhunui Streamway		
R7	N	SDP	Ruakuri	The Pretties		
T1	P	STR	Tumutumu/Okahua	cave exit ~5 m in		
T2	P	STR	Tumutumu/Okahua	"Hotspot" mainstem		
T3	P	SDP	Tumutumu/Okahua	Drip fed/flood fed side channel		
T4	P	SDP	Tumutumu/Okahua	TL trib just below cave exit		
T5	P	STR	Tumutumu/Okahua	mainstem just below cave exit		
WP1	N	STR	Waipuna	Main streamway US main tomo		
WP4	N	SDP	Waipuna	Trib running into Waipuna		
WP4U	N	STR	Waipuna	Waipuna mainstream		
WW2	N	SDP	Waitomo Waterfall			
WW3	N	SDP	Waitomo Waterfall			
MP1s	N	SPR	Stubbs 1		2685856	6324294
MP2s	N	STR	Staligtite Stream		2686339	6324926
MP3s	N	SPR	Mangapohue Cave		2685686	6324378
MP4s	N	SPR	Stubbs reserve-pre fence		2684782	6324742
MP5s	P	SPR	Nettle 1		2685434	6323974
MP6s	P	SPR	Weir 1		2685596	6323420
MW1s	P	SPR	Koropupu 2, right		2689996	6318085
MW2s	P	SPR	Koropupu 2, left		2689996	6318085
MW3s	P	SPR	Koropupu 1		2690199	6318126
MW4s	P	SPR	Mangawhitikau resurgence		2693250	6317465
MW5s	P	SPR	Mangawhitikau 1		2691442	6317644
MW6s	P	SPR	Koropupu 3		2690263	6318043
MW7s	P	SPR	Koropupu 4		2690061	6318111
WT1s	N	SPR	Aranui right		2692181	6324716
WT2s	P	SPR	Waitomo DS Cave		2694358	6324824
WT3s	N	SPR	Ruakuri		2692080	6324325
WT5s	N	SPR	Aranui left		2692135	6324549
WT6s	N	SPR	Gardners Gut		2691740	6324325
WT7s	P	SPR	Dimond 2		2693480	6324885
WT8s	P	SPR	Dimond 1		2692557	6324796

Appendix 2: New Zealand Map Grid references for 54 spring habitats sampled in five areas (and geology types) within the Waikato Region.

Site name	Site #	Date	East	North
Waihou (sand/sedimentary)				
Waihou 1	W1	17/08/2006	2759435	6347783
Waihou 2	W2	17/08/2006	2758677	6347706
Waihou 4	W4	17/08/2006	2758704	6347715
Whites Rd 1	W5	18/08/2006	2757155	6349585
Whites Rd 2	W6	18/08/2006	2757170	6349621
Whites Rd 3	W7	18/08/2006	2757168	6349531
Whites Rd 4	W8	18/08/2006	2757157	6349521
Whites Rd 5	W9	18/08/2006	2757933	6348639
Whites Rd 6	W10	18/08/2006	2757961	6348618
Kawhia (sand)				
S1	KW1	16/02/2006	2669860	6351200
S2	KW2	16/02/2006	2669736	6351417
S3	KW3	16/02/2006	2669796	6351535
S4	KW4	16/02/2006	2669750	6351500
S5	KW5	16/02/2006	2669795	6351493
Waitomo (karst)				
Ruakuri	WT2	27/02/2006	2692080	6324325
Nettle 1	WT3	1/03/2006	2685434	6323974
Mangawhitikau 1	WT4	2/03/2006	2691442	6317644
Mangapohue cave	WT5	28/02/2006	2685686	6324378
Staligtite stream	WT6	1/03/2006	2686339	6324926
Stubbs reserve, pre-fence	WT7	3/03/2006	2684782	6324742
Gardeners Gut	WT8	27/02/2006	2691740	6324325
Koropupu 1	WT9	2/03/2006	2690199	6318126
Stubbs 1	WT10	28/02/2006	2685856	6324294

Site name	Site #	Date	East	North
Koropupu 4	WT11	2/03/2006	2690061	6318111
Aranui left	WT12	27/02/2006	2692135	6324549
Aranui right	WT13	27/02/2006	2692181	6324716
Dimond 2	WT14	27/02/2006	2693480	6324885
Dimond 1	WT15	27/02/2006	2692557	6324796
Weir 1	WT16	1/03/2006	2685596	6323420
Koropupu 2 left	WT17	2/03/2006	2689996	6318085
Koropupu 2 right	WT18	2/03/2006	2689996	6318085
Lowland (sedimentary/ashes)				
Andrew 1	L1	22/01/2003	2742341	6379151
Haigh's 1	L2	22/01/2003	2742012	6379626
Hutchinson 1	L3	23/01/2003	2745617	6382047
Hutchinson 2	L4	23/01/2003	2745607	6381947
MWR 1	L5	22/01/2003	2736329	6384534
MWR 2	L6	22/01/2003	2736423	6384530
Verner 1	L7	23/01/2003	2729466	6378231
Kaimai (ignimbrite)				
Carmichael 1a	K1	20/01/2004	2762709	6381225
Sainsbury 2	K2	20/01/2004	2765051	6367945
Sainsbury 6	K3	20/01/2004	2765019	6368280
Kean 1	K4	20/01/2004	2763459	6369017
Stewart 1	K5	20/01/2004	2763563	6377065
Woods 1	K6	20/01/2004	2763434	6379184
Carmichael 2	K7	20/01/2004	2762715	6381243
Sainsbury 1	K8	20/01/2004	2765034	6367942
Sainsbury 4	K9	20/01/2004	2765160	6368356
Quarry 1	K10	20/01/2004	2765114	6372102
Native 1	K11	20/01/2004	2763100	6381450

Site name	Site #	Date	East	North
Young 1	K12	20/01/2004	2763581	6374200
Young 2	K13	20/01/2004	2763581	6374210
TeAroha 2	K14	11/02/2004	2750500	6402890
Quarry	K15	23/01/2003	2765201	6372183
Carmichael 1	K16	23/01/2003	2762719	6381230
Carmichael 2	K17	23/01/2003	2762735	6381485
Carmichael 3	K18	23/01/2003	2762688	6381295

Appendix 3: Species list and average relative abundance for invertebrates collected from three pooled habitat types sampled in the Maniapoto Karst. '*' = taxon makes up less than 1%. Individual sites shown in Appendix 4.

Taxon	Side passage	Spring	Streamway
Acarina		1.8	*
Amphipoda			
Paracalliope	*	*	
Paraleptamphopus	18.8	24.9	*
Taltridae		*	
Coleoptera			
Dytiscidae		*	
Elmidae	1.5	1.2	*
Hydraenidae		*	*
Hydrophilidae		*	
Ptilodactylidae	*	*	*
Scirtidae			*
Staphylinidae		*	
Diptera			
Aphrophila	*	*	
Austrosimulium		*	2.0
Ceratopogonidae	*	*	*
Chironomus	*		*
Empididae	*	*	*
Eriopterini	*	*	*
Harrisius	*	*	*
Hexatomini	*	*	*
Lobodiamesinae		*	
Molophilus	*	*	*
Orthocladiinae	*	*	1.4
Paradixa	*	*	*
Paralimnophila	*	*	*
Paucispinigera		*	*
Polypedilum	1.7	1.2	*
Psychodidae		*	
Tanyderidae		*	*
Tanypodinae	*	*	*
Tanytarsus	1.5	*	*
Ephemeroptera			
Acanthophlebia		*	*
Ameletopsis			*
Austroclima		1.3	*
Austronella		*	
Coloburiscus	*	1.1	5.8
Deleatidium	7.0	15.9	53.8
Ichthybotus			*
indet. Leptophlebiidae	*		
Mauiulus		*	*
Neozephlebia	*	*	*
Nesameletus		*	*
Zephlebia	3.7	2.1	11.0
Hemiptera			

Taxon	Side passage	Spring	Streamway
Sigara		*	
Isopoda	*		
Lepidoptera			
Hygraula		*	
Megaloptera			
Archichauliodes	*	*	*
Mollusca			
Gyraulus		*	
Physa		*	
Pisidium	*		
Potamopyrgus	4.9	39.4	3.6
Odonata			
Antipodochlora		*	
Oligochaeta	46.7	1.7	10.0
Ostracoda	4.8	1.2	*
Platyhelminthes	*	*	*
Plecoptera			
Acroperla		*	
Austroperla		*	
Megaleptoperla	*		*
indet. Notonemouridae			*
indet. Plecoptera	*		*
Spaniocerca	*	*	*
Stenoperla	*	*	*
Zelandobius		*	*
Zelandoperla		*	
Trichoptera			
Aoteapsyche		*	*
Confluens		*	
Costachorema			*
Helicopsyche			*
Hydrobiosidae	*	*	*
Hydrobiosis	*	*	*
Leptoceridae			*
Oeconesus		*	*
Olinga	*	1.4	*
Orthopsyche	1.9	*	2.9
Philopotamidae	*		*
Plectrocnemia	*	*	*
Polyplectropus		*	
Pseudoeconesus	*		*
Psilochorema		*	*
Pycnocentria		*	*
Pycnocentrodes		*	*
Triplectides		*	
Total taxa	41	66	58

Appendix 4: Species list and average relative abundance for invertebrates collected from three habitat types sampled in the Maniapoto Karst. '*' = taxon makes up less than 1%. Pooled habitat types species lists shown in Appendix 3. Site locations given in Appendix 1.

Streamway

	FC1	FRS	FR1	FR4	G1	G4	G5	K3	K4	LW1	LW2	LW6	M1	MP5	R3	R5	T1	T2	T5	WP1	WP4U	MP2s
Acarina	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Amphipoda																						
Paraleptamphopus	*	*	*	*	*	*	*	*	*	*	*	*	21.5	*	*	*	*	*	*	*	1.7	*
Coleoptera																						
Elmidae	*	*	*	*	*	*	*	*	*	1.1	*	*	*	*	*	*	*	*	*	*	*	*
Hydraenidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Ptilodactylidae	*	*	*	*	*	*	*	1.0	*	*	*	*	1.5	*	*	*	*	*	*	*	*	*
Scirtidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.6
Diptera																						
Austrosimulium	*	4.1	*	3.1	*	*	*	*	*	*	*	*	*	9.6	*	40.5	*	8.3	4.0	7.1	1.2	2.7
Ceratopogonidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Chironomus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Empididae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Eriopterini	*	*	*	*	*	*	*	*	*	*	*	*	1.5	*	*	*	2.1	1.1	*	*	*	*
Harrisius	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hexatomini	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.1
Molophilus	*	*	*	*	*	*	*	*	*	*	*	*	1.5	*	*	*	*	*	*	*	*	*
Orthocladiinae	*	*	*	*	*	*	*	1.6	*	*	7.6	*	6.2	2.3	*	*	*	*	*	1.1	1.7	*
Paradixa	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Paralimnophila	*	*	*	*	*	*	*	15.5	*	*	*	*	*	*	*	*	2.1	1.1	*	*	*	*
Paucispinigera	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Polypedilum	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tanyderidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tanypodinae	*	*	*	*	*	*	*	*	*	*	*	*	3.1	*	*	*	6.4	3.0	*	*	*	*
Tanytarsus	*	*	*	*	*	*	1.7	*	*	*	*	*	*	2.3	*	*	*	*	*	1.1	*	*
Ephemeroptera																						
Acanthophlebia	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Ameletopsis	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Austroclima	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	11.8
Coloburiscus	*	7.8	22.7	1.5	*	1.8	1.3	*	1.6	11.4	6.9	16.5	*	4.8	5.9	18.9	*	*	13.3	6.7	1.7	2.4
Deleatidium	88.7	46.3	43.1	1.9	85.3	90.7	85.9	22.8	56.5	46.2	74.9	38.3	20.0	6.4	25.9	18.9	6.4	61.7	51.6	21.3	10.4	39.7
Ichthybotus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.5	*	*	*	*
Mauiulus	*	*	*	*	*	*	*	*	*	*	1.0	*	*	*	*	*	*	*	*	*	*	*
Neozephlebia	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.5	*	*	*	*
Nesameletus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Zephlebia	*	2.7	4.9	3.4	*	*	*	2.6	*	9.8	1.8	13.8	1.5	64.9	6.7	10.8	12.8	9.5	16.4	32.1	67.6	34.3
Megaloptera																						
Archichauliodes	*	1.0	*	*	*	*	*	*	1.3	*	*	*	*	*	*	*	*	*	*	*	*	*
Mollusca																						
Potamopygrus	2.2	15.0	*	46.2	*	*	*	9.8	5.6	1.8	*	5.1	7.7	*	2.4	5.4	4.3	*	*	*	*	*
Oligochaeta	3.1	15.0	17.9	29.8	4.0	1.8	3.0	42.0	11.8	6.3	5.8	16.3	24.6	1.6	*	*	8.5	4.2	4.4	28.1	10.4	*
Ostracoda	*	2.4	*	9.9	*	*	*	1.6	1.3	*	*	*	1.5	*	*	*	53.2	*	*	*	1.2	*
Platyhelminthes	*	*	*	*	*	*	*	*	1.7	3.7	*	1.5	*	*	*	*	*	*	*	*	*	*
Plecoptera																						
Megaleptoperla	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Notonemouridae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Plecoptera indet.	*	*	*	*	*	*	1.7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Spaniocerca	*	1.4	*	*	9.3	*	3.0	*	*	*	*	*	6.2	*	*	*	*	*	1.3	*	*	*
Stenoperla	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Zealandobius	*	*	1.5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.3	*	*	*
Aoteapsyche	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Costachorema	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2.7	*	*	*	*	*	*
Helicopsyche	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4.3	*	*	*	*	*
Hydrobiosidae indet.	*	*	*	1.5	*	*	*	*	*	*	*	*	*	*	*	2.7	*	1.9	*	*	1.7	*
Hydrobiosis	*	*	*	*	*	*	*	*	*	*	*	*	*	4.8	1.2	*	*	1.9	*	*	*	*
Leptoceridae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Oeconesus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Olinga	*	*	*	*	*	*	*	*	5.4	*	*	*	*	*	*	*	*	*	*	*	*	*
Orthopsyche	*	*	5.7	*	*	*	*	*	*	14.4	*	1.2	*	*	52.5	*	*	*	2.2	*	*	*
Philopotamidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Plectrocnomia	*	*	*	*	*	*	*	*	7.3	*	*	*	1.5	*	*	*	*	*	*	*	*	*
Pseudoeconesis	*	*	*	*	*	*	*	*	*	*	*	*	1.5	*	*	*	*	*	*	*	*	*
Psilochorema	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.1	*	3.2
Pycnocentria	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.3	*	*	*
Pycnocentrodes	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Side passage

	FC2	FR2	FR2W	G1A	G2	G3	G7	K2	LW3	LW4	LW5	M2	M3	MP3	MP4	R2	R4	R7	T3	T4	WP4	WW2	WW3
Amphipoda																							
Paracalliope	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	50.0
Paraleptamphopus	*	22.5	*	*	1.7	1.8	*	*	100.0	*	88.8	46.7	38.7	9.5	3.2	*	*	*	*	*	*	82.3	*
Coleoptera																							
Elmidae	*	*	*	*	*	*	*	35.0	*	*	*	1.3	*	*	*	*	*	*	*	*	*	*	*
Ptilodactylidae	*	*	*	*	1.7	*	4.2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Diptera																							
Aphrophila	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4.3	*	*
Ceratopogonidae	1.2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Chironomus	*	*	*	*	*	*	*	3.8	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Empididae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Eriopterini	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	8.3	*	*	*
Harrisius	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hexatomini	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Molophilus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2.1	*	*
Orthocladiinae	*	*	*	*	1.7	1.8	*	*	*	*	*	*	*	3.6	1.9	*	*	*	*	*	6.4	*	*
Paradixa	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Paralimnophila	*	*	*	*	*	*	4.2	*	*	*	*	*	*	*	*	3.7	*	*	*	*	4.3	*	*
Polypedilum	*	*	*	*	*	*	*	*	*	*	*	*	1.1	2.4	5.8	*	*	*	*	*	34.0	1.6	*
Tanypodinae	1.6	*	*	*	*	*	*	*	*	*	*	*	4.0	*	*	*	*	*	*	*	2.1	*	*
Tanytarsus	*	*	*	*	1.7	*	*	1.3	*	*	*	*	*	1.2	16.8	*	*	*	*	*	*	*	*
Ephemeroptera																							
Coloburiscus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	3.9	*	*	12.0	*	*	*	*	*
Deleatidium	8.2	*	*	*	5.0	90.2	*	2.5	*	20.0	*	2.7	*	3.6	*	*	*	8.0	*	*	*	1.6	50.0
Leptophlebiidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2.1	*	*
Neozephlebia	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4.0	*	*	*	*	*
Zephlebia	4.5	*	*	*	8.3	*	*	1.3	*	*	*	*	2.0	2.4	24.5	*	1.4	8.0	*	8.3	*	*	*
Isopoda	*	2.5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Megaloptera																							
Archichauliodes	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Mollusca																							
Potamopygrus	20.9	*	*	5.0	18.3	*	*	*	*	*	3.0	1.3	7.1	*	*	*	*	*	*	16.7	*	*	*
Pisidium	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Oligochaeta	59.8	75.0	100.0	95.0	11.7	3.6	50.0	43.8	*	60.0	7.5	46.7	23.1	77.4	9.0	96.3	96.7	68.0	100.0	50.0	40.4	6.5	*
Ostracoda	*	*	*	*	33.3	*	16.7	3.8	*	*	*	1.3	17.7	*	*	*	*	*	*	8.3	2.1	*	*
Platyhelminthes	*	*	*	*	*	*	*	1.3	*	*	*	*	*	*	*	*	*	*	*	*	*	8.1	*
Plecoptera																							
Megaleptoperla	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.3	*	*	*	*	*	*	*	*
Plecoptera indet.	*	*	*	*	5.0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Spaniocerca	*	*	*	*	10.0	1.8	25.0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Stenoperla	*	*	*	*	1.7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Trichoptera																							
Hydrobiosidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2.6	*	*	*	*	8.3	2.1	*	*
Hydrobiosis	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.3	*	*	*	*	*	*	*	*
Olinga	*	*	*	*	*	*	*	6.3	*	20.0	*	*	*	*	*	*	*	*	*	*	*	*	*
Orthopsyche	*	*	*	*	*	*	*	*	*	*	*	*	2.0	*	20.0	*	*	*	*	*	*	*	*
Philopotamidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	9.7	*	*	*	*	*	*	*	*
Plectrocnomia	*	*	*	*	*	*	*	1.3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Pseudoeconesis	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Spring

	K1	MP1s	MP3s	MP4s	MP5s	MP6s	MW1s	MW2s	MW3s	MW4s	MW5s	MW6s	MW7s	WT1s	WT2s	WT3s	WT5s	WT6s	WT7s	WT8s
Acarina	*	*	*	*	79.6	1.3	*	*	*	*	3.7	*	*	*	*	*	*	*	5.6	*
Amphipoda																				
Paracalliope	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Paraleptamphopus	*	55.6	*	52.2	*	85.9	*	*	59.1	*	*	*	37.5	37.4	*	*	41.8	*	*	*
Talitridae	*	8.3	*	4.3	1.6	2.1	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Basommatophora																				
Gyraulus	*	*	*	*	1.1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Coleoptera																				
Dytiscidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Elmidae	1.2	*	*	*	*	*	8.4	5.9	*	6.1	*	10.0	*	*	*	*	*	*	*	*
Hydraenidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hydrophilidae	*	2.8	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Ptilodactylidae	*	*	*	*	*	*	*	*	2.8	*	*	*	*	*	*	*	*	*	*	*
Staphylinidae	*	*	*	*	1.6	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Diptera																				
Aphrophila	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Austrosimulium	*	2.8	2.3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Ceratopogonidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Eriopterini	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Harrisius	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	11.4	*	*	*
Hexatomini	*	*	2.3	*	*	*	*	*	*	*	*	*	*	*	*	*	1.3	*	*	*
Lobodiamesinae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Molophilus	*	2.8	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Orthocladiinae	1.5	*	*	*	*	*	*	*	*	3.7	*	10.4	*	*	15.9	*	1.3	*	*	*
Paradixa	*	*	*	8.7	1.1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Paralimnophila	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Paucispinigera	*	*	*	*	2.7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Polypedilum	1.3	*	*	*	2.2	*	*	*	*	*	*	*	*	10.2	*	*	2.5	2.6	*	*
Psychodidae	*	*	*	*	1.1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tanyderidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tanypodinae	*	*	*	*	*	*	*	*	1.7	*	*	*	*	*	3.0	*	*	*	*	*
Tanytarsus	*	*	*	*	*	*	*	*	*	1.6	*	*	*	*	*	*	*	*	*	*
Ephemeroptera																				
Acanthophlebia	*	*	*	*	*	*	*	9.8	*	*	*	*	*	*	*	*	*	*	*	*
Austroclima	*	*	30.2	*	*	*	*	2.0	*	*	*	9.1	*	*	*	40.9	*	*	*	*
Austronella	*	*	*	*	*	*	*	*	*	*	*	*	*	*	12.1	*	*	*	*	*
Coloburiscus	*	*	*	*	*	*	14.4	5.9	1.1	*	1.2	*	*	*	*	9.8	*	*	*	*
Deleatidium	54.7	*	25.6	*	*	*	40.2	15.7	4.4	4.7	1.2	29.9	*	*	*	4.7	*	75.6	*	40.0
Mauiulus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Neozephlebia	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Nesameletus	*	*	*	*	*	*	*	13.7	*	*	*	*	*	*	*	*	*	*	*	*
Zephlebia	*	19.4	32.6	*	*	4.6	*	9.8	*	3.0	7.3	10.0	*	*	2.3	29.3	*	6.9	*	20.0
Hemiptera																				
Sigara	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Mollusca																				
Physa	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Potamopygrus	18.1	8.3	*	34.8	8.1	*	6.0	2.9	13.8	74.4	84.1	24.9	60.6	47.4	21.2	10.2	38.0	*	94.4	*
Lepidoptera																				
Hygraula	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.3	*	*	*
Megaloptera																				
Archichauliodes	*	*	*	*	*	*	3.3	8.8	*	*	*	*	*	*	*	*	*	*	*	*
Odonata																				
Antipodochlora	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Oligochaeta	5.9	*	*	*	*	*	*	*	1.1	*	*	*	*	*	40.2	*	*	*	*	*
Ostracoda	6.5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Platyhelminthes	2.3	*	*	*	*	*	*	*	*	*	1.2	*	*	*	*	*	*	*	*	*
Plecoptera																				
Acroperla	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Austroperla	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Spaniocerca	*	*	*	*	*	*	*	*	*	*	*	1.7	*	*	*	*	*	6.6	*	*
Stenoperla	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Zealandobius	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4.0	*	*
Zealandoperla	*	*	4.7	*	*	*	*	*	*	*	*	1.7	*	*	*	*	*	1.3	*	*
Trichoptera																				
Aoteapsyche	*	*	*	*	*	*	4.7	2.0	*	*	*	*	*	*	*	*	*	*	*	*
Confluens	*	*	2.3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hydrobiosidae	*	*	*	*	*	*	*	2.0	*	*	*	*	*	*	*	*	*	*	*	*
Hydrobiosis	*	*	*	*	*	*	3.8	*	*	*	*	*	*	*	*	3.3	*	*	*	*
Oeconesus	*	*	*	*	*	*	*	*	1.1	*	*	*	*	*	*	*	*	*	*	*
Olinga	4.3	*	*	*	*	*	9.8	10.8	*	*	1.2	*	*	*	*	*	*	*	*	*
Orthopsyche	*	*	*	*	*	4.8	*	*	10.5	*	*	*	*	*	*	*	*	1.3	*	40.0
Plectrocnomia	*	*	*	*	*	*	2.0	*	*	*	*	*	*	*	*	*	*	*	*	*
Polyplectropus	*	*	*	*	*	*	*	*	2.8	*	*	*	*	4.0	3.0	*	2.5	*	*	*
Psilochorema	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Pycnocentria	*	*	*	*	*	*	*	2.9	*	*	*	*	*	*	*	1.9	*	*	*	*
Pycnocentrodes	*	*	*	*	*	*	*	*	*	1.4	*	*	*	*	*	*	*	*	*	*
Triplectides	*	*	*	*	*	*	*	*	*	3.3	*	*	*	*	*	*	*	*	*	*

Appendix 5: Species list and average relative abundance for invertebrates collected from springs in five areas of Waikato Region. '*' = taxon makes up less than 1%.

Taxa	Kaimai	Kawhia	Lowland	Waihou	Waitomo
Acarina	12.6	*		3.0	2.3
Amphipoda					
Paracalliope	27.3	10.9			*
Paraleptamphopus	1.5	37.6	12.8	7.9	32.3
Phreatogammarus	*				
Taltridae	*		*		*
Coleoptera					
Cyclomissus	*		*		
Elmidae	*		*		*
Enochrus			*		
Hydraenidae			*		*
Hydrophilidae	*		*	*	*
Liodessus			*		
Ptilodactylidae	*				*
Rhantus			*		
Scirtidae	*				*
Staphylinidae					*
Copepoda	*				
Decapoda					
Paranephrops	*			*	*
Diptera					
Aphrophila		*			*
Austrosimulium	*				*
indet. Chironomidae	*		*		
Chironomus	*		*		
Culicidae	*		*		
Diptera indet.3	1.9				
Diptera indet.6	*				
Empididae					*
Ephydridae	*				
Eriopterini	*			6.4	*
Harrisius	*				*
Hexatomini	*		*		*
Limonia	*		*	*	
Maoridiamesa				*	
Molophilus	*	*			*
indet. Muscidae	*				
Orthocladiinae	6.2		*	2.4	*
indet. Orthocladiinae 3	*				

Taxa	Kaimai	Kawhia	Lowland	Waihou	Waitomo
Paradixa	*	*	*		*
Paralimnophila	*			*	*
Parochlus	*				
Paucispinigera	*				*
Polypedilum	24.2	3.8	6.7	2.5	1.2
Psychodidae	*	*			*
Sciomyzidae	*		*		
Stratiomyidae			*		
Tanypodinae	*		*		*
Tanytarsus	*			1.7	*
indet. Tipulidae	*				
Zelandotipula	*	*	*	*	
Ephemeroptera					
Acanthophlebia					*
Arachnocolus	1.3				
Atalophlebioides	*				
Austroclima	1.7				2.0
Coloburiscus	*				1.4
Deleatidium	*				8.3
Ichthybotus	*				
Neozephlebia	*		*		*
Nesameletus					*
Zephlebia	2.6	*		2.3	4.0
Hemiptera					
Microvelia	*		*		
Hirudinea			*		
Isopoda				*	
Megaloptera					
Archichauliodes	*				*
Mollusca					
Gyraulus	*			*	*
Lymnaea			*		
Physa			*		*
Pisidium	*		2.9		
Potamopyrgus	4.1	39.9	10.0	70.4	41.2
indet. Sphaeriidae	*				
Nematoda	*				
Oligochaeta	1.6		3.1	*	*
Ostracoda	*		54.4		*
Platyhelminthes	*		*	*	*
Plecoptera					
Acroperla	*				*

Taxa	Kaimai	Kawhia	Lowland	Waihou	Waitomo
Austroperla	*				*
Megaleptoperla	*				
Spaniocerca	1.4			*	*
Stenoperla					*
Zelandobius					*
Zelandoperla	*				*
Trichoptera					
Aoteapsyche				*	*
Confluens					*
Hydrobiosella	*				
indet. Hydrobiosidae	*				*
Hydrobiosis	*				*
Oeconesus	*	*		1.7	*
Olinga	*				*
Orthopsyche	*				*
Oxyethira	*				
Plectrocnemia					*
Polyplectropus	*				*
Pseudoeconesus	*		3.1		
Psilochorema	*			*	*
Pycnocentria		5.9			*
Pycnocentrodes					*
Triplectidina	*				
Zelolessica	*				
Total taxa	73	13	32	22	58

Appendix 6: Species list and average relative abundance for invertebrates collected in five areas of Waikato Region. '*' = taxon makes up less than 1%. Pooled species lists shown in Appendix 5. Site locations given in Appendix 2.

Waihou (sand/sedimentary)					**Site**				
	W1	W2	W4	W5	W6	W7	W8	W9	W10
Acarina	16.7	*	4.5	21.7	34.2	*	*	*	*
Amphipoda									
Paraleptamphopus	23.3	23.1	1.5	17.4	36.8	5.9	9.5	11.7	1.4
Coleoptera									
Hydrophilidae	1.7	*	*	*	*	*	*	*	*
Decapoda									
Paranephrops	*	*	*	*	*	*	1.2	*	*
Diptera									
Eriopterini	*	*	90.2	*	*	*	*	*	*
Limonia	*	*	1.5	*	*	*	*	*	*
Maoridiamesa	*	*	*	*	*	*	*	*	*
Orthocladiinae	*	*	*	*	*	1.2	1.2	11.4	*
Paralimnophila	*	*	*	*	*	*	*	*	*
Polypedilum	21.7	*	*	*	5.3	*	*	1.7	*
Tanytarsus	*	*	*	*	*	*	*	*	4.0
Zelandotipula	*	*	*	*	*	*	*	*	*
Ephemeroptera									
Zephlebia	12.8	7.7	*	26.1	21.1	*	*	*	*
Isopoda	*	*	*	*	*	*	*	*	*
Mollusca									
Gyraulus	*	*	*	4.3	*	*	*	*	*
Potamopyrgus	22.8	61.5	1.5	21.7	2.6	91.0	84.6	74.4	88.4
Oligochaeta	*	*	*	*	*	*	1.2	*	*
Platyhelminthes	*	*	*	4.3	*	*	*	*	*
Plecoptera									
Spaniocerca	*	7.7	*	*	*	*	*	*	*
Trichoptera									
Aoteapsyche	*	*	*	*	*	*	*	*	*
Oeconesus	*	*	*	*	*	1.2	*	*	4.0
Psilochorema	*	*	*	4.3	*	*	*	*	*

Kawhia (sand)			**Site**		
	KW1	KW2	KW3	KW4	KW5
Acarina	*	*	*	*	6.1
Amphipoda					
Paracalliope	6.3	2.4	81.2	*	*
Paraleptamphopus	*	17.3	16.4	59.4	57.5
Diptera					
Aphrophila	*	*	*	*	*
Molophilus	*	*	*	*	*
Paradixa	*	1.0	*	*	*
Polypedilum	*	8.7	*	4.0	*
Psychodidae	*	*	*	*	*
Zelandotipula	1.2	*	*	*	*
Ephemeroptera					
Zephlebia	*	*	1.6	*	*
Mollusca					
Potamopyrgus	91.7	70.3	*	23.1	28.8
Trichoptera					
Oeconesus	*	*	*	*	*
Pycnocentria	*	*	*	11.9	7.1

Lowland (sedimentary/ashes)			Site			
	L1	L2	L3	L4	L5	L7
Amphipoda						
Paraleptamphopus	33.5	*	10.6	*	17.2	54.8
Taltridae	1.2	9.1	1.4	*	*	*
Coleoptera						
Cylomissus	*	*	*	*	*	*
Elmidae	*	*	*	*	*	*
Enochrus	*	*	*	*	*	*
Hydraenidae	*	*	*	*	2.4	*
Hydrophilidae	*	*	*	*	*	1.2
Liodessus	*	*	2.3	*	*	*
Rhantus	*	*	*	*	*	*
Diptera						
indet. Chironomidae	*	*	*	*	*	*
Chironomus	*	*	*	2.0	*	*
Culicidae	*	*	*	*	*	*
Hexatomini	1.9	*	1.3	*	*	4.8
Limonia	*	1.5	*	*	*	*
Orthocladiinae	*	*	*	*	*	1.2
Paradixa	*	*	*	*	*	*
Polypedilum	*	*	*	*	27.4	*
Sciomyzidae	*	1.5	*	*	*	*
Stratiomyidae	*	*	*	*	*	*
Tanypodinae	*	*	*	1.7	*	4.8
Zelandotipula	*	3.0	*	*	2.7	1.2
Ephemeroptera						
Neozephlebia	*	*	*	*	*	*
Hemiptera						
Microvelia	*	*	*	*	*	*
Hirudinea	*	*	*	*	*	*
Mollusca						
Lymnaea	*	*	*	*	*	1.2
Physa	*	*	*	*	*	1.2
Pisidium	*	*	*	*	11.8	*
Potamopyrgus	1.2	66.7	8.4	18.3	*	*
Oligochaeta	12.5	3.0	*	4.0	*	8.3
Ostracoda	24.5	*	74.1	71.6	34.5	20.2
Platyhelminthes	*	*	*	*	*	1.2
Trichoptera						
Pseudoeconesus	24.5	15.2	*	*	*	*

Kaimai (ignimbrite)									Site								
	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13	K15	K16	K17	K18
Amphipoda																	
Phreatogammarus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2.6	*	*
Coleoptera																	
Cylomissus	*	*	*	*	*	*	*	*	*	1.7	*	*	*	*	*	*	*
Elmidae	*	*	*	*	6.7	*	*	*	*	*	*	*	*	*	*	*	*
Copepoda	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Diptera																	
indet. Chironomidae	*	*	*	*	*	*	*	*	*	*	*	3.2	*	*	*	*	*
Culicidae	*	*	*	11.6	*	*	*	*	*	*	*	*	*	*	*	*	*
Diptera indet. 6	*	*	*	*	*	*	*	*	*	*	*	6.5	*	*	*	*	*
Eriopterini	*	*	*	*	*	*	*	1.1	*	*	*	*	*	*	*	*	*
Harrisius	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Molophilus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Parochlus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Sciomyzidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tipulidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Ephemeroptera																	
Arachnocolus	*	*	*	*	*	*	*	*	*	*	26.8	*	*	*	*	*	*
Atalophlebioides	*	*	*	*	*	1.6	*	*	*	*	*	*	*	*	*	*	*
Austroclima	*	*	*	*	*	20.9	*	*	*	*	*	*	*	*	*	*	*
Coloburiscus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Ichthybotus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Neozephlebia	*	*	*	*	*	*	*	*	*	*	8.9	*	*	*	*	*	*
Megaloptera																	
Archichauliodes	*	*	*	*	*	*	*	*	*	*	1.7	*	*	*	*	*	*
Mollusca																	
Gyraulus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Pisidium	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2.0
indet. Sphaeriidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Nematoda	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Plecoptera																	
Acroperla	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Megaleptoperla	*	*	*	*	*	*	*	*	*	*	1.0	*	*	*	*	*	*
Zelandoperla	*	*	*	*	*	1.4	*	*	*	*	*	*	*	*	*	*	*
Trichoptera																	
Hydrobiosis	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Oxyethira	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Triplectidina	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Zelolessica	*	*	*	*	*	1.0	*	*	*	*	*	*	*	*	*	*	*
Austrosimulium	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.1	*
Paucispinigera	*	*	*	*	*	*	*	*	*	*	1.4	*	*	*	*	2.1	*
Hydrobiosella	*	*	*	*	*	*	*	*	*	*	*	*	1.5	*	*	*	*
Oeconesus	*	*	*	*	*	*	*	*	2.1	*	*	*	*	*	*	*	*
Olinga	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hydrophilidae	*	*	*	*	*	*	*	*	*	1.7	*	3.2	*	*	*	*	*
Ptilodactylidae	*	*	*	*	*	*	*	*	*	2.3	*	*	*	2.1	*	*	*
Scirtidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Paranephrops	*	*	*	*	*	*	*	*	*	*	*	*	*	*	10.3	*	*
indet. Chironomidae	*	*	*	*	*	*	*	*	*	*	*	*	*	4.3	2.6	1.1	*
Chironomus	*	*	*	*	*	*	*	*	*	*	2.1	*	*	*	*	9.5	*
Diptera indet. 3	*	*	14.5	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Ephydridae	*	*	*	*	10.5	*	*	*	*	*	*	*	*	*	*	*	*
Deleatidium	*	*	*	*	1.9	*	*	*	*	*	1.4	*	*	*	*	*	*
Austroperla	*	*	*	*	*	*	*	*	*	*	*	9.7	27.2	*	*	*	*
Muscidae	*	1.3	1.2	*	*	*	*	*	*	*	*	*	*	*	*	1.1	*
Paralimnophila	*	*	*	*	*	*	*	2.2	*	*	*	*	*	*	*	*	*
Tanytarsus	*	*	*	*	*	7.8	*	*	*	*	*	*	*	*	*	*	*
indet. Hydrobiosidae	*	*	*	*	*	*	*	*	*	*	*	6.5	*	*	*	*	*
Paracalliope	91.9	*	*	*	*	*	29.1	*	*	*	*	*	*	*	7.7	52.6	*
Paradixa	*	*	*	*	*	*	*	*	*	2.3	*	*	*	*	*	*	*
Microvelia	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Platyhelminthes	*	*	*	*	*	*	4.5	*	*	7.3	*	*	*	8.0	2.6	*	*
Orthopsyche	*	*	*	*	*	*	3.6	*	*	*	*	6.5	5.9	*	*	*	*
Limonia	*	*	*	*	*	*	*	*	*	*	*	*	1.5	*	2.6	*	*
Pseudoeconesus	*	*	*	*	*	*	*	*	*	*	*	*	*	5.3	2.6	1.1	*
Psilochorema	*	*	1.8	*	1.9	*	4.9	*	*	*	*	*	*	*	*	*	*
Polyplectropus	*	*	*	2.1	*	*	*	1.1	2.4	*	1.0	*	*	*	*	5.3	8.2
Paraleptamphopus	*	*	1.8	2.3	*	*	*	22.5	*	*	*	*	*	*	*	2.1	71.4
Hexatomini	*	*	*	*	*	*	*	*	*	*	*	3.2	3.7	*	2.6	*	4.1
Psychodidae	*	1.3	*	*	*	*	*	2.2	*	4.0	*	6.5	2.2	*	*	*	*
Tanypodinae	*	*	*	*	1.9	*	4.0	*	*	*	2.7	*	*	*	7.7	6.3	10.2
Zelandotipula	*	9.0	1.8	*	*	*	*	5.6	*	*	*	*	2.9	*	2.6	2.1	*
Ostracoda	*	*	*	*	*	*	*	*	1.4	*	*	6.5	14.0	*	*	4.2	2.0
Spaniocerca	*	*	*	*	*	2.5	1.3	*	2.6	8.5	*	*	8.1	6.4	2.6	*	*
Taltridae	*	*	*	*	*	2.1	*	3.4	*	4.5	2.1	16.1	3.7	*	*	4.2	*
Zephlebia	*	*	*	*	*	4.7	1.8	*	3.0	19.2	8.2	6.5	6.6	17.1	*	*	*
Orthocladiinae	*	6.8	4.1	*	17.1	46.6	11.2	*	*	*	7.6	9.7	1.5	*	*	*	*
Potamopyrgus	*	*	*	*	46.7	*	11.7	*	*	20.9	2.1	*	*	48.1	35.9	*	*
Acarina	2.3	10.0	6.2	79.1	7.6	4.9	4.5	40.4	17.0	11.3	*	3.2	8.1	*	*	1.1	*
Polypedilum	1.1	65.8	64.8	*	*	2.5	12.1	18.0	66.5	2.8	25.4	3.2	11.0	5.3	10.3	*	*
Oligochaeta	*	*	*	1.7	1.9	*	7.6	3.4	1.6	10.2	1.7	9.7	*	*	7.7	6.3	2.0

Waitomo (karst)									**Site**								
	WT2	WT3	WT4	WT5	WT6	WT7	WT8	WT9	WT10	WT11	WT12	WT13	WT14	WT15	WT16	WT17	WT18
Acarina	*	79.6	3.7	*	*	*	*	*	*	*	*	*	5.3	*	1.3	*	*
Amphipoda																	
Paracalliope	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Paraleptamphopus	*	*	*	*	*	52.2	*	59.1	55.6	37.5	42.3	37.4	*	*	85.9	*	*
Taltridae	*	1.6	*	*	*	4.3	*	*	8.3	*	*	*	*	*	2.1	*	*
Coleoptera																	
Elmidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	5.9	8.4
Hydraenidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hydrophilidae	*	*	*	*	*	*	*	*	2.8	*	*	*	*	*	*	*	*
Ptilodactylidae	*	*	*	*	*	*	*	2.8	*	*	*	*	*	*	*	*	*
Scirtidae	*	*	*	*	1.6	*	*	*	*	*	*	*	*	*	*	*	*
Staphylinidae	*	1.6	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Decapoda																	
Paranephrops	*	*	*	*	*	*	*	*	*	*	*	*	5.3	*	*	*	*
Diptera																	
Aphrophila	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Austrosimulium	*	*	*	2.3	2.7	*	*	*	2.8	*	*	*	*	*	*	*	*
Empididae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Eriopterini	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Harrisius	*	*	*	*	*	*	*	*	*	*	11.5	*	*	*	*	*	*
Hexatomini	*	*	*	2.3	1.1	*	*	*	*	*	1.3	*	*	*	*	*	*
Molophilus	*	*	*	*	*	*	*	*	2.8	*	*	*	*	*	*	*	*
Orthocladiinae	*	*	*	*	*	*	*	*	*	*	1.3	*	*	*	*	*	*
Paradixa	*	1.1	*	*	*	8.7	*	*	*	*	*	*	*	*	*	*	*
Paralimnophila	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Paucispinigera	*	2.7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Polypedilum	*	2.2	*	*	*	*	2.6	*	*	*	2.6	10.2	*	*	*	*	*
Psychodidae	*	1.1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tanypodinae	*	*	*	*	*	*	*	1.7	*	*	*	*	*	*	*	*	*
Tanytarsus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Ephemeroptera																	
Acanthophlebia	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	9.8	*
Austroclima	40.9	*	*	30.2	11.8	*	*	*	*	*	*	*	*	*	*	2.0	*
Coloburiscus	9.8	*	1.2	*	2.4	*	*	1.1	*	*	*	*	*	*	*	5.9	14.4
Deleatidium	4.7	*	1.2	25.6	39.7	*	75.6	4.4	*	*	*	*	*	40.0	*	15.7	40.2
Neozephlebia	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Nesameletus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	13.7	*
Zephlebia	29.3	*	7.3	32.6	34.3	*	6.9	*	19.4	*	*	*	*	20.0	4.6	9.8	*
Megaloptera																	
Archichauliodes	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	8.8	3.3
Mollusca																	
Gyraulus	*	1.1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Physa	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Potamopyrgus	10.2	8.1	84.1	*	*	34.8	*	13.8	8.3	60.6	38.5	47.4	89.5	*	*	2.9	6.0
Oligochaeta	*	*	*	*	*	*	*	1.1	*	*	*	*	*	*	*	*	*
Ostracoda	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Platyhelminthes	*	*	1.2	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Plecoptera																	
Acroperla	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Austroperla	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Spaniocerca	*	*	*	*	*	*	6.6	*	*	*	*	*	*	*	*	*	*
Stenoperla	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Zelandobius	*	*	*	*	*	*	4.0	*	*	*	*	*	*	*	*	*	*
Zelandoperla	*	*	*	4.7	*	*	1.3	*	*	*	*	*	*	*	*	*	*
Trichoptera																	
Aoteapsyche	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2.0	4.7
Confluens	*	*	*	2.3	*	*	*	*	*	*	*	*	*	*	*	*	*
indet. Hydrobiosidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2.0	*
Hydrobiosis	3.3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	3.8
Oeconesus	*	*	*	*	*	*	*	1.1	*	*	*	*	*	*	*	*	*
Olinga	*	*	1.2	*	*	*	*	*	*	*	*	*	*	*	*	10.8	9.8
Orthopsyche	*	*	*	*	*	*	1.3	10.5	*	*	*	*	*	40.0	4.8	*	*
Plectrocnemia	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2.0
Polyplectropus	*	*	*	*	*	*	*	2.8	*	*	2.6	4.0	*	*	*	*	*
Psilochorema	*	*	*	*	3.2	*	*	*	*	*	*	*	*	*	*	*	*
Pycnocentria	1.9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2.9	*
Pycnocentrodes	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*