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Artificial substrate monitoring of macroinvertebrates in the Waikato River: 25 years on

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Abstract

Macroinvertebrates were monitored over 2006-07 using artificial multiplate samplers at 6 sites on the Waikato River: Huka Falls, Ohakuri, Narrows, Horotiu, Ngaruawahia and Rangiriri, repeating a survey conducted in 1980-82. The data provide (i) direct comparisons between surveys conducted 25 years apart, (ii) assessment of macroinvertebrate abundance and community composition on perspex samplers for 6 bimonthly occasions, and (iii) comparisons between hardboard or perspex samplers. In 2006-07, the macroinvertebrate community colonising substrates at these sites was dominated by Mollusca (primarily the snail *Potamopyrgus antipodarum*) in the upper river (Huka and Ohakuri sites) and by Crustacea (primarily the amphipod *Paracalliope fluviatilis*) in the lower river. The use of wood versus perspex substrates did not significantly influence the composition or diversity of macroinvertebrate communities but did affect the abundance of some taxa, indicating that comparisons of composition and diversity can be made between substrate types. Diversity of the macroinvertebrate community in 2006-07 tended to increase with distance downstream, reaching a peak at the Ngaruawahia site before declining at the Rangiriri site. These longitudinal changes likely reflect downstream patterns in water quality, shore-zone habitat diversity and flow variability within the river. Downstream patterns of diversity detected in 2006-07 corresponded to those reported by Davenport (1982), and were similar for taxonomic richness although more taxa were collected overall in 2006-07. There appeared to have been a change in macroinvertebrate community composition (excluding oligochaete worms) from the 1980-82 study with a shift in dominance from chironomid larvae to snails in the upper river in 2006-07, and a shift from dominance of snails to crustaceans in the lower river. Possible explanations for this apparent shift in community composition include (i) differences in methodologies between studies, (ii) variations in climatic conditions prevailing at the time of the two studies, and/or (iii) changes to the river in the intervening period.

1 Introduction

Macroinvertebrates are widely used in wadeable streams as indicators of water quality because of their sessile nature, short-life histories, relatively well-known taxonomy and habitat requirements, and ease of collection (Hellawell, 1978; Rosenberg & Resh, 1993; Boothroyd & Stark, 2000). In addition to integrating the effects of water quality, macroinvertebrate community composition can also be influenced by other environmental factors, including habitat quality, substrate type, and the flow regime prior to sampling. Collecting macroinvertebrates in large rivers is hampered by the physical difficulties associated with accessing deep flowing water, and consequently their responses to environmental conditions are less well known than for wadeable streams.

In the early 1980s, a monitoring survey was conducted at 6 sites down the Waikato River (Davenport 1982) aimed at expanding the limited information available on the distribution and relative abundance of macroinvertebrates. This study used multiplate hardboard samplers to create a consistent habitat for macroinvertebrate colonisation and enhance comparability among sites. Since then, the only other longitudinal survey covering the same spatial extent in the Waikato River has been that of Carter (2000) who used a combination of sweep-netting and air-lift sampling to collect invertebrates from shallow water (<1 m deep). The use of different sampling methods means the results of the Davenport (1982) and Carter (2000) studies cannot be compared directly.

We repeated the Davenport (1982) study in 2006-07 at the same sites and with the same frequency to evaluate any changes in the macroinvertebrate community, and to provide information on spatial and temporal patterns of the contemporary river fauna. This report details the findings of the 2006-07 monitoring and discusses differences between these findings and those conducted 25 years earlier. In addition, on every second sampling occasion in 2006-07, we compared samplers made from more widely available perspex with the hardboard samplers and retrieval methods used by Davenport (1982). On other occasions, only perspex samplers were used in association with a net mesh size consistent with current national monitoring protocols for wadeable streams (Stark et al. 2001). Consequently, the 2006-07 data provide (i) direct comparisons with the Davenport (1982) survey for 3 occasions ('study comparison'), (ii) assessment of macroinvertebrate abundance and community composition on perspex samplers on 6 bimonthly occasions ('seasonal comparison'), and (iii) quantification of differences between macroinvertebrate communities colonising hardboard (referred to hereafter as 'wood') or perspex samplers on 3 occasions ('sampler comparison').

2 Sampling sites

Artificial substrates were deployed at 6 sites on the Waikato River between Huka Falls and Rangiriri, spanning a river distance of around 240 km. The Huka site (2778918E, 6278661N) was above the falls on the true right side in a backwater area where there was some circulation of water along a steep bank. The river depth at this site was >5 m. The Ohakuri site (2779481E, 6306108N) was c.350 m below Ohakuri Dam in a backwater area on the true right with circulating water fed by the fast-flowing main channel. Depth during deployment and retrieval was around 2-3 m, and riparian vegetation comprised mainly native species, although willows (*Salix* sp.) on the river edge grew out over the water and provided convenient anchoring sites for substrate deployment. Bottom materials appeared to be mainly cobbles. The Narrows site (2716817E, 6370859N) was above Hamilton City in a gorge section of the river. Depth at the river edge where substrates were deployed was around 1-2 m; bottom substrates were not visible. The Horotiu site (2704864E, 6387048N) comprised a shallow gravel shelf that extended out into the river from the true right bank colonised by riparian poplar trees. The Ngaruawahia site (2699295E, 6391545N) was on the true left bank c.500 m below the confluence with Waipa River which dominated the flow and increased turbidity at this site, contributing to the development of muddy substrates. Riparian willows grew out over the channel and water depth was around 2 m during deployment and retrieval. The most downstream site was below the Rangiriri Bridge (2698676E, 6416834N) on the true right bank where rank pasture grass dominated riparian vegetation along with the occasional willow tree. In 2006-07, the riverbed substrate was mainly sand with abundant growths of aquatic macrophytes dominated by *Ceratophyllum demersum*.

3 Methods

3.1 1980-82 study

3.1.1 Deployment and retrieval

The sampling period of the Davenport (1982) study extended from 30/7/1980 to 22/3/1982. The then Waikato Valley Authority constructed artificial substrates from 3 mm thick tempered hardboard wood, modified from the design of Hester & Dendy (1962) and Fullner (1971). A central stainless steel rod had 15 hardboard plates (7.5 x 7.5 cm and 3 mm thick) mounted on it separated by 2 to 5 mm spacers creating different sized microhabitats (Davenport 1982). The total planar surface area available for colonisation by invertebrates was 0.17 m^2. At some sites the substrates were bolted to a heavy flat steel base and lowered to the required depth and position. At other sites, metal warratahs were driven into the river bed and the substrates bolted to these while using SCUBA apparatus. A long-handled net was used to help recovery of the substrates bolted to steel plates, while a draw string bag of the same mesh size was used for SCUBA retrievals.

A minimum of 3 substrates was deployed at each site on each date. The artificial substrates were deployed 9 times and most for approximately 8 weeks (range 28-143 days, mean 63, median 57) to allow for adequate invertebrate colonisation. Substrates were retrieved (and replaced with new ones) using a fine mesh net on 9 occasions at the Huka Falls, Narrows and Horotiu sites. Due to losses, 8 retrievals were made at Ohakuri, 6 at Ngaruawahia and 4 at the Rangiriri site. Any macrophytes retrieved with the substrates were added to the sample.

3.1.2 Laboratory processing

Individual plates from each substrate were removed and washed into a counting tray. The invertebrates present were then identified and enumerated. The results from each plate were combined to create a total composite for each sampling period at each site. The results from Huka Falls, Narrows and Horotiu were the composite of 3 substrates except for the March 1981 retrieval at Horotiu and the March 1982 retrieval at Narrows when only one sampler was retrieved. For Rangiriri, Ohakuri and Ngaruawahia results were the composite of two substrates except for the January 1981 retrieval at Ngaruawahia when only one sampler was retrieved. Any pieces of macrophyte recovered with the substrates were dried and weighed. All worms (mostly small Naididae) were not counted in 1980-82 so total numbers were underestimated.

3.2 2006-07 study

3.2.1 Deployment and retrieval

The second study was conducted from July 2006 to July 2007 using two types of multiplate samplers. The wood samplers were the same dimensions as those used by Davenport (1982) described above except the plates were 4 mm tempered hardboard because the thinner board was no longer available. Variable spacing was maintained between hardboard plates which were soaked in water until any colour from leaching was not visible. Hardboard plates were deployed in September 2006, and in January and May 2007 (i.e., on every second sampling occasion). Perspex multiplate samplers were identical in configuration to the hardboard samplers except that plates were 2-3 mm thick and had their upper and lower surfaces roughened with a grinder. Perspex multiplate samplers were deployed every two months (July, September and November 2006, January, March and May 2007).

The two types of multiplate samplers were deployed in pairs on metal pegs bolted to the ends of concrete pavers (23 x 16 x 4 cm) (Plate 1). The pegs elevated the samplers 6 cm above the pavers. Three sets of samplers were deployed at each site by tying a rope through the pegs on either end of each brick so that they could be lowered with the multiplate samplers oriented upwards, and retrieved with minimal disturbance. Substrates were deployed where water was flowing, and were at or near the bottom except at the Huka site where the water was very deep and the pavers rested on a submerged shelf. Deployment depths varied depending on the characteristics of the site and ranged from <1 m at Horotiu to around 5 m at Huka Falls. Deployment periods spanned 55-79 days. Water temperature loggers (StowAway TidbiT, -5 to +37^{o}C) were tied to concrete pavers over 19 January to 21 March 2007, when lowest river flows were expected, to indicate whether substrates had been exposed (see Appendix 1 for temperature data and Appendix 2 for flow data).

At each site samplers were retrieved in a downstream to upstream sequence by gently pulling them out of the water using ropes that had been tied off to nearby vegetation. Triangular hand-nets were placed around each substrate before they were removed from the water to capture any invertebrates dislodged during transfer to land. A 0.25 mm mesh net was used for retrieving wood substrates corresponding to the mesh size used in 1980-82, while a 0.5 mm mesh was used for perspex to match national protocols for monitoring wadeable streams (Stark *et al.* 1981). Any trapped macrophytes were dislodged from the sampler prior to removal. Material caught in the nets along with the intact substrates was placed in plastic containers with a little river water, and then transported on ice to the laboratory. Three substrates were retrieved on each occasion except in July at Narrows (n = 2), and at Horotiu and Rangiriri in March (n = 1 and 2, respectively).

Plate 1: Paired multiplate samplers constructed from hardboard (left) and perspex (right) showing position of samplers in relation to the concrete paver.

3.2.2 Laboratory processing

In the laboratory, multiplate samplers were disassembled and individual plates were lightly rubbed and rinsed to dislodge any invertebrates. Material from the perspex samplers was passed through a 0.5 mm sieve, whereas material from the wood samplers was washed through nested 0.5 mm and 0.25 mm mesh sieves. These fractions were preserved separately to enable direct comparisons between perspex and wood plate samples (i.e., 0.5 mm fraction), and between wood plate samples from the both studies (0.5+0.25 mm fractions combined in 2006-07). Samples were stored in 70% isopropanol until invertebrates could be picked out on a white tray for identification. Level of taxonomic resolution was mostly to genus for Insecta, Crustacea and Mollusca, whereas most other taxa were identified to family. Ectoprocta (formerly Bryozoa) and Porifera (sponges) were excluded from analysis because they could not be enumerated.

3.3 Statistical analyses

Data were analysed to enable 3 comparisons

- **Study comparison**: The 1980-82 and 2006-07 studies were compared for wood samplers only using material retained by fine mesh sampling (i.e., 0.25 and 0.5 mm fractions combined for 2006-07) for corresponding deployment periods as the more recent study used wood samplers on every second sampling occasion (November, March and June-July). As the 1980-82 study extended over a longer period, duplicate dates were available for some retrieval months (November at all sites; March at Narrows), although comparisons among the 2 studies were limited to the same number of samples where possible. For the purposes of this analysis, taxonomic data were condensed to the highest level used in either study; in addition *Phreatogammarus* and *Paraleptamphopus* were combined into “other amphipods”, and platyhelminth, rhabdocoel and nemertean worms were combined into “flatworms”. Cladocera, Copepoda, Nematoda, Tardigrada and *Hydra* were excluded as these were not counted in 1980-82. Densities (no. per sampler) were not compared between studies because variable numbers of samplers were combined into single samples at each site in 1980-82.

- **Seasonal comparison**: The perspex sampler data were used to investigate seasonal patterns (bi-monthly) in macroinvertebrate community abundance and composition over the 2006-07 sampling period.

- **Sampler comparison**: Comparisons between the 0.5 mm material retained by the wood and perspex samplers in 2006-07 were used to determine whether there was any effect of sampler type on macroinvertebrate communities.

Comparisons of macroinvertebrate community percent abundance data were conducted in *Primer-E v.6.1.13* for each site and date (all replicates combined) following square-root transformation and using the Bray-Curtis similarity measure. Data were ordinated by non-metric multidimensional scaling (NMDS) to identify groupings of sites with similar biotic composition, and a vector plot was used to identify taxa highly correlated (r_s >0.5) with samples in ordination space. PERMANOVA was conducted on Bray-Curtis similarity measures derived from log transformed taxa count data of individual replicates to test for date and site effects in the perspex sampler data, and for sampler effects by comparing wood and perspex data from 2006-07. PERMANOVA was used to test for study effects using square-root transformed percent abundance data (all replicates combined over November, March and June-July retrieval dates because replicate data were not available for the 1980-82 study).

Analysis of Variance (ANOVA) was used to determine differences in four diversity measures:

- Taxa richness - the number of different taxa identified in each sample;

- Margalef diversity - calculated as **$d = (S-1) / \ln N$**, where S is the number of species and N is the number of individuals (this index standardises the number of species against the total number of individuals encountered);

- Pielou evenness – calculated as **J = SUM (p_i * $log_e(p_i)$) / log(S)**, where S is the total number of species collected and p_i is the proportion of individuals in a sample that belongs to species *i* (this index accounts for the different relative abundances of taxa);

- Shannon diversity – calculated as **H' = SUM (p_i * $log_e(p_i)$)**, where p_i is the proportion of individuals in a sample that belong to species *i* (this index accounts for both abundance and evenness of the species present).

ANOVA was also conducted on densities (no. per sampler – 0.17 m^2) of total invertebrates and major taxa (>300 total individuals and occurring in >30 samples) for the seasonal and sampler comparisons described above. Data used for ANOVAs were examined for normality using normal probability plots and were log transformed for densities; no transformations were deemed necessary for the diversity metrics because the data appeared normally distributed. Repeated measures ANOVA was not used because clean samplers were deployed on each occasion (i.e., each introduction represented an independent colonisation event).

4 Results

4.1 Community composition

4.1.1 Site and seasonal differences (perspex substrates)

In 2006-07, Crustacea or Mollusca comprised >40% of macroinvertebrates colonising perspex plates across all sampling occasions, with Mollusca more common at the upper river sites (Huka, Ohakuri) and Crustacea more common in samples from the lower river (Table 1). The amphipod *Paracalliope* dominated the Crustacea at all sites whereas the dominant mollusc was the widespread native hydrobiid snail *Potamopyrgus antipodarum*. Larvae of the order Diptera were relatively common at most sites (>12% except at Rangiriri), and consisted mostly of Orthocladiinae or Tanytarsini midge larvae. Oligochaeta (all Naididae) were relatively abundant only at the Huka site where Trichoptera were also most common (all Hydroptilidae). At Narrows, Horotiu and Ngaruawahia, the hydropsychid caddis *Aoteapsyche* was also relatively common (3-6%). Plecoptera (mostly *Zelandobius*) was found at all sites except Ohakuri, whereas Ephemeroptera was only collected at lower river sites with 8 taxa recorded at Ngaruawahia. Four taxa of introduced snail were recorded on perspex plates during the monitoring period: *Pseudosuccinea columnella*, *Physa acuta*, *Planorbarius corneus* and *Planorbella* sp. Collectively, these taxa comprised from <0.1% of total numbers at Ohakuri to 4% at Huka. Of these snails, only *Physa acuta* was reported by Davenport (1982).

Non-metric multidimensional scaling plots of taxa percent abundances confirmed a clear separation in community composition between upper river sites (Huka and Ohakuri) and lower river sites (Figure 1, Table 2). Of the lower river sites, Narrows and Horotiu had the least variable community composition over time, despite some exposure of substrates at Horotiu during low flows in summer (Appendix 1), whereas composition was more variable at Ngaruawahia and Rangiriri (i.e., points were more widely separated in ordination space).

Community composition varied significantly by date (‘seasonal comparison’), and the interaction between date and site indicated that temporal patterns were different among the 6 sites (Table 2). The upper river sites showed a seasonal pattern in mollusc relative abundances which were highest in late summer (March) and lowest in September (Figure 2), but few consistent seasonal patterns were evident for the other macroinvertebrate groups at lower river sites. At some sites over summer, invertebrates assigned to the “other” group made up significant proportions of total numbers; at Ohakuri *Hydra* made up two-thirds of invertebrates in January, whereas in

March the flatworm *Cura* made up 48% at Ngaruawahia and this taxon along with nemertean worms made up 70% of numbers at Rangiriri. Macroinvertebrate communities were most similar at all sites in September and different to those collected in summer (Figure 1). September samples were characterised by higher percentages of the stonefly *Zelandobius*, the hydroptilid caddis *Oxyethira*, orthoclad midge larvae and naidid worms.

Table 1: Percent abundance of the main invertebrate groups found on perspex substrates at 6 sites on the Waikato River over 2006-07 (dominant group at each site shown in bold).

	Huka	Ohakuri	Narrows	Horotiu	Ngaruawahia	Rangiriri
Ephemeroptera	0.0	0.0	0.2	0.2	2.6	0.1
Plecoptera	1.3	0.0	3.2	2.9	2.0	1.2
Trichoptera	11.1	1.5	9.1	7.6	9.4	7.7
Diptera	15.7	13.5	29.5	34.3	15.1	6.7
Crustacea	3.5	29.4	**48.8**	**47.6**	**45.7**	**58.4**
Mollusca	**42.8**	**41.2**	6.3	4.3	5.0	3.6
Oligochaeta	17.8	1.9	0.6	1.7	6.3	2.4
Other	7.8	12.5	2.4	1.5	14.0	19.9

Table 2 PERMANOVA results testing for effects of retrieval date and site on taxa numbers colonising perspex substrates deployed in the Waikato River over 2006-07.

Source	df	Sum of squares	Mean square	Pseudo-F	P (perm)
Site	5	61789	12358.0	5.258	**0.001**
Date	5	30545	6109.1	5.598	**0.001**
DatexSite	25	59615	2384.6	2.185	**0.001**
Residual	68	74208	1091.3		
Total	103	2.28E+05			

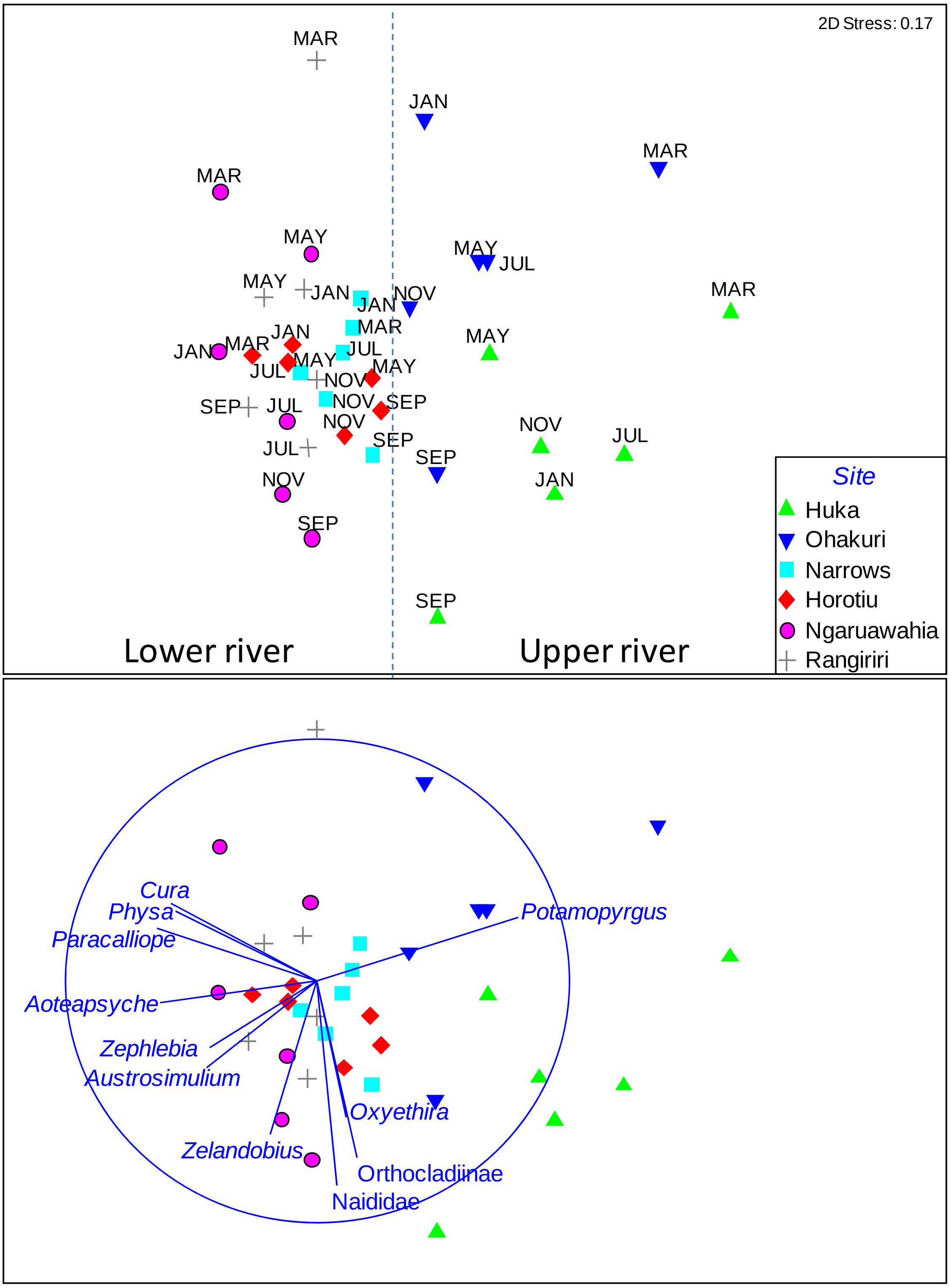

Figure 1: **Non-metric multidimensional scaling plot based on macroinvertebrate percent composition for 6 sites along the Waikato River using perspex multiplate samplers retrieved on 6 dates in 2006-07. Lower plot shows vectors of taxa highly correlated (r_s >0.5) with sample location in two-dimensional ordination space.**

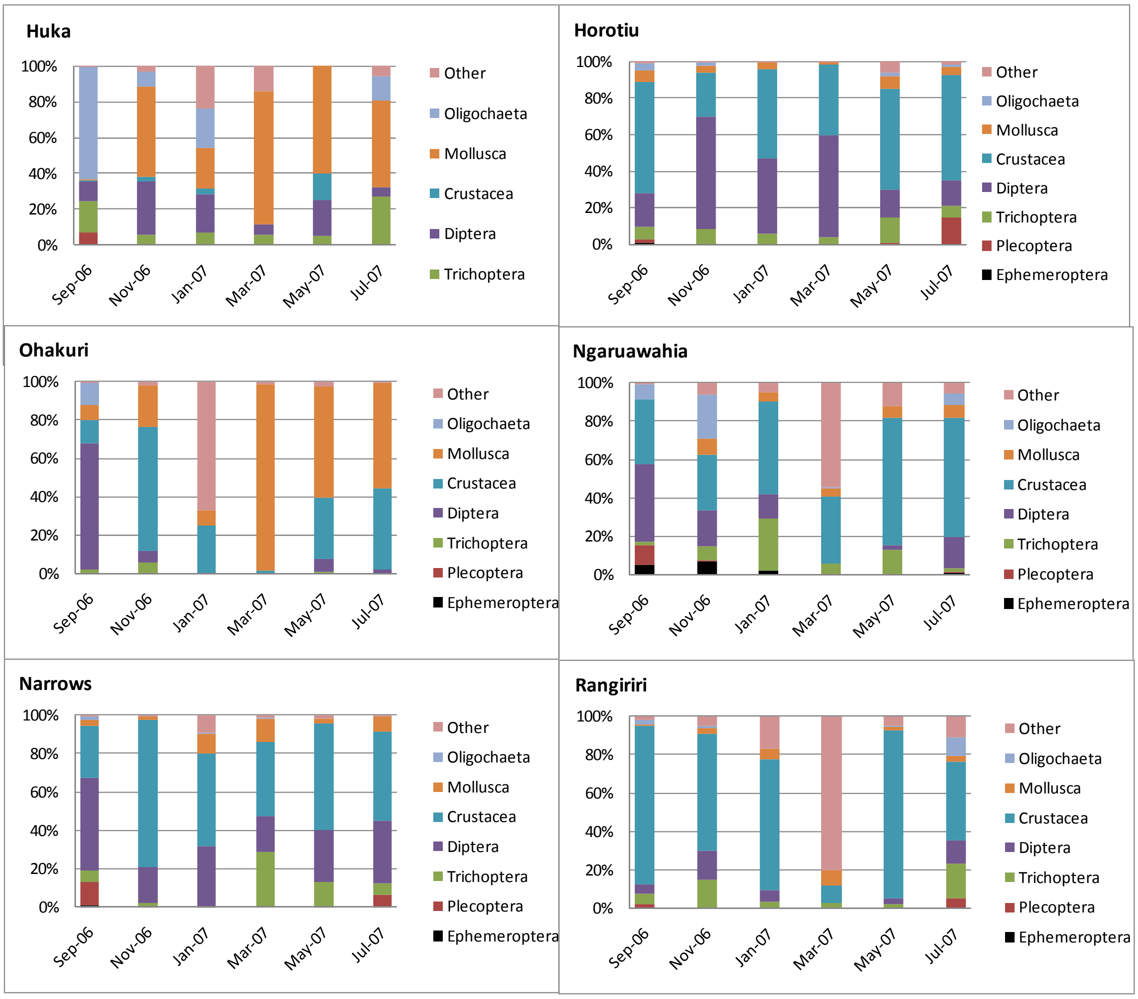

Figure 2: **Percent composition of main taxonomic groups at 6 sites along the Waikato River sampled using perspex multiplate samplers on 6 occasions over 2006-07.**

4.1.2 Sampler effects and study comparison

PERMANOVA indicated that the use of wood versus perspex plates ('sampler comparison') did not have a significant effect on macroinvertebrate community composition, and that this lack of difference was consistent across sites (Table 3). On the occasions that wood substrates were deployed in 2006-07, significantly different communities were collected compared to equivalent time periods in 1980-82 ('study comparison'), although the pattern of differences varied among sites (Table 4). Overall, Mollusca were relatively less common and Crustacea were relatively more common in the lower river in 2006-07 compared to 1980-82 (Figure 3). In contrast, at the upper river sites, Diptera were less common and Mollusca were more common at these times.

The non-metric multidimensional scaling plot confirmed a distinct compositional shift in macroinvertebrate communities retrieved from hardboard multiplate samplers in 2006-07 compared to 1980-82 (Figure 4). In 2006-07, community composition at the upper river site shifted towards the bottom left of the ordination, characteristic of samples dominated more by molluscs such as *Potamopyrgus* and *Physa*. The lower river samples moved towards the top of the ordination where samples were characterised more by the limpet *Ferrissia*, the amphipod *Paracalliope,* and other amphipods and flatworms (Figure 4). The upper river sites to the right of the ordination in 1982 reflected more Chironomidae.

Table 3: **PERMANOVA results testing for effects of site and sampler type (perspex or wood) on taxa numbers colonising artificial substrates deployed in the Waikato River over 2006-07.**

Source	df	Sum of squares	Mean square	Pseudo-F	P (perm)
Site	5	74623.0	14925	10.000	**0.001**
Sampler	1	2079.4	2079.4	1.393	0.171
SitexSampler	5	4823.8	964.8	0.646	0.975
Residual	90	1.3134E5	1492.5		
Total	101	2.1292E5			

Table 4: **PERMANOVA results testing for effects of site and study (1980-82 vs 2006-07) on taxa percent abundances (excluding Oligochaeta and Nematoda) colonising wood substrates deployed in the Waikato River.**

Source	df	Sum of squares	Mean square	Pseudo-F	P (perm)
Study	1	9550	9550.4	11.547	**0.001**
Site	5	18928	3785.6	4.577	**0.001**
StudyxSite	5	20566	4113.2	4.973	**0.001**
Residual	27	22332	827.12		
Total	38	73331			

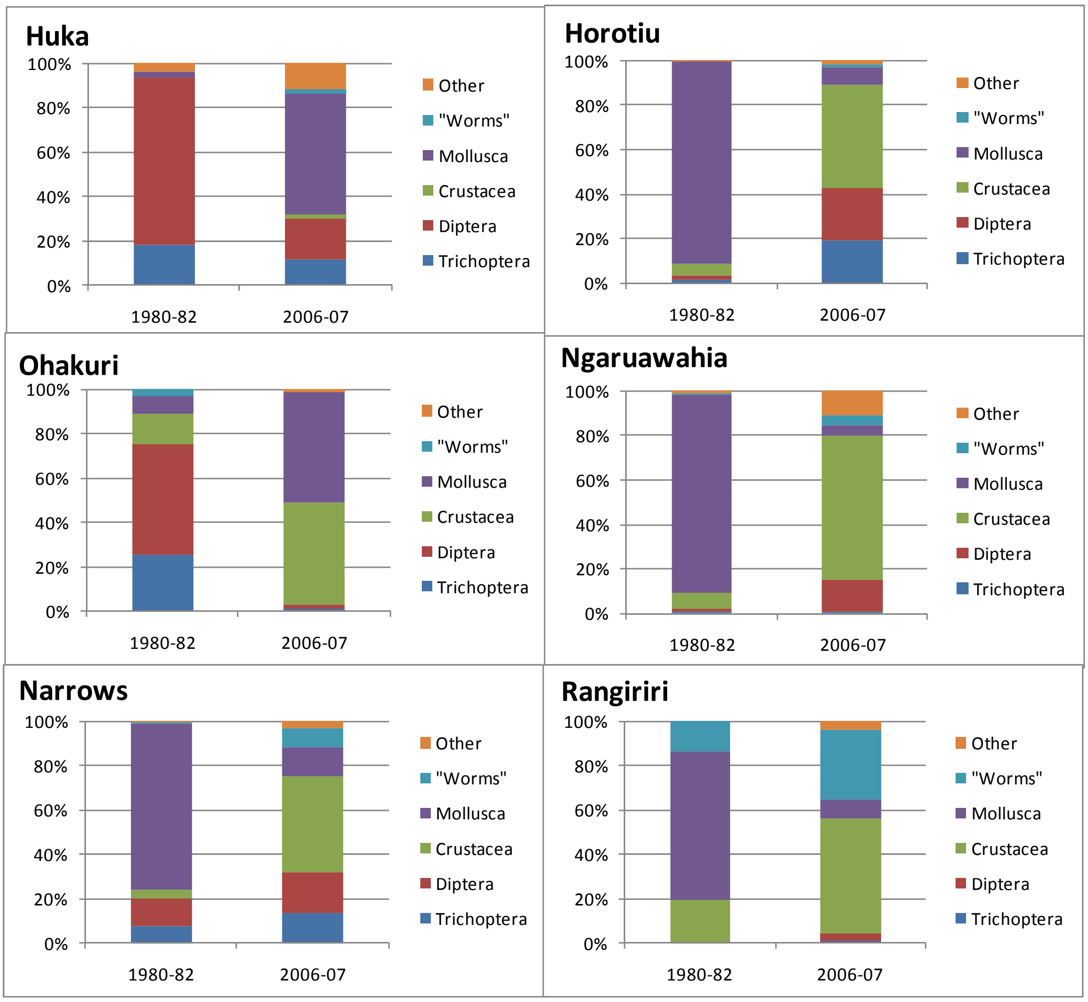

Figure 3: **Percent composition of main taxonomic groups at 6 sites along the Waikato River sampled using wood multiplate samplers on comparable dates over 1980-82 and 2006-07. "Worms" = Nemertea, Rhabdocoela and Platyhelminthes. Oligochaeta and Nematoda were excluded because they were not fully enumerated in 1980-82.**

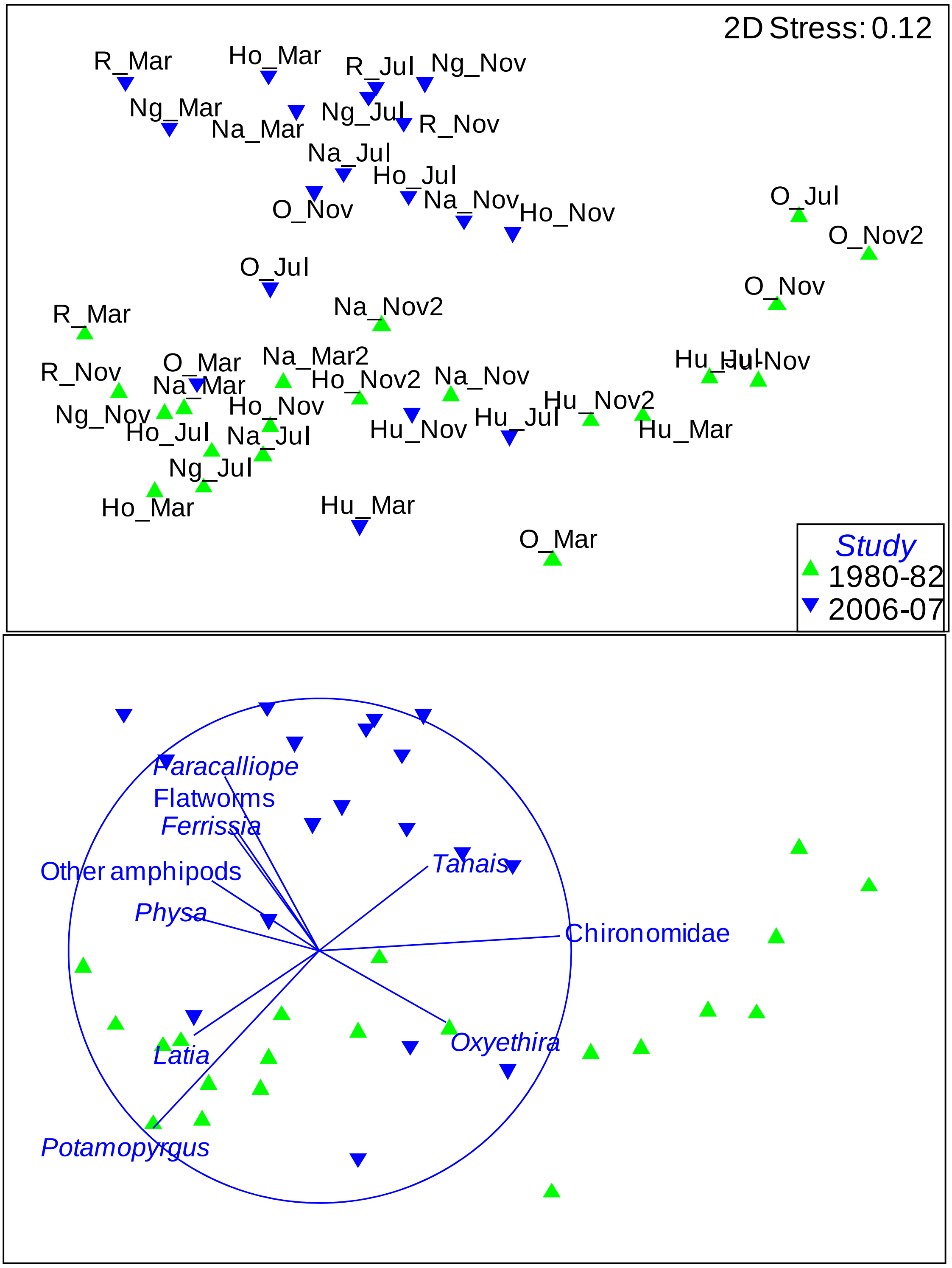

Figure 4: **Non-metric multidimensional scaling plot based on macroinvertebrate percent composition (excluding Oligochaeta and Nematoda) for 6 sites along the Waikato River sampled on 2-5 dates using wood multiplate samplers in 1980-82 and 2006-07. Lower plot shows vectors of taxa highly correlated (r_s >0.5) with sample location in two-dimensional ordination space.**

4.2 Diversity

4.2.1 Site and seasonal differences (perspex substrates)

In 2006-07, an average of 8 taxa per sampler was recorded across all sites, ranging from 5 at the Huka site to 11 at the Ngaruawahia site (Table 5, Figure 5). Margalef diversity was also highest on average at Ngaruawahia but lowest at Ohakuri. Similarly, Pielou evenness and Shannon diversity were lowest at Ohakuri, but there was little variability in these average measures among other sites. ANOVA indicated highly significant site effects for all diversity measures, and significant effects of retrieval date for taxa richness and evenness. Site by date interactions were evident for all measures except Margalef diversity, indicating that site differences were consistent across dates for Margalef diversity but not for other measures (Table 6).

4.2.2 Sampler effects and study comparison

The use of wood or perspex substrates did not have a significant effect on taxa richness, Margalef diversity, Pielou evenness or Shannon diversity (Tables 7 and 8). Overall, taxa richness was significantly lower ($F_{1,27} = 14.927$, $P < 0.001$) for the 1980-82 study than the 2006-07 study (averages of 8.2 and 11.3 taxa, respectively, across all comparable sampling occasions; Figure 6). Significant site effects were detected ($F_{5,27} = 11.455$, $P < 0.001$) and these were consistent over both sampling occasions (i.e., interaction terms were not significant; $F_{5,27} = 0.921$, $P > 0.05$). Other diversity measures were not compared between the 2 studies because they take account of abundances which were not fully quantified in 1980-82.

Table 5: Average measures of diversity per sampler (perspex) across all dates for 6 sites along the Waikato River in 2006-07.

Site	Taxa richness	Margalef diversity	Peilou evenness	Shannon diversity
Huka	5.2	1.4	0.8	1.2
Ohakuri	5.9	1.1	0.5	0.9
Narrows	7.9	1.6	0.7	1.3
Horotiu	10.5	1.9	0.6	1.4
Ngaruawahia	10.7	2.2	0.6	1.4
Rangiriri	8.9	1.8	0.6	1.2
Overall	8.2	1.7	0.6	1.2

Table 6: Analysis of Variance statistics for 4 measures of diversity based on macroinvertebrate numbers collected from perspex samplers retrieved on 6 dates in 2006-07 from 6 sites on the Waikato River.

Source	df	Sum-of-Squares	Mean-Square	F-ratio	P
Taxa richness					
Site	5	455.652	91.130	14.322	**0.000**
Date	5	130.513	26.103	4.102	**0.003**
SitexDate	25	307.003	12.280	1.930	**0.017**
Error	68	432.667	6.363		
Margalef					
Site	5	12.717	2.543	9.609	**0.000**
Date	5	1.598	0.320	1.208	0.315
SitexDate	25	10.913	0.437	1.649	0.054
Error	68	17.999	0.265		
Pielou					
Site	5	0.654	0.131	5.593	**0.000**
Date	5	0.423	0.085	3.613	**0.006**
SitexDate	25	1.474	0.059	2.521	**0.001**
Error	67	1.567	0.023		
Shannon					
Site	5	3.256	0.651	5.152	**0.000**
Date	5	0.451	0.090	0.714	0.615
SitexDate	25	8.392	0.336	2.656	**0.001**
Error	68	8.594	0.126		

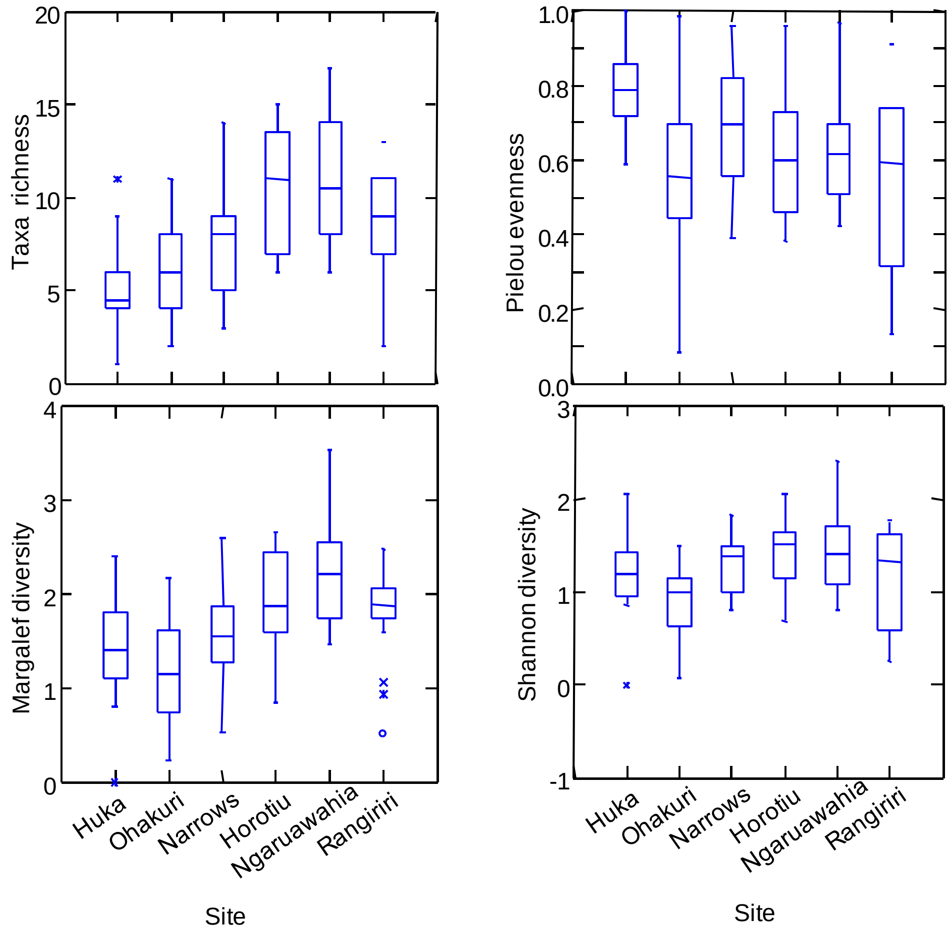

Figure 5: **Box and whisker plots of diversity measures derived from macroinvertebrate numbers on perspex artificial samplers deployed at 6 sites on the Waikato River (all dates combined) in 2006-07. Boxes = interquartile range within which 50% of values fall; line within boxes = median; hinges = 1.5 x H-spread; crossed and circles = outliers and extreme outliers, respectively.**

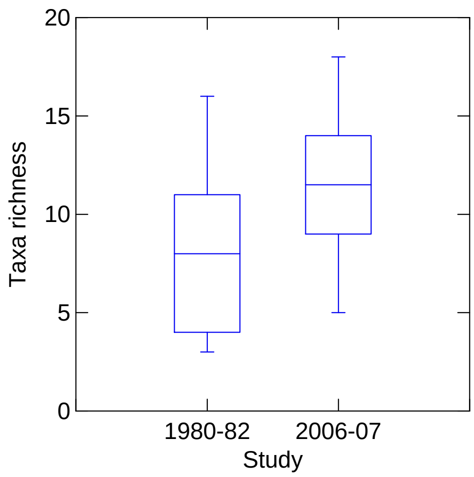

Figure 6: **Box and whisker plot of taxa richness from wood samplers deployed at 6 sites on the Waikato River in two studies (all dates combined; the same time periods in the two studies are compared). *n* = 55 for 1980-82 and *n* = 50 for 2006-07. Other diversity metrics were not analysed because they take into account abundance which was underestimated in the 1980-82 sample processing due to Oligochaeta and Nematoda not being fully enumerated. See Figure 5 for key to box plot.**

Table 7: Average measures of diversity per sampler for perspex or wood multiplate substrates sampled on 3 dates in 2006-07 for 6 sites along the Waikato River.

Site	Substrate	Taxa richness	Margalef diversity	Peilou evenness	Shannon diversity
Huka	Perspex	4.6	1.4	0.8	1.1
	Wood	5.7	1.3	0.7	1.1
Ohakuri	Perspex	4.9	0.9	0.5	0.7
	Wood	4.8	0.8	0.4	0.7
Narrows	Perspex	7.0	1.6	0.7	1.3
	Wood	9.1	1.7	0.5	1.2
Horotiu	Perspex	11.6	1.9	0.5	1.3
	Wood	12.0	1.9	0.5	1.3
Ngaruawahia	Perspex	11.3	2.4	0.7	1.6
	Wood	10.6	2.2	0.7	1.5
Rangiriri	Perspex	8.9	1.9	0.7	1.5
	Wood	10.8	1.9	0.5	1.1

Table 8: Analysis of Variance statistics for 4 measures of diversity based on macroinvertebrate numbers from perspex and wood samplers retrieved on 3 dates in 2006-07 from 6 sites on the Waikato River.

Source	df	Sum-of-Squares	Mean-Square	F-ratio	P
Taxa richness					
Site	5	732.756	146.551	17.199	**0.000**
Substrate	1	14.893	14.893	1.748	0.199
SitexSubstrate	5	27.411	5.482	0.643	0.667
Error	88	749.853	8.521		
Margalef					
Site	5	22.210	4.442	13.559	**0.000**
Substrate	1	0.105	0.105	0.320	0.573
SitexSubstrate	5	0.405	0.081	0.247	0.940
Error	88	28.829	0.328		
Pielou					
Site	5	0.713	0.143	3.361	**0.008**
Substrate	1	0.237	0.237	5.585	**0.020**
SitexSubstrate	5	0.138	0.028	0.648	0.664
Error	86	3.652	0.042		
Shannon					
Site	5	7.537	1.507	7.671	**0.000**
Substrate	1	0.283	0.283	1.441	0.233
SitexSubstrate	5	0.584	0.117	0.595	0.704
Error	88	17.291	0.196		

4.3 Density (perspex substrates)

Overall, the perspex multiplate samplers had lowest densities of invertebrates at the Huka site and highest densities at Horotiu, despite periodic exposure of substrates over summer at the latter site (Figure 7; see also Appendix 1). This pattern was generally consistent for the net-spinning caddis *Aoteapsyche*, the algal-piercing caddis *Oxyethria*, and the midges Orthocladiinae and Tanytarsini. Densities declined noticeably at the Ngaruawahia site for total invertebrates, *Oxyethira* and *Paracalliope* which otherwise tended to increase with distance down the river. Densities of the snail *Potamopyrgus* and Naididae worms were highest at the Ohakuri and Huka sites, respectively. Analysis of variance indicated statistically significant differences occurred across sites for all major invertebrate taxa, with only *Aoteapsyche* not displaying significant date effects. All major taxa exhibited variable site responses on different dates (i.e., significant site by date interactions; Table 9). Generally, total invertebrate densities were low at all sites in winter (July), and also in March and May at the upper river sites (Figure 8). In contrast, densities tended to increase over September-March at Narrows and decrease over September to July at the two most downstream sites (Ngaruawahia and Rangiriri). Significant effects of substrate type (wood versus perspex) were evident for densities of *Paracalliope* ($F_{1,88}$ = 11.260, P =0.001), *Potamopyrgus* ($F_{1,88}$ = 5.107, P <0.05), and total numbers ($F_{1,88}$ = 11.472, P =0.001), with densities of these taxa consistently higher on wooden plates across all sites (i.e., no significant interaction term). Densities were not compared between the 2 studies because abundances were not fully quantified in 1980-82.

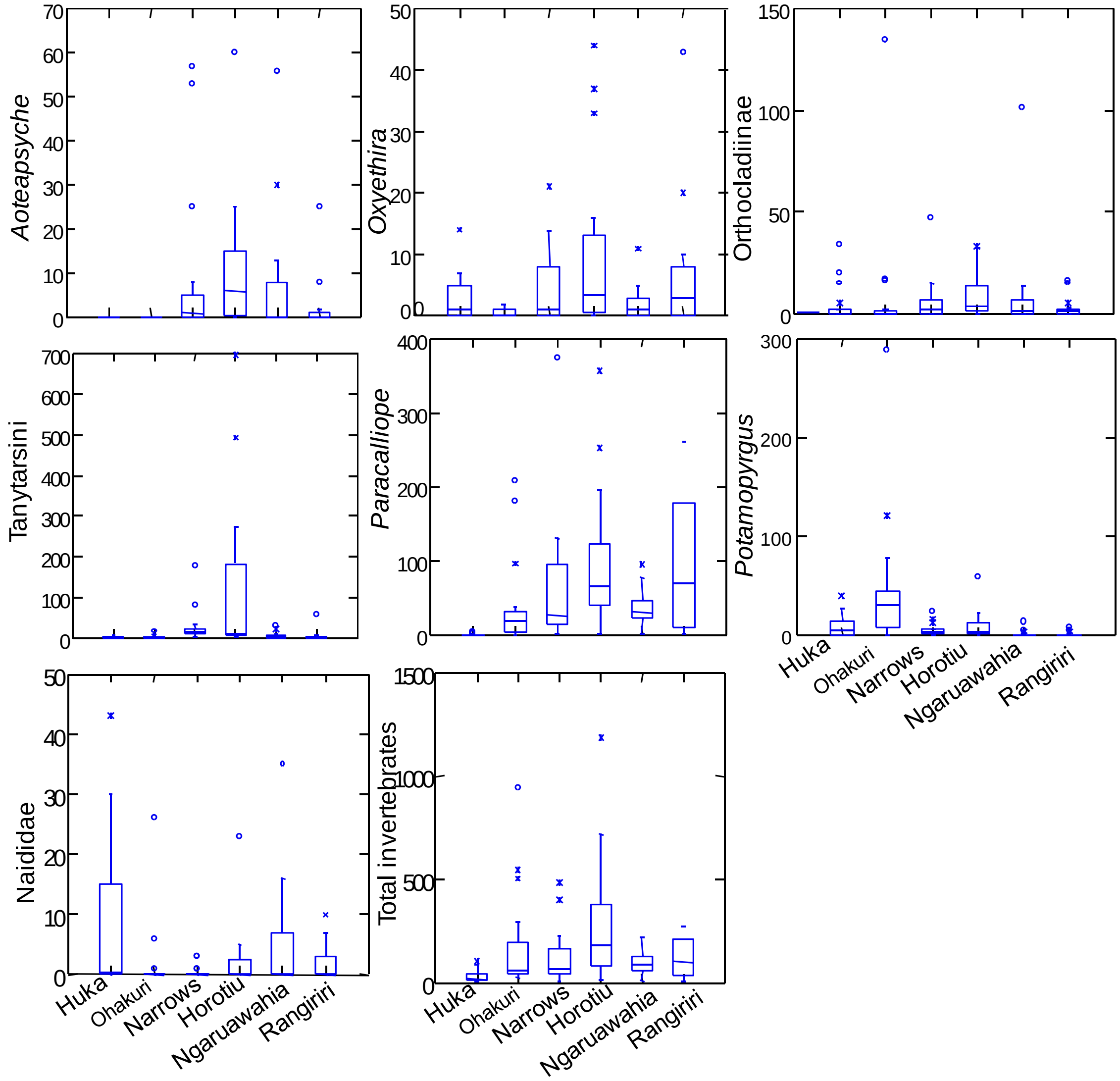

Figure 7: **Box plots of densities (no. per sampler; 0.17 m^2) for total macroinvertebrates and major taxa colonising perspex artificial samplers deployed at 6 sites on the Waikato River (all dates combined) in 2006-07. Note scales on y-axes differ. See Figure 5 for key to box plots.**

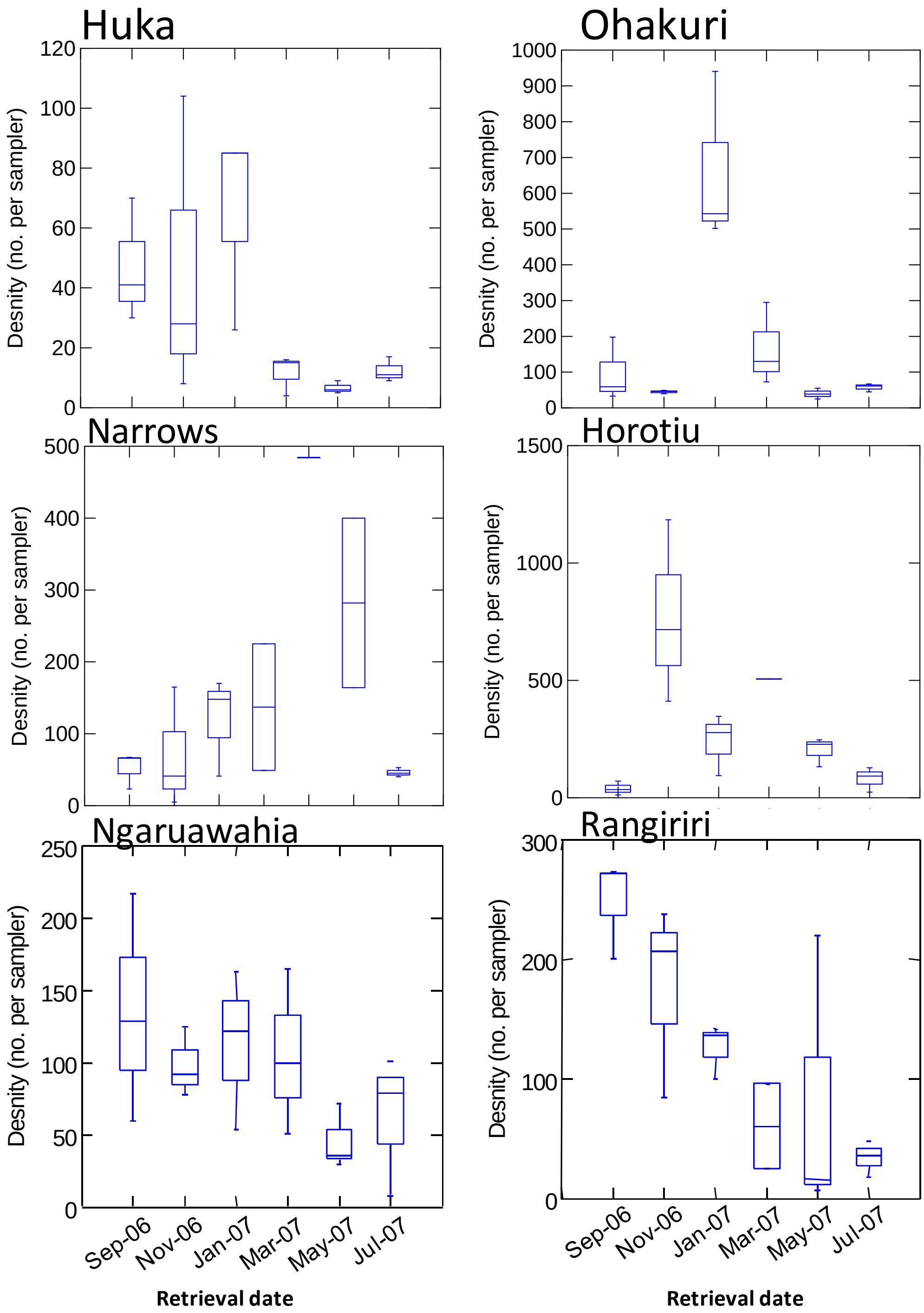

Figure 8: **Box plots for total macroinvertebrate densities (no. per sampler; 0.17 m^2) on perspex artificial samplers deployed at 6 sites on the Waikato River on each retrieval date in 2006-07. Note scales on y-axes differ. See Figure 5 for key to box plots.**

Table 9: Analysis of Variance statistics for densities (no. per sampler; 0.17 m^2) for total macroinvertebrates and major taxa colonising perspex artificial samplers deployed at 6 sites on the Waikato River in 2006-07.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Aoteapsyche					
Site	7.609	5	1.522	12.342	**0.000**
Date	1.481	5	0.296	2.402	**0.046**
SitexDate	10.380	25	0.415	3.367	**0.000**
Error	8.384	68	0.123		
Oxyethria					
Site	2.830	5	0.566	5.753	**0.000**
Date	3.141	5	0.628	6.385	**0.000**
SitexDate	8.049	25	0.322	3.273	**0.000**
Error	6.690	68	0.098		
Orthocladiinae					
Site	1.678	5	0.336	2.263	0.058
Date	6.030	5	1.206	8.130	**0.000**
SitexDate	11.152	25	0.446	3.007	**0.000**
Error	10.086	68	0.148		
Tanytarsini					
Site	23.461	5	4.692	28.828	**0.000**
Date	3.058	5	0.612	3.758	**0.005**
SitexDate	11.591	25	0.464	2.848	**0.000**
Error	11.068	68	0.163		
Paracalliope					
Site	32.146	5	6.429	42.266	**0.000**
Date	4.032	5	0.806	5.301	**0.000**
SitexDate	10.866	25	0.435	2.857	**0.000**
Error	10.344	68	0.152		
Potamopyrgus					
Site	14.922	5	2.984	28.428	**0.000**
Date	4.029	5	0.806	7.675	**0.000**
SitexDate	6.839	25	0.274	2.606	**0.001**
Error	7.139	68	0.105		
Naididae					
Site	2.132	5	0.426	4.176	**0.002**
Date	6.862	5	1.372	13.441	**0.000**
SitexDate	6.441	25	0.258	2.523	**0.001**
Error	6.943	68	0.102		
Total invertebrates					
Site	8.068	5	1.614	14.61	**0.000**
Date	3.870	5	0.774	7.008	**0.000**
SitexDate	9.634	25	0.385	3.489	**0.000**
Error	7.511	68	0.110		

5 Discussion

Multiplate substrate samplers provide a standardised habitat that can be used to compare macroinvertebrate communities among sites and across time by factoring out variations in substrate type. Communities colonising substrates will be influenced by the conditions at particular sites where samplers are deployed (e.g., local variations in current velocity) and the pool of local colonists available. Thus, substrates positioned along a river, as in this study, will reflect not only longitudinal changes in river conditions but also local conditions associated with particular sampling sites. Caution therefore needs to be exercised when attributing observed patterns to larger scale phenomena.

5.1 Spatial and temporal patterns in 2006-07

In 2006-07, the macroinvertebrate community colonising artificial substrates at the 6 Waikato River sites was dominated by Mollusca (primarily the snail *Potamopyrgus antipodarum*) in the upper river (Huka and Ohakuri sites) and by Crustacea (primarily the amphipod *Paracalliope fluviatilis*) in the lower river. This longitudinal change in community composition may partly reflect differences in food supplies along the length of the river, with greater water clarity potentially promoting more plant growth along shorezones in the upper river, and dominance of lower river food supplies by phytoplankton from hydrodams and fine particulate organic matter discharged from major tributaries or derived from the breakdown of riparian leaf fall.

Diversity of the macroinvertebrate community tended to increase with distance downstream, reaching a peak at the Horotiu and Ngaruawahia sites before declining at Rangiriri, potentially reflecting downstream changes in water level variability, and diversity of habitats and food types along river edges influencing the pool of available colonists at sites where substrates were deployed. Ngaruawahia's high diversity could partly reflect the coincidence of conditions provided by the proximity of the lower Waikato River, Waipa River and tributary streams of the Hakarimata Ranges. In contrast, densities of some invertebrate taxa were often low at Ngaruawahia.

Generally, densities of invertebrates on samplers were highly variable across the different river sites through time in 2006-07, although densities were consistently low in winter, most likely reflecting cooler temperatures and less light for algal growth, and the effects of higher and more variable flows. Some sites had highest densities over spring-summer (Huka), whereas Narrows exhibited increasing density over spring to autumn, and the lower river sites (Ngaruawahia and Rangiriri) declined in density over spring-winter. These patterns at the 2 lower river sites may partly reflect effects of increased sediment discharge associated with higher flows around winter from the Waipa River which enters the river approximately 500 m upstream of the Ngaruawahia deployment site. Differences at upstream sites may partly reflect the effects of flow regimes which can be highly variable on a day-to-day basis upstream of Narrows (see Appendix 2), causing periodic exposure of substrates at Horotiu during summer (see Appendix 1). Flow variability at the Huka and Ohakuri sites may also partly account for low densities of *Aoteapsyche* which are typically abundant below reservoir outlets (Harding 1994) and were once common around Huka Falls (Parsons 1979 – cited in Davenport 1982; see also Collier & Hogg 2010), although the sampling sites at these locations were out of the main river flow and would not have represented good habitat for these hydropsychids which generally require fast-flowing water. Nevertheless, hydropsychid communities have been reported to be adversely affected below some hydrodams on the river (Collier & Hogg 2010).

5.2 Sampler effects and study comparison

The use of wood versus perspex substrates did not significantly influence the composition or diversity of macroinvertebrate communities but did affect the abundance of some taxa. Notably, *Paracalliope* and *Potamopyrgus* showed higher densities on wood substrates and may have been deriving some nutritive value from the biologically active surfaces of the wood by feeding on epixylic biofilms or fine particles trapped in biofilm exudates. This finding suggests that perspex substrates, which provide an inert surface for colonisation, are more likely to provide an unbiased representation of the community colonising inorganic substrates in the river. However, analysis of the composition and diversity of macroinvertebrate communities (rather than densities) should enable valid comparisons to be made between studies that used wood substrates and those that used perspex.

Downstream patterns in diversity detected in 2006-07 corresponded to those reported by Davenport (1982), with diversity being lower in both studies in the upper river (Huka and Ohakuri), although taxa richness was higher overall in 2006-07 despite several changes in the river during the intervening period (see below). There was no evidence of a decrease in numbers of chironomids and an increase in snails through Huka to Rangiriri in 2006-07, as reported by Davenport (1982), with snail numbers dominating the fauna at the upper river sites, particularly over March-July 2006-07. Davenport (1982) suggested that abrasion from suspended sand and pumice, along with fluctuating river levels may be factors limiting macroinvertebrates at the Huka site. He also noted that the Ohakuri site was subject to frequent flow fluctuations, although sand was absent because it was trapped by upstream dams, suggesting that low densities there may be due in part to flow variability effects.

Davenport (1982) noted that snails were numerically dominant at the Narrows site, whereas in 2006-07 the fauna was dominated by Crustacea and Diptera, both of which were also reasonably common there in 1980-82, suggesting the change in dominance was due mainly to a decline in snails. Davenport (1982) reported the dominance of *Potamopyrgus* and also the presence of other snails including the native *Physastra* which has not been reported from the lower river for many years (Collier & Hogg 2010). In contrast, there appears to have been an increase in the distribution of exotic snail species within the river since the 1980-82 study. The mayfly and stonefly taxa reported at Narrows and Ngaruawahia by Davenport (1982) were also recorded in low numbers in 2006-07 at these sites, and additionally at Rangiriri where they were not collected in 1980-82.

There may be several possible reasons for the apparent shift from chironomids to molluscs in the upper river and from molluscs to crustaceans in the lower river on multiplate samplers between 1980-82 and 2006-07, and these are discussed below.

1. *Differences in methodology between studies –*

   Although we attempted to replicate the methods as closely as possible between the 2 studies there were some differences.

   - The net mesh size used in the 1980-82 study was not stated by Davenport (1982) but was assumed to have been 0.25 mm, as used in 2006-07. Early instar chironomid larvae can be very small and could have been collected in higher abundances if a finer mesh net had been used. Moreover, use of a draw string fine mesh bag in 1980-82 may have collected less drifting crustacean than the net used in the 2006-7 study (at Rangiriri at least). This is not considered to be a major source of variation between studies.

   - Substrates were deployed on metal plates or stakes in 1980-82 whereas in 2006-07 all substrates were attached to pegs on concrete pavers. While this may have affected local conditions around samplers and may have indirectly influenced trapping of macrophytes (see below), it is not considered to be a major direct source of variation between studies.

   - Macrophyte material entrained on samplers was dislodged prior to substrate removal in 2006-07 whereas in 1980-82 it was included in samples. This could have affected the types of invertebrates attributed to particular sites.

For example, chironomid larvae can be abundant on macrophyte material. However, trapping of macrophytes is less likely to have affected interpretation of taxonomic richness patterns.

- The efficiency of sample sorting could have differed between studies, although sorting efficiency was checked for most of the 2006-07 samples. Although taxonomic resolution differed between studies and small worms were not enumerated in 1980-82, these factors would not have affected the comparison as all data were condensed to the same level of resolution and small worms were omitted prior to analysis.

2. *Climatic variations between studies –*

- It is possible that the two sampling periods coincided with different phases of long-term climatic patterns which may have influenced rainfall, river flows and/or water temperature during the sampling periods. This possibility is supported by the analysis of Brown (2010) who showed that the 1980-82 sampling coincided with the onset of positive Interdecadal Pacific Oscillation weather patterns resulting in considerably higher rainfall compared to the long term average, whereas the 2006-07 rainfall patterns were closer to average. Lower rainfall, and hence reduced flood flows, may have enabled molluscs to become more dominant in the upper river.

3. *Changes to the river –*

Several changes have occurred in the river and its catchment since the 1980-82 study which could have impacted on the macroinvertebrate fauna.

- In 1991, the Tunawae slip in the Waipa catchment delivered large amounts of sediment to the lower river and continues to be a source of suspended sediment during periods of high rainfall (Hicks & Hill 2010). In addition, intensification of land use in the Waikato River catchment, including recent pine forest to pasture conversions, has increased nutrient loads to the river (Vant 2010). Erosion and land use intensification within the catchment have been associated with increasing trends over 1987-2007 for conductivity, nitrate and phosphorus at most of the water quality monitoring sites on the river, and increasing turbidity and declining water clarity from the Huntly site downstream (Vant 2008). Sediment from the Waipa River may have contributed to the lower river decline in densities of *Potamopyrgus* whose growth and food assimilation rates can be adversely affected by high sediment levels (Broekhuizen et al. 2001). Elevated nutrient levels may contribute in increased plant growth in some habitats, and could partly contribute increased snail dominance at upper river sites.

- Since 2001 flow management below hydrodams has changed to allow greater flexibility for peak power generation, resulting in increased daily water level fluctuations below dams (Brown 2010). Variable flow regimes also resulted in periodic exposure of samplers, although generally samplers were set deep enough for this not to have affected results at most sites, at least over summer when temperature loggers were deployed to monitor exposure.

- Koi carp and other introduced fish species have proliferated since the 1980s in the lower river below Karapiro Dam (Hicks et al. 2010), and as shown in this study there also appears to have been an expansion in the number of introduced snail species. The multiplate samplers are likely to provide refugia from fish predation and therefore are unlikely to have been directly affected by introduced fish, although these could potentially affect the pool of taxa locally available to colonise the samplers. Impacts of introduced snails are not known.

- Some other changes could potentially have had a positive effect on macroinvertebrate faunas. These changes include a decrease in some geothermal contaminants and ammonia due to improved waste treatment methods (Vant 2008), although this would not account for reduced lower river dominance of molluscs which are particularly susceptible to ammonia toxicity.

5.3 Conclusions

1. The macroinvertebrate community colonising artificial multiplate samplers in 2006-07 was typically more diverse in the lower river where the community was dominated by crustaceans, compared to the upper river where molluscs dominated. The longitudinal change in diversity is consistent with findings in 1980-82, although taxonomic richness was higher in 2006-07. However, a more diverse invertebrate community does not necessarily equate a more healthy river as a few sensitive taxa can be replaced by several tolerant taxa. The observed longitudinal change in both surveys is thought to reflect changes in water quality, habitat availability and flow regimes.

2. There appears to have been a shift between surveys in community dominance from chironomid larvae to molluscs in the upper river and from molluscs to crustaceans in the lower river . This shift may reflect a range of factors including differences in sampling methods, prevailing climatic conditions, increased numbers of pests, and changes to catchment and river management.

3. Although not without their problems, multiplate samplers provide a standardised habitat for comparing among large river sites. The fauna colonising them appeared to be influenced by flow and water quality conditions prevailing prior to sampling rather than by habitat. The Davenport (1982) study provides a baseline (excluding oligochaetes and nematodes) for interpreting changes over time prior to increased hydropeaking and land-use conversion in the upper catchment, and elevated sediment loads and pest fish abundance in the lower river.

4. Future use of perspex mutliplate samplers should not compromise comparisons of relative abundance and taxa richness with the 1980-82 study which used hardboard plates; however, densities should not be compared among wood and perspex substrates.

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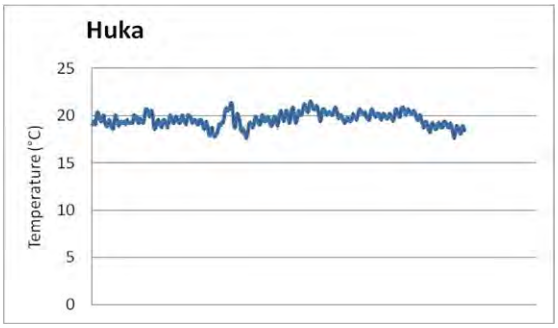
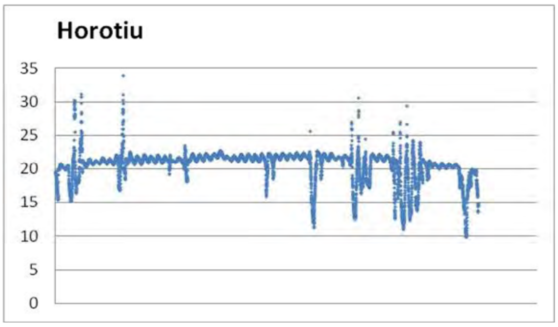
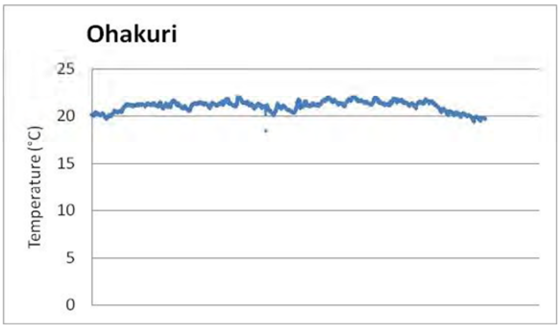
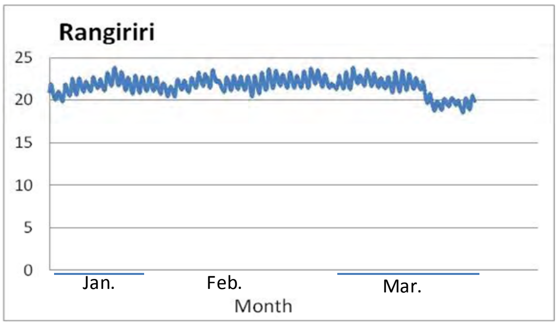
Appendix 1

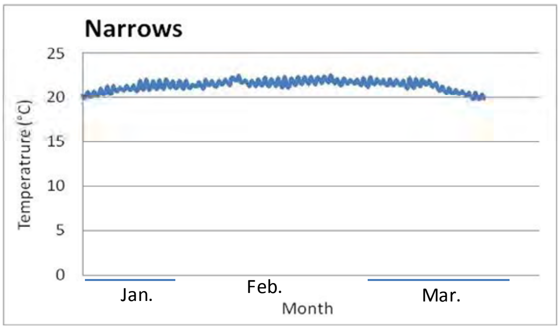
Water temperatures recorded over 19 January to 21March 2007 at five sites on the Waikato River using loggers attached to artificial substrates (the logger at Ngaruawahia was lost). Variation in temperatures at Horotiu indicate exposure of the loggers during the day or night.











Appendix 2

Flow records for 5 Waikato River locations over the period of artificial substrate deployment in 2006-07. "X" indicates substrate retrieval dates.