THE INFLUENCE OF NUTRIENT CONCENTRATION ON ALGAL BIOMASS AND INVERTEBRATE COMMUNITIES IN AGRICULTURAL STREAMS

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Ecology at Massey University, Palmerston North, New Zealand.

Mark Peter Hamer

2003

Erratum Sheet

Page 16 line 3. effect should be spelt affect, these words are mixed up throughout the thesis.

Page 20 line 5. Acid washed water bottles were used to store the water samples in.

Page 20 line 12. Minimum detection limits were given as zero for both nitrate and phosphorous in the DR/2010 spectrophotometer procedures manual.

Page 20 line 14. Stone size class was determined in the field using a "gravelometer".

Page 21 line 18. Metrices should be spelt Metrics, this word is spelt incorrectly throughout the thesis.

Page 23 line 8. The Spearman rank correlation coefficient symbol should be r_s.

Page 26 Table 1. The units for conductivity are μS/cm.

Page 28 Figure 2C. Conductivity units of ms/L should be μS/cm.

Page 32 Figure 4. The Trichoptera section of the graph does not include Hydroptilidae and the Diptera section does not include Chironomidae.

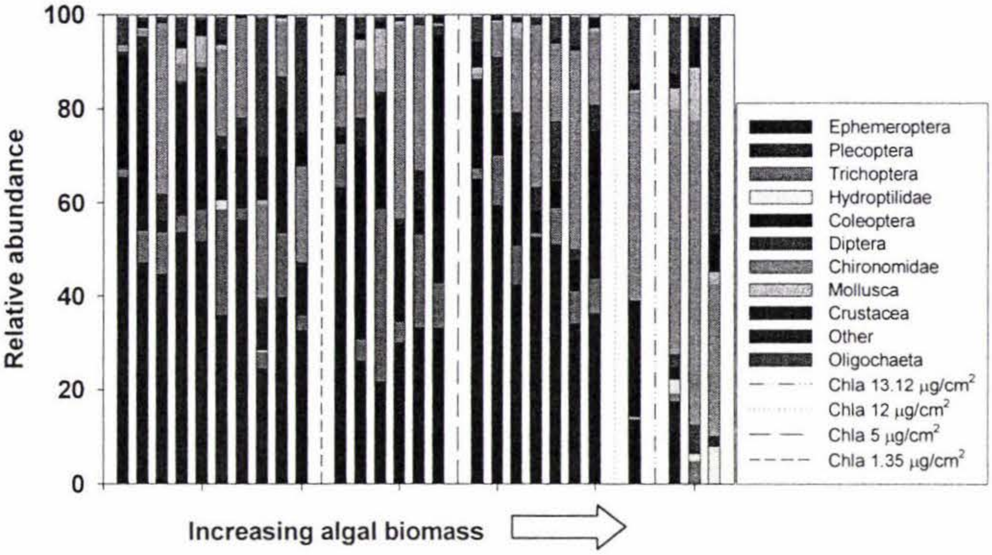

Figure 4. Mean relative abundance of invertebrate groups collected at 27 sites in the Manawatu, February 2002. Sites are arranged from lowest algal biomass (0.21 $\mu g/cm^2$) to greatest biomass (18.54 $\mu g/cm^2$). Ministry for the Environment maximum chlorophyll a (Chla) guidelines of 5 $\mu g/cm^2$ for high benthic biodiversity (long dashed line) and 12 $\mu g/cm^2$ for good recreational aesthetics (dotted line) are shown. This studies mean chlorophyll a recommendations to delineate differing stream health of 1.35 $\mu g/cm^2$ for clean water fauna (short dashed line) and 13.12 $\mu g/cm^2$ for severely polluted water (dash-dot line) are also shown.

Page 33 Figure 5. "time since" represents the time since the last rainfall event in which 20mm or more of rain fell.

Page 35 Table 6. Orthocladinae Sp 2 should be spelt Orthocladiinae Sp 2.

Page 37 line 15. Accrual times were estimated from the time since the last major rainfall event.

Page 55 line 17. Should read "Invertebrate densities however are rarely likely to be high enough to reduce algal biomass to any great extent (only locally) in natural streams due to varying biotic and abiotic dynamics (Clausen and Biggs 1997; Wellnitz and Ward 1998)."

Page 59 line 17. Add in "The Phankuch stability score was evaluated to determine the relative stability of the 3 sites."

Page 60 line 9. The distance measure used was Sorenson-Bray and the linkage technique was the Centroid clustering technique.

Page 62 figure 1. Replicates from sample occasion 1, 2 and 3 were used to calculate standard errors.

Page 70 line 9. Should read "Although the phosphorous addition did not significantly increase stream algal biomass, there were indirect effects on higher trophic levels, especially EPT."

Page 79 line 19. It should be noted that bacteria and fungi in streams can also attain nuisance proportions and have the potential to be important factors relating to dairy conversions as well.

Abstract

High nutrient inputs have generally been identified as responsible for the degradation of lowland rivers and lakes in New Zealand and internationally. Nutrients have been shown to influence algal community growth rate and composition. In turn algae can have strong effects on invertebrate communities (density, richness, composition, distribution, structure and function). This study investigates the effect of nutrients on algal biomass and higher trophic levels to determine the importance of nutrient loading on stream ecosystems.

Twenty six agricultural streams were surveyed in the Manawatu region in February, 2002. Algal biomass was greater in streams with high nitrate levels. Invertebrate communities differed in terms of the quantitative macroinvertebrate community index (QMCI), Ephemeroptera, Plecoptera and Trichoptera (EPT) individuals and taxa between sites with high and low algal biomass. Regression analysis was used to relate the "quality" of the invertebrate community to stream algal biomass. At 13.2 $\mu g/cm^2$ of chlorophyll *a* there was a dramatic shift in invertebrate community composition to more pollution tolerant taxa.

In the Hawke's Bay region nutrient concentration was experimentally increased in 3 low order streams in the summer of 2002/2003. Increased nutrient concentration did not affect stream algal biomass. There were however changes in the proportions of EPT in the enriched community. I propose that these changes in EPT were in response to increased algal growth rates and constrained any increase in algal biomass. Therefore changes in landuse intensity may affect invertebrate community structure.

Explanation of the text

This thesis consists of 4 chapters, a general introduction to the topics that I will cover, 2 data chapters and then a general discussion with implications for management. There is some repetition of introductions, methods and figure numbers throughout the thesis as I am planning to submit chapters 2 and 3 as stand alone scientific papers. The chapters are then followed by appendices containing additional data.

Acknowledgements

I extend a great deal of gratitude to my supervisor Dr Russell Death for all his assistance from the conception of this project to its completion. His guidance has been invaluable every step of the way from sampling protocols to statistical analysis and funding, his help was greatly appreciated.

I thank Nigel Ironside from the Hawke's Bay Regional Council for standing up to the Environmental Regulation officers for me and wavering the consent application fees. I would also like to thank Brett Stansfield and Neil Faulknor for help in identifying study sites.

I would like to thank all the landowners that gave me access to streams and rivers on their properties. A special thanks goes to John and Debbie Waldin, Dale Tatum and Ray and Carol Seymour for allowing me to add fertiliser to streams running through their properties.

Thanks to all the other postgraduate students that have encouraged, supported and helped and along the way. Getting drunk is so much easier with good friends like you guys around, cheers. Thanks to all the ecology department staff especially Barbara Just, Erica Reid, Ian Henderson, Mike Joy, Scott Carver and Jens Jorgensen.

A very big thank you has to go to my entire family for all their emotional, moral and financial support as my university tenure kept extending.

Table of contents

Chapter 1:

General Introduction

New Zealand is a mountainous temperate oceanic island archipelago in the South Pacific that covers a wide range of latitudes. The predominant weather patterns come from a westerly direction and large amounts of rainfall can occur at any time of year. New Zealand has a small population and large agricultural industry which results in diffuse nutrient inputs from agriculture being one of the dominant factors controlling ecosystem processes in many streams. The volume and strength of cow effluent from 6000 dairy farm milking sheds in the Waikato is equivalent to that of 1 million people (Quinn 2000). Therefore the potential impacts from an increase in dairy farming could be wide-ranging and severe.

Higher nutrient inputs to streams have been found in agricultural areas than in other land uses (Maasdam and Smith 1994; Quinn *et al.* 1997), but within agricultural landuse intensive dairy farming has been associated with greater nutrient inputs to streams than drystock farming (Harding *et al.* 1999). Quinn and Hickey (1990b) suggest that higher levels of catchment pastoral development resulted in reductions of invertebrate biomass and taxa sensitive to enrichment and increased the biomass of taxa associated with periphyton. The current trend towards greater numbers of dairy farms in New Zealand could therefore extensively alter stream environments and processes.

Maximum stream nutrient concentration is influenced by frequency of rainfall events (Biggs 1995; Holloway *et al.* 1998), inputs from the catchments geology (Maasdam and Smith 1994), upstream landuse (Biggs 1990; Dodds 1993) and the effectiveness of any riparian cover to remove nutrients from overland and shallow underground flow (Quinn 2000). Biotic uptake by autotrophic algae, microorganisms and abiotic absorption to particles can reduce stream nutrient concentration (Dodds 1993). Remineralisation from heterotrophic breakdown, predation or grazing can then increase loadings again (Dodds 1993; Dodds 2003). The effects of nutrient loading on algal biomass are reduced or observed less often in streams than in rivers (Chételat *et al.* 1999). Therefore the affects of increased nutrients on small streams with little or no shading to limit light needed to be investigated to evaluate the maximum affect (worst case scenario) that increased nutrient concentration could have on an agricultural stream.

Nitrogen (Scrimgeour and Kendall 2002) and phosphorous (Peterson *et al.* 1985; Sterling *et al.* 2000) have both been found to limit overall periphyton growth in streams although different algal taxa vary in their specific nutrient requirements (Tate 1990; Dodds and Welch 2000). Nutrient loadings can also effect periphyton community composition (Biggs 1990; Chételat *et al.* 1999) and growth form (Bourassa and Cattaneo 2000). Periphyton is the biofilm layer found on substrate surfaces in streams it comprises mainly of algae (Biggs 1995) but also bacteria, cyanobacteria, fungi, protists, a polysaccharide matrix, silt and detritus (Hill and Knight 1987; Burns and Ryder 2001). In this study I elucidated the chlorophyll *a* content of the periphyton communities to measure the amount of photosynthetically active algae present, and used this as an estimate of algal biomass.

Algae is generally accepted as the major energy resource in open agricultural streams and rivers (Biggs 1996; Burns and Ryder 2001). Higher light intensity, nutrient concentration, temperature and availability of suitable substrate all increase algal biomass (Welch *et al.* 1992; Biggs 1995; Burns and Ryder 2001). However it is reduced by a combination of flood disturbances, senescence and herbivory (Lamberti *et al.* 1989; Welch *et al.* 1992; Biggs 1995; Chételat *et al.* 1999; Burns and Ryder 2001). Periphyton productivity may determine the distribution and productivity of stream grazers (Hershey *et al.* 1988; Biggs and Lowe 1994). However periphytic algal biomass can be reduced by greater top down control from grazing invertebrates (Rosemond *et al.* 1993; Biggs and Lowe 1994; Rutherford *et al.* 2000), which can also lead to shifts in algal community composition and growth form (Lamberti *et al.* 1989; Rosemond *et al.* 1993; Bourassa and Cattaneo 2000). Thus in some circumstances herbivores can have stronger effects on algal communities than nutrients (Welch *et al.* 1992) but over a whole stream reach there will be an interplay of these 2 processes resulting in patchy algae and invertebrate distributions. Grazing can have both negative (physical removal) and beneficial (increased light and nutrient supply) impacts on periphyton communities (Steinman 1996; Burns and Ryder 2001) but consumptive losses generally overshadow any beneficial effects (McCormick 1994). Invertebrate distributions and community composition is therefore strongly linked to stream periphyton communities (Lamberti 1996). Again there is a complicated interplay between a variety of simultaneous processes that make deciphering the effect of algal biomass on stream invertebrate communities difficult. In this study I focus on the effects that nutrient concentration has on periphyton and how this in turn affects the invertebrate community.

The intent of this study was to identify local patterns in the relationships between nutrient concentration and algal biomass, the relationships between algal biomass and invertebrate communities and if possible to quantify those relationships. I also aimed to identify the effect on stream ecosystems of farm conversions from extensive drystock farms with lower stream nutrient inputs to intensive dairy farms with higher nutrient inputs.

Therefore the objectives of this study were to:

1: Identify if there is a link between stream nutrient levels and algal biomass.

2: Determine if there is a link between invertebrate communities and algal biomass.

3: Resolve if linkages can be used to establish guidelines for nutrient or chlorophyll *a* levels in pasture streams to maintain invertebrate communities indicative of clean water.

4: Increase the nutrient concentration of three streams in extensive landuse areas to simulate the effects of farm conversion.

5: Elucidate the effects of this increase on stream macroinvertebrate communities.

6: Provide information on how this could be used by managers to improve stream ecosystems in New Zealand.

REFERERENCES:

Biggs, B. J. F. 1990: Periphyton communities and their environments in New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research* 24: 367-386.

Biggs, B. J. F. 1995: The contribution of flood disturbance, catchment geology and land use to the habitat templete of periphyton in stream ecosystems. *Freshwater Biology* 33: 419-438.

Biggs, B. J. F. 1996. Patterns in Benthic Algae of Streams. Algal Ecology: freshwater benthic ecosystems. Stevenson, R. J., Bothwell, M. L. and Lowe, R. L. London, Academic Press 31-56.

Biggs, B. J. F. and Lowe, R. L. 1994: Responses of two trophic levels to patch enrichment along a New Zealand stream continuum. *New Zealand Journal of Marine and Freshwater Research* 28: 119-134.

Bourassa, N. and Cattaneo, A. 2000: Responces of a lake outlet community to light and nutrient manipulation: effects on periphyton and invertebrate biomass and composition. *Freshwater Biology* 44: 629-639.

Burns, A. and Ryder, D. S. 2001: Potential for biofilms as biological indicators in Australian riverine systems. *Ecological Management and Restoration* 2: 53-63.

Chételat, J.; Pick, F. R.; Morin, A. and Hamilton, P. B. 1999: Periphyton biomass and community composition in rivers of different nutrient status. *Canadian Journal of Fisheries and Aquatic Sciences* 56: 560-569.

Dodds, W. K. 1993: What controls levels of dissolved phosphate and ammonium in surface waters? *Aquatic Sciences* 55: 132-142.

Dodds, W. K. 2003: Misuse of inorganic N and soluble reactive P concentrations to indicate nutrient status of surface waters. *Journal of the North American Benthological Society* 22: 171-181.

Dodds, W. K. and Welch, E. B. 2000: Establishing nutrient criteria in streams. *Journal of the North American Benthological Society* 19: 186-196.

Harding, J. S.; Young, R. G.; Hayes, J. W.; Shearer, K. A. and Stark, J. D. 1999: Changes in agricultural intensity and river health along a river continuum. *Freshwater Biology* 42: 345-357.

Hershey, A. E.; Hiltner, A. L.; Hullar, M. A. J.; Miller, M. C.; Vestal, J. R.; Lock, M. A.; Rundle, S. and Peterson, B. J. 1988: Nutrient influence on a stream grazer: *Orthocladius* microcommunities respond to nutrient input. *Ecology* 69: 1383-1392.

Hill, W. R. and Knight, A. W. 1987: Experimental analysis of the grazing interaction between a mayfly and stream algae. *Ecology* 68: 1955-1965.

Holloway, J. M.; Dahlgren, R. A.; Hansen, B. and Casey, W. H. 1998: Contribution of bedrock nitrogen to high nitrate concentrations in stream water. *Nature* 395: 785-788.

Lamberti, G. A. 1996. The role of Periphyton in Benthic Food Webs. Algal Ecology : Freshwater Benthic Ecosystems. Stevenson, R. J., Bothwell, M. L. and Lowe, R. L. London, Academic Press 533-572.

Lamberti, G. A.; Gregory, S. V.; Ashkenas, L. R.; Steinman, A. D. and McIntire, C. D. 1989: Productive capability of periphyton as a determinant of plant-herbivore interactions in streams. *Ecology* 70: 1840-1856.

Maasdam, R. and Smith, D. G. 1994: New Zealand's National River Water Quality Network 2. Relationships between physico-chmical data and environmental factors. *New Zealand Journal of Marine and Freshwater Research* 28: 37-54.

McCormick, P. V. 1994: Evaluating the multiple mechanisms underlying herbivore-algal interactions in streams. *Hydrobiologia* 291: 47-59.

Peterson, B. J.; Hobbie, J. E.; Hershey, A. E.; Lock, M. A.; Ford, T. E.; Vestal, J. R.; McKinley, V. L.; Hullar, M. A. J.; Miller, M. C.; Ventullo, R. M. and Volk, G. S. 1985: Transformation of a Tundra River from Heterotrophy to Autotrophy by Addition of Phosphorus. *Science* 229: 1383-1386.

Quinn, J. M. 2000. Effects of pastoral development. New Zealand Stream Invertebrates: ecology and implications for management. Collier, K. J. and Winterbourn, M. J. Christchurch, New Zealand Limnological Society 208-229.

Quinn, J. M.; Cooper, A. B.; Davies-Colley, R. J.; Rutherford, J. C. and Williamson, R. B. 1997: Land use effects on habitat, water quality, periphyton, and benthic invertebrates in waikato, New Zealand, hill-country streams. *New Zealand Journal of Marine and Freshwater Research* 31: 579-597.

Quinn, J. M. and Hickey, C. W. 1990b: 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.

Rosemond, A. D.; Mulholland, P. J. and Elwood, J. W. 1993: Top-down and bottom-up control of stream periphyton: Effects of nutrients and herbivores. *Ecology* 74: 1264-1280.

Rutherford, J. C.; Scarsbrook, M. R. and Broekhuizen, N. 2000: Grazer control of stream algae: Modeling temperature and flood effects. *Journal of Environmental Engineering* 126: 331-339.

Scrimgeour, G. J. and Kendall, S. 2002: Consequences of livestock grazing on water quality and benthic algal biomass in a Canadian natural grassland plateau. *Environmental Management* 29: 824-844.

Steinman, A. D. 1996. Effects of Grazers on Freshwater Benthic Algae. Algal Ecology: freshwater benthic ecosystems. Stevenson, R. J., Bothwell, M. L. and Lowe, R. L. London, Academic press 341-373.

Sterling, M. S.; Ashley, K. L. and Bautista, A. B. 2000: Slow-Release Fertilizer for Rehabilitating Oligotrophic Streams: a Physical Characterization. *Water Quality Research Journal of Canada* 35: 73-94.

Tate, C. M. 1990: Patterns and controls of Nitrogen in tallgrass prairie streams. *Ecology* 71: 2007-2018.

Welch, E. B.; Quinn, J. M. and Hickey, C. W. 1992: Periphyton biomass related to point-source nutrient enrichment in seven New Zealand streams. *Water Research* 26: 669-675.

Chapter 2:

The influence of nutrient concentration on algal biomass and stream invertebrate communities in the Manawatu, New Zealand.

ABSTRACT

A survey of 27 agricultural stream reaches in the Manawatu, New Zealand was conducted in the summer (February) of 2002. I investigated the influence of nutrients on algal biomass and the effect algal biomass and other environmental factors have on macroinvertebrate communities. I found that algal biomass was linked to nitrate in the Manawatu region of New Zealand. However the relatively low nitrate concentrations (0 - 7.2 mg/L) corresponded to a wide algal biomass range (0.21 - 18.54 µg/cm^2). Algal biomass was found to effect invertebrate community composition and Ephemeroptera, Plecoptera and Trichoptera (EPT) proportions. There was little change in the invertebrate communities at low to medium algal biomass ranges but there was a dramatic change in the EPT proportions at high algal biomass. I found that 13.12 µg/cm^2 of chlorophyll *a* delineates "healthy" from "unhealthy" ecosystems when using macroinvertebrates as indicator taxa. I also suggest that a clean water fauna will be reflective of chlorophyll *a* concentrations below 1.35 µg/cm^2. Hydrological variables; depth, discharge, velocity and secondarily width and stream order strongly affected species richness and overall invertebrate abundance.

KEYWORDS: Algal biomass; community composition; geology; guidelines; invertebrates; landuse; nitrate; nutrients; periphyton.

INTRODUCTION

Although many large point source discharges of nutrients have been eliminated in New Zealand streams and rivers the diffuse release of nutrients from farm runoff is still widespread. Phosphorous (Peterson *et al.* 1985; Biggs and Close 1989; Sterling *et al.* 2000) or nitrogen (Scrimgeour and Kendall 2002) have been found to limit overall periphyton growth in streams and in many cases both may be involved in algal limitation (Gray and Fisher 1981; Hershey *et al.* 1988; Rosemond *et al.* 1993; Miltner and Rankin 1998). Often periphyton is nutrient limited only in summer in New Zealand streams (Friberg and Winterbourn 1997; Francoeur *et al.* 1999), although individual algal taxa and growth forms differ in their nutrient requirements (Tate 1990; Dodds and Welch 2000). Extremely high algal biomasses can result once the nutrient limiting concentration is exceeded (Welch *et al.* 1992). In streams where spates are rare, even small increases of nutrients can greatly increase the frequency of excessive biomass accrual (Biggs 2000a).

Stone biofilms, which at open pasture sites are often dominated by autotrophic algae, are a major energy source for aquatic ecosystems (Burns and Ryder 2001). Hart and Robinson (1990) found that the quantity of food resources affected the grazer communities rather than the quality of those resources. However the impact of increased enrichment can be mitigated by greater top down control of periphyton biomass by grazers (Biggs and Lowe 1994). It is unclear when and why in some cases herbivores have stronger effects on algal communities than nutrients (Welch *et al.* 1992) but in other cases biofilm productivity determines the distribution and productivity of stream grazers (Winterbourn 1990; Biggs and Lowe 1994).

Although it seems well established that increased nutrient supply can increase algal biomass it is still unclear how this may be negated by invertebrate grazing. Furthermore, although there are established guidelines for nutrient levels (Dodds and Welch 2000) and aesthetic algal biomass values (Biggs 2000b) there are few similar scientifically based guidelines relating these to "healthy" invertebrate communities. The objective of this study is to investigate the effects of elevated algal biomass generated by high nutrient levels in pastoral streams on aquatic invertebrate communities and if possible to quantify those relationships. If it is possible to quantify the link between nutrients, algal biomass and invertebrate communities there may be a case to establish guidelines in nutrient levels above which the quality of the invertebrate communities declines to unacceptable levels.

My specific research questions were therefore:

1. Is there a link between stream nutrient levels and algal biomass?
2. Is there a link between invertebrate biotic quality and algal biomass?
3. Can these linkages be used to establish guidelines for nutrient or chlorophyll *a* levels in pasture streams to maintain high invertebrate biotic quality?

METHODS

Study area

The 27 study sites comprised of 20 m reaches in 26 1st to 6th order rivers and streams in the Manawatu (Fig. 1) and were sampled in February (summer) of 2002. The majority of the sites were chosen from those sampled by the Manawatu Catchment Board in 1982/1983 (Lindsay 1983). Others were chosen if greater than 200 m downstream of native bush in open sunlit conditions to give a wider cross section of stream types and conditions. Land use surrounding the sites varies from intensive dairying and dry stock farming to retired farmland with regenerating riparian vegetation. The geology of the region consists of sedimentary rock and alluvium (Snelder and Biggs 2002). Largely consisting of greywacke, tertiary mudstone, loess (wind blown sand deposits), alluvium (water transported sediment deposits) and "other" (quarries, towns etc) (Snelder and Biggs 2002).

Sampling protocol

Five 0.1 m^2 Surber samples (mesh size 500 μm) were collected progressively upstream but otherwise at random from riffles in each reach during February 2002. They were preserved with 10% formalin until the collected invertebrates were counted and identified to the lowest possible level using the keys of McFarlane (1951), Winterbourn (1972), Winterbourn and Gregson (1989), and Harding (1991).

Four stones (approximately 6 cm longest dimension) were collected progressively upstream near Surber sample locations for algal biomass analysis. The stones were kept on ice until being frozen in the laboratory. Pigments were extracted in 90% acetone at 5 °C for 24 hours before using a Cary 50 Conc UV visible spectrophotometer to determine pigment concentrations following Steinman and Lamberti (1996). The length, width and depth of the stones was measured to give an estimate of stone surface area following Biggs and Close (1989). This area was halved to allow for the fact algal growth only occurs on upper stone surfaces.

Dissolved Oxygen was measured in the field using a YSI 58 meter, conductivity and temperature was measured with an Orion model 122 conductivity meter corrected to 25 °C and a pHTestr 2 was used to measure pH. Current velocity was measured at each

Surber location using a velocity head rod. Stream discharge (m^3/s) was measured by carrying out flow gauging, recording depth and velocity at five points: 10%, 30%, 50%, 70%, and 90% of the streams width. The area measured between each point was then multiplied by velocity.

A 500 ml water sample was filtered in the field using Whatman GF/C glass microfibre filters, then kept in the dark on ice for up to 8 hours until either analysing the sample for nutrients or it was frozen for later analysis. Nitrate concentration was measured using the Cadmium reduction method (Scrimgeour and Kendall 2002) and then determined photometrically with a Hach DR/2010 spectrophotometer. Dissolved reactive phosphorous (DRP) was analysed using the PhosVer 3 (ascorbic acid) method (Hach 1996) and the concentration determined photometrically with the Hach DR/2010 spectrophotometer.

The distribution of substrate size was evaluated by randomly choosing 100 stones, determining their size class (<2, 2-11.3, 11.3-16, 16-22.6, 22.6-32, 32-45.3, 45.3-64, 64-90.5, 90.5-128, 128-300, >300 mm), and converting to a percentage of total substrate. From this data a substrate index was calculated, by multiplying the midpoint of each size class category by the percentage occurrence and summing for all categories following Quinn and Hickey (1990b).

Seven 60 ml samples of suspendable sediment were taken from riffles in each reach using the method of Quinn *et al.* (1997). The samples from each reach were combined then filtered using Whatman GF/C glass microfibre filters in the lab and the sediment dried and weighed to give a value of suspendable sediment per unit area. The environmental characteristics of each site or catchment that were not measured in the field were obtained from the River Environment Classification (REC) GIS database using the ARCview program (Snelder and Biggs 2002).

Statistical Analysis

Linkages between biological and physicochemical variables were firstly examined with Spearman rank correlations to identify any trends then analysis of variance (ANOVA) was undertaken on the main trends found. Data was tested for normality using Shapiro-Wilks test in and if significant to $P = 0.05$ were log transformed to improve normality. These analyses were conducted using the SAS program (SAS 1996) and all correlations in text are significant to $P = 0.05$ unless otherwise stated. A Nonmetric Multidimensional Scaling (NMS) ordination was conducted using the PC-ORD program (McCune and Mefford 1995) to identify patterns in invertebrate community structure. Axes scores were correlated with environmental measures using Pearson correlation coefficients to determine what parameters were most important in determining the invertebrate community patterns found.

Regression analysis was conducted between the significantly correlated nitrate measure and chlorophyll *a*. From the slope of the regression, nitrate concentrations associated with chlorophyll *a* were obtained to potentially use as guidelines. Of the invertebrate metrices correlated with algal biomass (chlorophyll *a*) the quantitative macroinvertebrate community index (QMCI) has defined water quality descriptions associated with the invertebrate community scores. Hence, regression analysis was used to quantify the link between algal biomass and QMCI scores. From the slope of this regression, chlorophyll *a* concentrations associated with each QMCI grouping were made to link water quality, algal biomass and invertebrate communities.

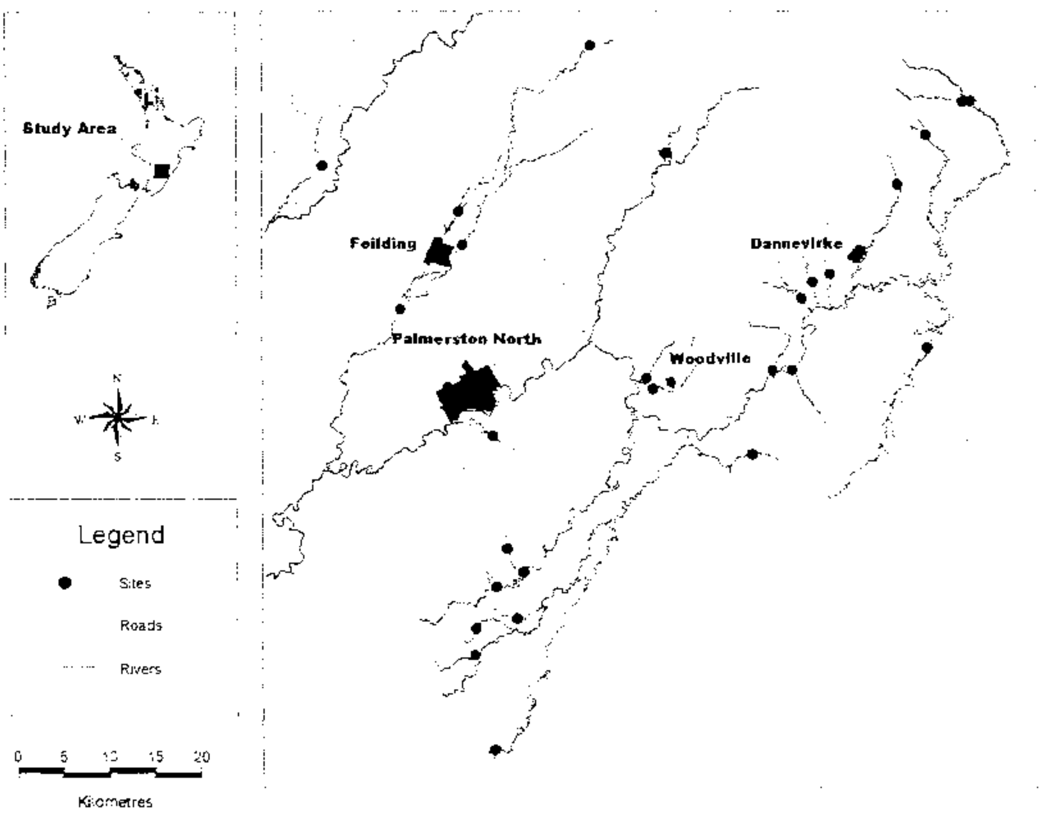

Figure 1. Location of 27 sites sampled in the Manawatu, New Zealand, February 2002.

RESULTS

What environmental variables effect stream nutrient concentrations?

Environmental parameters varied greatly between the 27 sites, resulting in DRP levels ranging from 0 – 1.77 mg/L and nitrate levels between 0 – 7.6 mg/L (Table 1). Of local site variables measured only depth was linked with conductivity (Table 2). Nitrate concentration was positively correlated with the proportion of farmland in the catchment (Spearman's r= 0.40) and negatively correlated with percentage scrub (r= -0.39). No other land use variables were correlated with nitrate concentration (Table 2).

Of the geological variables the proportion of loess, mudstone and "other" in the base rock had significant positive correlations with conductivity (Table 2). Altitude was negatively correlated with conductivity (r= -0.52). The amount of alluvium was positively correlated with nitrate concentration (r= 0.64) while the amount of mudstone was negatively correlated with nitrate concentration (r= -0.54). Interestingly, none of the measured variables correlated significantly with dissolved reactive phosphorous (DRP) concentration.

Is there a link between nutrients and periphyton biomass?

There was a positive relationship between nitrate concentration and chlorophyll *a* (ANOVA $F_{1,25}$= 8.44, P= 0.0076) but none with DRP ($F_{1,25}$= 1.38, P= 0.25) or conductivity ($F_{1,25}$=2.23, P= 0.148) (Fig. 2). Seven of the sites in this study were below 80 µg/L dissolved inorganic nitrogen (DIN) suggested to limit filamentous green algae *Cladophora* growth and 8 sites were below 25 µg/L DRP suggested to limit algal growth (Welch *et al.* 1992). Five sites were below Ministry for the Environment (MfE) nutrient and algal guidelines of 10 mg/m^3 for nitrate and 8 were below 1 mg/m^3 for DRP for high benthic biodiversity given 30 days accrual (Biggs 2000b). Only 7 sites were below the MfE nitrate (75 mg/m^3 given 30 days accrual) and DRP (6 mg/m^3 given 30 days accrual) guidelines to maintain good recreational aesthetics (Biggs 2000b). Sixteen sites had chlorophyll *a* concentrations below the guidelined 50 mg/m^2 for high benthic biodiversity and 23 of the 27 were below 120 mg/m^2 for good recreational aesthetics.

Regression analysis produced nitrate guidelines of -3.9 mg/m^3 for 13.5 mg/m^2 chlorophyll *a*, 1.69 mg/m^3 for 50 mg/m^2 chlorophyll *a*, 12.46 mg/m^3 for 120 mg/m^2 chlorophyll *a* and 14.18 mg/m^3 for 132 mg/m^2 chlorophyll *a*. Although the negative value obtained implies the accuracy of these guidelines is questionable.

Is there a link between periphyton and invertebrates community metrices?

There was a negative relationship between chlorophyll *a* concentration and quantitative macroinvertebrate community index (QMCI) (ANOVA $F_{1, 25} = 10.19$, $P = 0.0038$), Ephemeroptera, Plecoptera and Trichoptera (EPT) individuals ($F_{1, 25} = 8.43$, $P = 0.0076$) and EPT taxa ($F_{1, 25} = 9.02$, $P = 0.006$) (Fig. 3). None of the other invertebrate metrices were correlated with algal biomass (Table 3).

When the relative abundances of different invertebrate groups was investigated (Fig. 4) Ephemeroptera were shown to be reduced at the highest algal biomasses only. Hydroptilidae were generally more common at the highest algal biomasses. The Chironomidae were common at many sites but were generally more abundant at higher algal biomass. Mollusca suggested to be associated with algae (Quinn and Hickey 1990a), showed no changes with algal biomass. Trichoptera were most common with medium amounts of algae and Coleopteran abundances varied greatly amongst all the sites with a reduction at the highest values.

Regression analysis found that chlorophyll *a* concentrations below 1.35 µg/cm^2 correspond to a QMCI score of 6 above which indicates clean water fauna (Boothroyd and Stark 2000) (Fig. 3B, Table 4). Chlorophyll *a* concentrations above 13.12 correspond to QMCI scores below 4 (Table 4). For the purposes of this study the two middle groups were combined to represent doubtful water quality, probable moderate pollution as there weren't any obvious community differences between them (Table 4).

Is there a stronger link between other environmental variables and invertebrate community metrices, than with periphyton?

Width, depth, velocity and discharge were negatively correlated with species richness and invertebrate abundance (Table 3). Thus there were more taxa and individuals in small, shallow, slow flowing streams. Stream order was also negatively correlated with species richness (Spearman's r= -0.46) and Margalef's diversity index (r= -0.48). EPT taxa (r= -0.50), MCI (r= -0.48) and QMCI (r= -0.41) were all negatively correlated with temperature. The substrate index, indicative of stone size was strongly correlated with QMCI (r= -0.51).

Of the land use variables, the amount of urban area in a catchment had a negative correlation with both macroinvertebrate community index (MCI) (r= -0.43) and EPT taxa (r= -0.39). EPT taxa was negatively correlated with the proportion of farmland in the catchment (r= -0.43) and positively correlated with scrub (r=0.41). The proportion of exotic forest in a catchment was negatively correlated with MCI (r= -0.38).

Table 1. Nutrient, chlorophyll *a* and physicochemical parameters measured at 27 sites in the Manawatu, February 2002.

Site number	Site Name	Width (m)	Depth (cm)	Velocity (m/s)	Discharge (m^3/s)	Conductivity	DRP (mg/L)	Nitrate (mg/L)	Chlorophyll a ($\mu g/cm^2$)	Temperature ($^{\circ}C$)	Stream order	Altitude m a.s.l.
1	Oroua R	10.5	23	1.31	2.13	165	0.38	1.17	12.68	20.3	6	40
2	Tutaenui stm	2.27	8.1	0.72	0.04	264	1.77	0.13	14.67	24.8	4	40
3	Makino stm	2.38	5.34	0.46	0.02	260	0	7	14.57	18.6	4	120
4	Kiwitea stm	4.74	14.1	0.77	0.44	169.6	0	0.01	2.11	24	4	340
5	*Kiwitea stm (Feilding)*	6.18	11.4	0.76	0.44	193	0	2.22	7.13	26.2	5	90
6	Mangamokio stm	2.04	15.2	1.14	0.20	122.9	0.11	7.2	8.72	17.7	2	340
7	Manawatu R	5.95	12.2	0.87	0.90	85.9	0.37	1.79	8.98	21.6	4	320
8	Mangatewai-nui stm	5.14	14.5	0.84	0.38	94.5	0.5	1.47	6.95	23.6	2	320
9	Whakaruatapu stm	1.75	11.8	1.05	0.09	108	1.14	0.52	8.67	20.4	3	300
10	Coal Creek	9.15	22.6	1.09	0.92	214	0	0.03	1.06	17.5	4	160
11	Mangatoro R	8.51	21.6	1.12	1.06	327	0	1.66	3.99	19.1	5	200
12	Turitea stm	4.9	11.1	0.63	0.10	155.9	0.79	1.25	3.04	23.4	4	60
13	Makakahi R	6.04	16.2	0.58	0.54	53.1	0.76	0.93	0.28	14.4	3	280
14	Mangatainoka R	14.2	26.8	0.77	1.11	53.3	1.06	0.74	1.35	19.6	3	240
15	Mangaraupia stm	4.16	12	0.47	0.05	71.6	0.31	0.34	0.72	20.5	2	260
16	Tainui stm	3.16	7	0.66	0.08	141.8	0.29	0.41	5.90	14.5	1	160
17	Otangane stm	8.59	12.8	0.79	0.19	111.6	0.07	0.31	3.24	16.1	3	140
18	Mangahao R	21.06	20	0.97	1.53	77.1	0.4	0.07	1.68	18.9	5	140
19	Hukanui stm	2.67	13	0.49	0.06	95.7	0.28	3.01	18.54	19.3	3	200
20	Makairo stm	5.02	11	0.47	0.19	147.6	0.12	0	0.25	14.2	4	120
21	Otawhao stm	3.71	8.2	0.42	n/a	205	0	0	0.41	17.2	3	120
22	Raparapawai stm	3.76	11	1.15	0.19	106.1	0	0	0.33	16	4	120
23	Tamaki R	10.68	14.8	0.58	0.63	81.4	0.18	1.36	0.79	15	4	180
24	*Kumeti stm*	4.04	17	0.64	0.24	100.6	0.3	7.6	0.21	13	2	180
25	Oruakeretaki stm	4.64	23.2	0.63	0.59	107.5	0.23	6.1	3.20	18.1	4	160
26	Mangamania stm	2.46	8.8	0.25	0.01	221	0	0	0.79	22.1	3	80
27	Mangaatua stm	6.54	9	0.54	0.24	157.4	1.15	1.8	5.74	20.2	4	80

Table 2. Spearman Rank Correlation Coefficients between nutrient, chlorophyll *a* and physicochemical variables measured at 27 sites in the Manawatu, February 2002. Values shown in bold are significant at P = < 0.05.

	Conductivity	DRP	Nitrate	Chlorophyll a
Conductivity	**1.00**	**-0.45**	-0.14	0.28
DRP	**-0.45**	**1.00**	0.17	0.20
Nitrate	-0.14	0.17	**1.00**	**0.45**
Chl a	0.28	0.20	0.45	**1.00**
Altitude	**-0.53**	0.03	0.23	-0.02
Discharge	-0.24	0.05	0.11	-0.15
Width	-0.26	0.09	-0.05	-0.23
Depth	**-0.40**	0.10	0.26	-0.13
Velocity	-0.03	0.04	0.02	0.27
Temperature	0.25	0.22	0.03	**0.52**
pH	0.14	0.03	-0.12	-0.04
O2	0.36	-0.06	0.13	0.29
Substrate index	-0.34	0.16	0.07	0.13
Suspendable sediment	0.35	-0.23	-0.12	-0.06
Stream order	0.37	-0.15	-0.04	0.16
% of catchment Urban	0.23	0.34	0.17	0.25
% of catchment Farming	0.31	-0.26	**0.41**	0.30
% of catchment Native	-0.24	0.31	-0.15	-0.07
% of catchment Exotic	0.27	0.10	-0.12	0.09
% of catchment Scrub	0.05	-0.06	**-0.39**	-0.23
% of catchment Tussock	0.23	0.23	-0.26	0.22
% of catchment Bare_groun	0.11	0.23	-0.36	0.05
% of catchment Other	0.04	0.19	-0.05	0.08
% of catchment Basepeat	0.30	0.33	-0.15	0.30
% of catchment Baseloess	**0.58**	-0.06	-0.02	0.31
% of catchment Basealluv	-0.29	0.02	**0.64**	0.31
% of catchment Basesand	0.05	-0.08	-0.29	-0.30
% of catchment Baseother	**0.51**	-0.05	-0.23	0.19
% of catchment Basemud	**0.54**	-0.35	**-0.54**	-0.20
% of catchment Basevolsof	0.30	0.33	-0.15	0.30
% of catchment Basegrey	-0.32	0.22	-0.33	-0.36

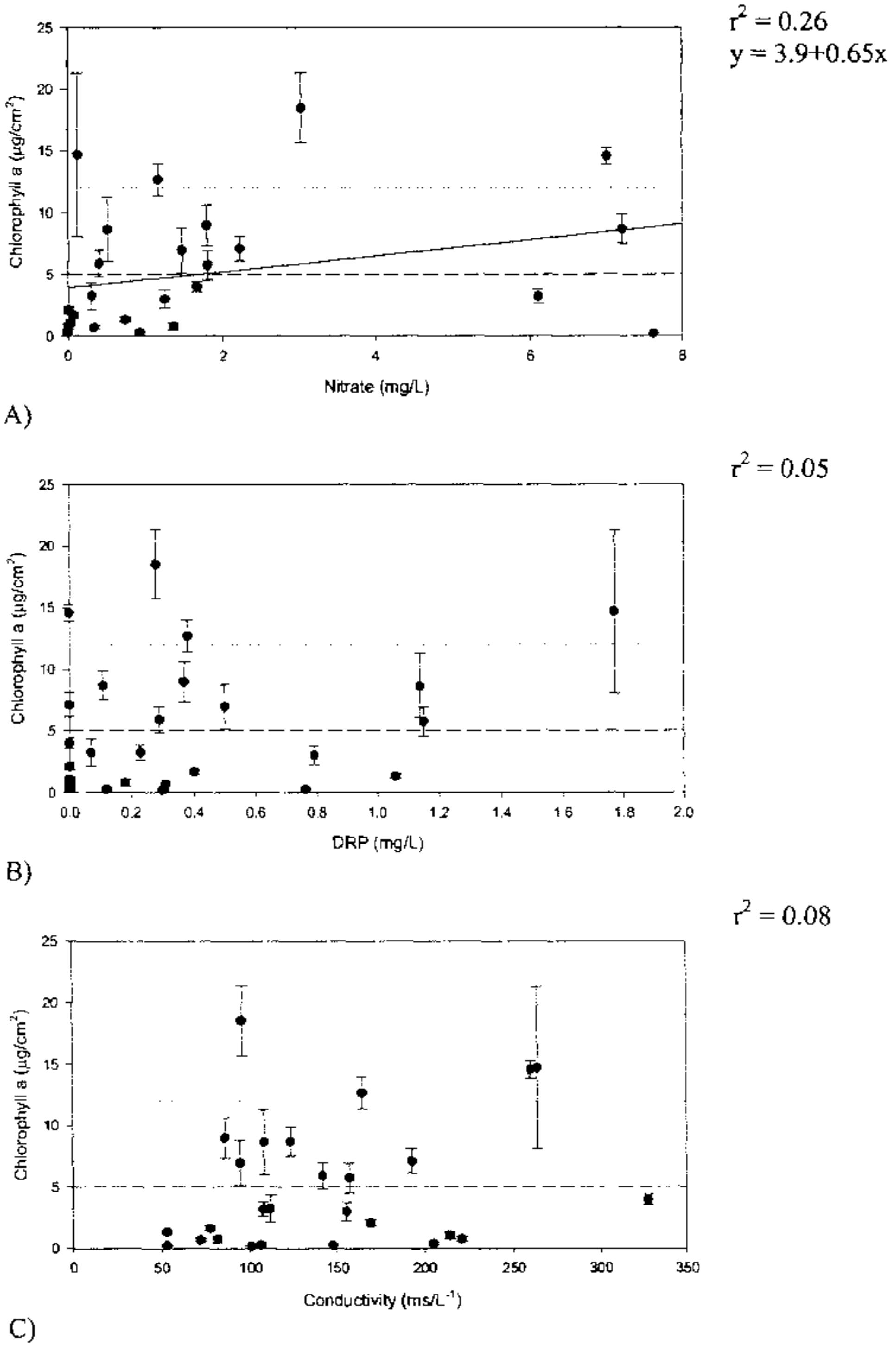

Figure 2. Plot of chlorophyll a means +/– 1 SE as a function of A) nitrate, B) dissolved reactive phosphorous (DRP) and C) conductivity. Ministry for the Environment maximum chlorophyll a guidelines of 5 µg/cm^2 for high benthic biodiversity (dashed line) and 12 µg/cm^2 for good recreational aesthetics (dotted line) are also shown.

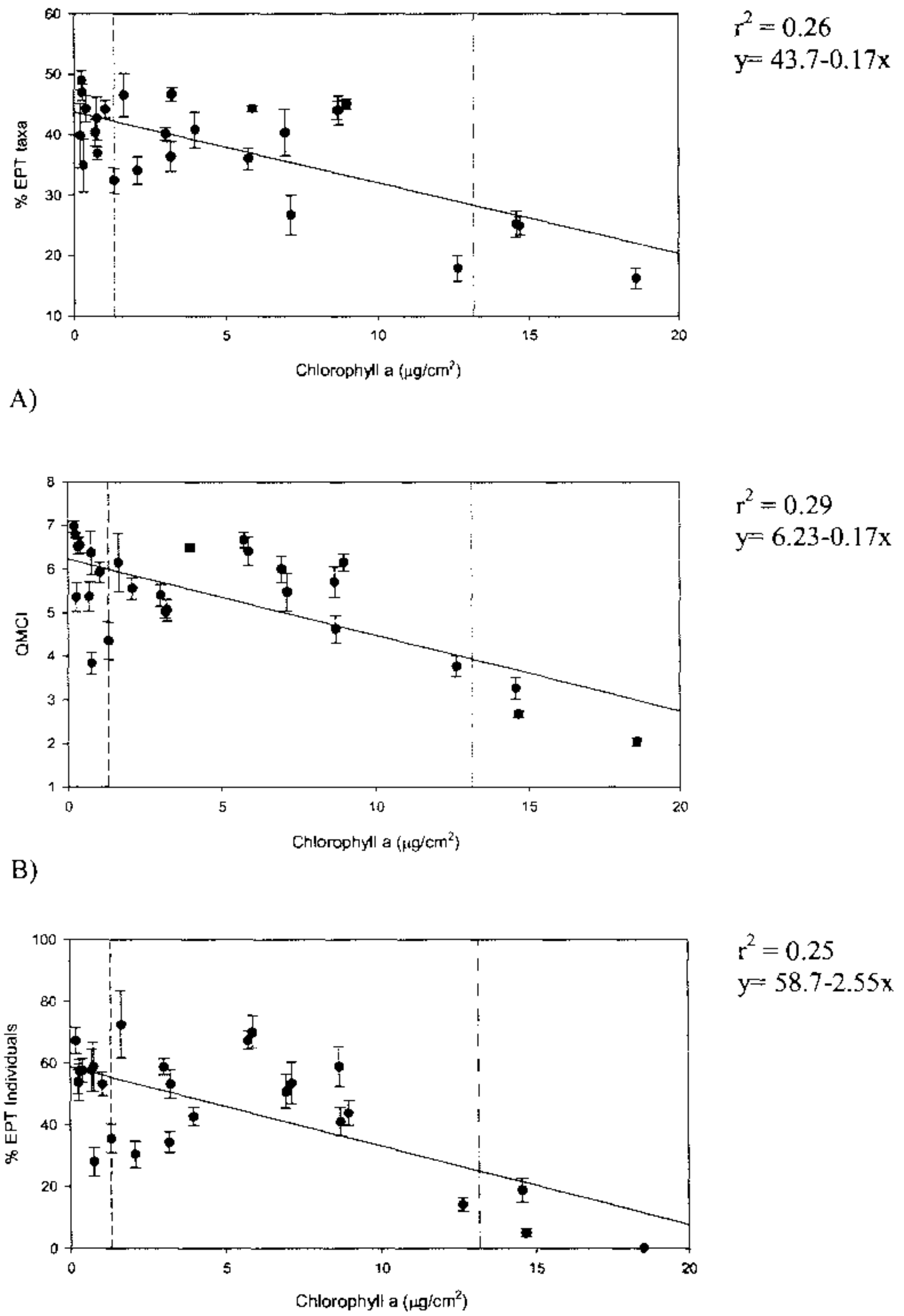

Figure 3. Plot of chlorophyll a means +/− 1 SE and A) EPT taxa, B) QMCI and C) EPT individuals recorded at 27 sites in the Manawatu. Mean chlorophyll a guidelines of 1.35 μg/cm^2 for clean water fauna (dashed line) and 13.2 μg/cm^2 for severely polluted water (dash-dot line) are also shown.

The proportion of base loess had significant negative correlations with MCI (r= -0.63) and EPT taxa (r= -0.51). While the proportion of base greywacke was positively correlated with EPT individuals (r= 0.40) and EPT taxa (r= 0.57). Algal biomass had stronger correlations with both QMCI and EPT individuals than any of the other environmental variables (Table 3). However all other invertebrate community metrices had stronger correlations with other environmental variables (Table 3).

Table 3. Spearman Rank Correlation Coefficients between nutrient, chlorophyll *a*, physicochemical variables and invertebrate metrices measured at 27 streams in the Manawatu, 2002. Values shown in bold are significant at P = < 0.05.

	Species richness	Invertebrate abundance	Margalef	Simpson	MCI	QMCI	EPT Ind	EPT taxa
Conductivity	0.04	0.17	-0.10	0.07	-0.26	-0.07	-0.33	-0.28
DRP	0.14	0.23	0.05	-0.05	-0.04	-0.10	0.22	-0.02
Nitrate	-0.28	-0.16	-0.32	-0.02	-0.06	-0.16	-0.13	-0.29
Chl a	0.04	0.11	-0.06	0.26	-0.37	**-0.52**	**-0.48**	**-0.42**
Altitude	0.02	-0.27	0.23	0.03	**0.47**	0.07	0.00	0.30
Discharge	**-0.58**	**-0.59**	-0.38	-0.35	0.16	0.26	0.06	0.18
Width	**-0.47**	-0.31	-0.35	-0.25	0.05	0.21	0.18	0.19
Depth	**-0.59**	**-0.61**	-0.36	-0.07	0.08	-0.09	-0.14	0.04
Velocity	**-0.41**	**-0.60**	-0.22	-0.18	0.18	0.06	-0.04	0.05
Temperature	0.12	0.22	0.06	0.26	**-0.48**	**-0.41**	-0.37	**-0.50**
pH	0.06	0.28	-0.11	-0.08	-0.25	-0.06	-0.06	-0.10
O2	0.01	0.30	-0.16	-0.01	-0.30	-0.23	-0.31	-0.19
Substrate index	-0.03	-0.03	0.05	0.35	-0.16	**-0.51**	-0.14	0.08
Suspendable sediment	0.24	0.19	0.17	-0.12	0.00	0.31	0.13	-0.11
Stream order	**-0.46**	-0.25	**-0.48**	-0.20	-0.29	0.02	-0.16	-0.24
% of catchment Urban	-0.22	0.03	-0.38	-0.21	**-0.43**	-0.08	0.05	**-0.39**
% of catchment Farming	-0.25	-0.15	-0.26	-0.15	-0.11	0.05	-0.26	**-0.43**
% of catchment Native	0.20	0.17	0.19	0.17	-0.21	-0.32	-0.14	0.01
% of catchment Exotic	0.21	0.17	0.16	0.21	**-0.38**	-0.34	-0.19	-0.17
% of catchment Scrub	0.04	-0.04	0.07	0.00	0.14	0.17	0.26	**0.41**
% of catchment Tussock	-0.15	-0.12	-0.16	-0.05	-0.33	-0.24	-0.17	-0.13
% of catchment Bare_groun	-0.07	0.01	-0.12	-0.06	-0.35	-0.18	-0.13	-0.11
% of catchment Other	-0.13	0.02	-0.26	-0.12	-0.15	-0.10	-0.06	-0.14
% of catchment Basepeat	0.11	0.30	-0.10	0.08	-0.30	-0.30	-0.30	-0.28
% of catchment Baseloess	0.03	0.11	-0.05	0.10	**-0.63**	-0.30	-0.25	**-0.51**
% of catchment Basealluv	-0.24	-0.31	-0.16	0.08	-0.12	-0.19	-0.20	-0.29
% of catchment Basesand	-0.03	0.03	-0.05	-0.15	0.33	0.30	0.08	0.33
% of catchment Baseother	-0.27	-0.26	-0.27	-0.20	-0.23	0.12	-0.19	-0.29
% of catchment Basemud	0.08	0.15	0.04	-0.13	-0.09	0.00	-0.26	0.03
% of catchment Basevolsof	0.11	0.30	-0.10	0.08	-0.30	-0.30	-0.30	-0.28
% of catchment Basegrey	0.33	0.33	0.30	0.07	0.32	0.13	**0.40**	**0.57**

Multivariate analysis

The nonmetric multidimensional scaling analysis of invertebrate communities graded communities from those at high algal biomass to that with low algal biomass. Algal biomass (Pearson's r =-0.71) and it's variance (r =-0.64) were the most strongly correlated variables with axis 1 (Table 5). The amount of rainfall in the catchment (r =-0.61), time since last rainfall (r =-0.65) and the substrate index (r =-0.61) were correlated with axis 2 (Fig. 5, Table 5). The right of axis 1 has invertebrate communities with taxa having low MCI scores i.e., Hydroptilidae, Chironomidae, Mollusca, Crustacea and large Oligochaeta (Table 6). The final stress value of 13.02 indicates a fairly good ordination (McCune and Grace 2002) with axis 1 explaining 72% and axis 2, 18% of the variance in the data. The analysis was rerun without the outlier S19 (Hukanui stream) and again algal biomass was found to be the most strongly linked parameter with the patterns in invertebrate communities found.

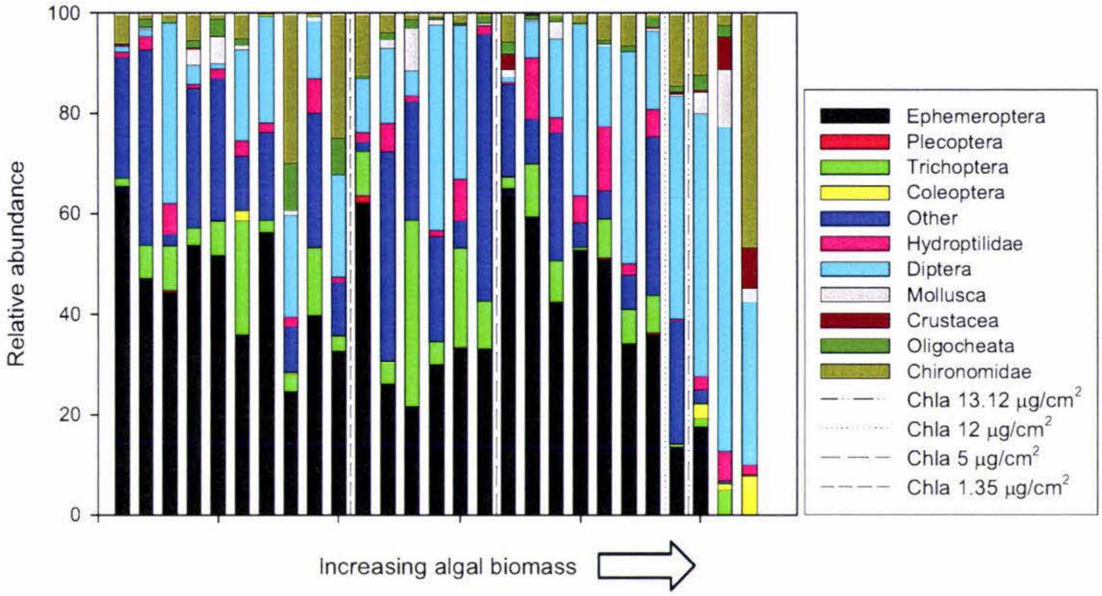

Figure 4. Mean relative abundance of invertebrate groups collected at 27 sites in the Manawatu, February 2002. Sites are arranged from lowest algal biomass (0.21 μg/cm^2) to greatest biomass (18.54 μg/cm^2). Ministry for the Environment maximum chlorophyll a (Chla) guidelines of 5 μg/cm^2 for high benthic biodiversity (long dashed line) and 12 μg/cm^2 for good recreational aesthetics (dotted line) are shown. This studies recommendations to delineate stream health of 1.35 μg/cm^2 for clean water fauna (short dashed line) and 13.2 μg/cm^2 for severely polluted water (dash-dot line) are also shown.

Table 4. Suggested nitrate and chlorophyll *a* guidelines and how they correspond to the established QMCI ranges (After Boothroyd and Stark 2000).

Nitrate (mg/L)	Chlorophyll a (μg/cm^2)	QMCI	Description
<-3.9	<1.35	>6	Clean water
-3.9 - 4.6	1.35 - 7.2	5 - 5.99	Doubtful water quality or possible mild pollution
4.6 - 14.2	7.2 - 13.12	4 - 4.99	Probable moderate pollution
>14.2	>13.12	<4	Probable severe pollution

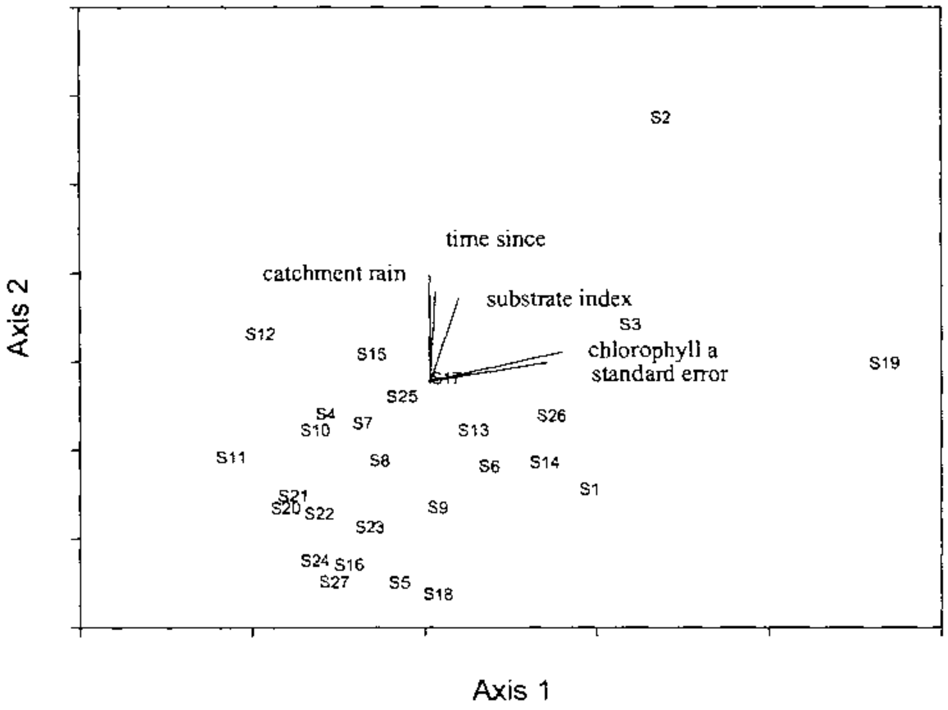

Figure 5. Nonmetric Multidimensional Scaling (NMS) ordination of invertebrate communities collected at 27 sites in the Manawatu, February 2002. Axis 1 is most strongly related to chlorophyll *a* while axis 2 is most strongly correlated with catchment rainfall, time since last rainfall and the substrate index. Axis 1 explains 72% of the variation in the data and axis 2 explains 18% with a final stress value of 13.

Table 5. Pearsons Correlation Coefficients between environmental variables axis 1 and axis 2. From a nonmetric multidimensional scaling ordination for invertebrate communities collected from 27 Manawatu sites in February 2002. Values are shown in bold if correlation coefficients are greater than +/- 0.5.

	Axis 1	Axis 2
Conductivity	-0.17	0.41
DRP	-0.32	-0.12
Nitrate	-0.16	-0.05
Chlorophyll a	**-0.71**	-0.28
SE	**-0.64**	-0.17
Altitude	0.12	-0.15
Discharge	0.06	0.20
Width	0.23	-0.05
Depth	0.07	0.11
Velocity	0.11	0.31
Temperature	-0.32	0.09
pH	-0.11	-0.05
O2	**-0.50**	-0.22
Time since	0.08	**-0.65**
Substrate index	-0.33	**-0.61**
Suspendable sediment	0.11	0.18
Stream order	-0.29	0.30
Catchment slope	0.30	0.15
Catchment rain	0.01	**-0.61**
Catchment temperature	-0.11	0.34
Catch evapotranspiration	-0.47	0.23
Catchment flow	-0.28	-0.42
% of catchment Urban	0.00	0.22
% of catchment Farming	-0.07	0.16
% of catchment Native	-0.06	-0.28
% of catchment Exotic	-0.10	-0.01
% of catchment Scrub	0.28	0.06
% of catchment Tussock	**-0.55**	0.02
% of catchment Bare_groun	-0.13	-0.18
% of catchment Topeat	0.06	0.01
% of catchment Toploess	-0.05	0.22
% of catchment Topalluv	-0.29	**-0.52**
% of catchment Topsand	0.18	0.13
% of catchment Topother	0.10	0.38
% of catchment Topmud	-0.11	0.06
% of catchment Topvolsof	**-0.55**	0.01
% of catchment Basepeat	**-0.55**	0.01
% of catchment Baseloess	-0.35	0.17
% of catchment Basealluv	-0.23	-0.33
% of catchment Basesand	0.18	0.13
% of catchment Baseother	0.08	0.42
% of catchment Basemud	-0.12	0.05
% of catchment Basevolsof	**-0.55**	0.01
% of catchment Basegrey	0.28	-0.03

Table 6. Pearson's Correlation Coefficients for taxa highly correlated with axis 1 and axis 2 of a nonmetric multidimensional scaling ordination for invertebrate communities collected from 27 Manawatu sites in February, 2000. Values are shown in bold if the correlation coefficients are greater than +/- 0.5.

Taxa	Axis 1	Axis 2
Oxyethira albiceps	**-0.71**	**-0.61**
Paroxyethira hendersoni	-0.46	**-0.61**
Eriopterini	**0.58**	0.17
Empididae	-0.46	**-0.67**
Chironomidae pupae	**-0.75**	-0.14
Orthocladiinae	**-0.85**	-0.36
Orthocladinae Sp 2	**-0.64**	-0.02
Corynoneura	**-0.60**	0.00
Chironomus	**-0.58**	-0.10
Lymnaeidae	-0.30	**-0.56**
Gyraulus	**-0.73**	-0.43
Amphipoda Sp 1	-0.46	**-0.61**
Amphipoda Sp 2	**-0.72**	-0.31
Ostracoda	**-0.56**	-0.11
Large Oligochaeta	**-0.52**	0.27

DISCUSSION

Which environmental variables affected stream nutrient concentrations?

Nutrient supply is reflective of the catchment's geology and landuse regime (Biggs 1995). In this study, sites with larger proportions of farmland in their catchments had higher nitrate concentrations. Conversely sites with comparatively more scrub in the catchment had lower nitrate concentrations. This infers that there is greater nitrate runoff entering streams in farmland dominated catchments (Quinn *et al.* 1997). Agricultural development generally increases nutrient loadings but small increases may be absorbed into the system through increased productivity while larger increases can have detrimental implications for the ecosystem (Harding *et al.* 2000). It also infers that in catchments or riparian zones with greater amounts of scrub there will be lower inputs of nitrate (Tate 1990; Scrimgeour and Kendall 2002). Scruby early succession plants in or near the riparian zone can affect the energy and matter flow of streams (Quinn and Hickey 1990a; Townsend *et al.* 1997a) limiting the flow of nutrients into stream environments (Quinn *et al.* 1997).

There were significant positive relationships between geological variables and conductivity. Erosion of sedimentary rock may contribute to these higher conductivity readings (Maasdam and Smith 1994; Chételat *et al.* 1999). Percentage of catchment in alluvium and mudstone had the strongest correlations with the nitrate loadings found in this study. Phosphorous and nitrogen bound in the soils micropores is released during high rainfall events (Holloway *et al.* 1998) ending up in streams and rivers. There were many high rainfall events early in the Manawatu summer of 2001/2002 prior to the commencement of this study. Stream nutrient concentration is greatest during and immediately after rainfall events, and it has been found that in seasonal environments nutrient concentration will decrease with each subsequent flood throughout the rainy season (Holloway *et al.* 1998). Nutrient concentration has been shown to be greatly affected by bedrock type and erosion (Maasdam and Smith 1994; Biggs 1995; Holloway *et al.* 1998). Thus, a catchment's bedrock composition will set the lower limit of any streams nutrient concentration, other natural and anthropogenic factors can then act on this. It appears that the geology of a region is the most important factor determining nutrient input into streams (Holloway *et al.* 1998) followed by landuse. These conclusions are tentatively drawn as there was only one nutrient sample taken from each site.

Was there a link between nutrients and periphyton?

In this study nitrate concentration was found to be the only nutrient linked with algal biomass. It appears that in the Manawatu region nitrogen is the element limiting periphyton growth. Increases in limiting nutrients result in greater periphytic primary productivity (Hershey *et al.* 1988) algal abundance and influences species composition (Sterling *et al.* 2000). Excessive algal proliferations can be produced with increased nitrate loadings (Dodds and Welch 2000) and suitable hydrologic conditions. With a longer accrual time algal biomass has been shown to be higher for given nutrient concentrations (Biggs 2000a).

The streams with higher nitrate concentrations were generally accruing greater algal biomass faster than streams with lower loadings. This process was assumed to be relatively unaffected by herbivory or senescence in early succession as floods remove invertebrates as well (Gray and Fisher 1981; Townsend *et al.* 1997b). The sample occasions were generally approaching the 30 days accrual considered ample for complete maturity of periphyton biomass (Welch *et al.* 1992) and the 40 days accrual associated with algal death leading to sloughing (Lamberti *et al.* 1989).

Five sites recording nitrate concentrations expected to limit growth, had low algal biomass. There were 11 other sites with algal biomass below the Ministry for the Environment (MfE) guideline but they had higher nutrient concentrations. Twenty sites had nitrate levels above the recommended 75 mg/m^3 but only 4 of these sites had periphyton biomass that exceeded the MFE aesthetics guideline (Biggs 2000b). Thus, while there is a link between algal biomass and nitrate it is not particularly strong.

The nutrient guidelines obtained in this study through regression analysis appear to be a reasonable predictor of algal biomass for this region. However, many factors influence nutrient-algal interactions and many others effect algal-invertebrate interactions. Therefore they should be used as a rough guide only. Trying to relate nutrient impacts on algal biomass is difficult and so far inconsistent.

It has been established that algae can take up excess nutrients when they are plentiful for use at a later time when those nutrients may be otherwise limiting (Dodds and Welch 2000). Different algal taxa have different nutrient requirements (Tate 1990; Chételat *et al.* 1999), but cyanobacteria can increase periphyton productivity by nitrogen fixation and periphyton mats are capable of recycling nitrogen (Burns and Ryder 2001). These processes may have contributed to give the observed patterns of nitrate loadings not relating well to algal biomass in the regression analysis (Fig. 4) and the relative inaccuracy of the nitrate guideline. Therefore, although there is a link between stream nitrate level and algal biomass, it is weak and the exact process behind this relationship is unclear.

Was there a link between periphyton and invertebrate community metrices?

Hydraulic disturbances scour algae and wash it away, thus, soon after floods there is little algae in stream environments (Biggs and Close 1989; Chételat *et al.* 1999). With time and suitable flow conditions algal biomass increases (Biggs and Close 1989; Lamberti *et al.* 1989; Biggs 2000a) at varying rates dependent on nutrient supply, suitable attachment surfaces, temperature (Francoeur *et al.* 1999) and growth rates (Biggs 2000a). This increase occurs until such time as grazer densities (Rosemond *et al.* 1993) through increased reproduction, immigration or reduced mortality or "functionality" (Lamberti *et al.* 1989), changes enough to start reducing algal standing stocks. With greater time since disturbance the affect that invertebrate grazers have on algae will increase, reducing algal biomass (Welch *et al.* 1992; Biggs and Lowe 1994; McCormick 1994; Wellnitz and Ward 1998; Burns and Ryder 2001) until grazer resistant taxa become more common (McCormick 1994) or until resources become limiting as in the intermediate disturbance hypothesis (Huston 1979).

The EPT indices and QMCI showed strong relationships with algal biomass indicating a shift in invertebrate composition and abundances with increased algae biomass. Multivariate analysis supported this by showing that algal biomass was the most important factor affecting the composition of invertebrate communities.

A reduction in the amount of Ephemeroptera, Plecoptera and Trichoptera (EPT) in streams was generally associated with an increase in Chironomidae, Mollusca, Oligocheata (Quinn *et al.* 1997) and Crustacea (Quinn and Hickey 1990a). In this study, as in others, the reduction in invertebrate "clean water taxa" or "biotic quality" occurred in association with increasing algal biomass (Quinn and Hickey 1990a; Biggs 2000a). Experimental studies have generally shown reductions of algal biomass by grazers (Lamberti *et al.* 1989; Poff *et al.* 2003) and suggest that herbivory is more important in controlling algal biomass than nutrient limitation (McCormick 1994).

Contrary to this study Biggs and Lowe (1994) found invertebrate density was related to algal biomass or enrichment. In this study algal biomass did not greatly affect taxa richness or invertebrate abundance (density), however, it did alter the community composition of these streams. Chironomidae, Crustacea and Hydroptilidae appear to be more suitable in terms of feeding mode and physiology, than many EPT taxa to high algal biomass conditions. The mechanism behind this is unclear, but many EPT taxa have mouthparts specialised to graze prostrate algae not high biomass filamentous green algae.

With increasing algal biomass the composition of the periphyton community changes (Biggs 1990). Various EPT taxa may be linked to certain algal growth forms or taxa, resulting in changes to the invertebrate communities. Various taxa respond differently to periphyton with mayflies suggested to effect algal composition while chironomid communities respond to algal biomass (Wellnitz and Ward 1998).

High benthic biodiversity occurs with chlorophyll *a* concentrations below 5 $\mu g/cm^2$, the maximum guideline is 12 $\mu g/cm^2$ for good aesthetics given suitable hydraulic and substrate requirements (Biggs 2000b). This study's regression analysis has found that chlorophyll *a* concentrations of < 1.35 $\mu g/cm^2$ correspond to QMCI score of > 6 which indicates clean water fauna (Boothroyd and Stark 2000). Chlorophyll *a* concentrations of > 13.12 $\mu g/cm^2$ correspond to QMCI scores of < 4 which is indicative of probable severe pollution (Boothroyd and Stark 2000). Between these two levels the community can be assumed to be suffering from doubtful quality, probable moderate pollution (Boothroyd and Stark 2000) (Table 4). Around 13 $\mu g/cm^2$ there appears to be a dramatic shift in community composition to pollution tolerant taxa. These significant changes in the biotic quality of invertebrate assemblages (i.e., the loss of clean water taxa) at levels considered to be aesthetically unacceptable (12 $\mu g/m^2$) by the MfE is interesting and useful. It suggests that environmental managers can manage waterways to maintain human recreational interests while simultaneously mitigating any adverse impacts on aquatic ecosystems. It is apparent that between 1.35 - 13.12 $\mu g/m^2$ the ecosystem is absorbing nutrient increases with little change to the community's structure and function (Harding and Winterbourn 1995). These values are intended for open pastoral streams, however in forested streams where light limits algal growth, it is likely that there would be more low algal biomass sites interpreted as "clean water" regardless of the actual water quality.

These guidelines may prove to be good approximations of oligotrophic, mesotrophic and eutrophic streams. As opposed to simply grouping the lower 1/3 as oligotrophic, middle 1/3 as mesotrophic and upper 1/3 as eutrophic as suggested by (Dodds *et al.* 1998). There is a clear change in macroinvertebrate biotic quality in relation to algal biomass near the guideline of 13.12 $\mu g/cm^2$, this may be most useful in dividing impacted invertebrate communities from non-impacted, in open pasture streams.

Are environmental – invertebrate links stronger than periphyton – invertebrate linkages?

All the streams sampled were potentially capable of maximum algal growth with open riparian zones, predominately of agricultural land. Landuse effects the larval and adult life stages (Townsend *et al.* 1997b; Collier and Scarsbrook 2000) and has been suggested to be of greater importance in the regulation of invertebrate community structure and function than geology (Quinn and Hickey 1990a; Quinn and Hickey 1990b; Harding and Winterbourn 1995). In this study however, there were stronger links between the geological variables and invertebrate communities than land usage.

This study has showed that hydrological conditions; width, depth, velocity, discharge and stream order were the most important parameters determining species richness and invertebrate abundance (density). Greater velocities disturb larger stones therefore a larger proportion of the substrate (Quinn and Hickey 1990b; Townsend *et* *al.* 1997b), more periphyton and more invertebrate inhabitants (Clausen and Biggs 1997). Species richness has been negatively correlated with stream size (Clausen and Biggs 1997) and more taxa tend to be collected where riffles are shallower (Collier 1995). Depth and velocity are linked (Dodds and Biggs 2002) and shape invertebrate communities with various invertebrates preferring different velocities (Miserendino 2001) and depths (Quinn and Hickey 1990a). More taxa may settle out from the drift at lower current speeds. Possibly smaller streams were more heterogeneous in terms of their substrate composition and velocities.

Many studies have shown that the physical environment is a very important factor involved in determining the structure and function of macroinvertebrate communities (e.g., Quinn and Hickey 1990b; Richards *et al.* 1993; Collier 1995; Miserendino 2001; Death 2002). A huge array of physical factors set limits on biotic communities and the interactions therein. Large scale landscape variables generally show relationships with various invertebrate community or indice aspects (Quinn *et al.* 1997; Townsend *et al.* 1997a; Miserendino 2001) but it is the localised, short term, small scale biotic and abiotic factors that have the greatest bearing on what invertebrate taxa are found where (Miserendino 2001).

Conclusion

This study examines the link between nutrients and algal biomass and the influence of this on invertebrate communities. Nutrients influence algal biomass and productivity, which in turn affects invertebrate biomass and community composition, although grazers may exert pressure back on algal structure and metabolism (Lamberti *et al.* 1989). There was a strong relationship found in this study was between chlorophyll *a* and invertebrate water quality indices. However, species richness and invertebrate abundance were influenced most by hydrological variables.

The importance of disturbance on periphyton accrual (Biggs and Close 1989; Clausen and Biggs 1997) and invertebrate communities has been found in several other studies (Townsend *et al.* 1997b). But as no samples were taken soon after floods it was assumed to be relatively unimportant in this study.

This work shows that the MfE periphytic guidelines of Biggs (2000b) are accurate and useful. However I suggest that in open pastoral Manawatu streams maximum chlorophyll *a* concentrations < 1.35 $\mu g/m^2$ represent oligotrophic conditions, between 1.35 $\mu g/m^2$ – 13.12 $\mu g/m^2$ represents mesotrophic conditions and that chlorophyll *a* concentrations > 13.12 $\mu g/m^2$ represent eutrophic conditions in terms of the algal and invertebrate communities. The invertebrate communities in the streams will be similar in the oligotrophic and mesotrophic systems but there will a dramatic change in biotic quality particularly community structure at high algal biomass, eutrophic sites.

REFERENCES:

Biggs, B. J. F. 1990: Periphyton communities and their environments in New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research* 24: 367-386.

Biggs, B. J. F. 1995: The contribution of flood disturbance, catchment geology and land use to the habitat templete of periphyton in stream ecosystems. *Freshwater Biology* 33: 419-438.

Biggs, B. J. F. 2000a: Eutrophication of streams and rivers: dissolved nutrient-chlorophyll relationships for benthic algae. *Journal of the North American Benthological Society* 19: 17-31.

Biggs, B. J. F. 2000b. New Zealand Periphyton Guideline: Detecting, Monitoring and Managing Enrichment of Streams. Wellington, Ministry for the Environment.

Biggs, B. J. F. and Close, M. E. 1989: Periphyton biomass dynamics in gravel bed rivers: the relative effects of flows and nutrients. *Freshwater Biology* 22: 209-231.

Biggs, B. J. F. and Lowe, R. L. 1994: Responses of two trophic levels to patch enrichment along a New Zealand stream continuum. *New Zealand Journal of Marine and Freshwater Research* 28: 119-134.

Boothroyd, I. and Stark, J. 2000. Use of invertebrates in monitoring. New Zealand Stream Invertebrates: ecology and implications for management. Collier, K. J. and Winterbourn, M. J. Christchurch, New Zealand Limnological Society 344-373.

Burns, A. and Ryder, D. S. 2001: Potential for biofilms as biological indicators in Australian riverine systems. *Ecological Management and Restoration* 2: 53-63.

Chételat, J.; Pick, F. R.; Morin, A. and Hamilton, P. B. 1999: Periphyton biomass and community composition in rivers of different nutrient status. *Canadian Journal of Fisheries and Aquatic Sciences* 56: 560-569.

Clausen, B. and Biggs, B. J. F. 1997: Relationships between benthic biota and hydrological indicies in New Zealand streams. *Freshwater Biology* 38: 327-342.

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. and Scarsbrook, M. R. 2000. Use of riparian and hyporheic habitats. New Zealand Stream Invertbrates: ecology and implications for management. Collier, K. J. and Winterbourn, M. J. Christchurch, New Zealand Limnological Society 179-206.

Death, R. G. 2002: Predicting invertebrate diversity from disturbance regimes in forest streams. *Oikos* 97: 18-30.

Dodds, W. K. and Biggs, B. J. F. 2002: Water velocity attenuation by stream periphyton and macrophytes in relation to growth form and architecture. *Journal of the North American Benthological Society* 21: 2-15.

Dodds, W. K.; Jones, J. R. and Welch, E. B. 1998: Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. *Water Research* 32: 1455-1462.

Dodds, W. K. and Welch, E. B. 2000: Establishing nutrient criteria in streams. *Journal of the North American Benthological Society* 19: 186-196.

Francoeur, S. N.; Biggs, B. J. F.; Smith, R. A. and Lowe, R. L. 1999: Nutrient limitation of algal biomass accrual in streams: seasonal patterns and a comparison of methods. *Journal of the North American Benthological Society* 18: 242-260.

Friberg, N. and Winterbourn, M. J. 1997: Effects of native and exotic forest on benthic stream biota in New Zealand: a colonization study. *Marine and Freshwater Research* 48: 267-275.

Gray, L. J. and Fisher, S. G. 1981: Postflood recolonization pathways of macroinvertebrates in a lowland sonoran desert stream. *The American Midland Naturalist* 106: 249-257.

Hach. 1996. DR/2010 Spectrophotometer Procedures Manual. U.S.A.

Harding, J. S. 1991: The larvae of Neurochorema Forsteri McFarlane (Trichoptera: Hydrobiosidae). *New Zealand Natural Sciences* 18: 51-54.

Harding, J. S.; Quinn, J. M. and Hickey, C. W. 2000. Effects of mining and production forestry. New Zealand Stream Invertebrates: ecology and implications for management. Collier, K. J. and Winterbourn, M. J. Christchurch, New Zealand Limnological Society 230-259.

Harding, J. S. and 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.

Hershey, A. E.; Hiltner, A. L.; Hullar, M. A. J.; Miller, M. C.; Vestal, J. R.; Lock, M. A.; Rundle, S. and Peterson, B. J. 1988: Nutrient influence on a stream grazer: *Orthocladius* microcommunities respond to nutrient input. *Ecology* 69: 1383-1392.

Holloway, J. M.; Dahlgren, R. A.; Hansen, B. and Casey, W. H. 1998: Contribution of bedrock nitrogen to high nitrate concentrations in stream water. *Nature* 395: 785-788.

Lamberti, G. A.; Gregory, S. V.; Ashkenas, L. R.; Steinman, A. D. and McIntire, C. D. 1989: Productive capability of periphyton as a determinant of plant-herbivore interactions in streams. *Ecology* 70: 1840-1856.

Lindsay, J. M. 1983. A Survey of the Benthic Macroinvertebrates in the Manawatu Catchment Board area. Palmerston North.

Maasdam, R. and Smith, D. G. 1994: New Zealand's National River Water Quality Network 2. Relationships between physico-chmical data and environmental factors. *New Zealand Journal of Marine and Freshwater Research* 28: 37-54.

McCormick, P. V. 1994: Evaluating the multiple mechanisms underlying herbivore-algal interactions in streams. *Hydrobiologia* 291: 47-59.

McCune, B. and Grace, J. B. 2002. Analysis of Ecological Communities. Gleneden Beach, MjM Software Design.

McCune, B. and Mefford, M. J. 1995. PC-ORD. Multivariate Analysis of Ecological Data, Version 2.0, MjM Software Design, Glendon Beach, Oregon, USA 77-84.

McFarlane, A. G. 1951: Caddis Fly Larvae (Trichoptera) of the Family Rhyacophilidae. *Records of the Canterbury Museum* 5: 267-289.

Miltner, R. J. and Rankin, E. T. 1998: Primary nutrients and the biotic integrity of rivers and streams. *Freshwater Biology* 40: 145-158.

Miserendino, M. L. 2001: Macroinvertebrate assemblages in Andean Patagonian rivers and streams: environmental relationships. *Hydrobiologia* 444: 147-158.

Peterson, B. J.; Hobbie, J. E.; Hershey, A. E.; Lock, M. A.; Ford, T. E.; Vestal, J. R.; McKinley, V. L.; Hullar, M. A. J.; Miller, M. C.; Ventullo, R. M. and Volk, G. S. 1985: Transformation of a Tundra River from Heterotrophy to Autotrophy by Addition of Phosphorus. *Science* 229: 1383-1386.

Poff, L. N.; Wellnitz, T. and Monroe, J. B. 2003: Redundancy among three herbivorous insects across an experimental current velocity gradient. *Oecologia* 134: 262-269.

Quinn, J. M.; Cooper, A. B.; Davies-Colley, R. J.; Rutherford, J. C. and Williamson, R. B. 1997: Land use effects on habitat, water quality, periphyton, and benthic invertebrates in waikato, New Zealand, hill-country streams. *New Zealand Journal of Marine and Freshwater Research* 31: 579-597.

Quinn, J. M. and Hickey, C. W. 1990a: 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.

Quinn, J. M. and Hickey, C. W. 1990b: 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.

Richards, C.; Host, G. E. and Arthur, J. W. 1993: Identification of Predominant Environmental-Factors Structuring Stream Macroinvertebrate Communities within a Large Agricultural Catchment. *Freshwater Biology* 29: 285-294.

Rosemond, A. D.; Mulholland, P. J. and Elwood, J. W. 1993: Top-down and bottom-up control of stream periphyton: Effects of nutrients and herbivores. *Ecology* 74: 1264-1280.

SAS 1996. SAS User's Guide: Statistics, SAS Inst. Inc.

Scrimgeour, G. J. and Kendall, S. 2002: Consequences of livestock grazing on water quality and benthic algal biomass in a Canadian natural grassland plateau. *Environmental Management* 29: 824-844.

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

Steinman, A. D. and Lamberti, G. A. 1996. Methods in Stream Ecology. San Diego, Academic press.

Sterling, M. S.; Ashley, K. L. and Bautista, A. B. 2000: Slow-Release Fertilizer for Rehabilitating Oligotrophic Streams: a Physical Characterization. *Water Quality Research Journal of Canada* 35: 73-94.

Tate, C. M. 1990: Patterns and controls of Nitrogen in tallgrass prairie streams. *Ecology* 71: 2007-2018.

Townsend, C. R.; Arbuckle, C. J.; Crowl, T. A. and Scarsbrook, M. R. 1997a: The relationship between land use and physiochemistry, food resources and macroinvertebrate communities in tributaries of the Taieri River, New Zealand: a hierachically scaled approach. *Freshwater Biology* 37: 177-191.

Townsend, C. R.; Scarsbrook, M. R. and Doledec, S. 1997b: The intermediate disturbance hypothesis, refugia, and biodiversity in streams. *Limnology and Oceanography* 42: 938-949.

Welch, E. B.; Quinn, J. M. and Hickey, C. W. 1992: Periphyton biomass related to point-source nutrient enrichment in seven New Zealand streams. *Water Research* 26: 669-675.

Wellnitz, T. A. and Ward, J. V. 1998: Does light intensity modify the effect mayfly grazers have on periphyton? *Freshwater Biology* 39: 135-149.

Winterbourn, M. J. 1972: A guide to the freshwater Mollusca of New Zealand. *Tuatara*: 141-159.

Winterbourn, M. J. 1990: Interactions among nutrients, algae and invertebrates in a New Zealand mountain stream. *Freshwater Biology* 23: 463-474.

Winterbourn, M. J. and Gregson, K. L. D. 1989: Guide to the Aquatic insects of New Zealand. *Bulletin of the Entomological society of New Zealand* 9.

Chapter 3:

The effects of experimental enrichment on stream invertebrate communities in the Hawke's Bay, New Zealand.

ABSTRACT

Dairy farming can generate higher nutrient inputs per unit area to pastoral streams than sheep or beef farming. As the conversion of drystock farms to dairy farms is increasing in the Hawke's Bay as well as many other parts of New Zealand, the effects of increased nutrient inputs on stream invertebrate communities needs to be evaluated. An *in situ* experimental phosphorous enrichment of 3 Hawke's Bay streams was carried out in the summer of 2002/2003. Phosphorous loadings of the 3 streams were increased by 0.02 - 0.37 mg/L to simulate a change in the surrounding landuse. The phosphorous addition did not result in an increase in algal biomass. This may have been a result of the shift in invertebrate community structure that occurred in the enriched downstream channels, with generally greater proportions of EPT individuals found in downstream channels. The enriched channels supported greater *Deleatidium* sp. populations than their upstream counterparts. Therefore percent EPT individuals and QMCI both increased with increased phosphorous loadings. These indices suggest that *Deleatidium* sp. were taking advantage of the increased productivity of the algal layers and in turn maintaining algal biomass at low levels.

KEYWORDS

Agriculture; enrichment; experiment; invertebrate; landuse; nutrient inputs; periphyton; phosphorous.

INTRODUCTION

Land use

Agriculture can increase nutrient inputs to streams by mobilising streambank sediments and the nutrients therein, fertilizer application, animal waste and by increased overland flow during rainfall events (Quinn *et al.* 1997; Quinn 2000; Scrimgeour and Kendall 2002). Small streams are often the interface between the land and water in much of the New Zealand landscape. Many point source discharges of nutrients have been eliminated but small rural streams generally still receive diffuse inputs of nutrients from the surrounding agricultural lands. Although there is a general view that agricultural runoff especially from dairying has negative impacts on the water "quality" of lowland rivers and lakes (Ministry for the Environment 1997), there are few quantitative studies that have specifically investigated the impacts of diffuse agricultural runoff on stream invertebrate communities. Scrimgeour and Kendall (2002) found that increased livestock grazing only affected nutrient concentration in 1 of 3 streams studied and nutrient levels were correlated with algal biomass in 2 of the 4 streams. In 1998 58% of New Zealand's agricultural land was used as drystock (sheep, sheep and beef) farming and 12% was used for dairy farming (Quinn 2000). Increasingly extensive sheep farming has become less profitable and therefore plantation forestry and conversions to dairy farming have increased (Foran and Wardle 1995; Harding *et al.* 1999). It is generally agreed that the higher stocking rates on dairy farms produce greater amounts of nutrients than drystock farming and therefore pass on more nutrients to aquatic environments (Harding *et al.* 1999). The effects the current increase in dairy farming has on aquatic ecosystems needs investigation so any adverse effects on streams can be mitigated. This study therefore aimed to simulate an increase in nutrient inputs associated with a conversion from extensive drystock to intensive dairy farming. This was to test whether there are any associated affects of increased nutrient supply on small stream ecosystems.

Periphyton

Autochthonous energy via primary production is the major food and energy source in open agricultural streams (Biggs and Lowe 1994; Biggs 1996). Algal growth rates are a function of cell nutrient absorption, light and temperature (Biggs 2000a). Nutrients (N and P) are used in algal cells in photosynthesis and can influence algal reproduction rates (Stevenson 1996). Deficits in nutrients such as nitrogen and phosphorous can limit algal growth rates (Bothwell 1993), productivity (Mosisch *et al.* 2001), biomass (Dodds and Welch 2000) and can affect algal growth form and community composition (Borchardt 1996).

Growth limiting nutrient criteria are difficult to set, but dissolved reactive phosphorous (DRP) concentrations below 0.3 - 0.6 µg/L have been shown to limit diatom growth in Canada, while 25 – 50 µg/L limits periphyton growth with filamentous algal taxa present (Borchardt 1996), higher DRP levels realise maximum growths and biomasses (Borchardt 1996). Low nitrate concentrations of 55 – 100 µg/L are growth limiting, but the limits are less clear than those for phosphorous (Borchardt 1996). Higher nutrient inputs from dairy farms should therefore result in greater stream algal biomass.

However it is the interaction between nutrients, light, temperature, hydrology, substrate type and herbivores that determines the periphyton communities of streams (Winterbourn 1990; Welch *et al.* 1992; Burns and Ryder 2001). Frequency and intensity of floods are important in determining algal biomass (Clausen and Biggs 1997). These effects can be spatially patchy (Matthaei *et al.* 2003) due to substrate type (Wellnitz and Ward 1998) and different algal taxa have differing susceptibilities to floods (Biggs 1995). Herbivory, by ingestion or dislodgement reduces algal biomass (Lamberti *et al.* 1989; Rosemond *et al.* 1993; Hillebrand 2002) and can change the composition and dominant growth form of periphyton communities (Steinman and Lamberti 1996; Wellnitz and Ward 1998). So many factors other than nutrients can impact on algal biomass therefore, this study will be replicated in 3 streams in an attempt to take these factors into account. However if higher nutrient levels do result in higher algal growth in streams running through dairy rather than drystock farming areas this could then impact in the invertebrate communities.

Algal – invertebrate interactions

Stream invertebrate communities are often a reflection of the periphytic community, because it is a major food resource (Biggs and Lowe 1994). Invertebrate distribution and productivity can be food quality and/or quantity limited (Hart and Robinson 1990; Rosemond *et al.* 1993; Biggs and Lowe 1994). Experimental studies have consistently shown the reduction of algal biomass by invertebrate grazers (Hill and Knight 1987; Biggs and Lowe 1994). Invertebrate densities however are rarely likely to be high enough to reduce algal biomass to any great extent in natural streams due to biotic (e.g., interspecific competition) (Wellnitz and Ward 1998) or abiotic processes (Clausen and Biggs 1997). Biggs and Lowe (1994) found that nutrient diffusing substrata (NDS) did not increase algal biomass, but did increase invertebrate density inferring that top down control was present. Winterbourn (1990) increased periphyton and chironomid biomass on NDS, but when insecticide was added to negate herbivory, algal biomass was increased further. Lower than expected algal biomass levels can therefore be associated with high invertebrate herbivore abundances (Welch *et al.* 1992; Steinman 1996).

Herbivores differ in their abilities to remove alga and this can impact on herbivore distributions (Poff *et al.* 2003) as can the algae's growth form (Steinman 1996). Therefore the growth of herbivorous invertebrates is closely linked to algal growth and vice versa (Rosemond *et al.* 1993).

In this study I experimentally increase nutrient concentrations in 3 New Zealand streams to test the hypothesis that increases in nutrients will increase algal biomass and change invertebrate community composition. The second hypothesis is that taxa richness and density will not be affected by the nutrient addition. *In situ* channels will be used to test these hypotheses, they were used to maintain near natural conditions while reducing the amount of nutrient needing to be added and therefore mitigating any possible negative impacts on downstream communities.

METHODS

Study area

The field experiment was conducted in 2nd and 3rd order streams in the central Hawke's Bay, New Zealand. The 3 streams were, Parikaka (NZMS T260 U22 917 344), Mangapohio (NZMS T260 U23 976 612), and Triplex tributary (NZMS T260 U22 872 516). All the sites are open with moderate water temperatures (e.g., 11 - 18 °C), cobble streambeds and relatively stable flow. The 3 study sites were situated in open agricultural land of either sheep or sheep and beef farming practices (drystock), this ensured any conclusions drawn would be applicable to drystock farming land usage. The altitude of the sites ranged from 210 to 500 m above sea level. Streams had mean widths of 1.17 to 2.26 m, mean riffle depth's ranged from 5.1 to 16.2 cm. The experiment was set up on the 19/11/02 and ran for 64 days in the southern hemisphere summer of 2002/2003.

Experimental set up

Physico-chemical, periphytic and invertebrate samples were taken from natural stream riffles prior to the experiment. Two 2.7 m long half round PVC pipes (30 cm in diameter) were embedded in the substrate of riffles in each stream and filled with cobbles from the stream. The top edge of the channels protruded out of the water so that any nutrients added would flow down the experimental channel only. The upstream channel was set as the control while the channel approximately 20 m downstream was the treatment. The channels were left for 2 weeks to equilibrate with periphyton and invertebrate communities. Nutrients were added in the form of "Triple Super" fertiliser (Ballance Agri-Nutrients LTD), which was 20.5 % phosphorous by weight (N:P:K 0:20.5:0). Phosphorous was used because it is the limiting nutrient in these streams. Weekly, two perforated 2 L ice cream containers containing "Triple Super" fertiliser were positioned at the upstream end of the treatment channel, level with the substrate to minimise flow alteration. Once the experiment commenced the *in situ* channels were sampled every 2 weeks for 1 month and then again on 1 occasion 1 month later. Mangapohio stream dried up toward the end of the experiment and in the Triplex tributary the channels were washed away. Therefore samples were not collected from these 2 sites on the last sample occasion.

Sampling protocol

Five 0.1 m^2 Surber samples (mesh size 500 μm) were collected from riffles in September and October 1 and 2 months before the first experimental sampling occasion to act as additional controls. The experimental channels were sampled by inserting a circular hand net (mesh size 500 μm) into the substrate of the channel to its PVC base. Then the entire channel 30 cm upstream of this was disturbed by hand. Three samples were taken progressively upstream approximately 50 cm apart in this manner from each of the *in situ* experimental channels, on each of the 2 week apart sampling occasions in December 2002 and the 1 month later sampling occasion in January 2003 (Table 1). Samples were preserved with 10% formalin until the collected invertebrates were counted and identified to the lowest possible taxonomic level using the keys of McFarlane (1951), Winterbourn (1972), Winterbourn and Gregson (1989) and Harding (1991).

One and 2 months prior to the experiment 4 stones (approximately 5 cm longest dimension) were collected at random from riffles for algal biomass analysis. Once the experiment commenced, 4 stones were collected at random from each experimental channel on each sampling occasion. The stones were kept on ice, in the dark for up to 8 hours during transport before being frozen in the lab for later analysis. Pigments were extracted in 90% acetone at 5 °C for 24 hours before using a Cary 50 Conc UV visible spectrophotometer to determine pigment concentrations following Steinman and Lamberti (1996). The length, width and depth of the stones was measured to give an estimate of stone surface area following Biggs and Close (1989). This area was halved to allow for the fact autotrophic algal growth only occurs on upper stone surfaces. From this pigment concentrations per unit area were determined.

Conductivity and temperature was measured with an Orion model 122 conductivity meter corrected to 25 ° C and pH was measured with a pHTestr 2. Current velocity was measured at each invertebrate sample location using a velocity head rod.

500 ml water samples were taken from each experimental channel for nutrient analysis, these were filtered in the field using Whatman GF/C glass microfibre filters. The samples were then kept in the dark, on ice for up to 8 hours, until either, the sample was analysed or frozen for later analysis. Dissolved reactive phosphorous (DRP) was used as the measure of phosphorous concentration and nitrate was used as the measure of nitrogen in this study. Nitrate concentration was measured using the Cadmium reduction method (Scrimgeour and Kendall 2002) and then determined photometrically with a Hach DR/2010 spectrophotometer. Dissolved reactive phosphorous (DRP) was analysed using the PhosVer 3 (ascorbic acid) method (Hach 1996) and the concentration determined photometrically with the Hach DR/2010 spectrophotometer.

Table 1. Sampling regime in relation to the commencement of the enrichment experiment. The 3rd treatment sampling occasion was only conducted at Parikaka stream.

Sample number	Sample occasion	Date	Time from enrichment
-2	Pre-sampling	30/9/2002	2 months prior
-1	Pre-sampling	29/10/2002	1 months prior
0	enrichment begins	19/11/2002	enrichment begins
1	1st treatment sampling	4/12/2002	2 weeks after
2	2nd treatment sampling	20/12/2002	1 month after
3	3rd treatment sampling	22//1/2003	2 months after

Substrate size distribution was evaluated by randomly choosing 100 stones, determining their size class (<2, 2-11.3, 11.3-16, 16-22.6, 22.6-32, 32-45.3, 45.3-64, 64-90.5, 90.5-128, 128-300, >300 mm), and converting to a percentage of total substrate. From this data a substrate index was calculated, by multiplying the midpoint of each size class category by the percentage occurrence and summing for all categories following Quinn and Hickey (1990b).

Statistical analysis

Three-Way Analysis of Variance (ANOVA) (SAS 1996) were conducted to identify differences in nutrient concentration, algal biomass and invertebrate metrices between the control and treatment channels at the 3 sites. Nonmetric multidimensional scaling (NMS) ordination was performed using PC-ORD (McCune and Mefford 1995) to identify the importance of site and treatment on invertebrate community composition. Pearson's Correlation was used to identify links between invertebrate communities and axes 1 and 2 scores. Cluster analysis was also conducted using PC-ORD (McCune and Mefford 1995) to explore groupings identified in the NMS.

RESULTS

Enriched treatment channels had higher (0.2 - 0.4 mg/L) phosphorous levels than upstream unenriched control channels (0.04 – 0.31 mg/L) across the sites (Table 2). At 2 of the 3 sites DRP concentrations were well above the 0.025 - 0.05 mg/L suggested to limit algal growth by Borchardt (1996). On every sample occasion but 2 DRP levels were higher in enriched treatment channels, with very large increases achieved at Mangapohio (Table 2, Fig. 1). Nitrate appeared to show no consistent trends although the ANOVA found there to be significant differences between control and treatment channels (Table 3). There was no consistent increase in algal biomass in the downstream treatment channels across the 3 sites, although it appeared to increase at Parikaka and the Triplex tributary (Table 2, Fig. 1). The substrate index of the streams ranged from 51.7 at Parikaka to 129.8 at Triplex tributary (Table 2). The Pfancuch bottom stability scores were given as 28 for the Triplex tributary, 33 for Mangapohio, and 44 for Parikaka stream.

Table 2. Means of physical variables and invertebrate metrices measured at 3 Hawke's Bay, New Zealand streams in 2002/2003. Samples were taken prior to the treatment in September and October, and then during the treatment in December and January.

	Pre -sampling			Control			Treatment		
	Parikaka	Mangapohio	Triplex tributary	Parikaka	Mangapohio	Triplex tributary	Parikaka	Mangapohio	Triplex tributary
DRP (mg/L)	0.00	0.00	0.03	0.28	0.04	0.31	0.40	0.31	0.20
Nitrate (mg/L)	3.15	24.60	1.25	0.56	12.65	1.70	1.30	7.90	1.40
Chlorophyll a (µg/cm^2)	3.96	3.72	1.83	9.05	3.13	2.44	9.77	2.72	3.05
Total pigment (µg/cm^2)	5.81	5.34	2.41	14.83	4.20	3.42	13.59	3.82	4.17
Width (m)	1.30	2.26	1.17	0.30	0.30	0.30	0.30	0.30	0.30
Depth (cm)	7.24	12.90	11.30	6.86	9.90	9.30	6.10	4.36	9.20
Velocity (m/s)	5.33	7.23	5.07	1.87	0.75	3.12	1.67	0.85	1.83
Temperature (°C)	13.80	15.50	11.60	15.00	16.60	16.55	15.00	16.60	16.55
Pfanchuch	112.00	97.00	80.00	112.00	97.00	80.00	112.00	97.00	80.00
Substrate index	51.74	55.05	129.85	51.74	55.05	129.85	51.74	55.05	129.85
Conductivity (µs/cm)	89.00	145.95	153.20	128.83	181.15	177.00	144.00	191.50	181.00
MCI	98.25	90.44	105.24	83.59	92.13	106.47	88.45	97.24	98.20
QMCI	4.83	6.55	7.09	2.45	3.32	7.27	2.56	4.40	7.17
Invertebrate abundance	437.00	527.90	137.30	833.78	828.33	271.33	920.11	640.50	289.83
Species richness	22.50	13.90	12.10	23.78	16.83	18.33	25.44	16.67	16.67
Margalef's	3.69	2.12	2.29	3.43	2.38	3.10	3.67	2.42	2.76
% EPT individuals	45.40	72.31	82.90	14.80	39.86	85.03	19.07	55.73	85.97
% EPT taxa	53.71	47.35	53.60	36.15	46.07	44.92	39.99	51.61	44.17

There was no increase in algal biomass at mangapohio even though enriched channels were released from DRP limitation. The highest algal biomass was recorded at Parikaka stream which also recorded the lowest invertebrate indice scores except for species richness, invertebrate abundance and Margalef's diversity index (Table 2). There were generally higher proportions of EPT individuals in the treatment channels although not more taxa (Table 2, 3). This was also reflected in the QMCI scores with comparatively more high scoring EPT individuals in the downstream treatments. *Deleatidium* sp. showed the same patterns as these 2 metrices and therefore could be the main influence on these (Fig. 1). The number of invertebrates in the channels varied greatly between sites and treatments (Table 2). However, the individuals present in enriched channels provided higher EPT indice and QMCI scores (Table 2, 3). Indicating that there were higher proportions of EPT present in the downstream treatment community.

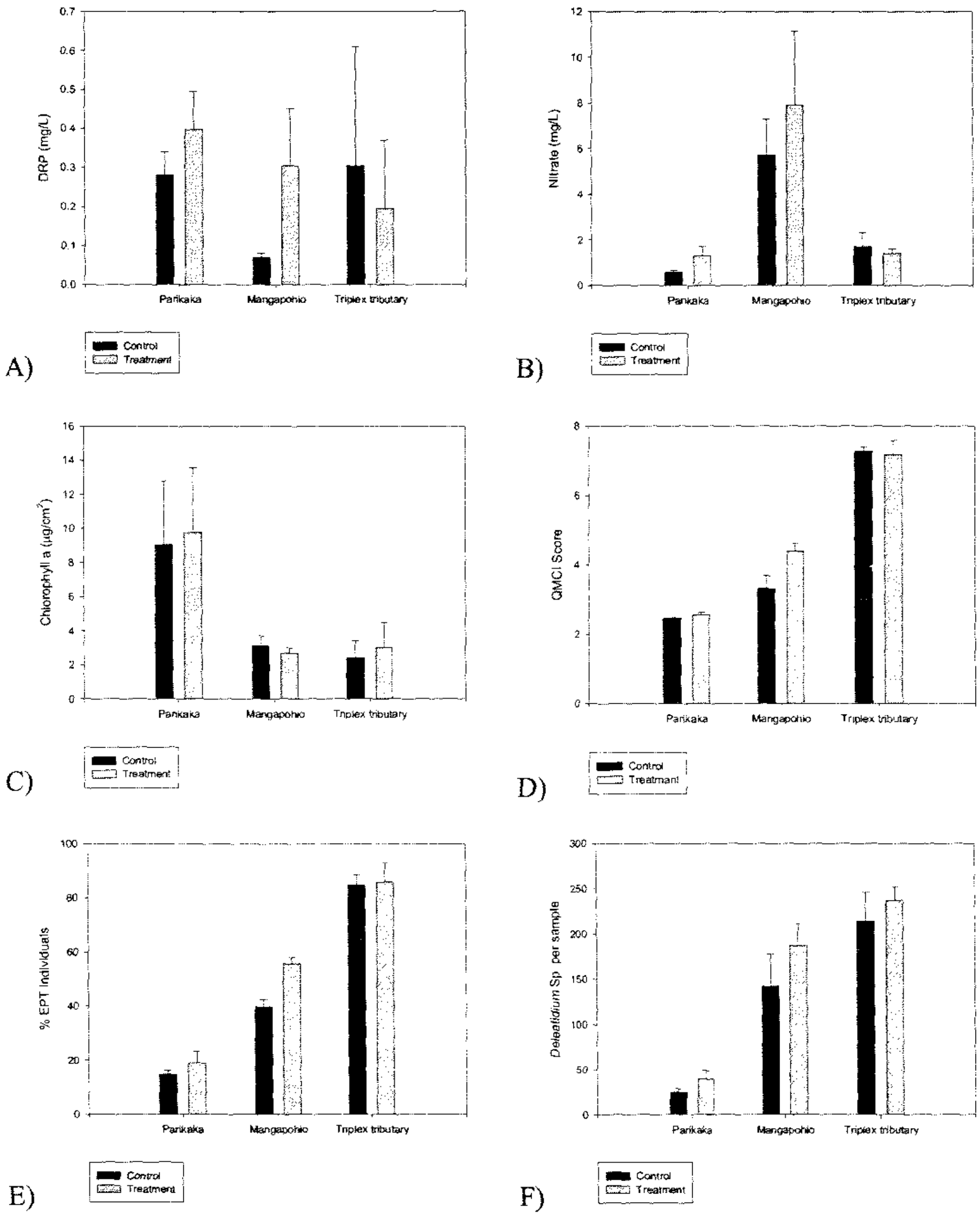

Figure 1. Relationships between control and treatment channels at the 3 sites in the Hawke's Bay. Showing means +1 standard error of A) Dissolved reactive phosphorous (DRP), B) Nitrate, C) Chlorophyll *a*, D) QMCI, E) % EPT individuals and F) *Deleatidium* sp. per sample.

Table 3. Results of 3-Way ANOVA tests of Control/Treatment and Site against various parameters from 3 Hawke's Bay, New Zealand streams in the summer of 2002/2003. Values in bold if significant to P = 0.05.

		Error	df	F value	P value
DRP	Control/Treatment	41	1	8.23	**0.007**
	Site	41	2	9.1	**0.0007**
Nitrate	Control/Treatment	41	1	4.38	**0.0439**
	Site	41	2	77.38	**<0.0001**
Chlororphyll a	Control/Treatment	41	1	0.15	0.69
	Site	41	2	24.51	**<0.0001**
Total pigment	Control/Treatment	41	1	0.11	0.74
	Site	41	2	32.14	**<0.0001**
MCI	Control/Treatment	41	1	0.08	0.77
	Site	41	2	34.6	**<0.0001**
QMCI	Control/Treatment	41	1	6.21	**0.02**
	Site	41	2	335.8	**<0.0001**
Invertebrate abundance	Control/Treatment	41	1	0.11	0.74
	Site	41	2	29.01	**<0.0001**
Species richness	Control/Treatment	41	1	0	0.95
	Site	41	2	26.92	**<0.0001**
Margalef's	Control/Treatment	41	1	0.02	0.87
	Site	41	2	16.72	**<0.0001**
% EPT Individuals	Control/Treatment	41	1	7.26	**0.01**
	Site	41	2	214.68	**<0.0001**
% EPT taxa	Control/Treatment	41	1	1.5	0.23
	Site	41	2	9.31	**0.0006**

There were greater differences in nutrient, algal and invertebrate metrices between the 3 sites than between treatments (Table 3). The invertebrate community at Triplex tributary was numerically dominated by *Deleatidium* sp. with very few *Aoteapsyche* sp., Oligocheata and none of the less common chironomid taxa (*Corynoneura, Tanytarsus*), Ostracoda and Nemertea found at the other 2 sites. The invertebrate community at Parikaka stream was dominated by Oligocheata and Chironomidae: *Orthocladinae* spp., *Diamesinae* spp., chironomid pupae, *Orthocladinae* sp. 2, *Physa* sp., Amphipoda, *Hydra*, *Hydrobiosis umbripennis* and more Ephydridae than the other 2 sites. The invertebrate community at Mangapohio was again dominated by *Deleatidium* sp. and high densities of *Aoteapsyche* sp.. There were slightly more *Hydrobiosis clavigera*, fewer *Olinga feredayi* and no *Pycnocentria* sp. when compared to the other 2 sites. Margalef's diversity index, MCI, species richness and the number of individuals (density) in the invertebrate community were not found to be habitually different between treatment and control channels (Table 3).

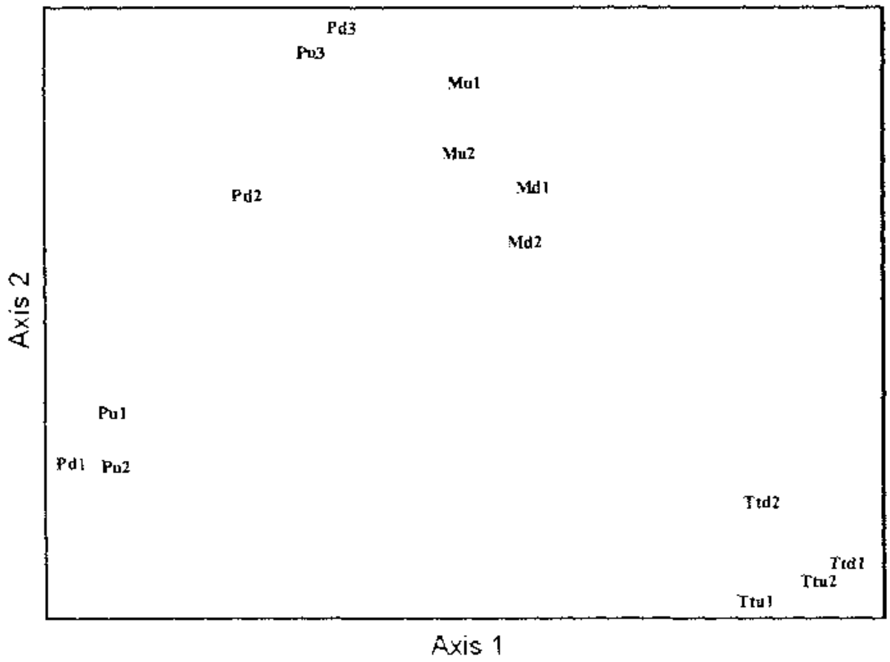

Figure 2. Nonmetric multidimensional scaling ordination of the macroinvertebrate communities (mean of 3 hand net samples) in nutrient enhanced (d) and control channels (u) at the 3 study streams (Parikaka = P, Mangapohio = M, Triplex tributary = Tt) on various sampling occasions (the first sample occasion = 1, the 2nd = 2, the 3rd = 3).

The nonmetric multidimensional scaling (NMS) ordination splits the Triplex tributary from the other 2 sites at the right side of axis 1 and the bottom of axis 2 (Fig. 2). Samples from Parikaka are spread along axis 2 to the left side of axis 1. At Mangapohio control and enriched treatments are separated along axis 1 (Fig. 2). The NMS ordination also identified *Deleatidium* sp. as a major differentiating factor between the invertebrate communities along axis 1 (Table 4). Early instar Hydrobiosidae larvae along with *Tanytarsus* sp. and Patyhelminthe were also important descriptors along axis 1. *Pycnocentrodes* sp. and Hydrophilidae explained a large amount of the variation in invertebrate communities along axis 2. Axis 1 of the NMS explained 78% of the variation in the data while axis 2 accounted for 18% of the variation. The total stress value of 3.16 indicated that this ordination was an excellent representation of the invertebrate communities (McCune and Grace 2002).

Table 4. Pearson's Correlation Coefficients for invertebrate taxa highly correlated with axis 1 and 2 of a nonmetric multidimensional scaling ordination for invertebrate communities collected from 3 Hawke's Bay, New Zealand streams. Highly correlated values are shown in bold if correlation coefficients are greater than +/- 0.05.

Taxa	Axis 1	Axis 2
Deleatidium sp.	**0.837**	0.032
Pycnocentrodes sp.	0.086	**0.819**
Hydrobiosidae early instar	**0.533**	0.109
Hydrophilidae	0.057	**0.621**
Tanytarsus sp.	**0.532**	0.258
Platyhelminthe	**0.529**	0.044

The cluster analysis again showed that the biggest differences were between sites (Fig. 3). The invertebrate community at Parikaka on the last sampling occasion (Pu3, Pd3), 1 month later than the second was very different to earlier sampling occasions. It also shows the separation of invertebrate communities between unenriched (Mu1, 2) and enriched (Md1, 2) channels at Mangapohio.

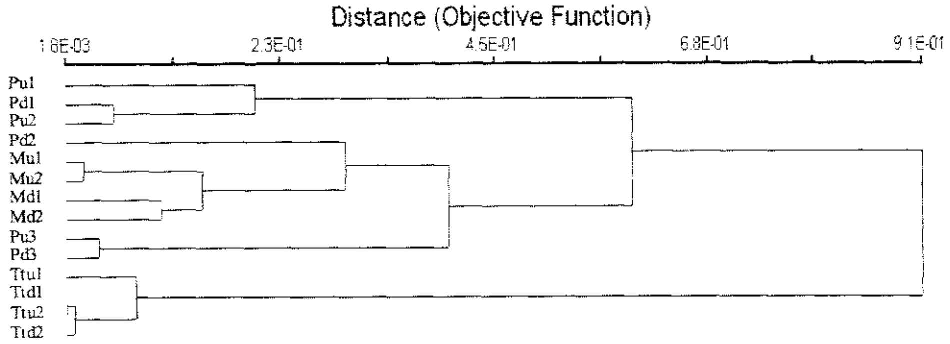

Figure 3. Cluster analysis of enriched (d) and control (u) channel invertebrate communities (mean of 3 hand net samples) at the 3 locations (P = Parikaka, M = Mangapohio, Tt = Triplex tributary) on the various sample occasions (the first sample occasion = 1, the 2nd = 2, the 3rd = 3).

DISCUSSION

Nutrient – algal interactions

There were large natural temporal fluctuations in stream nutrient concentrations, however the treatment additions raised downstream dissolved reactive phosphorous (DRP) levels. However this did not translate to an increase in algal biomass in the treatment channels. Nitrate concentrations at all the sites were above the level suggested by Borchardt (1996) to limit algal growth, so this was not a confounding influence. Variation in both control and treatment channel nutrient concentration between sample occasions was large suggesting that other processes such as periphytic uptake, light, temperature, substrate, increased flow or sediment inputs (Dodds 1993; Marti and Sabater 1996; Dodds *et al.* 2002; Dodds 2003) had stronger influences on treatment channel DRP concentration than my additions. However, Harding *et al.* (1999) found increases in stream nutrient levels with increasingly intensive land use practises in the South Island of New Zealand.

DRP concentrations do not appear to have been raised enough to promote increased algal growth at the Triplex tributary until near the end of the study. At Parikaka treatment channels had higher DRP levels than controls but both *in situ* channels were above the nutrient saturation level at the same time. The increase in DRP thus did not alter the algal biomass because both were free from DRP limitation simultaneously, so no difference showed through between the treatments. If DRP concentrations in the downstream enriched channels were above that limiting algal growth and the controls were below that guideline then stronger trends may have shown through. At Mangapohio however DRP was raised above that limiting to algal growth, but no increase in algal biomass was observed. Nitrate did not become limiting, there was suitable substrate and stable hydrology so perhaps invertebrate grazers were important.

Treatment effect on invertebrate communities

The greater proportion of EPT individuals found in the enriched channels was primarily a result of increased densities of the Leptophlebiid mayfly, *Deleatidium* sp.. This mayfly feeds largely on stone surface biofilms of detritus and algae (Winterbourn 2000). There may have been small increases in algal productivity in the treatment channels that resulted in increased mayfly densities but this wasn't recorded as increased algal biomass because of the increased grazing pressure (Lamberti *et al.* 1989; Welch *et al.* 1992; Rutherford *et al.* 2000). Rutherford *et al.* (2000) suggested that given stable flow conditions an equilibrium can develop between algal biomass and grazer densities. I suggest that this was occurring in the downstream enriched channels with increased diatom growth rates offset by higher EPT grazing pressure. The increase in DRP loading obtained in this study may have allowed EPT to absorb increases in algal productivity, but in with a larger prolonged increase these pollution sensitive EPT taxa could decline. Possibly the nutritional quality of the algae as a food resource increased (Steinman 1996) or certain algal taxa that do not attain high biomass and are readily feed upon grew faster in these conditions (Rosemond *et al.* 1993). More nutrients may have been taken up by algae in enriched channels but were stored for later use (Borchardt 1996) therefore not increasing biomass. At Mangapohio and Triplex tributary less mobile taxa like snails and Oligocheata may not have taken advantage of this experimentally enriched patch in the short term, but in the longer term more may have immigrated or had greater survival (Steinman 1996) and there may well have been a shift to these pollution tolerant taxa (Harding *et al.* 1999). Gradual effects of conversions (increased nutrient loadings) on stream invertebrate communities may show through even if there is no immediate dramatic change. There are a lot of generalist invertebrate taxa found in New Zealand streams which are able to take advantage of a wide range of resources and conditions (Winterbourn 2000) making them relatively resistant to small changes in water quality.

The greater proportion of high scoring *Deleatidium* sp. in downstream channels contributed to higher % EPT individuals and QMCI. Therefore small increases in nutrient loadings and productivity benefit EPT, generally it is only when large prolonged increases occur that these pollution sensitive taxa fade out of stream communities. A large increase in algal biomass to about 13 $\mu g/cm^2$ is needed to observe widespread changes in the invertebrate community composition (Chapter 2).

There were large differences in nutrient concentration, algal biomass and invertebrate metrices between the 3 sites (Table 1). This was not surprising as the sites were chosen to differ in ambient nutrient loadings but be similar in other physical characteristics. Different algal taxa naturally present in the different nutrient loadings and stream temperatures could have resulted in different reactions of the periphyton to increased phosphorous loadings (Borchardt 1996). Between the 3 streams there was considerable variation in the structure of the invertebrate communities and yet they responded similarly to the enrichment. Despite the initial taxonomic and numerical differences between the 3 streams invertebrate communities they showed increases in *Deleatidium* sp., QMCI and % EPT proportions in treatment channels. Invertebrate density has been shown previously to increase with enrichment (Welch *et al.* 1992; Biggs and Lowe 1994), in this study however this was not found to be the case. Neither species richness or invertebrate abundance were effected by nutrient enhancement, this may have been because there was no increase in algal biomass (Biggs and Lowe 1994), or that these metrices are more closely related to other physical parameters (Quinn and Hickey 1990a; Collier 1995; Miserendino 2001).

An increase in nutrients results in an increase in algal productivity (Borchardt 1996) which can result in more invertebrate taxa utilising the resource (Stevenson 1996). The invertebrate community metrices used in this study are designed to identify enrichment or degredation of water quality. The addition of fertiliser raised treatment phosphorous levels above control levels, this may have increased the productivity of the downstream channel. However the addition of phosphorous and resulting increase in algal productivity or biomass was not strong enough to reduce the number of pollution sensitive taxa or greatly increase the number of pollution tolerant taxa. In fact the opposite occurred with pollution sensitive EPT proportions increasing resulting in higher QMCI and % EPT individuals.

Conclusion

The aim of this experiment was to increase stream nutrient concentrations and to identify its effects on these Hawke's Bay stream invertebrate communities. Nutrient levels were increased, however the ecological consequences were minimal perhaps because the treatment and control channel algal communities were generally not nutrient limited. Although the phosphorous addition did not significantly increase stream algal biomass, there was flow on effects to higher trophic levels, especially the EPT. Invertebrate community composition in terms of the % EPT individuals and QMCI increased at downstream enriched channels across the 3 sites. Lower metric scores are meant to indicate increased enrichment, higher % EPT and QMCI may therefore seem counter intuitive. However it appears that these taxa are able to integrate small increases in primary production into their diet without a decline in index scores.

There were no consistent trends in species richness or overall invertebrate density which suggests that these metrices were not affected by the increase in stream nutrient concentrations.

The enrichment did not increase algal biomass but it did cause a shift in invertebrate community structure with greater proportions of EPT individuals in the community. The increase of nutrients was intended to simulate the increase of nutrient inputs associated with a conversion from extensive to intensive farming practices. I would therefore conclude that in stream catchments where these conversions occur there will be an increase in % EPT individuals and QMCI and therefore a change in community structure. With increasing farm conversion in a catchment there may well be a reduction in these indices and a shift in invertebrate community structure to more pollution tolerant taxa (Harding *et al.* 1999).

REFERENCES:

Biggs, B. J. F. 1995: The contribution of flood disturbance, catchment geology and land use to the habitat templete of periphyton in stream ecosystems. *Freshwater Biology* 33: 419-438.

Biggs, B. J. F. 1996. Patterns in Benthic Algae of Streams. Algal Ecology: freshwater benthic ecosystems. Stevenson, R. J., Bothwell, M. L. and Lowe, R. L. London, Academic Press 31-56.

Biggs, B. J. F. and Close, M. E. 1989: Periphyton biomass dynamics in gravel bed rivers: the relative effects of flows and nutrients. *Freshwater Biology* 22: 209-231.

Biggs, B. J. F. and Lowe, R. L. 1994: Responses of two trophic levels to patch enrichment along a New Zealand stream continuum. *New Zealand Journal of Marine and Freshwater Research* 28: 119-134.

Borchardt, M. A. 1996. Nutrients. Algal Ecology: freshwater benthic ecosystems. Stevenson, R. J., Bothwell, M. L. and Lowe, R. L. London, Academic Press 184-218.

Bothwell, M. L. 1993. Algal-nutrient dynamics. Pages 327-333. Research in artificial streams: applications, uses, and abuses. Lamberti, G. A. and Steinman, A. D., *Journal of the North American Benthological Society.* 12, 313-384.

Burns, A. and Ryder, D. S. 2001: Potential for biofilms as biological indicators in Australian riverine systems. *Ecological Management and Restoration* 2: 53-63.

Clausen, B. and Biggs, B. J. F. 1997: Relationships between benthic biota and hydrological indicies in New Zealand streams. *Freshwater Biology* 38: 327-342.

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.

Dodds, W. K. 1993: What controls levels of dissolved phosphate and ammonium in surface waters? *Aquatic Sciences* 55: 132-142.

Dodds, W. K. 2003: Misuse of inorganic N and soluble reactive P concentrations to indicate nutrient status of surface waters. *Journal of the North American Benthological Society* 22: 171-181.

Dodds, W. K.; Lopez, A. J.; Bowden, W. B.; Gregory, S.; Grimm, N. B.; Hamilton, S. K.; Hershey, A. E.; Marti, E.; McDowell, W. H.; Meyer, J. L.; Morrall, D.; Mulholland, P. J.; Peterson, B. J.; Tank, J. L.; Valett, H. M.; Webster, J. R. and Wollheim, W. 2002: N uptake as a function of concentration in streams. *Journal of the North American Benthological Society* 21: 206-220.

Dodds, W. K. and Welch, E. B. 2000: Establishing nutrient criteria in streams. *Journal of the North American Benthological Society* 19: 186-196.

Ministry for the Environment, 1997. Reducing the Impacts of Agricultural Runoff on Water Quality: a discussion of policy approaches. Wellington. 7.

Foran, B. and Wardle, K. 1995: Transitions in Land Use and the Problems of Planning: a Case study from the mountainlands of New Zealand. *Journal of Environmental Management* 43: 97-127.

Hach (1996). DR/2010 Spectrophotometer Procedures Manual. U.S.A.

Harding, J. S. 1991: The larvae of Neurochorema Forsteri McFarlane (Trichoptera: Hydrobiosidae). *New Zealand Natural Sciences* 18: 51-54.

Harding, J. S.; Young, R. G.; Hayes, J. W.; Shearer, K. A. and Stark, J. D. 1999: Changes in agricultural intensity and river health along a river continuum. *Freshwater Biology* 42: 345-357.

Hart, D. D. and Robinson, C. T. 1990: Resource limitation in a stream community: Phosphorus enrichment effects on periphyton and grazers. *Ecology* 71: 1494-1502.

Hill, W. R. and Knight, A. W. 1987: Experimental analysis of the grazing interaction between a mayfly and stream algae. *Ecology* 68: 1955-1965.

Hillebrand, H. 2002: Top-down versus bottom-up control of autotrophic biomass- a meta-analysis on experiments with periphyton. *Journal of the North American Benthological Society* 21: 349-369.

Lamberti, G. A.; Gregory, S. V.; Ashkenas, L. R.; Steinman, A. D. and McIntire, C. D. 1989: Productive capability of periphyton as a determinant of plant-herbivore interactions in streams. *Ecology* 70: 1840-1856.

Marti, E. and Sabater, F. 1996: High variability in temporal and spatial nutrient retention in mediterranean streams. *Ecology* 77: 854-869.

Matthaei, C. D.; Guggelberger, C. and Huber, H. 2003: Local disturbance history affects patchiness of benthic river algae. *Freshwater Biology* 48: 1514-1526.

McCune, B. and Grace, J. B. 2002. Analysis of Ecological Communities. Gleneden Beach, MjM Software Design.

McCune, B. and Mefford, M. J. 1995. PC-ORD. Multivariate Analysis of Ecological Data, Version 2.0, MjM Software Design, Glendon Beach, Oregon, USA 77-84.

McFarlane, A. G. 1951: Caddis Fly Larvae (Trichoptera) of the Family Rhyacophilidae. *Records of the Canterbury Museum* 5: 267-289.

Miserendino, M. L. 2001: Macroinvertebrate assemblages in Andean Patagonian rivers and streams: environmental relationships. *Hydrobiologia* 444: 147-158.

Mosisch, T. D.; Bunn, S. E. and Davies, P. M. 2001: The relative importance of shading and nutrients on algal production in subtropical streams. *Freshwater Biology* 46: 1269-1278.

Poff, L. N.; Wellnitz, T. and Monroe, J. B. 2003: Redundancy among three herbivorous insects across an experimental current velocity gradient. *Oecologia* 134: 262-269.

Quinn, J. M. 2000. Effects of pastoral development. New Zealand Stream Invertebrates: ecology and implications for management. Collier, K. J. and Winterbourn, M. J. Christchurch, New Zealand Limnological Society 208-229.

Quinn, J. M.; Cooper, A. B.; Davies-Colley, R. J.; Rutherford, J. C. and Williamson, R. B. 1997: Land use effects on habitat, water quality, periphyton, and benthic invertebrates in waikato, New Zealand, hill-country streams. *New Zealand Journal of Marine and Freshwater Research* 31: 579-597.

Quinn, J. M. and Hickey, C. W. 1990a: 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.

Quinn, J. M. and Hickey, C. W. 1990b: 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.

Rosemond, A. D.; Mulholland, P. J. and Elwood, J. W. 1993: Top-down and bottom-up control of stream periphyton: Effects of nutrients and herbivores. *Ecology* 74: 1264-1280.

Rutherford, J. C.; Scarsbrook, M. R. and Broekhuizen, N. 2000: Grazer control of stream algae: Modeling temperature and flood effects. *Journal of Environmental Engineering* 126: 331-339.

SAS 1996. SAS User's Guide: Statistics, SAS Inst. Inc.

Scrimgeour, G. J. and Kendall, S. 2002: Consequences of livestock grazing on water quality and benthic algal biomass in a Canadian natural grassland plateau. *Environmental Management* 29: 824-844.

Steinman, A. D. 1996. Effects of Grazers on Freshwater Benthic Algae. Algal Ecology: freshwater benthic ecosystems. Stevenson, R. J., Bothwell, M. L. and Lowe, R. L. London, Academic press 341-373.

Steinman, A. D. and Lamberti, G. A. 1996. Methods in Stream Ecology. San Diego, Academic press.

Stevenson, R. J. 1996. An introduction to Algal Ecology in Freshwater Benthic Habitats. Algal Ecology: freshwater benthic ecosystems. Stevenson, R. J., Bothwell, M. L. and Lowe, R. L. London, Academic Press 3-30.

Welch, E. B.; Quinn, J. M. and Hickey, C. W. 1992: Periphyton biomass related to point-source nutrient enrichment in seven New Zealand streams. *Water Research* 26: 669-675.

Wellnitz, T. A. and Ward, J. V. 1998: Does light intensity modify the effect mayfly grazers have on periphyton? *Freshwater Biology* 39: 135-149.

Winterbourn, M. J. 1972: A guide to the freshwater Mollusca of New Zealand. *Tuatara*: 141-159.

Winterbourn, M. J. 1990: Interactions among nutrients, algae and invertebrates in a New Zealand mountain stream. *Freshwater Biology* 23: 463-474.

Winterbourn, M. J. 2000. Feeding ecology. New Zealand Stream Invertebrates: ecology and implications for management. Collier, K. J. and Winterbourn, M. J. Christchurch 100-124.

Winterbourn, M. J. and Gregson, K. L. D. 1989: Guide to the Aquatic insects of New Zealand. *Bulletin of the Entomological society of New Zealand* 9.

Chapter 4:

General discussion and implications for management

Agricultural practices influence stream processes through a reduction in riparian cover, which impacts on stream shading, water temperature and allochthonous inputs (Townsend *et al.* 1997; Quinn 2000). Increases in sediment, animal effluent and pesticides can also occur along with increased nutrient loadings (Quinn 2000). The effect of nutrient concentration on stream invertebrate communities was the focus of this study, however nutrients only have a direct influence on algal biomass and secondarily effect invertebrates (Richards *et al.* 1993).

The nutrient and chlorophyll *a* guidelines developed in this study recommended that very low ambient nutrient concentrations are needed to maintain low algal biomass and clean water invertebrate faunas. This is because above these levels algae can be released from nutrient limitation and can therefore accrue high biomass if flow conditions are stable (Clausen and Biggs 1997; Burns and Ryder 2001). Increased algal biomass can have dramatic effects on stream macroinvertebrate functional feeding groups and community structure (Quinn and Hickey 1990b). In the development of very high algal biomass there is a shift in algal community composition from diatoms to filamentous growth forms (Biggs 1990; Rosemond *et al.* 1993; Burns and Ryder 2001) and this then affects the type of invertebrates that can consume the algae (Steinman 1996). The invertebrate taxa that feed on filamentous algae are generally regarded as pollution tolerant taxa (Scarsbrook *et al.* 2000).

Resource managers at local authorities such as regional councils can use the guidelines developed in chapter 2 to help classify stream health in their annual monitoring programs. This may allow more useful conclusions to be drawn from the data, which a wide cross section of the public will be able to understand. This in turn may also increase advocacy and public relations and therefore their willingness to comply and self regulate nutrient input to streams. The Ministry for the Environment (MfE) aesthetics guideline of 12 μg/cm^2 (Biggs 2000b) is similar to my finding of 13 μg/cm^2 chlorophyll *a* which is indicative of severe pollution resulting in large shifts in invertebrate community composition.

Every effort should be made by local authorities to maintain chlorophyll *a* concentrations below these levels or to mitigate and remedy the effects on stream invertebrate community composition if exceeded regularly. Waiting for or creating a hydrologic disturbance to wash away the excess algae could be one approach that may be acceptable if algal proliferations are rare. However, riparian plantings or fencing of riparian zones may be the best and easiest way to reduce nutrient inputs and avoid algal proliferations in the long term (Welch *et al.* 1992; Richards *et al.* 1993; Scrimgeour and Kendall 2002). In Delaware, USA restrictions have been placed on the application of certain nutrients depending on local soil type (Leytem *et al.* 2003), and this could be another option where there are severe ongoing water quality problems.

The experiment conducted in the Hawke's Bay to determine the possible effects of farm conversion from extensive to intensive landuse showed that shifts in QMCI and % EPT individuals occurred in downstream enriched channels. These indices increased with enrichment inferring that greater proportions of EPT insect larvae were taking advantage of changes to ecosystem processes, presumably higher productivity levels.

However, when farm landuse increases in intensity there can be a shift in invertebrate community structure reducing the amount of these pollution sensitive taxa from higher to lower proportions of EPT (Harding *et al.* 1999). Changes may need to be severe to effect overall invertebrate abundances or species richness.

I suggest that regional councils set in place long term monitoring schemes at large proposed conversion sites to identify any changes over time so that efforts can be made to remedy any adverse affects that occur in these agricultural stream ecosystems.

In this study no changes in invertebrate abundances or species richness were detected as a result of increased nutrients or algal biomass although changes were found to be linked to local instream physical variables. I observed that small scale or short term increases in nutrient inputs increase primary production with a resulting increase in EPT numbers. Generally studies have found decreases in EPT proportions and pollution sensitive taxa with increasing nutrient supply and algal biomass (Quinn and Hickey 1990a; Quinn and Hickey 1990b; Harding *et al.* 1999). This suggests that in the longer term there will be shifts in algal and invertebrate communities to filamentous algae and more efficient grazers of that algae (Suren *et al.* 2003). This implies that increased inputs of diffuse nutrients can influence community structure by increasing the proportion of EPT present but in extreme cases can eliminate sensitive species through changes in algal communities.

In conclusion stream nutrient concentration has been linked to algal biomass and algal biomass has been linked with EPT proportions. Resource managers should aim to maintain stream chlorophyll *a* levels below 13 $\mu g/cm^2$ in intensive agricultural areas. If this is achieved the invertebrate communities in the streams will represent clean water faunas of high biotic quality.

REFERENCES:

Biggs, B. J. F. 1990: Periphyton communities and their environments in New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research* 24: 367-386.

Biggs, B. J. F. 2000b. New Zealand Periphyton Guideline: Detecting, Monitoring and Managing Enrichment of Streams. Wellington, Ministry for the Environment.

Burns, A. and Ryder, D. S. 2001: Potential for biofilms as biological indicators in Australian riverine systems. *Ecological Management and Restoration* 2: 53-63.

Clausen, B. and Biggs, B. J. F. 1997: Relationships between benthic biota and hydrological indicies in New Zealand streams. *Freshwater Biology* 38: 327-342.

Harding, J. S.; Young, R. G.; Hayes, J. W.; Shearer, K. A. and Stark, J. D. 1999: Changes in agricultural intensity and river health along a river continuum. *Freshwater Biology* 42: 345-357.

Leytem, A. B.; Sims, J. T. and Coale, F. J. 2003: On-farm evaluation of a phosphorus site index for Delaware. *Journal of Soil and Water Conservation* 58: 89-101.

Quinn, J. M. 2000. Effects of pastoral development. New Zealand Stream Invertebrates: ecology and implications for management. Collier, K. J. and Winterbourn, M. J. Christchurch, New Zealand Limnological Society 208-229.

Quinn, J. M. and Hickey, C. W. 1990a: 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.

Quinn, J. M. and Hickey, C. W. 1990b: 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.

Richards, C.; Host, G. E. and Arthur, J. W. 1993: Identification of Predominant Environmental-Factors Structuring Stream Macroinvertebrate Communities within a Large Agricultural Catchment. *Freshwater Biology* 29: 285-294.

Rosemond, A. D.; Mulholland, P. J. and Elwood, J. W. 1993: Top-down and bottom-up control of stream periphyton: Effects of nutrients and herbivores. *Ecology* 74: 1264-1280.

Scarsbrook, M. R.; Boothroyd, I. K. G. and Quinn, J. M. 2000: New Zealand's National River Water Quality Network: long-term trends in macroinvertebrate communities. *New Zealand Journal of Marine and Freshwater Research* 34: 289-302.

Scrimgeour, G. J. and Kendall, S. 2002: Consequences of livestock grazing on water quality and benthic algal biomass in a Canadian natural grassland plateau. *Environmental Management* 29: 824-844.

Steinman, A. D. 1996. Effects of Grazers on Freshwater Benthic Algae. Algal Ecology: freshwater benthic ecosystems. Stevenson, R. J., Bothwell, M. L. and Lowe, R. L. London, Academic press 341-373.

Suren, A. M.; Biggs, B. J. F.; Duncan, M. J.; Bergey, L. and Lambert, P. 2003: Benthic community dynamics during summer low-flows in two rivers of contrasting enrichment 2. Invertebrates. *New Zealand Journal of Marine and Freshwater Research* 37: 71-83.

Townsend, C. R.; Arbuckle, C. J.; Crowl, T. A. and Scarsbrook, M. R. 1997: The relationship between land use and physiochemistry, food resources and macroinvertebrate communities in tributaries of the Taieri River, New Zealand: a hierachically scaled approach. *Freshwater Biology* 37: 177-191.

Welch, E. B.; Quinn, J. M. and Hickey, C. W. 1992: Periphyton biomass related to point-source nutrient enrichment in seven New Zealand streams. *Water Research* 26: 669-675.

Appendices

Appendix 1: Mean densities of macroinvertebrates collected in 5 0.1 m^2 Surber samples in 27 Manawatu February, 2002.

Site		1	2	3	4	5	6
	MCI score	Oroua	Tutaenui	Makino	Kiwitea (Junction rd)	Kiwitea (Feilding)	Mangamokio
Mayfly							
Deleatidium sp.	8	29.4	3.2	135.2	83.6	228.6	132
Coloburiscus humeralis	9	0	0	0	0.4	0.2	3.8
Nesameletus sp.	9	0	0	0	0	0	0
Zephlebia dentata	7	2.4	0.2	3	5.2	0.8	2.4
Zephlebia borealis	7	0	0	0	0	0	0
Neozephlebia scita	7	0	0	0	0	0	0
Mauiulus luma	5	0	0	0	0	0	0
Arachnocolus phillipsi	8	0	0	0	0	0	0
Stonefly							
Zelandoperla decorata	10	0	0	0	0	0.2	0.2
Austroperla cyrene	9	0	0	0	0	0	0
Stenoperla prasina	10	0	0	0	0	0	0
Spaniocercoides cowleyi	8	0	0	0	0	0	0
Megaleptoperla diminuta	9	0	0	0	0	0	0
Cased Caddis							
Olinga feredayi	9	0	0	0	0	0	1.2
Oxyethira albiceps	2	0.2	30.6	31.4	0.4	0	0
Paroxyethira hendersoni	2	0	0	0	0	0	0
Pycnocentria funerea	7	0	0	0.2	0	0	0
Pycnocentria evecta	7	0	0	0	0.2	0	2.2
Pycnocentria sp.	7	0	0	0	0	0	0
Helicopsyche sp.	10	0	0	0	0	0	0.2
Beraeoptera roria	8	0	0	0	0	0	0
Hudsonema amabilis	6	0	0	1	0	0	0
Triplectides obsoleta	5	0	0	0	0	0	0
Pycnocentrodes sp.	5	0	0	0	0.6	0.2	3.4
Uncased Caddis							
Hydrobiosidae early instar	5	0	23.4	11.6	5.2	1.2	4.8
Psilochorema sp.	8	0	0	0.4	0.4	0.2	0.8
Hydrobiosis parumbripennis	5	0	1.2	0	0	0.2	0.6
Costachorema xanthoptera	7	0	0	0	0	0	0
Neurochorema confusum	6	0	0	0	0	0	1.6
Hydrobiosis clavigera	5	0	0.4	0	0.2	0	0
Hydrobiosis umbripennis	5	0	0.4	0	2	0.2	1
Aoteopysche sp.	4	0.8	93.4	0.8	7.4	1.2	11.6
Plectronemia maclachlani	8	0	0	0	0	0	0
Hydrobiosis frater pupae	5	0	0	0	0	0	0
Beetle Larvae							
Elimidae	6	70.8	13.6	18.8	141.6	20.6	23.4
Hydraenidae	8	0	0	0	0	0	5.6
Staphylinidae	5	0	0	0	0	0	0
Hydrophilidae	5	0	0	0	0	0.2	0
Berosus sp.	5	0	0	0	0	0	0
Dytiscidae	5	0	0	0	0	0	0
Gyrinidae	5	0	0	0	0	0	0
Fly Larvae							
Eriopterini sp.	9	0	0	0	2.2	2	0.2
Aphrophila neozelandica	5	0.6	0.6	0.4	8.6	0.2	1.2
Muscidae Limnophora	3	0	0	0.2	0	0	0
Empididae	3	0.2	0	0	0	0	0
Austrosimulium tillyardianum	3	0	128.2	19.2	7.8	19.4	7.8
Tanyderidae Mischoderus	4	0	0	0	0.2	0	0
Molophilus sp.	5	0	0	0	0.2	0	0
Paralimnophila skusei	6	0	0	0	0	0	0
Tabanidae	3	0	0	0	0.2	0	0
Ephydrella thermarum	4	0	0	1	0	0.2	0.2
Psychodidae (Sp2)	1	0	0	0	0	0	0
Zelandotipula sp.	6	0	0	0	0	0	0
Culicidae	3	0	0	0	0	0	0
Chironomidae					0		
Orthocladiinae	2	90.2	285.6	183.6	14.6	14.6	122.4
Orthocladiinae Sp 2 (dark head)	2	12.8	956.6	252	23.6	23.6	26.4
Corynoneura	2	0	20.6	2.8	0	0	0.2
Tanypodinae	5	0.4	0.4	0.8	0	0	1.2
Diamesinae	3	0	0	0	0	0	0.8
Sp no 1	3	1	0.2	0	0	0	0
Chironomus sp.	1	0	3.4	2.2	0	0	0
Tanytarsus sp.	3	4.4	53	12.2	4	4	0.4
Polypedilum sp.	3	0	0	0	0	0	0
Harrisius sp.	6	0	0	0	0	0	0.2
Chironomidae pupa	3	9.6	96.6	26.6	2.8	2.8	12.8
Other		0	0	0	0	0	0
Potamopyrgus sp.	4	1.6	219.2	34	6	0	0
Physa sp.	3	0.2	1.2	0.2	0	0	0
Ferrissia sp.	3	0	0	0	0	0	0
Gyraulus sp.	3	0	0.2	0	0	0	0
Lymnaea sp.	3	0	0	0	0	0	0
Amphipoda sp 1	5	0	0	0	0	0	0
Amphipoda sp 2	5	1	156.8	3.4	0	0	0
Ostracoda	3	0	0.4	0.4	0	0	0
Sigara sp.	5	0	0	0	0	0	0
Polycheata	5	0	0	0	0	0	0
Small Oligochaete	1	25	57	115.6	10.8	7.4	27.4
Medium Oligochaete	1	0.2	0.2	0.8	0	0.6	1
Large Oligochaete	1	0.4	1	0	0	0	0
Platyhelminthe	3	0	18.4	7.2	0	0	0.2
Nemertea	3	1.8	34.6	15.2	0	0.6	0
Archichauliodes diversus	7	0.2	0	0	3.2	0.2	3.8
Nematoda	3	0.2	0	2	0.6	0.4	0.6
Acari	5	0	0	0	0.4	0	0
Isopoda	5	0	0	0.2	0	0	0
Collembolla	6	0	0.2	0.4	0.6	0	0.2
lans Nemertea	3	0	0	0	0	0	0
Xanthocnemis sp.	5	0	0.2	0	0	0	0
Veliidae	5	0	0	0	0	0	0
Mesoveliidae	5	0	0	0	0	0	0
Daphnia sp.	5	0	0	0	0	0	0
Metrices							
MCI		75.44	70.61	76.89	92.95	84.07	102.20
QMCI		3.77	2.68	3.29	5.57	5.49	4.63
No of individuals		253.4	2201	882.8	333	438.8	402
sp rich		13.2	21.4	21.6	19	15.4	23
Margalef's d		2.25	2.68	3.08	3.11	2.38	3.67
%EPT individuals		14.16	5.06	19.27	30.56	53.51	41.12
EPT taxa		18.05	26.13	26.42	34.88	26.73	44.07

Site	8	9	10	11	12	13	14	15	16
	Mangatewai-nui	Whakarautapu	Coal creek	Mangatoro	Turitea	Makakahi	Mangatainoka	Mangarupiu	Tainui
Mayfly									
Deleatidium sp.	150.2	177.6	54.8	198.4	184.8	247	190.4	467.6	762.8
Coloburiscus humeralis	5.4	15.2	0.4	0.4	4.8	3.4	0.2	14.8	29
Nesameletus sp.	0	0	0	0	0	4.4	0	0.8	0.2
Zephlebia dentata	2	22.8	16.6	0.8	13.8	3.6	0	0	19.8
Zephlebia borealis	0	0	0	0	0	0	0	4.8	0
Neozephlebia scita	0	0	0	0	0	0	0	0	0
Mauiulus luma	0	0	0	0	0	0	0	0	0
Arachnocolus phillipsi	0	0	0.4	0	0	0	0	0	0
Stonefly									
Zelandoperla decorata	0	1.2	0	0	0	1.8	0.2	1.4	2
Austroperla cyrene	0	0	0	0	0	0.2	0	0	0
Stenoperla prasina	0	0	0	0	0	0	0	0	0
Spaniocercoides cowleyi	0	0	0	0	0	0	0	0	0
Megaleptoperla diminuta	0.2	0	0	0	0	0	0	0	0
Cased Caddis									
Olinga feredayi	0.4	1.8	0	0	0	1.2	0	0.6	0.8
Oxyethira albiceps	0	0	0.4	0	0	0.6	0.6	22.8	0.2
Paroxyethira hendersoni	0	0	0	0	0	0	0	0	0
Pycnocentria funerea	0	0	0	0	0	0.4	0.4	2.2	2.6
Pycnocentria evecta	0.6	1.2	0	0	0.2	3.4	0	1.6	0.2
Pycnocentria sp.	0	0	0	0	0	0	0	1.6	0
Helicopsyche sp.	0	0	0	0	0.4	0	0	4	0.2
Beraeoptera roria	0	0	0	0	0	2	0	0	0
Hudsonema amabilis	0	0	0	0	0	0.2	0	0.2	0.4
Triplectides obsoleta	0	0	0	0.2	0.4	0	0	0	0
Pycnocentrodes sp.	17.8	6.8	1.2	9.4	155.4	4.4	1.2	55	20.6
Uncased Caddis									
Hydrobiosidae early instar	4.6	3.8	3.6	0.8	8	15.4	10.6	42.2	15.8
Psilochorema sp.	2	0	0	2	2.2	1.2	0.8	4	2
Hydrobiosis parumbripennis	0	0.4	0	0.2	1	1	0.2	1.4	0.6
Costachorema xanthoptera	0.2	0.4	0.4	0	0.6	0.6	0	0.2	0.6
Neurochorema confusum	0	0	0.4	0	0	0	0	0.2	0
Hydrobiosis clavigera	0.2	0.2	0.4	0.4	0.2	0	0	0	0.2
Hydrobiosis umbripennis	1	0.8	1.6	0	1	0.2	0.2	1.6	0.6
Aoteopysche sp.	7.8	16.4	15.8	49.2	169.6	25.6	3.2	274	93
Plectronemia maclachlani	0.2	0	0	0	0	0	0	0	0
Hydrobiosis frater pupae	0	0	0.2	0	0	0	0.2	0	0
Beetle Larvae									
Elimidae	97	17.4	50	328.6	223	11.4	53	144	115.6
Hydraenidae	1.4	5.8	0	0.2	0.6	2.4	0.2	2.2	1.8
Staphylinidae	0	0	0	0	0	0	0.2	0	0
Hydrophilidae	0	0	0	0.2	0	0	0	0	0
Berosus sp.	0	0	0	0	0	0	0.2	0	0
Dytiscidae	0.2	0	0	0	0	0	0	0	0
Gyrinidae	0	0	0	0	0	0	0	0	0
Fly Larvae						0		0	
Eriopterini sp.	0	2	1.6	5	0	1	0.2	3.2	6
Aphrophila neozelandica	1	2.4	5.2	2.8	3.2	6.6	1.6	19	7.4
Muscidae Limnophora	0	0.2	0	0	0	0	0	0	0
Empididae	0	0	0.4	0	0	2	0.2	0.8	0.8
Austrosimulium tillyardianum	10.6	51.4	5	2	7.6	26.2	2.4	21.2	130.2
Tanyderidae Mischoderus	0	0	0	0	0	0	0	0	0
Molophilus sp.	0	0	0	0	0	0	0	0	0
Paralimnophila skusei	0	0	0	0	0	0	0	0	0
Tabanidae	0	0	0	0.4	0	0	0	0	2.2
Ephydrella thermarum	0	0	0	0	0	0	0.2	0	0
Psychodidae (Sp2)	0	0	0	0	0	0	0.2	0	0
Zelandotipula sp.	0.2	0	0	0	0	0	0	0	0
Culicidae	0	0	0	0	0	0	0	0	0
Chironomidae									
Orthocladiinae	39.8	39.2	1.8	1.6	15.4	113.4	111.2	36.6	11.4
Orthocladiinae Sp 2 (dark head)	13.2	19.4	15.8	0	13.4	12.6	0.8	25	43.6
Corynoneura	0	0	0	0	0	0	0	0	0
Tanypodinae	0	0.8	0	0	0	0.4	0	2.2	0
Diamesinae	0	0.6	0	0	8.6	20.8	1.8	4.8	1.8
Sp no 1	0	0	0	0	0.6	1.2	0	0	0
Chironomus sp.	0	0	0	0	0	0	0	0	0
Tanytarsus sp.	0.6	1	1.6	0.2	0.6	93.8	10.6	196	12
Polypedilum sp.	0	0.8	0	0	0	0	0	0	0
Harrisius sp.	0	0	0	0	0	0	0	0	0
Chironomidae pupa	8.2	5.2	2.2	0	3.2	16.6	1.8	8.4	6.2
Other	0	0	0	0		0	0	0	0
Potamopyrgus sp.	14	0.8	1.4	1.4	76.6	0.8	0	10.4	5
Physa sp.	0	0	0	0	0.6	0	0	0	0
Ferrissia sp.	0	0	0	0	0.2	0	0	0	0
Gyraulus sp.	0	0	0	0	0	0	0	0	0
Lymnaea sp.	0	0	0	0	0	0	0	0.2	0
Amphipoda sp 1	0	0	0	0	0	0	0	0	0
Amphipoda sp 2	0.2	0	0	0	0.2	0	0	0	0
Ostracoda	0	0	0	0	0	0	0	0	0
Sigara sp.	0	0	0	0	0	0	0	0	0
Polycheata	0	0	0	2.2	0	0	0	0	0
Small Oligochaete	2.2	21.4	0.6	1.4	10.8	8	181.2	60	4
Medium Oligochaete	0.2	0	0	0	0	0	0	1.6	0.4
Large Oligochaete	0	0	0	0	0.4	0	0	0	0
Platyhelminthe	0.2	0.8	0	0.2	10.8	0.4	0.2	0.8	5
Nemertea	0.4	0	0	0	0	0	46.6	1.4	0
Archichauliodes diversus	1.8	2	0.6	8	3	2.6	0.2	13.8	3.8
Nematoda	0.4	0.2	0	0	0	0	0.2	0.4	0.4
Acari	0.4	0	0	0	1.2	0.2	0.6	3.2	0
Isopoda	0	0	0	0	0	0	0	0	0
Collembolla	0.2	0	0	0	0	0	0	0	0
lans Nemertea	0	0	0	0	0.4	0	0	0	0
Xanthocnemis sp.	0	0	0	0	0	0	0	0	0
Veliidae	0.4	0	0	0	0	0	0	0	0
Mesoveliidae	0	0.2	0	0	0	0	0	0	0
Daphnia sp.	0	0	0	0	0	0	0	0	0
Metrices									
MCI	100.59	105.95	99.13	107.43	95.62	105.4300325	83.54	101.36	105.91
QMCI	6.00	5.71	5.93	6.50	5.40	5.36	4.36	5.43	6.41
No of individuals	385.2	420.4	182.4	616	922.8	637	621.8	1456.2	1309.2
sp rich	19.2	22.8	16.6	13.8	22.4	25.8	17.4	29.2	26.4
Margalef's d	3.05	3.61	3.01	1.99	3.14	3.89	2.59	3.91	3.55
%EPT individuals	50.86	59.08	53.21	42.78	58.77	53.68	35.74	58.71	70.10
EPT taxa	40.39	44.04	44.63	40.83	40.13	47.71	33.46	41.71	44.65

Site	17	18	19	20	21	22	23	24	25	26	27
	Otangane	Mangahao	Hukanui	Makairo	Otawhao	Raparapawai	Tamaki River	Kumeti	Oruakeretaki	Mangamania	Mangaatua
Mayfly											
Deleatidium sp.	151.6	313.4	0.2	270	507.4	157.8	133.6	192.4	49	630.8	1115.2
Coloburiscus humeralis	1.4	1	0	3.4	19.8	1.6	0.8	1	0	4	2.6
Nesameletus sp.	0	2.2	0	0.2	0	0	0	0	0	0	0
Zephlebia dentata	0.6	0	0	0.6	18.6	0	0	3	0	47	1.6
Zephlebia borealis	0	0	0	0	0	0	0	0	0	0	0
Neozephlebia scita	0	0	0	0	0.2	0	0	0	0	0	1.2
Mauiulus luma	0.4	0	0	0	0	0	0	0.8	0	0	0
Arachnocolus phillipsi	0	0	0	0	0	0	0	0	0	0	0
Stonefly											
Zelandoperla decorata	0.8	6.4	0	0.4	0.2	0	0.4	0.2	0	1	0
Austroperla cyrene	0	0	0	0	0	0	0	0	0	0	0
Stenoperla prasina	0.2	0	0	0	0	0	0	0	0	0	0
Spaniocercoides cowleyi	0.2	0	0	0	0	0	0	0	0	0	0
Megaleptoperla diminuta	0	0	0	0	0	0	0	0	0	0	0
Cased Caddis											
Olinga feredayi	1.6	0	0	7.6	0.8	0	0.4	1	0	0.8	0.2
Oxyethira albiceps	0	0	88	0.2	1.4	0	0	0	0	10.4	0.4
Paroxyethira hendersoni	0	0	1.6	0	0	0	0	0	0	0	0
Pycnocentria funerea	0	0	0	0	11.6	0	0.2	0	0	7.8	0
Pycnocentria evecta	0	0.6	0	0.4	0.4	0	0	1.2	0.2	5.2	0.4
Pycnocentria sp.	0	0	0	0	0	0.4	0	0	0	0	0
Helicopsyche sp.	0	0	0	0.2	0	0	0	0	0	0	0
Beraeoptera roria	0	1	0	0	0.8	0	0	0	0	0	0
Hudsonema amabilis	0	0	0	0.4	0	0	0	0	0	0.2	0.2
Triplectides obsoleta	0	0	0	0	0	0	0	0	0	0.2	0
Pycnocentrodes sp.	39.4	0.2	1	8.6	9.4	0.4	0.2	0	0.2	9.6	0.6
Uncased Caddis											
Hydrobiosidae early instar	12.2	11.4	0	6.6	7.4	1.8	0.6	0.8	2.4	29.2	15.2
Psilochorema sp.	2	2	0	1.8	1.8	0.6	1.8	0.6	0.6	1	0.4
Hydrobiosis parumbripennis	0.2	0.6	0	0.4	0.2	0	0	0	0	7.4	1.8
Costachorema xanthoptera	2.6	2.2	0	0.4	0	0	0.2	0	0.4	0.2	0
Neurochorema confusum	0.2	0	0	0	0	0	0	0	0	0.2	0
Hydrobiosis clavigera	0.4	0.4	0	1.4	2.8	0.4	0.2	0	0.2	0.4	1.2
Hydrobiosis umbripennis	0	0.8	0	0	0.4	0	0.6	0	1.4	9	1.4
Aoteopysche sp.	33.8	24.2	0.6	8.2	35.2	5.8	1.6	1.4	2.4	23	19.2
Plectronemia maclachlani	0	0	0	0	0	0	0	0	0	0	0
Hydrobiosis frater pupae	0	0.2	0	0	0	0	0	0	0	0	0
Beetle Larvae											
Elimidae	25	10	0.8	233.6	316.4	96.2	44.6	77.8	34.6	278	305
Hydraenidae	0.8	0	0	0	0	0.2	0	0	0.2	0	0
Staphylinidae	0	0	0	0	0	0	0	0	0	0	0
Hydrophilidae	0	0.2	0	0	0	0.2	0	0.2	0	0.2	0
Berosus sp.	0	0	0	0	0	0	0	0	0	0	0
Dytiscidae	0	0	0	0	0	0	0	0	0	0	0
Gyrinidae	0	0	0	0.2	1.6	0	0	0	0	0.4	0
Fly Larvae					0					0	
Eriopterini sp.	0	0.4	0	3.6	2	1	3.6	2	0.6	2.4	3
Aphrophila neozelandica	7.4	2.8	0	0.2	2.8	0.2	0	0	0.2	19	0.2
Muscidae Limnophora	0.2	0	0	0	0	0	0	0	0	2.4	0
Empididae	0.2	0	10	0	0	0	0.2	0	0	1	0
Austrosimulium tillyardianum	28.6	5.4	5.6	11.6	11.4	1	1.2	0.6	0.8	15.2	5.2
Tanyderidae Mischoderus	0	0	0	0	0.2	0	0	0	0	0	0
Molophilus sp.	0	0	0	0.2	0	0.2	0	0	0.6	0	0
Paralimnophila skusei	0	0	0	0	0	0	0	0.2	0	0	0
Tabanidae	0.2	0	0	0.2	0	0	0	0	0	0	0
Ephydrella thermarum	0	0	1.4	0	0	0	0	0	0	4.4	0
Psychodidae (Sp2)	0	0	0	0	0	0	0	0	0	6.6	0.4
Zelandotipula sp.	0	0	0	0.2	0	0	0	0	0	0	0
Culicidae	0	0	0	0	0	0	0	0	0	0	0
Chironomidae											
Orthocladiinae	45.6	20.2	142.4	0.2	2.2	0	13.4	0.6	16.8	288	7.8
Orthocladiinae Sp 2 (dark head)	29.4	10.6	3	6.2	4.6	9.4	32.6	2.4	21.4	162	8.4
Corynoneura	0	0	0	0	0	0	0	0	0	0.6	0.2
Tanypodinae	0	0	0	0	0.4	0	0	0	0.2	3	0
Diamesinae	14.4	6.4	26	0	0	0	0.4	0.2	0	0.8	0
Sp no 1		0.2	0	0	0	0	0	0	0.6	0	0
Chironomus sp.	0	0	0	0	0	0	0.2	0	0	4.4	0
Tanytarsus sp.	52.4	15.2	177.8	0.4	0.4	0.8	2.2	0	1	67.6	2.4
Polypedilum sp.	0	0	0	0.2	0	0	0	0	0	0.2	0
Harrisius sp.	0	0	0	0	0	0	0	0	0	0	0
Chironomidae pupa	5.6	1.6	19.6	0	0.6	0	18	0	32	40.2	1.6
Other		0		0	0		0			0	
Potamopyrgus sp.	0.6	0	15.6	2.2	114.8	8.6	0	0.8	1	28	19.6
Physa sp.	0.2	0	0	0	0	0	0	0	0	2.2	0
Ferrissia sp.	0	0.2	5.6	0	0	0	0	0	0	0	0
Gyraulus sp.	0	0	0.2	0	0	0	0	0	0	0	0
Lymnaea sp.	0	0	0.2	0	0	0	0	0	0	0	0
Amphipoda sp 1	0	0	1	0	0	0	0	0	0	0	0
Amphipoda sp 2	0	0	94.2	0	1.2	0.6	0	0.4	0.2	1.6	5.2
Ostracoda	0	0	0.2	0	0.4	0	0	0	0	0	0
Sigara sp.	0	0	0	0	0	0	0.2	0	0	0	0
Polycheata	0	0	0	4.8	0.4	0	0	0	0	0	0
Small Oligochaete	10	65.2	627.2	6.8	14	15.2	0.4	18	1	810.8	92.8
Medium Oligochaete	0	0	0	0	0.2	0.6	0	2.8	0	0.4	10
Large Oligochaete	0	0	0	0	0	0.2	0	0	0.2	0	0
Platyhelminthe	0.4	0.6	0	0.4	31.4	2.2	0.4	0.2	0	4	21
Nemertea	0	3.4	0	0	0	0.2	0	0	0	274.8	19
Archichauliodes diversus	0.6	0	0.2	3.8	7.4	1.4	0	0.4	0.6	2.2	1.4
Nematoda	0	0	0	0	0	0	0.2	0	0	0.4	0
Acari	0.6	0	0	0	0.2	0	0	0	0	5.4	0.2
Isopoda	0	0	0	0	0	0	0	0	0	0	0
Collembolla	0	0	0	0	0	0.2	0.2	0	0	0	0
Ians Nemertea	0	0	0	0	1.6	0.2	0	0	0	0.4	0
Xanthocnemis sp.	0	0	0	0	0	0	0	0	0	0	0
Veliidae	0	0	0	0	0	0	0	0	0	0	0
Mesoveliidae	0	0	0	0	0	0	0	0	0	0	0
Daphnia sp.	0	0	0	0	0	0	0	0	0	0	58.8
Metrices											
MCI	102.66	100.23	64	111.07	101.24	96.74	100.47	106.55	91.15	90.61	87.87
QMCI	5.06	6.15	2.05	6.77	6.66	6.52	6.37	6.97	5.06	3.84	6.67
No of individuals	470.4	509	1222.4	585.8	1137.4	307.4	258.4	309	169	2816.4	1723.8
sp rich	21.4	20.8	14.4	19.8	24.4	14.8	13.4	12	14.8	35.8	21.8
Margalef's d	3.33	3.19	1.94	2.96	3.38	2.46	2.24	1.94	2.71	4.39	2.79
%EPT individuals	53.20	72.56	0.19	53.88	58.58	57.33	58.81	67.26	34.60	28.16	67.43
EPT taxa	46.67	46.58	17.92	49.43	44.96	34.88	42.67	39.82	36.35	37.70	36.31

Appendix 2: Environmental parameters and macroinvertebrate metrices for the 27 Manawatu sites sampled in February 2002.

Site no	1	2	3	4	5	6
Site name	Oroua River	Tutaenui stream	Makino stream	Kiwitea stream (Junction rd)	Kiwitea stm (Feilding)	Mangamako stream
Altitude (m A.S.L.)	40	40	120	340	90	340
Discharge (m^3/s)	2.133	0.044	0.019	0.438	0.436	0.203
Mean Width (m)	10.5	2.27	2.38	4.74	6.18	2.04
Mean Depth (cm)	23	8.1	5.34	14.1	11.4	15.2
Mean Velocity (m/s)	1.314	0.725	0.456	0.774	0.755	1.139
Conductivity	165	264	260	169.6	193	122.9
Temperature °C	20.3	24.8	18.6	24	26.2	17.7
pH	9.5	8.8	9.3	6.6	8.6	8.6
O_2	10.1	12.95	12.7	8.32	9.2	9.9
Accrual time (days)	9	9	9	9	9	19
Substrate index	55.341	57.500	48.224	58.319	75.513	88.447
Suspendable sediment (g/cm^2)	4.22385E-07	5.0286E-08	7.36703E-07	2.27053E-07	1.56327E-07	9.10423E-08
DRP (mg/L)	0.38	1.77	0	0	0	0.11
Nitrate (mg/L)	1.17	0.13	7	0.01	2.22	7.2
Mean Chlorophyll a (mg/cm^2)	12.68	14.67	14.57	2.11	7.13	8.72
SE	1.31	6.64	0.70	0.26	9.99	1.17
Stream order	5	4	4	4	5	2
Area	734291008	3505712896	41931900	101826016	246271600	10459800
Caofginpvl	CD/H/M/P/HO/LG	CW/H/M/P/MO/LG	WD/L/A/P/MO/LG	CW/H/M/P/MO/LG	CD/H/A/P/HO/LG	CW/H/A/P/LO/LG
Lake_catch	0	0	0	0	0	0
Aveelev	416.57	742.16	191.44	478.86	379.48	447.12
Lcdbarea	734322496	3505175232	41931900	101826016	246271600	10459800
Accarea	734351040	3505732800	41931900	101826016	246271472	10459800
Site no	1	2	3	4	5	6
Accslope	15.89	26.31	4.13	18.45	12.61	10.52
Accrain	1163.76	1263.54	972.12	1244.1	1127.07	1701.16
Acctemp	109.83	93.92	120.13	106.36	110.66	109.08
Accevap	704.5	688.81	725.7	702.3	707.94	704.48
Accflow	11.13835	53.86509	0.32743	1.74823	3.27083	0.33036
Ctcharea	53900	1859400	1447200	83700	1710000	4681800
Ctchslope	0.44	2.55	2.13	10.7	1.17	4.18
Ctchrain	861.99	914.84	956.85	1126.46	971.52	1497.53
Ctchtemp	128	127.56	124.4	112.87	125.14	113.42
Ctchevap	742	748.27	733.39	704.77	733.28	713.68
Ctchflow	0.00024	0.00981	0.01025	0.00112	0.01291	0.11626
Length	402.426	2098.234	3112.203	307.279	1872.792	7774.121
Reachlen	402.42641	2098.23376	3112.20346	307.27922	1872.79221	7774.11255
Euclen	391.15214	1570.35028	2645.78911	271.66155	1464.78667	5556.90476
Upelev	40.00001	58.03035	115.881	333.516	101.2279	413.661
Downelev	38.33932	57.85666	95.75729	335.5972	88.46251	304.8249
Latitude	-40.28	-40.15	-40.20	-40.02	-40.21	-40.07
Totvol	9.24239E+11	5.02073E+12	38354365024	1.1443E+11	2.45309E+11	18625081344
Rainall	9.23963E+11	5.02239E+12	38354313984	1.1443E+11	2.45308E+11	18625082572
Urban	0.01175	0.00145	0	0	0.00059	0
Farming	0.82598	0.54839	0.99469	0.94165	0.95617	0.84445
Native	0.07511	0.1363	0	0.00897	0.00463	0.06403
Exotic	0.00197	0.01213	0.00412	0.00301	0.00172	0
Scrub	0.08058	0.09951	0.00119	0.04543	0.03531	0.09152
Tussock	0.02208	0.19076	0	0	0	0
Bare_groun	0.002307	0.004532	0	0	0	0
Coastal	0	0	0	0	0	0
Other	0	0.00126	0	0	0	0
Topeat	0	0.001441	0	0	0	0
Toploess	0.410723	0.083631	0.726395	0.253693	0.436765	0.811596
Topalluv	0.162234	0.051578	0.267515	0.052056	0.143147	0
Topsand	0	0	0	0	0	0
Site no	1	2	3	4	5	6
Topother	0.279079	0.296546	0.006077	0.513988	0.345661	0.027731
Topmud	0.025	0.082858	0	0.180286	0.074543	0
Topcalcar	0	0	0	0	0	0
Topplufel	0	0	0	0	0	0
Toppluultra	0	0	0	0	0	0
Topvolhard	0	0	0	0	0	0
Topvolsft	0	0.35008	0	0	0	0
Topgreywac	0	0	0	0	0	0
Basepeat	0	0.001441	0	0	0	0
Baseloess	0.144522	0.022847	0.236845	0.104084	0.047892	0
Basealluv	0.335551	0.083922	0.650144	0.054167	0.463756	0.811086
Basesand	0	0	0	0	0	0
Baseother	0.371359	0.459098	0.112997	0.661486	0.413815	0.028241
Basemud	0.025	0.086965	0	0.180286	0.074543	0
Basecalcar	0	0	0	0	0	0
Baseplufel	0	0	0	0	0	0
Basepluult	0	0	0	0	0	0
Basevolsof	0	0.069742	0	0	0	0
Basevolhar	0	0	0	0	0	0
Basegreyt	0.113477	0.271292	0	0	0	0.160717
Llake	0.00023	0.00284	0	0.00693	0.00038	0
Sp richness	13.4	22.4	22.6	19.4	15.2	22.8
Invertebrate abundance	253.5	2231.6	914.2	333.4	438.8	401.8
Margalefs	2.29	2.81	3.22	3.18	2.35	3.64
Rarefaction	8.04	10.47	10.90	8.71	7.13	10.52
Simpsons	0.73	0.75	0.83	0.73	0.62	0.75
MCI	75.06	89.24	75.22	91.86	84.07	102.20
QMCI	3.77	2.67	3.26	5.56	5.48	4.63
EPT individuals	14.15	4.98	18.82	30.51	53.49	41.12
EPT taxa	17.86	24.96	25.21	34.11	26.73	44.07

Site no	7	10	11	12	13	14
Site name	Manawatu River	Coal creek	Mangatoro River	Turitea stream	Makakahi River	Mangatainoka River
Altitude (m A.S.L.)	320	160	200	60	280	240
Discharge (m^3/s)	0.903	0.915	1.060	0.098	0.544	1.109
Mean Width (m)	5.95	9.15	8.51	4.9	6.04	14.2
Mean Depth (cm)	12.2	22.6	21.6	11.1	16.2	26.8
Mean Velosity (m/s)	0.871	1.093	1.118	0.635	0.576	0.774
Conductivity	85.9	214	327	155.9	53.1	53.3
Temperature °C	21.6	17.5	19.1	23.4	14.4	19.6
pH	8.6	8.9	8.9	8.9	9.9	9.1
O_2	9.35	9.53	9.93	8.13	9.45	9.16
Accrual time (days)	19	21	14	15	40	40
Substrate index	50.058	83.643	59.892	89.057	106.831	103.69
Suspendable sediment (g/cm^3)	2.50741E-07	1.3754E-07	8.58901E-08	1.42435E-07	4.19076E-08	2.61463E-08
DRP mg/L)	0.37	0	0	0.79	0.76	1.06
Nitrate (mg/L)	1.79	0.03	1.66	1.25	0.93	0.74
Mean Chlorophyll a (mg/cm^2)	8.98	1.06	3.99	3.04	0.28	1.35
SE	1.65	0.27	0.43	0.74	0.07	0.16
Stream order	4	4	5	4	3	3
Area	30676500	131985904	101866536	36832500	19010700	11969100
Csofginpvi	CW/H/AI/P/MO/LG	CW/H/M/P/MO/LG	CW/H/HS/P/HO/LG	CW/L/HS/P/MO/LG	CX/H/HS/IF/MO/LG	CX/L/HS/P/MO/LG
Lake_catch	0	0	0	0	0	0
Aveelev	497.62	517.67	414.76	292.62	544.58	395.04
Lcdbarea	30714678	131985904	101866536	36832500	18998862	11969100
Accarea	30747600	131985904	101866504	36832500	19010700	11969100
Site no	7	10	11	12	13	14
Accslope	17.34	24.25	23.41	25.79	37.88	27.81
Accrain	1774.6	1384.15	1425.2	1370.99	2584.46	2376.71
Acctemp	106.28	104.06	108.69	111.95	95.06	103.3
Accevap	702.08	692.36	692.38	709.12	679.84	688.63
Accflow	1.04499	2.89329	2.36551	0.7725	1.14737	0.64025
Ctcharea	765000	406800	703800	2929500	1103400	821700
Ctchslope	9.83	16.2	15.62	6.59	5.05	4.38
Ctchrain	1381.18	1087.34	1239.1	1119.14	2168.9	2206.44
Ctchtemp	115.82	122.03	120.6	127.21	109.97	113.03
Ctchevap	715.46	710.9	708.35	731.76	705.37	704.66
Ctchflow	0.01614	0.00485	0.01184	0.03596	0.05117	0.0391
Length	1925.513	1308.823	1468.234	3114.336	2068.234	1945.219
Reachlen	1925.51299	1308.82251	1468.23376	3114.3355	2068.23376	1945.21861
Euclen	1369.52546	937.70998	1015.13546	2404.68293	1726.75997	1500.29997
Upelev	331.6835	172.5405	199.9992	62.62538	299.9999	250.7797
Downelev	320	155.7019	199.8854	39.18118	276.751	238.0307
Latitude	-40.06	-40.12	-40.30	-40.39	-40.71	-40.61
Totvol	54185746432	2.18671E+11	1.61331E+11	47909011456	40209854464	30109026304
Rainall	54185740800	2.18671E+11	1.61331E+11	47908997880	40209854624	30109028510
Urban	0	0	0	0.00221	0	0
Farming	0.85191	0.79526	0.93314	0.40723	0.20692	0.53038
Native	0.09354	0.04213	0.00717	0.26211	0.66201	0.42827
Exotic	0.00028	0.00191	0	0.03784	0.07093	0
Scrub	0.05428	0.15354	0.05969	0.2832	0.06013	0.03916
Tussock	0	0.00653	0	0	0	0
Bare_groun	0	0.000633	0	0	0	0.002187
Coastal	0	0	0	0	0	0
Other	0	0	0	0	0	0
Topeat	0	0	0	0	0	0
Toploess	0.448339	0.116601	0	0.390258	0.025906	0.004522
Topalluv	0.21423	0.044709	0.049789	0.040725	0.10456	0.215574
Topsand	0	0	0	0	0	0
Site no	7	10	11	12	13	14
Topother	0.035735	0.715013	0.309601	0.054281	0	0.232027
Topmud	0	0.005914	0.063847	0	0	0
Topcalcar	0	0	0	0	0	0
Toplufel	0	0	0	0	0	0
Topluultra	0	0	0	0	0	0
Topvolhard	0	0	0	0	0	0
Topvolsft	0	0	0	0	0	0
Topgreywac	0	0	0	0	0	0
Basepeat	0	0	0	0	0	0
Baseloess	0	0.007914	0	0.036063	0	0
Basealluv	0.62951	0.102104	0.049789	0.040725	0.10456	0.220095
Basesand	0	0	0	0	0	0
Baseother	0.068794	0.758149	0.309601	0.101511	0	0.232027
Basemud	0	0.013677	0.063847	0	0.025906	0
Basecalcar	0	0	0	0	0	0
Baseplufel	0	0	0	0	0	0
Basepluult	0	0	0	0	0	0
Basevolsof	0	0	0	0	0	0
Basevolhar	0	0	0	0	0	0
Basegrey1	0.301936	0.118164	0.576755	0.821738	0.869653	0.547871
Llake	0	0	0	0.0074	0	0
Sp richness	22.4	16.8	13.4	22.4	26.2	17.8
Invertebrate abundance	454	182.8	616	922.8	637.6	622.4
Margalefs	3.52	3.05	1.93	3.14	3.95	2.66
Rarefaction	10.95	10.38	5.26	9.04	11.17	7.34
Simpsons	0.80	0.78	0.59	0.80	0.75	0.75
MCI	109.46	98.58	107.43	95.62	104.49	82.21
QMCI	6.15	5.92	6.49	5.40	5.36	4.35
EPT Individuals	43.88	53.12	42.76	58.77	53.65	35.69
EPT taxa	45.12	44.16	40.83	40.13	47.02	32.43

Site no	15	18	19	20	21	22
Site name	Mangarupiu stream	Mangahao River	Hukanui stream	Makairo stream	Otawhao stream	Raparapawai stream
Altitude (m A.S.L.)	260	140	200	120	120	120
Discharge (m^3/s)	0.052	1.532	0.057	0.192	n/a	0.185
Mean Width (m)	4.16	21.06	2.67	5.02	3.71	3.76
Mean Depth (cm)	12	20	13	11	8.2	11
Mean Velosity (m/s)	0.466	0.968	0.490	0.474	0.424	1.145
Conductivity	71.6	77.1	95.7	147.6	205	106.1
Temperature °C	20.5	18.9	19.3	14.2	17.2	16
pH	8.6	6.6	8.9	9.1	8.7	9
O_2	8.78	10.01	10.72	10.06	9.56	9.27
Accrual time (days)	40	40	40	26	19	19
Substrate index	68.725	141.457	163.258	42.53	39.135	38.319
Suspendable sediment (g/cm^3)	2.76363E-07	1.83426E-08	1.23728E-07	3.56525E-07	9.34096E-07	2.90951E-07
DRP mg/L)	0.31	0.4	0.28	0.12	0	0
Nitrate (mg/L)	0.34	0.07	3.01	0	0	0
Mean Chlorophyll a (mg/cm^2)	0.72	1.68	18.54	0.25	0.41	0.33
SE	0.13	0.20	2.84	0.07	0.11	0.11
Stream order	2	5	3	4	3	4
Area	8382600	208071040	8715600	28182600	27996300	44812800
Csofginpvl	CW/L/HS/P/LO/LG	CX/H/HS/IF/HO/LG	CW/L/AI/P/MO/LG	CW/H/HS/P/MO/MG	CW/L/HS/P/MO/LG	CW/L/AI/P/MO/LG
Lake_catch	0	82106104	0	0	0	0
Aveelev	363.98	554.27	216.1	426.44	323.08	299.59
Lcdbarea	8382600	208059648	8715600	28182600	27996300	44812800
Accarea	8382600	208102592	8715600	28182600	27996300	44812800
Site no	15	18	19	20	21	22
Accslope	25.22	41.42	3.33	37.21	26.69	16
Accrain	2188.52	2366.11	1850.34	1461.69	1368.96	1342.7
Acctemp	104.24	94.86	115.69	106.82	113.56	114.57
Accevap	691.5	680.76	712.33	688.49	697.25	698.52
Accflow	0.39765	11.1138	0.3143	0.69051	0.59591	0.91474
Ctcharea	31500	50400	2637000	345600	855900	1101600
Ctchslope	7.8	1.28	0.5	16.68	2.81	10.53
Ctchrain	2035.74	1526.57	1781	1160.99	1202.19	1201.79
Ctchtemp	112.74	122	116.99	122.36	124.97	124.07
Ctchevap	705	711.39	712.32	710	718.36	712.08
Ctchflow	0.00133	0.0013	0.0893	0.00494	0.01312	0.01709
Length	144.853	332.132	2997.351	1066.69	2260.66	1540.66
Reachlen	144.85281	332.13203	2997.35065	1066.69048	2260.66017	1540.66017
Euclen	134.16408	308.8689	2518.03495	706.11614	1863.86695	1423.02495
Upelev	256.5082	136.8931	197.1799	144.7664	118.5273	120
Downelev	256.5082	135.3207	198.3339	119.9999	115.8224	115.8224
Latitude	-40.59	-40.51	-40.57	-40.41	-40.33	-40.33
Totvol	19227580416	6.2727E+11	15715563520	41259065344	37076176896	58077716480
Rainall	19227578048	6.28102E+11	15715563520	41259072000	37076177024	58077715136
Urban	0	0	0	0	0	0
Farming	0.50104	0.16416	0.96586	0.49654	0.95085	0.7839
Native	0.46224	0.48045	0.00406	0	0.00498	0.00104
Exotic	0	0.00237	0	0	0	0
Scrub	0.03672	0.32054	0.03008	0.50346	0.04334	0.21505
Tussock	0	0.02022	0	0	0	0
Bare_groun	0	0.010863	0	0	0.000831	0
Coastal	0	0	0	0	0	0
Other	0	0	0	0	0	0
Toppeat	0	0	0	0	0	0
Toploess	0.043005	0.023247	0.095594	0	0.01707	0.496877
Topalluv	0.138131	0.108095	0.900584	0.082002	0.157089	0.167145
Topsand	0	0	0	0.022929	0	0
Site no	15	18	19	20	21	22
Topother	0	0.027409	0	0.266526	0.237304	0.121651
Topmud	0	0.003537	0	0.0894	0.174442	0
Topcalcar	0	0	0	0	0	0
Toplufei	0	0	0	0	0	0
Topluultra	0	0	0	0	0	0
Topvolhard	0	0	0	0	0	0
Topvolsft	0	0	0	0	0	0
Topgreywac	0	0	0	0	0	0
Basepeat	0	0	0	0	0	0
Baseloess	0	0.006419	0	0	0	0
Basealluv	0.181136	0.120535	0.996178	0.082002	0.100082	0.516755
Basesand	0	0	0	0.022929	0	0
Baseother	0	0.027409	0	0.266526	0.311381	0.270918
Basemud	0	0.003537	0	0.0894	0.174442	0
Basecalcar	0	0	0	0	0	0
Baseplufel	0	0	0	0	0	0
Basepluult	0	0	0	0	0	0
Basevolsof	0	0	0	0	0	0
Basevolhar	0	0	0	0	0	0
Basegrey1	0.818924	0.840525	0.00387	0.539125	0.414048	0.212365
Llake	0	331570.9414	0	0	0	0
Sp richness	30.2	20.8	15.8	19.8	24.4	14.8
Invertebrate abundance	1479	509	1312	585.8	1138.8	307.4
Margalefs	4.04	3.19	2.11	2.96	3.37	2.46
Rarefaction	11.63	8.67	8.63	7.19	8.30	6.75
Simpsons	0.79	0.54	0.75	0.62	0.67	0.61
MCI	99.33	100.23	61.98	110.46	100.40	96.74
QMCI	5.37	6.15	2.04	6.77	6.54	6.52
EPT individuals	57.70	72.56	0.18	53.87	57.54	57.33
EPT taxa	40.32	46.58	16.26	49.01	44.25	34.88

Site no	23	24	25	26	27
Site name	Tamaki River	Kumeti stream	Oruakeretaki stream	Mangamania stream	Mangaatua stream
Altitude (m A.S.L.)	180	180	160	80	80
Discharge (m^3/s)	0.634	0.237	0.593	0.015	0.237
Mean Width (m)	10.68	4.04	4.64	2.46	6.54
Mean Depth (cm)	14.8	17	23.2	8.8	9
Mean Velosity (m/s)	0.580	0.644	0.634	0.250	0.538
Conductivity	81.4	100.6	107.5	221	157.4
Temperature °C	15	13	18.1	22.1	20.2
pH	9.1	8.4	8.5	8.7	9.3
O_2	9.8	9.67	10.22	11.18	12.53
Accrual time (days)	20	20	20	20	22
Substrate index	57.8795	37.592	80.043	50.025	30.98
Suspendable sediment (g/cm^3)	1.1203E-07	2.96294E-07	3.73387E-08	4.48259E-07	5.67308E-07
DRP mg/L)	0.18	0.3	0.23	0	1.15
Nitrate (mg/L)	1.36	7.6	6.1	0	1.8
Mean Chlorophyll a (mg/cm^2)	0.79	0.21	3.20	0.79	5.74
SE	0.28	0.04	0.60	0.19	1.21
Stream order	4	2	4	3	4
Area	73611896	3162600	54308700	20005200	95539488
Csofglnpvl	CW/H/HS/P/MO/LG	CW/L/Al/P/LO/LG	CW/L/HS/P/MO/LG	CW/L/SS/P/MO/LG	CW/L/M/P/MO/LG
Lake_catch	0	0	0	0	0
Aveelev	483.99	229.46	381.47	203.98	225.98
Lcdbarea	73611896	3162600	54308700	20005200	95539488
Accarea	73611912	3162600	54308700	20005200	95539472
Site no	23	24	25	26	27
Accslope	28.88	1.89	20.66	19.73	15.7
Accrain	1678.89	1274.96	1464.98	1249.73	1278.28
Acctemp	105.25	119.73	110.13	119.17	118.35
Accevap	687.98	711.92	692.5	702.2	703.64
Accflow	2.31141	0.05643	1.32939	0.34709	1.73968
Ctcharea	1629000	782100	702900	567000	533700
Ctchslope	3.86	1.94	3.59	16.11	0.05
Ctchrain	1219.91	1283.04	1306.36	1270.24	1268.88
Ctchtemp	122.02	121.43	122.75	124.76	127
Ctchevap	714.1	713.92	714.3	710.89	719.77
Ctchflow	0.02611	0.0141	0.01319	0.01005	0.00929
Length	1858.234	2213.087	561.838	1588.234	1840.66
Reachlen	1858.23376	2213.08658	561.83766	1588.23376	1840.66017
Euclen	1410.31911	1919.29675	524.78567	1015.13546	1025.28045
Upelev	196.756	208.7978	160	76.56264	63.48542
Downelev	174.5882	179.9999	159.6949	65.65437	63.48542
Latitude	-40.23	-40.24	-40.26	-40.34	-40.34
Totvol	1.45437E+11	4156064512	81544011776	24066115584	1.17649E+11
Rainall	1.45437E+11	4156064480	81544003104	24066112688	1.17649E+11
Urban	0.00743	0	0	0	0.0092
Farming	0.62187	1	0.69445	0.86153	0.86423
Native	0.02026	0	0.00049	0.02301	0.003
Exotic	0.00076	0	0	0.00678	0.00019
Scrub	0.34583	0	0.30506	0.10868	0.1232
Tussock	0	0	0	0	0
Bare_groun	0	0	0	0	0
Coastal	0	0	0	0	0
Other	0.003853	0	0	0	0
Topeat	0.013683	0	0	0	0
Toploess	0.265142	0.319167	0.331546	0.027658	0.382708
Topalluv	0.133568	0.680903	0.306956	0.231743	0.206534
Topsand	0	0	0	0	0
Site no	23	24	25	26	27
Topother	0.001486	0	0	0.030636	0.223559
Topmud	0	0	0	0.492824	0
Topcalcar	0	0	0	0	0
Toplufel	0	0	0	0	0
Topluultra	0	0	0	0	0
Topvolhard	0	0	0	0	0
Topvolsft	0	0	0	0	0
Topgreywac	0	0	0	0	0
Basepeat	0	0	0	0	0
Baseloess	0	0	0	0.027658	0.048894
Basealluv	0.272308	1.00007	0.606638	0.231743	0.351815
Basesand	0	0	0	0	0
Baseother	0.127888	0	0.031864	0.030636	0.412093
Basemud	0	0	0	0.492824	0
Basecalcar	0	0	0	0	0
Baseplufel	0	0	0	0	0
Basepluult	0	0	0	0	0
Basevolsof	0	0	0	0	0
Basevolhar	0	0	0	0	0
Basegrey1	0.599806	0	0.361509	0.217138	0.17182
Llake	0	0	0	0	0.00018
Sp richness	13.4	12	14	36.4	22
Invertebrate abundance	258.4	309	169	2825.6	1724.2
Margalefs	2.24	1.94	2.56	4.47	2.82
Rarefaction	6.95	5.51	8.59	10.85	6.60
Simpsons	0.60	0.52	0.80	0.81	0.53
MCI	100.47	106.55	91.15	89.52	87.53
QMCI	6.37	6.97	5.02	3.84	6.67
EPT Individuals	58.81	67.26	34.37	28.07	67.42
EPT taxa	42.67	39.82	36.35	36.88	36.02

Appendix 3. NZMS T 260 map references for the 27 Manawatu sites sampled in February 2002.

Site no	Site name	Map	E	N
1	Oroua River	S23	2724300	6100300
2	Tutaenui stream	S23	2715900	6115900
3	Makino stream	T23	2730700	6110900
4	Kiwitea stream (Junction rd)	T23	2745100	6128900
5	Kiwitea stm (Feilding)	T23	2731100	6107300
6	Mangamokio stream	U23	2785500	6122800
7	Manawatu River	U23	2786300	6122900
8	Mangatewai-nui stream	U23	2781500	6119200
9	Whakaruatapu stream	U23	2778500	6113800
10	Coal creek	T23	2753100	6117200
11	Mangatoro River	U24	2781700	6096100
12	Turitea stream	T24	2734400	6086500
13	Makakahi River	T25	2734600	6052400
14	Mangatainoka River	T25	2732400	6062700
15	Mangarupiu stream	T25	2732500	6065600
16	Tainui stream	T24	2735900	6074200
17	Otangane stream	T24	2737700	6071700
18	Mangahao River	T24	2734800	6070100
19	Hukanui stream	T25	2737000	6066700
20	Makairo stream	T24	2762300	6084500
21	Otawhao stream	T24	2766900	6093700
22	Raparapawai stream	T24	2764600	6093700
23	Tamaki River	U23	2771100	6104100
24	Kumeti stream	T23	2769200	6103200
25	Oruakeretaki stream	T23	2767900	6101500
26	Mangamania stream	T24	2751000	6092800
27	Mangaatua stream	T24	2751700	6091600

Appendix 4.1: Mean densities of macroinvertebrates from 5 0.1 m^2 Surber samples for the pre-sampling (P-2 and P-1) and during treatment stream controls (Ps2 and Ps3). Also from 3 30 cm diameter hand net samples taken from each experimental channel (Pd1, Pu1, Pd2, Pu2, Pd3, Pu3) during the nutrient enrichment experiment conducted at Parikaka stream in summer 2002/2003.

Mayfly	**MCI score**	**Parikaka**	**P-2**	**P-1**	**Pd1**	**Pu1**	**Pd2**	**Pu2**	**Ps2**	**Pd3**	**Pu3**	**Ps3**
Deleatidium sp.	8		106.2	63.2	36.7	17.3	56.7	24.67	206.67	25	31.67	115
Coloburiscus humeralis	9		1.4	3.2	0.0	0	0	0	0	0.33	0	0
Nesameletus sp.	9		0	0	0.0	0	0	0	0	0	0	0
Zephlebia dentata	7		3.2	3.2	0.3	5	0.67	18.33	37.67	6	6.33	15.67
Zephlebia versicolor	7		0	0.6	0.0	0	0	0.67	0.67	0	0	0
Rallidens mcfarlanei	7		0	0	0.0	0	0	0	0.33	0	0	0
Neozephlebia scita	7		12.2	5.6	2.7	1.33	0	1.00	6.67	0	0.33	0
Austroclima sp	9		14	13.2	9	0	14.33	6.67	27.67	3.67	0	20.67
Stonefly												
Zelandobius sp.	5		0	0.4	0	0	0	0	0	0	0	0
Austroperla cyrene	9		0	0	0	0	0	0	0	0	0	0
Stenoperla prasina	10		0	0	0	0	0	0	0	0	0	0
Megaleptoperla diminuta	9		0	0	0	0	0.33	0	0	0	0	0
Spaniocerca zelandica	8		0	0	0	0	0	0	0	0	0	0
Cased Caddis												
Olinga feredayi	9		5.2	4	0	0.3	0	0.67	4.33	0.3	2.33	7.67
Oxyethira albiceps	2		1.6	6.6	33.33	81	7.33	35.33	3	18	52.33	19
Paroxyethira hendersoni	2		0	0	0	0	0	0	0	0	0	0
Pycnocentria funerea	7		0	0	0	0	0	0	0	6	0	0
Pycnocentria evecta	7		0	0	0	0.67	11	1	1	1	2.33	13
Pycnocentria sp.	7		0	0	0	0	0	0	0	0	0	0
Helicopsyche sp.	10		0	0	0	0	0	0	0	0	0	0
Beraeoptera roria	8		0	0	0	0	0	0	0	0	0	0
Hudsonema amabilis	6		0	0	0	0	6	0	0	2.67	0.67	0
Triplectides obsoleta	5		0	0.2	0	0	0	0	0	0	0	0
Pycnocentrodes sp.	5		2.4	3	0.67	0.33	8	0.33	10.7	27.67	19	49
Oeconesidae			0	0	0	0	0	0	0	0	0	0
Uncased Caddis												
Hydrobiosidae early instar	5		10.8	8.4	55.67	24.33	55	46	20.67	8.67	9.67	37.67
Psilochorema sp.	8		3.2	1.2	2.67	0.67	5.67	6.33	11.33	7.33	3	10
Hydrobiosis parumbripennis	5		4.8	3.6	12	1.33	2	2.33	3.67	0.67	0	2.67
Costachorema xanthoptera	7		0	0	0	0	0	0	0.33	0	0	0
Neurochorema forsteri	6		0	0	0	0	0	0	2.67	0	0	0
Hydrobiosis clavigera	5		0.2	0	0	0	0	0	0	0	0	0
Hydrobiosis umbripennis	5		4.4	1.4	2	1.67	10.33	5.33	12.33	0	0	3.67
Aoteopysche sp.	4		10.2	0.6	19.33	31.33	46.33	46	64.33	10.67	3.33	65.67
Polyplectropus sp.	8		0	0	0	0	0.00	0	0	1.33	0	0.00
Plectronemia maclachlani	8		0	0	0	0	2.33	0	0	0.00	1.33	0.33
Hydrobiosis frater pupae	5		0	0	0	0	0	0	0	0	0	0
Beetle Larvae												
Elimidae	6		5	2.6	3.67	2	5	2.3	35.67	8.33	3	24.33
Berosus sp.	5		0	0	0	0	0	0	0	0	0	0
Hydraenidae	8		0.6	0.6	0	0	0	0	0.33	0	0	0.33
Staphylinidae	5		0	0	0	0	0	0	0	0.33	0.33	0
Hydrophilidae	5		0	0	0	0	0	0	0	0.33	0.33	0
Dytiscidae	5		0	0	0	0	0	0	0	0	0	0
Gyrinidae	5		0	0	0	0	0	0	0	0	0	0
Fly Larvae												
Eriopterini sp.	9		0	0	0	0	0	0	1.33	0	0	0
Aphrophila neozelandica	5		0.8	2.8	0.33	0.67	0	0	0.00	0	0	3.67
Muscidae Limnophora	3		0.2	0	0.00	0	0	0	0.33	1.67	0	0.67
Empididae	3		0.2	0.2	0.33	0	0	0	0.00	0.00	1	1.33
Austrosimulium sp.	3		10.8	134.2	16.33	28.67	5	44.33	6.33	3.67	2.67	6.33
Tanyderidae Mischoderus	4		0	0.2	0	0	0	0	0	0	0	0
Paradixa fuscinervis	5		0	0	0	0.33	0	0	0	0	0	0
Limonia sp.	6		0	0	0	0	0	0	0	0	0	0
Molophilus sp.	5		0	0	0	0.00	0	0.33	0	0	0	0
Hexatomini sp.	6		0	0	0	0.00	0	0.00	0	0.33	0	0
Paralimnophila skusei	6		0	0	0	0	0	0	0	0	0	0
Tabanidae	3		0	0	0	0	0	0	0	0	0	0
Ephydrella thermarum	4		0.2	0	1	2.67	0.33	0.33	0	1	0	0
Psychodidae (Sp2)	1		0.2	0	0	0.33	0	0.00	0	0.33	0	0
Zelandotipula sp.	6		0	0	0	0	0	0	0	0	0	0
Culicidae	3		0	0	0	0	0	0	0	0	0	0
Chironomidae												
Orthocladiinae	2		3.2	76	544.33	283.33	117.67	586.67	51	0	0	233.3
Tanypodinae	5		0	0.2	0.33	0.00	8	1.67	0	0	0	7
Diamesinae	3		19.2	121	170.67	13.33	9.33	11.33	58.67	0	0	10
Sp no 1	3		0	0	0.00	0	0	0	0	0	0	0
Chironomus sp.	1		0	0	0.00	1	12.67	6	0.67	0	0	1
Chironomidae pupa	3		3.4	72	49.67	20.67	20.67	57.33	64.33	0	0	27.67
Orthocladiinae Sp 2	2		15.2	56.2	151.67	63.33	40.33	67	63.67	0	0	77.67
Corynoneura sp.	2		0.6	0	7	7.67	19	17	0.33	0	0	1
Tanytarsus sp.	3		2.4	1.4	18	10	9	20	15	0	0	35.33
Polypedilum sp.	3		0	0	0	0	0	0	0	0	0	0
Harrisius sp.	6		0	0	0	0	0	0	0	0	0	0
Other												
Potamopyrgus sp.	4		4.2	0.6	0.67	0.67	2	0	4.33	5.33	5	6.33
Physa sp.	3		0	0	1	1.67	2	3	0.33	2.33	8.33	0.67
Amphipoda sp 2	5		0	0	0	0.00	2.67	1.67	2.33	1.67	7.67	2
Ostracoda	3		0	0	0.33	0.33	0	1	0.00	3.33	21.67	0.67
Sigara sp.	5		0	0	0	0.00	0	0	0.00	0.00	0.33	0.00
Polycheata	5		0	0	0	0	0	0	0	0	0	0
Small Oligochaete	1		11.6	28	243.33	160.33	420	228	55.67	275.33	257.33	99.67
Medium Oligochaete	1		0	0	0	0.33	0	0	0.33	0.00	1.33	0
Large Oligochaete	1		0	0	0	0	0	0	0	0	0	0
Platyhelminthe	3		0	0.2	0	0	0	0.33	0.00	0.33	0.00	3
Nemertea	3		0	0	1	1	20.33	3.67	2.33	6.67	17.67	12.33
Archichauliodes diversus	7		0.6	0.4	0	0	0.33	0.00	0.33	1	1	1.67
Nematoda	3		0	0.6	1	1	1.33	1.67	0.67	2	0.33	0.33
Acari	5		0	0	0	0	0.00	0.33	0	0	0.00	0.00
Collembolla	6		0	0	0.67	0	0.33	0	1.33	0	0.00	0.00
Hydra sp.	3		0.2	0	0.33	0.33	7.67	15	7.67	7.67	10.33	6.67
Ians Nemertea	3		0	0	0	0	0.00	0.33	0.00	0.00	1	0.33
Xanthocnemis sp.	5		0	0	0	0	0	0	0	0	0	0
Veliidae	5		0	0	0	0	0.00	0	0.33	0.33	0.33	0.00
Mesoveliidae	5		0	0	0	0	0.00	0	0	0.00	0	0.33
Copepoda	5		0	0	0.667	0	1.67	0	0	0.67	0	0
Daphnia sp.	5		0	0	0	0	0	0	0	0	0	0
Neuroptera			0	0	0	0	0	0	0	0	0	0
MCI			100.35	96.14	81.52	74.33	86.61	82.73	96.04	97.22	93.71	89.07
QMCI			6.00	3.66	2.45	2.44	2.63	2.42	4.98	2.60	2.49	3.92
Invertebrate abundance			258.4	615.6	1387	765	931.33	1264.33	787.67	442	472	923.67
Species richness			22.8	22.2	23	22	28.33	28	30.67	25	21.33	32.33
Margalef's			3.98	3.39	3.04	3.22	4.02	3.78	4.45	3.95	3.30	4.69
%EPT individuals			70.09	20.71	10.75	14.92	23.28	12.54	52.41	23.18	16.94	38.75
%EPT taxa			56.15	51.27	35.48	31.64	38.76	37.86	47.06	45.74	38.96	36.15

Appendix 4.2: Mean densities of macroinvertebrates from 5 0.1 m^2 Surber samples for the pre-sampling (M-2 and M-1) and a during treatment stream control (Ms1). Also from 3 30 cm diameter hand net samples taken from each experimental channel (Md1, Mu1, Md2, Mu2) during the nutrient enrichment experiment conducted at Mangpohio stream in summer 2002/2003.

Mayfly	**MCI score**	**Mangapohio**	**M-2**	**M-1**	**Md1**	**Mu1**	**Ms1**	**Md2**	**Mu2**
Deleatidium sp.	8		137.2	423.2	211.66	178.33	554.66	163	106.5
Coloburiscus humeralis	9		0	0	0	0	0	0	0
Nesameletus sp.	9		0	0	0	0	0	0	0
Zephlebia dentata	7		0	0.4	11.33	0.33	6.3	9.66	10
Zephlebia versicolor	7		0	0	0	0.33	0	0	0
Rallidens mcfarlanei	7		0	0	0	0	0	0	0
Neozephlebia scita	7		0	0	0	0	0	0	0
Austroclima sp	9		0	5.4	40.33	9	21.33	1.33	1
Stonefly									
Zelandobius sp.	5		0	0	0	0	0	0	0
Austroperla cyrene	9		0	0	0	0	0	0	0
Stenoperla prasina	10		0	0	0	0	0	0	0
Megaleptoperla diminuta	9		0	0	0	0	0	0	0
Spaniocerca zelandica	8		0	0	0	0	0	0	0
Cased Caddis									
Olinga feredayi	9		0.2	0.2	0	0.3	2	0	0
Oxyethira albiceps	2		0	0	0	0	0	0	0
Paroxyethira hendersoni	2		0	0	0	0	0	0	0
Pycnocentria funerea	7		0	0	0.33	0	0	0	0
Pycnocentria evecta	7		0	0	0	0	0	0	0
Pycnocentria sp.	7		0	0	0	0	0	0	0
Helicopsyche sp.	10		0	0	0	0	0	0	0
Beraeoptera roria	8		0	0	0	0	0	0	0
Hudsonema amabilis	6		1.2	0.4	0	0	0.67	0	0
Triplectides obsoleta	5		0.4	0	0	0	0	0	0
Pycnocentrodes sp.	5		25.6	43	3.66	10	33	6	6.5
Oeconesidae	10		0	0	0	0	0	0	0
Uncased Caddis									
Hydrobiosidae early instar	5		0.4	12.2	17.33	12.33	16.33	12	8
Psilochorema sp.	8		1	7	5	4.33	9	2	4.5
Hydrobiosis parumbripennis	5		0	4.6	0	3	3.67	0.3	2.5
Costachorema xanthoptera	7		0	0	0	0	0	0	0
Neurochorema forsteri	6		0	0	0	0	0	0	0
Hydrobiosis clavigera	5		0.2	0.8	0.67	0.33	0.67	0.33	0.5
Hydrobiosis umbripennis	5		0	0	0.67	0.00	3.00	0.00	0
Aoteopysche sp.	4		1.8	38.8	134.67	175.67	271.67	92.33	132.5
Polyplectropus sp.	8		0	0	0	0	0	0	0
Plectronemia maclachlani	8		0	0	1.67	0	0	0.33	0
Hydrobiosis frater pupae	5		0	0	0	0	0	0	0
Beetle Larvae									
Elimidae	6		35.6	152.6	15	9.33	108	9	10.5
Berosus sp.	5		0	0	0	0	0	0	0
Hydraenidae	8		0	0	0	0	0.33	0	0
Staphylinidae	5		0	0	0	0	0	0	0
Hydrophilidae	5		0	0	0	0	0	0	0
Dytiscidae	5		0	0	0	0	0	0	0
Gyrinidae	5		0	0	0	0	0	0	0
Fly Larvae									
Eriopterini sp.	9		0	0	0	0	0	0	0
Aphrophila neozelandica	5		0.2	0.2	0	0	0.33	0	0
Muscidae Limnophora	3		0	0	0	0.67	0	0	0
Empididae	3		0	0	0	0	0	0.67	0.5
Austrosimulium sp.	3		1	3.2	23.7	8.67	27	7	9.5
Tanyderidae Mischoderus	4		0	0	0.3	0	0	0	0
Paradixa fuscinervis	5		0	0	0	0	0.33	0	0
Limonia sp.	6		0	0	0	0	0	0	0
Molophilus sp.	5		0	0	0	0	0	0	0
Hexatomini sp.			0	0	0	0	0	0	0
Paralimnophila skusei	6		0	0	0	0	0	0	0
Tabanidae	3		0	0	0	0	0	0	0
Ephydrella thermarum	4		0	0	0	0	0	0	0
Psychodidae (Sp2)	1		0	0	0	0	0	0	0
Zelandotipula sp.	6		0	0	0	0	0	0	0
Culicidae	3		0	0	0	0	0	0	0
Chironomidae									
Orthocladiinae	2		3.2	1	6	24.33	0.33	0	0
Tanypodinae	5		0	0	0.33	0	0	0	0
Diamesinae	3		0.6	0	0	0	0	0	0
Sp no 1	3		0	0	0	0	0	0	0
Chironomus sp.	1		0	0.2	19.33	7.33	0	0	0
Chironomidae pupa	3		0.8	0	0.67	2	0	0	0
Orthocladiinae Sp 2	2		1.2	7.2	0	6.33	3	0	0
Corynoneura sp.	2		0	0	3.33	4	0.33	0	0
Tanytarsus sp.	3		0.2	0.2	0.67	3.33	0	0	0
Polypedilum sp.	3		0	0	0	0	0	0	0
Harrisius sp.	6		0	0	0.67	0	0	0	0
Other									
Potamopyrgus sp.	4		0.6	1.2	0	0	2.33	0	0
Physa sp.	3		0	0	0	0.33	0	0	0
Amphipoda sp 2	5		0	0	0	0	0	0	0
Ostracoda	3		0	0.4	21	5.33	0.67	2	1.5
Sigara sp.	5		0	0	0	0	0	0	0
Polycheata	5		0	0	0	0	0	0	0
Small Oligochaete	1		3.2	134	189	422.7	94.33	218.67	432
Medium Oligochaete	1		0.4	1	0	0.0	0.67	0	0
Large Oligochaete	1		0	0.6	0	0.0	1.33	0	0
Platyhelminthe	3		0	0.2	0	0.0	0.33	0.33	0
Nemertea	3		0	0	45.67	30.7	4.67	1.67	3
Archichauliodes diversus	7		0.2	0.2	0	0	0	0	0
Nematoda	3		0	1	0.33	0	1	0	0
Acari	5		0	0.2	0	0	0	0	0
Collembolla	6		0.2	0	0.3	6.33	0.33	0.33	0.5
Hydra sp.	3		0	0	0.3	0.33	0	0	0
Ians Nemertea	3		0	1	0	0	0	0	0
Xanthocnemis sp.	5		0	0	0	0	0	0	0
Veliidae	5		0	0	0	0	0	0	0
Mesoveliidae	5		0	0	0	0	0	0	1.5
Copepoda	5		0	0	0	0	0	0	0
Daphnia sp.	5		0	0	0	0	0	0	0
Neuroptera			0	0	0	0	0.67	0	0
MCI			89.02	91.87	91.25	84.04	90.72	103.22	100.21
QMCI			7.01	6.10	4.60	3.68	5.95	4.19	2.95
Invertebrate abundance			215.4	840.4	754	925.67	1168.3	527	731
Species richness			11.2	16.6	20.7	19.7	20	12.7	14
Margalef's			1.92	2.32	2.96	2.79	2.71	1.87	1.97
%EPT individuals			78.89	65.73	58.04	42.52	78.18	53.42	37.20
%EPT taxa			43.75	50.95	45.58	39.01	46.49	57.64	53.13

Appendix 4.3: Mean densities of macroinvertebrates from 5 0.1 m^2 Surber samples for the pre-sampling (Tt-2 and Tt-1) and a during treatment stream control (Tts2). Also from 3 30 cm diameter hand net samples taken from each experimental channel (Ttd1, Ttu1, Ttd2, Ttu2) during the nutrient enrichment experiment conducted at Triplex tributary in summer 2002/2003.

Mayfly	**MCI score**	**Triplex tributary**	Tt-2	Tt-1	Ttd1	Ttu1	Ttd2	Ttu2	Tts2
Deleatidium sp	8		114.8	101	252	182.33	222.67	246.3	152
Coloburiscus humeralis	9		0.2	0	0	1	0	0	0
Nesameletus sp	9		0	0	0	0	0	0	0
Zephlebia dentata	7		0.4	0.2	2	0.33	0.67	1.33	0.67
Zephlebia versicolor	7		0	0	0.33	0	0	0.33	0
Rallidens mcfarlanei	7		0	0	0	0	0	0	0
Neozephlebia scita	7		0.4	1.6	0.67	0.67	0	0.67	0.67
Austroclima sp	9		0	0	0	0.67	0	0	0
Stonefly									
Zelandobius sp.	5		0.2	0.6	0	0	0	0	0
Austroperla cyrene	9		0	0	0	0	0	0	0
Stenoperla prasina	10		0	0	0	0.33	0	0	0
Megaleptoperla diminuta	9		0	0	0.67	0	0	0	0
Spaniocerca zelandica	8		0	0	0	0	0.33	0	0
Cased Caddis									
Olinga feredayi	9		4.8	6	1.67	4.33	1	1.67	0.67
Oxyethira albiceps	2		0	0	0	0	1	0	0
Paroxyethira hendersoni	2		0	0	0	0	0	0	0
Pycnocentria funerea	7		0	0	0	0	0	0	0
Pycnocentria evecta	7		0.2	1	0.33	0	1	2	0.33
Pycnocentria sp	7		0	0	0	0	0	0	0
Helicopsyche sp.	10		1	0	0	0	0.33	0.33	0
Beraeoptera roria	8		0	0	0	0	0	0	0
Hudsonema amabilis	6		0	0	0	0	0	0	0
Triplectides obsoleta	5		0	0	0	0	0	0	0
Pycnocentrodes sp.	5		3.6	2.2	0.67	0.67	0	0	0.33
Oeconesidae	10		0	0	0	0	0	0	0.33
Uncased Caddis									
Hydrobiosidae early instar	5		3.2	3	5	7.33	4.67	6	0.33
Psilochorema sp.	5		0.6	0.2	0.67	2.33	2	1.33	2
Hydrobiosis parumbripennis	5		0.6	0.2	1.33	0	0.67	1.33	1
Costachorema xanthoptera	7		0	0	0	0	0	0	0
Neurochorema forsteri	6		0	0	0	0	0	0	0
Hydrobiosis clavigera	5		0	0	0.33	0	0	0.33	0
Hydrobiosis umbripennis	5		0	0.2	0	1	0	0	0
Aoteapsyche sp	4		0	0.4	0	0.33	1	0.67	0
Polyplectropus sp.	8		0	0	0	0	0	0	0
Plectrocnemia maclachlani	8		0	0	0	0	0	0.33	0
Hydrobiosis frater pupae	5		0	0	0	0	0	0	0
Beetle Larvae									
Elmidae	6		1.4	3.6	0.33	1.67	1.67	0.67	1.67
Berosus sp	5		0	0	0	0	0	0	0
Hydraenidae	8		2.8	2	2	10.33	1.67	3.67	2
Staphylinidae	5		0	0	0	0	0.33	0	0
Hydrophilidae	5		0	0	0	0	0	0	0
Dytiscidae	5		0	0	0	0.33	0	0	0
Gyrinidae	5		0	0	0	0	0	0	0
Fly Larvae									
Eriopterini sp	9		0	0	0	0	0	0	0
Aphrophila neozelandica	5		0.2	0	0	0.33	0	0	0
Muscidae Limnophora	3		0	0	0	0	0.33	0	0
Empididae	3		0.2	0	0	0	0	0	0
Austrosimulium sp	3		31.8	18.8	3.67	5.33	17.33	16	5
Tanyderidae Mischoderus	4		0	0	0	0	0	0	0
Paradixa fuscinervis	5		0	0	0	0	0.33	0	0
Limonia sp.	5		0	0	0	0	0	0	0
Molophilus sp.	5		0	0	0	0	0	0	0
Hexatomini sp			0	0	0	0	0	0	0
Paralimnophila skusei	6		0	0	0	0	0	0	0
Tabanidae	3		0	0	0	0	0	0	0
Ephydrella thermarum	4		0	0	0	0	0	0	0.33
Psychodidae (Sp2)	1		0	0	0	0	0	0	0
Zelandotipula sp.	6		0	0	0	0	0	0	0
Culicidae	3		0	0	0	0	0	0	0
Chironomidae									
Orthocladiinae	2		4	13.4	0.67	9.33	1.67	1.67	0.33
Tanypodinae	5		0	0.6	0.33	0	0	0	0
Diamesinae	3		0.8	0	0	0	0	0	0.33
Sp no 1	3		0	0	0	0	0	0	0
Chironomus sp	1		0	0.6	0.33	0	0	0	0
Chironomidae pupa	3		1.4	2	0.33	1	0.67	0.67	1
Orthocladiinae Sp 2	2		4	11.2	3	7.67	3.67	4	2.67
Corynoneura sp	2		0	0	0	0	0	0	0
Tanytarsus sp	3		0	0	0	0	0	0	0
Polypedilum sp.	3		0	0	0	0	0	0	0
Harrisius sp	6		0	0	0	0	0	0	0
Other									
Potamopyrgus sp	4		0	2	2.67	2.33	5	2.33	4.7
Physa sp	3		0	0	0	0	0	0	0
Amphipoda sp 2	5		0	0	0	0	0	0	0
Ostracoda	3		0	0	0	0	0.33	0	0
Sigara sp.	5		0	0	0	0.33	0	0	0
Polycheata	5		0	0	0	0	0	0	0
Small Oligochaete	1		0.4	2.8	5	3.67	22.67	2.33	5.33
Medium Oligochaete	1		0.2	0	0	0	0.33	0	1
Large Oligochaete	1		0.2	0.4	0	0	0	0	0
Platyhelminthe	3		3.2	4.4	0.67	0.67	0.33	0.67	2
Nemertea	3		0	0	0	0	0.67	0	0
Archichauliodes diversus	7		0.6	0.4	0	0	0	0.67	1
Nematoda	3		0	0	0	0.33	1	0	0
Acari	5		0	0	0.33	0.33	0.33	0.67	0.33
Collembola	6		0	0	0	0.67	0	0	0.33
Hydra sp	3		0	0	0	0	0	0	0
lans Nemertea	3		0.2	0	0	0	0	0	0
Xanthocnemis sp	5		0	0	0	0	0	0	0
Veliidae	5		0	0	0	0	0	0.33	0
Mesoveliidae	5		0	0.4	0.67	0.67	0.33	0	0
Copepoda	5		0	0	0	0	0	0	0
Daphnia sp.	5		0	0	0	0	0	0	0
Neuroptera			0	0	0	0	0	0	0
MCI			101.05	90.35	104.99	106.66	91.41	106.27	105.16
QMCI			6.55	6.22	7.57	7.15	6.76	7.40	7.18
Invertebrate abundance			181.4	179.2	285.67	246.33	294	296.33	188.33
Species richness			14.4	13.4	15	19.33	18.33	17.33	14.33
Margalef's			2.80	2.40	2.47	3.34	3.05	2.87	2.61
%EPT individuals			71.12	66.57	92.97	81.45	78.97	88.81	83.41
%EPT taxa			43.64	35.74	48.50	43.44	39.84	46.41	39.67