**“SQMCI assessment of eight volunteer-monitored sites in the Styx River Catchment, Christchurch”**

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## Abstract

Restoration of waterways is important in preserving and enhancing ecological and aesthetic values, with most lowland waterways being severely degraded in Canterbury (Wright-Stow 2001) due to anthropogenic changes to the landscape. Aquatic macroinvertebrates are an integral part of the food web in lotic ecosystems, fulfilling a large number of ecological niches. Eight sites, seven within the Styx River catchment and a control site, were assessed using the biotic index SQMCI. Further restoration within riparian margins is likely to result in continued improvements along the length of the waterways; in particular, Kaputone Stream is likely to benefit from restoration efforts. Eventual comparisons between the data in this study and volunteer data collected since 2004 will provide feedback and lead to potential changes in methods being instigated.

## Introduction

The Styx Mill Conservation Reserve is approximately 57 hectares in size, and includes both native and exotic plantings (Macfarlane 2007), with the area undergoing extensive planting of native trees, bushes and flax since 1998 to increase the area's conservation value (Macfarlane 2007). The reserve is associated with the 'Styx Vision 2000-2040' project, which has five aims. These are: 1. to achieve a viable spring fed river ecosystem to complement other reserves in and around Christchurch. 2. To create a “source to sea” experience from the local rivers to Brooklands lagoon. 3. To develop a “living laboratory” to enhance teaching and research. 4. To establish the site as a place to visit. 5. To develop partnerships with the community, as well as regional, national and international bodies (Anon 2000). This research is associated with the third and fifth aims; develop a “living laboratory” and develop partnerships with the community.

The Styx river itself is relatively short (about 23.8 km long), and is spring fed. Contributory waterways such as the Kaputone Stream and Smacks Creek are also spring fed. These waterways flow through a mixture of developed urban, agricultural, horticultural, and vegetatively restored lands. The Styx River itself is a contributory waterway to the Waimakariri River, which it discharges into at Brooklands Lagoon (Robb 1980; Hill 2002).

A range of research topics have been investigated as summer scholarships in the Styx catchment, including algae, lizard abundance, terrestrial invertebrate abundance and potential bioindicator species. Research on aquatic macroinvertebrates focussed around their spatial distribution, and how restoration has affected the Radcliffe Road Drain’s invertebrate fauna.

A community volunteer sampling program has been in place since 2004 to monitor the long term changes in the aquatic macroinvertebrate communities, with particular reference to the effects of the habitat restoration on the waterway quality. Training in sampling methods and macroinvertebrate identification is given to the volunteers, who often reside in the local area. Macroinvertebrate sampling is done twice a year by taking two kick samples, one from each end of the site in the centre of the waterway. The volunteers preserve the samples on site in a 70% ethanol solution to be processed at a later date. When processing the samples, the first 200 specimens are recorded, and any rare or unusual taxa found are also removed and identified to a broad taxonomic ranking such as order or phylum (McMurtie 2005). This rapid bioassessment method is meant to provide a cheap, time effective method to monitor changes to the waterways.

Rapid bioassessment is a measurement of a waterways health by sampling or otherwise measuring the biotic organisms present (Barbour *et al*. 1999). Aquatic insects and other aquatic macroinvertebrates are widely used in biomonitoring of lotic ecosystems, particularly where the impacts of human activities are concerned (Bonada *et al*. 2006). This is derived from these macroinvertebrates being relatively easy to sample, rapidly responding to the presence of pollution, and being so specialised in their habitat selection (Boothroyd & Stark 2000). Aquatic macroinvertebrates have long been used in biomonitoring, initially arising from the need to assess water for human health reasons (Stark *et al.* 2001). This evolved into the use of biomonitoring being used to assess stream ecosystem health (Stark *et al.* 2001). The macroinvertebrates present reflect how tolerant they are to organic pollution and nutrient enrichment in the water (Stark *et al.* 2001).

The organic pollution within the rivers sampled for this study comes largely from non-point sources, although potential point sources do occur along the waterways such as the business selling firewood. Possible sources of organic pollution in these waterways include run off from agricultural and horticultural land, and from direct stock access to the waterways. Organic pollution in this form can alter the macroinvertebrate community present; by decreasing dissolved oxygen and increasing contaminants such as nitrates, favouring those macroinvertebrate species that can live in these degraded habitats. Other pollution, such as sedimentation, can also affect the macroinvertebrate community by changing the substrate structure, increasing downstream drift and affecting feeding and respiration (Wood & Armitage 1997).

The objective of this study was to quantitatively assess the stream health of the streams and creeks within the the Styx River catchment area so as to be compared to the data collected by the volunteer run sampling programme. It is hoped an understanding of the influence of restoration efforts on reducing organic pollution levels will be gained. The quantitative sampling was done using the kick-sampling technique to obtain three samples from each site, and the specimens were identified to the taxonomic rank required for Semi-Quantitative Macro Invertebrate Community Index, or SQMCI (usually genus).

**Materials & Methods**

Eight sites in the Styx River catchment (Appendix 2) were sampled for aquatic macroinvertebrates. Each site was pre-existing and is sampled twice a year for macroinvertebrates and water quality for long term monitoring of waterway health by The Styx Living Laboratory Trust volunteers. Each site was 10 metres in length, but varied in width (Table 1.). Three random samples, selected using a random number table, were taken from within each site. Kick sampling was used to sample the aquatic macroinvertebrates, with it being standardised to kicking for one minute as used by the community volunteer monitoring program (Victor Brown; personal communication). The kick sampling was performed approximately the width of the net and approximately 30 cm upstream of the net. The severe sedimentation at sites K1 and K3 meant a scooping sampling technique had to be used instead. A sampling net was placed into the sediment approximately 10 cm deep and scooping the substrate about 30 cm downstream.

Debris removal was carried out using a sieve with a mesh size of 600 µm. The macroinvertebrates found were placed into a 70% ethanol solution and then identified to the appropriate taxonomic rank for Semi-Quantitative Macroinvertebrate Community Index (SQMCI) analysis.

The chironomidae that were found required special preparation to identify. The larvae were placed into a 10% potassium hydroxide solution for 48 hours. The head capsule was then removed and placed onto a slide with Euparal, a preserving agent. The head capsule was then examined using a compound microscope to identify the specimen to the required taxonomic rank.

A range of physical variables were also measured using the same data collecting sheets as the volunteers. Macrophyte depth was recorded, but due to its rare occurrence, was excluded from analysis. A Wolman walk was performed, taking approximately 100 steps back and forth across the waterway, recording whether underfoot was mud/silt, sand, gravel, small cobbles, large cobbles, boulder, or bedrock. Also recorded was what % the lower banks were brick/concrete, earth, rock, wood, or other. Bank stability was estimated as extremely stable, moderately stable, moderately unstable, unstable, or extremely unstable. Surrounding land use was recorded as rural horticultural, rural stocked, reserve/park, lifestyle block, or urban area. Riparian vegetation was also qualitatively recorded. The range of categories where impervious, unvegetated, moss/liverworts, lawn, grass and herb mix, low ground cover, ferns, rush/sedge/tussock, native course vegetation, exotic course vegetation, native shrubs, exotic shrubs, native trees, exotic deciduous trees, exotic evergreen tree. These were then recorded as either uncommon (<10%), common (11-50%), or abundant (>50%).

**Data analysis**

The biotic index called Semi-Quantitative Macroinvertebrate Community Index (SQMCI) analysis was performed (Appendix 3), with species richness (number of different taxa present at each site) and species diversity also calculated. SQMCI is a biotic index that is based on all aquatic specimens having an allocated tolerance score between 1 and 10, and their abundance when the samples from each site are combined. Species diversity was calculated using Simpsons Diversity Index, which is a measure of both species richness, and how evenly distributed the numbers are of each specimen. The top five abundant taxa at each site were also recorded, and percentage EPT calculated. Percentage EPT is the percentage of all specimens found at a site that belong to the EPT taxa group, which can be considered 'good' speciemens.

**Table 1.** A brief overview of the eight sites sampled and some basic details recorded that characterise each site.

| Site Name | Site Description | Site Details |
|---|---|---|
| **Styx one (S1)** | Above Styx Mill Conservation Reserve. Horticultural land on TLB, developed urban land on TRB.<br>Located: 5748545 2476569 | Mean water depth 38.3 cm. Mean width 341.7 cm. Sediment 19.4 cm. Water velocity 0.4 m/s. Rural horticultural land use on |

| | | |
|---|---|---|
| | | TLB, urban area on TRB |
| **Styx two (S2)** | Within Styx Mill Conservation Reserve. Unmanaged grasses on TLB and TRB. Some Riparian planting.<br>Located: 5749348 2477931 | Mean water depth 22.1 cm. Mean width 476.7 cm. Sediment 0.0 cm. Water velocity 1.1 m/s. Reserve/park on both TLB and TRB |
| **Styx three (S3)** | Below Styx Mill Conservation Reserve. Within a small reserve with mowed grass up to TLB and TRB.<br>Located: 5748843 2479041 | Mean water depth 40.9 cm. Mean width 513.3 cm. Sediment 0.0 cm. Water velocity 1.0 m/s. Reserve/park on both TLB and TRB |
| **Smacks Creek one (SM1)** | Within a reserve. Riparian planting and tussocks/sedges on TLB and TRB.<br>Located: 5749519 2476847 | Mean water depth 11.8 cm. Mean width 180.0 cm. Sediment 0.0 cm. Water velocity 0.8 m/s. Reserve/park on both TLB and TRB |
| **Kapitone Stream one (K1)** | Flows through agricultural land. Unmanaged grass mix on TLB and TRB.<br>Located: 5750485 2480820 | Mean water depth 19.9 cm. Mean width 373.7 cm. Sediment 51.4 cm. Water velocity 0.2 m/s. Rural stock land use on TLB and TRB |
| **Kapitone Stream two (K2)** | Within Ouruhia Reserve. Unmanaged grass mix on TLB and TRB.<br>Located: 5751735 2481763 | Mean water depth 13.8 cm. Mean width 347.5 cm. Sediment 3.7 cm. Water velocity 0.9 m/s. Reserve/park on TLB, Lifestyle block on TRB |
| **Kapitone Stream three (K3)** | Flows through agricultural land. Grasses, tussocks and sedges on TLB and TRB.<br>Located: 43457494 172632106 | Mean water depth 21.0 cm. Mean width 194.3 cm. Sediment 7.1 cm. Water velocity 0.1 m/s. Rural stock land use on TLB and TRB |
| **Control site (C1)** | The theoretically most pristine site. Some access to waterway by farm animals. Predominantly grasses and tussocks on TLB, exotic plantings on TRB.<br>Located: 5749601 2475395 | Mean water depth 16.0 cm. Mean width 1058.3 cm. Sediment 2.2 cm. Water velocity 0.9 m/s. Rural stock land use on TLB and TRB |

**Site S1:** Looking upstream

**Site S2:** Looking upstream

**Site S3:** Looking upstream

**Site SM1:** Looking downstream. Note TRB upstream orange marker peg.

**Site K1:** Looking upstream.

**Site K2:** Looking upstream

**Site K3:** Looking upstream

**Site C1:** Looking upstream

**Figure 1.** Photographs of all eight sites sampled. Sites S2, S3, SM1, K2, and C1 can all be considered riffle habitats. Details about each site and location are in Table 1.

**Results**

**Table 2.** Displays each site and their respective SQMCI score, species richness, and species diversity. SQMCI scores of >6.00 are considered clean water, 5.00-5.99 are considered doubtful quality or possible mild pollution, 4.00-4.99 probable moderate pollution, <4.00 probable severe pollution.

| Site | S1 | S2 | S3 | SM1 | C1 | K1 | K2 | K3 |
|---|---|---|---|---|---|---|---|---|
| SQMCI score | 5.1 | 3.6 | 4.9 | 4.2 | 4.9 | 3.4 | 4.0 | 3.4 |
| Species richness | 10 | 9 | 14 | 14 | 18 | 6 | 7 | 11 |
| Species diversity | 0.22 | 0.28 | 0.22 | 0.18 | 0.19 | 0.52 | 0.71 | 0.70 |

Site S1 scored the highest using SQMCI with a score of 5.1 indicating it has possible mild organic enrichment, with S3 and C1 scoring the second highest. SM1 the third highest, and K2 the fourth highest. K1, K3, and S2 were the lowest, scoring less than 4 which equates to probably severely polluted.

Species richness was highest in the C1 site (18), which is slightly unexpected since it has probable moderate pollution. S3 and SM1 are equal second. Interestingly, K3 was third highest for species richness, despite probable severe pollution. S1 is fourth and S2 fifth. K1 and K2 had the lowest species richness of 6 and 7 respectively.

The best species diversity was at SM1, with an index value of 0.18, followed by C1. S1 and S3 have the third equal best diversity and S2 has the fourth best diversity. K1, K2, and K3 all have poor species diversity compared to the other sites, indicating some specimens are much more abundant than others.

**Table 3.** Displays the five most common taxa at each site, starting with the most common.

| Site | S1 | S2 | S3 | SM1 | C1 | K1 | K2 | K3 |
|---|---|---|---|---|---|---|---|---|
| **Top five dominant taxa at each site (descending order)** | Amphipoda | Oligochaeta | *Pycnocentria* | Oligochaeta | Oligochaeta | *Potamopyrgus* | *Potamopyrgus* | *Potamopyrgus* |
| | Oligochaeta | *Pycnocentria* | *Pycnocentrodes* | *Pycnocentrodes* | *Deleatidium* | Oligochaeta | Oligochaeta | Oligochaeta |
| | *Potamopyrgus* | *Deleatidium* | *Aoteapsyche* | Platyhelminthes | *Pycnocentrodes* | *Chironomus* | Orthocladiinae | Ostracoda |
| | *Pycnocentria* | *Pycnocentrodes* | Amphipoda | *Deleatidium* | *Potamopyrgus* | Ostracoda | Ostracoda | *Chironomus* |
| | *Deleatidium* | *Aoteapsyche* = Orthocladiinae | Platyhelminthes | *Hudsonema* | Elmidae | Amphipoda | *Physa* | Acari |

Oligochaeta (worms), feature highly as one of the most dominant types of macroinvertebrate present and are in the top two most dominant taxa at all but the S3 site. Trichoptera (*Pycnocentrodes* spp., *Pycnocentria* spp., and *Aoteapsyche* spp.) and Ephemeroptera (*Deleatidium* spp.) genus' are prevalent in the S1, S2, S3, SM1, and C1 sites. K1, K2, and K3 are dominated by genus' and groups that are tolerant of moderate and severe organic pollution such as *Potamopyrgus* spp., oligochaeta, and ostracods.

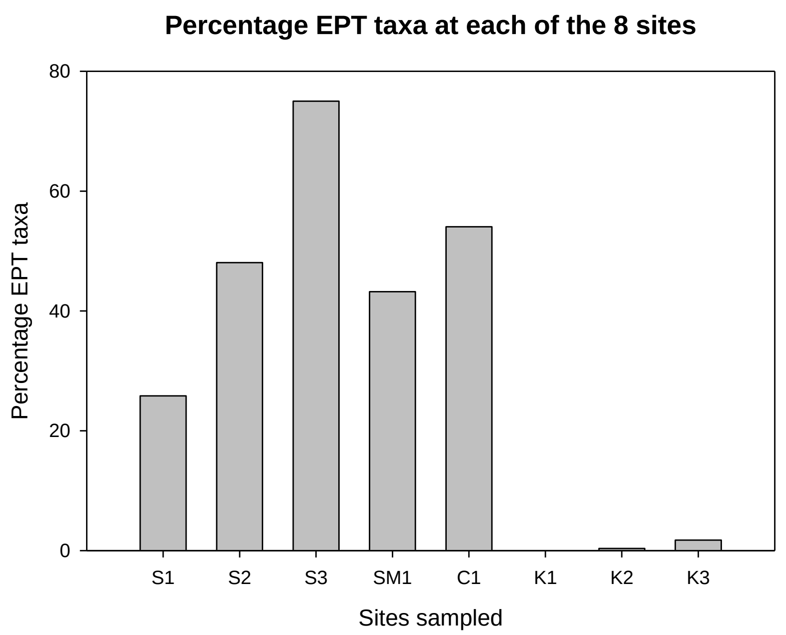


**Figure 2.** Shows the percentage of Ephemeroptera, Plecoptera, and Trichoptera (EPT) abundance out of the total individuals found at each site.

There is no strict interpretation of what percentage EPT represents clean, good, poor, or very poor water quality. However, a higher percentage of EPT taxa would indicate a healthier waterway. Only S3 and C1 record over 50% EPT taxa, with S2 recording just less than 50%. SM1 had a credible 43%

EPT. S1 only has 25% EPT taxa, consistant with the most dominant taxa found at that site (Table 3). K1, 2, and 3 all barely register any EPT taxa.

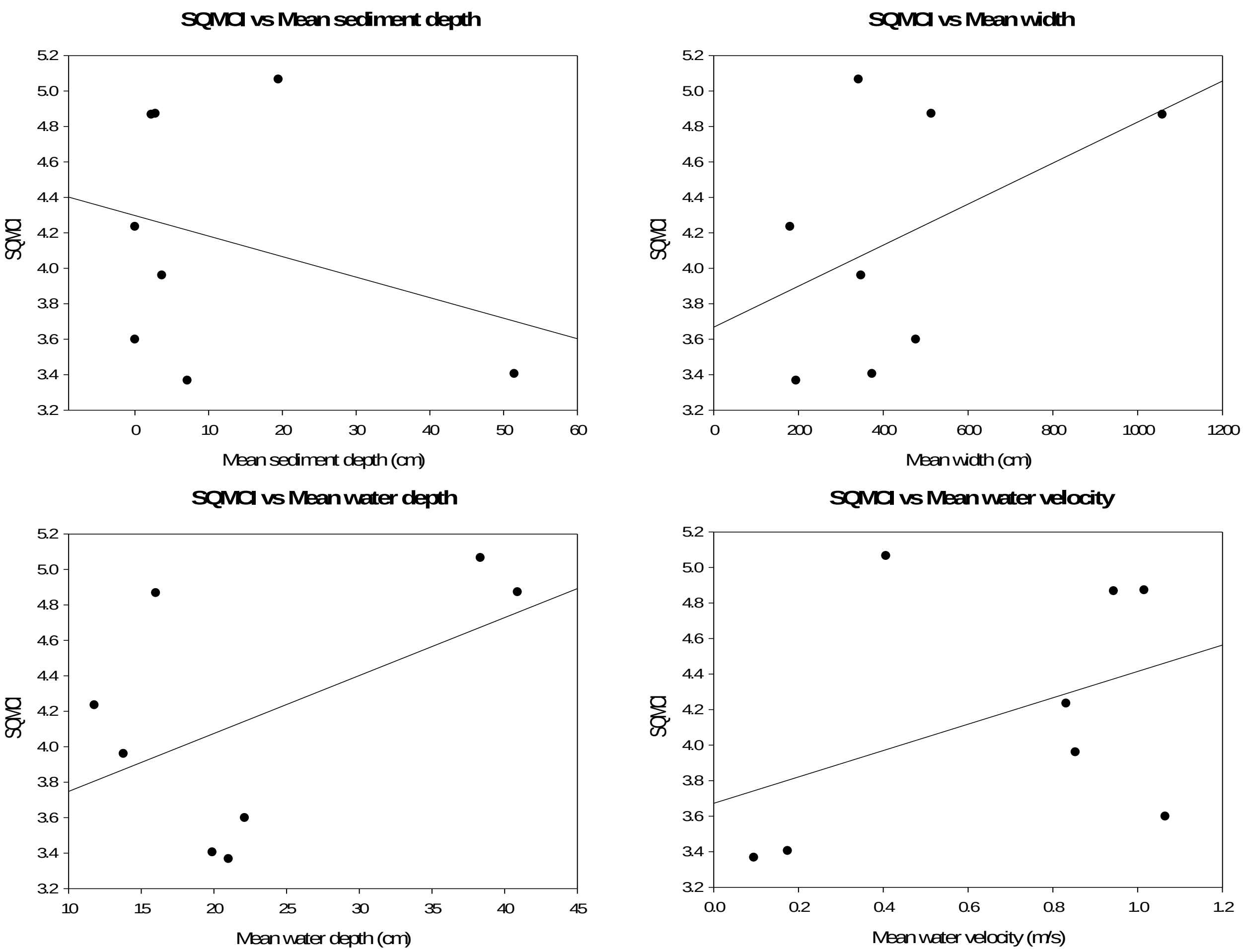


**Figure 3.** Displays the effect of mean sediment depth, waterway width, mean water depth, and mean water velocity on the SQMCI scores.

Mean sediment depth, or how deep the rigid substrate was located below silt and sand deposits had a negative effect on the SQMCI. The width of the waterway, mean water depth, and mean water velocity all had a positive influence on the SQMCI score. None of these factors had a particularly strong correlation with their influence on the SQMCI score

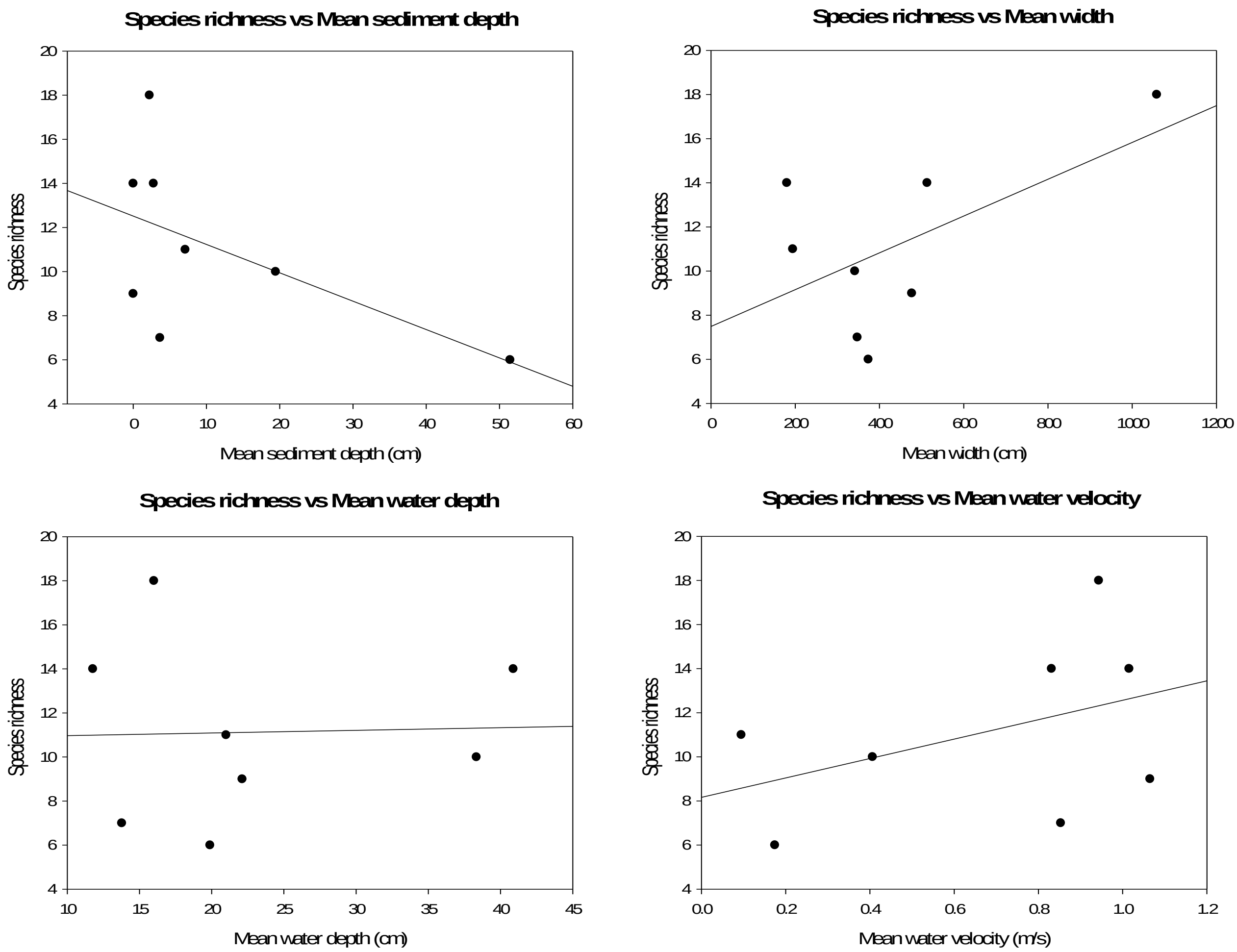


**Figure 4.** Displays the effect of mean sediment depth, waterway width, mean water depth, and mean water velocity on species richness (the number of unique species present).

Mean sediment depth had a negative effect on species richness, while width of the waterway and mean water velocity had a positive effect on species richness. Mean water depth had almost no discernable impact on species richness in this instance.

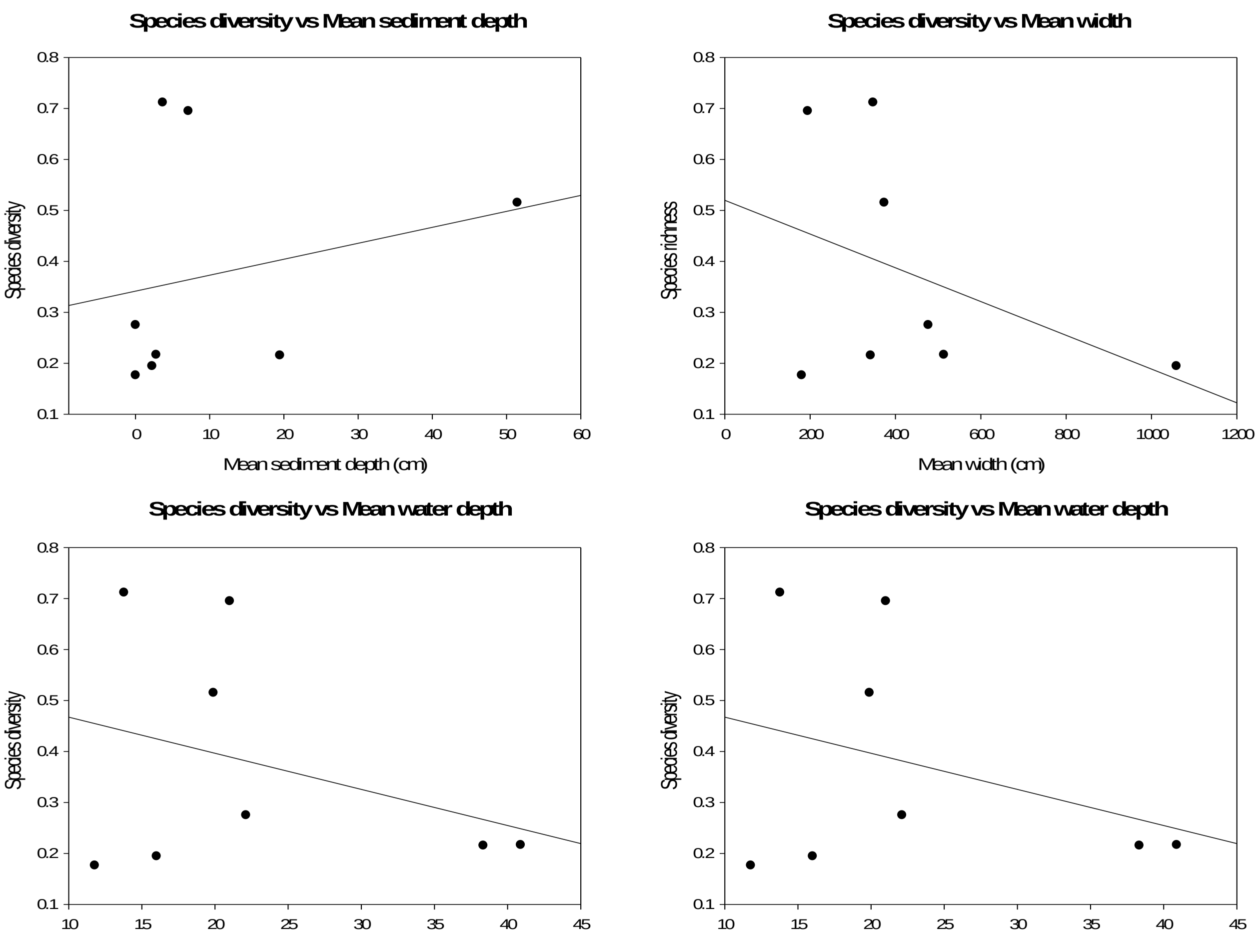

**Figure 5.** Shows the effect of mean sediment depth, waterway width, mean water depth, and mean water velocity on species diversity.

Species diversity is a measure of how species rich, and the how relatively abundant these species are in an area. Mean sediment depth had a negative impact on species diversity. Width, mean water depth, and mean water velocity all had a positive effect on species diversity.

**Discussion**

It is recommended by Boothroyd & Stark (2000) that analysis of aquatic macroinvertebrate data be performed by several different methods, not just a single biotic index. Those methods of analysis that are recommended are species richness, percentage EPT taxa, top five most abundant taxa, and if possible, macroinvertebrate densities.

There is no apparent, one definitive reason for the differences in the SQMCI scores, species richness, or species diversity between sites sampled. Rather, it is probably a combination of a number of factors, dubbed a "hierarchical arrangement of such parameters" by Winterbourne (1981). Stark (1993) concluded that physical variables will always impact on the biotic indices between sites, and can impede the interpretation of the level of organic pollution. These factors in this study include mean sediment depth, mean width of the waterway, mean water depth, mean water velocity, and possible organic pollution. These factors are recognised as having a major influence on the aquatic macroinvertebrate communities (Bunn & Arthington 2002; Boothroyd & Stark 2000).

Water flow (depth, width, and velocity), are major determinants in the physical conditions of a waterway, which is critical in determining the aquatic macroinvertebrates that are present, directly affecting abundance and diversity (Bunn & Arthington 2002). For example, a stable, constant flow with little seasonal variation often leads to an increase in the abundance of macrophytes (Bunn & Arthington 2002), favouring those aquatic macroinvertebrates capable of gaining sustenance from such a source. Collier (1995) found increased water depth to have a significant nagative impact on the aquatic macroinvertebrate community, but a later study found water depth had little effect (Collier *et al*. 1998).

A slowing of the water velocity has previously been show to increase numbers of Orthocladiinae and other Chironomids in Northern America (Munn & Brusven 1991), providing an explanation for their relatively high abundance in the Kaputone sites (Table 3), which had slower water velocities than many other sites. The Kaputone Stream has in recent years had a recorded decrease in water flow (Taylor & McMurtie 2004). While this is more of a problem further upstream, where pumping of subsurface water has decreased spring outputs into the water way (Taylor & McMurtie 2004), undoubtedly there has been impacts on water flow further down the Kaputone where the samples in this study were taken from. Higher water flows also reduce sedimentation by keeping the particles suspended in the water column, not allowing the particles to settle (Madsen *et al*. 2001; Taylor *et al*. 2000) thus keeping the substrate more suitable for a more species rich and diverse range of aquatic macroinvertebrates, particularly EPT taxa.

The substrate of some sites (K1 and K3) had a layer of very fine sediment covering the more suitable, rigid substrate below. Substrate size has been found by Collier (1995) to have a significant impact on aquatic macroinvertebrate communities. The substrate on which aquatic macroinvertebrates are most commonly found is gravels (0.2-6cm), small cobble (6-12 cm), and large cobble (12-25 cm) substrates (Quinn & Hickey 1990a; Jowett 1993). The smaller a substrates particle size, the more likely it is to trap organic debris in the inter-sediment gaps (Parker 1989), which leads to a higher level of organic pollution in the lotic environment. Larger particle size also provides more micro habitats and increases the exchange of dissolved gases, in particular oxygen, as well as nutrients in the relatively still 'boundary layer zone', often enhancing the environment for key macroinvertebrate groups such as Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (Wiley & Kohler 1980; Williams *et al.* 1987). High levels of fine sediment are thought to increase downstream drift, and smother the both macroinvertebrates and their food supply (Ryan 1991). Interestingly, *Potamopyrgus* spp., and oligochaeta have been found to be unaffected by increased sedimentation (Ryder 1989), consistent with the results found in K1 and K3 sites.

Within New Zealand, the surrounding land use in a waterways catchment area has been identified as the major factor driving aquatic macroinvertebrate community composition (Quinn & Hickey 1990b; Harding & Winterbourn 1995). However, surrounding land use appeared to not have a major impact on the waterway health in this study. The sites that stock had access to, and potential run off from agricultural land included both the lowest scoring sites on the SQMCI (K1 & K2), and the C1 site which had the second equal highest SQMCI score, as well as the highest species richness (Table 2). The C1 site also recorded the presence of two taxa extremely intolerant of organic pollution, *Coloburiscus* spp. (ephemeroptera), and *Olinga* spp. (trichoptera) (Appendix 1), all of which indicates it may not be surrounding land use having the biggest impact on water quality in The Styx catchment. Differing farm management practices may account for this difference too.

What cannot be forgotten though is SQMCI is first, and foremost a measure of organic pollution (Boothroyd & Stark 2000). The prominence of oligochaeta in all but the S3 site (Table 3), which are obligate feeders on organic material, indicates all sites have organic pollution, which fits with the SQMCI scores that showed even the 'best' sites had probable moderate organic pollution (Table 2).

Other potential factors that are known to have a large negative impact on aquatic macroinvertebrate communities are flooding and weed clearance (Quinn & Hickey 1990a). These were not known to have occurred at any site within the critical six week period before the sampling date. However, factors such as water temperature, and pH were not measured. A volunteer programme also exists that measures water quality; this however is undertaken by different volunteers and does not cover all sites in this study.

The volunteer monitoring programme performs an important role in tracking the long term changes in The Styx River and its tributary, spring fed waterways. Whether or not the identification levels that are reached by the volunteers are sufficient to show this trend is an issue up for debate, and so comparisons to the data obtained in this study are desirable. It may be volunteers efforts are better focussed elsewhere, or more training is needed.

## Conclusions & Recommendations

It can be concluded that restoration of the riparian margins are usually reducing the organic pollution within the restored waterways. Careful consideration must be given to those plant species used though, with shading identified as an important factor in maintaining stream health in many instances of waterway restoration in New Zealand (Parkyn *et al*. 2003). It is also important to not choose plant species that will droop into the waterway, creating slow patches of water where fine sediments can settle.

It must also be taken into account that a distinct boundary does not occur between an area where riparian restoration has occurred, and the upstream unrestored waterway section. It takes some distance for the effects of restoration to actually have an effect on the waterway as outlined by Storey & Cowley (1997). They found it took 300 metres for temperature and dissolved oxygen to return to natural levels, and 600 metres for nitrate, nitrite, phosphate, and suspended solids to significantly reduce. Storey & Cowley (1997) also found that at 600 metres, while the macroinvertebrate fauna returned to those less tolerant of organic pollution, their densities were still increased above natural levels indicating residual effects of organic enrichment. This means potentially, if a one kilometre length of waterway is restored; only 400 metres or less actually sees the positive effect of this restoration effort.

The lack of clean water systems in surrounding areas means there is a paucity of sources for colonisation of the Styx River, Smacks Creek by the terrestrial adults of important EPT taxa, particularly species intolerant of organic pollution. Remedying this issue is not easy, with the most obvious solution translocating EPT taxa into the restored waterways, however the feasibility and likely success of such action is debatable.

Although randomisation of the sampling is desirable, it is considered non-essential in many situations, such as state of the environment (SOE) monitoring, monitoring associated with compliance regulations, or community driven monitoring (Stark *et al*. 2001). Nonetheless, randomisation is considered a standard practice in experimental design to reduce sampling bias, intentional or not, and thus should be considered. Refresher courses on methods used to sample should also be considered, as this helps standardise the methods, and reduce variability in the data.

It would appear from the SQMCI data that the control site selected for this monitoring is not of acceptable quality to have such a role. A control site is meant to reflect the pristine, or near pristine state of a waterway so that sites undergoing restoration can be compared to its data, providing a way to work out how close restoration as brought the waterway to a pristine state. In this project, the control site did manage to score the highest species richness, but only second equal highest SQMCI.

## Acknowledgements

The Styx Living Laboratory Trust and Lincoln University for funding the scholarship. Kelly Walker and Victor Brown for technical and logistical help. Mike Winterbourne for assistance with the difficult task of identifying the orthocladiinae.

**Benefits of the scholarship**

I gained an appreciation of aquatic macroinvertebrate diversity. Freshwater ecology is largely untaught at undergraduate level, and so having an opportunity to sample and identify aquatic macroinvertebrates widened my horizons in appreciating and understanding a different field of ecology. It also reinforced and improved my taxonomic identification skills of aquatic macroinvertebrates. Although I was familiar with much of the terminology already, the process of identifying reinforced the terminology, and I became adept at identifying the more common of the aquatic macroinvertebrates. The field work, collecting the specimens from the waterways was also an enjoyable experience, as was the satisfaction of successfully identifying specimens to the required taxonomic rank.

**References**

Anon. (2000) *Vision 2000-2040: The Styx – Community Planning for the Future.* Christchurch City Council, Christchurch, New Zealand.

Barbour, M.T., Gerritsen, J., Snyder, B.D. & Stribling, J.B. (1999) Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Bonada, N., Prat, N., Resh, V.H., Statzner, B. (2006) Developments in aquatic insect biomonitoring: A comparative analysis of recent approaches. *Annual Review of Entomology*, **51**, 495-523.

Boothroyd I. & Stark J (ed.) in Coller, K.J. & Winterbourne, M.J. (2000) New Zealand Stream Invertebrates: Ecology and implications for management. New Zealand Limnological Society, Cacton Press, Christchurch, New Zealand.

Bunn, S.E. & Arthington, A.H. (2002) Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. *Environmental Management*, **30**, 492-507.

Collier, K.J. (1995) Environmental factors affecting the taxonomic composition of aquatic macroinvertebrate communities in lowland waterways of Northland, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, **29**, 453-465.

Collier, K.J., Wilcock, R.J. & Meredith, A.S. (1998) Influence of substrate type and physico-chemical conditions on macroinvertebrate faunas and biotic indices of some lowland Waikato, New Zealand streams. . *New Zealand Journal of Marine and Freshwater Research*, **32**, 1-19.

Death, R.G. (ed.) in Coller, K.J. & Winterbourne, M.J. (2000) New Zealand Stream Invertebrates: Ecology and implications for management. New Zealand Limnological Society, Cacton Press, Christchurch, New Zealand.

Harding, J.S. & Winterbourn, M.J. (1995) Effects of contrasting land use on physico-chemical conditions and benthic assemblages of streams in a Canterbury (South Island, New Zealand) river system. *New Zealand journal of marine and freshwater research*, **29**, 479—492

Hill, D. (2002) The Styx story – a study of a Christchurch river. Styx history group, Christchurch.

Jowett, I.G. (1993) A method for objectively identifying pool, run, and riffle habitats from physical measurements. *New Zealand journal of marine and freshwater research*, **27**, 241-248.

Macfarlane, R. (2007) Styx Mill Conservation Reserve invertebrate assessment. Christchurch City Council, New Zealand.

Madsen, J.D., Chambers, P.A., James, W.F., Koch, E.W. & Westlake D.F. (2001) The interaction between water movement, sediment dynamics and submersed macrophytes. *Hydrobiologia*, **444**, 71-84.

McMurtie, S. (2005) Styx River community invertebrate monitoring programme. EOS Ecology Report. Report No. 05011-CCC01-01.

Munn, M.D. & Brusven, M.A. (1991) Benthic invertebrate communities in nonregulated and regulated waters of the Clearwater River, Idaho, USA. *Regulated Rivers: Research and Management*, **6**, 1–11.

Parker, M.S. (1989) Effect of substrate composition on detritus accumulation and macro invertebrate distribution in a southern Nevada desert stream. *Southwestern Naturalist*, **34**, 181-187.

Parkyn, S.M., Davies-Colley, R.J., Halliday, N.J., Costley, K.J. & Croker, G.F. (2003) Planted Riparian Buffer Zones in New Zealand: Do They Live Up to Expectations? *Restoration Ecology*, **11**, 436-447.

(a)Quinn, J.M. & Hickey C.W. (1990) Magnitude of effects of substrate particle size, recent flooding, and catchment development on benthic invertebrates in 88 New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research*, **24**, 411-427.

(b)Quinn, J.M. & Hickey C.W. (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.

Robb, J. (1980) A biological survey of the rivers in the metropolitan Christchurch area and outlying districts – the Avon, Heathcote and Styx Rivers and their tributaries. Christchurch Drainage Board.

Ryan, P.A. (1991) Environmental effects of sediment on New Zealand streams: a review. *New Zealand Journal of Marine and Freshwater Research*, **25**, 207-221.

Ryder, G.I. (1989) *Experimental studies on the effects of fine sediments on lotic invertebrates*. Ph.D Thesis, University of Otago, Dunedin, New Zealand.

Stark, J.D. (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.

Stark, J.D.; Boothroyd, I.K.G; Harding, J.S.; Maxted,J.R. & Scarsbrook, M.R. (2001) Protocols for sampling macroinvertebrates in wadeable streams. New Zealand Macroinvertebrate Working Group Report No. 1. Prepared for the Ministry for the Environment. Sustainable Management Fund Project No. 5103.

Storey, R.G. & Cowley, D.R. (1997) Recovery of three New Zealand rural streams as they pass through native forest remnants. *Hydrobiologia*, **353**, 63-76.

Taylor, M. & McMurtie,S. (2004) The Aquatic ecology of the upper Kaputone Stream and the effects of reduced flows. Styx Report: 2004/2 AEL23. Christchurch City Council, New Zealand.

Taylor, M., Suren, A., & Sorrell, B. (2000) A consideration aspects of the Styx River ecolgy, and implications for whole river management. NIWA client 29 report CHC00/34. Waterways and Wetlands team, Water Services Unit, Christchurch City Council.

Wiley, M.J. & Kohler, S.L. (1980) Position changes of mayfly nymphs due to behavioural regulation of oxygen consumption. *Canadian journal of zoology*, **58**, 618-622.

Williams, D. D., Taveres, A.F. & Bryant, E. (1987) Respiratory device or camoflage?—A case for the caddisfly. *Oikos*, **5O**, 42-52.

Winterbourn, M.J., Rounick, J. S. & Cowie, B. (1981) Are New Zealand stream ecosystems really different? *New Zealand Journal of Marine and Freshwater Research* **15**, 321–328.

Wood, P.J. & Armitage, P.D. (1997) Biological Effects of Fine Sediment in the Lotic Environment. *Environmental Management*, **21**, 203-217.

Wright-Stow, A.E. (2001) *Biomonitoring, and the macroinvertebrate faunas of Canterbury streams.* Ph.D Thesis, University of Canterbury, Christchurch, New Zealand.

**Appendix 1.** A record of all taxa, and their abundance from samples taken at all eight sites.

| INSECTA | S1 | S2 | S3 | SM1 | C1 | K1 | K2 | K3 |
|---|---|---|---|---|---|---|---|---|
| **Ephemeroptera** | | | | | | | | |
| *Coloburiscus* | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| *Deleatidium* | 6 | 9 | 1 | 20 | 179 | 0 | 0 | 0 |
| **Odonata** | | | | | | | | |
| *Xanthocnemis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| **Coleoptera** | | | | | | | | |
| Elmidae | 0 | 0 | 0 | 0 | 40 | 0 | 0 | 0 |
| **Diptera** | | | | | | | | |
| Ceratopogonidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| *Chironomus* | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 9 |
| Orthocladiinae | 0 | 4 | 7 | 11 | 9 | 0 | 12 | 0 |
| Stratiomyidae | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Tanypodinae | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Trichoptera** | | | | | | | | |
| *Aoteapsyche* | 0 | 4 | 15 | 0 | 38 | 0 | 0 | 0 |
| *Costachorema* | 1 | 1 | 0 | 1 | 5 | 0 | 0 | 0 |
| *Hudsonema* | 3 | 1 | 2 | 19 | 1 | 0 | 3 | 0 |
| *Hydrobiosis* | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| *Neurochorema* | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| Oeconesidae | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| *Olinga* | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 |
| *Oxyethira* | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 |
| *Psilochorema* | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 0 |
| *Pycnocentria* | 9 | 16 | 55 | 0 | 20 | 0 | 0 | 0 |
| *Pycnocentrodes* | 4 | 6 | 38 | 46 | 145 | 0 | 0 | 0 |
| *Triplectides* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| **ACARI** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| **CRUSTACEA** | | | | | | | | |
| Amphipoda | 35 | 1 | 12 | 0 | 6 | 2 | 0 | 0 |
| Ostracoda | 0 | 0 | 1 | 11 | 0 | 4 | 6 | 26 |
| **MOLLUSCA** | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Physa* | 0 | 0 | 1 | 1 | 7 | 0 | 6 | 2 |
| *Potamopyrgus* | 11 | 0 | 3 | 10 | 50 | 135 | 966 | 322 |
| Sphaeriidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| **OLIGOCHAETA** | 19 | 35 | 5 | 62 | 226 | 42 | 168 | 28 |
| **PLATYHELMINTHES** | 0 | 0 | 9 | 21 | 8 | 1 | 0 | 0 |
| **NEMATODA** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

**Appendix 2.** Location of each site within the Styx River catchment and Control site.

**Appendix 3.** Biotic index scores and there corresponding water quality category.

| Stark (1998) descriptions | MCI | SQMCI and QMCI |
|---|---|---|
| Clean water | > 119 | > 5.99 |
| Doubtful quality or possible mild pollution | 100-119 | 5.00-5.90 |
| Probable moderate pollution | 80–99 | 4.00-4.99 |
| Probable severe pollution | < 80 | < 4.00 |