![Bay of Plenty Regional Council Toi Moana logo]

Ecological communities of springs in the Bay of Plenty

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Prepared by/He mea whakarite nā

Alastair Suren (Freshwater Ecologist - BOPRC)

Approved for issue by/Kua Whakaaetia Kia Tāngia nā

Rob Donald (Science Manager)

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Executive summary/ Whakarāpopototanga Matua

1   Springs are unique ecosystems that occur where the water table meets the surface, or where groundwater can rise to the surface through rock fissures. They are regarded as ecotones - zones of interaction and exchange between groundwater, surface water and terrestrial ecosystems. Springs often support a unique fauna and flora, containing species not found in other habitats and therefore more likely be affected by human activities such as abstraction or landuse changes.

2   Historic volcanic activity within the Bay of Plenty has played a huge role in influencing the underlying geology, resulting in large number of springs there. For example, the Rotorua lakes are set amongst highly fractured volcanic material, some of which are sources of the largest springs in the region. Many of these springs (e.g., Whakarewarewa, Wai Tapu, Wai Manga) are hugely important from a cultural perspective, while others (e.g, Hamurana, Braemar/Te Waiu o Pukemarie) also represent significant resources for water supply.

3   In 2015, BOPRC commenced a program to document the locations of springs within the region, and to characterise their water chemistry and water quality. The present study was undertaken to characterise the ecological conditions of these springs, including assessments of water chemistry and water quality, invertebrate communities, and bryophytes (mosses and liverworts). Fifteen springs were surveyed in 2019 in the Tauranga Harbour, Kaituna Maketu Pongakawa, Tarawera, and Rangitāiki Water Management Areas. A summary of the results is presented below.

Water chemistry

1   Monitored springs were sourced from three major rock types: ignimbrite, rhyolite, and gravel. They displayed a wide range in water chemistry. For example, dissolved reactive phosphorus (DRP)and carbonates ranged by a factor of 100 between different springs. Factors such as the location of each spring, the dominant riparian vegetation, stock access and rock class explained a significant proportion of the variability in water chemistry. Water chemistry signatures also differed springs and rivers. Dissolved oxygen, pH, DRP and manganese concentrations were significantly higher in river samples, while Total_N and nitrate-nitrite_N were significantly higher in springs. The higher nitrogen concentrations in spring water may reflect long-term nitrogen accumulation from inputs from surrounding land percolating into the aquifers from where the springs flowed. River water also had a higher variability of measured calcium, magnesium and manganese, sulphate, hardness and temperature. This higher variability may reflect different signatures coming from rainfall-derived water during times of high flow, and ground flow-derived water during low flow.

2   These results highlight the inherent spatial differences of the underlying geology on the Bay of Plenty and reinforces the notion that historic volcanic activity has had a major influence on contemporary water quality conditions in springs. In particular, the spring water draining from areas of clastic sediments had different chemical signatures than springs in either intermediate or felsic extrusive rock classes. The results also suggest that historic land use activities may have enriched spring water with nitrogen.

Invertebrate communities

1   A total of 81 aquatic invertebrates were identified from the 15 springs. Snails, insects, and aquatic mites were the most abundant and widespread invertebrates. A significant proportion of the variability in invertebrate community composition was explained by the spring's location, and the rock stratigraphic unit classification. No associations were found between invertebrate communities and measured physical habitat, water chemistry or spatial data. These results suggest that the invertebrate communities in the springs were largely independent of these factors. Instead, the invertebrate communities at the springs may simply reflect the site's local geomorphological history and the pool of potential colonists present there.

2   Large differences existed in the invertebrate community composition between springs and the other first order streams in the region. More taxa were identified from the 36 first order streams than the springs (129 vs 81), although this may have simply reflected the greater number of streams sampled. As with the spring fauna, the snail *Potamopyrgus* was the most common invertebrate in the streams, although it had a much lower relative abundance (about 10% compared to 44%). Three other taxa (the mayfly *Zephlebia*, Polypedilum midges, and worms) were common in springs and first-order streams. Species evenness, a measure of how equal the community is numerically, was much higher in first order streams than in springs.

3   Large differences also existed in the invertebrate community composition between springs throughout the country. After correcting for differences in taxonomic resolution between different studies, most taxa (66) were found in the Bay of Plenty springs, and fewest in the Waitaki region in South Canterbury (26). Crustaceans such as amphipods (including *Paraleptamphopus*) and isopods were most widespread in Southland springs, but absent from springs in the western Waikato region.

4   Calculated biotic indices such as the MCI, QMCI and EPT were very much lower in springs than in streams. Under the current NPSFM (2020), our data suggests springs would score poorly for these metrics, implying a reduction in "ecosystem health". However, such low scores may simply reflect natural processes. It is thus suggested the NPSFM attribute scores are not particularly useful for adequately assessing the ecological health of spring habitats.

5   Collections were also made of adult mayflies, stoneflies and caddisflies. Caddisflies dominated the fauna, followed by mayflies and stoneflies. A total of 42 species from 11 families were found, the vast majority of which are regarded as not threatened. However, the caddisfly *Paroxyethira hintoni,* and the mayflies *Zephlebia tuberculata* and *Z. nebulosa* were regarded as "naturally uncommon". Five individuals could not confidently be identified, although four of these are possibly a new species of *Paroxyethira*. Another unidentified hydropsychid caddisfly may also represent a previously undescribed species. No clear patters were found to explain the distribution of the adult aquatic insects.

6   Implementation of environmental DNA (eDNA) as a parallel bioassessment technique within spring sites could be useful to provide comparative as well as additional ecologically information to assist with informed management decisions both for detecting threatened or rare (or cryptic) species and wider ecosystem health of springs in the region.

Aquatic bryophytes

1   Aquatic bryophytes were sampled and identified to document the distribution of these ecologically important plants. The number of species at each site was low, and bryophytes were absent from six sites. These plants were restricted to large stable substrates such as bedrock, boulders, and cobbles, and were absent from soft-bottomed springs. There was little pattern in the bryophyte data, with only Rock Class having some effect on species composition. As with the invertebrate data, no clear patterns existed between bryophyte communities and environmental parameters, suggesting that their colonisation of springs is also based on random colonisation events.

Conclusions

1   The survey clearly showed that historic volcanic activity has had a major influence on contemporary water quality conditions in springs, reflecting underlying geological differences. Spring sites showed higher nitrogen concentrations than the samples streams, possibly reflecting long-term nitrogen inputs from the surrounding land percolating into the aquifers. This emphasises the strong links between springs and their aquifers, which can be affected by agricultural land use in surrounding catchments.

2   Springs also supported a relatively diverse array of invertebrates, numerically dominated by snails, insects, and aquatic mites. Their community composition also differed between springs within each Water Management Areas, implying that invertebrate communities within individual springs may simply reflect the local geomorphological history and the pool of potential colonists present within their local vicinity. This means that in effect, individual springs represent unique ecosystems within the region. Any large changes to springs in terms of alterations to groundwater chemistry or flow are thus likely to have potentially large consequences to local biodiversity values.

Contents/Rārangi Upoko

Part 1:
Introduction/Kupu Whakataki

1.1 A background to springs and their ecosystems

Springs are unique freshwater ecosystems that form where the water table meets the surface, or where groundwater can rise to the surface through rock fissures. Springs are thus regarded as groundwater dependent ecosystems, and their flows are closely linked to groundwater levels. Non-spring fed streams and rivers have flows that are largely dependent upon rainfall, and consequently can exhibit large temporal changes in stream discharge. Non-spring fed streams also exhibit large changes in water temperature, whereas springs are renowned for their thermal constancy (Scarsbrook et al. 2007). Water chemistry in springs reflects the chemical signature the parent aquifer and is thus relatively constant, in contrast to non-spring fed streams whose chemistry is influenced by rainfall run-off patterns and by surrounding land use activities.

Springs are regarded as ecotones acting as a zone of interaction and exchange between adjacent groundwater, surface water and terrestrial ecosystems. Springs can therefore be affected by human activities occurring in any of these separate ecosystem interfaces. For example, excessive water extraction from aquifers may reduce spring outflow pressure, with potential adverse effects on local hydrology and, potentially, ecosystem values. Land use changes associated with agricultural activities may result in loss of riparian vegetation, potentially increasing nutrient and sediment-rich surface water run-off from the surrounding catchment. Increased direct sunlight as well as increased nutrient enrichment and fine sediment can lead to the prolific growth of aquatic plants such as macrophytes and algae, and smother or limit habitat suitability and availability for the instream fauna.

Early studies of New Zealand springs in the 1970s provided detailed descriptions of the biological communities in Auckland (Johnstone 1972; Russel and Rodgers 1977), Christchurch (Marshall 1973), Waikoropupu Springs near Takaka (Michaelis 1976; 1977) and Middle Bush Stream, an alpine spring near Cass, central South Island (Cowie and Winterbourn 1979). Further studies were conducted in late 1990s–early 2000s (i.e., Young et al. 1999, Scarsbrook and Haase 2003 and Barquin 2004). The unique fauna and flora and the biodiversity values of springs were also discussed by Collier and Smith (2006) and Barquin and Death (2006). The importance of springs for their biodiversity values was also highlighted in a book chapter in "Freshwaters of New Zealand" (Death et al. 2004) and a Science for Conservation publication by Scarsbrook et al. (2007). The latter document was particularly important in highlighting the paucity of New Zealand spring studies and emphasised that more attention to these habitats was warranted, especially given their biodiversity values.

These biodiversity values are exemplified in work by Haase (2008), who described 46 new species of Tateidae snails (formally Hydrobiidae) from seepages, springs and groundwater habitats throughout New Zealand. The high diversity of these snails, particularly around north-west Nelson was thought to have reflected regional patterns of karst or limestone geology. Haase suggested that fewer snail species are found in areas in the North Island (particularly the north-east and east of the central plateau) as a result of the (geologically) recent volcanic eruptions there, and inability of these poorly dispersing snails to recolonise affected areas.

Crustaceans such as the amphipod *Paraleptamphopus* or the isopod *Phreatoicus* also show a high biodiversity in springs. For example, the blind, subterranean *Paraleptamphopus* are endemic to New Zealand. They are common in aquifers (especially in Canterbury) with the greatest genetic diversity being found in the upper West Coast of the South Island (Sutherland 2005). Nearly 30 species of this poorly dispersing amphipod are known with least 13 morphologically distinct species known from the Southland, Taranaki, Waikato, and Waitaki (Scarsbrook and Haase 2003). *Paraleptamphopus* have not been recorded in the north-east and east of the North Island, including the Bay of Plenty, East Cape, and northern Hawke's Bay. As with snails, Sutherland (2005) attributed the notable absence of *Paraleptamphopus* in these areas to volcanic activity. Other Crustacea commonly found in springs include the freshwater shrimp (*Paratya*) and the freshwater crayfish or koura (*Paranephrops*). High flow events can affect koura populations, however, springs provide constant temperature and hydrology, as well as often abundant macrophytes upon which they can feed (Parkyn and Collier 2004). Many species of aquatic insect such as mayflies (e.g., *Zephlebia nebulosa*) or chironomid midges (e.g., *Polypedilum opimum*) are restricted to small streams, springs or on wet rock faces. Other insects, such as *Oeconesus* caddisflies are commonly found in springs amongst leaf litter (Scarsbrook and Haase, 2003; Collier and Smith 2007)

Springs also provide ideal habitats for a range of aquatic plants such as macrophytes and bryophytes (mosses and liverworts). Michaelis (1977) identified 19 algae, 13 mosses, seven liverworts, and 11 vascular plants across five cold-water springs in New Zealand, with the Waikoropupu Springs alone supporting 35 species. Aquatic bryophytes also provide important food resources for some freshwater invertebrates as well as habitat and refugia for a range of others, and therefore contribute to the overall biodiversity values of springs (e.g., Suren 1991).

In addition to describing the fauna and flora of springs, several studies have also examined the effects of land use activities on spring ecology. Scarsbrook and Haase (2003) found little evidence to suggest stock access had direct adverse effects on the overall biodiversity values of the 34 springs they studied across four regions. However, their findings did support a Swiss study by Zollhofer (1999) who showed that mayflies were absent from springs with unlimited stock access. However, Scarsbrook and Haase (2003) did find mayflies in springs with limited stock access, and where some remnant native forest remained. They also found that the immediate canopy cover around each spring had a much stronger effect on the invertebrate composition in springs, with shaded springs supporting different invertebrate community composition than unshaded springs. Scarsbrook and Haase (2003) concluded due to a constant supply of clean, relatively cool groundwater, springs are able to buffer against potential adverse effects of stock access.

The above examples indicate the importance of springs in providing important sources of unique, local biodiversity. Springs can also provide stable environmental conditions of relatively cool, constantly flowing water which may partially mitigate adverse effects of local landuse.

1.2   Springs within the Bay of Plenty

The Bay of Plenty (BOP) region is rich in freshwater resources, and is home to a wide diversity of lakes, wetlands rivers and streams. Volcanism has played a huge role in influencing the underlying geology within the BOP, with large prehistoric pyroclastic eruptions having shaped much of the region's geography and geomorphology. For instance, many of the Rotorua lakes were formed from a series of pyroclastic eruptions over 20,000 years ago. Such eruptions have had profound effects on the distribution of water resources, and on how rainfall percolates through the surrounding catchment and into the deeper aquifers. Many of the Rotorua lakes are set amongst highly fractured volcanic material, some of which are sources of large springs. While many of these springs are geothermal (e.g., Whakarewarewa, Wai Tapu, Wai Manga), others represent significant cold-water springs (e.g, Hamurana, Braemar/Te Waiu o Pukemarie). Both types are hugely important from a cultural standpoint to local iwi, as well as representing important international and national tourist attractions.

Many of the larger aquifer springs in the Rotorua region have been modified to supply drinking water to the Rotorua district, and many other smaller springs provide water for both domestic supply and stock purposes. Examination of the BOPRC's consents database shows that there are 26 consents for water takes from springs in the region (Figure 1). The largest of these takes are around Lake Rotorua, where 421 l/s is taken from a spring near the Utuhina Stream for domestic supply, and from a spring in the Waipa Stream (110 l/s). Other large municipal supplies are at Awahou (115 l/s) and two takes at Kawerau (240 l/s combined). The vast majority of water takes from springs (80% of total abstraction rate) is for municipal supply. Other uses are for horticultural or pastoral irrigation (7% and 2%, respectively), and for commercial/industrial uses (1.2% of total abstractive rate).
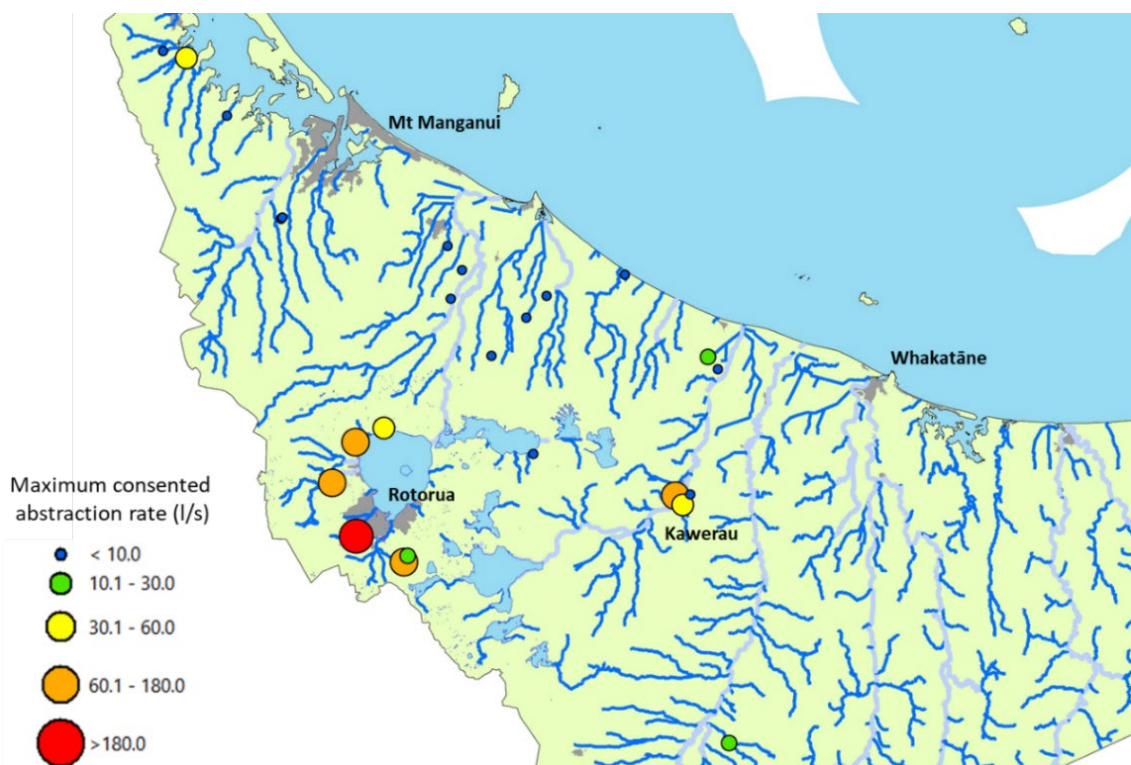

Figure 1   Location of consented takes from springs, colour-coded by the maximum consented abstraction rate. Note the large abstractions from springs in the urban areas of Rotorua, Ngongotahā and Kawerau, for municipal water supplies.

In addition to their importance in providing water for out-of-stream uses, many of the region's rivers have significant spring water input, resulting in relatively constant flows, even during times of low rainfall (e.g., Wilding 2002). Spring systems also do not respond to rainfall events in the same way as rainfall-dominated systems and can have fewer, and smaller flood peaks than rainfall-dominated streams. A useful statistic to examine flow variability is the coefficient of variation (CV) of flow, defined as the standard deviation of flow divided by the mean flow. Examination of calculated CVs of flow for the spring fed Waitahanui and some rainfall dominated rivers clearly illustrate this point. The CV of the Waitahanui is much less than that of most other rivers in the region (Table 1), with the exception of the Tarawera River. This is lake-fed, and so would not be expected to respond quickly to rainfall events.

Table 1   Calculated coefficients of variation (CV) of waterways in the region, showing the very low CV in the spring fed Waitahanui, in contrast to rainfed rivers.

River	Dominant source	CV
Waitahanui	Spring fed	14.17
Nukuhou	Rainfall	195.8
Otara	Rainfall	167.9
Tarawera	Lake-fed	24.3
Tuapiro	Rainfall	179.1
Wairoa	Rainfall	106.2
Whakatāne	Rainfall	168

Given the importance of springs in providing water for human activities, there is an obvious potential conflict whereby the abstraction of too much water from springs and nearby groundwater resources may result in a reduction in ecosystem health on the receiving waterbodies. In 2015, to determine whether water abstraction was having an adverse effect on spring ecology, BOPRC commenced a program to document the locations of springs within the region, including characterising water chemistry and quantify water quantity (Green 2018; 2022). To date, spring surveys have been conducted in six of the nine Water Management Areas identified in the BOP region, with a total of 715 "areas of interest" recorded. Areas of interest included confirmed springs, springfields, seepages, as well as spring confluences and inferred spring locations. Of the 145 confirmed springs identified by BOPRC, 41 were selected for more frequent monitoring and the results recently summarised by Green (2022). However, despite our overall increase in knowledge of springs within the region, little if any ecological studies have been conducted.

This study was therefore undertaken to characterise invertebrate communities within springs and, where applicable, characterise any macrophyte and/or bryophytes communities present. In particular it was designed to:

1   Describe the water quality and physical conditions of the springs.

2   Describe the nature of the invertebrate/bryophyte communities.

3   Understand the relationships between invertebrate communities and their environment.

4   Compare communities between springs and first order streams in the BOP region.

5   Compare communities between springs in the BOP region and elsewhere.

Part 2: Methods/Huarahi

2.1   Sites

Fifteen springs were surveyed throughout the region which were found in four of the nine Water Management Areas (WMAs) that Council has divided the region into: Tauranga Harbour, Kaituna-Maketū-Pongakawa, Tarawera, and Rangitāiki (Figure 2). Of the 15 springs, 12 were classified as rheocrene (discharge emerges into a defined channel), while the remaining three were considered as limnocrene (spring discharges through the bed of a pond or lake). The substrate in nine of the springs was dominated by large gravels, cobbles, or bedrock, whilst the substrates in the remaining six were dominated by finer gravels and pumice sands (Table 2). Because substrate size plays such a dominant role in influencing invertebrate community composition, each spring was subsequently allocated to either a hard bottomed or soft bottomed substrate class. The dominant riparian cover around each spring was also classified as either native forest, exotic forest, or grassland. These different classifications of WMA, spring type, substrate and dominant riparian cover were used in later analyses to determine their influence on invertebrate and bryophyte community composition.
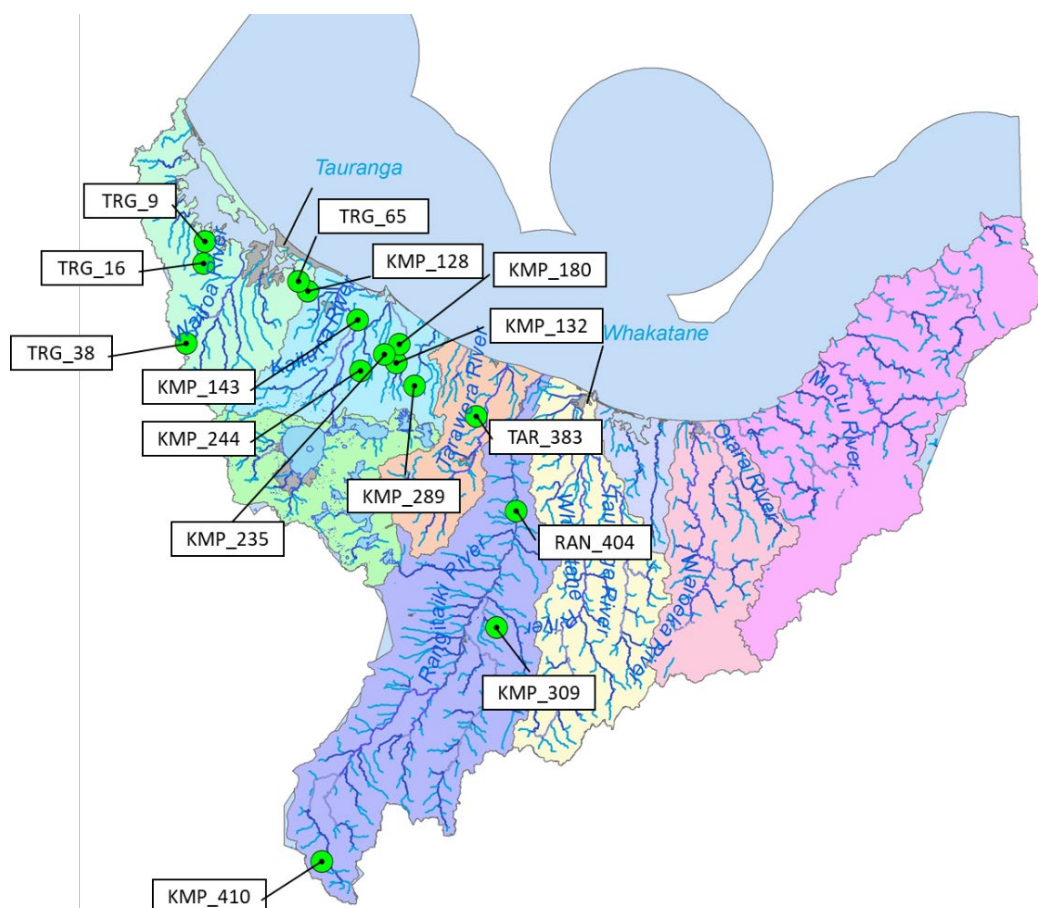

Figure 2   Location of the 15 spring sites throughout the Bay of Plenty region where the ecological surveys were conducted. Also shown are the nine Water Management Areas within the region: KMP = Kaituna, Maketu, Pongakawa, RAN = Rangitāiki; TAR = Tarawera; TRG = Tauranga.

Table 2　　　*Summary of physical conditions of the 15 springs surveyed in the region.*

WMA	Spring	Main_Rock	Stream Type	Flow	Rip_Veg	Cattle	Shade	Altitude	Distance to sea
Kaituna-Maketu-Pongakawa	KMP_128	ignimbrite	Hard	Rheocrene	Native_trees	No	Shaded	84.3	15.2
	KMP_132	ignimbrite	Soft	Rheocrene	Native_trees	No	Unshaded	45.4	18.1
	KMP_143	gravel	Hard	Rheocrene	Grass	Limited	Unshaded	18.2	19.5
	KMP_180	gravel	Soft	Rheocrene	Grass	Yes	Unshaded	42.5	13.8
	KMP_235	gravel	Soft	Rheocrene	Grass	Limited	Shaded	67.6	13.4
	KMP_244	gravel	Hard	Rheocrene	Native_trees	No	Shaded	127.4	21.6
	KMP_289	ignimbrite	Hard	Rheocrene	Native_trees	No	Shaded	105.1	18.6
Rangitāiki	RAN_309	gravel	Hard	Rheocrene	Grass	Yes	Unshaded	271.7	84.1
	RAN_404	gravel	Hard	Rheocrene	Native_trees	No	Unshaded	132.7	46.0
	RAN_410	ignimbrite	Soft	Limnocrene	Grass	Limited	Unshaded	724.7	188.3
Tarawera	TAR_383	ignimbrite	Hard	Rheocrene	Native_trees	No	Shaded	40.3	17.2
Tauranga	TRG_16	ignimbrite	Hard	Rheocrene	Native_trees	No	Shaded	156.3	8.1
	TRG_38	rhyolite	Soft	Limnocrene	Native_trees	No	Shaded	398.9	31.9
	TRG_65	ignimbrite	Soft	Rheocrene	Grass	No	Unshaded	44.2	3.6
	TRG_9	ignimbrite	Hard	Limnocrene	Exotic_trees	No	Shaded	25.0	3.1

2.2   Field sampling

Water chemistry samples were collected from each site in summer and winter, between August 2015 and June 2019, and analysed for a range of anions and cations, metals, and nutrients. At most sites, spring discharge was measured by placing a heavy-duty nylon bag placed across the flow to collect all the water during a known time, and measuring the total volume collected. The volume at the remaining springs was similarly measured by timing the volume of water passing through existing polythene discharge pipes. At four springs, HOBO temperature loggers were deployed from February 2019 to February 2020 to collect continuous temperature data at 15-minute intervals.

Invertebrates were sampled from 15 spring sites between March 2019 and May 2019 using a small hand-held "kick net", (0.5 mm mesh). This was placed in the water and the substrate material upstream of this was vigorously disturbed, dislodging all the invertebrates. A variety of habitats was sampled, including gravels, macrophytes, woody debris and bryophytes (mosses and liverworts) in the stream. All samples were collected within 10 m of the spring source to minimise species not restricted to springs. All invertebrate samples were preserved with 100% isopropyl alcohol.

Tent-like Malaise traps were deployed across the spring at each site as close to the source as possible to intercept the winged adult stage of predominately mayflies, caddisflies, and stoneflies (Figure 3). Malaise traps are considered a very effective method of trapping adult aquatic insects because they trap continuously over a 24-hr period, and for extended periods when aquatic insects are most active, and more likely to collect species that are diurnally active. Malaise traps were constructed of fine mesh netting and were 176 cm tall at the top end, 110 cm tall at the lower end, 165 cm long, and 180 cm wide. Insects flying from an upstream or a downstream direction fly into a vertical net panel which they then generally fly or crawl up. The top of one end of the net was lower (1.3 m from the ground) than the other (1.6 m) to encourage trapped insects to move towards the higher end, where a sampling jar containing a polyethylene glycol preservative was located. Each Malaise trap was typically placed 0.3 m–0.5 m above the stream surface to avoid any damage to the net from floating debris. Malaise traps were deployed for a median time of three weeks in late summer, although one trap (RAN_309) was removed after only eight days due to impending bad weather that may have affected the collecting ability of the trap.

RAN_404

TAR_383

Figure 3　　　*Example of the Malaise traps deployed at two of the 15 springs. These traps were placed perpendicular to the stream flow to intercept insects flying up or down the channel.*

In the laboratory, all aquatic samples were processed by a modification of Protocol P2 or the 200-fixed count plus a scan for missed taxa (Stark et al. 2001). The sample was spread out uniformly on a white tray, and a gridded "cookie cutter" placed into the tray. A random square was selected, from which all material was removed and placed into a "Bogorov" counting tray (Winterbourn et al. 2006). The contents of this tray were scanned under a binocular microscope and all invertebrates were identified and counted. This process was repeated until at least 200 individual invertebrates had been counted. The remaining sample was then scanned for taxa not identified in the initial 200-count sub-sample. Because we were interested in documenting biodiversity at each site, all invertebrates were identified to as low a taxonomic resolution as practical, including species where possible, using keys provided by Winterbourn et al, (2006, and references therein).

Malaise traps samples were gently washed in water and transferred to 70% isopropanol alcohol. Only adults of the aquatic insect orders mayflies, caddisflies and stoneflies were identified (mostly to species).

All bryophytes encountered in the springs were sampled and dried prior to identification to species in the laboratory using keys to New Zealand mosses (Allison and Child 1971; Beever et al, 1992; Beever et al. 2002) or liverworts (Allison and Child1975; Scott 1985).

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2.3   Statistical analysis – water chemistry

Between six and nine water chemistry samples were collected from each spring, with the exception of one spring (RAN_309), where only two samples were collected. To reduce the complexity of the water chemistry data (14 factors from 15 sites on multiple occasions), a Principal Components Analysis (PCA) was used to reveal any structure to the water chemistry data. Prior to the PCA, the average of all measured water chemistry parameters was calculated and normalised so that measures with different units could be analysed together.

Following the PCA, a similarity matrix was calculated to show the similarity of all sites to each other based on their water chemistry signatures. The Euclidean distance measure was used for this analysis, which measures the "straight-line" distance between samples, and is appropriate for environmental data. Thus, for example, consider three springs: A, B and C. If springs A and B were high in nutrients, conductivity and metals, and spring C had low levels of these was parameters, then springs A and B would have a very small Euclidean distance measure. However, there would be a greater Euclidean distance between springs A and C, and B and C, reflecting the fact that spring C was different. The resultant similarity matrix for all 15 springs thus summarised the similarity of all sites to each other, based on their water chemistry.

Analysis of Similarity (ANOSIM) was then used to measure the degree to which the observed variability in water chemistry could be explained by classifying the samples according to four defined factors:

- Geographic location in each of the WMAs (Rangitāiki, Tarawera, Kaituna-Maketu-Pongakawa, Tauranga).

- Type of spring (rheocrene or holocrene).

- Type of stream bed (hard-bottomed or soft-bottomed).

- Type of immediate riparian vegetation (native bush, exotic forest, pasture grasses).

We also investigated whether stock access or shade affected spring communities (after Scarsbrook and Haas 2003) by assigning three levels of stock access (yes, no, limited) and two levels of shade (unshaded, shaded) to each spring.

Since water chemistry of springs is thought to reflect the geology of their source aquifers, three additional factors describing components of the underlying geology surrounding each spring were included (after GNS Science 2013):

- Main rock: a description of the main rock type.

- Rock class: a broad classification of geological units.

- Stratigraphic unit: applied to very high-level grouping of geological mapping units, which comprises stratigraphic age and depositional environment or rock type (e.g., Late Quaternary River deposits; Neogene sedimentary rocks).

Analysis of Similarity produces a statistic (called Global R) that is a measure of the degree to which a factor (e.g., the different WMAs, or whether a spring was a rheocrene or limocrene) explained variability to (in this case) the water chemistry data. A high global R means that a factor explained a lot of the observed variation in the data. Significant differences were set at a level of 0.05%.

Where ANOSIM showed significant differences in PCA scores and individual factors, an ANOVA was conducted on the raw water chemistry data to see what chemical parameters differed between groupings within each factor.

Springs water chemistry was compared to 14 rivers throughout the BOP region. This data was obtained from "Physiographic Environments New Zealand" (PENZ), a programme classifying the geographical drivers of water-quality using geospatial datasets. PENZ data were collected monthly between December 2017 and June 2018. For this analysis, we calculated the mean of all water chemistry parameters and mean flow data at each site. All data was log transformed and normalised so that measures with different units could be analysed together. The combined spring and rivers data was then analysed by a PCA to show the similarity of all sites to each other based on their water chemistry signatures. Analysis of Similarity was also used to measure the degree to which water chemistry differed between samples collected from springs and rivers. The variability of all water chemistry parameters from both the springs and PENZ dataset was finally compared by calculated the coefficient of variation for each parameter. It is acknowledged that any conclusions from this analysis may be somewhat limited given the different frequency and timing of data collection (springs: biannual data from 2015 – 2019 vs PENZ data: monthly from December 2019 to July 2018). All these analyses were conducted using the PRIMER 7.0 package.

2.4 Statistical analysis - invertebrates

2.4.1 Patterns to invertebrate community structure

All invertebrate data was fourth root transformed to down-weight the effect of dominant taxa on the analysis, while increasing the weight of less dominant taxa. A non-metric multidimensional scaling ordination (NMDS) was used to examine and explore relationships and patterns in the invertebrate community composition. Ordination is a statistical method used in exploratory data analysis to search for patterns in the data, such as being done here, rather than in testing specific hypothesis. It orders objects (in this case individual springs) that are characterized by values of multiple variables (in this case the relative abundance of different invertebrates) so that similar sites are located near each other on an x-y graph, and dissimilar sites are located farther from each other. The first step in an ordination is to calculate a similarity matrix of all sites to each other. The Bray-Curtis similarity measure was used for this analysis. This measure results in scores ranging from zero (i.e., two sites having no taxa in common) to one (i.e., two sites having the same taxonomic composition). An NMDS ordination was then run on this similarity matrix to examine relationships between all the individual sites. NMDS produces a statistical score (called stress) that indicates the strength of the resultant ordination. Stress values greater than 0.3 indicate the resultant sample configurations are no better than arbitrary (i.e., there are no underlying patterns to the invertebrate community composition at each site). This would occur where the invertebrate communities do not differ greatly between the different springs. Sample configurations should not be interpreted unless the stress value is less than 0.2 (Clarke and Gorley 2001). The ordination thus identifies major gradients in the data, with the x-axis representing the greatest difference between samples, and the y axis representing the second greatest difference. Analysing correlations of both species-distribution and environmental variables against these two axes allows us to determine which species and environmental variables were responsible for the observed gradients in the data.

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Following the NMDS of the invertebrate data, Analysis of Similarities (ANOSIM) was used to measure the degree to which the observed variability of the invertebrate communities could be explained by classifying the samples according to the same factors as used in the analysis of the water chemistry data:

- geographic location in each of the WMAs
- type of spring
- type of stream bed
- type of immediate riparian vegetation
- stock access
- shade
- main rock
- rock class
- stratigraphic unit.

A high global R means that a particular factor explained a lot of the observed variation in the data. Significant differences were set at a level of 0.1%.

A similar analysis was done for the adult Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly), commonly known as EPT. These three insect orders are sensitive to landuse change, organic enrichment and increased temperatures. Unlike the previous analysis of the aquatic invertebrate data, the ANOSIM used for the adult insect data did not include the underlying geological factors, as it was assumed that these would not directly influence the distribution of adult EPT. Instead, this would be expected to reflect the presence of the immature stages of these insects, as well as any local conditions that may affect adult insect habitat. Note, however, that the identification of adults to species is usually possible, whereas many immature forms of EPT can only confidently be identified to genus.

2.4.2 Environmental drivers of invertebrate communities

The following analyses were designed to identify environmental divers that may help explain observed variation to the invertebrate communities in the springs. Firstly, environmental factors such as elevation, distance to sea and catchment land cover were extracted from databases such as the Freshwater Environments of New Zealand (FENZ) and the Land Cover Database, based on the NZReach identification as used in the River Environment Classification (REC) version 1 GIS layer (Snelder and Biggs 2002). Four of the sampled springs were too small to appear on the REC, so these springs were allocated to the appropriate NZReach of the nearest first-order stream. These were mostly less than 1 km away, and so would not have greatly influenced data on elevation, distance to sea and catchment land cover. A total of eight environmental factors describing the physical condition of each spring was thus derived. Because this data was measuring factors with different units, all data was normalised and a PCA used to identify any patterns to the data.

Another data matrix describing the spatial location of the springs was also constructed, based on the geographic coordinates of each spring (NZTM easting and NZTM northing). This was used to examine spatial patterns in the biological data. If geographic coordinates explained more variability to the ecological data than the other explanatory variables, it suggests that either unmeasured physical variables or inherent biogeographic patterns were associated with the geographic distribution of the invertebrate communities. Because spatial patterns can vary at differing scales, the easting (x) and northing (y) coordinates were converted to a cubic trend surface regression curve (Legendre and Legendre, 1998) such that:

$$Z = x + y + xy + x^2 + y^2 + x^{2y} + xy^2 + x^3 + y^3$$

Where Z represents the invertebrate community at each site and x and y are the eastings and northings (i.e., geographic coordinates) of the sites obtained from their physical location data. The x and y terms of the trend surface describe any simple linear spatial patterns in the data, while the higher order terms model more complex landscape features such as patches and gaps.

Three similarity matrices based on the Euclidian distance measure were thus produced to show the similarity of all sites to each other based on their environmental data, water quality data, and spatial data. These three similarity matrices were then used to determine how well they were related to the invertebrate data. For this analysis we used the RELATE command in Primer (Ver 7.0), which calculates the Spearman rank correlation of the similarity matrices that were created using either ecological or environmental data. If the invertebrate communities were structured by, say the physical variables, then we would expect a strong correlation between the two similarity matrices. If, however, invertebrate communities were responding to other non-measured environmental variables, and such strong correlations would not exist.

2.4.3 Comparison to first order streams

The invertebrate community composition within the 15 spring sites was compared to the invertebrate community composition collected from riverine samples throughout the region. To reduce potential confounding effects of comparing ecological communities from small first-order springs to larger order rivers, this analysis was restricted to 36 samples collected from first-order streams either as part of the Council's ongoing State of Environment monitoring programme, or as part of other studies conducted throughout the region. Where multiple samples had been collected from a site over time, the average invertebrate community composition was used.

This analysis was done by an NMDS ordination of the invertebrate data, and ANOSIM used to determine whether the community composition differed between springs and first-order riverine streams. Prior to the NMDS, all taxonomic resolution was carefully examined to ensure consistency of identification between the different studies. Following the NMDS and ANOSIM, the SIMPER analysis in PRIMER was used to identify which invertebrates were contributing to the dissimilarity between defined groups. In this way it was possible to determine what species were responsible for any observed differences in community composition when grouped according to either spring or first-order streams.

Species evenness of each sample was then calculated. Species evenness is an assessment as to how close in abundance each species in a specific sample is to other species. For example, if species A, B and C have relative abundances of 38%, 12% and 7%, then this is not particularly even. However, if the relative abundance classes of the same species was 25%, 28% and 31%, the community is quite even.

Following this analysis, several biotic metrics were calculated from all samples, including the macroinvertebrate community index (MCI) score, and its quantitative variant (QMCI), as well as the number of sensitive EPT taxa, the percentage abundance of EPT taxa, and the percentage of EPT taxa to total species richness. The MCI is commonly used by ecologists throughout the country to assess the ecological condition of waterways, with an MCI score <80 (or QMCI scores <3.0) indicating sites in "poor" ecological condition, and MCI scores >120 (or QMCI scores greater than six) indicating sites in "excellent" ecological condition. Note however that these scores were developed for surface water streams only, and so their relevance to spring fed streams in terms of the ecological bandings is discussed. T-tests were used to determine whether the calculated metrics differed between either springs or first- order streams.

2.4.4   Comparison to other springs

Finally, the invertebrate community composition within the 15 spring sites was compared to that of other spring samples collected throughout the country. Data was gleaned from work by Scarsbrook and Haase (2003) and Collier and Smith (2006), and all taxonomic identifications were converted to a common taxonomic level prior between all studies to the analysis. All data was also converted into presence-absence, as not all studies were semi-quantitative. A total of 53 springs were included in this analysis: 15 from the Bay of Plenty and Waikato; 10 from Taranaki, eight from Southland and five from the Waitaki in North Otago.

As with the previous analyses, NMDS ordination was used on the presence-absence data to examine differences between springs. ANOSIM and SIMPER analyses were then used to determine whether the community composition differed between springs in the different regions, and to calculate the contribution of each species (%) to the dissimilarity between springs in other regions. T-tests were also used to assess whether calculated biotic metrics differed between springs throughout the country.

2.5   Statistical analysis – bryophytes

All data describing the aquatic bryophytes in the springs was analysed by NMDS to examine relationships and patterns in their composition. As with the invertebrate data, ANOSIM was also used to measure the degree to which the observed variability of the bryophyte communities could be explained by classifying the samples according to the same factors as used in the analysis of the water chemistry and invertebrate data. Significant differences were set at a level of 0.1%.

Part 3:
Results/Ngā Otinga

3.1   Water chemistry

Water chemistry varied widely between the 15 springs. For example, parameters such as measured Discharge, dissolved reactive phosphorus (DRP) and carbonates ranged by a factor of 100 across the springs, while other parameters such as water temperature, conductivity, and nitrite-N had much lower variability (Table 3). The principal components analysis (PCA) of the water chemistry data explained 65% of the variance, with the first axis explaining 45% of the variation, and the second explaining 20%. Site TRG_65 (lower right of Figure 4) was indicative of high concentrations of ammonia (NH_3) and manganese, very low dissolved oxygen (DO) levels, and warmer spot water temperatures. This site also had the lowest discharge of the monitored springs. Another gradient occurred along the PC1 axis, reflecting differences in water chemistry parameters such as bicarbonate (HCO_3), calcium (Ca), magnesium (Mg), conductivity, total phosphorus (P) and nitrate-nitrite nitrogen (NNN: Figure 4). Thus, sites clustered on the left hand of Figure 4 (e.g. KMP_235, KMP_180, KMP_143, RAN_309) had higher values of these parameters than sites clustered on the right hand (e.g. TRG_16, TRG_38, TRG_38, RAN_404, and TAR_383).

Table 3   *Summary table showing the average water quality conditions (pH, Temperature, conductivity, dissolved oxygen, and nutrients) in water samples collected from the 15 springs during the study.*

| Spring	Flow (l/s)	Temperature	Conductivity	DO (%)	pH	DRP (mg/L)	Phosphorus	Total N (mg/L)	Nitrite Nitrate	Ammoniacal Nitrogen (mg/L)
KMP_128	0.79	13.9	78.6	71.4	6.5	0.074	0.081	1.171	1.085	0.006
KMP_132	3.56	14.1	88.4	94.9	6.5	0.136	0.152	1.335	1.352	0.003
KMP_143	0.91	16.3	160.6	64.6	6.1	0.098	0.112	3.093	3.103	0.005
KMP_180	1.67	16.2	252.7	72.8	6.4	0.186	0.216	2.273	2.320	0.002
KMP_235	1.86	15.3	101.2	92.1	6.4	0.123	0.155	3.899	3.989	0.003
KMP_244	21.94	14.6	84.1	86.7	6.4	0.125	0.144	2.201	2.193	0.002
KMP_289	27.88	14.9	161.1	77.5	6.7	0.104	0.115	0.695	0.694	0.002
RAN_309	6.53	13.1	165.6	78.2	6.6	0.045	0.105	2.375	2.405	
RAN_404	10.50	13.2	57.9	88.5	6.3	0.044	0.060	0.716	0.710	0.003
RAN_410	8.45	11.0	70.0	65.7	6.2	0.009	0.018	2.692	2.766	0.003
TAR_383	20.00	15.5	75.8	63.6	6.4	0.042	0.064	0.957	0.865	0.004
TRG_16	2.50	15.2	63.1	74.3	5.4	0.002	0.015	1.595	1.530	0.002
TRG_38	10.00	12.1	60.6	85.1	6.0	0.032	0.055	0.370	0.324	0.005
TRG_65	0.26	16.6	64.6	23.2	5.8	0.007	0.102	0.674	0.249	0.013
TRG_9	16.25	18.3	95.7	80.5	6.5	0.057	0.077	0.265	0.253	0.003
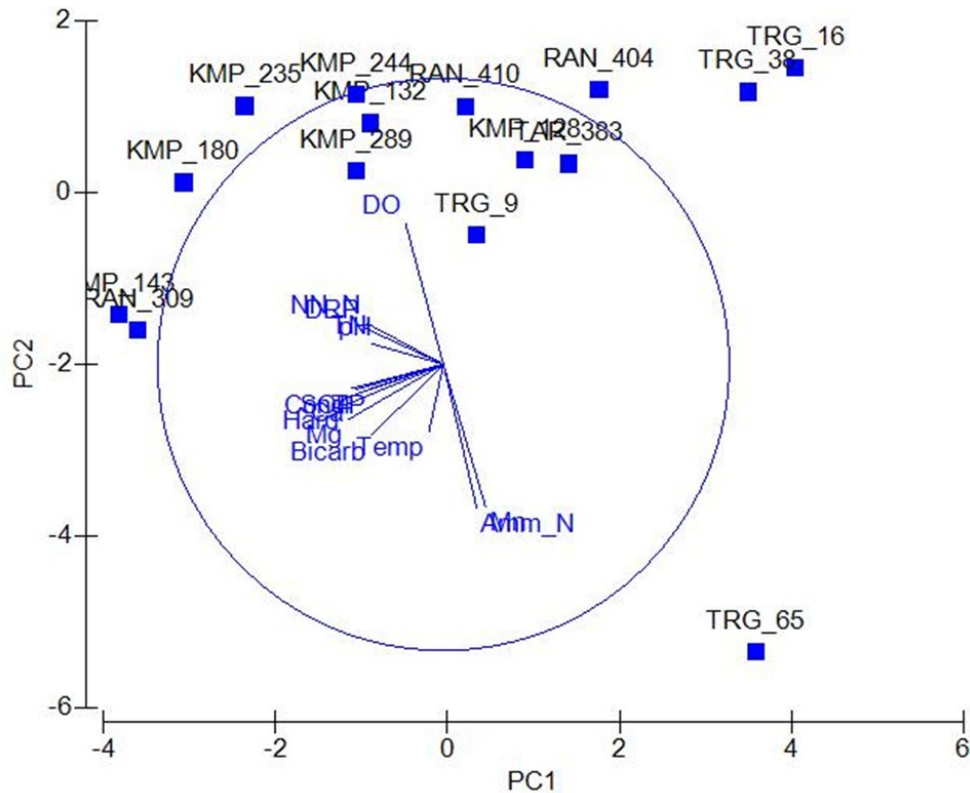
Figure 4   *Results of a Principal Components Analysis (PCA) of water quality of the 15 springs surveyed during the study. Also shown are the dominant water chemistry parameters responsible for the observed sample pattern. KMP = Kaituna, Maketu, Pongakawa, RAN = Rangitāiki; TAR = Tarawera; TRG = Tauranga.*

The ANOSIM analysis showed that factors such as the Water Management Area that each spring was in, the dominant riparian vegetation, stock access and rock class explained a significant proportion of the variability in water chemistry (Table 4). For example, springs in the Tauranga WMA were clustered on the right hand of the PCA ordination, while springs in the Kaituna, Maketu and Pongakawa WMA were clustered in the upper left of the ordination (Figure 5). For riparian vegetation, springs flowing from native bush areas were clustered in the upper portion of the PCA ordination, while springs flowing from sites surrounded by grasses had a much wider spread in the ordination diagram (Figure 5). The similar patterns observed between springs when grouped by riparian vegetation or cattle access. This most likely reflected the high degree of correlation between these two factors with cattle absent from streams surrounded by native bush but may be present in springs flowing from areas surrounded by grasses.

Table 4   *Results of the ANOSIM test showing the degree to which water chemistry was structured by location either within each Water Management Area, dominant substrate type, spring source or dominant riparian vegetation. Significant structure in the data exists when the global R value has a corresponding p-Value less than 0.05 (bold).*

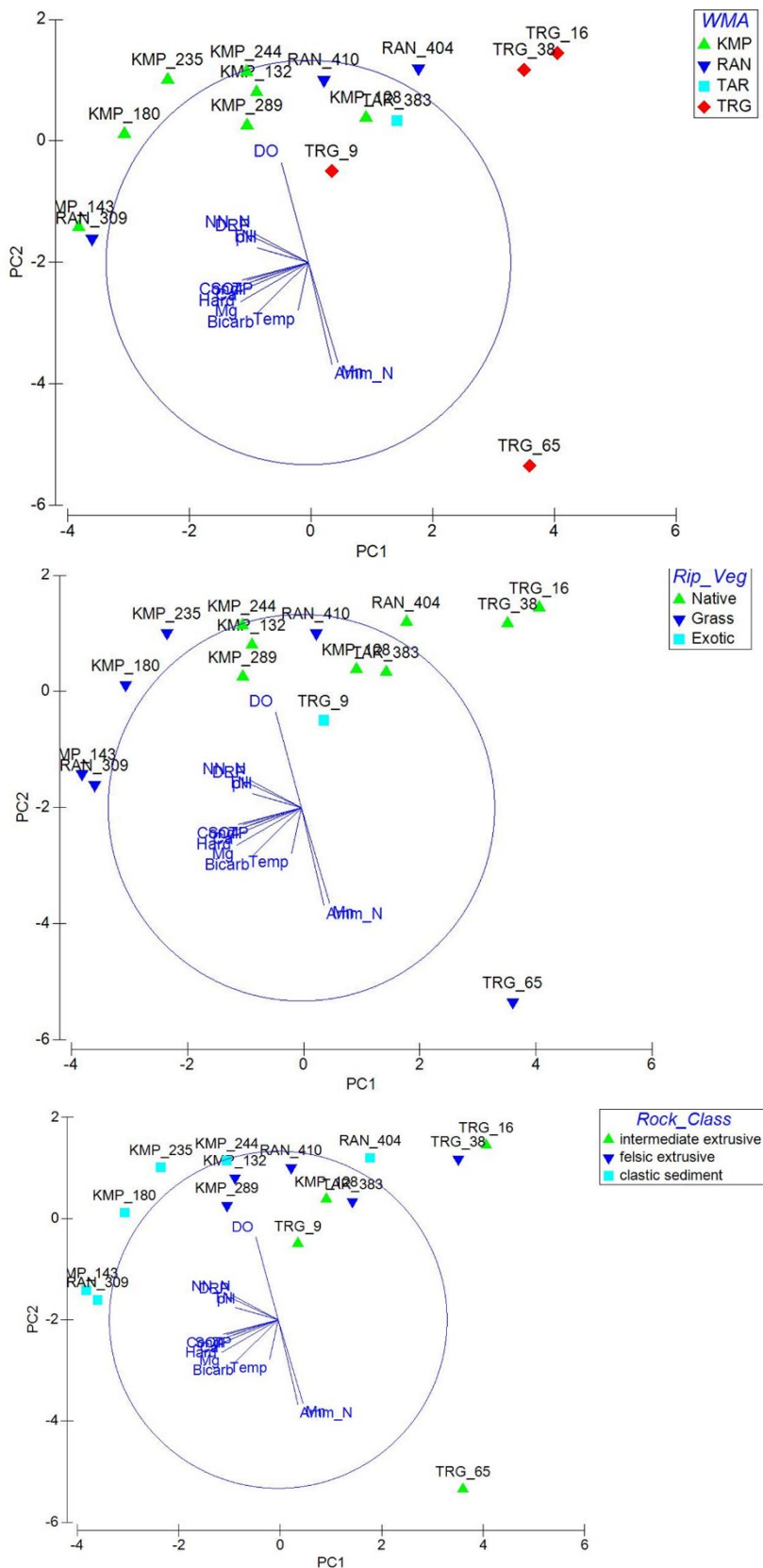| Factor type	Grouping	Global R	P-value
Location	**WMA**	**0.378**	**0.007**
Spring nature	Substrate type	0.033	0.326
	Spring source	0.056	0.356
Landuse	Landuse	-0.274	0.923
	Riparian vegetation	**0.360**	**0.007**
	Stock access	**0.332**	**0.007**
	Shade	0.060	0.197
Underlying geology	Main Rock	0.124	0.165
	Rock Class	**0.167**	**0.05**
	Stratigraphic Unit	0.165	0.116

Figure 5   *Results of a Principal Components Analysis (PCA) of water chemistry data of the 15 springs surveyed during the study, colour coded by either their WMA, the dominant riparian vegetation or dominant rock class.*
KMP = Kaituna, Maketu, Pongakawa, RAN = Rangitāiki; TAR = Tarawera; TRG = Tauranga.

ANOVA of the water chemistry data showed which water chemistry parameters differed between springs with contrasting riparian vegetation. Thus, springs surrounded by native bush were generally cool and had high DO levels and could be regarded as having "soft" water, with low amounts of sulphate, Ca, Mg, bicarbonate and hardness. In contrast, springs flowing from grassed areas had lower flow and lower DO, and were considered to have "hard" water, with high sulphate, Ca, Mg and hardness, as well as high levels of TN (Figure 6, Figure 7, Figure 8.)
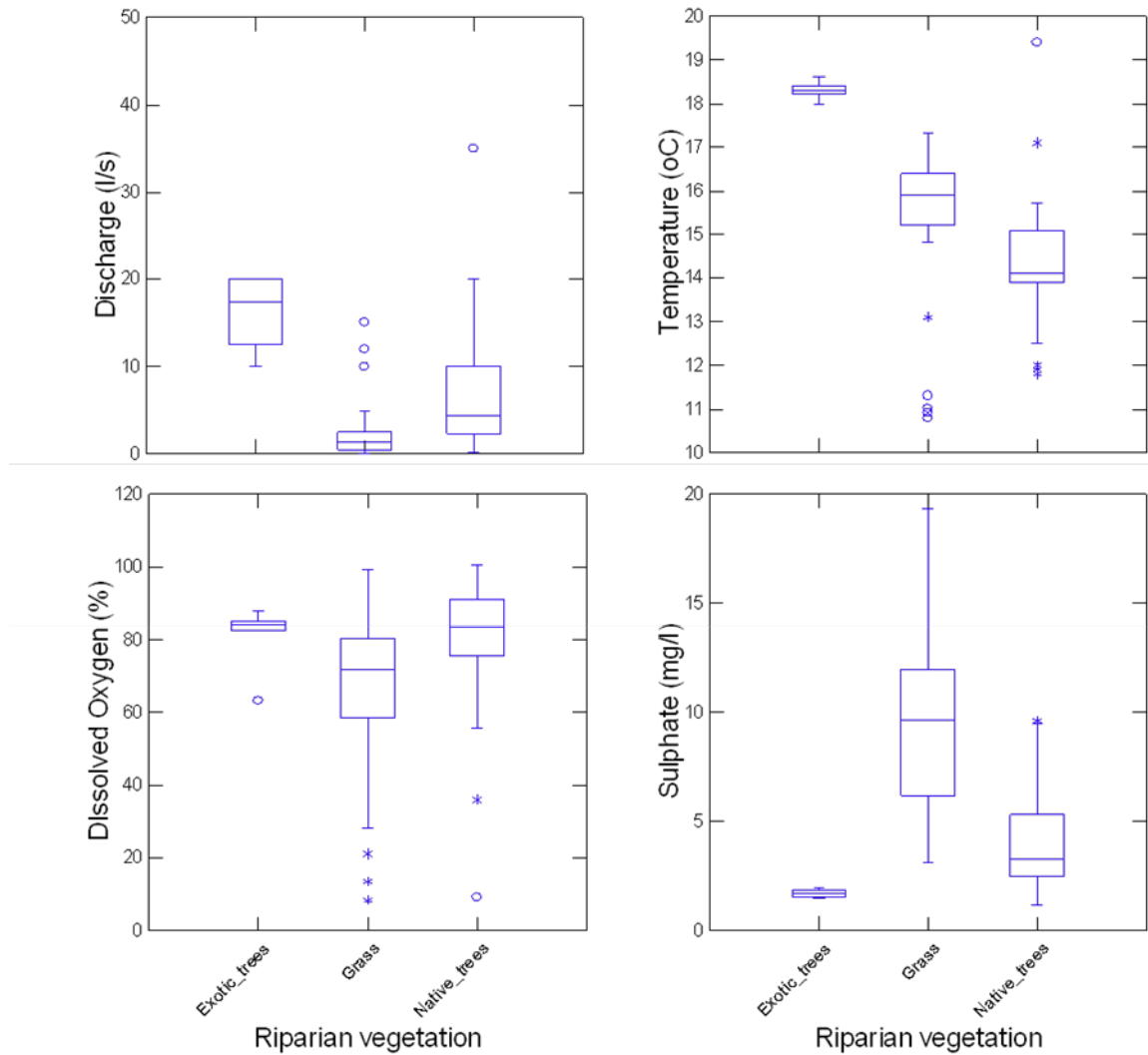

Figure 6   Box plots of measured discharge, temperature, dissolved oxygen (DO) and sulphate from samples collected from the 15 springs in the region, when grouped by dominant riparian vegetation. The central horizontal line indicates the median value, and the bottom and top of the box indicate the 25th and 75th percentile values. The whiskers extend to the 10th and 90th percentiles. Numbers exceeding the 5th and 95th percentiles are also shown (stars or circles).
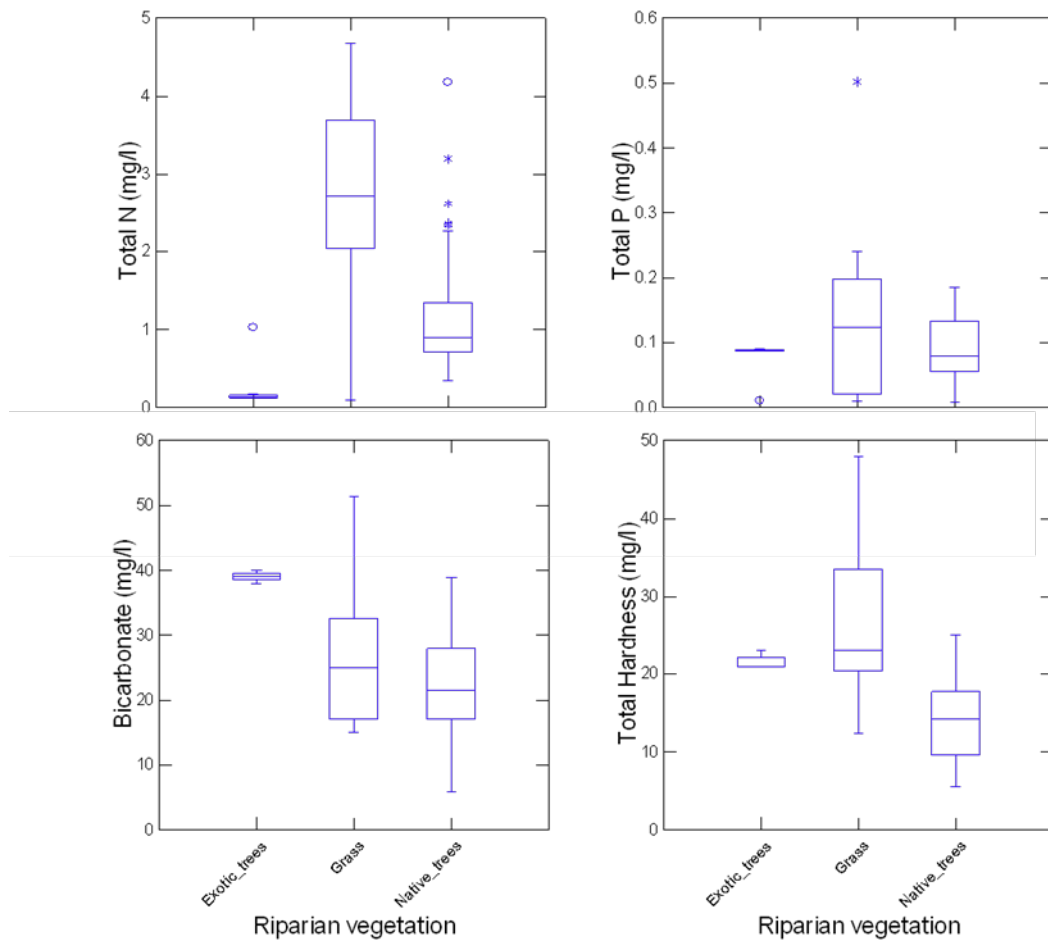
Figure 7   Box plots of measured total nitrogen (N) and phosphorus (P), as well as bicarbonate and hardness from samples collected from the 15 springs in the region, when grouped by dominant riparian vegetation. Conventions as per Figure 6.
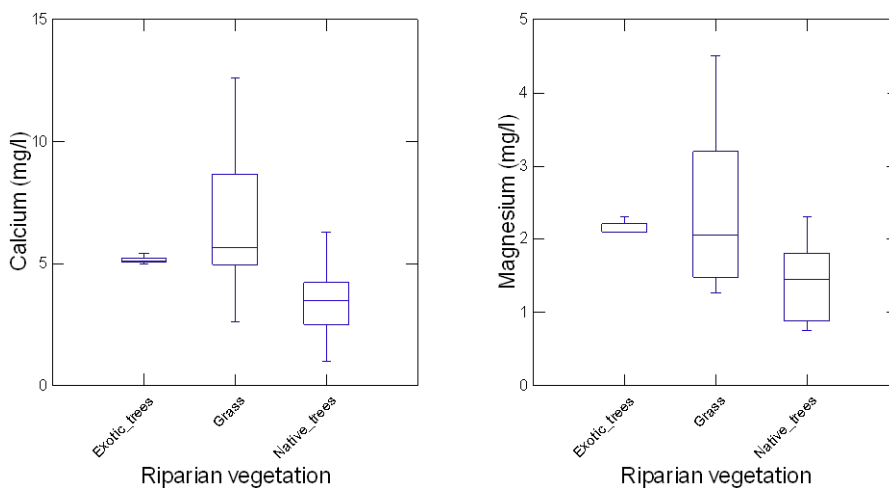

Figure 8   Box plots of total Calcium (Ca) and Magnesium (Mg) from samples collected from the 15 springs in the region, when grouped by dominant riparian vegetation. Conventions as per Figure 5.

Examination of the temperature data from the loggers showed a very high degree of thermal constancy in the four monitored springs. Although there was some variation in the temperature data over the recording period, this was very low (Figure 9). For example, at KMP_132, temperatures hardly fluctuated around the long-term mean of 14.1°C until September 2019, after which time variability increased considerably – although this range was still relatively small (12.2 – 19.9°C). At TRG_38, temperatures varied considerably in the middle of the record, but there were preceded and followed by periods of stable temperature. Closer examination of this data revealed significant diurnal temperature fluctuations at the sites on occasion (Figure 10). However, the cause of this diurnal fluctuation at times of the year is unknown.
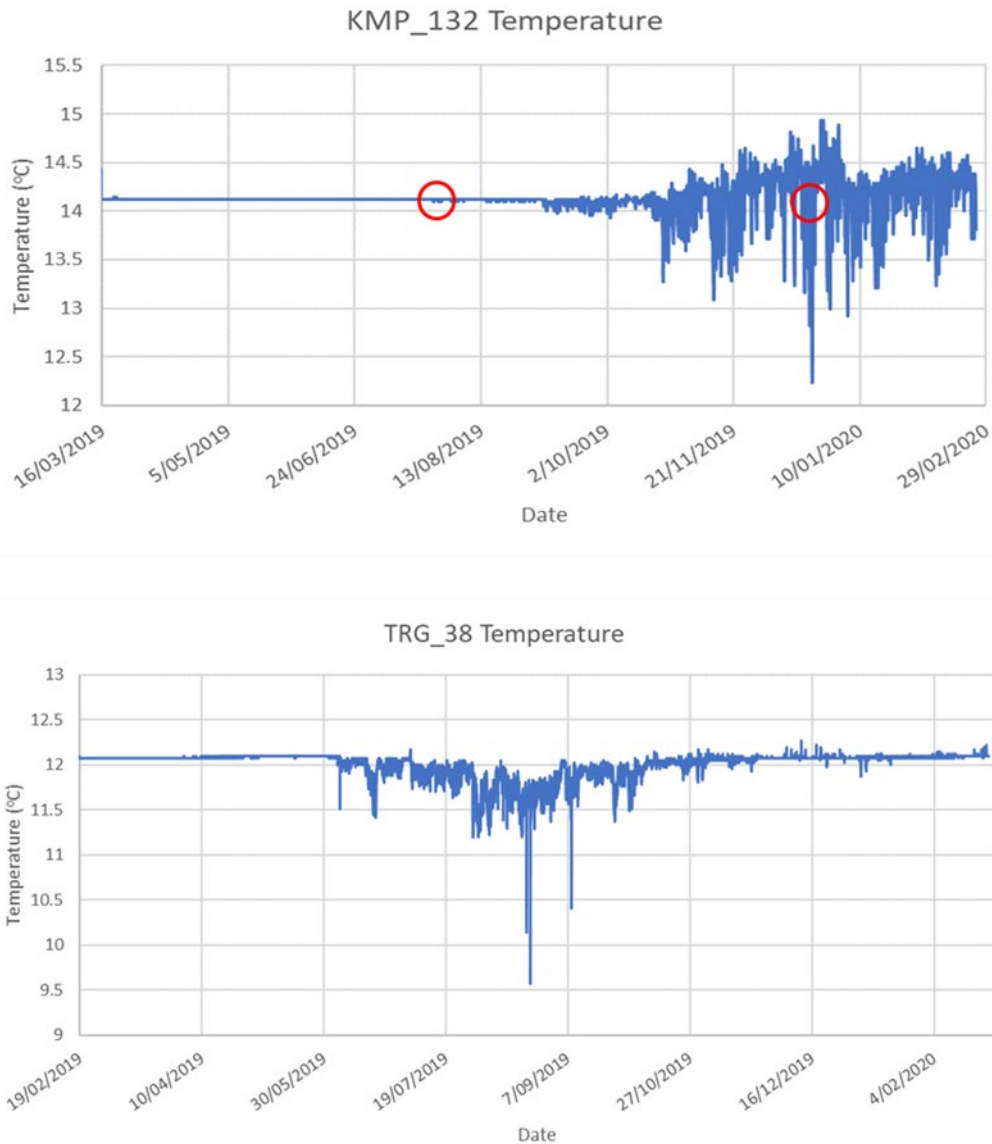

Figure 9   *Instantaneous temperature records of two of the spring sites where loggers were deployed. Note that despite periods of very little temperature fluctuation, there were times with a greater degree of temperature fluctuation. An example of these fluctuations is shown in Figure 10, where the records indicated by the red circles were plotted at a higher temporal resolution.*
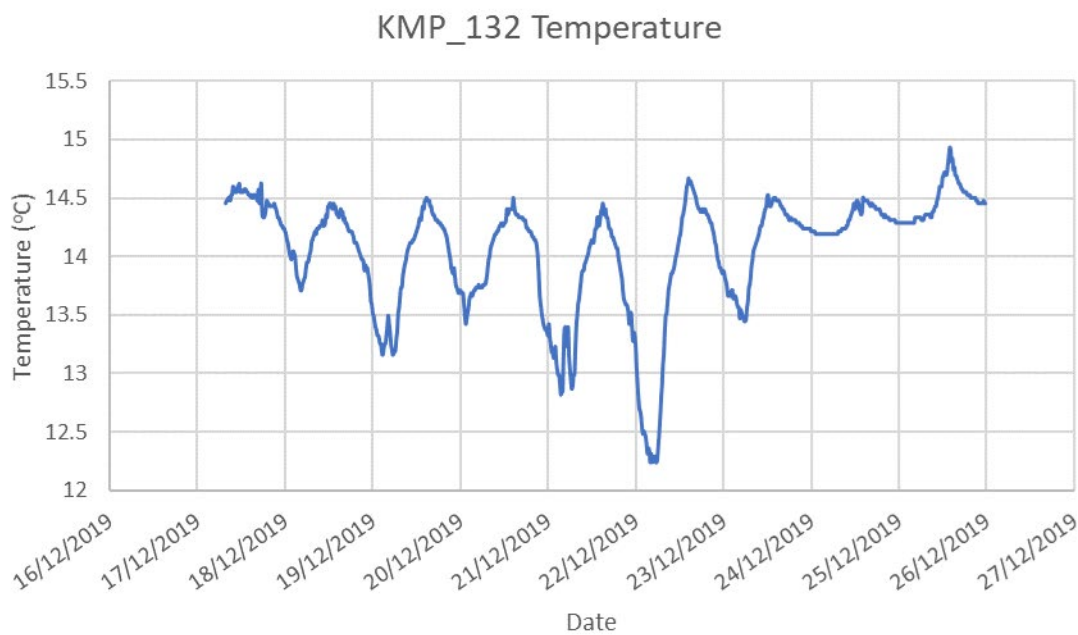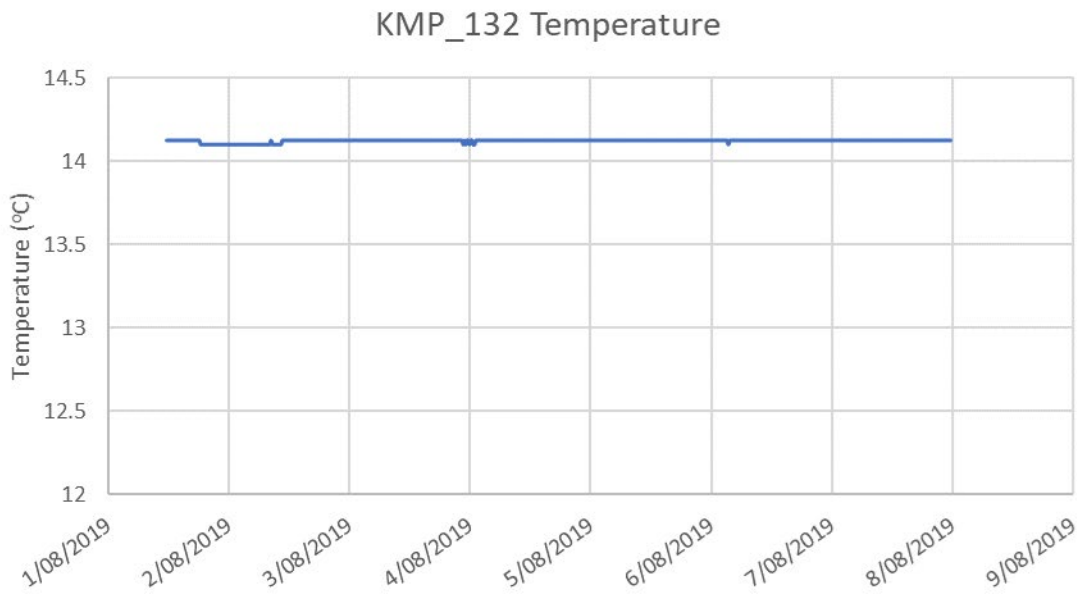
Figure 10   Examples of diurnal temperature fluctuations from spring KIMP_132. Note the almost constant temperature in early August 2019, followed by a clear diurnal temperature fluctuation in December 2019.

Despite these diurnal fluctuations, the overall range of temperatures in each spring was small, emphasising their overall thermal constancy. There were also significant differences in the average temperature of the four monitored springs over the year that the loggers were deployed for, with warmer temperatures being found in the two springs in the Kaituna-Maketu-Pongakawa WMA, and cooler water in the Tauranga WMA (Figure 11).

Figure 11   Average temperatures (+ 1 standard deviation) from the four springs where the temperature data loggers were d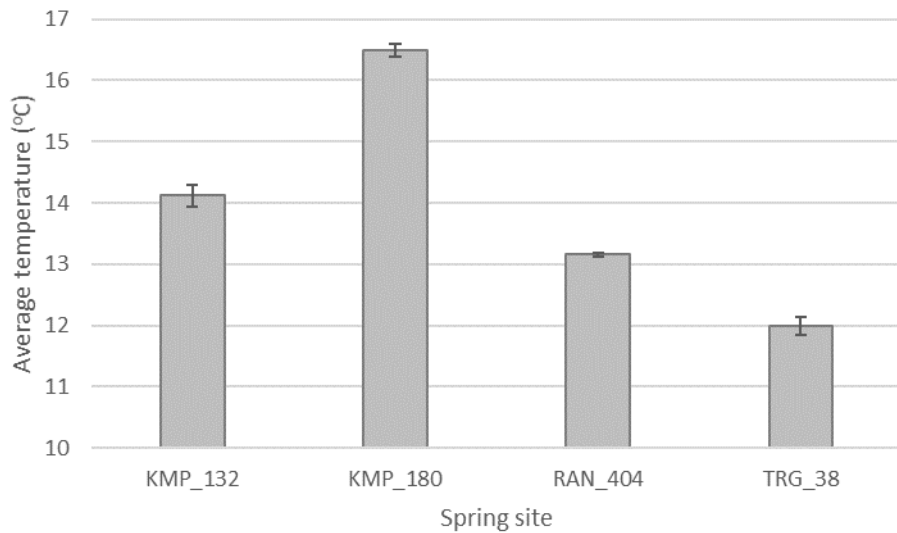eployed. Note the high thermal constancy, as evidenced by the very small error bars. KMP = Kaituna, Maketū, Pongakawa, RAN = Rangitāiki; TAR = Tarawera; TRG = Tauranga.

Water chemistry signatures displayed significant (ANOSIM R=0.425, P, 0.001) differences between springs and rivers (Figure 12). T-tests showed that factors such as DO, pH, DRP and concentrations of manganese (Mn) were significantly higher in the river samples, whereas both Total_N and nitrate-nitrite_N were significantly higher in the springs (Figure 13, Figure 14). Not suprisingly, flow and temperature were also higher in the river samples, although the temperature data may have been somewhat biased towards slightly higher water temperatures in these samples as only one was collected in winter.
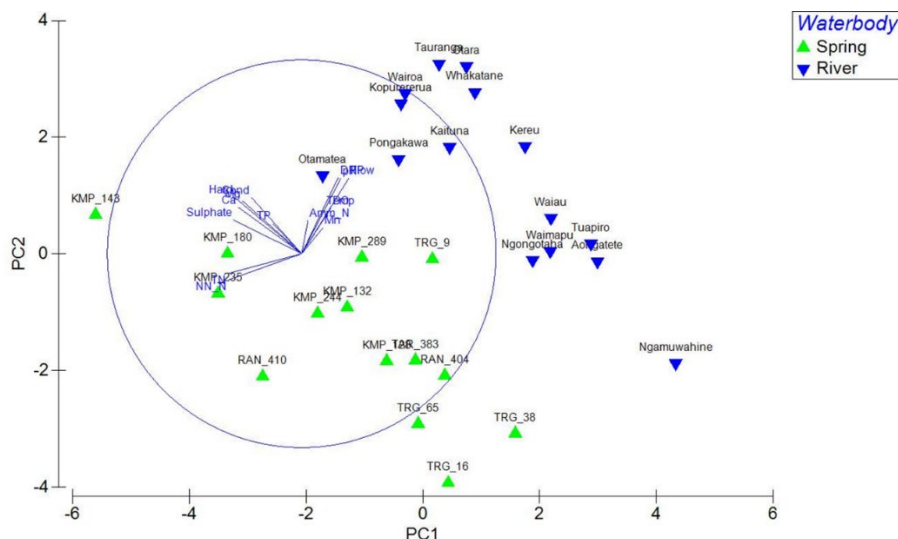
Figure 12   PCA ordination of average water chemistry (and flow) signatures in rivers (blue symbols) or springs (green symbols) throughout the region. The large degree of separation between these waterbodies emphasises their unique water chemistry signatures. KMP = Kaituna, Maketu, Pongakawa, RAN = Rangitāiki; TAR = Tarawera; TRG = Tauranga.
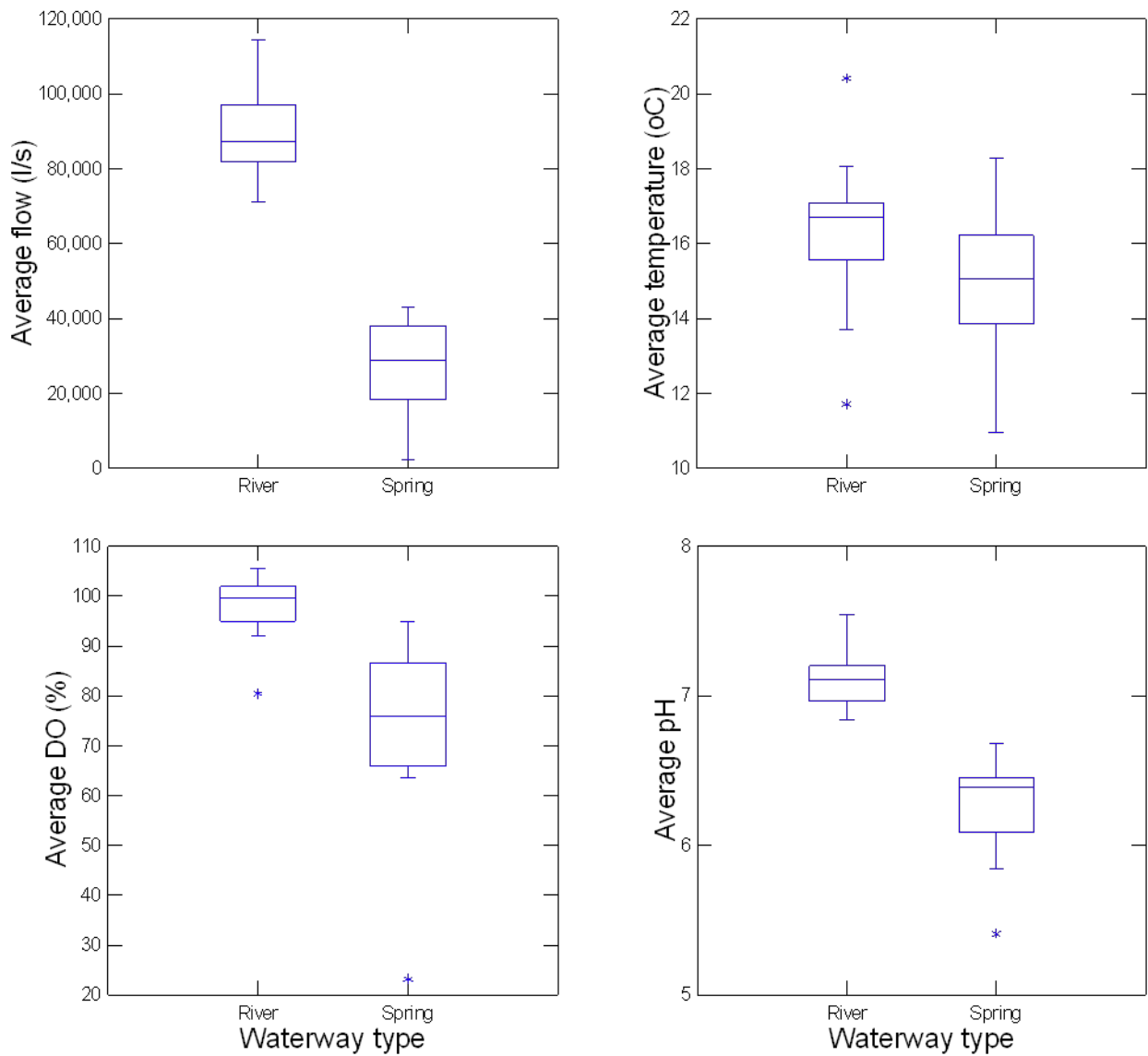
Figure 13   Box plots of average flow, spot temperature, DO and pH of water collected from both springs and rivers throughout the region. Conventions as per Figure 5.

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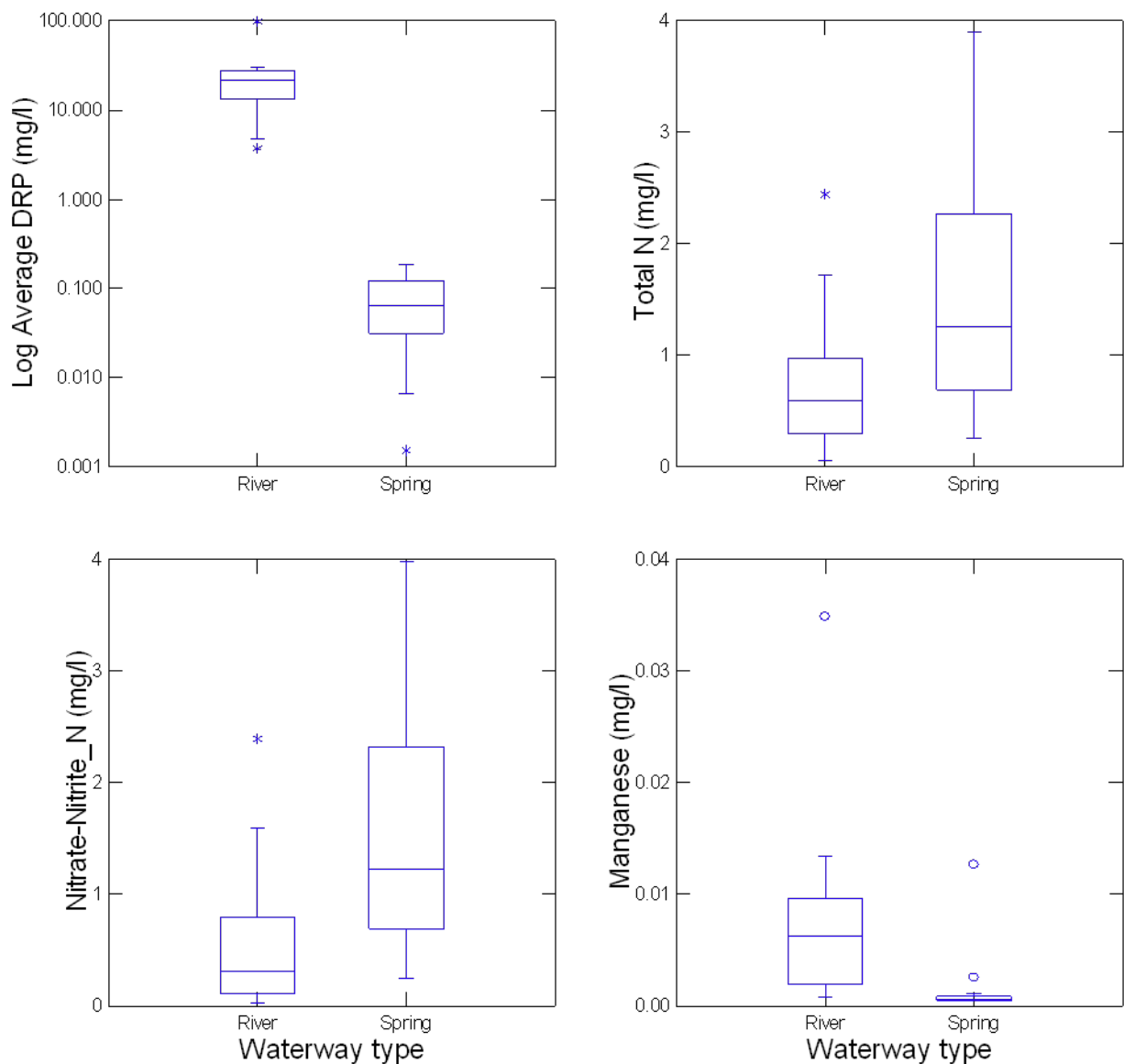
Figure 14   Box plots of average DRP (log transformed to better show the range of values), total_N, nitrate-nitrite N and Manganese in water collected from both springs and rivers throughout the region. Conventions as per Figure 5.

Examination of the temporal variability of the water chemistry data revealed some intresting diffrences. The coefficient of variation (CV) of ammoniacal-N (NH₃-N), conductivity and dissolved oxygen was almost twice as high from the springs ammonical-N than the river samples, while the CV of calcium, the metals magnesium and manganese, sulphate, hardness and temperature was almost as twice as high in river samples than springs (Table 5).

Table 5 *Calculated variability (measured as the coefficient of variation (CV)) of different water chemistry parameters collected from the 15 springs, or from 15 rivers throughout the region. Red shading = cases where the CV in springs larger than in rivers, blue shading equal = cases where the CV in rivers larger than in springs; Green shading = CV appeared similar in both rivers and springs.*

Parameter	Units	CV_Springs	CV_PENZ_Rivers
Ammoniacal Nitrogen (NH3-Npl)	mg/l	150.8	94.0
Calcium (Ca)	mg/l	7.2	15.6
Conductivity_	µS/cm	52.7	27.3
Dissolved Oxygen (DO)	%	17.3	5.1
Dissolved Reactive Phosphorus (DRP)	(mg/l)	30.9	25.4
Flow Rate	(l/s)	75.4	83.9
Magnesium (Mg)	(mg/l)	7.6	19.1
Manganese (Mn)	(mg/l)	24.1	50.6
Nitrite Nitrate-N (NO2-N)	(mg/l)	37.5	43.6
Total-N (N)	(mg/l)	39.5	42.6
pH		2.8	3.0
Total Phosphorus (P)	(mg/l)	34.1	47.2
Sulphate (SO$_4^{2-}$)	(mg/l)	8.8	21.2
Total Hardness	(mg/l)	7.2	17.8
Water Temperature	(°C)	3.6	19.7

3.2 Physical conditions of the springs

A wide range of springs were sampled, including 12 rheocrenes and three limocrenes. Nine of the springs were dominated by large substrates or bedrock, while six were dominated by fine pumice sands and small gravels. Riparian vegetation around eight of the springs was dominated by native trees, while productive pasture grassland was the dominant vegetation around six springs. One spring was dominated by exotic vegetation in the riparian area.

Most springs were at low elevations (average 152 asl) and were close to the coast (average 33 km), although most of the sites in the Rangitāiki and one site in the Tauranga WMA were at higher elevations, and further inland. Catchment land use in most sites was dominated by either pasture or exotic forestry, although some sites also had significant amount of native vegetation or horticulture in them (Table 6).

Table 6   Summary of physical attributes of the 15 springs sampled showing their altitude, distance to sea, and percentage land cover within the catchment.

Spring site	Altitude (m)	Distance to sea (km)	Percentage land cover within the catchment				
			Native	Exotic Forest	Exotic Scrub	Horticulture	Pasture
KMP_128	84.3	15.2	9	48	0	0	43
KMP_132	45.4	18.1	1	0	0	0	99
KMP_143	18.2	19.5	0	0	0	30	70
KMP_180	42.5	13.8	6	0	0	0	94
KMP_235	67.6	13.4	5	23	0	0	73
KMP_244	127.4	21.6	0	80	0	0	20
KMP_289	105.1	18.7	50	49	0	0	0
RAN_309	271.7	84.1	52	0	0	0	48
RAN_404	132.7	45.9	0	88	5	0	8
RAN_410	724.7	188.3	6	5	0	39	50
TAR_383	40.3	17.2	0	0	0	0	100
TRG_16	156.3	8.2	0	13	0	4	82
TRG_38	398.9	31.8	13	0	0	0	87
TRG_65	44.2	3.6	32	12	6	5	40
TRG_9	25.0	3.1	0	0	0	19	80

A PCA of the physical data clearly showed gradients in the data reflecting elevation and distance to sea, as well as the dominant land use (Figure 15). Thus, sites such as RAN_410, and RAN_309 were clustered in the lower left of the PCA diagram, reflecting their greater distance inland and higher elevation than other sites. Landcover was also a dominant gradient, with sites in the lower right of the PCA such as RAN_404, KMP_289, KMP_244 and TRG_65 being found in sites dominated by either native vegetation or exotic forest or scrub, while sites in the upper portion of the PCA2 axis such as TAR_383, KMP_132, KMP_180, TAR_383, TRG_9, TRG_16 and TRG_38 being found in catchments dominated by pasture.
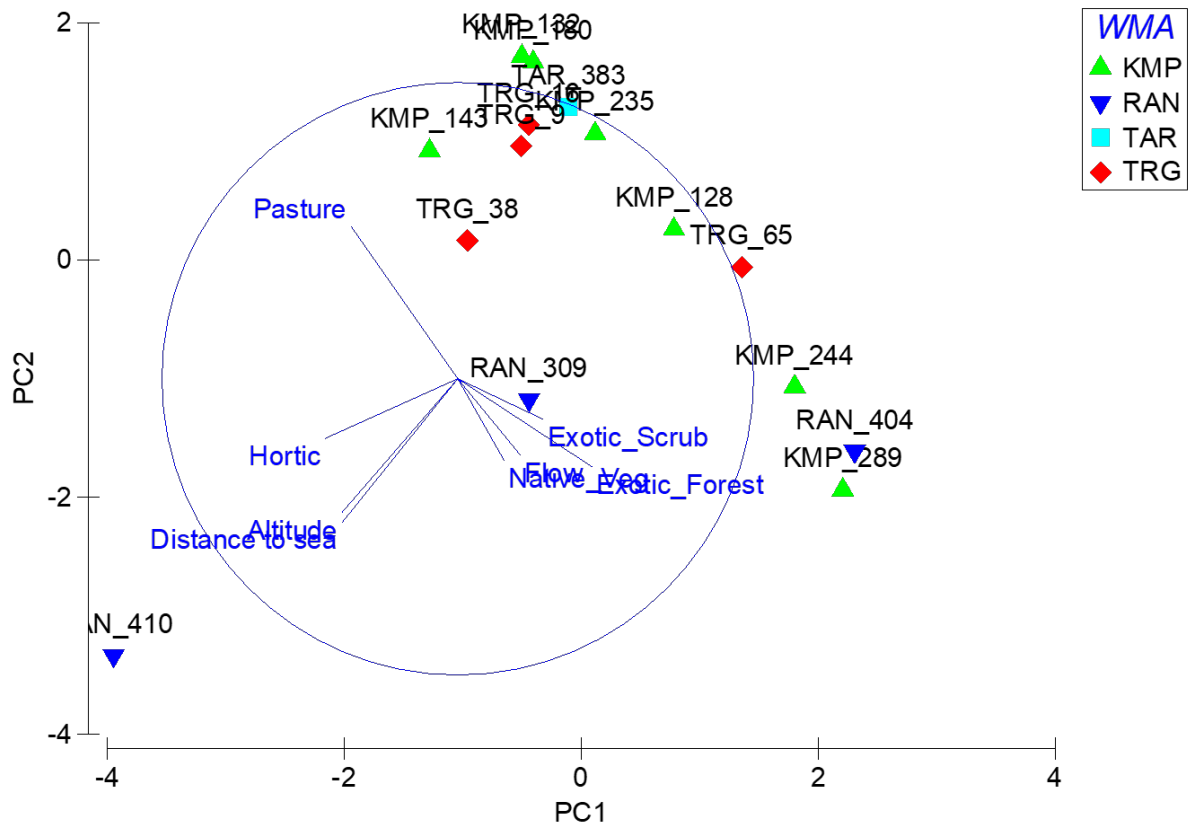
Figure 15   *Results of a principal components analysis (PCA) of the physical data of the 15 springs surveyed during the study. Also shown are the dominant physical factors responsible for the observed sample pattern.*
KMP = Kaituna, Maketū, Pongakawa, RAN = Rangitāiki; TAR = Tarawera; TRG = Tauranga.

3.3 Spring Invertebrate communities

3.3.1 Community composition

A total of 81 invertebrate taxa were identified from the 15 springs. The fauna at all sites was numerically dominated by snails (44%) insects (41%), and mites (7%). Of the aquatic insects, the most abundant groups were the true flies (Diptera, 16%), caddisflies (Trichoptera, 12%), and mayflies (Ephemeroptera, 5.8%). The six most abundant individual taxa were *Potamopyrgus* snails, *Polypedilum* non-biting midge larvae, oribatid mites, *Pycnocentrodes* caddisflies, *Zephlebia* mayflies, and the surface-dwelling water strider *Microvelia*, respectively (Figure 16).
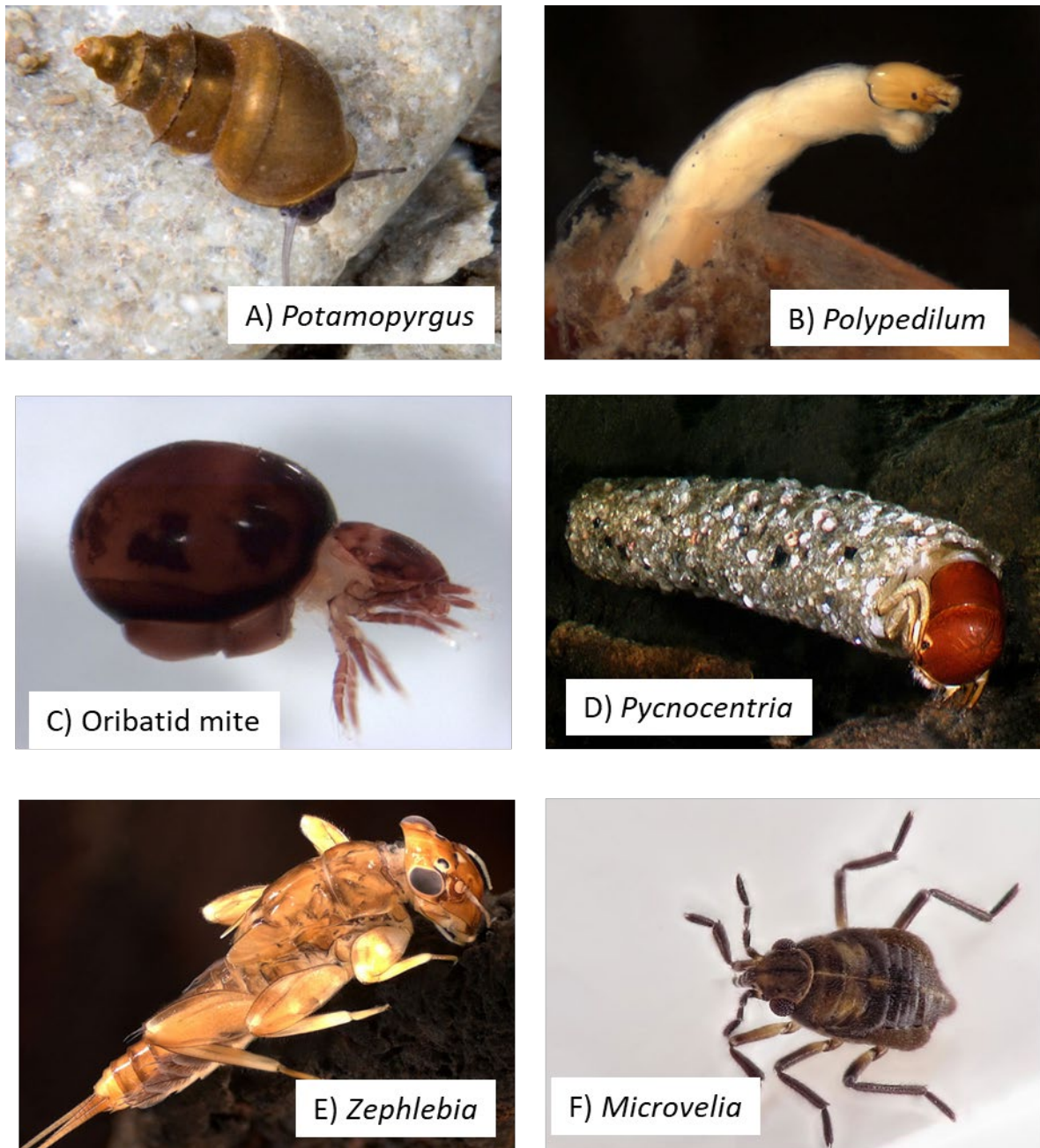

Figure 16   *Examples of the most numerically dominant aquatic invertebrates commonly collected from the 15 springs throughout the region.*

The most widespread taxa collected from the 15 springs included three of the most numerically dominant invertebrates: *Polypedilum* and *Potamopyrgus* (found in all springs), and oribatid mites (found in 10 springs). Other widespread taxa included other mites (Acari) and worms (oligochaetes) (found in 10 springs), as well as flatworms (Platyhelminthes, found in nine springs) and the non-biting midges Macropelopiini and *Eukiefferiella*, found in seven and six springs respectively. Despite taxa such as *Zephlebia*, *Microvelia*, *Pycnocentria* being abundant at some sites, they were not particularly widespread as they were recorded in three to five springs.

3.3.2 Patterns to invertebrate communities

The NMDS ordination plot (Figure 17A) indicated that springs sites within each WMA supported generally similar invertebrate communities (i.e., same mix of taxa and relative abundance) and were thus grouped together. For example, springs from the Rangitāiki (RAN) WMA were clustered in the lower left of the plot, while springs from the Tauranga (TRG) WMA were mostly clustered in the upper centre (Figure 17A). The stress of the ordination was low (0.016) and considered to accurately represent differences in the community structure. The ANOSIM analysis (Table 7) showed that grouping the springs into the four different WMAs explained a significant (P=0.05) proportion of the variability in invertebrate community composition (Figure 17A). The ANOSIM analysis also indicated rock stratigraphic unit classification was significantly (P<0.05) associated with spring invertebrate communities (Table 7). This was shown on the NMDS ordination plot (Figure 17B) whereby springs draining neogene igneous material were generally clustered to the upper right of the ordination plot, while springs draining Holocene River deposits were largely located in the centre-left of the ordination (Figure 17B).
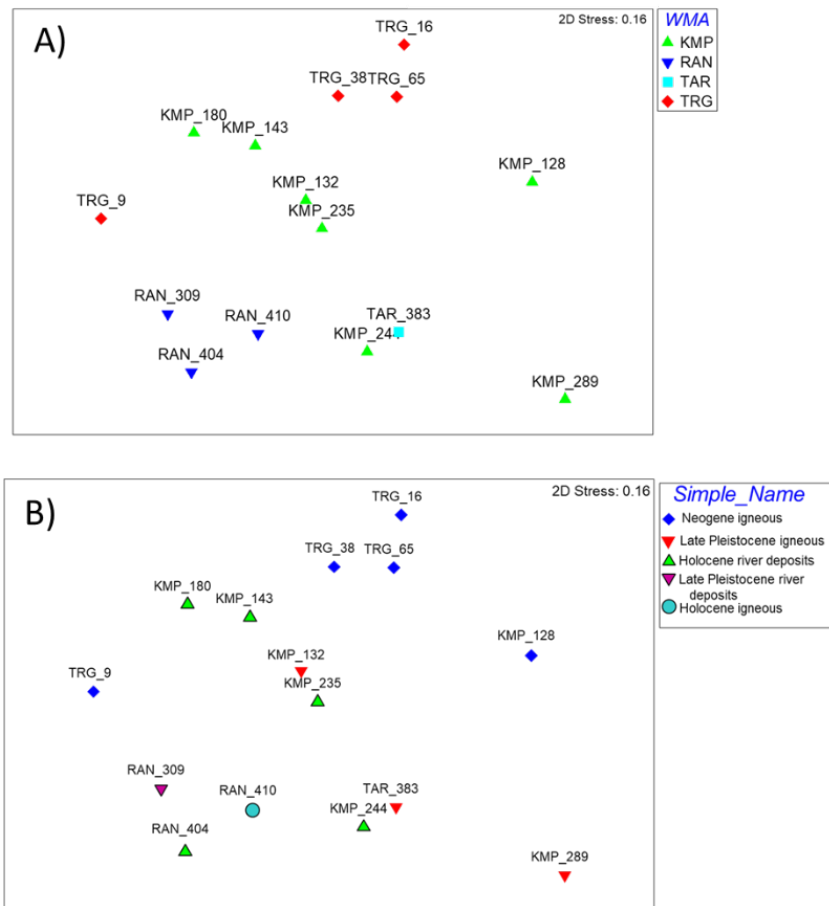

Figure 17   A: Results of the NMDS of the invertebrate community data showing the samples according to WMA. B: Simple_Name rock classification based on stratigraphic age and rock type. KMP = Kaituna, Maketu, Pongakawa, RAN = Rangitāiki; TAR = Tarawera; TRG = Tauranga.

The ANOSIM also showed that grouping of springs into dominant substrate type (hard-bottomed vs soft-bottomed), springs source (rheocrene versus limocrene), and dominant riparian vegetation (native forest, exotic forest, grassland) was not significantly ($P>0.05$) correlated with invertebrate community composition (Table 7). There was also no significance difference ($P>0.05$) in the invertebrate community composition in the 15 springs draining land uses, springs with or without stock presence, or springs with different degrees of shade.

Table 7   *Results of the ANOSIM test showing the degree to which invertebrate communities were structured by location either within each WMA, dominant substrate type (hard-bottom vs soft bottom), spring source (rheocrene versus limocrene) or dominant riparian vegetation (native forest, exotic forest, grassland). Significant differences (P≤0.05) are in bold.*

Factor type	Grouping	Global R	P-value
Location	**WMA**	**0.258**	**0.05**
Spring nature	Substrate type	0.024	0.562
	Spring source	0.078	0.64
Landuse	Riparian vegetation	0.008	0.44
	Stock access	-0.025	0.94
	Shade	0.096	0.16
Underlying geology	Main Rock	-0.011	0.535
	Rock Class	0.146	0.088
	Stratigraphic Unit	**0.258**	**0.043**

3.3.3   Drivers of invertebrate communities

Results of the RELATE analysis showed no significant ($P>0.05$) relationships between the invertebrate communities from the springs and any of the three resemblance matrices that described the physical habitat, water chemistry or the spatial data (Table 5). This suggests that the invertebrate communities in these springs were largely independent of all the variables that made up these three environmental data matrices, and that other, unmeasured factors were influencing their distributions.

Table 8   *Results of the RELATE analysis showing the relationships between the invertebrate communities and the environmental data matrices describing the physical nature of the springs, their water chemistry, and their spatial distribution. Significant differences are indicated by P≤0.05.*

Data table	Sample statistic (Rho)	P-value
Physical Habitat	0.184	0.146
Water chemistry	-0.087	0.703
Spatial Data	0.196	0.099

3.4 Comparison of springs to riverine first-order streams

A total of 129 invertebrate taxa were identified from the 36 first order streams in the region. As with the spring sites, the stream fauna was dominated by the snail *Potamopyrgus*, although at a much lower relative abundance (c. 10%) compared to that found in the springs (c. 44%: Table 9). Other commonly encountered invertebrates included a wide range in aquatic insects, including midges (Orthocladiinae and *Polypedilum*), mayflies (*Zephlebia*, *Coloburiscus*, and *Deleatidium*) and worms (oligochaetes). Non-insect taxa also dominated the invertebrate fauna in springs, contributing to 56% of total abundance, compared to only 44% of insect taxa (Figure 18). This is markedly different to the dominance of insect taxa (73%) in the comparison first-order streams.
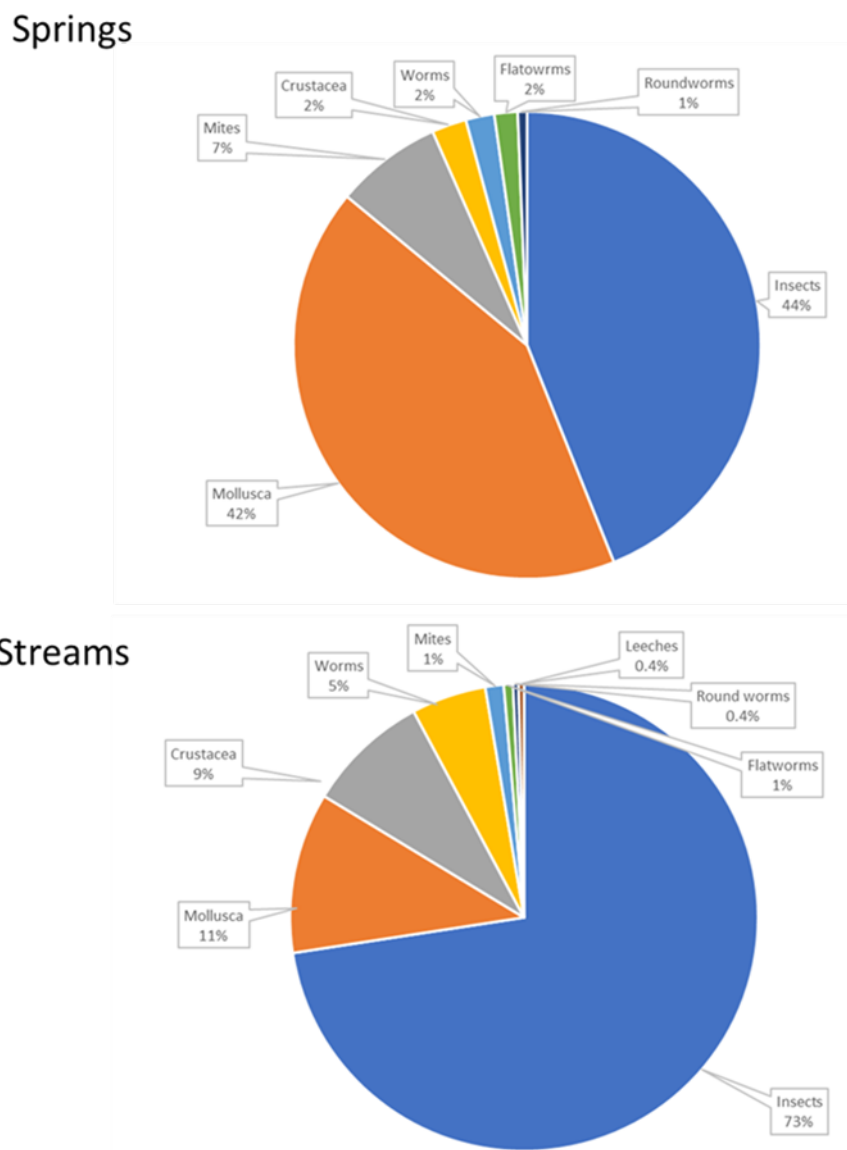
Figure 18   Pie charts showing the percentage composition to total density of dominant invertebrate groups in 15 springs and 36 first order streams sampled in the Bay of Plenty.

The NMDS ordination plot showed significant (R = 0.367, P< 0.001) differences in the invertebrate community composition between springs and the other first order streams examined (Figure 19). Only four taxa (*Potamopyrgus*, *Zephlebia*, *Polypedilum* and worms) were common to springs and first-order streams (Table 9), however, the relative abundance of *Potamopyrgus* was marker greater in springs.
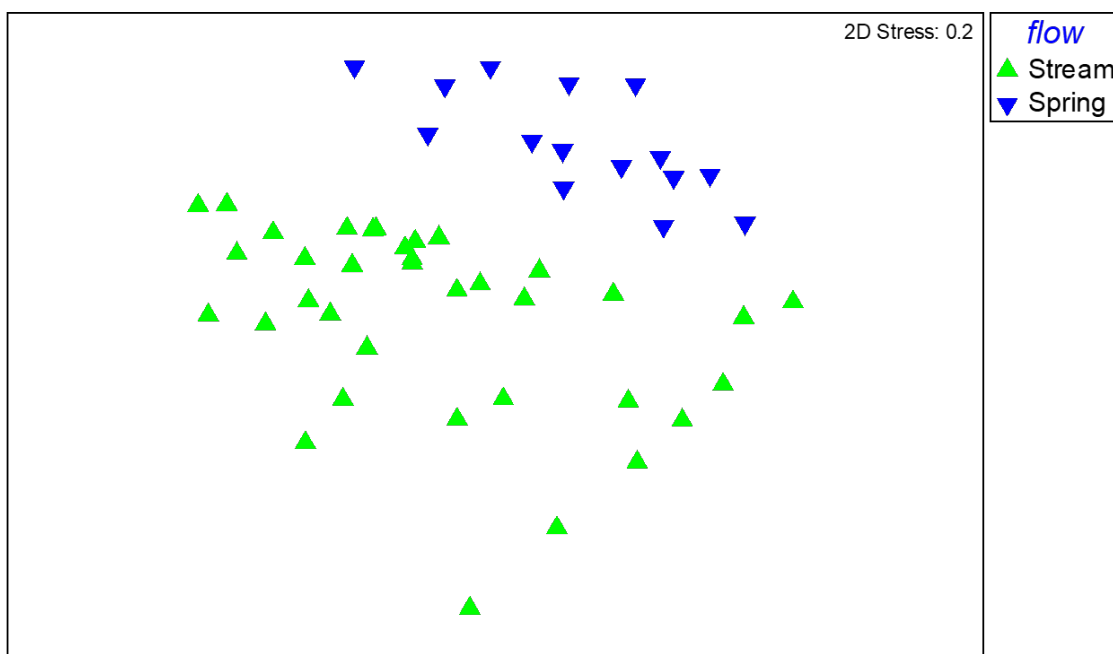
Figure 19   Results of the NMDS ordination on invertebrate communities found in 35 streams (green symbols) and 15 springs (blue symbols) throughout the region. Note the degree of separation between both stream and spring samples, suggesting that these ecosystems support very different invertebrate communities.

Table 9   Relative abundance of the 10 most common taxa found in either stream or spring samples collected throughout the region. Red shading indicates taxa that were common to both springs and first order streams.

Stream samples		Spring samples	
Potamopyrgus	9.8	*Potamopyrgus*	43.6
Zephlebia	8.9	*Pycnocentria*	7.6
Orthocladiinae	7.4	*Polypedilum*	7.5
Coloburiscus	5.4	Acari	7.4
Oligochaeta	5.2	*Zephlebia*	4.1
Ostracoda	3.9	*Microvelia*	2.9
Deleatidium	3.3	*Oxyethira*	2.2
Polypedilum	3.0	Oligochaeta	2.0
Austrosimulium	2.9	Platyhelminthes	1.6
Orthopsyche	2.8	*Eukiefferiella*	1.5

Figure 20 demonstrates that fewer taxa dominated the invertebrate community at spring sites, while first order streams had a far greater number of relatively common taxa. This was further supported by calculations of species evenness, a measure of how equal the community is numerically, which was much higher in first order streams (0.726) than in springs (0.538) indicating more similar invertebrate communities were present in streams.
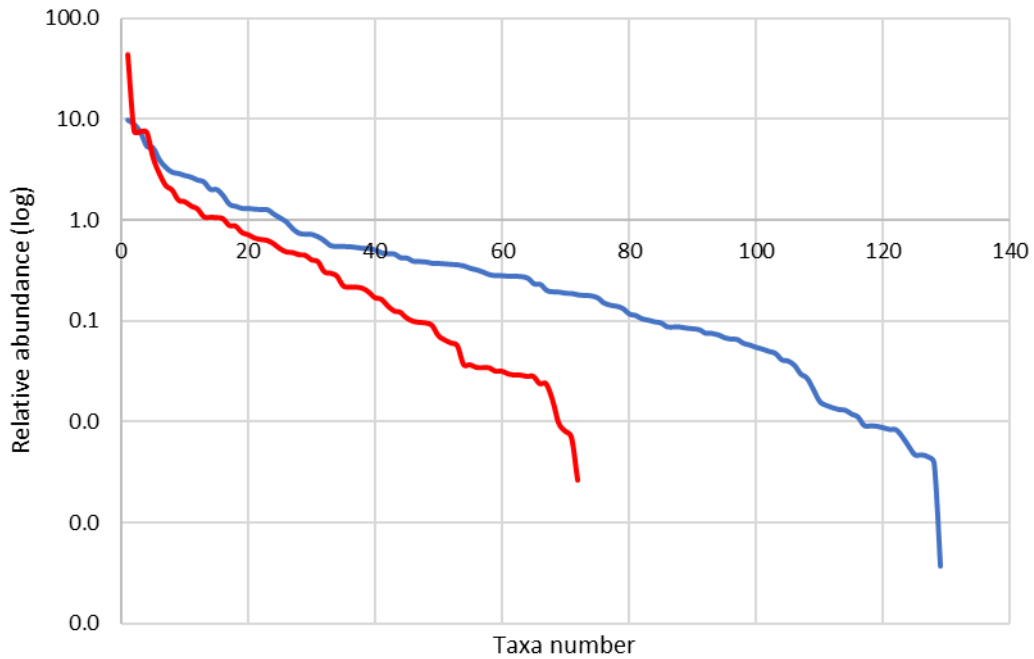
Figure 20   Taxa dominance (percent relative abundance) against number of taxa in 1st order streams (blue line) and springs (red line) throughout the Bay of Plenty. Note that springs had a much higher dominance of a few taxa, as well as fewer taxa.

Significant differences (P≤0.05) were detected in five of the six biotic indices between the 15 springs and the 36 first order streams, with all greater in the first order streams than the spring fed streams (Figure 21). Only the MCI scores were considered to be similar (P≥0.05) between springs and streams (Figure 21).
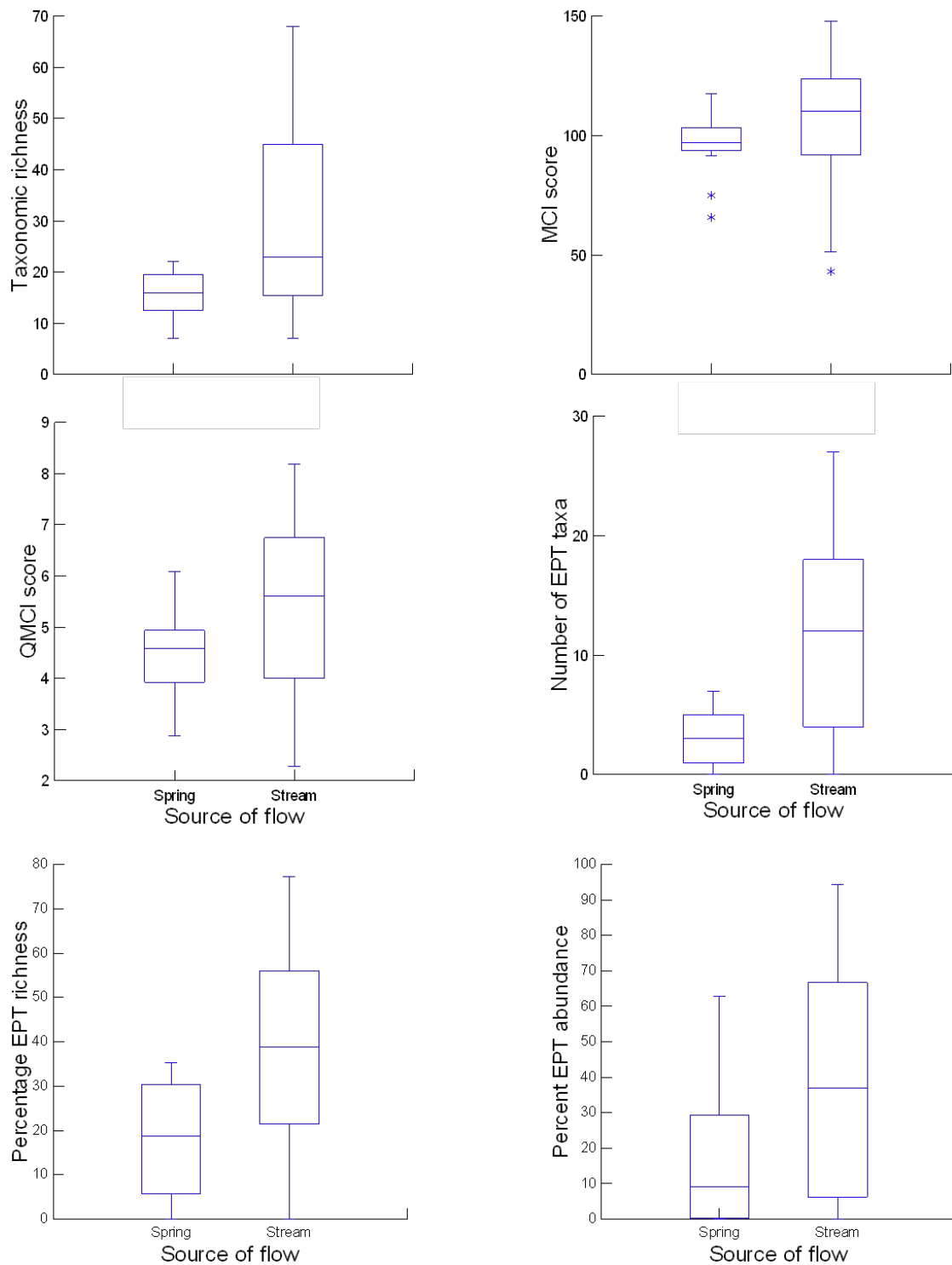
Figure 21   Box plots of taxonomic richness, calculated MCI and QMCI scores, the number of EPT taxa, the percentage of EPT taxa richness, and the percentage of EPT taxa abundance in springs and 1st order streams throughout the region. The central horizontal line indicates the median value, and the bottom and top of the box indicate the 25th and 75th percentile values. The whiskers extend to the 10th and 90th percentiles. Numbers exceeding the 5th and 95th percentiles are also shown (stars or circles).

3.5   Comparison to other springs

The NMDS ordination plots showed clear differences in the invertebrate community composition between springs in different regions throughout the country (Figure 22), and this was confirmed with the highly significant ANISOM statistic (R = 0.492, P< 0.001). Taxonomic richness and invertebrate community composition was highest in the Bay of Plenty, and lowest in the Waitaki region in South Canterbury, but differed greatly between regions (Table 10). Crustaceans such as amphipods (including *Paraleptamphopus*) and isopods were most widespread in Southland springs, but absent from west Waikato springs, whereas only amphipods (including *Paraleptamphopus*) were present central Waikato springs. The SIMPER analysis (Table 10) indicated springs in Southland and Waikato had the highest similarity across invertebrate communities. Given that these locations were the most geographically distant, their high degree of similarity suggests that their location within New Zealand was not a good predictor of their invertebrate communities.
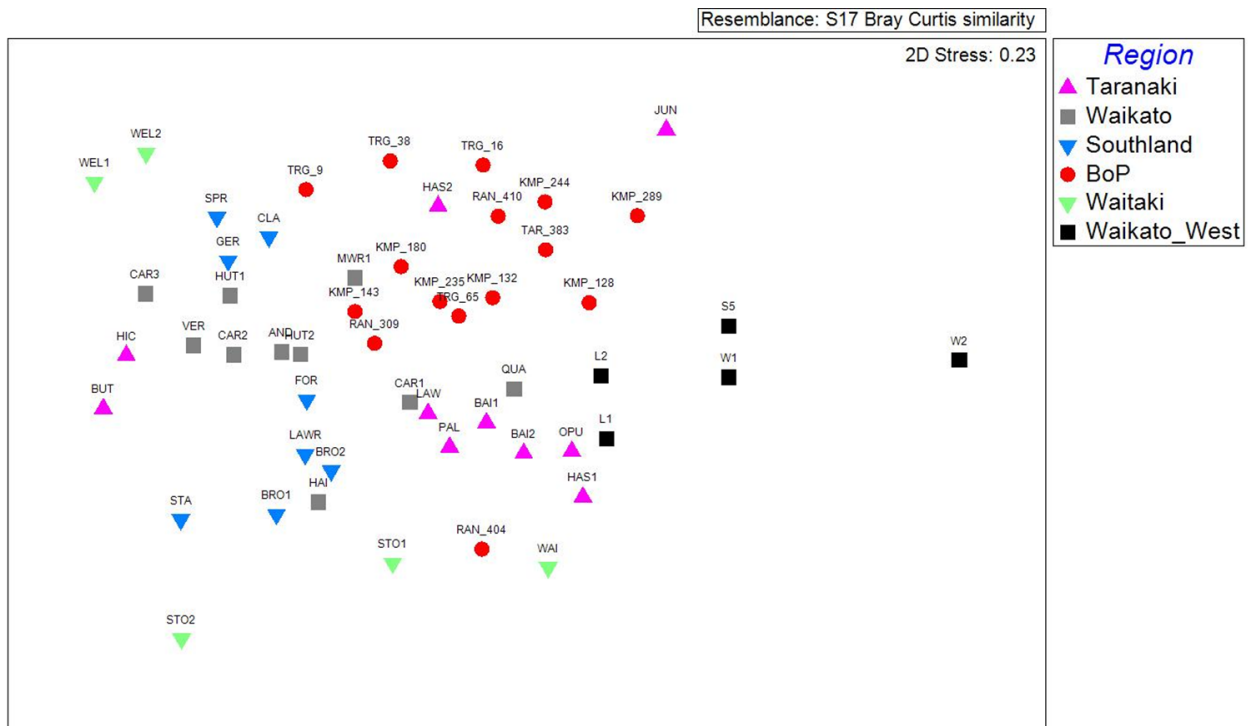
Figure 22   Results of the NMDS ordination on invertebrate communities found in springs in different regions of New Zealand. Note the distinct grouping of springs from Southland and Waikato, which had the highest similarity, and the more spread-out nature of springs in Taranaki and the Waitaki region, which had the lowest similarity.

Table 10   *Total number of taxa found in springs in each of six distinct regions in New Zealand. Also shown is the average within spring Bray-Curtis similarity in each region, as well as the five most widespread taxa found in each region.*

	Southland	Waitaki	Taranaki	Waikato	Waikato west	Bay of Plenty
Number of taxa	38	26	33	44	34	66
Average similarity	43.8	22.3	29.7	41.5	30.3	37.5
Most widespread taxa	*Paraleptamphopus*	Oligochaeta	*Polypedilum*	Oligochaeta	*Zephlebia*	*Polypedilum*
	Oligochaeta	Ostracoda	Oligochaeta	Amphipoda	*Austrosimulium*	*Potamopyrgus*
	Amphipoda	*Phreatogammarus*	*Paradixa*	Hexatomini	*Potamopyrgus*	Acari
	Isopoda	*Cricotopus*	*Potamopyrgus*	Ostracoda	Elmidae	Oligochaeta
	Platyhelminthes	Hydrobiosidae	Oeconesidae	*Paraleptamphopus*	*Orthopsyche*	Platyhelminthes

3.6   Adult aquatic insects

Fifteen Malaise traps were deployed between eight to 24 days, with an average deployment time of 20 days. A total of 5431 adult aquatic insects belonging to mayflies, stoneflies, and caddisflies (EPT taxa) were collected, comprising of 42 species from 11 families (Table 11). Caddisflies provided the greatest diversity and numerical dominance of all EPT captured, followed by an order of magnitude fewer mayflies and stoneflies, respectively. The microcaddisfly, or axe-head caddisfly, *Oxyethira albiceps*, provided the greatest single contribution of a taxon, with over 75% of the total abundance. Other species included the caddisfly *Pycnocentria funerea* (10%), the stonefly *Spaniocerca zelandica* (3%), the purse-case caddisfly (another microcaddisfly) *Paroxyethira hintoni* (2%), and the mayfly *Austroclima sepia* (1%). Five caddisfly species, including three species of *Polyplectropus*, were found in seven or more Malaise traps (Table 12).

The vast majority of these EPT species are regarded as not threatened, however, *P. hintoni* and the mayflies *Zephlebia tuberculata* and *Z. nebulosa* were regarded as "naturally uncommon" according to Grainger et al. (2018) (Table 11). *Paroxyethira hintoni* was found at sites RAN_404 and TRG_9, *Z. tuberculata* at KMP_128 and KMP_147, and *Z. nebulosa* was found only at KMP_128.

Four *Paroxyethira* males were captured at RAN_404 and could not be placed within the 15 described species. These specimens most closely resembled *P. hughwilsoni*, a "data deficient" South Island species known only from two Canterbury locations (Narbey Stream on Banks Peninsula and the Otaio River near Timaru) but could also potentially represent a new species of microcaddisfly. A female hydropsychid from KMP_244 showed morphological aspects of both *Orthopsyche* and *Aoteapsyche* and could not be reliably assigned to either genus. This individual may also represent a previously undescribed species.

Table 11   Summary table showing the number of families and species, as well as a total number of individuals belonging to the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). Also shown are the number of species belonging to four different conservation categories (after Grainger, 2018).

	Families	Species	Total no.	Not threatened	Data deficient	Naturally uncommon	No data
Ephemeroptera	2	11	206	8	0	2	1
Plecoptera	3	4	170	4	0	0	0
Trichoptera	9	27	5055	23	1	1	2
Totals	**14**	**42**	**5431**	**35**	**1**	**3**	**3**

Table 12 *List of the 10 most common adult aquatic insect species according to relative abundance, or the number of sites where they were found. (C) = caddisfly, (M)= mayfly*

Taxa	Percent abundance	Taxa	Number of sites
Oxyethira albiceps (C)	75.8	*Pycnocentria funerea* (C)	10
Pycnocentria funerea (C)	10.1	*Psilochorema mimicum* (C)	8
Spaniocerca zelandica (C)	3.0	*Oxyethira albiceps* (C)	8
Paroxyethira hintoni (C)	2.0	*Polyplectropus altera* (C)	8
Austroclima sepia (M)	1.0	*Polyplectropus aurifusca* (C)	7
Polyplectropus altera (C)	0.9	*Polyplectropus impluvii* (C)	7
Pseudoeconesus bistirpis (C)	0.9	*Oeconesus maori* (C)	6
Zephlebia dentata (M)	0.7	*Pseudoeconesus bistirpis* (C)	6
Tepakia caligata (M)	0.7	*Austroclima sepia* (M)	5
Oeconesus maori (C)	0.7	*Zephlebia dentata* (M)	5

The number of insects collected in the traps was highly variable, ranging from a low of only nine adults in TRG_9, to over 3900 adults at RAN_404. This was one of the main drivers of the significant differences ($P<0.05$) in abundance between Malaise traps deployed in the different WMAs (Figure 23). No significant differences ($P<0.05$) were observed between the number of adults caught in the Malaise traps and whether the streams were hard or soft bottomed, whether they were from rheocrenes or limocrenes, or what type of immediate riparian vegetation surrounded the Malaise traps. No relationships were found between the number of insects caught and either altitude or the percentage dominant catchment landuse.
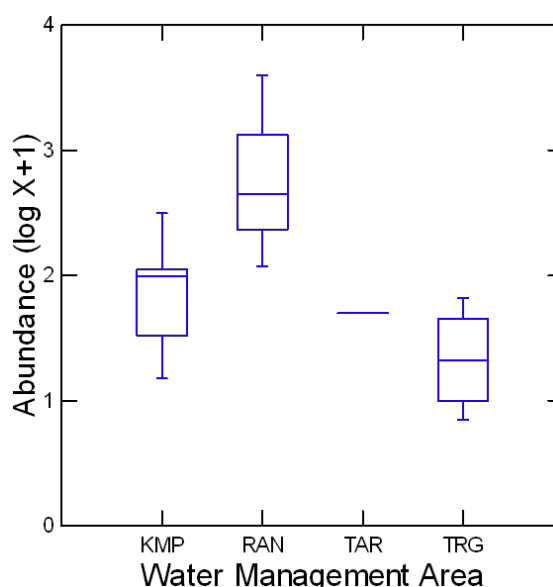

Figure 23 *Box plot of the numbers of adult EPT taxa collected in the Malaise traps deployed in springs in the different Water Management Areas (WMAs): KMP = Kaituna, Maketu, Pongakawa, RAN = Rangitāiki; TAR = Tarawera; TRG = Tauranga.*

An NMDS ordination of the adult aquatic insect data showed little pattern. Although Malaise traps in the Rangitāiki Catchment were clustered in the centre of the NMDS graph (Figure 24), samples from the other locations were spread widely on the NMDS graph. Furthermore, the results of the ANOSIM showed no patterns to the adult aquatic insect data when classified to any of the six categorical factors (Water Management Areas , dominant substrate type, spring type, or dominant riparian vegetation, stock access or shade), although the calculated P-value for shade (0.056) was only slightly higher than the arbitrary cut-off significance value of 0.050 (Table 13).
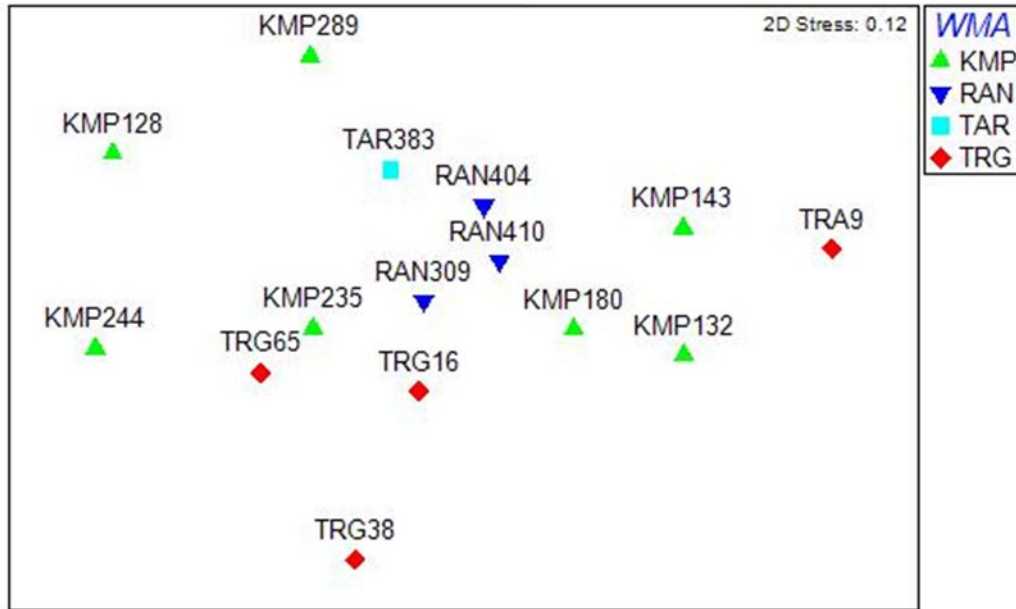
Figure 24   Results of the NMDS of the adult EPT data showing the samples when colour coded according to WMA. KMP = Kaituna, Maketu, Pongakawa, RAN = Rangitāiki; TAR = Tarawera; TRG = Tauranga.

Table 13   Results of the ANOSIM test showing the degree to which adult EPT community structure were organised by any of the six categorical classes. Significant structure in the data exists when the global R value has a corresponding p-Value less than 0.05

Grouping	Global R	P-value
WMA	-0.146	0.87
Substrate type	-0.038	0.59
Spring source	0.117	0.26
Riparian vegetation	0.029	0.37
Stock access	-0.284	0.97
Shade	0.168	0.056

3.7 Aquatic bryophytes

Aquatic bryophytes were present only at nine of the 15 springs (Table 14). Taxonomic richness at each site was low, with four sites supporting only a single species, and three sites supporting two species. The highest number of species at any site was five (Table 14). The most widespread bryophytes were the mosses *Fissidens rigidulus var rigidulus* (four sites) and *Amblystegium riparium* (three sites), as well as the liverwort *Lophocolea bidentata* (three sites). All these plants are widely distributed throughout New Zealand.

Aquatic bryophytes were restricted to large stable substrates such as bedrock, boulders and cobbles, and were generally absent from soft-bottomed springs. The only two exceptions to this were at one site (KMP_180) where *A. riparium* was growing on a stable concrete structure that housed a water pump, and at a second site (KMP_132) where *F. asplenoides* was growing on bedrock at the source of the spring itself. Streambed cover by bryophytes was considered high (i.e., > 20% of the streambed) only at two sites: on a bedrock dominated waterfall at TRG9 just below the main spring source, and on a mix of bedrock and large stable boulders at KMP128. Streambed cover by bryophytes at the remaining seven sites were < 5%.

Table 14   *Summary table showing what bryophtyes (mosses and liverworts) were collected at each of the 15 spring sites. Springs without bryophytes are shaded in red.*

Spring	Mosses						Liverworts		Total richness
	Amblystegium riparium	*Achrophyllum dentatum*	*Fissidens asplenoides*	*Fissidens rigidulus* var *rigidulus*	*Raccomitrum*	*Thamnium pandum*	*Aneura*	*Lophocolea bidentata*	
KMP_128				Y	Y		Y		3
KMP_132			Y						1
KMP_143	Y								1
KMP_180	Y								1
KMP_235									0
KMP_244								Y	1
KMP_289									0
RAN_309									0
RAN_404	Y	Y	Y		Y			Y	5
RAN_410									0
TAR_383				Y				Y	2
TRG_16				Y		Y			2
TRG_38									0
TRG_65									0
TRG_9				Y		Y			2

An NMDS ordination of the aquatic bryophyte data showed little pattern in the data (Figure 26).
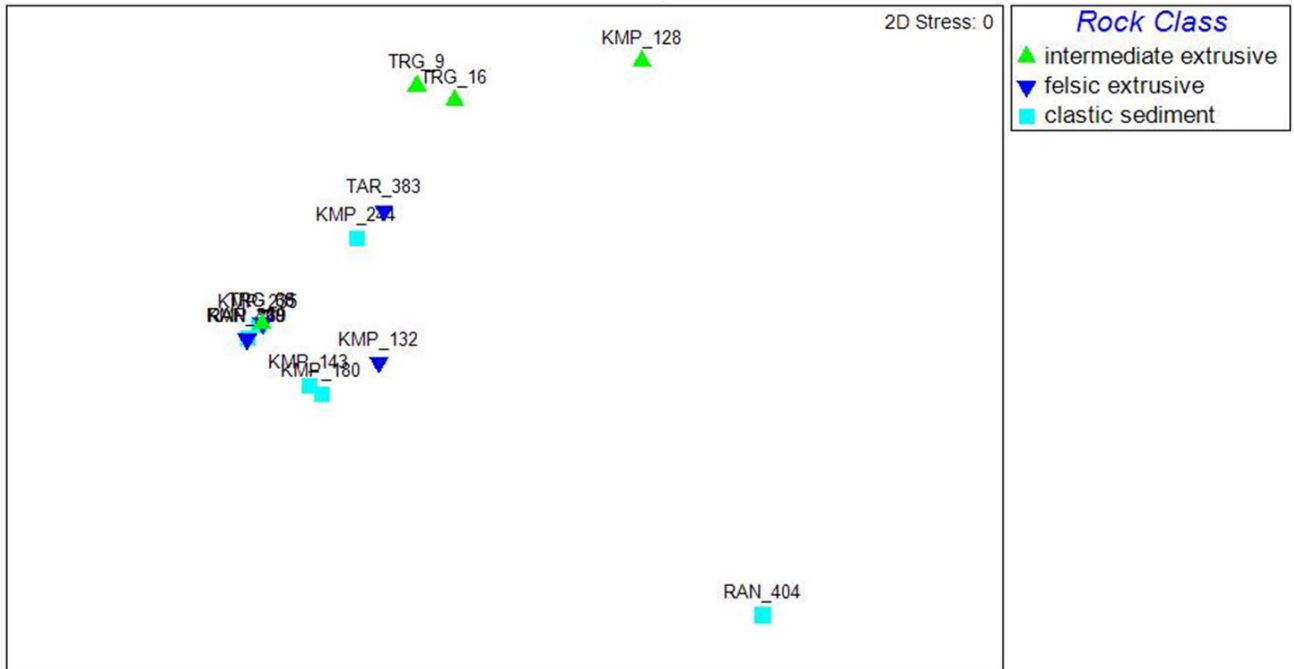

Figure 25   *All springs without bryophytes were clustered in the left-hand centre part of the ordination. Sites with the highest bryophyte species richness (RAN_404 and KMP-128) were located the furthest from the sites with no bryophytes, while sites with only one species were closest to these sites. Results of the ANOSIM only showed a statistically (P<0.05) significant association of aquatic bryophytes with only the rock class classification (Table 15). No significant (P>0.05) correlation was detected within the Rock Class groups and springs with, and without bryophytes. Any patterns to the bryophyte data thus reflected more subtle difference in species composition between springs sourced from the different rock classes. For example, the F. rigidulus var rigidulus was not recorded from springs sourced from clastic sediments, while A. riparium was found only in these springs, and the moss Thamnium pandum was found only in springs sourced from intermediate extrusive rocks.*
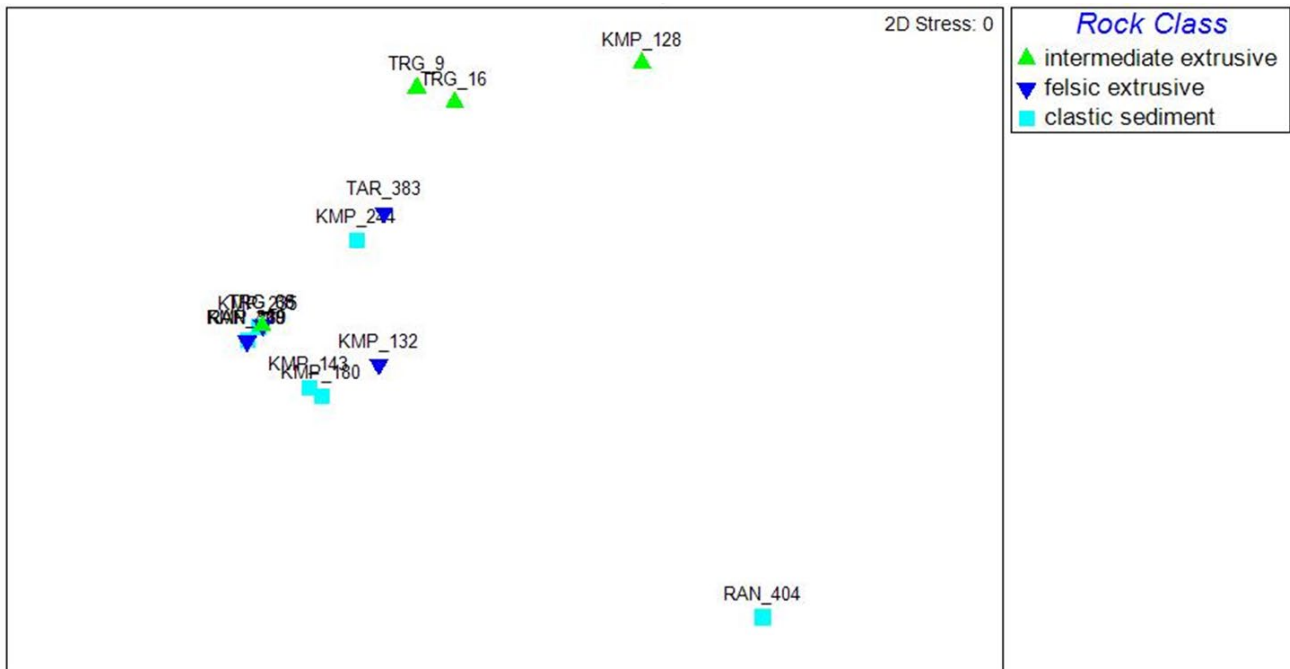
Figure 26   Results of the NMDS of aquatic bryophytes (presence-absence data). Note the lack of any patterns with this ordination.

Table 15   Results of the ANOSIM test showing the degree to which aquatic bryophyte community structure were organised by any of the six categorical factors. Significant structure in the data exists when the global R value has a corresponding p-Value less than 0.05 (bold).

Grouping	Global R	P-value
WMA	0.098	0.234
Substrate type	0.012	0.366
Spring source	-0.151	0.725
Riparian vegetation	0.069	0.251
Stock access	-0.227	0.905
Shade	0.092	0.095
Main Rock	0.027	0.311
Rock Class	**0.22**	**0.021**
Stratigraphic Unit	0.148	0.131

Part 4:
Discussion/Matapakitanga

This study was done as part of a programme to enhance our knowledge of springs in the region over and above studies by Green (2018, 2022) which quantified the volume of water discharging from each spring and characterised their water quality. More specifically, it was designed to better characterise the ecological conditions within springs, including invertebrates and aquatic bryophytes, and examine their associations with environmental factors. Given that springs occur at the interface of groundwater, surface water and terrestrial ecosystems, any current use of springs as a water resource may place springs (and their associated ecosystems) under increasing pressure. However, the ecological implications of such resource use are currently unknown

4.1   Water chemistry

The study springs were sourced from three major rock types: ignimbrite, rhyolite and gravel. These rock types have different origins and are expected to have very different chemistry. For example, ignimbrite is sourced from pumice-dominated pyroclastic flow deposits, while rhyolite is an extrusive rock that is slowly forced from the ground and then piled up to form lava domes. It is also high in minerals which are rich in silicon, aluminium, sodium and potassium. Gravels, in contrast, are sourced from eroding parent material and deposited elsewhere. This material is consequently expected to have lost some of the easily eroded nutrients and other chemicals within it. These differences in rock types are likely to affect water chemistry and porosity, which may influence springs in terms of their overall chemistry, discharge, and links to surface features.

Spring water chemistry was consequently thought to reflect the chemical signature the parent aquifer and is assumed to be relatively constant in contrast to non-spring fed streams, whose chemistry is expected to be influenced by rainfall run-off patterns and by surrounding land use activities. The ANOSIM highlighted that water quality differed with regards to location between the individual Water Management Areas (WMAs), and with the rock class classification. This result highlights the inherent spatial differences of the underlying geology on the Bay of Plenty and reinforces the notion that historic volcanic activity has had a major influence on contemporary water quality conditions in springs, reflecting these geological differences. In particular, the spring water draining from areas of clastic sediments had different chemical signatures to spring water in either intermediate or felsic extrusive rock classes. This is a similar finding to work by Donath et al. (2015), who examined groundwater-surface water interactions in the Lake Rotorua Catchment where seeps, springs and streams were sampled. Analysis of the water chemistry data showed that variation at both the catchment and sub catchment scales reflected natural water-rock interactions and that water chemistry was largely affected by rock type.

Landuse, as defined by the river environment classification (REC) appeared to have little consistent effect on spring water quality, which was surprising, given the strong effects of catchment landuse on groundwater quality (e.g., Lerner and Harris 2009). Lack of observed relationships between water quality and land use in this study may however simply reflect the relatively coarse resolution of the REC land cover classification. For example, a catchment with more than 20% agriculture is automatically defined as "pasture", whereas five of the 11 streams classified as "pasture" had their riparian areas dominated by native bush. The REC rules governing the landuse classification may thus not be relevant in this scenario, and local riparian conditions within sub-catchments may be more important in influencing the nature of the spring water than the overall catchment landcover. Indeed, the ANOSIM results showed that the immediate riparian cover

explained a large proportion of variability to water chemistry. Another potential reason for lack of any concordance between catchment land use and spring water quality may simply reflect the fact that surface water catchments are defined based on topographic contours, whereas groundwater aquifers are defined on sub-surface features such as pervious and impervious rock layers that dictate where water can flow. A single groundwater aquifer can thus span many surface catchments, potentially reducing the applicability of a land use classification based on surface catchments.

Rivers and springs were displayed very different water chemistry. Springs had a slightly lower dissolved oxygen (DO) percentage saturation (75%) than rivers (98%), which was somewhat surprising given that the spring water was generally cooler than the river water, and that cold water naturally holds more dissolved oxygen than warmer water. However, the lower DO in springs may have simply reflected that these sites had been sampled almost immediately at their spring source, where not enough reaeration had occurred to increase oxygen levels at the sample point. Moreover, White et al. (2004) reported that most groundwaters in the Rotorua region had low concentrations of iron (Fe) and magnesium (Mn) which indicated that the aquifers there were either predominantly oxic, or only moderately anoxic. This would explain the slightly lower DO saturation in spring water despite being cooler, but it is unlikely that DO would be limiting to ecological communities at most of the spring sites. The exception to this was at TRG_65, where median DO saturation was only 28%. This spring had the lowest discharge (0.26 L/s) and the second highest water temperature (16.5°C), so re-aeration here would have been lower than at other cooler and more turbulent sites with higher discharge.

Higher dissolved reactive phosphorus (DRP) concentrations measured at river sites may have reflected increased phosphorus inputs through natural erosion processes from sediment rich rocks and soil in the surrounding catchments. Higher total nitrogen (N) and nitrate nitrite-N (NO_3-N) detected in spring water may reflect long-term nitrogen inputs from the surrounding land percolating into many of the receiving aquifers. Furthermore, elevated concentrations of nitrate-nitrogen have been found in groundwater in the Rotorua region and are mostly likely attributable to agricultural landuse (White et al. 2004). Finally, some water quality parameters such as anions and cations, hardness and temperature were more variable in rivers than springs. The higher variability in rivers may reflect different signatures coming from rainfall-derived water, and ground flow-derived water, where the former would dominate in rivers during times of high flow, and the latter would dominate in rivers more during times of low flow.

4.2   Invertebrate communities

The 15 springs sampled supported a relatively diverse array of invertebrates. The ubiquitous snail *Potamopyrgus antipodarum* numerically dominated (44%) the invertebrate communities at all sites. Small lymnaeids were the only other snail found in the springs but contributed less than 0.3% of total abundance. The low snail diversity contrasts with high snail diversity observed in north-west Nelson (e.g, Haase 2008). Part of this high snail diversity may reflect the many seepage habitats sampled by Haase, as these habitats are known for their diversity and specialised range of taxa that can inhabit them (Collier and Smith 2006). In contrast, the low snail diversity in the BOP may reflect legacy effects of historic volcanic eruptions which may have extirpated any locally endemic snails from the region.

Average taxonomic richness in the springs was lower than in first order streams in the region, as was the total numbers of taxa found in each habitat (129 taxa in streams, 72 taxa in springs). The lower taxonomic richness in springs was also reported in studies in the northern hemisphere (Davidson and Wilding 1943; Meffe and Marsh 1983; Anderson and Anderson 1995; Barquin and Death 2004). These results are different to findings of other New Zealand studies where springs supported more taxa than streams (Death 1995; Death et al. 2004; Barquin and Death 2006). Barquin and Death (2006) explained the higher invertebrate diversity in New Zealand springs by the presence of a more predatory invertebrates in New Zealand springs than in streams elsewhere in the world. They hypothesised that the higher predator diversity and numbers in New Zealand springs would lead to intraspecific competition between predators, thus relieving potential predation pressure on prey populations and consequently enhancing total invertebrate diversity in springs. However, the 15 Bay of Plenty spring sites studied supported a lower average diversity of predators (4.2 per site) than first-order streams in the region (7.6 per site). Furthermore, the average predator relative abundance was similar in springs (14%) and streams (10.5%). This suggests that the effects of predators in structuring invertebrate communities in these Bay of Plenty springs was not as apparent as it may have been in other New Zealand springs.

Another potential reason for the higher species diversity in springs observed by Barquin and Death (2006) relates to the common occurrence of bryophytes in the springs they studied. Bryophytes are widely recognised as providing beneficial environments for aquatic invertebrates (Suren 1991). In contrast to the springs examined by Barquin and Death, aquatic bryophyte occurrence in the Bay of Plenty springs sampled was low: indeed only two springs had bryophyte cover > 20% and bryophytes were absent from 6 of the sampled springs. Such low bryophyte cover reflects a lack of large stable substrates required for bryophytes growth, as many of the springs flowed over soft pumice streambeds, or the streambeds dominated by large gravels or small cobbles not large enough to support bryophyte growth. As such, any beneficial effects of aquatic bryophytes on increasing invertebrate biodiversity in springs would have been limited.

Invertebrate communities at a particular location are thought to reflect a combination of an individual's ability to firstly colonise the site, and secondarily be able to persist under favourable environmental conditions. The potential source of colonists for springs are thus three-fold: a) aerial dispersal of aquatic insects; b) upstream movement of insect and non-insect taxa from downstream areas; c) presence of non-insect taxa in the groundwater. This is somewhat different to the colonisation processes found throughout streams and rivers, where a fourth source of colonists exists in the form of downstream drift of individuals from upstream.

Downstream drift of invertebrates in streams and rivers is often thought of as a major behavioural mechanism behind insect colonisation patterns. Studies have shown that there are different types of drift exhibited by aquatic insects (e.g. Brittain and Eikeland 1987). These include:

- Catastrophic drift, where organisms are simply washed downstream during floods.

- Behavioural drift, where animals may accidentally enter the water column indirectly because of their normal activities, or they may choose to enter the water column to escape from predators.

- Distributional drift, which is used as a deliberate means of dispersal, particularly for young stages of insects soon after egg hatching.

Large densities of drifting invertebrates are common in streams, and this has been explained as one reason why invertebrate populations can recover relatively quickly after large flood events (e.g., Matthaei et al. 1997; Death 2008). However, this downstream drift is not available as a colonisation mechanism in springs due to a lack of an upstream source of colonists. This may also partially explain the lower species diversity observed in springs when compared to streams.

The ANOSIM analysis showed that both the location of the springs within each WMA and the stratigraphic unit explained some variation to the invertebrate communities. This implies the importance of biogeographic and geological factors in structuring invertebrate communities. Many of the common invertebrates in the springs such as snails, worms, flat worms, and amphipods would not be expected to have particularly strong dispersal abilities, and so their distributions are likely to reflect more chance colonisation processes. Furthermore, the "typical" downstream drift processes of aquatic insects found in streams simply cannot occur at these spring sources, which may explain why non-insect taxa dominated the invertebrate faunas of these springs.

A lack of significant statistical associations between invertebrate communities from the springs and physical habitat, water quality or spatial data suggests communities in these habitats to be largely independent of these variables. Barquin and Death (2006) also suggested that the invertebrate communities at specific sites may simply reflect local geomorphological history and the pool of potential colonists present. Their argument implies that invertebrate communities in springs may not be driven by major environmental drivers but based on random colonization events from the pool of available colonists. The lack of strong associations between invertebrate communities and measured environmental data supports Barquin and Death's argument.

Contrary to some overseas studies (e.g., Zollhofer 1999), the results from this study support findings from Scarsbrook and Haase (2003) that stock access did not significantly adversely affect the biodiversity of the springs sampled. However, in contrast to Scarsbrook and Haase (2003), we found no consistent evidence that local riparian conditions (immediate canopy cover) had any effect on the invertebrate communities (composition or abundance) in springs. This, may in part, reflect the ability of spring ecosystems to buffer against potential stressors associated with landuse changes by receiving a constant supply of clean, relatively cool groundwater.

To improve the health of the nation's freshwaters, the New Zealand Government developed the National Policy Statement for Freshwater Management (NPS-FM) 2020. Under the NPS-FM, a number of National Objective Framework (NOF) attributes have been identified to ensure the maintenance of healthy ecosystems. The NOF attributes define bands and minimum acceptable states (i.e. "national bottom lines") that councils must ensure are met to support ecosystem health. Our data shows that springs would score below the National Bottom line (attribute band D) for metrics such as MCI and QMCI, yet this may simply reflect natural processes. It is thus suggested the NPS-FM attribute bands are not accurate for assessing the ecological health of spring habitats, particularly when both the MCI and QMCI were developed from data derived from stream ecosystems (Stark 1985, Stark and Maxted 2007).

4.3   Adult aquatic insects

The use of the Malaise traps deployed at the spring sites provided some intriguing data on the biodiversity of the springs. Trapping of adults EPT enabled a greater taxonomic resolution, as almost captured insects, unlike the benthic juveniles, could be identified to species. Although the vast majority of EPT taxa identified in the study were not threatened, a caddisfly (*Paroxyethira hintoni*) and two mayfly species (*Zephlebia tuberculata* and *Z. nebulosa*) are regarded as "naturally uncommon" by Grainger et al. (2018). *Paroxyethira hintoni* was found at two sites (RAN_404 and TRG_9) separated by 93km. *Zephlebia tuberculata* was also found at two sites (KMP_128 and KMP_143) separated by 13 km apart. Insufficient Malaise trapping has been done in other parts of the region to determine whether these discrete locations represent parts of a larger, well-connected population, or a more fragmented population structure. Lack of this basic ecological knowledge has implications for interpreting biodiversity assessments in the region and of assessing the effectiveness of riparian planting programmes, as we don't know whether the absence of a species from a location reflects natural processes or is due to anthropogenic stressors such as the historic loss of riparian vegetation.

A small number of male *Paroxyethira* found at RAN_404 could not be accurately assigned to any of the known species, but most closely resembled *P. hughwilsoni*, endemic to the South Island. Both the *Paroxyethira* and the indeterminant hydropsychid from KMP_244 could equally represent a new species of caddisflies. The taxonomic status of these two caddisflies will require the capture of more specimens, and a more detailed investigation that is currently outside the scope of this report.

Finding three naturally uncommon species, plus two potentially new species highlights the biodiversity values of springs, and the importance of targeting multiple life-history stages using techniques such as Malaise traps, light traps or sticky traps when undertaking biodiversity surveys. Such studies may provide further evidence of new populations of disjunct species and may help explain distributional patterns over differing landuse and large geographical scales. This is particularly pertinent when considering the lack of observed patterns between the adult EPT data and environmental factors considered in this study. An alternative to using traditional taxonomic approaches for biodiversity surveys is the use of eDNA, which is routinely able to identify organisms to species level from DNA fragments collected in water. This method has successfully been used for freshwater fish surveys in New Zealand (David et al. 2021), but more work is required to increase the known genetic library upon which species identifications are made.

4.4   Aquatic bryophytes

In a survey of bryophyte distributions throughout the South Island, Suren (1996) examined the effects of macroscale (e.g., catchment land use, geology), mesoscale (e.g., flood frequency and water quality) and microscale variables (e.g., substrate size, water flow type, streambed stability and stream slope). He found that microscale variables were mostly responsible for presence of bryophytes within streams, and bryophytes were generally absent from low gradient streams dominate by unstable and small substrates. A similar finding was observed in the springs sampled in this report, as aquatic bryophytes were only found on large stable substrates such as bedrock, boulders and cobbles, or stable concrete structures within the springs. As expected, bryophytes were absent from shallow gradient springs dominated by fine, highly mobile substrates such as pumice or gravel.

Suren (1996) also found that bryophyte distribution patterns were regulated by macroscale and mesoscale variables and showed that mosses were more common in catchments with some catchment land use modification and in streams with higher phosphorus content, while liverworts were generally in catchments dominated by native

vegetation, and in lower nutrient water. No such clear demarcation was observed in this study, as mosses were the most common bryophyte found in all but two springs. Bryophytes are important habitats for stream invertebrates (Stream Bryophyte Group 1997), representing highly stable environments where organisms can find shelter from high velocities and shear stress (Nikora et al. 1998), and where food resources such as trapped detritus or periphytic algae are enhanced (Suren 1992). Given their importance to invertebrates, some association was expected between the invertebrate community composition and bryophytes. However, a RELATE analysis of both invertebrate and bryophyte community composition showed no significant statistical patterns. There were also no statistically significant differences detected between invertebrate taxon richness, or the relative abundance of insects between streams with, and without bryophytes. This was somewhat surprising, as Suren (1991, 1993) found that insect taxa were often the dominant invertebrate group found within bryophytes. One possible reason for the lack of any apparent relationship between invertebrates and bryophytes is that flood disturbance in the springs would be very low, and so any gains from additional shelter within bryophytes would not be as great. Another reason could also simply reflect the fact that bryophyte cover in most of the springs was relatively low in proportion to the total area of streambed, and thus these plants did not represent particularly large habitats.

Part 5:
Conclusions/Whakakapinga

This study was done as part of a programme to enhance our knowledge of springs in the region, including the volume of water discharging from the spring, and water quality emerging from the spring (Green 2018, 2022). In particular, it was designed to better characterise the ecological conditions within springs, including water chemistry, invertebrates and bryophytes.

Given their location at the interface of groundwater, surface water and terrestrial ecosystems, springs are arguably more at risk from human activities than streams, which are affected mainly by activities either within the stream, or surrounding landuse. However, because springs are so intimately linked to their groundwater resource, any activities that are using this resource will also potentially place springs (and their associated ecosystems) under increasing pressure.

This study suggested that historic volcanic activity has had a major influence on contemporary water quality conditions in springs, which clearly reflected underlying geological differences. Water chemistry also differed greatly between springs and rivers. For example, springs had higher total N and nitrate nitrite-N than rivers which may be attributable to long-term nitrogen inputs from the surrounding land percolating into the parent aquifer. This finding emphasises the strong links between springs and their aquifers, which in turn can be affected by agricultural land use anywhere in the aquifers contributing catchment. However, unlike surface water quality, changes in the water quality of aquifers may be much slower, reflecting potentially large lag times between landuse change and observed elevated concentrations of nutrients in spring waters. Because these changes occur over many years, any alteration to aquifer water chemistry from human activities have the potential for long lasting ecosystem effects, given the slow rate at which changes in aquifer water chemistry can occur.

Despite their small size, springs supported a relatively diverse array of invertebrates, numerically dominated by snails, insects, and aquatic mites. Their community composition was very different to that of first order streams as they had a lower taxonomic richness, and their communities were dominated by non-insect taxa. Community composition also differed between springs within each WMA and was controlled to some extent by the stratigraphic unit of the underlying aquifer. However, no significant association was observed between the invertebrate communities and physical habitat, water quality or the spatial data in the spring sampled. This implies that benthic invertebrate communities within individual springs may simply reflect the local geomorphological history and the pool of potential colonists present within their local vicinity.

Accurate species-level identification and assignment of conservation threat classifications of almost all aquatic insects require the examination of adult reproductive structures. The Malaise trapping of adult aquatic insects at the spring sites provided a greater taxonomic resolution (and means of identifying new species) than could be achieved using benthic data alone. Consequently, the biodiversity values of the springs were further enhanced as three "Nationally Uncommon" aquatic insects as well as a potential new species of caddisfly were captured, further highlighting the importance of collecting adults. The implementation of environmental DNA (eDNA) based methods are becoming more commonly applied in species detection. It is suggested the implementation of eDNA collection in future or ongoing spring studies will compliment traditional bioassessment techniques. These data will provide comparative as well as additional ecologically information to assist with informed management decisions both for detecting threatened or rare (or cryptic) species and wider ecosystem health.

In summary, springs represent unique ecosystems, with only a relatively low degree of similarity between them, and a fauna that is distinctive to that of streams. Any large changes to springs in terms of alterations to groundwater chemistry or flow are thus likely to have potentially large consequences to local biodiversity values within the region.

Part 6:
References/Ngā Tohutoro

Allison, K. W., & Child, J. (1971). The mosses of New Zealand. Dunedin: University of Otago Press.

Allison, K. W., & Child, J. (1975). The liverworts of New Zealand. Dunedin: University of Otago Press.

Anderson, T.M., & Anderson, N.H. (1995). The insect fauna of spring habitats in Sydney arid rangelands in central Oregon. *Journal of the Kansas Entomological Society, 68,* 65-76.

Barquin, J., & Death, R. G. (2004). Patterns of invertebrate diversity in streams and freshwater springs in northern Spain. *Archiv für Hydrobiologie 161,* 329-349

Barquin, J., & Death, R. G. (2006). Spatial patterns of macroinvertebrate diversity in New Zealand springbrooks and rhithral streams. Journal of the North American Benthological Society, 25, 768-786.

Beever, J. E., Allison, K. W., & Child, J. (1992). The mosses of New Zealand (2nd ed.). Dunedin: University of Otago Press.

Beever, J. E., & Stone, I. G. (1999). Studies of *Fissidens* (Bryophyta: Musci): new taxa and records for New Zealand. *New Zealand Journal of Botany, 37*, 643-657.

Brittain, J. E., & Eikeland, T. J. (1988). Invertebrate drift - a review. *Hydrobiologia, 166*, 77-93

Clarke, K., & Gorley, R. (2001). PRIMER v5: User Manual / Tutorial. Plymouth: PRIMER-E.

Collier, K., & Smith, B. J. (2006). Distinctive invertebrate assemblages in rockface seepages enhance lotic biodiversity in northern New Zealand. *Biodiversity and Conservation, 15*, 3591-3616

Cowie, B., & Winterbourn, M. J. (1979). Biota of a subalpine springbrook in the Southern Alps. *New Zealand Journal of Marine and Freshwater Research, 13*, 295-301.

David, Bruno, O, Daniel R. Fake, Andy S. Hicks, Shaun P. Wilkinson, Michael Bunce, Josh S. Smith, David W. West, Katie E. Collins & Dianne M. Gleeson (2021): Sucked in by eDNA – a promising tool for complementing riverine assessment of freshwater fish communities in Aotearoa New Zealand, New Zealand Journal of Zoology, DOI: 10.1080/03014223.2021.1905672

Davidson, F.A., & Wilding, J.L. (1943). A quantitative a formal investigation of a cold spring community. *American Midland Naturalist 29*, 200-209

Death, R. G. (1995). Spatial patterns in benthic invertebrate community structure: products of habitat stability or are they habitat specific? *Freshwater Biology, 33*, 455-467.

Death, R.G. (2008). The effect of floods on aquatic invertebrate communities. Aquatic Insects: Challenges to Populations. p103-121.

Death, R. G., Barquin, J., & Scarsbrook, M. (2004). Chapter 30. Biota of cold water and geothermal springs. In J. Harding, M. P. Mosley, C. P. Pearson, & B. K. Sorrell (Eds.), Freshwaters of New Zealand. Christchurch: The Caxton press.

Donath, F. M., Daughney, C. J., Morgenstern, U., Cameron, S. G., & Toews, M. W. (2015). Hydrochemical interpretation of groundwater-surface water interactions at catchment and local scales, Lake Rotorua catchment, New Zealand. *Journal of Hydrology New Zealand*, *54*, 11–32.

Duncan, M. J., Suren, A. M., & Brown, S. L. R. (1999). Assessment of streambed stability in steep, bouldery streams: development of a new analytical technique. *Journal of the North American Benthological Society, 18*, 445-456

Green, M. (2018). Interim summary of spring survey and monitoring in the Bay of Plenty. Bay of Plenty Regional Council internal report 2018/02. Whakatāne. 38p.

Green, M. (2022). Spring survey and sampling programme in the Bay of Plenty Region – Intermediate Report. Bay of Plenty Regional Council Environmental Publication 2022/06. 162p.

Haase, M. (2008). The radiation of hydrobiid gastropods in New Zealand: a revision including the description of the new species based on the morphology and mtDNA sequence information. *Systematics and biodiversity, 6*, 99-159.

Johnstone, I. M. (1972). Limnology of Western Springs, Auckland, New Zealand. *New Zealand Journal of Marine and Freshwater Research, 6*, 298-328.

Legendre, P. and L. Legendre, 1998. Numerical Ecology. Elsevier, Amsterdam, The Netherlands.

Lerner, D. N., & Harris, B. (2009). The relationship between land use and groundwater resources and quality. *Land use policy, 265*, 5265-5273.

Marshall, J. W. (1973). A benthic study of the Avon Spring Stream, Christchurch. *Mauri Ora, 1*, 79-90.

Matthaei, C. D., Uehlinger, U., & Frutiger, A. (1997). Response of benthic invertebrates to natural versus experimental disturbance in a Swiss pre-Alpine River. *Freshwater Biology, 37*, 61-77.

Meffe, B.A., & Marsh, P.C. (1983). Distribution of aquatic macroinvertebrates in three Sonaran Desert Springbrooks. *Journal of arid environments 6*,363-371.

Michaelis, F. B. (1976). Physicochemical features of Pupu springs. *New Zealand Journal of Marine and Freshwater Research, 10*, 317-325.

Michaelis, F. B. (1977). Biological features of Pupu Springs. *New Zealand Journal of Marine and Freshwater Research, 11*, 357-373.

Nikora, V. I., Suren, A. M., Brown, S. L. R., & Biggs, B. J. F. (1998). The effects of the moss *Fissidens rigidulus* (Fissidentaceae: Musci) on near- bed flow structure in an experimental cobble bed flume. *Limnology and Oceanography, 43*, 1321-1331.

Parkyn, S. M., & Collier, K. (2004). Into action of the press and pulse disturbance on crayfish populations: flood impacts in pasture and forest streams. *Hydrobiologia, 527*, 113-124.

Scarsbrook, M. R., et al. (2007). New Zealand cold water springs and their biodiversity. Wellington, Department of conservation. *Science for conservation 278*: 279pp.

Scarsbrook, M., & Haase, M. (2003). Invertebrate diversity patterns in lowland springs: regional comparison and effects of stock access. NIWA consultancy report number HAM2003 – 104. 38p.

Scott, G. A. M. (1985). Southern Australian Liverworts. Candberra: Australian Government Publishing Service.

Snelder, T., & Biggs, B. J. F. (2002). Multiscale river environment classification for water resources management. *Journal of the American Water Resources Association, 38*, 1225-1239.

Stark J.D. (1985) A Macroinvertebrate Community Index of Water Quality for Stony Streams. Water & Soil Miscellaneous Publications, 87, 1-53.

Stark, J. D., & Maxted, J. R. (2007). *A user guide for the macro invertebrate community index.* Cawthron Report No 1166. Prepared to the Ministry for the Environment. 58p.

Stream Bryophyte Group (1997). Roles of bryophytes in stream ecosystems. *Journal of the North American Benthological Society, 18*, 151-184.

Suren, A. M. (1991). Bryophytes as invertebrate habitat in two New Zealand alpine streams. *Freshwater Biology, 26*, 399-418.

Suren, A. M. (1992). Enhancement of invertebrate food resources by bryophytes in New Zealand alpine headwater streams. *New Zealand Journal of Marine and Freshwater Research, 26*, 229-239.

Suren, A. M. (1993). Bryophytes and associated invertebrates in first-order alpine streams in Arthur's Pass, New Zealand. *New Zealand Journal of Marine and Freshwater Research, 27*, 479-494.

Suren, A. M. (1996). Bryophyte distribution patterns in relation to macro, meso, and micro-scale variables in South Island streams. *New Zealand Journal of Marine and Freshwater Research, 30*, 495-517.

Sutherland, D. (2005). Phylogeography and ecology of New Zealand freshwater Amphipoda. (Ph.D. thesis). University of Waikato, Waikato.

Russell, W. J., & Rodgers, K. A. (1977). Waters of the Western Springs catchment, Auckland. *New Zealand Journal of Marine and Freshwater Research, 11*, 713-728.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., & Cushing, C. E. (1980). The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences, 37*, 130-137.

Wilding, T. K. (2002). Minimum flow report for streams of the Kaimai Area. Environment Bay of Plenty. Environmental publication 2002/05. Whakatāne. 46p.

Winterbourn, M. J., Gregson, K. L. D., & Dolphin, C. H. (2006). Guide to the aquatic insects of New Zealand. *Bulletin of the Entomological Society of New Zealand, 14*, 1-108.

White, P. A., Cameron, S. G., Kilgour, G., Mroczek, E., Bignall, G., Daughney, C., & Reeves, R. R. (2004). Review of groundwater in the Lake Rotorua catchment. Prepared for Environment Bay of Plenty. Institute of geological and nuclear sciences, Wellington. Report number 20014/130 231p.

Young, R. G., Strickland, R., Harding, J. S., & Hayes, J. (1999). The ecology of Spring Creek - Awarua. Cawthron Report 611. Prepared for Marlborough district Council and fish and game in New Zealand. Cawthron Institute, Nelson. 52p.

Zollhoefer, J. M. (1999). Spring biotypes in northern Switzerland: habitat heterogeneity, zoobenthic communities and colonisation dynamics. (Ph.D. thesis). Zurich.