

REPORT NO. 2731

**INFLUENCE OF THE TAHARUA RIVER ON THE
UPPER MOHAKA RIVER FOOD BASE FOR ADULT
TROUT**

INFLUENCE OF THE TAHARUA RIVER ON THE UPPER MOHAKA RIVER FOOD BASE FOR ADULT TROUT

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Prepared for Hawke's Bay Regional Council

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EXECUTIVE SUMMARY

There is ongoing concern regarding the potential impact of the degraded Taharua River on water quality in the upper Mohaka River. Hawke's Bay Regional Council (HBRC) has undertaken a longitudinal survey in the Mohaka River to assess the effects of the Taharua River on the ecology of the Mohaka River. The survey involved the collection of benthic invertebrate and environmental data at two sites upstream of the confluence and up to fourteen sites downstream over four sampling occasions. The food base for adult trout is one area of concern which we address in this report through analysis of the invertebrate (density and biomass) and environmental data.

Size-structured invertebrate density and biomass data were summarised and visually assessed. Multivariate analyses were undertaken to detect spatial patterns in invertebrate density and biomass data, and assess changes in invertebrate community assemblages in relation to the environmental data. The relationship between invertebrate density and biomass and potential changes in community composition, in light of the potential effect of invertebrate prey availability to adult trout, were also explored. This involved the application of adult trout prey quality indices recently developed by Cawthron Institute (Cawthron). Finally, statistical analyses were undertaken to assess whether there was a change in standardised invertebrate density and/or biomass with increasing distance downstream. We found:

- A distinct and statistically significant change in invertebrate community assemblage based on abundance data in the Mohaka River below the Taharua confluence on all sampling occasions. On three occasions this change was driven by an increase in dipteran diversity and abundance associated with increased periphyton cover and biomass. On the fourth occasion periphyton cover and biomass was relatively similar at the downstream sites to upstream, but the invertebrate community structure downstream of the confluence still differed significantly from upstream.
- No indication from the size-structured invertebrate data that food would be limiting to trout up or down stream of the Taharua River confluence. However, the change in community assemblages downstream suggested that a benthic-browsing feeding strategy would be a more successful than drift-feeding.
- On the three sampling occasions, drift-feeding and benthic-browsing trout prey indices indicated the quality of food for adult trout was reduced below the Taharua confluence (for at least 0.5 to 1.0 km downstream).
- Longitudinal patterns in benthic density, biomass and quantitative trout prey index scores, beyond 1 km downstream, were probably confounded by the inflow of other tributaries or segment-scale influences. The biomass of net-spinning caddis (*Aoteapsyche*) was significantly higher beyond 3.7 km downstream of the confluence than upstream—most likely due to their association with seston (mainly drifting algae). The pattern in the drift-feeding and benthic-browsing trout prey indices (TPIs) confirmed a significant reduction in the quality of the invertebrate food base for adult

trout downstream of the confluence for a distance of typically 0.5 km, and up to 3.7 km depending on occasion.

- The densities along with TPI and QTPI scores in the Mohaka River longitudinal survey compared favourably to 88 rivers sampled throughout New Zealand suggesting a generally good quality of food in the river for trout.

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1. INTRODUCTION

The upper Mohaka River contains a nationally outstanding trout fishery recognised with Water Conservation Order status. The Mohaka trout fishery includes brown and rainbow trout with brown trout dominant upstream of Pakaututu. Agricultural development in the Taharua catchment began in the 1980s, and biomonitoring by the Hawke's Bay Regional Council (HBRC) since the 1999 conversions to dairying indicates that water quality in the Taharua has declined (see Hayes & Hay 2006). Anecdotal evidence suggests the Taharua trout fishery has also declined; trout size has decreased in this river and the upper Mohaka below the Taharua confluence, since the dairy conversions. This has led to concerns that dairy farming in the upper Taharua River catchment may be adversely affecting the trout fishery in that river and in the Mohaka River below the Taharua confluence.

Hawke's Bay Regional Council (HBRC) has been investigating whether the Taharua River is having detrimental effects on the Mohaka River trout fishery. As part of its investigation, benthic invertebrate samples were collected longitudinally from sites in the Mohaka River from 2 km upstream of the Taharua confluence to 57 km downstream of the confluence.

HBRC commissioned Cawthron Institute (Cawthron) to undertake a preliminary analysis of the size-structured invertebrate density and biomass community data, assessing whether a change in the invertebrate food-base could be detrimentally affecting adult trout growth and / or angling opportunities. The findings of the preliminary analysis indicated no apparent longitudinal trends (*i.e.* increase or decrease) of invertebrate densities or biomass below the confluence of the Mohaka with the Taharua River.

However, biomass and density metrics do not account for changes in invertebrate taxonomic composition and the resulting differences in physical and behavioural traits of invertebrate species, which can influence their availability as prey to trout (*e.g.* whether they are drift-prone).

In this report we present a more comprehensive analysis of the Mohaka River invertebrate data. With a focus on the food base for adult trout the analyses include:

1. multivariate analysis of the patterns in invertebrate community composition (based on density and biomass data) with regard to biological, physiochemical, and hydrological variables collected at the Mohaka River sites by HBRC (*e.g.* nutrients, periphyton coverage or biomass, temperature, dissolved oxygen, flow)
2. application of adult trout prey quality indices that Cawthron has recently developed
3. analysis of longitudinal trends in invertebrate indices and metrics.

2. METHODS FOR INVERTEBRATE DATA ANALYSIS

2.1. Sample collection

Benthic invertebrate samples were collected longitudinally from sites in the Mohaka River. Two sites were located upstream and fourteen sites downstream of the confluence with the Taharua River. Sampling was undertaken on four occasions—February 2013 (summer 2013), May 2013 (winter 2013), March 2014 (autumn 2014) and January 2015 (summer 2015). Only 13 of the 16 sites were sampled on all four occasions (Table 1). During the March 2014 survey, samples were also collected from four sites in the Taharua River.

Table 1. Sites sampled for benthic invertebrates in the Mohaka River relative to the Taharua River confluence on four sampling occasions (summer and winter 2013 (S13 and W13), autumn 2014 (A14) and summer 2015 (S15)).

Site distances relative to Taharua River confluence	Occasions sites were sampled
Mohaka 2.3 km upstream	S13, W13, A14, S15
Mohaka 1.9 km upstream	S13, W13, A14, S15
Mohaka 0.5 km downstream	S13, W13, A14, S15
Mohaka 1.0 km downstream	S13, W13, A14, S15
Mohaka 3.7 km downstream	S13, W13, A14, S15
Mohaka 5.4 km downstream	S13
Mohaka 6.8 km downstream	S13, W13, A14, S15
Mohaka 9.8 km downstream	S13, W13, A14, S15
Mohaka 14.4 km downstream	S13, W13, A14, S15
Mohaka 21.9 km downstream ^a	S13, W13, A14, S15
Mohaka 24.2 km downstream ^b	S13, W13, A14, S15
Mohaka 30.3 km downstream ^c	S13, W13, A14, S15
Mohaka 35.7 km downstream ^d	S13, W13, A14, S15
Mohaka 38.3 km downstream ^e	S13, W13, A14, S15
Mohaka 39.9 km downstream ^f	A14, S15
Mohaka 56.9 km downstream ^g	A14, S15

^aMohaka upstream of Mangatainoka River; ^bMohaka upstream of Makino River; ^cMohaka upstream of Mangatutu Hot Springs; ^dMohaka upstream of Mangatutunui Stream; ^eMohaka at Pakatutu Road; ^fMohaka downstream of Ripia River; ^gMohaka at McVicars Bridge.

Benthic invertebrate samples were collected from sites using a Surber sampler (0.09 m²). Five samples were collected from each site and pooled prior to processing

giving a total stream bed surface area sampled of 0.45 m². Processing of the invertebrate samples was undertaken by Stephen Moore (Landcare Research) and EOS Ecology. Animals were identified, sorted into 3-mm size classes and counted. Preliminary summarisation of the data included the calculation of total density (numbers of individuals/m²), taxa richness, Macroinvertebrate Community Index (MCI), quantitative MCI (QMCI), and Ephemeroptera, Plecoptera, Trichoptera (EPT) indices. Subsequently, invertebrate biomass (mg/m²) was estimated for each sample by the lead author using invertebrate length:dry weight relationships.

2.2. Calculation of invertebrate biomass

Size-class specific drift densities (number/m²) for each sample were calculated by dividing numbers of invertebrates per size class by area sampled. Where sub-sampling was necessary during processing, the abundance of invertebrates was multiplied by the fraction sub-sampled before densities were calculated. Dry weights (mg) were calculated for each taxon using length:dry weight relationships from the literature (Sample *et al.* 1993; Towers *et al.* 1994). Overall invertebrate biomass (mg/m²) was calculated by summing density × mean dry weight of all the 3 mm size classes. Mean dry weight was a weighted average of all the taxa in each size class. These calculations were automated with Microsoft Excel™ Visual Basic macros.

Using length-biomass relationships from the literature to estimate biomass is much more cost-effective than measuring length-specific dry weights for individual drift samples, or establishing length-biomass relationships specifically for the study river.

2.3. Analysis of invertebrate community spatial patterns and environmental variables

Multivariate analyses were undertaken to detect spatial patterns in invertebrate density and biomass data using Primer version 6.1.9 (Primer-E, Plymouth PL6 7DX, United Kingdom) and the PERMANOVA add-in (Anderson & Gorley 2007). The analyses were based on Bray-Curtis similarities of the fourth-root transformed invertebrate abundance and biomass data.

2.3.1. Visual comparison of invertebrate community assemblage between the Mohaka and Taharua rivers

Differences in invertebrate community structure between the Mohaka River and Taharua River samples were visualised using multidimensional scaling (MDS). MDS analysis provides a graphical ordination of the samples based on the relative similarity of community assemblages.

2.3.2. Mohaka River invertebrate community assemblage analyses

Differences in assemblage structure between sites in the Mohaka River were tested using a distance-based permutational analysis of variance (PERMANOVA, Anderson 2001). The sites were split into four 'site groups' based on distance from the Mohaka River confluence with the Taharua. The 'upper' sites consisted of the two sites upstream of the confluence (2.3 and 1.9 km). The 'mid' sites included 0.5, 1.0 and 3.7 km downstream from the confluence. The 'lower' sites were 5.4, 6.8, 9.8 and 14.4 km downstream of the confluence, and 'lowermost' – 21.9, 24.2, 30.3, 35.7, 38.3, 39.9, and 56.9 km downstream of the confluence.

The experimental design consisted of two factors: (1) 'site group' (fixed, with four levels: Upper, Mid, Lower and Lowermost) and (2) 'sampling occasion' (fixed, with four levels: summer 2013, winter 2013, autumn 2014 and summer 2015). Within the 'site groups' effect the specific *a priori* contrast of interest 'upstream vs. downstream' of the river confluence was also examined.

Differences in community structure among treatment levels were visualised by principal coordinate (PCO) analysis. Taxa that had a high correlation with the PCO axis (> 0.6) were displayed as vectors in the ordination plots.

2.3.3. Relationship between Mohaka River invertebrate community assemblages and environmental variables

The relationship between species data and environmental variables was analysed using multivariate multiple regression (McArdle & Anderson 2001), more specifically the distance-based linear model (DistLM) routine in PRIMER 6 & PERMANOVA (Anderson & Gorley 2007). A marginal test was used where individual variables were fitted separately to test their relationship with the invertebrate assemblage data, followed by a forward-selection procedure, conditional on variables already included in the model. The conditional test identifies the subset of variables that best predicts the species data. Environmental variables used in the analyses were: nitrate (mg/L), dissolve reactive phosphorus (DRP) (mg/L), ash-free dry weight (AFDW) (g/m²), chlorophyll-a (chl-a) (mg/m²), filamentous algae (%), thick periphyton mats (%), *Phormidium* (%), periphyton weighted composite cover (PeriWCC¹) (%), sludge (%), total algae (%), dissolved oxygen (DO) (%), water hardness (mg/L), black disk (m), turbidity (NTU) and temperature (°C). Environmental variables not included in the analyses were flow (m³/s), total phosphorus (mg/L), suspended solids (mg/L) and *Escherichia coli* (*E. coli*) (cfu/100 mL) because they had a large proportion of missing values.

¹ PeriWCC is calculated as %filamentous algal cover + (%mat cover/2). It is a composite cover measure for identifying nuisance periphyton growth in instances where both filamentous growths and mats occur (Matheson *et al.* 2012).

Draftman's plots were used to check for severe skewness among predictor environmental variables. Filamentous algae, chl-*a*, thick mats, PeriWCC and turbidity were *log*+1 transformed, whereas AFDW was square root transformed before the analyses to improve severe right skewness. After checking Draftman's plots for multi-collinearity² total nitrogen (mg/L), dissolved inorganic nitrogen (DIN) (mg/L) and dissolved oxygen (mg/L) were excluded. Total nitrogen and DIN were represented by nitrate in the analysis and dissolved oxygen (mg/L) by dissolved oxygen (%).

Distance-based redundancy analysis (RDA; Legendre & Anderson 1999) was used to visualise the resulting model, where the ordination axes are linear combinations of the environmental variables that maximally explain biotic variation.

2.4. Trout prey indices

Benthic invertebrate samples provide an insight into the food resources available for fish. The Macroinvertebrate Community Index (MCI) and quantitative MCI have been used as surrogate tools to assess the adverse effects of nutrient enrichment on higher trophic levels, *e.g.* fish and birds. However, the interpretation of these indices regarding the quality of the food resources for fish can be ambiguous (Hayes 2014). A major problem with using the MCI and QMCI to infer effects on higher trophic levels is that they do not incorporate fundamental information on invertebrate size and availability as prey to fish (see Hayes 2014). These are important links for assessing the quality of invertebrate food for fish growth and abundance.

Cawthron has developed adult trout prey indices that are specifically designed to assess benthic or drift invertebrate data in relation to food value. Three separate indices have been developed for the different trout foraging strategies: benthic-browsing, drift-feeding and cruise-feeding (the latter mode of feeding being relevant in a backwater or lake environment). The indices are based on the premise that some invertebrates will be more suitable as prey for the fish than others. Invertebrate traits for size, activity and availability are weighted for vulnerability to predation. Taxa weightings are multiplied over a sample taxa list to calculate trout prey indices according to a specific foraging behaviour. The indices have been only recently developed and still require further testing and validation. Nevertheless, they will allow managers to interrogate invertebrate data to infer flow-on effects for highly valued recreational trout fisheries. Ultimately we see this approach as adaptable to other predatory fish such as eels. Currently, no such tools exist for New Zealand water managers, or overseas managers to our knowledge. At present the indices provide a theoretical basis to evaluate if changes in an invertebrate community result in a change to the quality of invertebrate food for adult trout. With this in mind, trout prey

² Multi-collinearity is a phenomenon in which two or more predictor variables in a multiple regression model are highly correlated, meaning that one can be linearly predicted from the others with a non-trivial degree of accuracy

indices (TPIs) for drift-feeding and benthic-browsing foraging strategies have been calculated for the Mohaka benthic invertebrate dataset.

The TPIs are calculated based on the presence / absence of taxa using a modified version of the equation used by Stark (1985) to calculate the Macroinvertebrate Community Index (MCI).

$$TPI_x = \frac{\sum_{i=1}^{i=S} a_i}{S}$$

Where x = the TPI foraging strategy being calculated (drift-feeding, benthic-browsing or cruise-feeding), S = the total number of taxa in the sample, and a_i is the score for the i -th taxon. The highest TPI site scores attainable for TPI drift-feeding and benthic-browsing are 378 and 90, respectively, and the lowest score zero (when no taxa are present). However, TPI scores calculated using invertebrate benthic datasets from 107 rivers throughout NZ (including the 88 rivers dataset by Quinn & Hickey 1990) have not exceeded 154 for drift-feeding or 34 for benthic-browsing (K Shearer unpublished data).

A quantitative version of the TPI can also be calculated (the QTPI) based on the presence of taxa and the percentage community composition to weight the overall index value towards the scores of the dominant taxa. The equation used to calculate QTPI below is a modification of the quantitative MCI calculation in Stark (1993).

$$QTPI_x = \sum_{i=1}^{i=S} \frac{(n_i \times a_i)}{N}$$

Where x = the QTPI foraging strategy being calculated (drift-feeding, benthic-browsing or cruise-feeding), S = the total number of taxa in the sample, n_i is the number of individuals in the i -th scoring taxon, a_i is the TPI score for the i -th taxon, and N is the total number of individuals collected in the samples. To date, QTPI scores calculated using invertebrate benthic datasets from the 88 rivers dataset by Quinn and Hickey (1990) have not exceeded 206 for drift-feeding, or 24 for benthic-browsing (K Shearer unpublished data).

The QTPI can be a more sensitive (and variable) index of food quality because it reflects changes in percentage abundances or relative abundances as well as presence / absence of taxa. For example, if two places have exactly the same invertebrate fauna present (independent of fauna abundance) they would have identical TPI values. However, if one site is numerically dominated by mayflies, then it will have a higher QTPI than the other site if small chironomids dominate there.

2.5. Longitudinal trends in invertebrate indices and metrics

Statistical differences in aquatic drift density and biomass between 'site groups' were tested for each sampling occasion with 1-way analysis of variance (ANOVA) using STATISTICA version 8 (StatSoft, Incorporated, Tulsa OK, USA). To maintain balance in the sample design, only the thirteen sites that were sampled on all four occasions were included in the analysis. Each sampling occasion was treated as a replicate sample (*i.e.* $n = 4$ for each site). To account for samples collected at different flows and times, density and biomass data for each sampling occasion were standardised by subtracting the mean density (or biomass) across all sites from the measured density (or biomass) estimate at that site, and then dividing by the standard deviation across all sites.

Standardised data were tested for normality and / or equality of variances and were transformed, if necessary, to meet the requirements of parametric tests. The analysis included the following metrics and indices: total density and biomass, density and biomass of invertebrates greater than 6 mm, density and biomass of Ephemeroptera, Plecoptera, Trichoptera (EPT), density and biomass of EPT greater than 6 mm, drift-feeding TPI and QTPI, benthic-browsing TPI and QTPI. Total density and biomass of the mayfly *Deleatidium* and net-spinning caddis *Aoteapsyche* were also assessed as these were the most abundant and common taxa across sites and sampling occasion.

Analyses for total density and biomass, density and biomass of invertebrates greater than 6 mm, density and biomass of EPT, density and biomass of EPT greater than 6 mm, and *Aoteapsyche* biomass were conducted on \log_{10} -transformed data. Analysis for EPT density greater than 6 mm, *Aoteapsyche* density and *Deleatidium* biomass were performed using non-parametric Kruskal-Wallis tests after log-transformation failed to improve the heterogeneity of the data.

The EPT taxa were assessed as they are generally good food for drift-feeding trout; many of them are drift-prone and reach relatively large size. Initial invertebrate density and biomass by size class results suggested the food base for adult trout in the Mohaka River including EPT taxa is good throughout its length, with the contribution to the total biomass of invertebrates > 6 mm in length not falling below 50% at any site on any sampling occasion (Appendices 1 and 2).

The energy requirements for drift-feeding fish, such as trout, increase with size, and the presence of large food items to maintain growth is important, especially during the main growth periods—summer and autumn. Food items larger than 6 mm would generally be a minimum prey size requirement for a 50 cm fish, with smaller prey being more likely to pass through the mouth and out through the spaces between the gill rakers (Wankowski 1979).

3. RESULTS AND DISCUSSION

3.1. Results from preliminary density and biomass analysis

The Mohaka River invertebrate densities and biomass were lower directly below the confluence in summer and winter 2013, but higher on the other two sampling occasions (see Appendices 1 and 2). Over all sampling occasions, the density range was between 1,476–10,533 invertebrates/m² (lowest density being recorded in May 2013 and highest in January 2015). This range of invertebrate densities was in the top 50% of 88 New Zealand rivers surveyed during the '100 Rivers Survey' (Quinn & Hickey 1990). The highest density recorded during the Mohaka River survey was in the top 2% of the 88 New Zealand rivers. Overall, the total biomass of invertebrates collected in the Mohaka was higher than has been found in two South Island rivers valued for their trout fisheries—the Pomahaka and Waikaia rivers (K Shearer, unpublished data).

3.2. Multivariate analysis of invertebrate density and biomass data

Exploratory multivariate analysis revealed that invertebrate community assemblages were very dissimilar between the Mohaka and Taharua rivers (Figure 1). The same pattern was seen for the biomass data. This result is not surprising given the river catchments have very different catchment geologies and flow patterns (*i.e.* the spring-fed Taharua vs. the mountain-fed Mohaka).

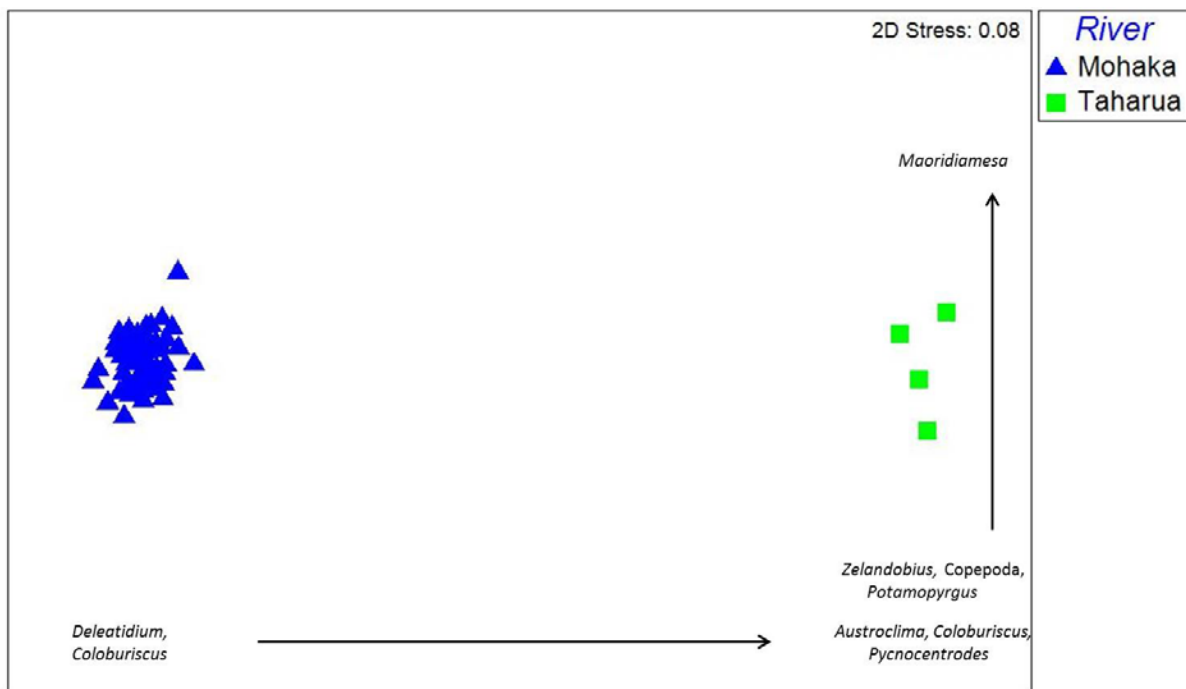


Figure 1. Non-metric multi-dimensional scaling ordination plot of the invertebrate communities from the Mohaka and Taharua rivers. Based on benthic abundance data collected from all sites in the Mohaka River (on all four sampling occasions) and from four sites in the Taharua River collected in March 2014.

Principal coordinates ordination of invertebrate communities based on abundance and biomass is presented in Figures 2 and 3, respectively. The separation between sites and sampling occasions is indicative of the relative similarity of their invertebrate communities. Characteristic taxa are plotted near the sites where they were most commonly represented. The separation between the sites in the Mohaka in Figures 2 and 3 is not as distinct as the separation seen with the Taharua in Figure 1 because a number of taxa were found in common between all the Mohaka River sites, such as the common mayfly *Deleatidium* and the net-spinning caddis *Aoteapsyche*.

High scores on the first axis (PCO1) of both ordinations (density and biomass data) were associated with communities with high numbers of algal-associated midge fly larvae (*i.e.* Tanytarsini and *Maoridiamesa*). These taxa characterised the samples collected in summer and autumn of 2013. Low scores in both ordinations were associated with high numbers of cased caddis flies (*Beraeoptera* and *Pycnocentroides*), the mayfly *Austroclima* and the common snail *Potamopyrgus*. These taxa were more characteristic of the summer 2015 samples (Figure 2 and 3).

The invertebrate communities upstream of the Taharua River confluence were separated from those downstream on the second axis (PCO2), with the community at the upstream sites being dominated by taxa generally regarded as being more sensitive to organic enrichment (the stonefly *Austroperla*, and the caddis fly *Olinga*

[the latter for density only]), but also the sand fly larvae *Austrosimulium* (Figures 2 and 3). It should be noted that the separation between the sites in the Mohaka (Figures 2 and 3) is not as distinct as the separation seen with the Taharua River (Figure 1), because several taxa were in common at all Mohaka River sites, such as the mayfly *Deleatidium*.

Statistically the upstream / downstream difference was significant for both abundance and biomass data (upstream vs. downstream, $P < 0.001$; Table 2). However, for the biomass comparison this difference varied depending on the sampling occasion (upstream vs. downstream \times sampling occasion, $P < 0.05$, Table 2). Significant differences detected between site groups for abundance and biomass also varied between sampling occasions (site groups \times sampling occasion, Table 2).

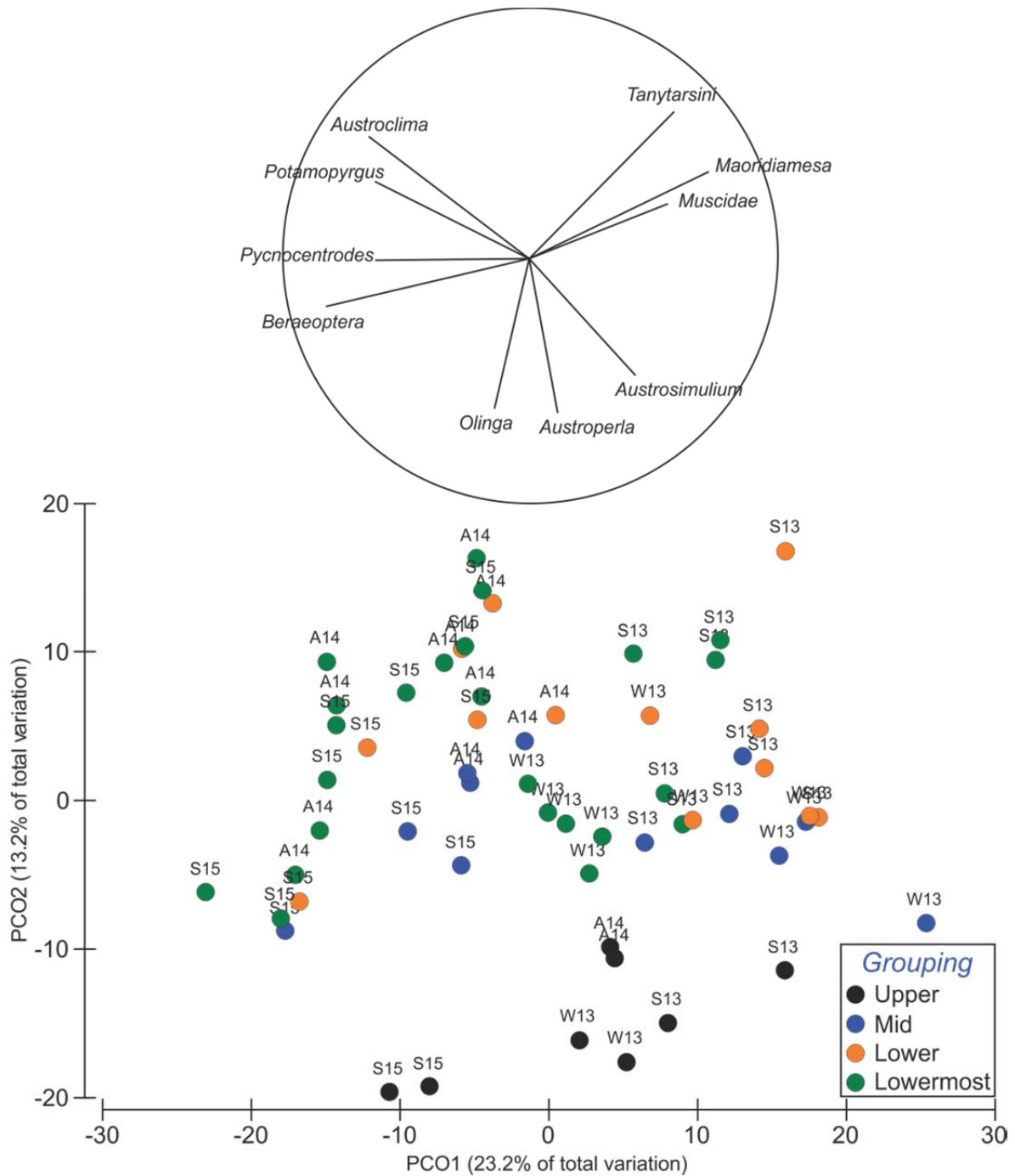


Figure 2. Principal Coordinates Ordination (PCO) plots for invertebrate density data from the Mohaka River. Sites have been divided into groups based on distance downstream from the confluence to show similarities between sites with progression downstream. Upper = 2.3 and 1.9 km upstream of confluence; Mid = sites 0.5 m to 3.7 km downstream; Lower = sites 5.4 to 14.4 km downstream; Lowermost = sites 21.2 to 59 km downstream. Invertebrate taxa vectors were separated from the main plot and placed above for clarity. The first two axes (PCO1 and PCO2) explained 36.4% of the total variation in the community data. S13 = summer 2013, A13 = autumn 2013, W14 = winter 2014, S15 = summer 2015 (see also Table 1).

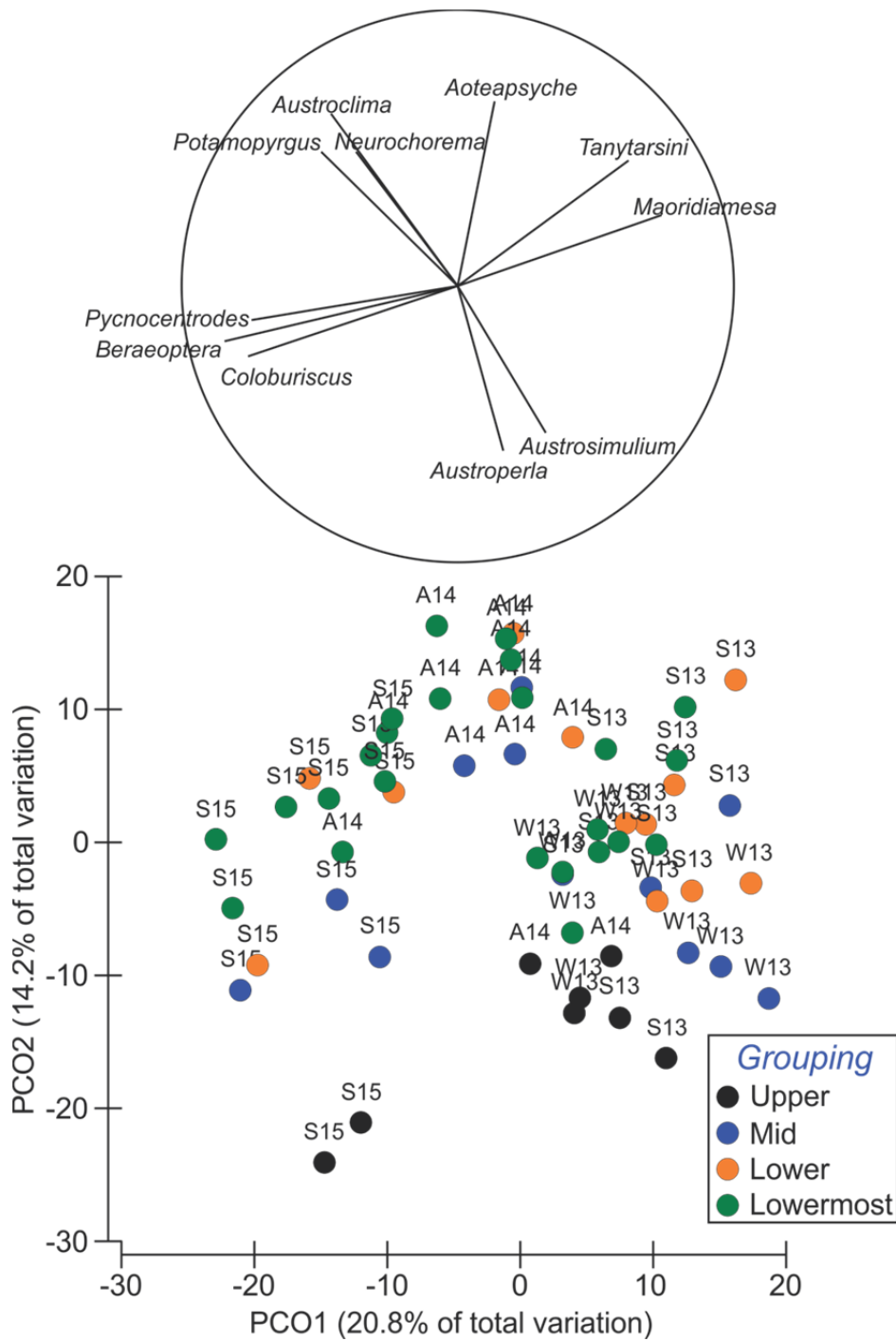


Figure 3. Principal Coordinates Ordination (PCO) plots for invertebrate biomass data from the Mohaka River. Invertebrate taxa vectors were separated from the main plot and placed above for clarity. Sites have been divided into groups based on distance downstream from the confluence to show similarities between sites with progression downstream (see Figure 4 caption for explanation of the divisions). The first two axes (PCO1 and PCO2) explained 35.0% of the total variation in the community data. S13 = summer 2013, A13 = autumn 2013, W14 = winter 2014, S15 = summer 2015 (see also Table 1).

Table 2. Permutational multivariate analysis of variance (PERMANOVA) results of density and biomass invertebrate data from the Mohaka River. d.f. = degrees of freedom, $P < 0.05$ 'significant', $P < 0.01$ 'very significant', $P < 0.001$ 'highly significant'.

	d.f.	Density		Biomass	
		F-value	P	F-value	P
Site groups	3	5.8	< 0.001	5.3	0.001
upstream vs. downstream	1	6.6	< 0.001	6.6	0.001
Sampling occasion	3	7.3	< 0.001	7.7	0.001
Site group x sampling occasion	9	1.4	0.006	1.4	0.011
upstream vs. downstream x sampling occasion	3	1.2	0.177	1.5	0.041
Residual error	41				

The non-parametric multivariate regression analysis showed that all environmental variables included in the model, with the exception of DRP and turbidity, individually had a significant relationship with invertebrate assemblage density data (Table 3a), with greatest amount of variation explained by AFDW (10%), and followed by water hardness and chl-a (9%). The sequential model using the step-wise selection method showed that AFDW, water hardness, temperature, nitrate, *Phormidium* and filamentous algae explained 34.0% of the total variation of the invertebrate assemblage structure (Table 3b). The percentage of variation in the biotic data explained by temperature, nitrate, *Phormidium* and filamentous algae was reduced after fitting the AFDW and water hardness variables (Table 3b).

Table 3. Results of multivariate multiple regression (DistLM) of invertebrate assemblage density data on individual environmental variables for (a) each variable taken individually (ignoring other variables) and (b) forward-selection of variables, where amount explained by each variable added to model is conditional on variables already in the model (*i.e.* those variables listed above it). Variation explained (%): percentage of variance in species data explained by that variable; Cumulative variation explained (%): cumulative percentage of variance explained. $P < 0.05$ 'significant', $P < 0.01$ 'very significant', $P < 0.001$ 'highly significant'.

Variable	<i>F</i>	<i>P</i>	Variation explained (%)	Cumulative variation explained (%)
<i>a) Marginal tests</i>				
Nitrate	3.9	< 0.001	7	
DRP	1.7	0.060	3	
AFDW	6.2	< 0.001	10	
Chl- <i>a</i>	5.2	< 0.001	9	
Filamentous algae	2.5	0.007	4	
Thick mats	1.9	0.034	3	
<i>Phormidium</i>	5	< 0.001	8	
PeriWCC	4.2	< 0.001	7	
Sludge	4.7	< 0.001	8	
Total algae	2.6	0.005	5	
Dissolved oxygen	3	0.002	5	
Water hardness	5.4	< 0.001	9	
Black disk	3.6	< 0.001	6	
Turbidity	1.1	0.366	2	
Temperature	4.7	< 0.001	8	
<i>b) Sequential test</i>				
AFDW	6.2	< 0.001	10	10
Water hardness	5.8	< 0.001	9	19
Temperature	2.7	0.002	4	23
Nitrate	2.8	0.001	4	27
<i>Phormidium</i>	2.8	0.002	4	30
Filamentous algae	2.5	0.003	3	34

The dbRDA ordination (Figure 4) shows a separation between upstream and mid, mid-lower and lowermost assemblages mostly along the second dbRDA axis³. The environmental predictors that best explain the spatial pattern of the invertebrate assemblages according to the multivariate multiple regression are displayed as vectors in Figure 4⁴. The high scores on the second axis of the ordination plot (dbRDA2) were indicative of invertebrate community compositions more strongly associated with high values of variables related to periphyton (AFDW, *Phormidium*

³ Note the invertebrates characterising the spatial pattern in Figure 4 are shown in Figure 2. They were not included in Figure 4 for reasons of clarity.

⁴ Scatterplots of all the environmental variables (including those not used in the multivariate analyses) collected from each site along the Mohaka River on the four sampling occasions are shown in Appendix 3.

and filamentous algae), nitrate, temperature and water hardness. For example, the algal-associated chironomid larvae were found in the summer and winter 2013 samples in Figure 2 and 3. The summer 2015 sampling round was the only time that periphyton biomass and cover at the sites downstream of the Taharua River confluence were similar to those upstream (HBRC 2015 and unpublished data). Interestingly, despite the communities being less associated with periphyton in the 2015 summer survey, downstream community assemblages were still different to those upstream in the ordination plot (Figure 4). This indicates that changes in other environmental variables in the Mohaka, as a result of the Taharua River inflow (e.g. water hardness and temperature), may be directly or indirectly driving the observed change in invertebrate communities (Figure 4). Additionally, invertebrate assemblages downstream of the Taharua confluence were associated with higher values of nitrate that is indicative of nutrient enrichment. Nitrate was highly correlated with dissolved inorganic nitrogen (DIN) and total nitrogen (TN), thus similar relationships between invertebrate assemblages and these variables are expected.

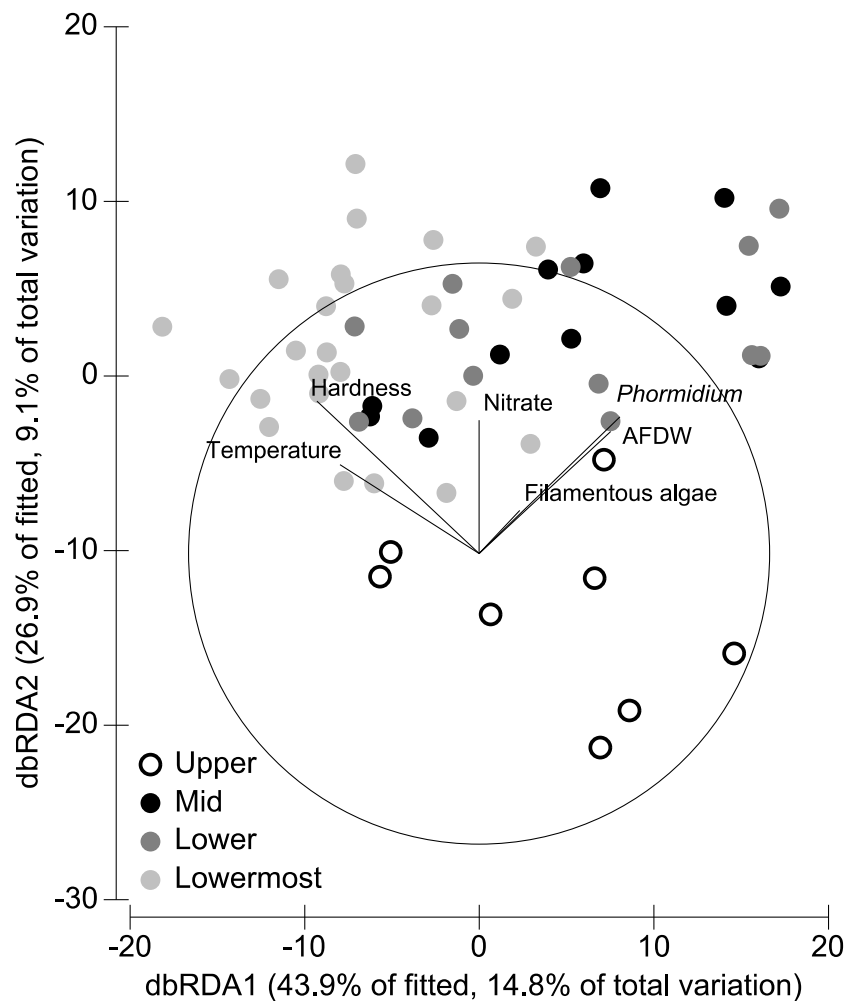


Figure 4. Redundancy analysis ordination plot of invertebrate community density data with best environmental predictors overlaid as vectors. Sites were divided into groups based on

distance downstream from the confluence to show similarities between sites with progression downstream (see Figure 4 caption for explanation of the divisions).

Overall, the multivariate results indicate that a definite change in invertebrate community structure occurs in the Mohaka River downstream of the confluence with the Taharua River. In general, communities below the Taharua confluence became more diverse and dominated by Diptera and net-spinning caddis, *Aoteapsyche*. This finding corroborates earlier work undertaken by HBRC comparing invertebrate communities upstream and downstream of the Taharua River confluence (Stansfield 2008). However, the change is not necessarily an issue for adult trout as long as there are large-sized invertebrates present *and* they are accessible to trout. Preliminary analysis of the size-structured benthic invertebrate data indicated that the density and biomass (*i.e.* quantity) of large prey was unlikely to be a food-limiting factor for trout in the Mohaka River upstream or downstream of the Taharua confluence (Shearer 2015; HBRC 2015). The multivariate results indicate that despite an increase in the abundance of smaller midge larvae (< 6 mm in length) below the confluence, a corresponding increase in the abundance of some larger taxa such as *Aoteapsyche* and larger dipterans such as Muscidae (*cf.* Anthomyiidae) may contribute to the dietary needs of large fish. Should invertebrate communities downstream of the Taharua become increasingly dominated by smaller algal-associated fly larvae and correspondingly fewer larger invertebrates, adult trout will struggle to maintain growth and condition. Interestingly, over all sampling occasions the dobsonfly *Archichauliodes* and net-spinning caddis *Aoteapsyche* were prominently the very large taxa (> 12 mm) in the benthic density and biomass data immediately below the Taharua River. A study by Shearer and Hayes (2009) found these taxa in low abundance in invertebrate drift samples collected from the Mohaka 0.4 km downstream of the Taharua confluence in 2009, indicating they would not be available for adult trout that were drift-feeding during base-low flows but maybe available to trout that are benthic-browsing. In the present study, mayflies (*Deleatidium* in particular) were a relatively dominant feature by density and biomass of the 6-12 mm size range at sites below the Taharua confluence on all sampling occasions (second only to *Aoteapsyche*). *Deleatidium* are commonly collected in the drift (as was the case in the 2009 study), and are well known to be a staple invertebrate in the diet of drift-feeding trout throughout New Zealand.

3.3. Trout prey indices

Multivariate analysis has indicated that changes in invertebrate assemblages occur in the Mohaka River downstream of the confluence with the Taharua. However, this analysis and preliminary analysis of the size-structured benthic invertebrate data indicated that the density and biomass (*i.e.* quantity) of large prey was unlikely to be a food-limiting factor for trout in the Mohaka River upstream or downstream of the Taharua confluence (Shearer 2015; HBRC 2015). In the following section we use the trout prey indices to complement the size-structured density and biomass analysis.

The TPIs account for how changes in invertebrate community assemblage affect the quality of the food base for adult trout.

The drift-feeding and benthic-browsing TPI scores dropped for the Mohaka 0.5 km below the Taharua confluence compared to upstream on all sampling occasions, sometimes markedly (Figure 5). The falls in TPI scores directly below the confluence were associated with a marked increase in the diversity of algal-associated midge-fly larvae. These larvae have a low individual TPI score (~12 for drift-feeding and 3-6 for benthic-browsing). Although they are often found drifting in the water column, their small size precludes them from being a high quality prey item for adult trout.

The drift-feeding TPI scores improved at sites further downstream of the confluence (to levels comparable to upstream). However, the distance at which scores improved varied between the sampling occasions— from around 1.0 km downstream in February 2013, March 2013 and January 2015, to 21.9 km downstream in May 2013 (Figure 5). Improvement in the benthic-browsing TPI scores downstream of the confluence, to levels similar to upstream, generally occurred between 1.0 km to 3.7 km, except in May 2013 where benthic-browsing TPI scores remained depressed, relative to upstream, for the length of the river (Figure 5).

The drift-feeding QTPI fell on all sampling occasions at 0.5 km downstream of the confluence, except for January 2015. This was associated with increases in the diversity *and* abundance of algal-associated larval midge-fly larvae. By contrast, there was little change in the QTPI scores between sites up- and downstream of the confluence in January 2015, associated with low diversity and abundance of fly larvae (Figure 6). Improvement in the downstream drift-feeding QTPIs varied between the sampling occasions, from around 1.0 km downstream in February 2013 and March 2014, to 14.4 km downstream in May 2013. Benthic-browsing QTPIs also varied below the confluence, attaining scores similar or higher than scores upstream of the confluence at 24.2 km in February 2013, 14.4 km in May 2013, and 1.0 km in March 2014 (Figure 6).

Overall TPI and QTPI scores indicated that the Taharua is, in general, having a local (< 1.0 km) negative impact on the food base for adult trout in the Mohaka River regardless of feeding strategy. The apparent negative influence of the Taharua extended for a variable distance downstream depending on the sampling occasion (range 1–24 km). The true extent to which the Taharua River influences TPI scores beyond a kilometre downstream is difficult to separate from the potential confounding influence of other environmental factors that may influence the Mohaka River invertebrate communities between sites, e.g. the inflow of other Mohaka River tributaries.

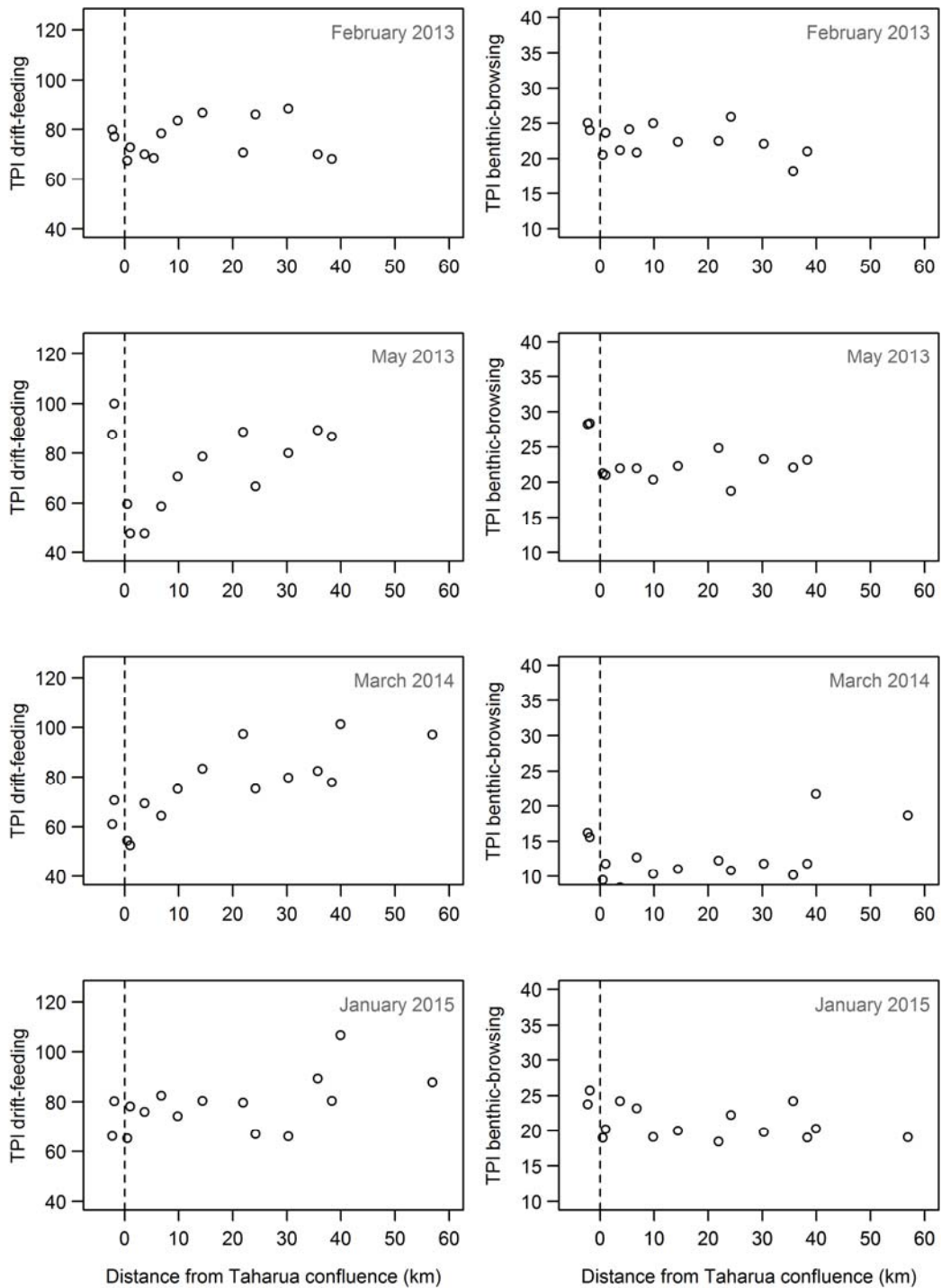


Figure 5. Trout prey indexes (TPIs) for drift-feeding (left), and benthic-browsing (right) foraging strategies by adult trout calculated from benthic samples collected on different occasions during the Mohaka River longitudinal survey. The dotted line indicates the point at which the Taharua River enters the Mohaka River.

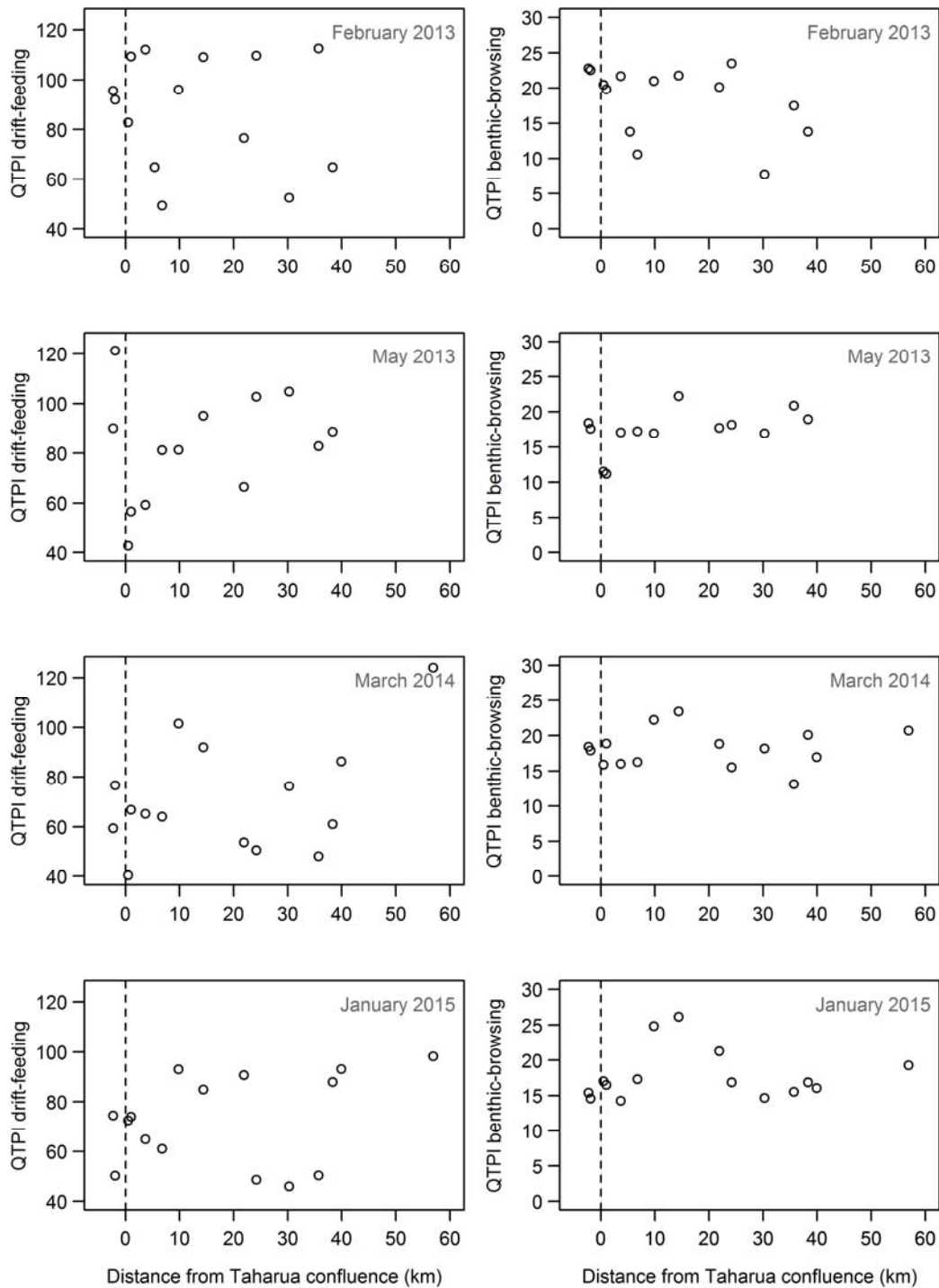


Figure 6. Quantitative trout prey indexes (QTPIs) for drift-feeding (left), and benthic-browsing (right) foraging strategies by adult trout calculated from benthic sample collected on different occasions during the Mohaka River longitudinal survey. The dotted line indicates the point at which the Taharua River enters the Mohaka River.

The Mohaka River TPI and QTPI scores were compared with scores calculated for 88 rivers sampled throughout New Zealand during the 100 Rivers Survey (Quinn & Hickey 1990). The Mohaka River was one of the 88 rivers surveyed in the Quinn and Hickey study, returning drift-feeding TPI and QTPI scores of 73 and 120 respectively. These scores were within the range of scores calculated during the Mohaka River longitudinal survey for drift-feeding: TPI 40–101; QTPI 40–121. Overall, the Mohaka River TPI and QTPI drift-feeding scores place the river in the mid to upper quartile of the 88 rivers scores, suggesting a generally good quality of food in the river for trout.

3.4. Longitudinal trends in invertebrate indices and metrics

No longitudinal trends were detected between the two upstream sites and the sites downstream of the Taharua River confluence for any of the density and biomass measures. Of the individual taxa assessed (*i.e.* *Deleatidium* and *Aoteapsyche* density and biomass) only *log Aoteapsyche* biomass showed a significant difference between site groups ($F_{3,48} = 3.56$, $P = 0.020$), with *post hoc* testing indicating that *Aoteapsyche* biomass at the 'upper' sites was significantly less than at the 'lower', and 'lowermost' sites. *Aoteapsyche* feed on seston (algae, organic material, bacteria) caught in their nets. Seston levels in the Mohaka below the Taharua River will be higher owing to contribution from the Taharua and elevated periphyton biomass immediately below the confluence. However, with increasing distance downstream seston levels will be increasingly influenced by periphyton production within the Mohaka and other tributaries.

Of the trout prey indices over all seasons, drift-feeding TPI and benthic-browsing TPI were significantly different between sites groups (drift-feeding TPI $F_{3,48} = 6.80$, $P = 0.001$; benthic-browsing TPI $F_{3,48} = 9.70$, $P = < 0.001$). *Post hoc* tests indicated that drift-feeding TPI scores were significantly lower at the 'mid' site group (up to 3.7 km downstream of the Taharua River confluence) than all the other site groups. Benthic browsing TPI scores at the upper sites were higher than the 'mid', 'lower' and 'lowermost' site group.

The boxplots shown in Figures 7 to 9 for the density, biomass and TPI/QTPI scores at each site are based on standardised data (see Section 2.5 for standardisation methodology). Generally there is less variation in the density and biomass data at the two upstream sites than sites downstream of the confluence (Figure 7 and 8). A likely explanation for this is that tributaries entering the Mohaka River above sites located downstream of the Taharua River confluence are also influencing invertebrate communities to varying degrees. While the immediate effect of the Taharua River on the Mohaka is in no doubt, the ongoing influence of it will be masked by cumulative effects of other water sources entering the Mohaka river system.

The inherent spatial variation in the data cannot be accounted for, and may be influencing the longitudinal assessment by ANOVA for which contiguous sites were necessarily grouped. As such, a visual assessment of patterns in the data provides finer resolution of spatial patterns.

In general, the total density and density > 6 mm plots show an increase immediately downstream of the Taharua confluence compared to upstream (Figure 7). This pattern is not reflected as strongly in the EPT density data, although by 1.0 km downstream EPT density data is generally higher than upstream. This suggests a localised enrichment effect that does not favour the more sensitive EPT taxa, but this effect dissipates reasonably quickly. A similar pattern to the density data is seen for the biomass boxplots in Figure 8.

Despite the high total invertebrate and EPT density and biomass across all sampling sites, the TPI and QTPI scores boxplots (and the significant ANOVA results for TPI) indicate the quality of trout food immediately below the confluence is generally poorer than upstream (Figure 9). The apparent 'recovery'⁵ in the indices with distance downstream varies with sampling occasion, but was typically within 1 km of the Taharua confluence, sometimes up to 3.7 km downstream depending on sample occasion. At some downstream sites the TPI and QTPI scores are higher than upstream (Figure 9, see also Figures 5 and 6). The full implications of TPI and QTPI results for adult trout cannot be fully addressed at this stage until food quality bands have been developed for these new monitoring tools.

Overall, the general longitudinal patterns in density, biomass and TPI data indicate there is an immediate impact of the Taharua River on Mohaka invertebrate communities downstream of the confluence within at least 0.5 - 1.0 km downstream. This impact is likely to negatively affect adult trout food potential for at least 1.0 km downstream. Any longitudinal patterns seen in the data beyond the 1.0 km site vary annually, and are not clearly attributable to the Taharua owing to the inflow of other tributaries into the Mohaka River.

⁵ The term 'recovery' is used very loosely here, as it implies that invertebrate communities downstream of the Taharua confluence were comparable to upstream, which was not the case in the Mohaka River as community assemblages remain fundamentally changed regardless of what summary data metrics show – *i.e.* totals and indices (Figures 2 and 3).

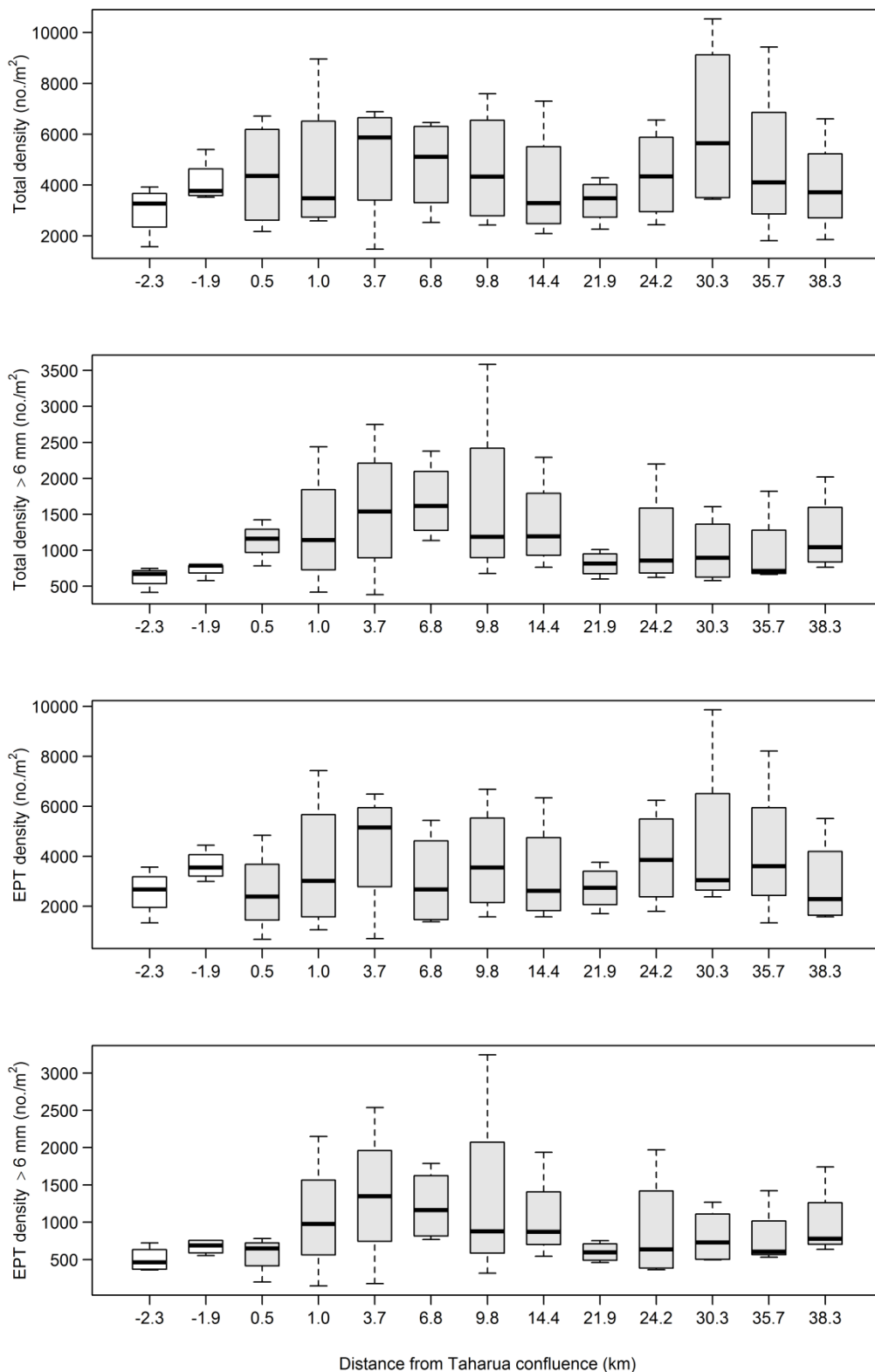


Figure 7. Box and whisker plots of standardised total density, total density > 6 mm, Ephemeroptera, Plecoptera, Trichoptera (EPT) density, and EPT density > 6 mm for sites (averaged across sample occasion) in the Mohaka River upstream (white boxes) and downstream (grey shaded boxes) of the Taharua River confluence. Dark bars in the middle of the boxes are median values, the top and bottom of the boxes represent the upper and lower quartiles, and whiskers the minimum and maximum values.

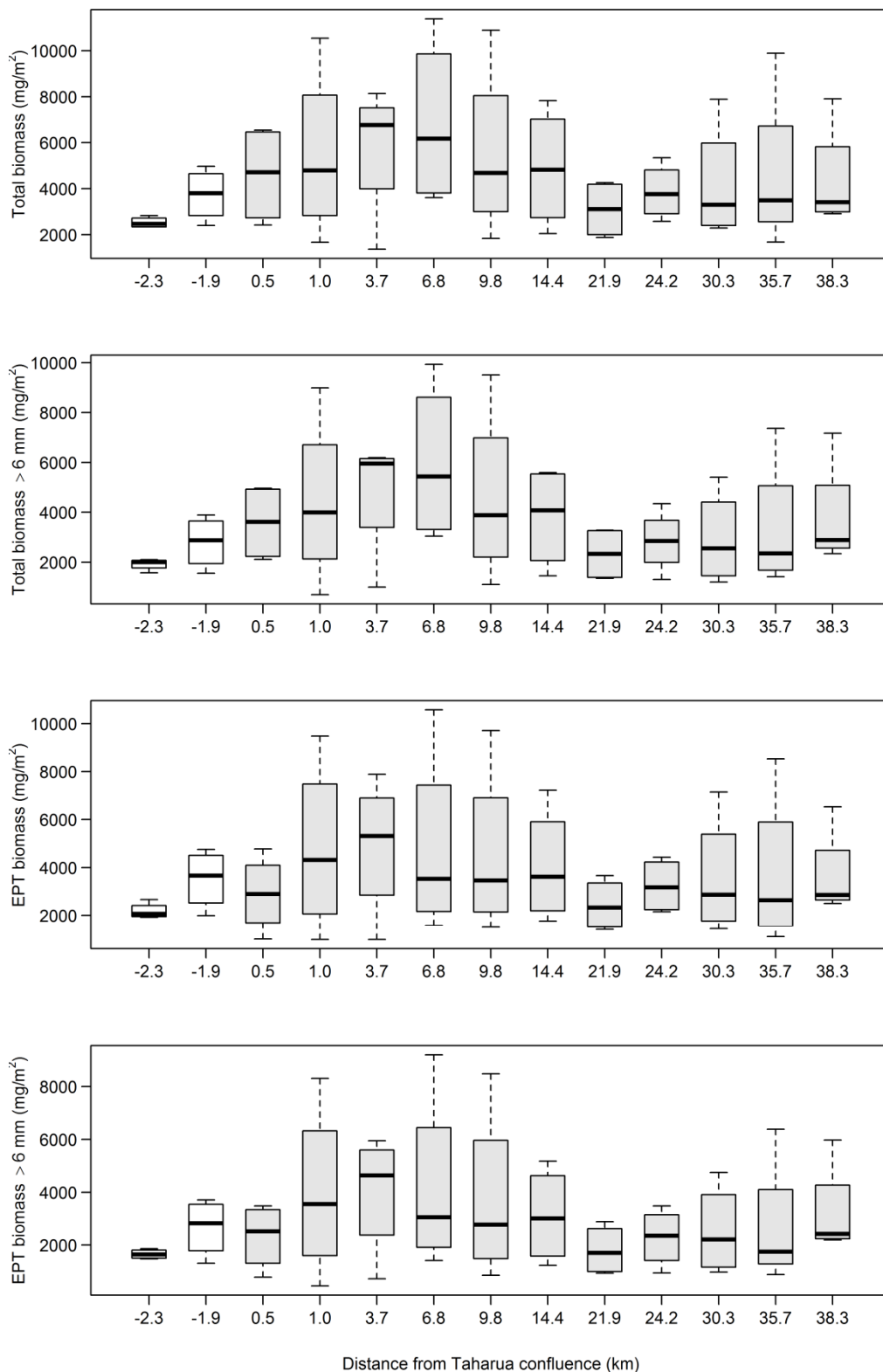


Figure 8. Box and whisker plots of standardised total biomass, total biomass > 6 mm, Ephemeroptera, Plecoptera, Trichoptera (EPT) biomass, and EPT biomass > 6 mm for sites (averaged across sample occasion) in the Mohaka River upstream (white boxes) and downstream (grey shaded boxes) of the Taharua River confluence. Dark bars in the middle of the boxes are median values, the top and bottom of the boxes represent the upper and lower quartiles, and whiskers are the minimum and maximum values.

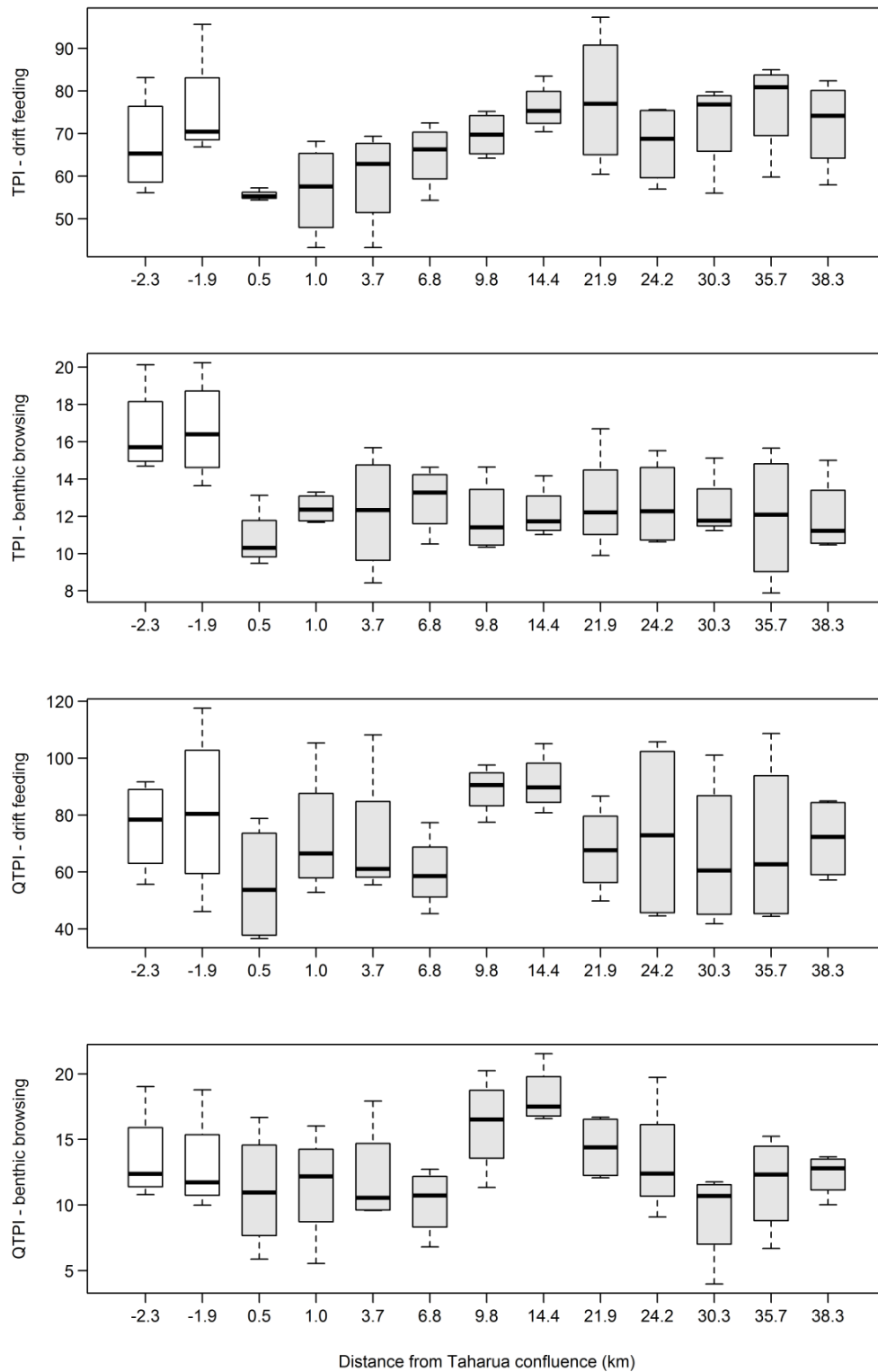


Figure 9. Box and whisker plots of standardised trout prey indices (TPIs) for drift-feeding and benthic-browsing feeding strategies, and quantitative TPIs (QTPIs) for drift-feeding and benthic-browsing feeding strategies for sites (averaged across sample occasion) in the Mohaka River upstream (white boxes) and downstream (grey shaded boxes) of the Taharua River confluence. Dark bars in the middle of the boxes are median values, the top and bottom of the boxes represent the upper and lower quartiles, and whiskers are the minimum and maximum values.

4. CONCLUSIONS

- There was a distinct and statistically significant change in invertebrate community assemblage based on abundance data in the Mohaka River immediately below the confluence with the Taharua on all sampling occasions. On three sampling occasions this change was driven by an increase in dipteran diversity and abundance associated with increased periphyton cover and biomass.
- On the three sampling occasions drift-feeding and benthic-browsing trout prey indices indicated the quality of food for adult trout was reduced below the Taharua confluence (at least between 0.5 to 1.0 km downstream).
- Longitudinal patterns in benthic density, biomass and QTPI scores, beyond 1 km downstream, were probably confounded by the inflow of tributaries or other segment-scale influences.
- The densities, TPI and QTPI scores in the Mohaka River longitudinal survey compared favourably to rivers outside of the Hawke's Bay region.

5. ACKNOWLEDGEMENTS

We thank Annika Wagenhoff (Cawthron) for statistical advice and analysis in R, and Robyn Dunmore for statistical advice and presentation of results.

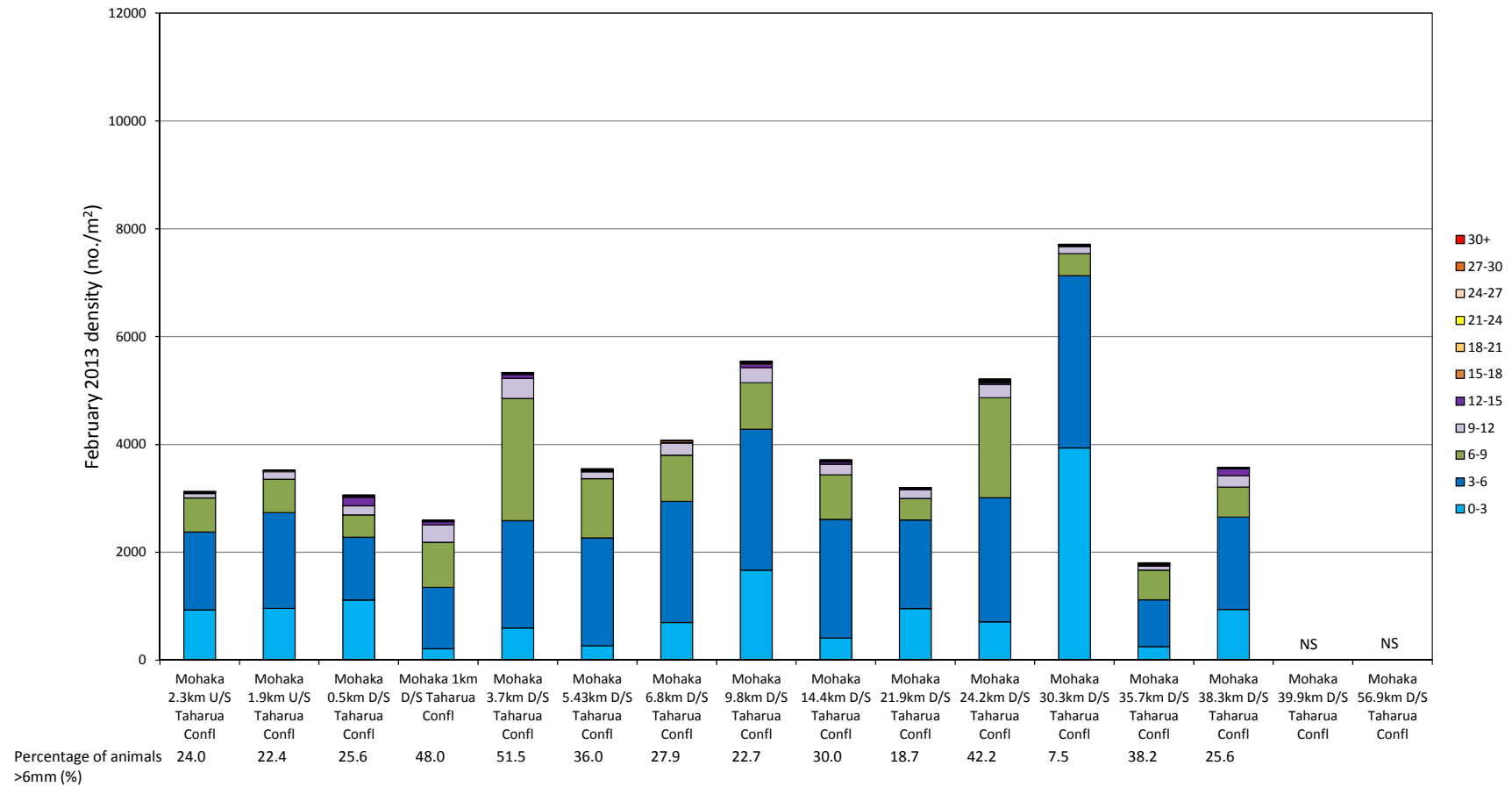
6. REFERENCES

- Anderson MJ 2001. A new method for non-parametric multivariate analysis of variance. *Austral Ecology* 26: 32-46.
- Anderson MJ, Gorley RN 2007. PERMANOVA+ for PRIMER: guide to software and statistical methods. PRIMER-E, Plymouth, UK.
- Clarke KR 1993. Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* 18:117-143.
- Clarke KR, Gorley 2006. PRIMER v6.1.6: User manual/tutorial. Plymouth, UK.
- Hawke's Bay Regional Council (HBRC) 2015. Mohaka River catchment. State and trends of river water quality and ecology. HBRC DRAFT Report No. 4644.
- Hayes JW 2014. Evidence on potential effects of changes to water quality conditions, periphyton and benthic macroinvertebrates on trout and native fish associated with Palmerston North City Council's Wastewater Treatment Plant discharge to the Manawatu River. Presented on behalf of Palmerston North City Council to the Environment Court in the matter of a review under section 128(1)(a)(iii) of the RM Act of Palmerston North City Council's resource consent to discharge treated wastewater to the Manawatu River. Cawthron Institute, Nelson.
- Hayes JW, Hay J 2006. Review of water quality and ecological monitoring of the Taharua River. Cawthron Report No. 1233. 23 p.
- Legendre P, Anderson MJ 1999. Distance-based redundancy analysis: testing multispecies responses in multifactorial ecological experiments. *Ecological Monographs* 69: 1-24.
- Matheson F, Quinn J, Hickey C 2012. Review of the New Zealand instream plant and nutrient guidelines and development of an extended decision making framework: Phases 1 and 2 final report. Report prepared for the Ministry of Science & Innovation Envirolink Fund. Client report number HAM2012-081.
- Quinn JM, Hickey CW 1990. Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors. *New Zealand Journal of Marine and Freshwater Research* 24:387-409.
- Sample BE, Cooper RJ, Greer RD, Whitmore RC 1993. Estimation of insect biomass by length and width. *The American Midland Naturalist* 129: 234-240.
- Shearer K 2105 Potential effects of Taharua River outflows on the upper Mohaka River in relation to drift-feeding fish - cursory analysis of results. Letter to HBRC dated 30 March 2015. Cawthron Institute, Nelson.
- Shearer KA, Hayes JW 2010. Invertebrate drift and trout growth potential in the Taharua and upper Mohaka rivers: an investigation of effects of dairy farming across three seasons. Cawthron Report No. 1832. 54 p. plus appendices.

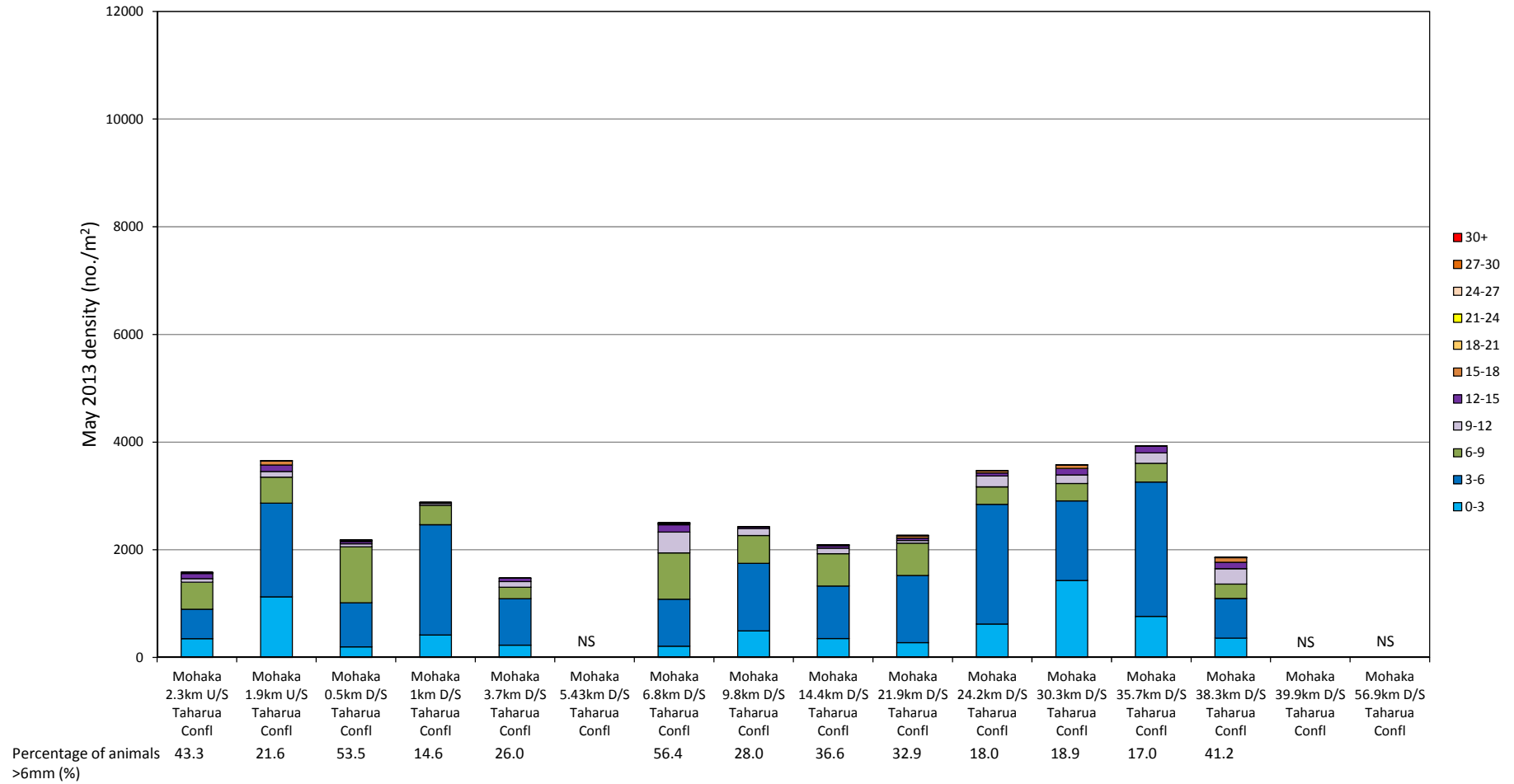
- Stansfield B 2008. Upper Mohaka catchment water quality and benthic ecology. Environmental Management Group Technical Report, Hawke's Bay Regional Council.
- Stark JD 1985. A macroinvertebrate community index of water quality for stony streams. Water & Soil Miscellaneous Publication 87. Wellington, Ministry of Works and Development. 53 p.
- Stark JD 1993. Performance of the Macroinvertebrate Community Index: effects of sampling method, sample replication, water depth, current velocity and substratum on index values. New Zealand Journal of Marine and Freshwater Research 27: 463-478.
- Towers, DJ, Henderson IM, Veltman CJ 1994. Predicting dry weight of New Zealand aquatic macroinvertebrates from linear dimensions. New Zealand Journal of Marine and Freshwater Research 28: 159-166.
- Wankowski JWJ 1979. Morphological limitations, prey size selectivity, and growth response of juvenile Atlantic salmon, *Salmo salar*. Journal of Fish Biology 14: 89-100.

7. APPENDICES

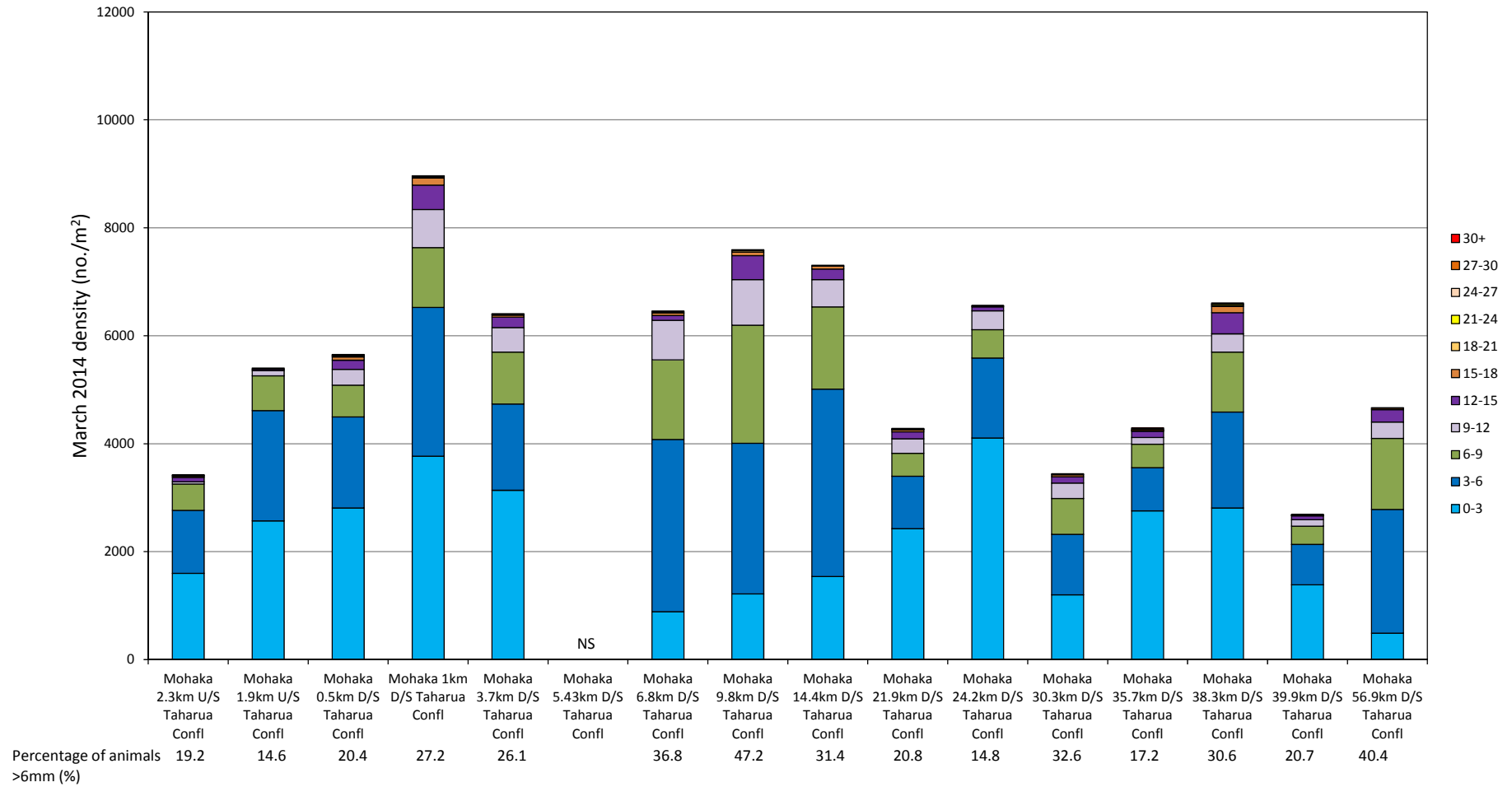
Appendix 1. Aquatic invertebrate benthic density (no./m²) by 3-mm size class for the Mohaka River upstream and downstream of the confluence with the Taharua River for the four sampling occasions (February 2013, May 2013, March 2014 and January 2015). The proportional contribution of invertebrates greater than 6 mm to the total biomass are given for each site below the graphs. NS indicates site not sampled.



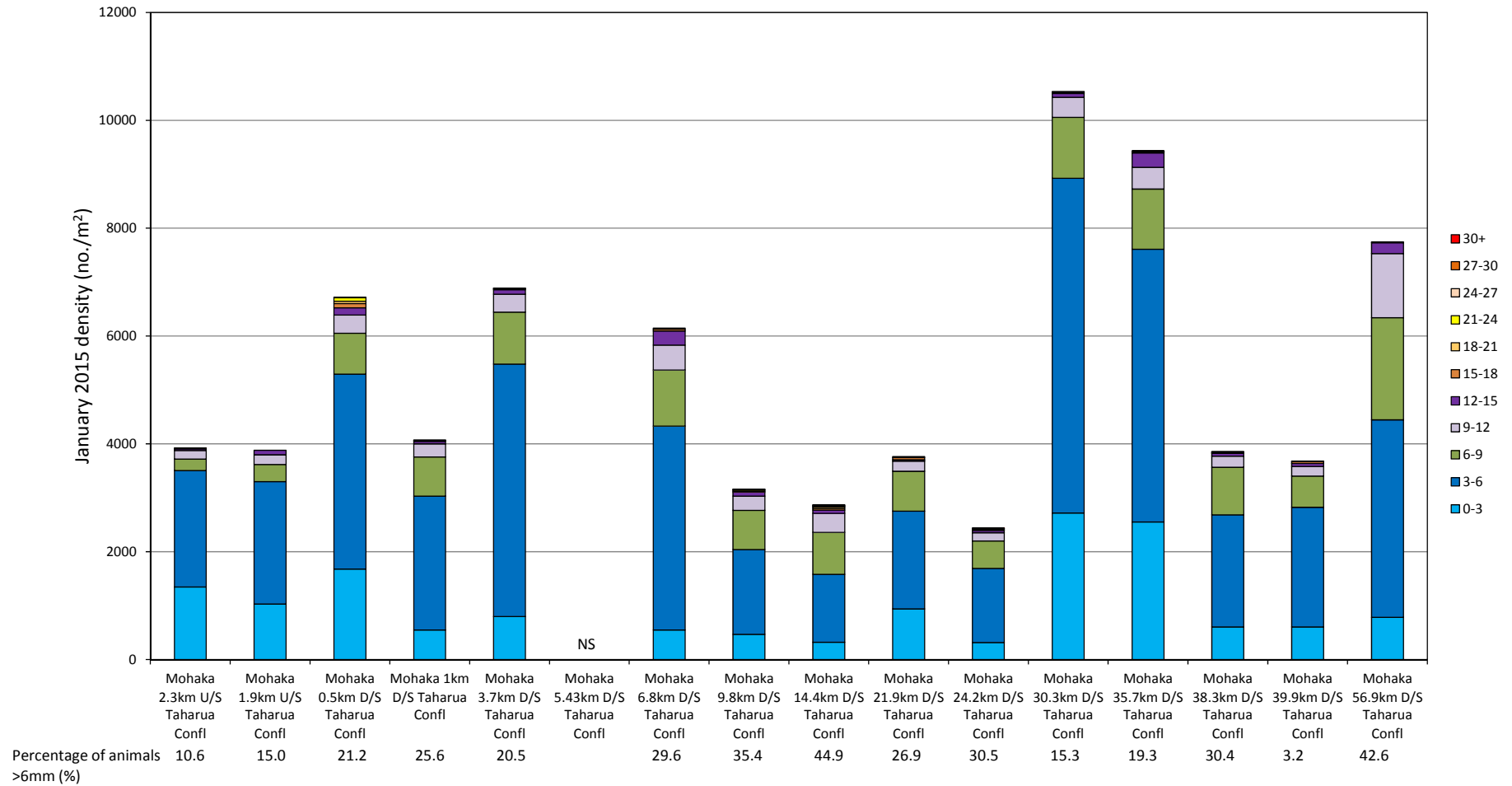
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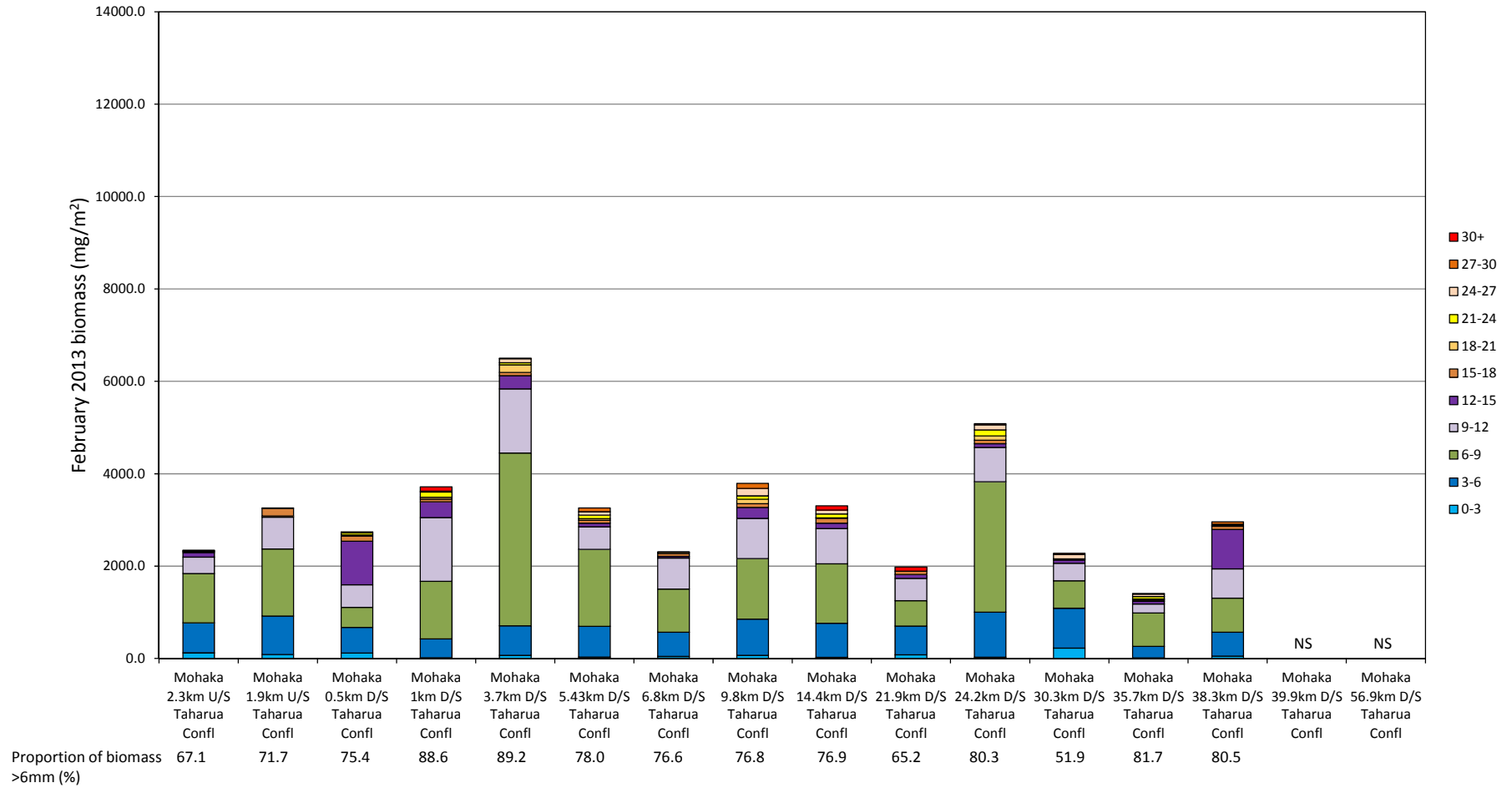
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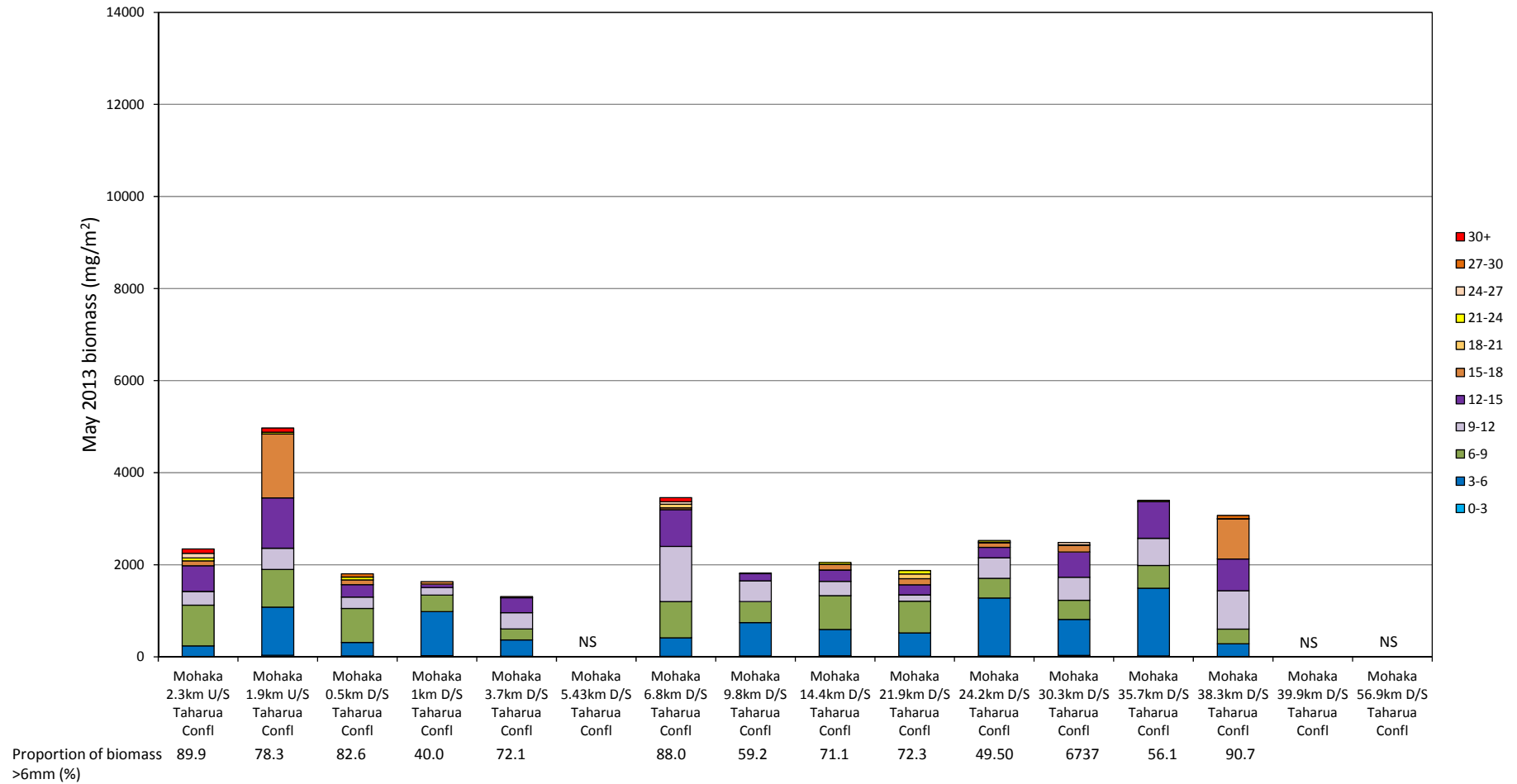
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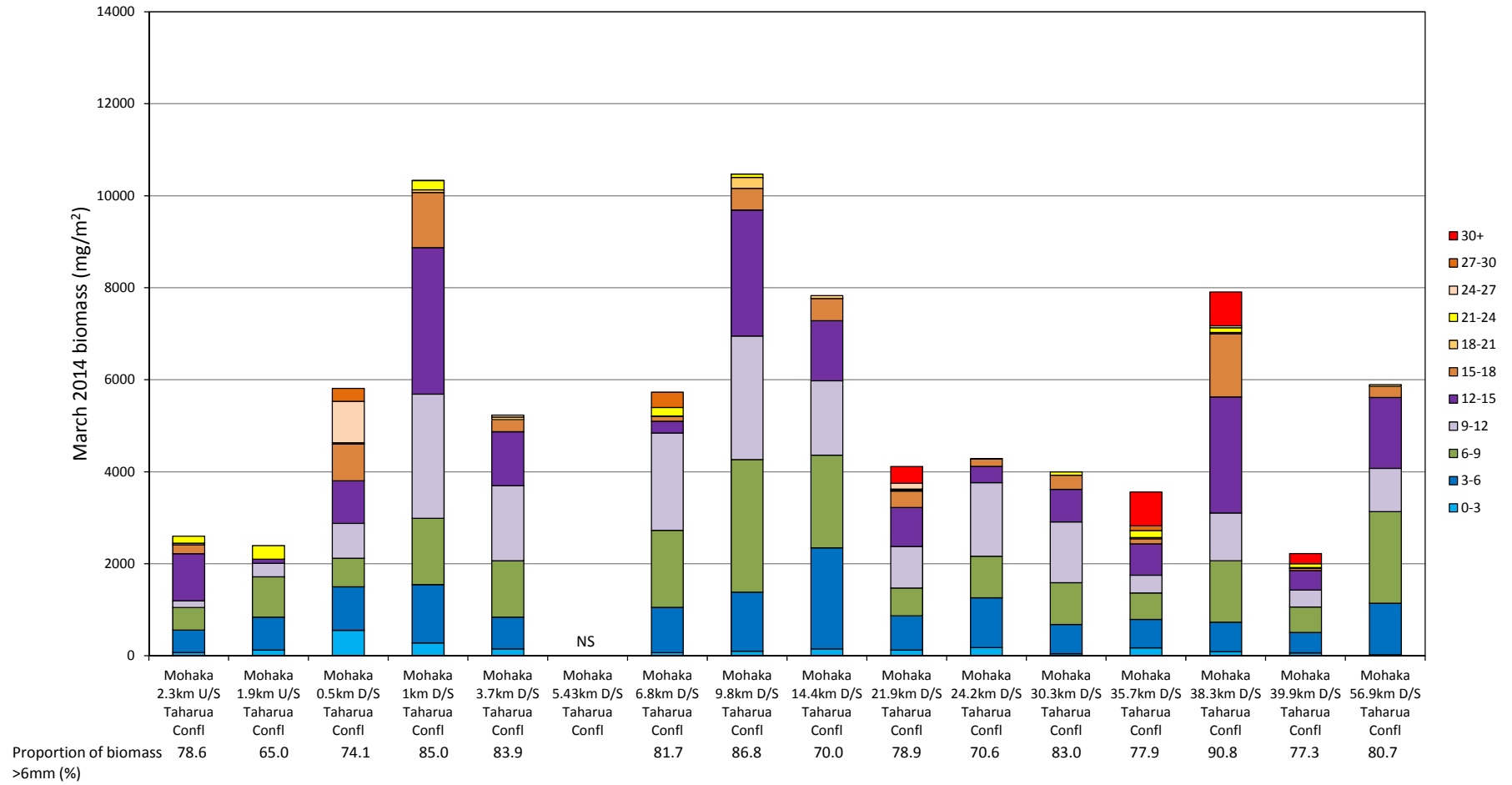
Appendix 2. Aquatic invertebrate benthic biomass (mg/m²) by 3-mm size class for the Mohaka River upstream and downstream of the confluence with the Taharua River for the four sampling occasions (February 2013, May 2013, March 2014 and January 2015). The proportional contribution of invertebrates greater than 6 mm to the total biomass are given for each site below the graphs. NS indicates site not sampled.



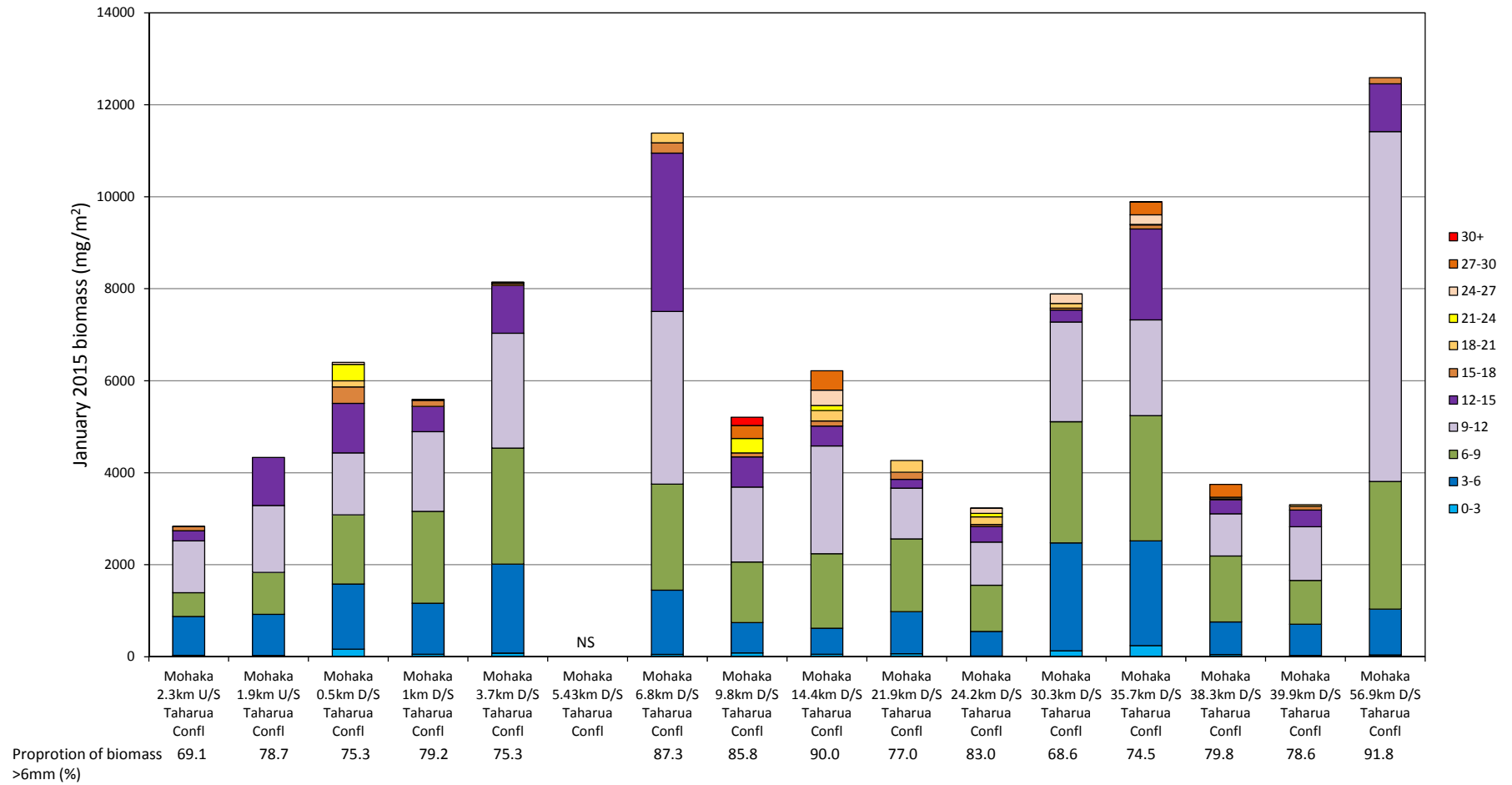
Appendix 2 continued



Appendix 2 continued



Appendix 2 continued



Appendix 3. Scatterplots of all environmental variables measured at each site along the Mohaka River on all four sampling occasions. Loess smoothers (blue lines) $\pm 95\%$ confidence intervals (grey shading) were fitted to the data to aid visualisation. See Methods section 2.2.3 for a description of the variable abbreviations and units.

