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The Effects of Water Supply Intakes on Macroinvertebrate Communities in the Waikato Region during Summer 2008

Matatoki Stream downstream of water intake weir, February 2008

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Table of contents

List of figures

List of tables

Executive summary

As an extension of a previous study in summer 2006-2007, we sampled macroinvertebrates from small, stony streams above and below water intakes in predominantly native forest catchments in mid-February 2008.

The previous study had found that with a few exceptions, water takes at these sites had little impact on stream macroinvertebrate communities over the summer low flow period. However, there was a rainfall event prior to the second sampling that may have influenced this finding. This study compares the new data (February 2008) to that collected in December the previous summer (2006).

Sites downstream of water takes generally had lower water velocity, depth and wetted width than upstream sites at the time of sampling, but this varied considerably among streams.

Decreases in flow had little or no effect on spot measurements of water temperature, conductivity, pH or dissolved oxygen. There was no overall consistent response of chlorophyll *a* concentrations to water abstraction in either December 2006 or February 2008, but variable differences between upstream and downstream sites in individual streams.

There was no consistent relationship between the volume of water removed and upstream-downstream changes to invertebrate density, number of taxa, percentages of Ephemeroptera, Plecoptera and Trichoptera taxa and individuals, MCI or QMCI relative to December 2006. The greatest changes to invertebrate metrics were seen in two streams that had some of the largest abstractions. However, another stream with an equally large abstraction showed minimal change to the invertebrate community between upstream and downstream, and significant changes to the invertebrate community were observed in a stream with a small take.

Despite minimal changes to invertebrate density downstream of water takes, declining wetted widths suggest that the overall abundance of benthic invertebrates would have decreased at the reach scale.

The impact of water removal on small, stony streams in forested catchments appears to be site specific, making it difficult to predict its effect on benthic macroinvertebrates based solely on abstraction volume.

1 Introduction

Water is removed from streams for a variety of reasons, including domestic water supply and irrigation. The demand to take water from streams increases during the summer period, when many New Zealand waterways are at their lowest flow. Taking water from streams can extend the severity and duration of the low flow period, and result in numerous changes to the instream environment and physical habitat, such as reduced wetted width, decreased water velocities, and decreased depths (Dewson et al. 2007a). These hydrological changes might have a negative impact on aquatic life and water quality (Jackson et al. 2001), by altering the characteristics and availability of instream habitat for invertebrates (Statzner & Higler 1986, Hart & Finelli 1999).

Changes to invertebrate community abundance, diversity or composition could indicate that water takes are having an impact on the stream ecosystem. Reduced flows can result in reduced taxonomic richness if habitat diversity decreases with decreasing discharge (e.g., Cazoubon & Giudicelli 1999, McIntosh et al. 2002), or if there are changes in the quality of the habitat (Wood & Armitage 1999, Wood et al. 2000). Invertebrate densities may respond either positively or negatively to reduced discharge (e.g., Englund & Malmqvist 1996, McIntosh et al. 2002, Dewson et al. 2007a), and some studies have noted that invertebrate responses to water abstractions vary between streams (Castella et al. 1995, Rader & Belish 1999, Suren et al. 2003, Dewson et al. 2007b).

Sites upstream and downstream of existing water abstractions, in catchments dominated by native forest cover, were sampled in early summer and again at the end of summer 2006-2007, to assess the influence of these water takes on forested stream ecosystems over the summer period (Dewson & Death 2007). Results of this study showed that despite decreases in velocity, depth and wetted width at downstream sites, invertebrate community composition, density, number of taxa, and the percentages of Ephemeroptera, Plecoptera and Trichoptera (EPT) individuals and taxa (excluding Hydroptilidae), remained fairly similar for most of the streams studied (Dewson & Death 2007). Flow in all streams was low during December 2006, but substantial rainfall during January and early February 2007 interrupted the expected summer low flow period and this may have reduced the observed effects of water takes on these streams (Dewson & Death 2007).

In mid-February 2008, we returned to the sites sampled the previous summer to investigate the effects of water abstraction on the same streams during a low flow season that was not interrupted by significant rainfall. It was expected that water abstractions would exacerbate the natural low flow conditions in these streams and there would be a greater effect on invertebrate and periphyton communities than was observed the previous summer. We expected that changes to flow characteristics downstream of water abstractions, such as lowered water velocity and depth, and decreased wetted channel width would decrease habitat availability and suitability at downstream sites, resulting in lower benthic invertebrate taxonomic richness or density, and lower water quality as measured by invertebrate community metrics. These changes to habitat characteristics were common in our previous study of these streams, but did not result in substantial changes to the invertebrate community sampled in the summer of 2007, although the decrease in wetted width would imply that there was a decline in invertebrate abundance at the reach-scale (Dewson & Death 2007).

2 Methods

2.1 Study sites

To assess the influence of water abstractions during the 2008 summer, we revisited sites that had previously been sampled for invertebrates and periphyton during the summer of 2007 (Dewson & Death 2007). These sites were upstream and downstream of water abstractions on ten small forested streams. The streams were Pepe Stream (Tairua, Plate 1), Oturu Stream (Tairua, Plate 2), Mangarehu Stream (Thames, Plate 3), Matatoki Stream (Waihou, Plate 4), Omahu Stream (Waihou, Plate 5), Waitete Stream (Waihi, Plate 6), Walmsley Stream (Waihi, Plate 7), Mangauika Stream (Pirongia, Plate 8), Pohomihi Stream (Te Aroha, Plate 9) and Pohomihi Stream tributary (Te Aroha, Plate 10). The study streams are all small, relatively pristine, riffle-pool streams, used for municipal and rural water supply. They were all between 3 and 14 m wide (total channel width), with average velocities between 0.24 and 0.59 m/s at upstream control sites (Table 1). The specific conductivity of the water in these streams was between 65 and 300 μS/cm during the 2008 sampling visit (Appendix 1). At each site, the channel was partially shaded, with native trees and shrubs in the riparian zone. In each stream, weirs separated upstream and downstream sites, and the streams utilised a diversity of water collection structures (Plates 10-16). The volume of water abstracted from each of the streams varies over time depending on demand (Appendix 3). In some streams, water takes cease completely when stream flow drops below a certain level and alternative water supplies are used (e.g., Mangarehu Stream and Waitete Stream). Pohomihi Stream and tributary feed a storage dam. At times when the water in the dam is being drawn down at this site it may appear abstraction is greater than discharge but this not necessarily causing severe low flows in the stream itself.


Plate 1. Pepe Stream (Tairua), upstream (right) and downstream (left) of the water intake.

Plate 2. Oturu Stream (Tairua), upstream (top) and downstream (bottom) of the water intake.


Plate 3. Mangarehu Stream (Thames), upstream (right) and downstream (left) of the water intake.

Plate 4. Matatoki Stream (Waihou), upstream (left) and downstream (right) of the water intake weir.

Plate 5. Omahu Stream (Waihou), upstream (left) and downstream (right) of the water intake weir.

Plate 6. Waitete Stream (Waihi), upstream (left) and downstream (right) of the water intake weir.

Plate 7. Walmsley Stream (Waihi), upstream (top) and downstream (bottom) of the water intake weir.

Plate 8. Mangauika Stream (Pirongia), upstream (top) and downstream (bottom) of the water intake weir.

Plate 9. Pohomihi Stream (Te Aroha), upstream (top) and downstream (bottom) of the water intake weir.

Plate 10. Pohomihi Stream tributary (Te Aroha) upstream (left) and downstream (right) of the water intake structure.

Plate 11. Weir structure at Mangarehu Stream (Thames).

Plate 12. Pepe Stream (Tairua). The water intake structure is marked with a red arrow.

Plate 13. Weir structure at Walmsley Stream (Waihi). Photo taken looking upstream.

Plate 14. Weir structure at Mangauika Stream (Pirongia). Note the fish pass at the far bank.

Plate 15. Weir structure at Matatoki Stream (Waihou).

Plate 16. Weir structure at Oturu Stream (Tairua).

2.2 Survey design

Each site was sampled in early summer (December 2006), in March 2007, and again towards the end of the following summer (February 2008) in the Waikato Region. This report compares the pre-summer 2006 condition with the 2008 summer low flow conditions (see Dewson & Death 2007 for comparison of December 2006 and March 2007 data). Hydrographs for each site were developed from regressions with nearby flow monitoring sites and are presented along with daily water take data and Q5 discharges in Appendix 3. Samples were collected from riffle habitat, within a 50 m long study reach at each site. Study reaches were generally located within 100 m upstream or downstream of the weir on each stream, however, our priority was to select sites that were outside the direct influence of the weir (e.g., pooling above and below the weir, sharp changes in gradient, bedrock at weir sites). Our sampling focused on riffles, as they were the dominant habitat type in these streams. We expected that this habitat type would be most sensitive to water abstraction, since at very low flows, riffles may dry completely, leaving a series of isolated pools (Gordon et al. 2004).

One drawback of investigating the effects of existing water intakes on the instream environment and invertebrate communities, is that affected sites must necessarily be located downstream of the water removal, with control sites upstream. This complicates the results, since changes unrelated to the water abstraction could also occur between sites. Changes to invertebrate communities between upstream and downstream sites could result from changes in land usage between the sites. To avoid this confounding variable, upstream and downstream sites in this study were located in pristine forested catchments. We also visually selected upstream and downstream sites for their similarity in terms of gradient, substrate size, and proportion of habitat types available (i.e., pool/riffle/run).

2.3 Sampling protocols

In December 2006, specific conductivity, dissolved oxygen and pH were measured on each occasion using a YSI Incorporated multi-probe system instrument (YSI 556 MPS) (YSI Incorporated, Yellow Springs, OH, U.S.A.). The same variables were measured in February 2008, using ExStik II handheld meters (EC500 and DO600, Extech Instruments, Waltham, MA, U.S.A.). We measured the wetted width and total width (to edge of active channel/bank full width) of the channel at 11 locations at 5-m intervals along the 50 m study reach at each sampling, and recorded the habitat type at each cross section (i.e., pool, run, riffle). We used regular intervals for these measurements to get an idea of the loss of wetted width in proportion to the amount of each habitat type in the stream.

In December 2006, we assessed the percentage cover of each substrate size category (bedrock, boulder, cobble, gravel, sand, silt) by measuring and categorising 50 substrate elements, selected using the Wolman walk method (Wolman 1954). A habitat score was also calculated for each site (Collier & Kelly 2005).

At each site, five Surber samples (500 μm mesh, area = 0.1 m^2) were collected within riffle habitat and preserved with 10% formalin (December, 2006) or 90% iso-propyl alcohol (February, 2008) until processing. Water velocity and depth were recorded for each sample location. Water velocity was measured using a timed float. Discharge, abstraction and Q5 statistic data was provided by Environment Waikato.

In the laboratory, samples were rinsed through a 500 μm Endecott sieve and invertebrates were sorted and identified using the keys of Winterbourn (1973), Winterbourn et al. (2000) and Smith (2003).

We collected one stone (< 60 mm, a-dimension) adjacent to each Surber sample for periphyton biomass analysis. Samples were transported on ice in the dark and stored at minus 20°C until analysis. Photosynthetic pigments were extracted from cobbles by submerging them in 90% acetone for 24 hours at 5°C. Absorbance was read at 750, 665 and 664 nm on a Varian Cary 50 Conc. UV-Visible spectrophotometer™ before and after 0.1M HCl was added. The amount of chlorophyll *a* ($\mu g/cm^2$) was calculated for each cobble as described by Steinman & Lamberti (1996) and corrected for stone surface area, calculated using the length, width and depth of each cobble (Graham et al. 1988).

2.4 Data analysis

One-way analysis of variance (ANOVA) was used to examine differences in spot measures of temperature and chemical variables between sites upstream and downstream of water intakes during February 2008 using STATISTIX 8 (Analytical Software, Tallahassee, FL). Each stream was a replicate in this analysis.

We calculated invertebrate density, number of taxa, and the percentage of Ephemeroptera, Plecoptera and Trichoptera (% EPT) individuals and taxa (Lenat 1988), excluding Hydroptilidae (Boothroyd & Stark 2000). We also calculated the Macroinvertebrate Community Index (MCI) (Stark 1985) and the Quantitative Macroinvertebrate Community Index (QMCI) (Stark 1985) for each sample to describe the invertebrate communities, although this index was not specifically designed to assess the effects of water abstraction. Two-way analysis of variance (ANOVA) was used to examine differences in these invertebrate community indices and the chlorophyll *a* concentrations of periphyton between sites upstream and downstream of water intakes on each stream using STATISTIX 8. In this before-after (BA), control-impact (CI) design, treatment factors were sampling occasion (early and late summer, before and after the highest water use period) and upstream/downstream of abstraction (control-impact). In this case, both the control-impact (CI) and BA×CI interaction terms in this model can be used as tests for the impact of flow reduction. All factors were treated as fixed effects, since sites and times were chosen, not a random selection of all possible options. We used the five samples taken from each site as replicates for this analysis.

We calculated the average abundance of each invertebrate taxon on each sampling occasion for upstream and downstream sites on each of the ten streams. These data were fourth-root transformed to reduce the importance of abundant taxa. Non-metric multi-dimensional scaling (MDS) was carried out using the Bray Curtis similarity measure and we used analysis of similarities (ANOSIM) to test the differences between upstream and downstream groups on each sampling occasion for all streams using PRIMER (Clarke & Gorley 2006).

Water take data (% of discharge abstracted) was obtained and regressed against percentage change of the invertebrate metrics (no. of taxa, no. of individuals, %EPT individuals, %EPT taxa, MCI, QMCI) and percent similarity of upstream and downstream communities (calculated in PRIMER). The two Pohomihi sites were excluded, as the water take data for these streams was combined and could not be related directly to each site. Water take data was unavailable for Mangauika Stream.

3 Results

3.1 Physicochemical characteristics

Mean water velocities decreased downstream in eight of ten streams in December 2006 and five of ten streams in February 2008 (Table 1). Mean water depths and wetted widths were lower at downstream sites on most streams on both sampling occasions (Table 1). The percentage decreases in velocity, depth and wetted width between upstream and downstream sites varied considerably among the ten streams, but in two-thirds, values decreased downstream by at least 10% (Table 1). The mean percentage change for velocity, depth and wetted width all indicated a decrease downstream, and changes were greater in February than December (velocity: Dec -20%, Feb -25%; depth: Dec -12%, Feb -24%; wetted width: Dec -17%, Feb -23%). All streams retained flowing water habitats at the time of sampling, with mean velocities ranging from 0.08 m/s to 0.50 m/s at downstream sites, compared to a range of 0.19 m/s to 0.79 m/s at sites upstream of water intakes (Table 1).

There were no differences to spot measures of conductivity ($F_{1, 18}$ = 1.05, p = 0.32), pH ($F_{1, 18}$ = 1.67, p = 0.21) or temperature ($F_{1, 18}$ = 0.28, p = 0.60) between upstream and downstream sites on these streams during February 2008. Spot temperatures, specific conductivity and pH tended to be higher in February 2008 at most sites compared to December 2006 (Appendix 1). Dissolved oxygen was significantly greater upstream of water takes ($F_{1, 18}$ = 4.65, p = 0.04).

Substrate size was the same in February and December, but there was an increase in coarse and fine organic material in February 2008 at many of the sites (compare Appendix 2 with that of Death & Dewson 2007).

Table 1: **Mean velocity (*n* = 5), depth (*n* = 5) and wetted width (*n* = 11 or 13) at sites upstream and downstream of water intakes in ten streams in the Waikato Region in December 2006 and February 2008 (± 1 SD). Percentage changes in these variables from upstream to downstream sites are shown in red (decreases) and blue (increase or no change).**

	Stream	**Oturu**	**Pepe**	**Omahu**	**Mangarehu**	**Waitete**	**Walmsley**	**Matatoki**	**Pohomihi**	**Pohomihi trib.**	**Mangauika**
Velocity	Dec 2006 upstream (m/s)	0.31±0.22	0.36±0.18	0.79±0.07	0.31±0.14	0.38±0.22	0.19±0.05	0.38±0.19	0.61±0.14	0.52±0.12	0.49 ± 0.20
	Dec 2006 downstream (m/s)	0.38±0.26	0.31±0.13	0.50±0.19	0.20±0.06	0.17±0.12	0.26±0.16	0.32±0.16	0.30±0.17	0.32±0.12	0.48 ± 0.29
	% change	22	-14	-37	-36	-56	32	-18	-51	-38	-3
	Feb 2008 upstream (m/s)	0.31±0.12	0.36±0.12	0.38±0.11	0.37±0.08	0.29±0.09	0.29±0.09	0.26±0.09	0.34±0.02	0.38±0.07	0.50 ± 0.09
	Feb 2008 downstream (m/s)	0.36±0.05	0.39±0.12	0.44±0.09	0.45±0.13	0.10±0	0.31±0.07	0.08±0.04	0.17±0.07	0.15±0	0.13 ± 0.10
	% change	14	9	14	22	-65	5	-69	-49	-61	-74
Depth	Dec 2006 upstream (m)	0.15±0.04	0.12±0.04	0.12±0.01	0.18±0.06	0.14±0.04	0.15±0.06	0.11±0.02	0.17±0.03	0.10±0.02	0.20 ± 0.05
	Dec 2006 downstream (m)	0.21±0.05	0.13±0.04	0.16±0.03	0.12±0.04	0.08±0.05	0.10±0.03	0.11±0.03	0.11±0.02	0.08±0.02	0.12 ± 0.03
	% change	39	10	30	-34	-41	-32	2	-39	-16	-41
	Feb 2008 upstream (m)	0.21±0.06	0.15±0.02	0.14±0.02	0.22±0.06	0.16±0.09	0.12±0.04	0.13±0.04	0.17±0.04	0.12±0.06	0.20 ± 0.02
	Feb 2008 downstream (m)	0.23±0.04	0.14±0.05	0.17±0.03	0.16±0.05	0.09±0.02	0.12±0.05	0.08±0.03	0.08±0.02	0.04±0	0.13 ± 0.03
	% change	9	-5	16	-26	-46	3	-40	-52	-69	-33
Wetted width	Dec 2006 upstream (m)	8.92±1.50	8.46±1.27	8.24±2.40	4.22±1.14	2.08±0.83	3.55±0.45	3.91±1.55	6.10±1.36	1.92±0.57	6.97 ± 1.37
	Dec 2006 downstream (m)	6.79±0.94	5.80±0.89	4.60±0.90	4.35±2.01	2.16±1.34	4.13±1.06	3.50±1.16	4.51±2.46	1.40±0.39	4.63 ± 1.18
	% change	-24	-31	-44	3	4	16	-10	-26	-27	-34
	Feb 2008 upstream (m)	8.15±1.62	6.78±1.10	7.76±2.96	5.63±3.20	1.80±0.53	3.20±0.59	3.27±1.45	4.38±1.37	1.81±0.55	6.55 ± 1.51
	Feb 2008 downstream (m)	6.52±0.82	6.08±1.45	5.80±1.37	4.54±1.45	1.60±0.86	3.82±0.97	1.84±0.83	2.77±1.11	1.19±0.45	3.30 ± 1.40
	% change	-20	-10	-25	-19	-11	19	-44	-37	-34	-50

3.2 Periphyton biomass

Mean chlorophyll *a* concentrations did not consistently increase or decrease downstream of water intakes compared to upstream sites in these ten streams (Table 2, Fig. 1). Periphyton biomass was greater in late summer than early summer in Mangarehu, Mangauika, Omahu, Walmsley and Pepe streams. Only Matatoki and Oturu streams had significantly greater periphyton biomass downstream of the water takes (Appendix 4). The mean percentage change showed an overall increase in chlorophyll *a* at downstream sites with this being greater in February 2008 (34%) than in December 2006 (17%).

Table 2: Mean chlorophyll *a* concentration of periphyton on cobbles (n = 5) collected from sites upstream and downstream of water intakes on ten streams in the Waikato Region in December 2006 and February 2008.

	December 2006		February 2008	
	Upstream ($\mu g/cm^2$)	Downstream ($\mu g/cm^2$)	Upstream ($\mu g/cm^2$)	Downstream ($\mu g/cm^2$)
Oturu	1.24	2.10	1.50	4.42
Pepe	2.67	1.35	7.40	3.13
Omahu	3.21	3.23	9.57	6.07
Mangarehu	0.63	0.69	1.50	2.08
Waitete	2.69	3.79	3.08	4.43
Walmsley	1.55	1.54	4.38	2.86
Matatoki	2.10	5.05	2.65	6.98
Pohomihi	1.33	1.41	1.91	1.80
Pohomihi trib.	4.71	2.76	3.93	4.82
Mangauika	1.42	1.32	2.56	2.95
Mean ± 1 S.D.	2.15 ± 1.20	2.32 ± 1.36	3.85 ± 2.67	3.95 ± 1.70

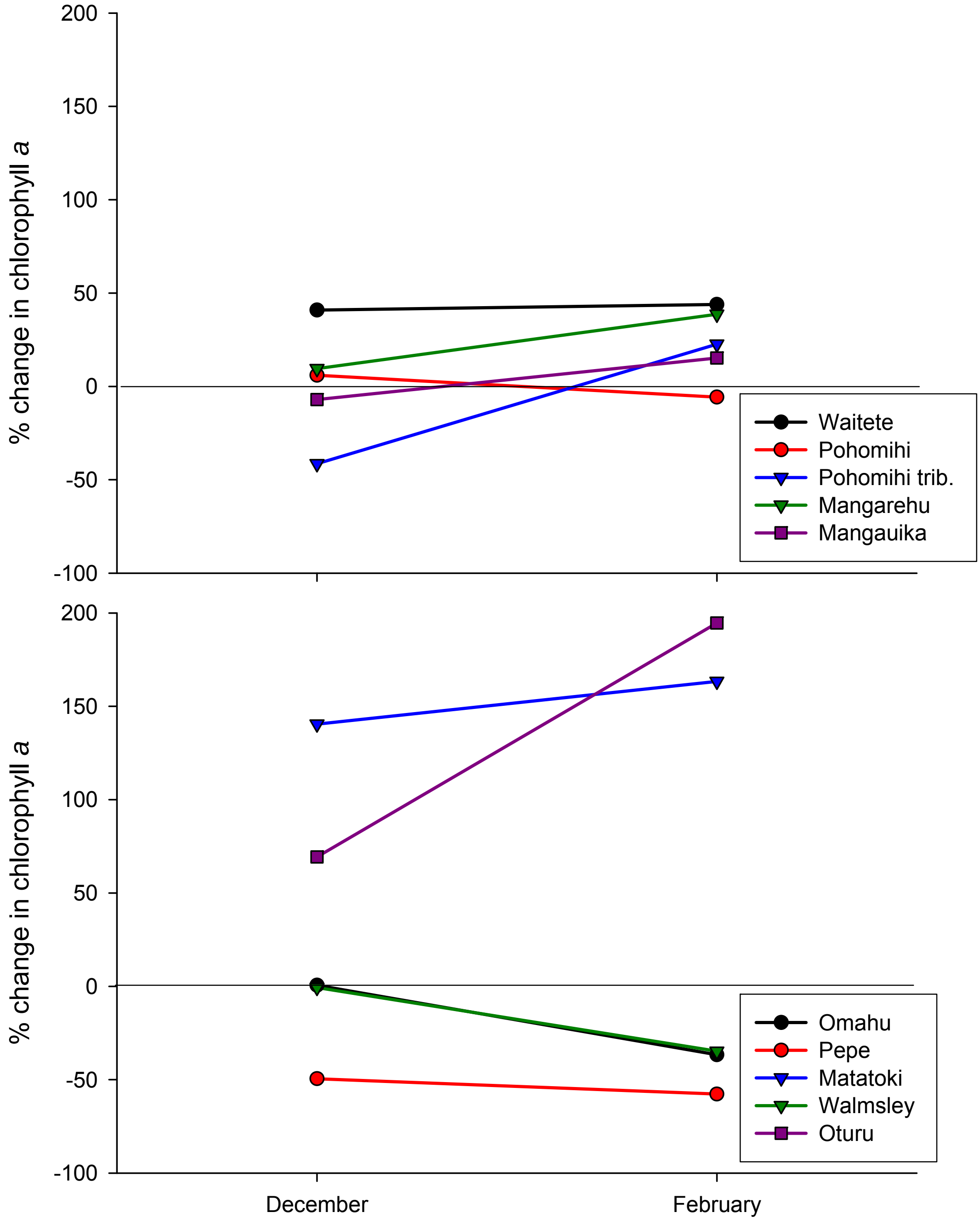

Figure 1: Percent change in the chlorophyll *a* concentration of periphyton on cobbles between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and February 2008. Negative percent change values indicate that the concentration of chlorophyll *a* decreased downstream of the water intake and positive percent change values indicate that the concentration of chlorophyll *a* increased downstream of the water intake.

3.3 Invertebrate community diversity

There was no significant difference to the number of invertebrate individuals per 0.1 m^2 found at upstream sites compared with downstream sites on each stream (Fig. 2, Appendices 4 & 5). The mean numbers of animals collected per Surber sample in December 2006 were generally similar to those collected in February 2008, but numbers were significantly higher in February 2008 at upstream and downstream sites on Omahu, Pepe and Walmsley streams (Appendices 4 & 5). Waitete was the only stream where the number of taxa was significantly lower at the downstream site (Fig. 3, Appendices 4 & 5). The number of taxa per sample was otherwise similar at upstream and downstream sites in both December 2006 and February 2008 (Fig. 3). The percentage of EPT individuals (Fig. 4) and EPT taxa (Fig. 5) decreased markedly at the downstream site on Waitete Stream. There were also decreases in either the percentage of EPT individuals or taxa between the early and late summer samples from Mangauika, Omahu, Pepe and Walmsley streams (Appendices 4 & 5). The only significant decreases to MCI (Fig. 6) and QMCI (Fig. 7) between upstream and downstream sites were observed for Waitete Stream. MCI values were also lower for the late summer (February) samplings of Omahu, Pepe and Walmsley streams compared to early summer samplings (Appendices 4 & 5). The changes to invertebrate community indices that are indicative of water quality are summarised in Table 3. Water quality appears to decline downstream of the water intake on Oturu, Waitete and Matatoki streams (Table 3).

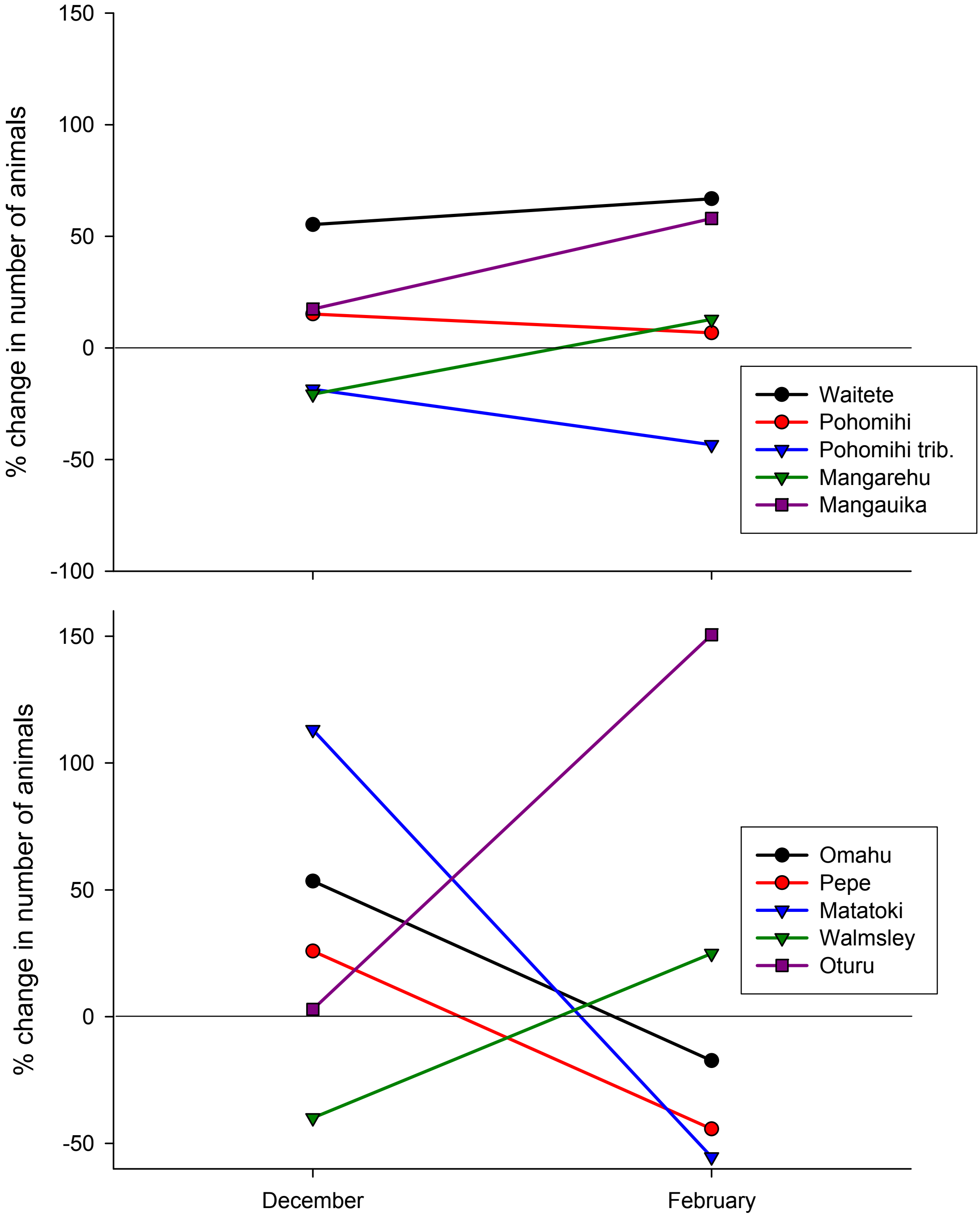

Figure 2: **Percent change in the number of animals between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and February 2008. Negative values indicate that the number of animals has decreased downstream of the water intake and positive values indicate that the number of animals has increased downstream of the water intake.**

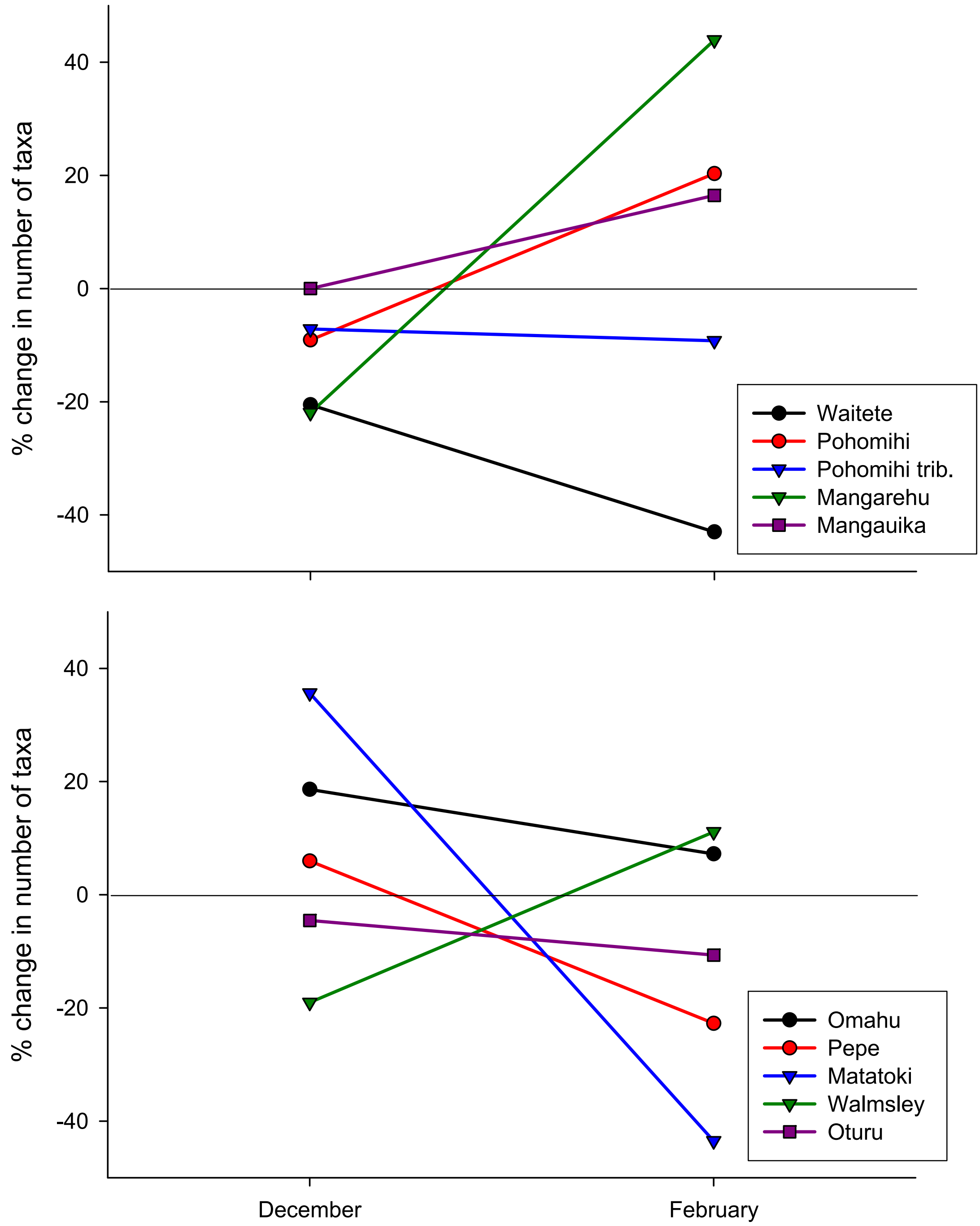

Figure 3: **Percent change in the number of taxa between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and February 2008. Negative percent change values indicate that the number of taxa has decreased downstream of the water intake and positive percent change values indicate that the number of taxa has increased downstream of the water intake.**

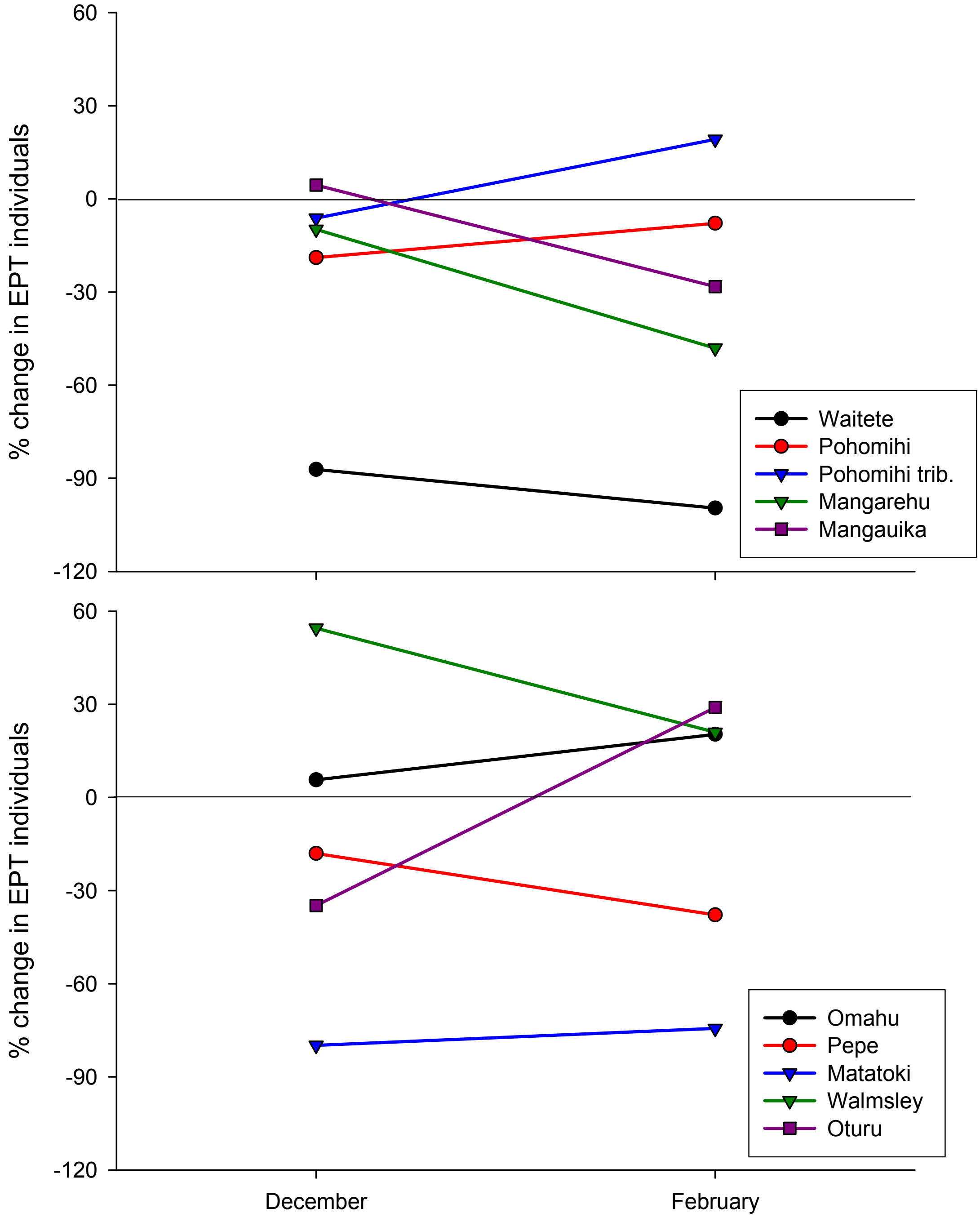

Figure 4: **Percent change in the percentage of EPT individuals between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and February 2008. Negative percent change values indicate that the percentage of EPT individuals has decreased downstream of the water intake and positive percent change values indicate that the percentage of EPT individuals has increased downstream of the water intake.**

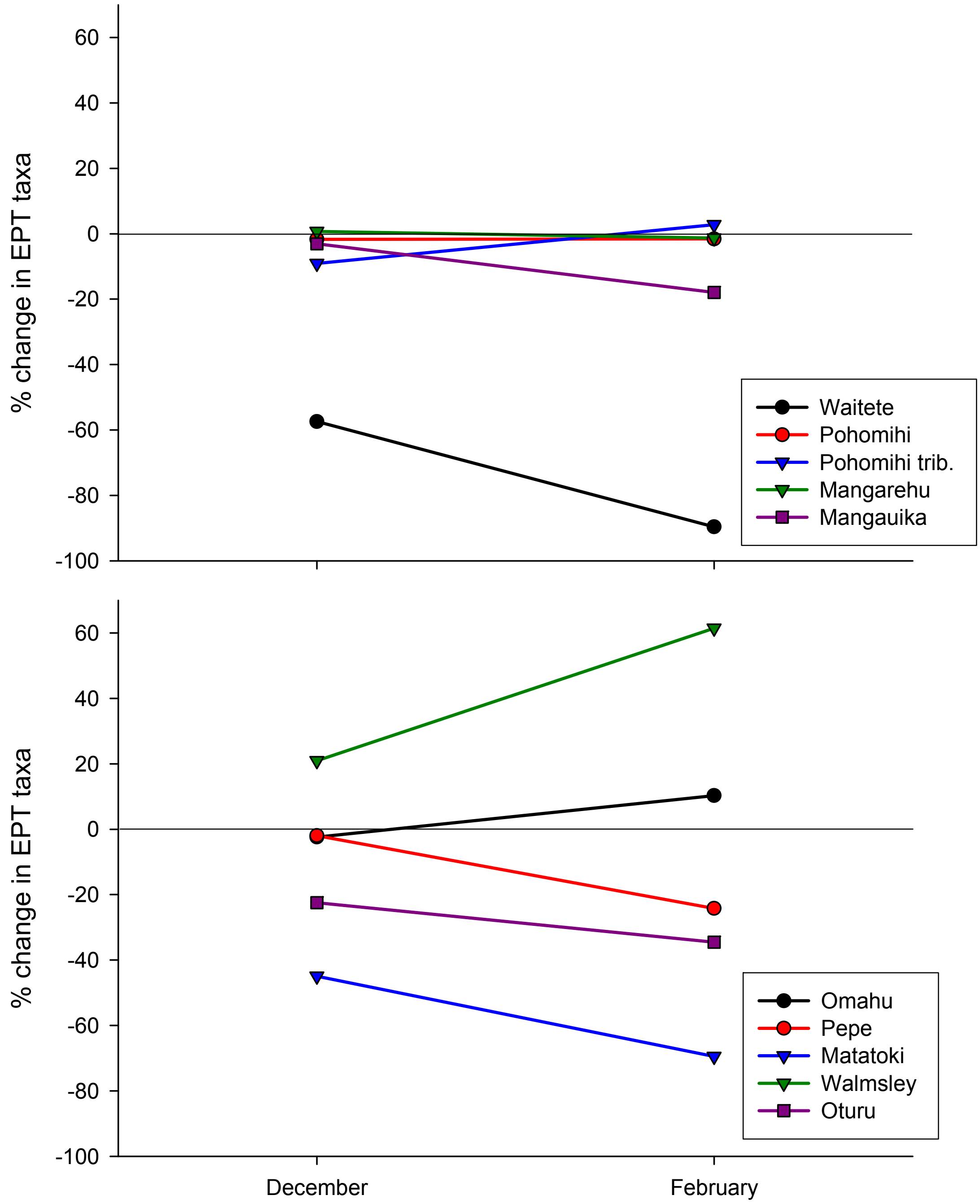

Figure 5: Percent change in the percentage of EPT taxa between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and February 2008. Negative percent change values indicate that the percentage of EPT taxa has decreased downstream of the water intake and positive percent change values indicate that the percentage of EPT taxa has increased downstream of the water intake.

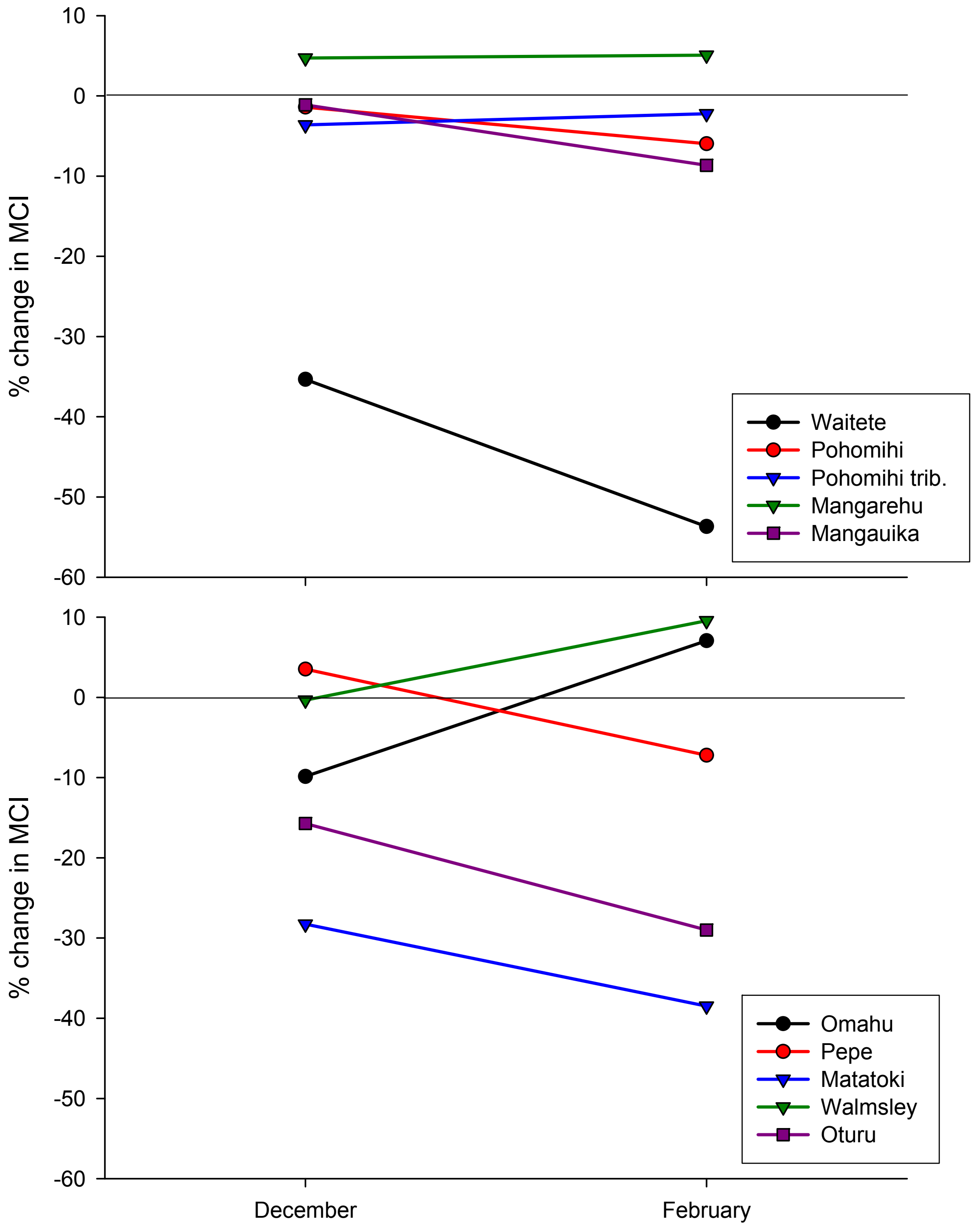

Figure 6: **Percent change in MCI between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and February 2008. Negative percent change values indicate that the MCI has decreased downstream of the water intake and positive percent change values indicate that the MCI has increased downstream of the water intake.**

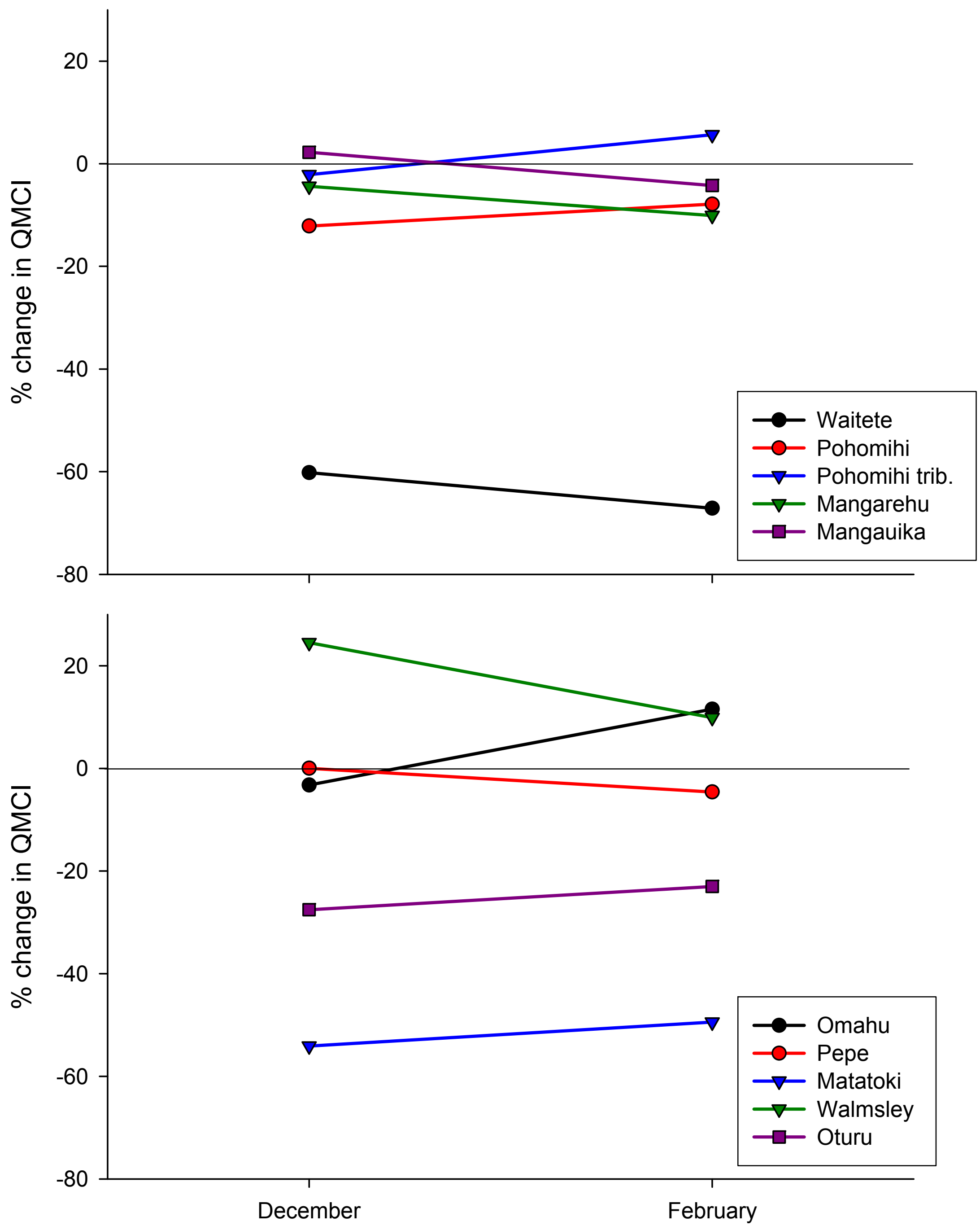

Figure 7: Percent change in QMCI between sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and February 2008. Negative percent change values indicate that QMCI has decreased downstream of the water intake and positive percent change values indicate that QMCI has increased downstream of the water intake.

Table 3: Summary of changes to invertebrate community metrics between sites upstream and downstream of water intakes in December 2006 and February 2008. Arrows indicate the direction of changes that are significant at the 5% level (see Appendix 4), and – represents no significant change. A 'decline' is where three or more metrics show a decrease.

Stream	% EPT individuals	% EPT taxa	MCI	QMCI	Overall change
Oturu	-	⬇	⬇	⬇	Decline
Pepe	-	-	-	-	No change
Omahu	-	-	-	-	No change
Mangarehu	⬇	-	-	-	No change
Waitete	⬇	⬇	⬇	⬇	Decline
Walmsley	-	-	-	-	No change
Matatoki	⬇	⬇	⬇	⬇	Decline
Pohomihi	-	-	-	-	No change
Pohomihi tributary	⬇	-	-	-	No change
Mangauika	⬇	-	-	-	No change

3.4 Invertebrate community composition

Sites upstream of water intakes were not significantly different between December 2006 and February 2008 (ANOSIM R = 0.04, *p* = 0.20) (Fig. 8). However, sites downstream of water intakes differed between the two sampling occasions (ANOSIM R = 0.15, *p* = 0.05) indicating a shift in community composition following abstraction during the prolonged dry spell (Fig. 9). Two-way ANOSIM of mean invertebrate communities comparing the averages between sites and years showed that there was no difference between upstream and downstream sites over both sampling times (ANOSIM R = 0, *p* = 0.43), however there was a significant difference between the communities found in December and February (ANOSIM R = 0.16, *p* = 0.02) (Fig. 10).

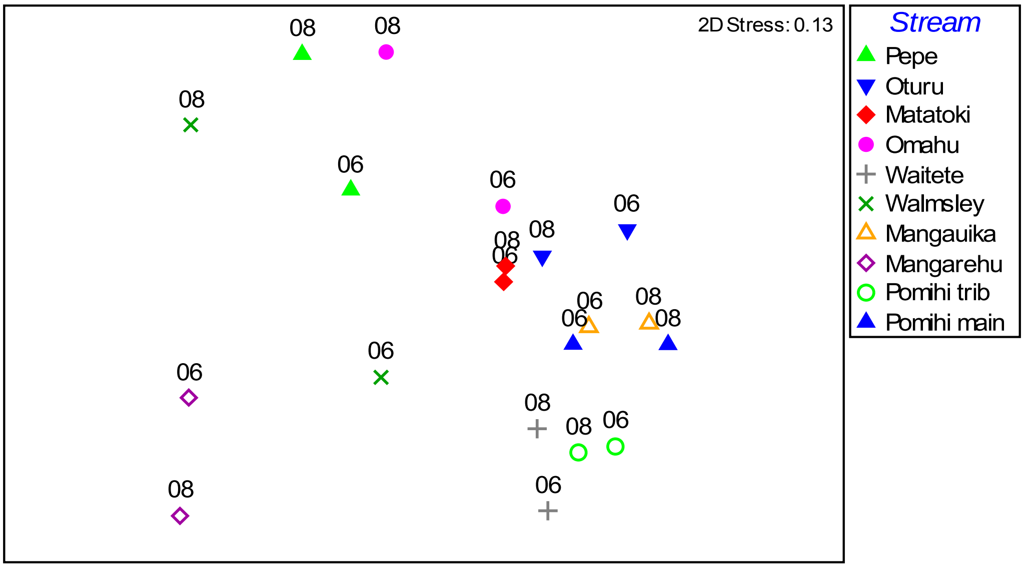

Figure 8: Non-metric multi-dimensional scaling (MDS) of mean (*n* = 5) invertebrate abundance collected at sites upstream water intakes in ten Waikato Region streams during December 2006 (06) and February 2008 (08).

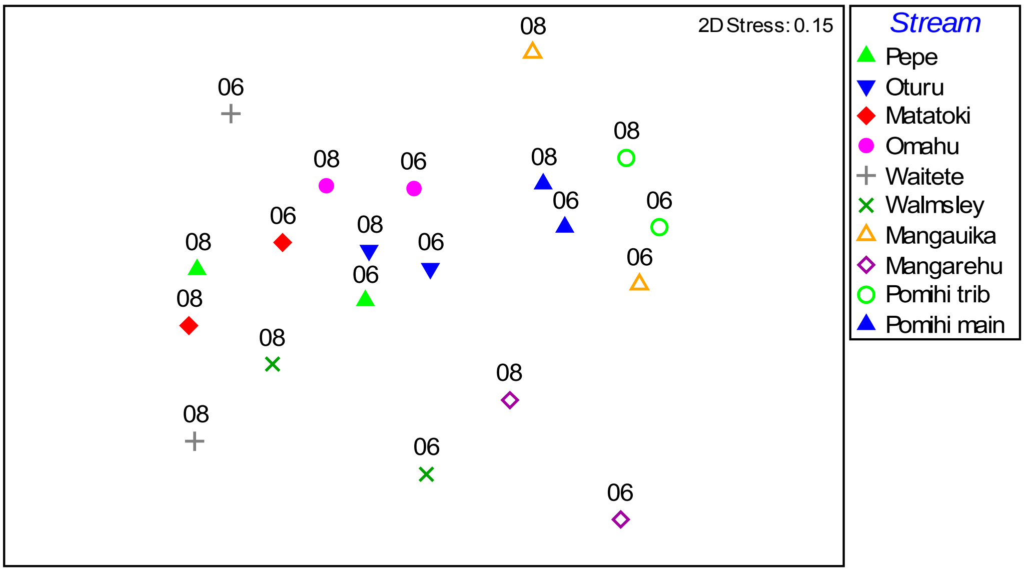

Figure 9: **Non-metric multi-dimensional scaling (MDS) of mean (*n* = 5) invertebrate abundance collected at sites downstream of water intakes in ten Waikato Region streams during December 2006 (06) and February 2008 (08).**

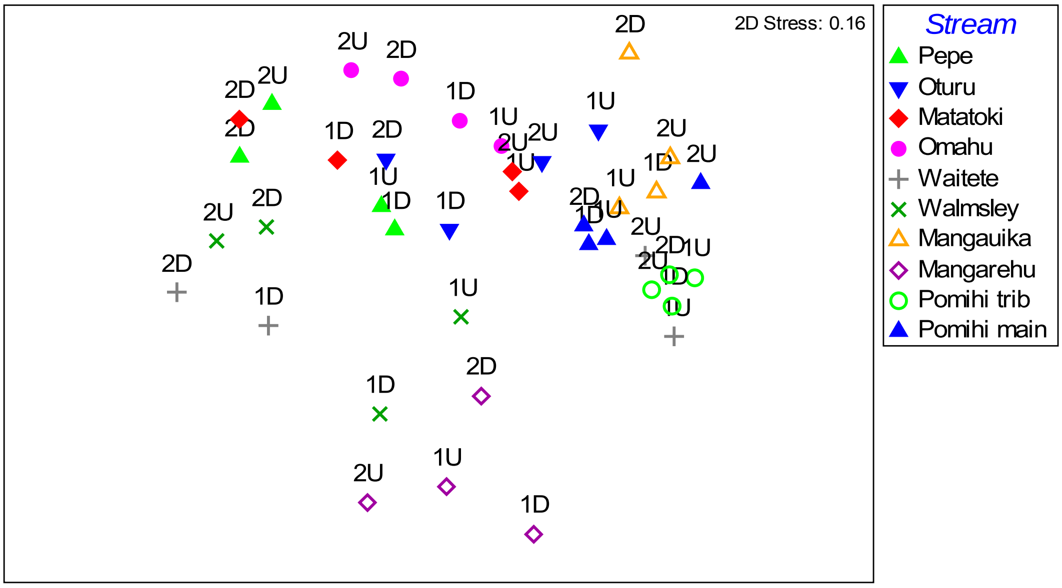

Figure 10: **Non-metric multi-dimensional scaling (MDS) of mean (*n* = 5) invertebrate abundance collected at sites upstream (U) and downstream (D) of water intakes in ten Waikato Region streams during December 2006 (1) and February 2008 (2).**

The greatest difference between the invertebrate community at upstream and downstream sites was on Waitete Stream in both December and February. The greatest similarity between upstream and downstream sites was on Mangauika Stream in December and Walmsley Stream in February (Table 4). The overall mean similarity between upstream and downstream sites was less in February 2008.

Table 4: Percentage similarity of invertebrate communities at sites upstream and downstream of water intakes in ten Waikato Region streams during December 2006 and February 2008 (using similarity values from a multivariate resemblance matrix calculated in PRIMER).

Stream	% similarity between upstream and downstream sites		Increase/decrease in similarity between two sampling times
	December 06	February 08	(relative to 2008)
Oturu	60.1	66.4	Increase
Pepe	80.5	78.6	Decrease
Omahu	80.4	78.5	Decrease
Mangarehu	75.6	61.5	Decrease
Waitete	44.1	35.3	Decrease
Walmsley	69.4	80.8	Increase
Matatoki	62.3	52.7	Decrease
Pohomihi	76.4	64.8	Decrease
Pohomihi trib.	81.3	79.2	Decrease
Mangauika	83.2	55.4	Decrease
Mean	**71.3**	**65.3**	**Decrease**

3.5 Invertebrate metrics and abstraction volume

There is no strong relationship between the mean amount of water removed and the percent change in number of taxa or number of individuals (Fig. 11). With the exception of Walmsley Stream, streams with a greater amount of water removed tend to have decreased individuals downstream of water takes albeit non-significantly. There is no effect of abstraction percentage on %EPT taxa (Fig. 12). There is a statistically non-significant relationship between the amount of water abstracted and percent change in MCI or QMCI. However, excepting Walmsley Stream, the sites with the greatest water removal exhibited the greatest downstream decrease in these indices (Fig. 13). The same can be said for the community percent similarity (Fig 14).

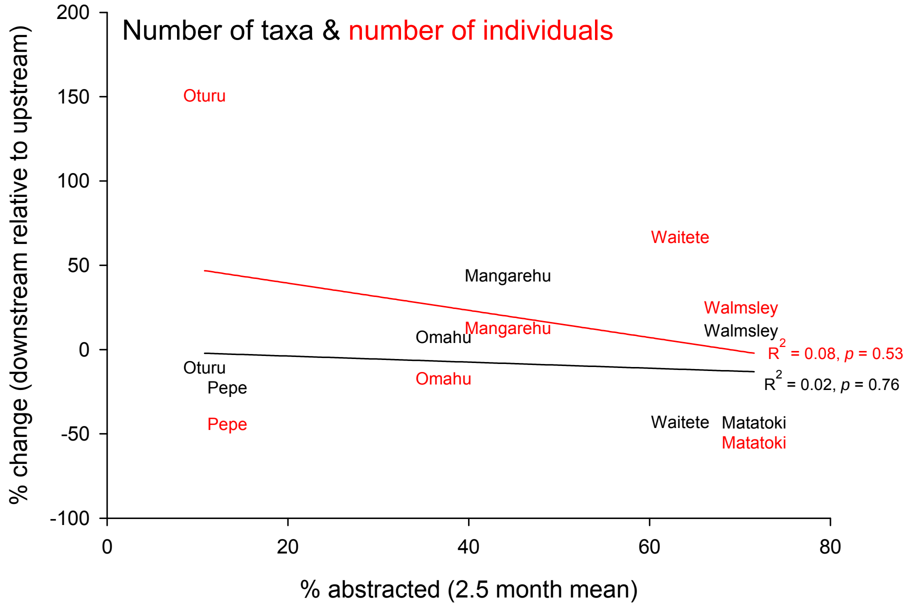

Figure 11: The relationship between the 2.5 month mean % of water removed and the % change in number of taxa and individuals.

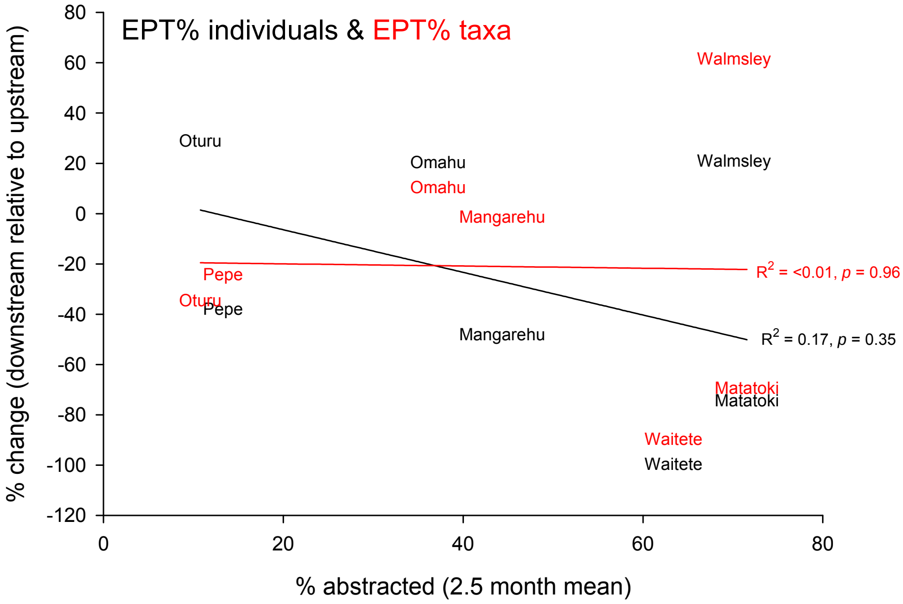

Figure 12: The relationship between the 2.5 month mean % of water removed and the % change in percent EPT individuals and EPT taxa.

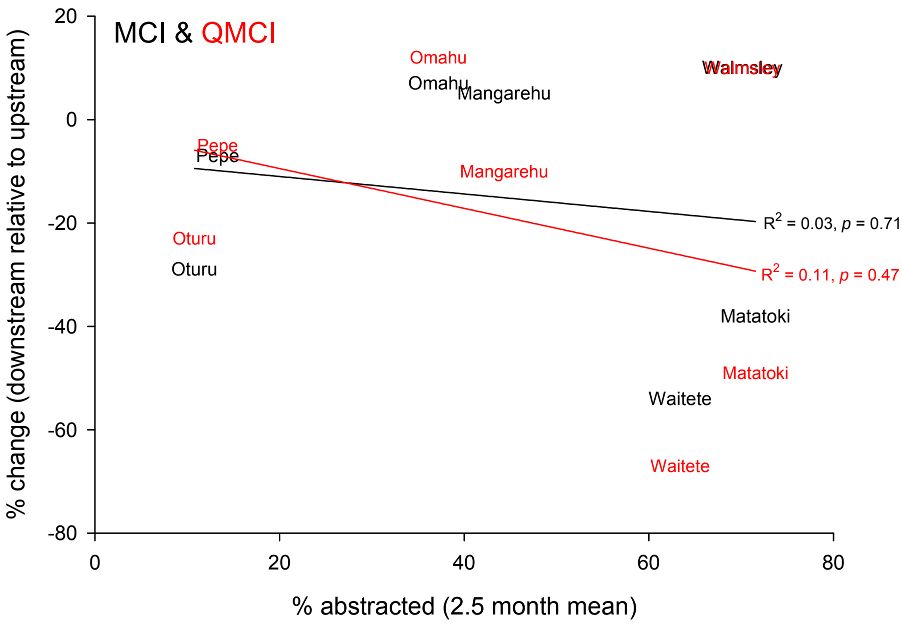

Figure 13: The relationship between the 2.5 month mean % of water removal and the percent change in MCI and QMCI.

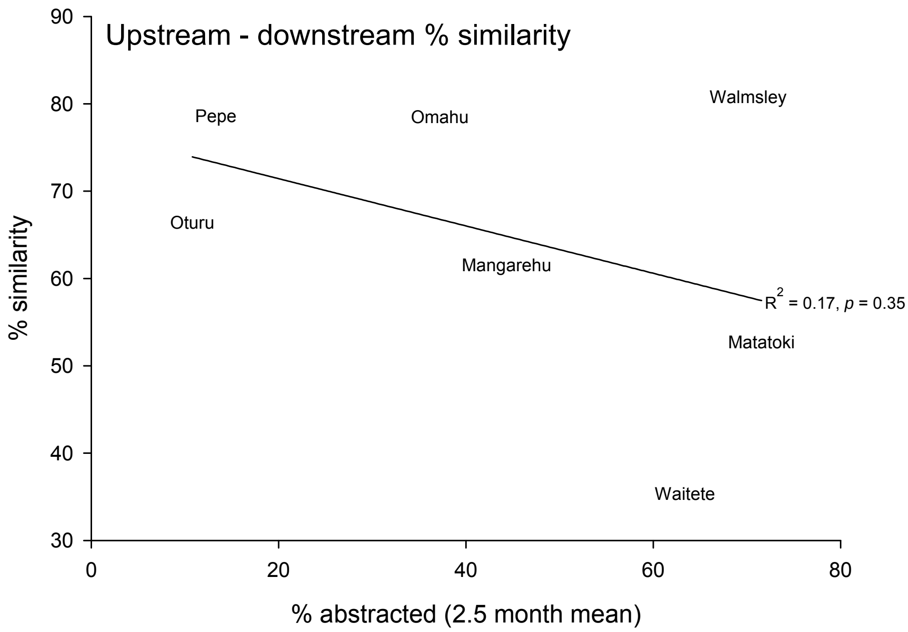

Figure 14: The relationship between the 2.5 month mean % of water removal and the community percent similarity.

4 Conclusions

To assess the influence of water abstractions on the invertebrate communities of ten small, permanent, stony streams in the Waikato Region during summer 2008, we compared sites upstream and downstream of existing water abstractions as a continuation of sampling undertaken the previous summer. We used samples collected in December 2006 as a measure of the invertebrate community before the summer period of highest water usage. Samples collected in February 2008, were compared to our "before" samples to assess the impact of water takes on the invertebrate and periphyton communities in these streams in the absence of a large rainfall event, one of which occurred between the sampling occasions in the previous study. The water abstractions on these streams were located at sites dominated by native forest cover, to minimise the potentially confounding effects of changing land use between upstream and downstream sites (Dewson & Death 2007). We would expect the effects of water abstractions on these streams to differ between years, depending on the prevailing weather conditions and the level of water use.

The discharge of a number of streams spent more time at or below Q5 discharge in summer 2007/08 than in summer 2006/2007 (Oturu, Mangarehu, Matatoki, Omahu, Waitete, Walmsley, and Pohomihi). These periods were relatively short (days to 2 weeks) and truncated by a number of higher flow events. Where data is available, abstraction appears to be similar in the two summers. Decreases in water velocities, depths and wetted widths occurred downstream of water intakes for the majority of streams in this study. As was found in our previous work on these streams, the percentage decreases in these variables between upstream and downstream sites varied considerably among the ten streams, probably in response to the differing proportions of total flow abstracted from each stream, differences in channel morphology among the streams and possibly variations in groundwater recharge.

In February 2008, riffle habitat was the dominant habitat type at both upstream and downstream sites (mean 82% vs. 79% of reach length respectively) in the study streams (Appendix 1). In addition, the proportion of reach length that was riffle habitat actually increased between the December 2006 and February 2008 samplings in most streams as water levels dropped (Appendix 1). Downstream sites maintained mean velocities of between 0.08 m/s to 0.50 m/s within riffles suggesting that the quality of hydraulic habitat was maintained even though the quantity was reduced. The stream that was most visibly altered by water removal was Waitete Stream, as in our previous study. The substrate at this site was covered with fine sediment and algae were more abundant downstream of the water intake.

Our measures of conductivity, pH and dissolved oxygen did not reveal any consistent changes in response to water removal, although these were based only on spot measurements. However, conductivities were considerably higher in February 2008 than in December 2006, suggesting a concentration of solutes in a reduced volume of water. As we found last year, periphyton biomass (as measured by chlorophyll *a* concentration) increased in several of the streams between early and late summer samplings, but did not consistently differ in response to water abstraction. There was generally a higher percentage cover of fine and coarse organic detritus in February 2008 than in December 2006, probably as a result of lower flows and a longer time since the last flood event.

There was generally less similarity between invertebrate communities at upstream and downstream sites in late summer than in early summer, suggesting that invertebrate community composition might be affected by water abstraction during this dry period. There was a greater decline in the similarity of upstream and downstream communities compared with the previous study, however, there was also a greater time interval between the sampling occasions in this case. Numbers of invertebrates per sample did not change significantly in response to water abstractions in these streams, however, the decrease in wetted area (and therefore habitat area) in most of the streams suggests that at the reach scale, invertebrate populations will have decreased in response to the water abstractions.

We anticipated that if water abstractions at these forested sites were having a significant impact on stream invertebrate communities, the difference between upstream and downstream sites would be greatest for the late summer sampling (February 2008). This sampling followed the higher water usage holiday period, which often coincides with naturally lower stream flows. The BA×CI interaction term in our ANOVA model would detect such general effects, by assessing whether changes between before and after at the impact site were similar or different to changes at the control site. Our results showed few significant interactions, suggesting that the high water take period had little influence on the impact of the water takes at these sites. There were a number of control-impact differences, mainly at Waitete, Matatoki and Oturu, suggesting that the water abstractions have an effect on the streams, not only during the low flow period. At these sites the percent EPT, MCI and QMCI metrics tended to decrease downstream of water takes. Waitete and Matatoki had some of the largest volumes of water removed indicating there may be some critical threshold of water removal that will result in detectable changes to the macroinvertebrate community. However, quarrying operations were impacting Matatoki Stream downstream of the water take, thus the impacts observed here may not have been solely due to abstraction. Conversely, Walmsley had an equally great volume of water removed but changes to invertebrate metrics were minimal. It must be noted that at this stream the reach directly below the water take was dry during the initial December 2006 sampling, thus the sampled reach was some distance (200-300 m) downstream where flow had resumed. This illustrates the importance of the role of inflows (tributaries, groundwater) in some situations in the recovery of invertebrate communities from large water takes. Additionally, a decline in invertebrate metrics at Oturu Stream resulted from a relatively small water take, but on site there was an obvious increase in filamentous algae downstream. It is unclear what influence the water take had on the algae in this stream, but the changes to algal abundance may have been responsible for the observed changes to the invertebrate community.

Because of these variable results, there were no strong relationships between the amount of water abstracted and the percent change in any of the invertebrate community metrics or upstream-downstream community percent similarity within samples, however at the reach-scale the decrease in wetted area would imply that there is an overall decrease in invertebrate abundance. Whilst the removal of large amounts of water may influence macroinvertebrate communities, such changes are not universal indicating that other factors (e.g. floods, periphyton composition) may play a greater role. The impact of water removal may often be site specific, thus it is hard to predict its effects on benthic macroinvertebrates based solely on abstraction volume.

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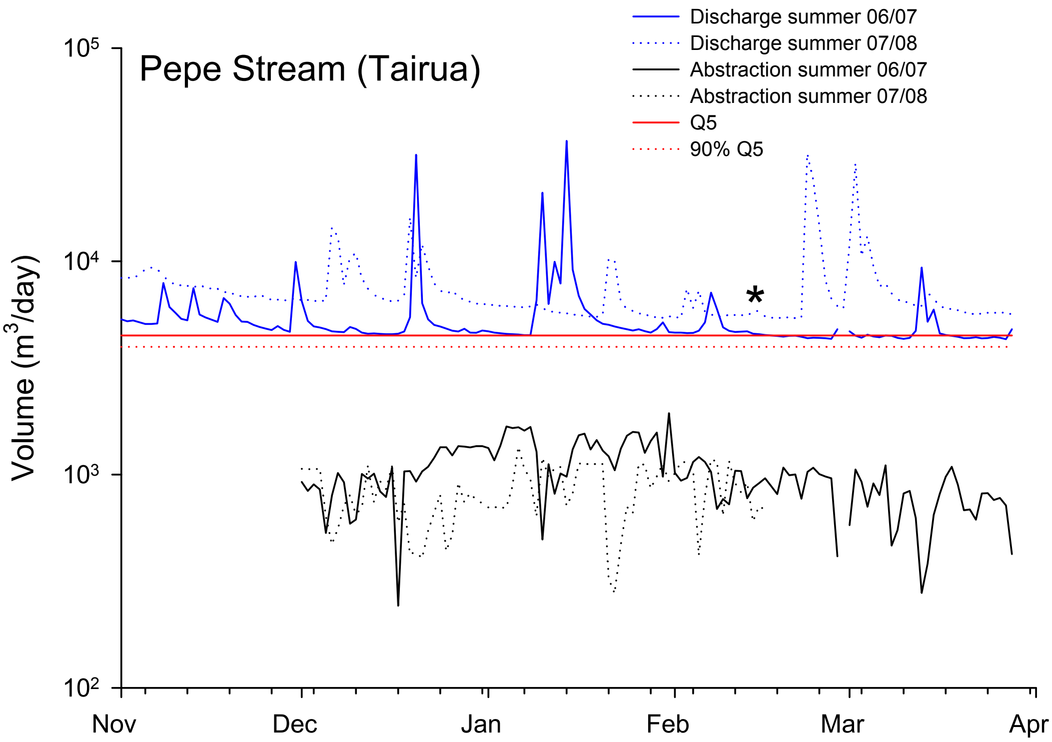
Appendix 1. Spot values of chemical variables, mean total channel width, % wetted habitat and %riffle/run/pool recorded at sites upstream and downstream of water intakes on ten Waikato Region streams in December 2006 and February 2008. nd = missing data

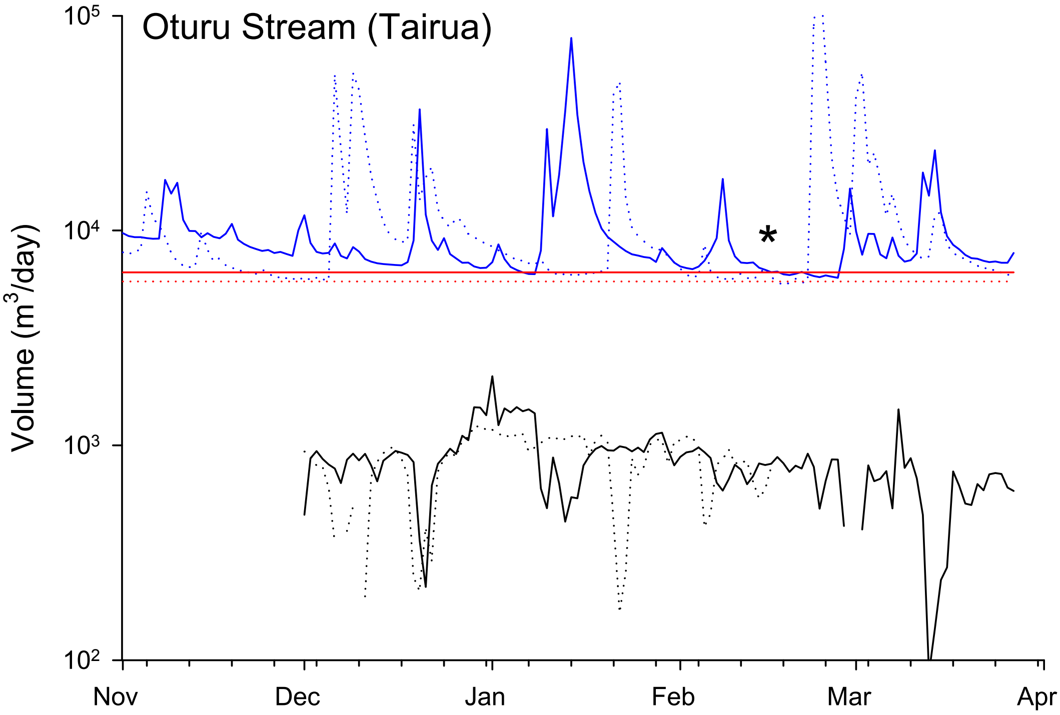
	Chemical								Habitat size									
Stream	Specific conductivity (µS/cm)		Dissolved oxygen (mg/L)		pH		Temperature (°C)		Stream channel width (m)		Wetted width (% of channel)		% riffle		% run		% pool	
	Dec	Feb	Dec	Feb	Dec	Feb	Dec	Feb	Dec	Feb	Dec	Feb	Dec	Feb	Dec	Feb	Dec	Feb
Oturu upstream	54	67	8.4	8.9	7.2	7.4	15.8	19.8	10.6	10.3	85	79	55	100	46	0	0	0
Oturu downstream	55	69	9.9	9.3	nd	7.6	16.1	19.9	8.2	7.8	83	83	27	100	64	0	9	0
Pepe upstream	56	85	7.4	9.3	6.9	7.5	18.6	17.1	12.0	9.3	71	73	64	54	0	0	36	46
Pepe downstream	56	69	7.4	9.1	nd	7.2	18.1	17.6	6.6	7.7	87	79	91	85	9	15	0	0
Omahu upstream	57	84	8.4	9.1	6.7	7.5	17.4	20.0	9.3	13.8	89	56	55	69	27	0	18	31
Omahu downstream	59	77	7.9	8.9	6.6	7.7	16.3	19.7	9.9	10.3	46	56	64	69	18	8	18	23
Mangarehu upstream	98	165	10.0	8.9	6.9	6.7	12.6	17.7	10.6	11.8	40	48	64	100	18	0	18	0
Mangarehu downstream	98	154	9.9	8.9	6.7	6.7	13.0	17.7	10.6	10.3	41	44	36	69	9	31	55	0
Waitete upstream	63	82	7.8	8.9	6.8	7.6	12.1	15.9	2.8	3.2	74	56	91	92	0	0	9	8
Waitete downstream	68	93	11.3	8.0	6.3	7.4	12.7	16.6	3.9	3.8	55	42	64	100	0	0	36	0
Walmsley upstream	51	65	6.9	9.0	6.7	7.2	14.9	16.6	3.8	4.0	94	79	64	100	36	0	0	0
Walmsley downstream	53	67	6.4	8.8	6.6	7.0	17.1	17.1	5.4	5.9	76	64	55	70	27	15	18	15
Matatoki upstream	65	96	8.8	8.6	7.0	7.7	16.7	20.7	5.9	7.9	67	41	64	70	27	15	9	15
Matatoki downstream	96	300	9.0	7.5	7.0	7.5	17.0	22.6	4.7	5.5	75	33	73	nd	18	nd	9	nd
Pohomihi upstream	62	89	7.7	10.0	6.4	7.7	13.7	17.1	6.9	8.6	88	51	100	85	0	0	0	15
Pohomihi downstream	67	138	7.0	7.8	6.6	6.9	13.6	17.3	10.4	11.1	43	25	80	50	10	0	10	50
Pohomihi trib. upstream	92	127	7.7	10.2	6.9	8.0	12.6	15.9	4.6	3.8	41	47	73	85	18	15	9	0
Pohomihi trib. downstream	102	129	7.4	9.3	7.0	7.7	12.9	15.9	2.5	3.5	55	34	83	92	0	8	17	0
Mangauika upstream	60	93	7.8	8.5	6.8	7.8	13.6	17.9	9.8	9.0	71	73	73	69	18	31	9	0
Mangauika downstream	61	104	9.4	8.0	6.8	7.5	13.1	18.6	7.9	7.6	59	43	36	77	64	23	0	0

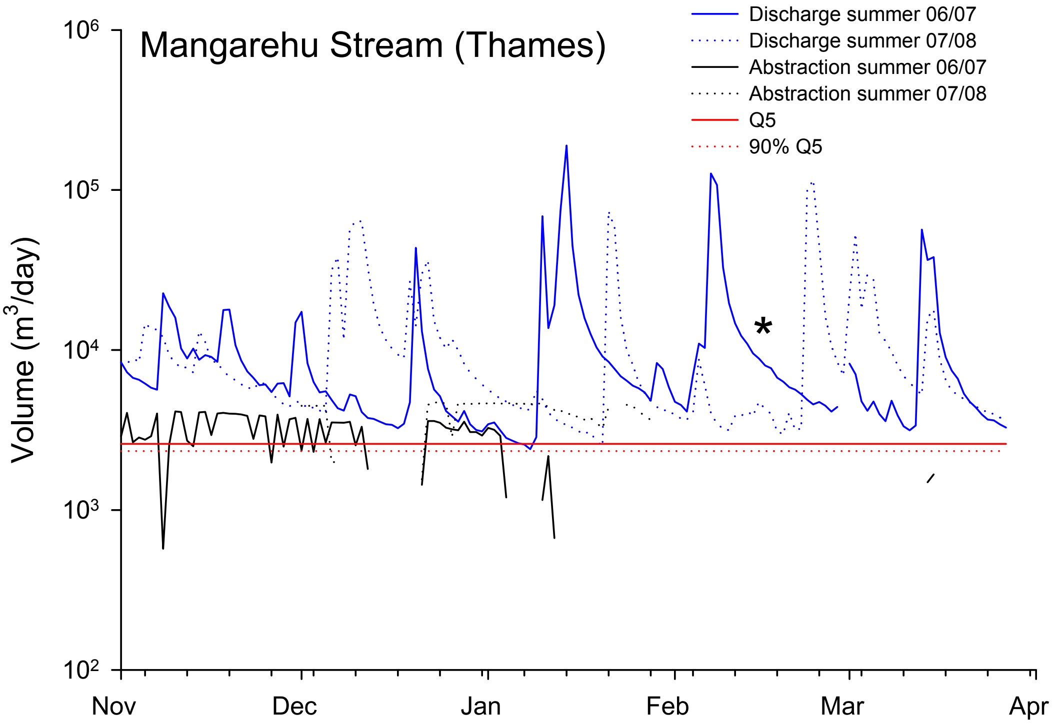
Appendix 2. Values of the Environment Waikato habitat score (maximum score of 180) (Collier & Kelly 2005), substrate size and the percentage cover of organic matter recorded at sites upstream and downstream of water intakes on ten Waikato Region streams during February 2008.

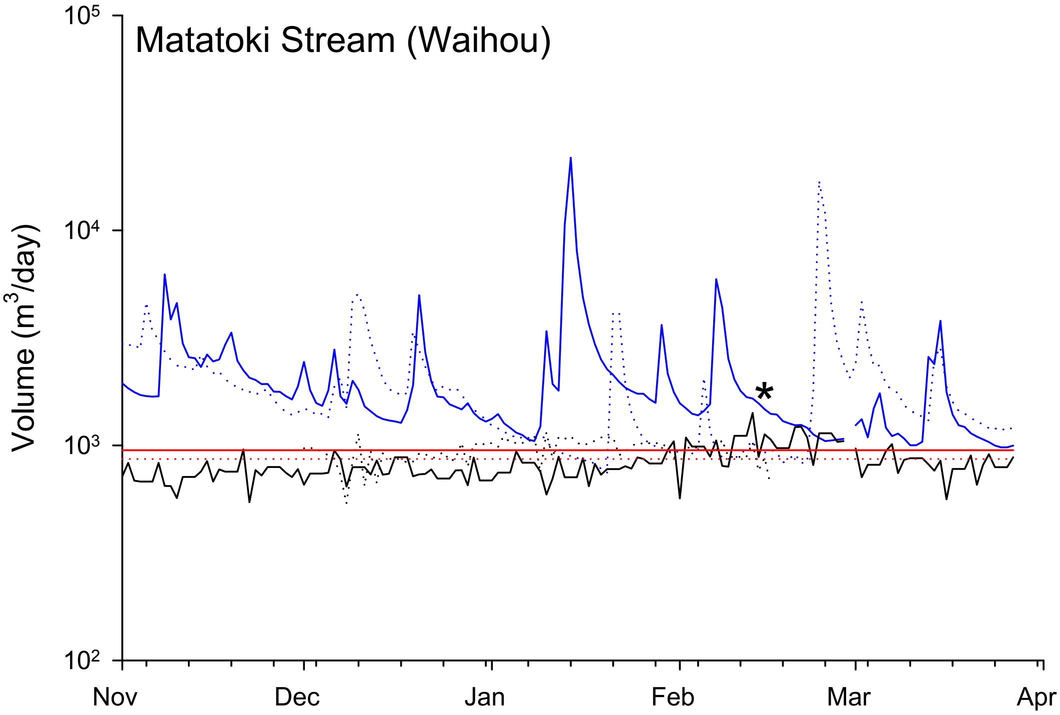
Stream	**Habitat score (EW)**	**Substrate**					**Organic material cover**		
		% bedrock	**% boulder** (>256 mm)	**% cobble** (>64-256 mm)	**% gravel** (>2-64 mm)	**% sand** (>0.06-2 mm)	**% large wood**	**% coarse detritus**	**% fine organics**
Oturu upstream	160	0	49	29	22	0	<5	<5	<5
Oturu downstream	157	0	27	55	16	2	<5	<5	<5
Pepe upstream	163	0	21	52	27	0	<5	<5	<5
Pepe downstream	166	0	12	37	51	0	<5	<5	5-25
Omahu upstream	171	0	13	60	24	4	<5	5-25	<5
Omahu downstream	171	0	13	58	27	2	<5	<5	<5
Mangarehu upstream	117	0	21	50	29	0	26-50	5-25	5-25
Mangarehu downstream	141	3	14	43	38	2	<5	26-50	5-25
Waitete upstream	159	0	29	42	29	0	5-25	5-25	<5
Waitete downstream	114	2	46	40	10	2	<5	26-50	51-75
Walmsley upstream	164	0	9	58	21	11	5-25	5-25	5-25
Walmsley downstream	164	0	33	63	19	6	<5	5-25	<5
Matatoki upstream	151	16	25	18	36	5	<5	5-25	5-25
Matatoki downstream	158	0	20	55	23	2	<5	5-25	5-25
Pohomihi upstream	166	0	31	42	23	4	<5	5-25	5-25
Pohomihi downstream	166	0	25	36	40	0	<5	5-25	5-25
Pohomihi trib. upstream	168	0	2	28	64	6	<5	26-50	26-50
Pohomihi trib. downstream	161	0	14	24	56	6	5-25	26-50	26-50
Mangauika upstream	180	0	30	56	14	0	<5	5-25	5-25
Mangauika downstream	180	0	26	40	34	0	<5	5-25	5-25

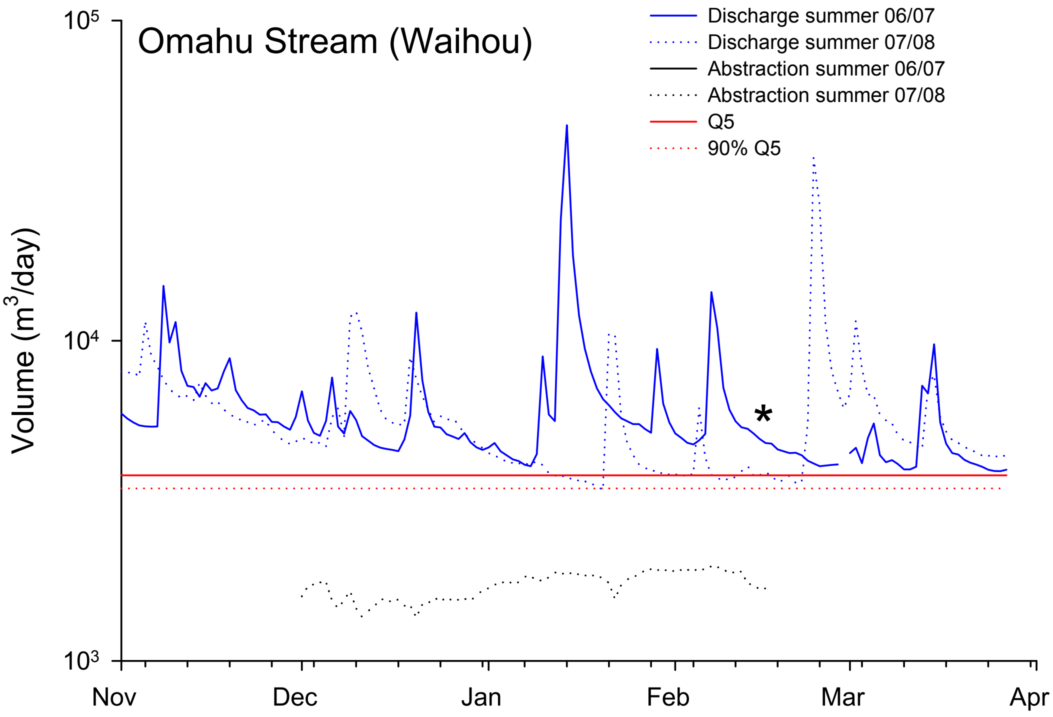
Appendix 3. Daily synthesised discharge, abstraction volumes and Q5 statistics (m^3/day) for summer 06/07 and summer 07/08 for the streams included in this study (where available). Asterisks on each graph indicate the time of the 2008 invertebrate sampling.

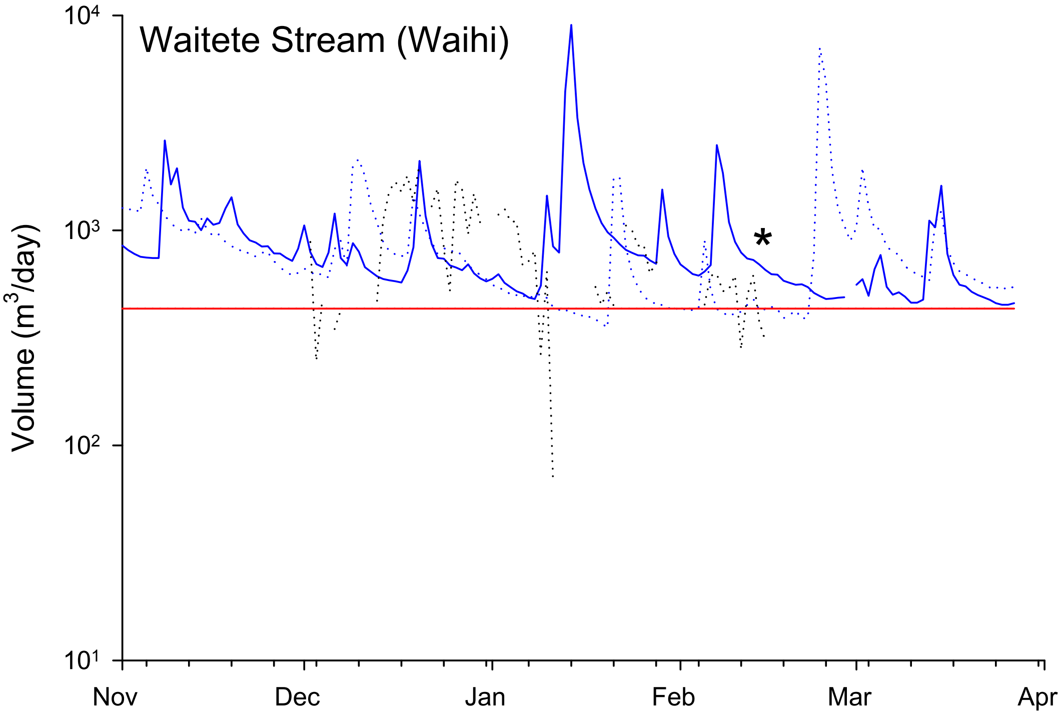


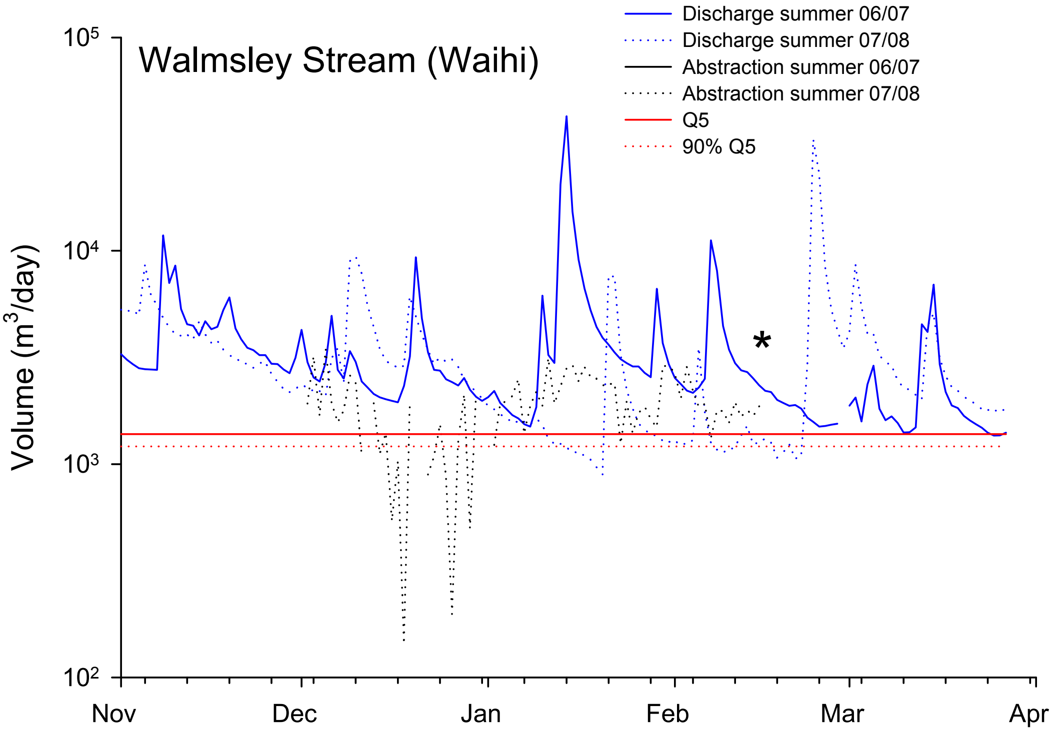



Mangarehu Stream (Thames)
Discharge summer 06/07
Discharge summer 07/08
Abstraction summer 06/07
Abstraction summer 07/08
Q5
90% Q5
Volume (m3/day)
10^6
10^5
10^4
10^3
10^2
*
Nov
Dec
Jan
Feb
Mar
Apr

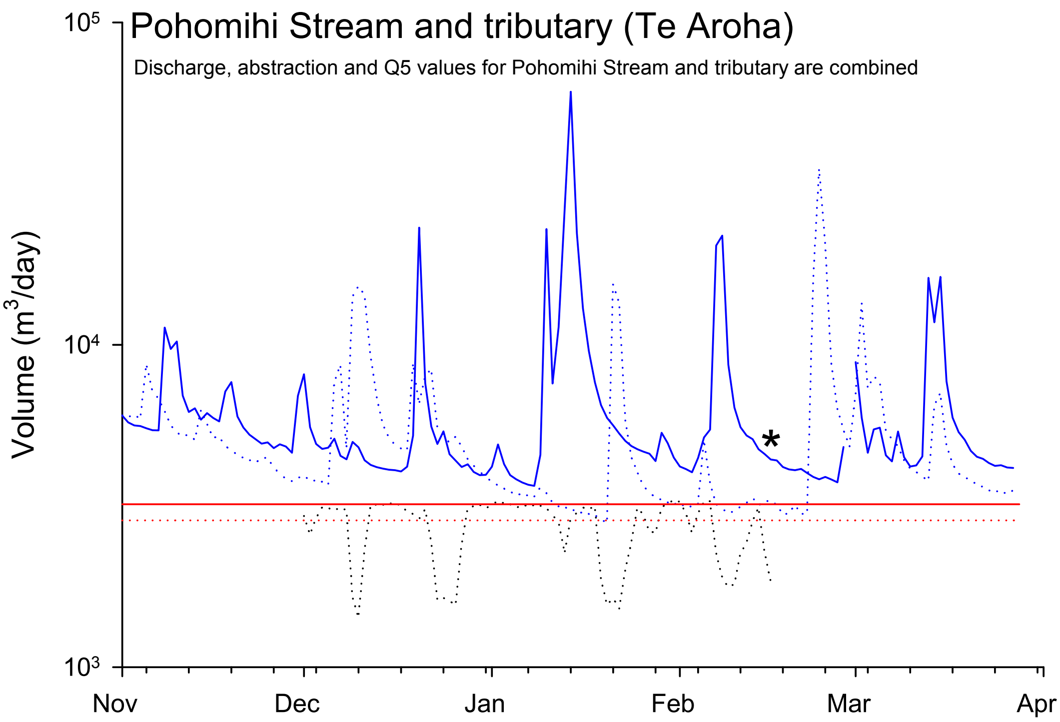

Matatoki Stream (Waihou)
Volume (m3/day)
10^5
10^4
10^3
10^2
*
Nov
Dec
Jan
Feb
Mar
Apr


Omahu Stream (Waihou)
Discharge summer 06/07
Discharge summer 07/08
Abstraction summer 06/07
Abstraction summer 07/08
Q5
90% Q5
Volume (m3/day)
10^5
10^4
10^3
*
Nov
Dec
Jan
Feb
Mar
Apr

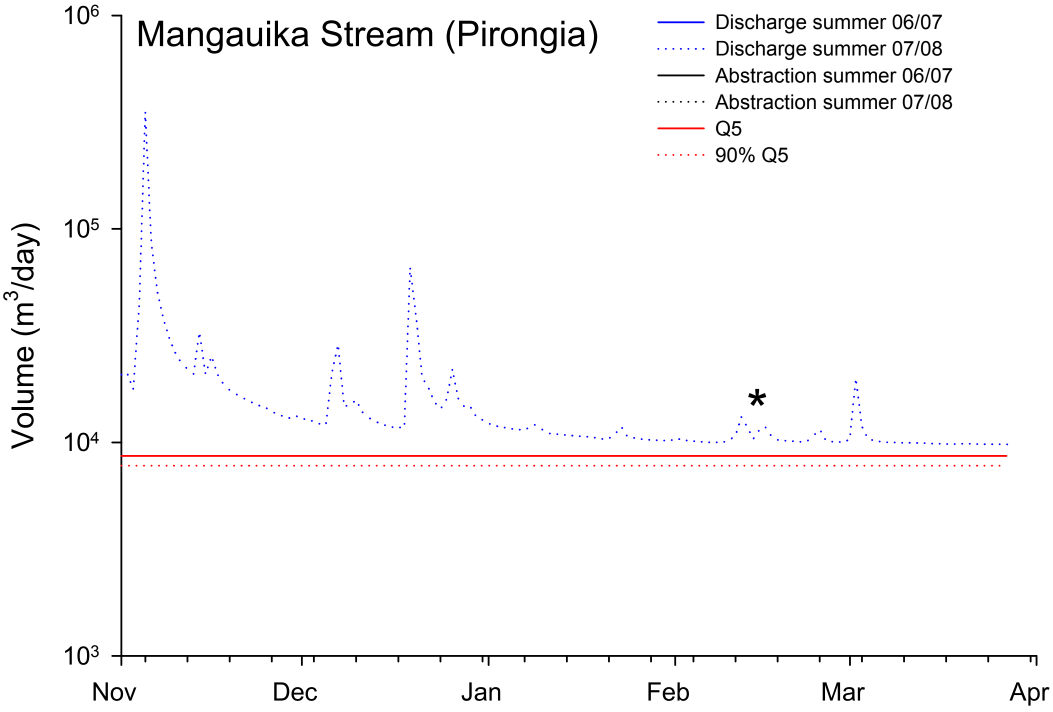

Waitete Stream (Waihi)
Volume (m3/day)
10^4
10^3
10^2
10^1
*
Nov
Dec
Jan
Feb
Mar
Apr



Walmsley Stream (Waihi)
Discharge summer 06/07
Discharge summer 07/08
Abstraction summer 06/07
Abstraction summer 07/08
Q5
90% Q5
10^5
10^4
10^3
10^2
Volume (m^3/day)
*
Nov
Dec
Jan
Feb
Mar
Apr



Pohomihi Stream and tributary (Te Aroha)
Discharge, abstraction and Q5 values for Pohomihi Stream and tributary are combined
10^5
10^4
10^3
Volume (m^3/day)
*
Nov
Dec
Jan
Feb
Mar
Apr


Mangauika Stream (Pirongia)
Discharge summer 06/07
Discharge summer 07/08
Abstraction summer 06/07
Abstraction summer 07/08
Q5
90% Q5
Volume (m3/day)
10^6
10^5
10^4
10^3
*
Nov
Dec
Jan
Feb
Mar
Apr

Appendix 4. P-values for ANOVAs testing for differences between before (Dec 06) and after (Feb 08) (BA), control and impact sites (CI), and the interaction (BA×CI). The BA×CI interaction is the term of interest in this model. Results significant at the 5% level are displayed in red.

Stream		d.f.	Individuals	Taxa	% EPT individuals	% EPT taxa	MCI	QMCI	Chlorophyll *a*
Oturu	BA	1, 16	0.032	0.179	0.036	0.295	0.642	0.613	0.024
	CI	1, 16	0.073	0.582	0.598	<0.001	<0.001	<0.001	0.002
	BA×CI	1, 16	0.082	0.854	0.002	0.1475	0.016	0.615	0.063
Pepe	BA	1, 16	<0.001	0.489	0.022	<0.001	<0.001	0.097	0.009
	CI	1, 16	0.118	0.195	0.086	0.256	0.636	0.692	0.020
	BA×CI	1, 16	0.036	0.080	0.730	0.548	0.159	0.712	0.186
Omahu	BA	1, 16	<0.001	0.821	0.520	<0.001	0.002	0.003	0.006
	CI	1, 16	0.701	0.155	0.035	0.379	0.476	0.555	0.244
	BA×CI	1, 16	0.335	0.372	0.222	0.571	0.156	0.192	0.240
Mangarehu	BA	1, 16	0.377	0.919	0.017	0.867	0.713	0.177	0.001
	CI	1, 16	0.611	0.860	0.048	0.698	0.452	0.478	0.278
	BA×CI	1, 16	0.088	0.394	0.209	0.999	0.927	0.810	0.373
Waitete	BA	1, 16	0.384	0.809	0.529	0.017	0.330	0.913	0.558
	CI	1, 16	0.738	0.009	<0.001	<0.001	<0.001	<0.001	0.177
	BA×CI	1, 16	0.197	0.276	0.270	0.042	0.087	0.355	0.884

Appendix 4 (continued). P-values for ANOVAs testing for differences between before (Dec 06) and after (Feb 08) (BA), control and impact sites (CI), and the interaction (BA×CI). The BA×CI interaction is the term of interest in this model. Results significant at the 5% level are displayed in red.

Stream		d.f.	Individuals	Taxa	% EPT individuals	% EPT taxa	MCI	QMCI	Chlorophyll *a*
Walmsley	BA	1, 16	0.003	0.596	0.096	<0.001	<0.001	0.323	<0.001
	CI	1, 16	0.807	0.690	0.327	0.068	0.456	0.264	0.053
	BA×CI	1, 16	0.307	0.195	0.585	0.716	0.346	0.598	0.057
Matatoki	BA	1, 16	0.946	1.000	0.003	0.007	0.018	0.002	0.234
	CI	1, 16	0.923	0.374	<0.001	<0.001	<0.001	<0.001	0.002
	BA×CI	1, 16	0.022	0.007	0.015	0.236	0.302	0.042	0.501
Pohomihi	BA	1, 16	0.379	0.623	0.264	0.883	0.290	0.355	0.058
	CI	1, 16	0.786	0.733	0.173	0.984	0.364	0.183	0.945
	BA×CI	1, 16	0.874	0.571	0.469	0.969	0.492	0.798	0.704
Pohomihi trib	BA	1, 16	0.676	0.079	<0.001	0.301	0.349	0.002	0.487
	CI	1, 16	0.101	0.387	0.340	0.404	0.237	0.487	0.561
	BA×CI	1, 16	0.399	0.846	0.018	0.146	0.758	0.099	0.133
Mangauika	BA	1, 16	0.286	0.230	0.005	0.014	0.365	0.961	0.008
	CI	1, 16	0.306	0.709	0.087	0.095	0.112	0.762	0.756
	BA×CI	1, 16	0.725	0.559	0.019	0.346	0.221	0.365	0.597

Appendix 5. Mean (*n* = 5) values of invertebrate community metrics for upstream and downstream sites on ten streams in the Waikato Region, sampled in December 2006 and February 2008.

Stream	No. of animals/0.1m^2		No. of taxa		% EPT individuals		% EPT taxa		MCI		QMCI	
	Dec	Feb	Dec	Feb	Dec	Feb	Dec	Feb	Dec	Feb	Dec	Feb
Oturu upstream	130	162	18	15	75	66	61	69	130	139	6.6	6.6
Oturu downstream	134	406	17	13	49	86	48	45	110	99	4.8	5.1
Pepe upstream	175	666	17	21	49	35	46	31	101	91	4.0	3.7
Pepe downstream	220	385	18	16	40	21	44	24	104	84	3.9	3.5
Omahu upstream	252	1644	17	19	71	64	59	40	127	103	6.9	5.4
Omahu downstream	387	1335	22	20	75	78	60	45	114	110	6.7	6.0
Mangarehu upstream	54	44	9	7	73	61	54	55	112	114	6.4	5.7
Mangarehu downstream	43	51	7	11	66	30	51	53	117	120	6.1	5.1
Waitete upstream	93	107	15	17	75	78	67	64	137	143	6.9	7.3
Waitete downstream	145	76	12	9	12	1	33	7	88	66	2.7	2.4
Walmsley upstream	62	135	13	12	38	25	46	18	110	80	4.9	4.5
Walmsley downstream	37	175	10	13	56	30	53	29	109	88	6.1	5.0
Matatoki upstream	181	399	18	26	72	42	66	57	132	125	7.1	5.8
Matatoki downstream	385	178	24	15	40	11	42	18	94	77	3.3	2.9
Pohomihi upstream	112	83	16	13	89	92	77	76	144	154	7.7	8.1
Pohomihi downstream	129	87	15	15	72	87	77	76	143	145	6.8	7.5
Pohomihi trib. upstream	324	413	20	24	94	67	69	61	144	140	7.9	7.0
Pohomihi trib. downstream	264	234	19	22	88	80	63	63	140	137	7.7	7.4
Mangauika upstream	272	173	18	15	92	89	73	66	147	148	7.9	8.2
Mangauika downstream	320	269	18	16	96	65	70	56	145	135	8.1	7.9