# CHARACTERISATION OF HAWKES BAY RIVERS BASED ON BIOTIC COMMUNITIES

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fulfilment of the requirements
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# ABSTRACT

Environmental data, aquatic macroinvertebrates and periphyton were sampled in 52 rivers throughout Hawkes Bay primarily between January and March, 1995. The 97 invertebrate taxa collected comprised predominantly Trichoptera (27), Ephemeroptera (17), Diptera (11) and Coleoptera (10). 49 periphyton taxa were collected which comprised of 30 diatoms, 10 Green algae and 9 Blue-Green algae. An ordination of sites by macroinvertebrate data using Detrended Correspondence Analysis (DECORANA) produced two interpretable axes. Axis 1 was correlated with measures reflecting terrain, land use and nutrient levels. Axis 2 was correlated with measures of periphyton abundance. DECORANA analysis of periphyton indicated pH had most influence over community structure, with measures of periphyton abundance, leaf litter, and water colour (absorbance at 440nm) having a secondary influence. Classification of macroinvertebrate communities using Two-Way Indicator Species Analysis (TWINSPAN) produced six groups. Sites within each group were generally found to fall into restricted areas of Hawkes Bay and these are suggested as bioregions. Each bioregion is described and could be used as a management unit by appropriate organisations. Analysis of periphyton with TWINSPAN classified sites into seven groups, but no geographical pattern was evident.

Direct analysis of environmental variables and macroinvertebrate taxa using Canonical Correspondence Analysis (CANOCO) indicated that gradient, altitude, substrate size, conductivity, $SO_4$ and K had most influence over macroinvertebrate communities. Two widely used biotic indices of water quality (MCI and EPT) were strongly positively correlated with several chemical variables and negatively correlated with substrate related factors so it was difficult to know if macroinvertebrates were responding to water quality or physical features. Ranking taxa by their CANOCO axis scores is suggested as a way of recalibrating taxa MCI scores for a region and assigning appropriate MCI scores to new taxa.

The bioregions generated from the TWINSPAN analysis of macroinvertebrates are compared to an existing New Zealand-wide ecoregion classification and also to ecoregions developed from a cluster analysis of six climatic and geomorphological factors of the 52 sites in Hawkes Bay. Little correlation was found between the bioregions and the cluster analysis, however some similarity between bioregions and the existing ecoregion classification was found, and the bioregions are suggested as possible "subecoregions".

Environmental data and macroinvertebrates were also sampled in nine sites on each of two major Hawkes Bay rivers to look at longitudinal patterns in macroinvertebrate communities. Both rivers exhibited a zonation pattern rather than a continuum, and the zonation is related to degree of human disturbance.

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The macroinvertebrate pictures on the title pages for each chapter are copied from Winterbourn and Gregson (1989).

# TABLE OF CONTENTS

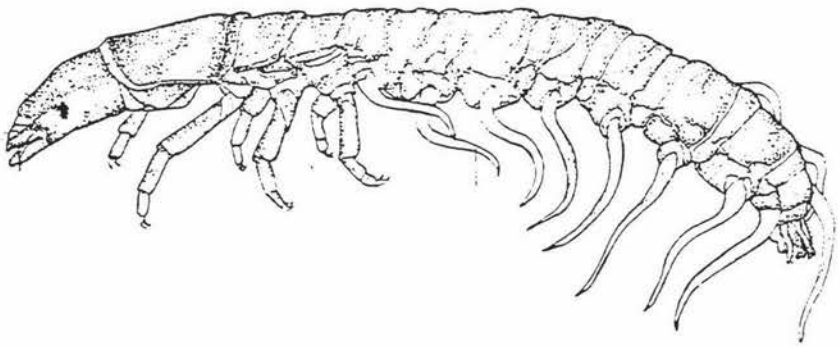
# LIST OF TABLES

# LIST OF FIGURES

# LIST OF PLATES

# CHAPTER 1:

# INTRODUCTION



# CHAPTER 1:

## INTRODUCTION

There has been an increasing recognition of the need and usefulness of biological monitoring, surveillance and surveys of aquatic systems to assess water quality (Roper, 1985; Carter, 1985), particularly with the implementation of the Resource Management Act 1991. There are several benefits to studying the distribution of the biota on a regular basis:

(1) Because the biota act as integrators of the physical and chemical characters of the water, the species and their condition observed one day give a summation of the environmental history;

(2) The biota is sensitive to intermittent discharges which may be missed by chemical or physical surveillance;

(3) By moving upstream until no effect is found, it may be possible to locate the source of an illicit discharge, or one violating its water right;

(4) The biota responds to new or unsuspected pollution caused by substances which may not have been known to be present, or unsuspected synergistic effects caused by combinations of chemicals (Roper, 1985).

Water management authorities such as Regional Councils, have looked to manage the water bodies in their jurisdiction at a catchment level. However, because rivers flow through diverse landforms, it has often been difficult for workers to predict distributional patterns of biotic communities and to apply any predictions reached to other river catchments (Corkum, 1989). For this reason, there may be a need for management authorities to look for patterns that occur across river catchments (e.g. Wright et al., 1984; Moss et al., 1987; Corkum, 1989).

A biological survey of a region may detect patterns in distribution of biotic communities. This, in turn, can lead to attempts to classify the aquatic communities based on their relative homogeneity. A regional water classification based on the biological communities can provide a useful framework for studying and managing streams in different geographical areas by allowing investigations into how biological communities interact with their environment, and also to assess the effect of changes that occur across large geographical areas (Whittier, 1988; Harding, 1994).

This thesis investigates spatial patterns in macroinvertebrate and periphyton communities in Hawkes Bay rivers and streams, and identifies the main causal factors of these patterns.

The second and third chapters of this thesis present the findings from the survey of 52 sites sampled in Hawkes Bay. Chapter 2 focuses on the macroinvertebrate communities, and the results of the first regional classification based on macroinvertebrates are presented in this chapter. The third chapter repeats this analysis but with periphyton communities of the same sites.

Chapter 4 looks at two of the main rivers of Hawkes Bay and seeks to identify longitudinal patterns that occur within each of these rivers along their main branch. The main factors causing these changes are investigated and differences occurring between the two rivers are discussed.

Multivariate analyses are capable of condensing data sets of many variables to pick out the important patterns. There are two broad categories of analysis. Firstly, techniques that divide samples into discrete sets based on their comparative similarities (or dissimilarities) are known as classification techniques. Two-Way INdicator SPecies ANalysis (TWINSPAN) which is used in Chapter 2 to classify sites and provide the basis for the bioregions is a classification technique and has been used in numerous studies of freshwater communities (e.g. Wright et al., 1984; Ormerod and Edwards,

1987; Quinn and Hickey, 1990a; Harding, 1994; Collier, 1995). The alternative multivariate analyses take all samples and arrange them into patterns, again reflecting the degree of similarity or difference. Such patterns can be spread along several axes, the coordinates being a relative measure of the similarities (Jeffries and Mills, 1990). These are called ordination techniques. DEtrended CORrespondence ANAlysis (DECORANA), used in Chapters 2 and 3 is an example of this type of technique. In Chapter 5 I use a relatively recently developed ordination technique called Canonical Correspondence Analysis (CCA) to relate the composition of the macroinvertebrate communities to their environment (ter Braak, 1988). CCA escapes the assumption of linearity and is able to detect unimodal relationships between taxa and external variables. The advantage of CCA over other techniques is it looks directly at sites, species and environmental variables to detect patterns and greatly improves the power to detect the specific effects one is interested in (ter Braak, 1988). Patterns of invertebrate distribution are usually related to physico-chemical factors, and the value of classification and ordination techniques for exploring this relationship has been apparent for some time (Wright et al., 1984; Jenkins et al., 1984; Hawkes, 1975).

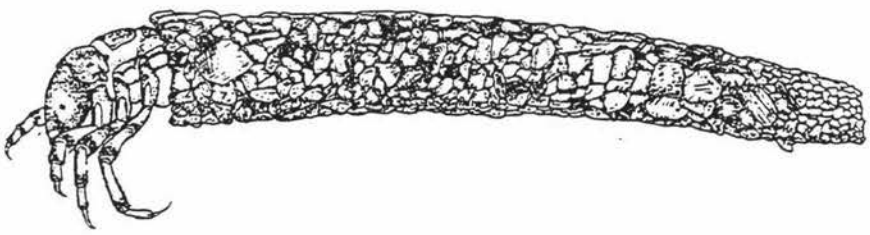
A number of biological monitoring indices using benthic macroinvertebrates to reflect water quality have been developed over the last decade or so (Wright et al., 1984; Jeffries and Mills, 1990). Most indices combine the presence or absence of taxa, their abundance and some weighting, based on tolerance to pollution, to arrive at a numerical score. In Chapter 5 I use CCA to test the validity of two of these indices; the MCI (Stark, 1985) and EPT (Lenat, 1988).

Because Chapter 2 produces some interesting findings and raises some interesting questions on ecoregions, in Chapter 6 the question of how ecoregions are defined and the results of the different types of techniques is explored. It is important that the method used to define ecoregions is accurate and robust, as the development of a river classification system within an ecoregion framework has enormous potential for biologists, conservators, and water managers (Harding, 1994).

This project was initiated by the Hawkes Bay Regional Council in order for them to better manage and conserve the aquatic communities present within their region. It is hoped that the findings of this thesis will provide effective baseline data which the Hawkes Bay Regional Council can use to help manage their aquatic communities, and as time goes by, validate, refine, and improve upon the findings presented here.

# CHAPTER 2:

# CHARACTERISATION OF HAWKES BAY RIVERS AND STREAMS BASED ON BENTHIC MACROINVERTEBRATES



# CHAPTER 2:

# CHARACTERISATION OF HAWKES BAY RIVERS AND STREAMS BASED ON BENTHIC MACROINVERTEBRATES

## 2.1. INTRODUCTION

Aquatic macroinvertebrates are normally abundant and important components of river ecosystems and are commonly used for the assessment of water quality. Individual species have different habitat preferences or tolerances, and consequently, the community present in a given situation reflects its environment (Stark, 1993).

Concern has increased in recent years that provisions are not being made for resident biota when allocating flows to rivers (Biggs, 1990). In 1991 the Resource Management Act 1991 was enacted and emphasised the need for monitoring to meet the purposes of the Act (Berry, 1995). The objectives of the Act are:

(1) Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations;
(2) Safeguarding the life supporting capacity of air, water, soil and ecosystems; and
(3) Avoiding, remedying, or mitigating any adverse effects of activities on the environment.

The range of aquatic habitats present within a Regional Councils boundaries will be very diverse and may require different monitoring and management actions. A useful preliminary step is to see if particular types of aquatic communities are associated with

particular geographic areas or "bioregions". Each bioregion will have particular natural values and threats and could be treated as a management unit. The term "bioregion" is used in this chapter because regions are constructed directly from analysis of biological sampling of communities. "Ecoregion" is used to describe a geographic pattern of climatic and geomorphological variables that are assumed to be major determinants of biological communities. Both approaches can be seen in terms of testing a hypothesis: in the case of ecoregions (e.g. Harding, 1994), a regional pattern of climate and geomorphology establishes the ecoregions and these are tested by looking for matching patterns of biodiversity or community structure. In the case of bioregions, groups of similar communities are established and these are tested by looking for regional patterns and/or correlations with climate and geomorphology.

Over the past few decades there have been numerous attempts at classifying lotic freshwater systems into ecoregions. Early attempts aimed to classify rivers on the basis of the dominant fish species present (e.g. Burton & Odum, 1945), but aquatic macroinvertebrates have found increasing use in classifications. Ecoregions are defined to be regions of relative homogeneity in ecological systems or in relationships between organisms and their environments (Omernik, 1987).

In the United States ecoregions have been established extensively and have been defined at several hierarchical levels, with continued development continuing in some states and in the planning stage in others (Omernik & Griffith, 1991). In the early to mid 1980's extensive work was also carried out in the United Kingdom and the use of biological collections, particularly macroinvertebrates, to describe spatial patterns in rivers and streams has become well established (Jenkins et al., 1984).

In New Zealand, the first nation-wide perspective on water quality and biology of rivers using a consistent methodology was known as "The 100 Rivers Project" (Biggs et at.,

1990). This project aimed to characterise, classify and model New Zealand rivers according to hydrological, water quality and biological properties. It was hoped that the project would provide managers with robust models for predicting the effect of changes in flow regimes and catchment land use on aquatic biota (Biggs et al., 1990). As part of this project, Quinn & Hickey (1990a) aimed to group rivers according to their macroinvertebrate communities and investigate the relationships between macroinvertebrate communities and selected environmental factors.

An alternative approach to distinguishing ecoregions was adopted by Harding (1994). He developed ecoregions based on six macro-environmental variables (climate, geology and landforms). The water chemistry and benthic communities of streams considered to be characteristic of these ecoregions were then sampled to see if they matched up with the ecoregions generated with the macro-environmental variables. He found the forested ecoregions had distinctive macroinvertebrate communities, but the pastoral ecoregions had similar macroinvertebrate assemblages. Water chemistry distinguished less successfully between ecoregions.

Previous studies have indicated some regional variation in New Zealand such as greater diversity of Ephemeroptera (Mayflies) in the north of the North Island (Summerhays, 1983; Towns, 1983) and more Plecoptera (Stoneflies) in Westland (Cowie, 1980; Collier and Winterbourn, 1987). However, it appears that in New Zealand, ecoregions based on macroinvertebrates are not so clearly defined as in some areas of the continental North America (e.g. Tate and Heiny, 1995)(Quinn and Hickey, 1990a). Similarly, Biggs (1990) could not readily distinguish ecoregions based on periphyton, however he did manage to identify eight distinctive periphyton communities. Nevertheless, when all of the biotic and environmental characteristics were used, five principle ecoregions were distinguished in New Zealand by Biggs et al. (1990).

In terms of management of rivers on a regional level, the scale of these ecoregions identified by Biggs et al., (1990) is too broad because there is too much heterogeneity within them. Therefore, the major aim of this chapter is to attempt to classify Hawkes Bay rivers and streams into bioregions, if possible, or else to identify areas and aquatic communities of interest for management purposes.

## 2.2. STUDY SITES

52 sites on 16 different Hawkes Bay river catchments were sampled. 47 of the sites corresponded with Hawkes Bay Regional Council (HBRC) water quality sampling sites. The sites were chosen to cover a wide range of catchment types, land use, altitudes, and river sizes. Fig. 2.1 shows the location and name for each site.

## 2.3. METHODS

### 2.3.1. Data Collection

*Invertebrates*

Sites were sampled from 12th January 1995 to 22nd March 1995 during summer and early autumn low flows (except sites 56 and 57, sampled on 8th June 1995). Three replicate samples were taken in a transect across the river or stream using a standard 'kick'-sampler (mesh size 280μm). If the river was too deep or dangerous to cross to the other side for sampling, then the replicates were taken progressively up the river. For each replicate the substrate was kicked for 30 seconds. Where possible, all sampling took place in riffle habitat, but if riffles weren't available the sampling was in runs. For sites 22 and 48 there was no discernible water movement so the net was swept around at the bottom of the river for 30 seconds. Samples were preserved in 70% ethanol.

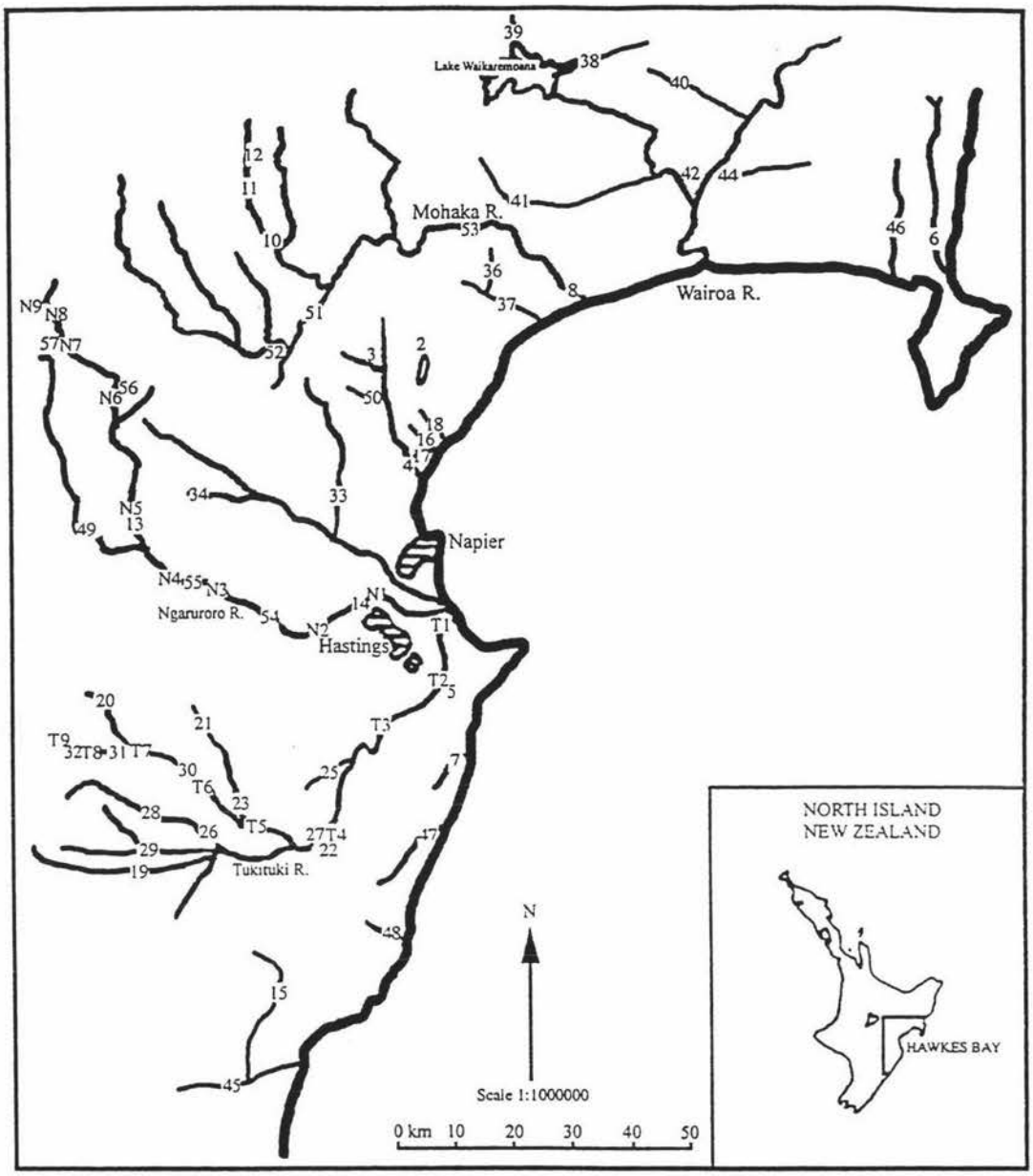



Fig. 2.1. Location of study sites and major river catchments in Hawkes Bay. N1 - N9 designate Ngaruroro River longitudinal sites. T1 - T9 designate Tukituki River longitudinal sites.

2 Sandy Ck
3 Esk R. at Berry Rd bridge
4 Esk R. at Ellis Wallace Rd
5 Maraetotara Rd
6 Kopuawhara R.
7 Pohukio Stm.
8 Mohaka R.
10 Mokomokonui R.
11 Waiarura Stm.
12 Waipunga R.
13 Ngaruroro R. at Kuripapango
14 Ngaruroro R. at Fernhill
15 Porangahau R.
16 Pakuratahi Stm.
17 Tamingimingi Stm.
18 Te Ngaru R.
19 Makaretu R.
20 Makaroro R.
21 Mangamata Stm.
22 Mangamohaki Stm.
23 Mangaonuku Stm.
25 Papanui Stm.
26 Tukituki R. at Ongaonga Waipukurau Rd
27 Tukituki R. at Tamumu Bridge
28 Tukituki R. at Highway 50
29 Tukipo R.
30 Waipawa R. at Highway 50
31 Waipawa R. Wakarara Rd Bridge
32 Waipawa R. at North Block Rd
33 Mangaone R.
34 Tutaekuri R.
36 Anaura Stm.
37 Waikari R.
38 Aniwaniwa R.
39 Hopuruahine R.
40 Ruakituri R.
41 Waiau R.
42 Te Iringaowhara Stm.
44 Mangapoike R.
45 Mangaorapa Stm.
46 Nuhaka R.
47 Mangakuri R.
48 Ikanui R.
49 Taruarau R.
50 Deep Stm.
51 Mohaka R. at Highway 5
52 Makahu Stm.
53 Mohaka R. at Willowflat
54 Ngaruroro R. at Omapere
55 Ngaruroro R. at Whanawhana
56 Rocks Ahead Stm.
57 Gold Ck.

### *Periphyton*

Periphyton was sampled from the 12th January 1995 to 22nd March, 1995 during summer and early autumn low flows (except site 57, sampled on 8th June, 1995). On rivers wider than 3 m, five stones were randomly selected at equally spaced points across the rivers. If the river was less than 3 m wide then three stones were taken.

An area of 0.00159$m^2$ (i.e., a circle of diameter 45 mm) was thoroughly scraped into a pottle of water using a knife or scalpel. The pottles were then kept chilled until they could be stored frozen. Samples were sent to the National Institute of Water and Atmospheric Research Ltd. (NIWA) for analysis.

### *Environmental Data*

Physical and chemical data to complement the species lists for each site were obtained from a variety of sources. Table 2.1 lists the environmental variables used together with their units and abbreviations used in later chapters. Altitude and gradient were determined from 1:50000 NZMS maps. Because most of the sites correspond to regularly sampled water quality sites, most of the chemical and hydrological data was obtained from the Hawkes Bay Regional Council (HBRC). The data supplied by the council was converted to the mean over summer for ease of analysis. Additional information was collected while in the field as follows:

Dissolved oxygen was measured using a YSI model 58 dissolved oxygen meter. An Orion model 122 conductivity meter was used to measure conductivity and water temperature. Depth was measured at five evenly spaced points along a transect across the river. These five measurements were then averaged. Width was recorded along the same transect used for depth. Stability was measured using the method developed by

Pfankuch (1975). Land use, canopy cover, leaf litter and periphyton cover were all visually assessed.

Table 2.1. Environmental variables used in the analysis together with their units and abbreviations used in later tables and figures. n.a. = not applicable

| Environmental Factor | Units | Abbreviation |
|---|---|---|
| Altitude | m | ALT |
| Gradient | degrees | G |
| Current Velocity | $m\ s^{-1}$ | CV |
| Mean Depth | cm | D |
| Mean Width | m | W |
| Canopy Cover | % | CAN |
| Leaf Litter | % | LL |
| Land Use near site | n.a. | LUNS |
| Periphyton Cover | % | PERI |
| Stability Score | n.a. | STAB |
| Substrate Index | n.a. | SI |
| Conductivity | $\mu S\ cm^{-1}$ | COND |
| Water Temperature | $^0C$ | WT |
| Dissolved Oxygen | ppm | DO |
| pH | n.a. | pH |
| Alkalinity | $mg\ CaCO_3\ l^{-1}$ | ALK |
| Chloride | $mg\ l^{-1}$ | $CL^-$ |
| Sulphate | $mg\ l^{-1}$ | $SO_4$ |
| Hardness | $mg\ l^{-1}$ | HARD |
| Magnesium | $mg\ l^{-1}$ | Mg |
| Calcium | $mg\ l^{-1}$ | Ca |
| Sodium | $mg\ l^{-1}$ | Na |
| Potassium | $mg\ l^{-1}$ | K |
| Turbidity | NTU | TURB |
| Total Phosphorous | $mg\ l^{-1}$ | TP |
| Nitrogen | $mg\ l^{-1}$ | $NO_3$ |
| Ammonia | $mg\ l^{-1}$ | $NH_4$ |
| Suspended Solids | $mg\ l^{-1}$ | SS |
| Black Disk visibility | m | BD |
| Bicarbonate | $mg\ l^{-1}$ | BICAR |
| Total Nitrogen | $mg\ l^{-1}$ | TN |
| Ash-Free Dry Weight of Periphyton | $g\ m^{-2}$ | AFDM |
| Chlorophyll a | $mg\ m^{-2}$ | Chl a |
| Macroinvertebrate Community Index | n.a. | MCI |

Substrate sediment composition was visually assessed as the percentage cover by the following size categories: silt (<0.063mm); sand (0.063 - 2mm); gravel (2 - 60mm); small cobble (60 - 120mm); large cobble (120 - 260mm); boulders (>260mm); and bedrock. To aid statistical analysis of the substrate data, field size assessments were transformed into a single index by summing weighted substrate percentages following Jowett and Richardson (1990) and Jowett et al. (1991).

Substrate Index = 0.08 boulders % + 0.07 large cobbles % + 0.06 small cobble % + 0.05 gravel % +0.04 sand % + 0.03 silt %.

This gives a number between 3 and 8, larger values representing larger particle sizes.

### 2.3.2. Laboratory Procedures

*Invertebrates*

In the laboratory the invertebrates were split into three size classes by sieving through 4, 0.5, and 0.25mm mesh sieves. Taxa with abundance's below 200 individuals per sample in each size class were identified and counted. Taxa with abundance's greater than 200 individuals were randomly sub-sampled using a tray divided into sections.

Invertebrate identifications followed Chapman and Lewis (1976) (Crustacea), Winterbourn (1973) (Mollusca), and McFarlane (1951), Towns and Peters (1996), and Winterbourn and Gregson (1989) (Insecta). Most invertebrates could be identified to species or genus level, but many dipteran larvae could only be identified to family level and Oligochaeta were not identified below class.

*Periphyton*

Samples were processed by NIWA for measurement of chlorophyll *a* content and ash-free dry mass (AFDM) as follows.

The sample was homogenised using a hand held kitchen blender and made up to a known volume. Sub-samples of known volume were taken from this solution and filtered on to fibre-glass filters, one sample for chlorophyll *a*, and one for AFDM. To ensure representative sub-sampling the solution was shaken thoroughly before removal of each aliquot. For chlorophyll *a*, the pigment was extracted in boiling 90% ethanol and the chlorophyll concentration measured using spectrophotometry. For AFDM, the sub-sample was dried at 105°C for 24 hours, weighed then ashed at 400°C for 4 hours and re-weighed. The results are presented in terms of mg $m^{-2}$ chlorophyll *a* and g $m^{-2}$ AFDM. For further details see Biggs (1987).

### 2.3.3. Data Analysis

*Diversity Indices*

The total number of individuals captured and three diversity indices were calculated. These were Margalef's index (Margalef, 1968), the Berger-Parker dominance index (Berger and Parker, 1970), and the Simpson diversity index (Simpson, 1949). Margalef's index is a measure of species richness, while the other two are measures of evenness. The Berger-Parker and Simpson indices were expressed as reciprocals so that in all indices, an increase in the index indicates an increase in diversity.

Macroinvertebrate Community Index (MCI) scores were also calculated, following Stark (1993). An MCI score of greater than 120 indicates high water quality, while a

score of less than 100 indicates poor water quality. Seven species to which Stark (1993) had not assigned scores were excluded from this analysis.

***Classification and Ordination***

The sites were classified into groups using data on densities of invertebrate taxa using two-way indicator species analysis (TWINSPAN) (Hill, 1979a) and ordinated by detrended correspondence analysis (DECORANA) (Hill, 1979b). Pseudo-species cut levels for use in TWINSPAN were 1, 10, 100 and 1000 per sample. Rare taxa were downweighted to reduce their influence in the classifications and ordinations.

Classification by TWINSPAN arranges sites into a hierarchy on the basis of the differences in densities of taxa between sites. Taxa are simultaneously classified according to their abundance in the site groups. Those taxa showing the greatest differences in abundance between the site groups are also identified as indicators (Quinn and Hickey, 1990a). The TWINSPAN classification of sites was stopped at level 5 beyond which classes contained few sites and differences were relatively small.

DECORANA arranges sites in four dimensional space, those with similar composition occurring most closely together. Pearson correlations between DECORANA axes 1 and 2, and environmental variables were used to investigate relationships with invertebrate community composition.

Pearson correlations were also investigated between various biotic variables, including the diversity indices, and all of the environmental variables measured. Data was transformed where appropriate using log or arcsine square root (for percentage variables) transformations to give approximately normal distributions.

## 2.4. RESULTS

### 2.4.1. Taxonomic Composition of Invertebrate Communities

A total of 97 taxa were identified from the 52 sites. The majority of these were aquatic insects (79), and of these most belonged to the orders Trichoptera (27), Ephemeroptera (17), Diptera (11), Coleoptera (10) and Plecoptera (8). Of the non-insects, Mollusca provided most taxa (7), followed by Crustacea (6).

Some of the rarer species found included the mayfly *Austronella planulata*, (Towns and Peters, 1996) two specimens of a caddis from the families Ecnomidae or Psychomyidae, several Lepidopteran larvae (*Hygraula nitens*), two unidentified caddisflies (possibly *Traillochorema* sp.) and a rare freshwater polychaete from the family Nereidae was found at several sites.

The mean number of taxa per site was 17. The highest taxonomic richness was recorded from a stable, native forest river (Site 38:31 taxa), with more than 20 taxa being recorded from 16 sites which represent a range of channel sizes and environmental conditions. Ten or fewer taxa were recorded at 6 sites (Sites 14, 15, 22, 32, 45 and 47) which generally had fine substrate and are located on farmland. The MCI averaged 113, with 13 sites having a score of greater than 130 and 6 sites less than 80. Lowland and coastal sites had lower MCI scores indicating poor water quality. Sites with high MCI scores tended to be at medium-high altitude and fairly stable.

The most widespread taxa were Elmidae and Chironomidae larvae which were found at 48 sites, followed by *Deleatidium* sp. at 44 sites, and *Aoteapsyche* sp. and *Pycnocentrodes* sp. were collected at 40 sites. Twenty-nine taxa were collected at only one site.

### 2.4.2. Ordination of Sites

The site scores on DECORANA Axes 1 and 2 are shown in Fig. 2.2. Axis 1 explained 55.7% of the variation. The combination of Axes 1 and 2 explained 77.9% of the variation.

DECORANA axis 1 is strongly correlated with invertebrate diversity measures, the MCI and many chemical measures of water quality. Axis 1 can thus be interpreted as a measure of water quality, also correlated with altitude, gradient and substrate size, reflecting the fact that inland, mountain rivers in Hawkes Bay are less modified than the lowland coastal sites. Axis 2 reflects variation in periphyton abundance that is independent of water quality (Fig. 2.2).

Examination of the Axis 1 loadings suggest a trend of increasing dominance by molluscs crustacea, diptera and other slow water or pollution tolerant taxa. Of the common invertebrate taxa, the most highly correlated with axis 1 is the snail, *Potamopyrgus*.

Axis 2 loadings did not suggest any simple interpretation in terms of invertebrate taxa. The caddis fly *Olinga* was the most highly correlated common taxon.

### 2.4.3. Correlations Between Biotic and Environmental Variables

Pearson correlation's were used to explore the inter-relationships amongst biotic variables and between biotic and environmental variables (Table 2.2).

Periphyton variables (AFDM, Chl a, periphyton cover and taxonomic richness) are mostly correlated with each other, and with Axis 2. Measures of invertebrate diversity are also strongly inter-correlated, but not with periphyton variables. Axis 1 and MCI

correlate with the same variables, these being altitude, gradient, substrate size and a number of chemical variables.

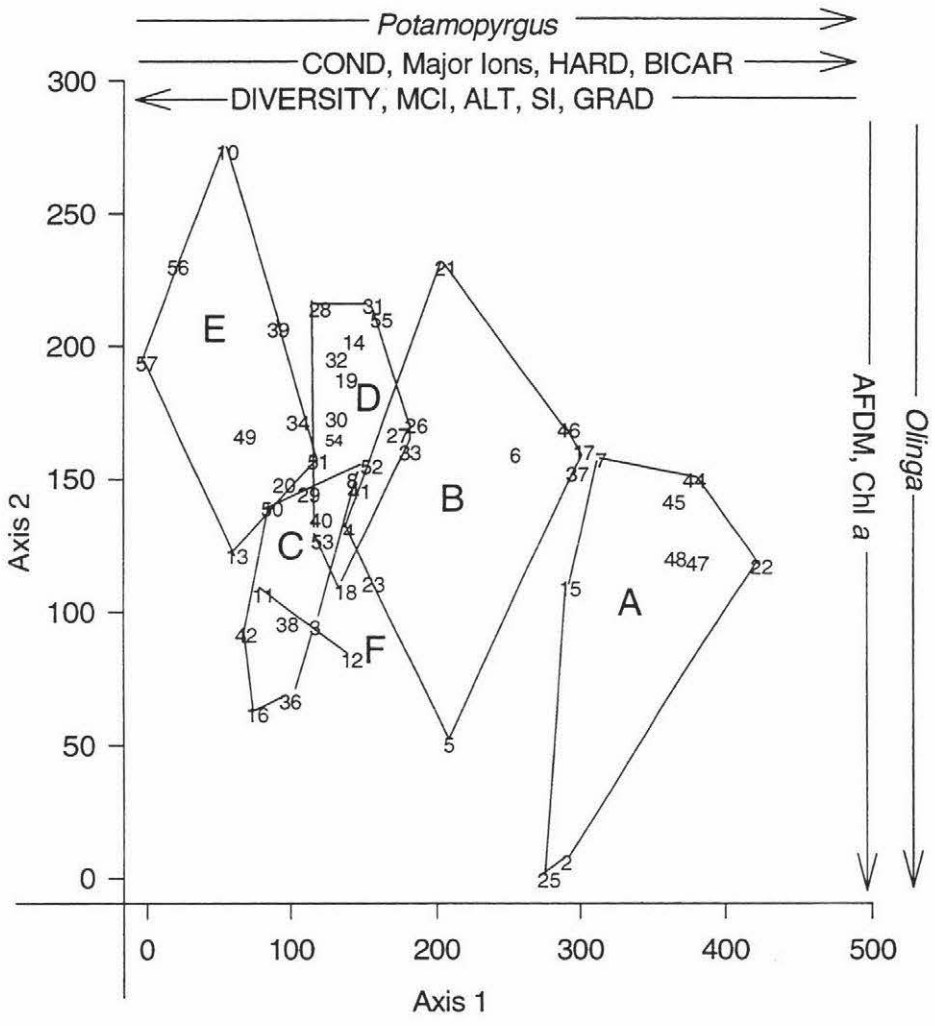



Fig. 2.2. Ordination along the two main DECORANA axes of the 52 rivers. The relationship of the environmental variables significantly correlated with DECORANA axes (see Table 2.2) is indicated. Polygons enclose all sites in each TWINSPAN group (see Fig. 2.3).

Table 2.2 Matrix of Pearson correlation coefficients. Significance levels are corrected for multiple comparisons by the Bonferroni method. n = 52. n.s., not significant; *, P<0.05; **, P<0.01; ***, P<0.001. Variable names and units as for Table 1. ITR = Invertebrate Taxonomic Richness; PTR = Periphyton Taxonomic Richness; MAR = Margelef's Index; IBP = Inverse Berger Parker Diversity Index; ISIMP = Inverse Simpson Diversity Index.

Biotic Variables

| | AFDM | Chl *a* | ITR | PTR | PERI | MAR | IBP | ISIMP | MCI | AXIS 1 | AXIS 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AFDM[b] | | | | | | | | | | | |
| Chl *a*[b] | 0.80*** | | | | | | | | | | |
| ITR | n.s. | n.s. | | | | | | | | | |
| PTR | n.s. | 0.61** | n.s. | | | | | | | | |
| PERI[a] | 0.60** | 0.56* | n.s. | n.s. | | | | | | | |
| MAR | n.s. | n.s. | 0.92*** | n.s. | n.s. | | | | | | |
| IBP | n.s. | n.s. | n.s. | n.s. | n.s. | 0.51* | | | | | |
| ISIMP | n.s. | n.s. | 0.58** | n.s. | n.s. | 0.63*** | 0.94*** | | | | |
| MCI | n.s. | n.s. | 0.52* | n.s. | n.s. | 0.59** | n.s. | n.s. | | | |
| AXIS 1 | n.s. | n.s. | -0.57** | n.s. | n.s. | -0.61*** | -0.51* | -0.55** | -0.88*** | | |
| AXIS 2 | -0.58** | -0.57* | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | |
| ALT | n.s. | n.s. | n.s. | n.s. | n.s. | 0.53* | n.s. | n.s. | 0.60*** | -0.58** | n.s. |
| GRAD[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | 0.60*** | -0.54* | n.s. |
| DEPTH[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| WIDTH[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| CAN[a] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| COND[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | -0.60** | 0.63*** | n.s. |
| TEMP | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| LL[a] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| DO | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| pH | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| STAB | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| SI | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | 0.60*** | -0.68*** | n.s. |
| ALK[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | -0.61** | 0.59* | n.s. |
| $Cl^{-}$[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | -0.62** | 0.71*** | n.s. |
| $SO_4$[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | -0.66*** | 0.67*** | n.s. |
| HARD[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | -0.61** | 0.63** | n.s. |
| Mg[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | -0.60** | 0.64** | n.s. |
| Ca[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | -0.61** | 0.62** | n.s. |
| Na[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | -0.61** | 0.70*** | n.s. |
| K[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | -0.57* | 0.60** | n.s. |
| TURB[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| TP[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| $NO_3$[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| $NH_3$[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| SS[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| BD[b] | n.s. | n.s. | 0.67** | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| BICAR[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | -0.60** | 0.57* | n.s. |
| TN[b] | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | -0.67** | n.s. | n.s. |

[a] Arcsine square root transformed [b] Log transformed

### 2.4.4. Classification of Sites

The TWINSPAN analysis separated the invertebrate data into six groups at the fifth level of division (Fig. 2.3).

The first level of division separated group A from the other groups with the main indicator species of group A being *Potamopyrgus(2)*[1], while for the other groups the best indicator species were *Aoteapsyche(1)*, *Psilochorema(1)*, *Deleatidium(2)*, *Olinga(1)* and *Pycnocentrodes(1)*. Group B was separated from groups C to F at level 2 with Ostracoda(1) and *Potamopyrgus(2)* being identified as indicator species for group B and *Coloburiscus(1)* and *Olinga(1)* separating the other groups. Level 3 separated group C with *Hudsonema(1)*, *Pycnocentria(2)* and *Zephlebia dentata(1)* being the indicator species. Groups D and E are separated from group F at level 4. The caddisfly *Aoteapsyche(1)* was the indicator species for this separation. The fifth level of division separates groups D and E with the indicator species being *Beraeoptera(1)* and *Zelandoperla(1)*.

All, or nearly all, of the sites within each group fall into a particular geographical area of Hawkes Bay. The proposed bioregions for Hawkes Bay based on these groups are shown in Fig. 2.4.

The environmental factors characteristic of the TWINSPAN groups are described below (also see Table 2.3).

**Group A** These 9 sites score low on the diversity indices and MCI. They are low altitude, higher temperature sites that had small substrate sizes and low stability[2]. Nutrient concentrations tended to be high. These sites are located near the coast (Fig. 2.4) with the only outlier in this Group being Site 25.

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[1] The number in brackets after each taxon name represents the pseudospecies (abundance) cut level.
[2] The higher the STAB score, the lower the stability.

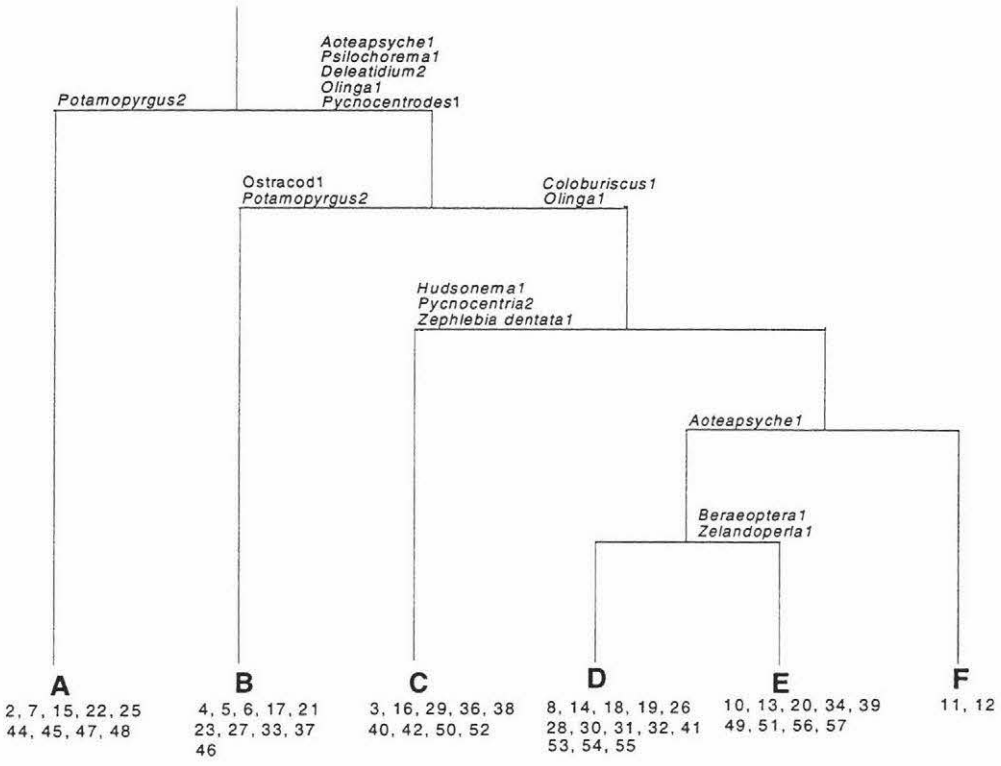



Fig. 2.3. TWINSPAN dendrogram showing the classification of the 52 Hawkes Bay sites. Indicator species that were particularly diagnostic of each division are shown.

**Group B** These 10 sites also had low mean altitudes and high mean temperatures. Alkalinity, Ca, and bicarbonate were moderate. They have medium MCI scores and number of species. The sites in this group are generally located immediately inland from Group A (Fig. 2.4).

**Group C** These 9 medium altitude sites had high percentage periphyton cover, stability and diversity. Substrate size tended to be large cobble. Group C's sites are located in the northern half of Hawkes Bay, immediately inland from ecoregion B (Fig. 2.4). Sites 16 and 29 are outliers.

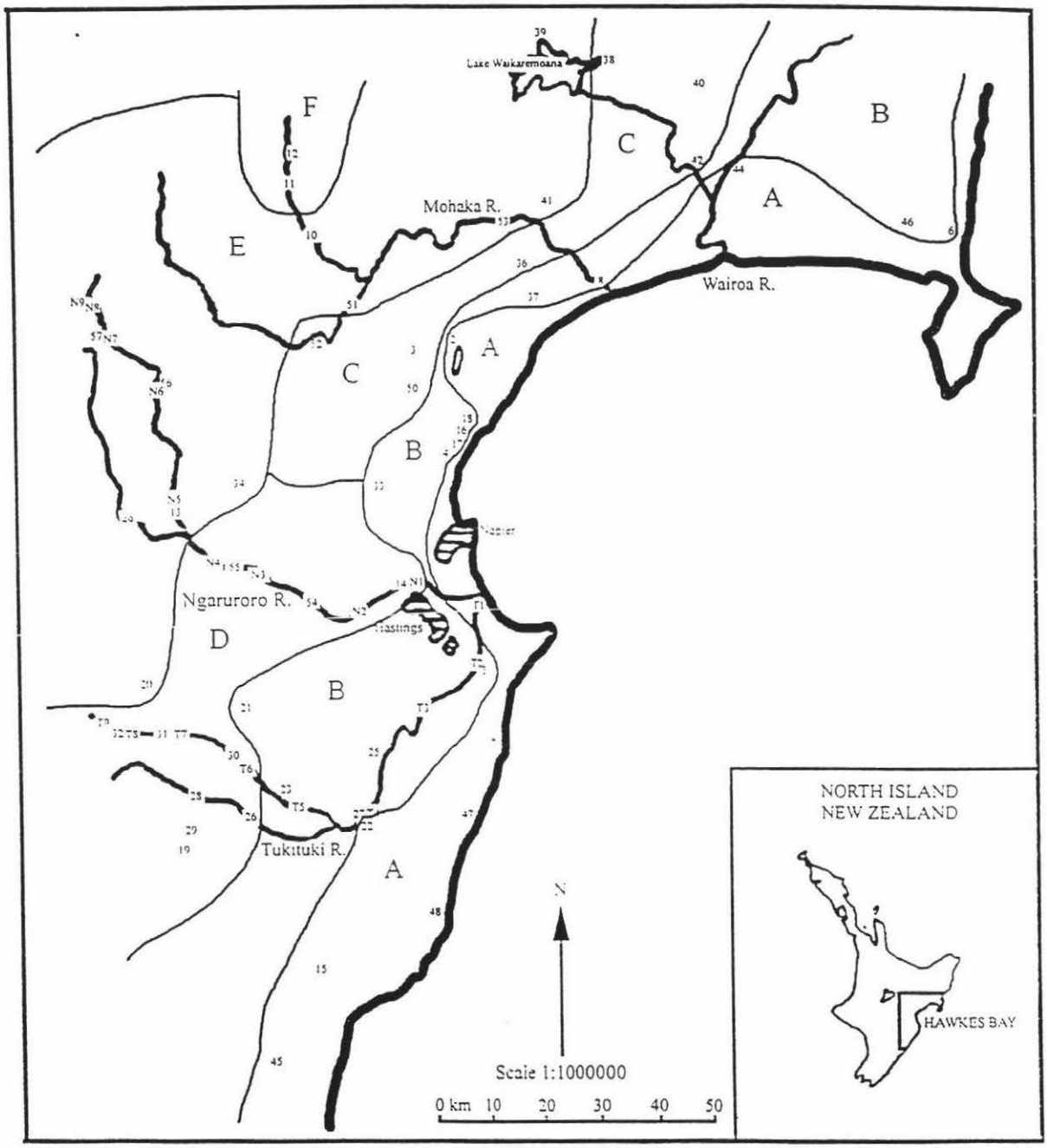



Fig. 2.4. Proposed bioregions for the Hawkes Bay region based on a TWINSPAN analysis of macroinvertebrates data (see Fig. 2.3).

**Group D** Also at medium altitude, the 13 sites in this group had little leaf litter, high suspended solids, and low black disk and diversity. Small cobble was the main substrate size and MCI indicated medium water quality. These sites are located in the southern half of Hawkes Bay inland from Group B and include the major braided rivers (Fig. 2.4). The four outlying sites are Sites 8, 18, 41 and 53.

**Group E** These 9 sites were at reasonably high altitude and had little canopy cover, low AFDM and Chl *a*, low periphyton cover and low suspended solids. They also had high black disk readings, medium to high diversity, very high MCI scores and large substrate size. The sites in this group are located well inland.

**Group F** The 2 sites in this group were at high altitude and had high canopy cover, high AFDM and Chl *a*, low temperatures, high leaf litter, and low nutrient concentrations. They also had high MCI scores, were quite stable and are located well inland in a pumice filled valley.

Sites that are representative of each of these groups are shown in Plates 2.1 to 2.6.

The mean values for those environmental factors that were found to be significantly variable across the six bioregions are shown in Table 2.3. TWINSPAN groups are constructed just from the macroinvertebrate data but this table shows that the groups are strongly related to many environmental factors, particularly altitude and substrate size. The MCI was found to have the highest F ratio.

Table 2.3. Mean values (± S.E.) and ANOVA statistics for selected environmental factors analysed by TWINSPAN groups.

| | TWINSPAN group | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | $F_{5}$-ratio | P |
| ALT | 55 ± 48.7 | 75.6± 46.2 | 216 ±48.7 | 170.4± 40.6 | 532.2± 48.7 | 690± 103.4 | 17.14 | 0.000 |
| CAN | 17 ±5.6 | 14 ±5.4 | 13.3± 5.6 | 5.2 ±4.6 | 5 ±5.6 | 50± 12 | 2.94 | 0.022 |
| AFDM | 27.2 ±10.8 | 22.6 ±7.6 | 28.7± 8 | 10± 6.7 | 4.2± 8 | 104.8± 17 | 6.54 | 0.000 |
| Chl a | 28.7± 35.1 | 60.5 ±24.8 | 97.5± 26.1 | 26.3 ±21.8 | 12.1± 26.1 | 295.7± 55.4 | 5.31 | 0.001 |
| TEMP | 14.6± 0.5 | 14.5± 0.5 | 13.5 ±0.5 | 13.9± 0.4 | 12.6± 0.5 | 10.6± 1 | 4.22 | 0.003 |
| LL | 4.7± 1 | 3.3± 0.9 | 5.3± 1 | 1.5 ±0.8 | 1.5 ±0.8 | 12.5± 2 | 7.09 | 0.000 |
| pH | 8± 0.1 | 8± 0.1 | 8.1± 0.1 | 7.8 ±0.1 | 7.6± 0.1 | 7.2± 0.2 | 5.31 | 0.001 |
| PERI | 24.4± 7.6 | 28.4 ±7.2 | 45.7± 7.6 | 15.8± 6.3 | 5.1 ±7.6 | 37.5± 16.2 | 3.4 | 0.011 |
| STAB | 105.9± 6.2 | 95.8± 5.2 | 79± 5.4 | 88.9± 4.5 | 87.1 ±5.4 | 80.5 ±11.5 | 2.6 | 0.038 |
| SI | 4.3± 0.2 | 5.6± 0.2 | 6.4± 0.2 | 5.9 ±0.2 | 6.2± 0.2 | 5.5 ±0.5 | 10.0 | 0.000 |
| ALK | 136.3±12.2 | 99.7±12.2 | 88.1±13.9 | 42.6±11.6 | 32.7±15 | 21.1±26 | 9.9 | 0.000 |
| Ca | 69.3±7 | 36.8±7 | 33.9±8 | 12.4±6.7 | 11.2±8.6 | 3.7±14.9 | 9.4 | 0.000 |
| TP | 0.05±0.01 | 0.02±0.01 | 0.02±0.01 | 0.03±0.01 | 0.02±0.01 | 0.01±0.01 | 2.68 | 0.035 |
| $NH_3$ | 0.04±0.01 | 0.01±0.01 | 0.03±0.01 | 0.01±0.01 | 0.01±0.01 | 0.01±0.01 | 3.86 | 0.010 |
| SS | 11.3±2.7 | 5.2±2.5 | 6.5±2.8 | 14.7±2.4 | 3.2±3.3 | 5.4±5.7 | 2.59 | 0.043 |
| BD | 1.3±0.3 | 3.1±0.3 | 2.8±0.5 | 1.2±0.4 | 3.1±0.5 | 1.8±0.6 | 5.99 | 0.001 |
| BICAR | 129.6±12.1 | 99.4±12.1 | 85.2±13.7 | 44.6±11.5 | 34.4±14.8 | 21.7±25.7 | 8.29 | 0.000 |
| ITR | 10±1.3 | 17.8±1.2 | 24.7±1.3 | 13±1 | 20.8±1.3 | 17.5±2.7 | 18.65 | 0.000 |
| MARG | 1.4±0.2 | 2.2±0.2 | 3±0.2 | 1.8±0.2 | 3±0.2 | 2.8±0.4 | 12.98 | 0.000 |
| IBP | 1.6±0.3 | 2±0.2 | 3.1±0.3 | 2.3±0.2 | 2.8±0.3 | 3.2±0.5 | 4.74 | 0.001 |
| ISIMP | 2.3±0.4 | 3.1±0.4 | 5.2±0.4 | 3.4±0.4 | 4.7±0.4 | 5.5±0.9 | 6.73 | 0.000 |
| MCI | 75.8±2.6 | 103.2±2.5 | 127±2.6 | 119±2.2 | 136.6±2.6 | 130±5.6 | 67.83 | 0.000 |

## 2.5. DISCUSSION

### 2.5.1. Characterisation of Invertebrate Communities

Benthic invertebrate communities in the rivers surveyed varied markedly in taxonomic richness, diversity, and density due to the wide range of catchment types, land use and channel sizes sampled. Because sites were sampled during the late summer to early autumn baseflows, any temporal variation in aquatic communities would be minimised,

Plate 2.1. Site 48, Ikanui River. Bioregion A.

Plate 2.2. Site 33, Mangaone River. Bioregion B.

Plate 2.3. Site 3, Esk River. Bioregion C.

Plate 2.4. Site 55, Ngaruroro River. Bioregion D.

Plate 2.5. Site 39, Hopuruahine River. Bioregion E.

Plate 2.6. Site 12, Waipunga River. Bioregion F.

although temporal variation in New Zealand stream communities is considered to be minor (Winterbourn et al., 1981). Sampling during baseflows also allows populations of periphyton and invertebrates to build up over the stable-flow season and reflect river and catchment conditions (Biggs et al., 1990).

The dominance of aquatic insects in the invertebrate fauna (81% of 97 taxa) is consistent with other studies (e.g. 82% of the 107 taxa in Quinn and Hickey (1990a); and 81% of the 90 taxa in Winterbourn and Collier (1987)).

There were four species found that could be of possible conservation interest. The mayfly *Austronella planulata* was found at four sites (6, 38, 42 and 46) that were slow-medium flowing with moderate amounts of canopy cover and had wide riparian vegetation zones. All four sites were located in the northern part of Hawkes Bay. Other records of this species are from scattered locations in the northern parts of the North Island, with one outlying record near Wellington (Towns and Peters, 1996), and it has been listed as being of conservation interest by Collier (1993). Two specimens from the family Ecnomidae or the family Psychomyidae were found at site 5. The family Ecnomidae has just one species (*Ecnomina zealandica*) that has been listed as the rarest caddisfly in New Zealand (Collier, 1993). A freshwater polychaete from the family Nereidae (the species *Namalycastis tiriteae*) was found at six sites (4, 23, 30, 33, T4 and T5). Previously this species had only been found in the Manawatu catchment; i.e. Turitea stm. near Palmerston North (Winterbourn, 1969), Mangatainoka R. on the eastern side of the Tararua Ranges (Ian Henderson, pers. comm.) and Mangatewai R. in Northern Wairarapa (Reece Fowler, pers. comm.). Findings in this study show this species may be reasonably wide spread in central and southern Hawkes Bay. It may normally inhabit the hyporheic zone which would explain why it has only rarely been found. Another species listed by Collier (1993) as being of conservation interest is the caddisfly *Traillochorema* sp.. Two caddisflies that could be this species were found at sites 10 and 34. Both sites were large cobbled, native forest streams.

A diverse mayfly fauna consisting of 17 taxa was found in Hawkes Bay. The family Leptophlebiidae dominated (71% of mayfly taxa) as has been found elsewhere (e.g. Collier (1995) found Leptophlebiidae made up 67% of the mayfly taxa). Collier (1995) found *Zephlebia dentata* was the most widespread mayfly in his Northland survey. This contrasts with other studies (e.g. Rounick and Winterbourn, 1982; Collier et al., 1989), including this one in which *Deleatidium* sp. was the most widespread of the mayflies.

### 2.5.2. Environmental Factors Affecting Biotic Factors

The biotic variable that is most noticeably affected by the environmental factors measured is MCI. There is a negative correlation between MCI and many chemical water quality measurements. This is understandable as the MCI was intended as a water quality indicator so a low MCI score (indicating "polluted" water) should correspond to an increase in nutrient levels which is indicative of a lowering of water quality. MCI is also positively correlated with altitude, gradient and substrate index. This reflects the fact that as altitude increases, land use tends to change from enriched highly productive farmland to native vegetation. Sites that have a high gradient are more likely to be located on undeveloped farmland, forestry or in native vegetation and therefore don't receive much nutrient input. The correlation between MCI and substrate index does not necessarily mean that sites with small substrate have low water quality, but probably reflects that different types of invertebrate community comprising, on average, taxa that score low on the MCI, inhabits silty or sandy substrate types (Stark, 1993). The MCI was designed specifically for stony bottom streams (Stark, 1985).

Axis 1 of the DECORANA analysis is significantly correlated with nearly all the same variables as MCI. It appears that chemical concentrations, substrate size, altitude and gradient are the main factors influencing community composition.

AFDM and Chl *a* seem to have a secondary and independent effect on community composition. This may be due to species dependent on high levels of periphyton or detritus for food being more abundant when there are high AFDM and Chl *a* levels. *Olinga*, for example, is a collector/browser that was generally found in higher numbers when AFDM and Chl *a* was abundant.

### 2.5.3. Bioregions

This study is the first attempt in New Zealand to classify the rivers of an area the size of Hawkes Bay into bioregions based on the aquatic macroinvertebrates. The distribution of the rivers in the various TWINSPAN groups suggests that, when rivers are sampled at this intensity, they can be grouped into bioregions, as appears possible in the United States (e.g. Tate and Heiny, 1995; Whittier et al., 1988).

Six bioregions are distinguishable in Hawkes Bay. However it should be noted that even though all, or nearly all, of the sites fall within the boundary assigned to each bioregion (Fig. 2.4), there are some sites misclassified. For example, an area located 10-20 km north of Napier has four sites that are assigned to three different TWINSPAN clusters (Sites 4 and 17 are assigned to group B; Site 16 is assigned to group C; and Site 18 is assigned to group D). Sites 8, 41 and 53 are also located well away from bioregion C which they have been assigned to. However, with these few exceptions, the proposed bioregions shown in Fig. 2.4 are reasonably accurate and could be helpful for the management of Hawkes Bay rivers in the future. By monitoring selected representative sites from each bioregion on a regular basis, any change detected in these sites could represent a change occurring over the whole bioregion.

Bioregion A is the most coastal of the bioregions. Crustaceans were most common here, and slow/still water species such as *Sigara*, *Oecetis unicolor* and molluscs were also found in this region. Most species were low scoring on the MCI but, as mentioned in the

previous section, this may be due to these species preferring the smaller average substrate size in this region rather than being a reflection of water quality. However, in this case, it is likely that water quality is structuring the invertebrate communities to some extent because sites in this bioregion do have much higher chemical levels than sites in other regions (Table 2.3). Site 47, and to a lesser extent Site 48, have more than ten or even one hundred times the level of chemical enrichment or conductivity than any other site but this may be due to their proximity to the sea and therefore they can be influenced by salt water or sea spray.

Bioregion B seems to be the transition area between the low water quality sites at the coast and the "cleaner" water sites inland. It contains taxa such as *Potamopyrgus* and Ostracoda that are abundant in bioregion A as well as taxa associated more with higher water quality such as mayflies.

The high stability of sites in bioregion C may explain why they have such high diversities and would explain why there is a high periphyton cover. *Archichauliodes diversis*, which is found most often in stable streams (Russell Death, pers. comm.) was found at all of the sites in this bioregion, and there was also a diverse mayfly fauna.

Bioregion D corresponds well with the braided, cobble bottomed rivers on the plains of southern Hawkes Bay. Sites 14, 54 and 55 on the Ngaruroro River are particularly braided. Most of this bioregion is on high-producing farmland which may explain the moderate water quality indicated by the MCI. There were few molluscs but *Psilochorema*, *Pycnocentrodes* and Eriopterini were present at most sites.

Most of bioregion E is located within mountain ranges and encompasses most of the midreaches and headwaters of the Mohaka, Tutaekuri and Ngaruroro rivers. The very high MCI scores are due to these areas being in forest or low-producing hilly farmland so receive little enrichment. As expected, "clean" water species are common in this bioregion and stoneflies are most common here.

There is a reasonable amount of variation in the two sites in bioregion F. Site 12 has more species and higher abundance than site 11. Abundant periphyton and bedrock being the dominant substrate at site 11 may explain some of the differences. Moss is also indicated at site 11 by the presence of *Zelolessica cheira* (Cowie and Winterbourn, 1979).

Biggs et al. (1990) classified most of Hawkes Bay into their Eastern ecoregion. They describe the biological characteristics of this ecoregion as being enriched water with green algae and "enrichment-tolerant" midges, snails and worms. The inland, high altitude areas of Hawkes Bay are classified into their Central ecoregion which they characterise as low-moderate enrichment, green and red algae, and "clean-water" mayflies, caddisflies, stoneflies and beetles. This study indicates that bioregions E and F compare reasonably well with the Central ecoregion of Biggs et al. (1990). However, the only part of Hawkes Bay that can be described as being similar to their Eastern ecoregion is bioregion A, or the coastal sites. The rest of the bioregions from this study tend to show characteristics of both the Central and Eastern ecoregion described by Biggs et al. (1990) but with more of a tendency toward the "clean-water" species.

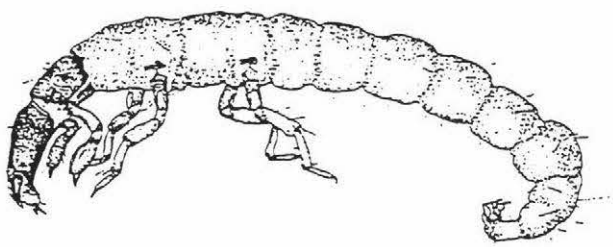
There appears to be a reasonable correspondence between the bioregions found in this study and those generated by Harding et al. (1994). Four of Hardings (1994) ecoregions had a range that falls significantly within the Hawkes Bay region, these being his Taupo Plateau, East Cape Highlands, Eastern Arable Lowlands and Volcanic Plateau. If ecoregions A, B and D from the present study are combined, they have a good correspondence with the boundaries of the Eastern Arable Lowlands. The East Cape Highlands appear to be compatible with bioregion C, while bioregion E falls within Hardings (1994) Taupo Plateau, Volcanic Plateau and also a little bit of the Central Mountains ecoregion. Bioregion F is found only in the Taupo Plateau. In the United States, subecoregions have been found within larger ecoregions (Barbour et al., 1996). This study indicates that bioregions A, B and D could be called subecoregions of

Hardings (1994) Eastern Arable Lowlands ecoregion, while the same could be said of the bioregion F which is in the Taupo Plateau. Bioregion E encompasses much of the western ranges of Hawkes Bay. Although these ranges include three of Hardings (1994) ecoregions, there is a fairly continuous tract of vegetation through these areas which may account for the reasonably homogenous macroinvertebrate community associated with this area (see chapter 6).

In summary, this chapter described the regional patterns of variation in composition of macroinvertebrate communities and how these patterns relate to environmental factors. These patterns were also found to have some (but not perfect) correspondence with previous ecoregion classifications.

# CHAPTER 3:

# CHARACTERISATION OF HAWKES BAY PERIPHYTON COMMUNITIES



# CHAPTER 3:

# CHARACTERISATION OF HAWKES BAY PERIPHYTON COMMUNITIES

## 3.1. INTRODUCTION

Lotic epilithic periphyton communities consist of bacteria, cyanobacteria, eukaryotic algae, protozoa, and fungi, with extracellular products and accumulated debris (Biggs and Close, 1989). Periphyton are the dominant primary producers in most temperate stream ecosystems (Biggs, 1990; Biggs, 1995).

There are several controlling factors of periphyton community dynamics. The main hydrological determinants are the frequency and intensity of flood events (e.g. Fisher et al., 1982), water velocity (e.g. Reiter and Colson, 1986) and bed sediment stability (Biggs and Close, 1989). Diatom assemblages have been found to be closely associated with a number of environmental factors, including flow, land use, and wastewater discharge patterns (Chessman, 1986). Productivity and biomass gain are controlled mainly by light, nutrients (nitrogen and phosphorus) and temperature (e.g Boston and Hill, 1991). Invertebrate grazing has been shown to be an important variable controlling biomass loss (Lamberti and Resh, 1983; McAuliffe, 1984; Biggs and Close, 1989; Horner et al., 1990; Winterbourn, 1990).

Periphyton is one of the communities most responsive to changes in habitat. In the "100 Rivers Project" periphyton programme (Biggs, 1990) it was found that periphyton composition and biomass was fundamentally linked to catchment geology, with land use playing a secondary role. Other studies have looked at periphyton development in relation to macro-scale and micro-scale limiters (Biggs and Gerbeaux, 1993). Macro-scale features such as geology, climate and land use are expected to affect large areas and be influential over long time periods. Micro-scale features such as nutrient regimes, hydraulics and substrate characteristics affect

local geomorphic and biotic processes which occur over periods of less than 1 year (Naiman et al., 1992).

This section aims to characterise Hawkes Bay rivers based on the periphyton communities. Periphyton distribution will also be investigated and compared with the invertebrate distributions found in chapter 2.

## 3.2. STUDY SITES

Periphyton was collected from 46 sites on 14 different Hawkes Bay river catchments. The sites cover a wide range of land uses, altitudes, and river sizes. Fig. 2.1 shows the location and name for each site. The six sites not sampled in this figure are Sites 2, 22, 44, 48, 55 and 56. Most of the sites also correspond with Hawkes Bay Regional Council water quality monitoring sites so information such as nutrient concentrations could be easily gathered.

## 3.3. METHODS

### 3.3.1. Data Collection

See chapter 2 for details of periphyton and environmental data collection.

### 3.3.2. Laboratory Procedures

For the taxonomic analysis, homogenised sub-samples for each sample were examined under a microscope. Samples were first scanned at x125 magnification for an overview of the important taxa, and then at x500 (and occasionally x780) magnification for more detailed identifications. Major taxa were assessed on a scale of 1 (rare) to 8 (dominant), with all non-dominants being scored relative to the dominant taxa.

Identifications of the non-diatomaceous algae are often tentative, and for the blue green algae in particular definite identification is only possible using fresh material. Therefore some descriptive groups (e.g. thick filaments) are included.

Measurement of chlorophyll *a* content and ash-free dry mass (AFDM) are described in chapter 2.

### 3.3.3. Data Analysis

***Classification and Ordination***

The rivers were classified into groups based on densities of periphyton taxa using two-way indicator species analysis (TWINSPAN) (Hill, 1979a) and ordinated by detrended correspondence analysis (DECORANA) (Hill, 1979b). Pseudo-species cut levels for use in TWINSPAN were the abundance scores 1, 3, 5 and 7 (see above).

## 3.4. RESULTS

### 3.4.1. Community Characteristics

A total of 49 periphyton taxa was identified. Of these, 30 were diatoms, 10 were Green algae, and 9 were Blue-Green algae.

A mean of 11.2 taxa per site was recorded. The highest number of taxa (20) was collected from the lower reaches of the Mohaka river (site 8). Four other sites had more than 15 taxa (sites 12, 36, 38 and 41) and nine sites had less than 8 taxa (sites 15, 25, 29, 33, 39, 42, 47, 52 and 55).

The most widespread taxon was *Gomphoneis herculeana* which was found at 38 of the 46 sites, followed by *Cymbella kappii* and *Synedra ulna* (34 sites), *Fragilaria vaucheriae* (31 sites) and *Cocconeis placentula* (29 sites). All of the above are diatoms. The diatoms *Melosira granulata* and *Nitzchia linearis*, and the Blue-Green algae *Nostoc* sp. were found at only one site.

At most sites, diatoms were the most taxonomically diverse. However, it is usually the multicellular algae, in particular Green algae, that are dominant in biomass.

### 3.4.2. Ordination of Sites

The site scores on DECORANA axis 1 and 2 are shown in Fig. 3.1. Axis 1 explained 39.6% of the variation between the sites. The combination of axis 1 and 2 explained 68.4% of the variation.

DECORANA axis 1 was found to correlate significantly with pH ($r=0.425$, $p<0.01$). Periphyton ash-free dry mass ($r=0.497$, $p<0.001$), chlorophyll *a* concentration ($r=0.516$, $p<0.001$), percentage leaf litter ($r=0.441$, $p<0.01$), and G440 ($r=-0.562$, $p<0.001$) were all found to be significantly correlated with axis 2 (Fig. 3.1).

### 3.4.3. Classification of Sites

The TWINSPAN analysis classified the periphyton data into seven groups at the fourth level of division. Fig. 3.2 shows the dendrogram that was produced from the TWINSPAN analysis, including those species and their abundance level that were most indicative of each division.

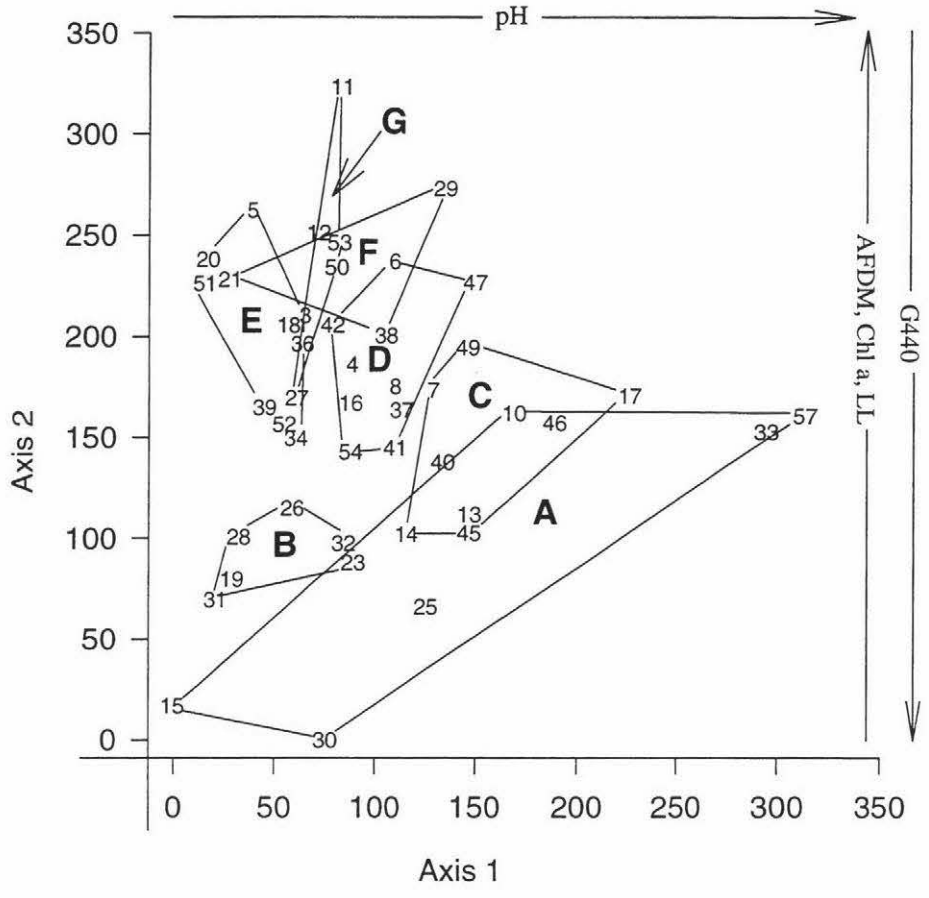



Fig. 3.1. Ordination along the two main DECORANA axes of the 47 sites. The relationship of environmental variables significantly correlated with DECORANA axes is indicated. Polygons enclose all sites in each TWINSPAN group.

The first level of division separates group A from the other groups, where several species were indicators (see Fig. 3.2). Group A has low dissolved oxygen and chlorophyll *a* concentration, and high G440 (Table 3.1).

Groups B, C and D are then separated from E, F and G at the second level of division. *Phormium/Oscillatoria*(1) was the indicator species for groups E, F and G,

while *Epithemia sorex*(1), *Stigeoclonium* sp.(1) and *Spirogyra* sp.(1) were indicators for B, C and D.

The third level of division separates group B from C and D, and group G from E and F. The indicator species for group B was *Stigeoclonium* sp.(2), while *Epithemia sorex* (1) and *Cladophora glomerata*(1) were indicators for groups C and D. *Nitzschia* sp.(1) was the indicator species for group G. Group B is characterised by having low leaf litter, alkalinity, bicarbonate and low invertebrate diversity, while group G has high chlorophyll *a* and dissolved oxygen concentrations, high leaf litter, low temperature and low G440 (Table 3.1).

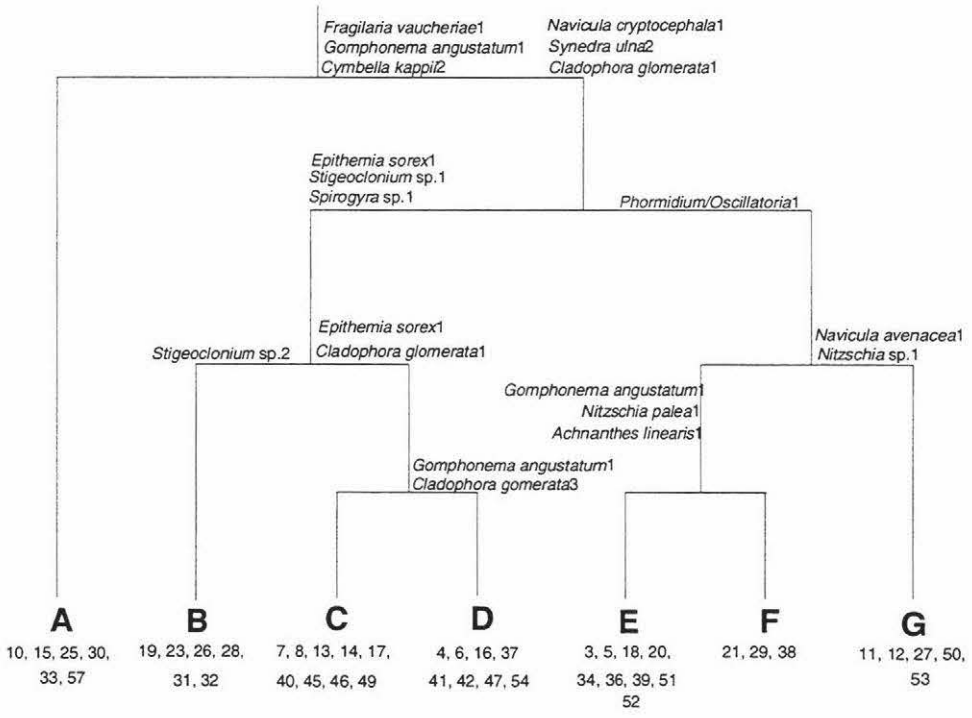



Fig. 3.2. TWINSPAN dendrogram showing the classification of the 47 sites. Indicator species that were particularly diagnostic of each division are shown.

Table 3.1. Mean values (± S.E.) and ANOVA statistics for selected environmental factors analysed by TWINSPAN groups. Variable names and units as for Table 2.1. ITR = Invertebrate Taxonomic Richness.

| | TWINSPAN group | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | $F_{6}$-ratio | P |
| Chl a | 6.6 ± 35 | 22.7± 35 | 26.2± 28.6 | 40.6± 30.3 | 101.6± 28.6 | 38.9± 49.5 | 180.2± 38.4 | 2.89 | 0.020 |
| TEMP | 18.4± 1.5 | 19.3± 1.5 | 21.6± 1.3 | 20.3± 1.3 | 16.4± 1.3 | 20.1± 2.2 | 15.4± 1.7 | 2.35 | 0.049 |
| LL | 3± 1.3 | 1.3± 1.3 | 1.8± 1.1 | 3.9± 1.2 | 3± 1.1 | 5.7± 1.9 | 8.2± 1.5 | 2.84 | 0.022 |
| DO | 8.7± 0.5 | 9.7± 0.4 | 10.1± 0.4 | 9± 0.4 | 10.3± 0.4 | 8.2± 0.6 | 10.5± 0.5 | 3.50 | 0.007 |
| pH | 7.8± 0.1 | 7.6± 0.1 | 8± 0.1 | 8.1± 0.1 | 7.9± 0.1 | 7.6± 0.2 | 7.5± 0.2 | 2.92 | 0.022 |
| ALK | 97.2± 20.7 | 33.1± 13.9 | 82.3± 17.5 | 135.3± 18.9 | 75.8± 17.5 | 41.3± 26.7 | 49± 23.1 | 3.21 | 0.014 |
| TURB | 2.5± 4.3 | 2.4± 4 | 17.3± 3.4 | 6.5± 3.7 | 2.5± 3.4 | 0.8± 5.6 | 1.8± 4.8 | 2.51 | 0.041 |
| BICAR | 87.5± 19.8 | 38.4± 18.1 | 77.9± 16.8 | 126.9± 18.1 | 79.4± 16.8 | 38.5± 25.6 | 50.2± 22.2 | 2.68 | 0.033 |
| G440 | 1.1± 0.2 | 1± 0.2 | 0.6± 0.1 | 0.5± 0.1 | 0.4± 0.1 | 0.4± 0.2 | 0.2± 0.2 | 3.79 | 0.005 |
| ITR | 14.2± 2.3 | 13.3± 2.3 | 15.4± 1.9 | 18.6± 2 | 21.3± 1.9 | 24.7± 3.3 | 17.4± 2.5 | 2.65 | 0.030 |

Group C was separated from group D at the fourth level of division with *Gomphonema angustatum*(1) and *Cladophora glomerata*(3) being the indicator species for group D. Groups E and F are also separated at the fourth level of division with the indicator species for group E being *Gomphonema angustatum*(1), *Nitzschia palea*(1) and *Achnanthes linearis*(1). Sites in group C were generally found to have high temperatures and turbidities, but low leaf litter, while group D sites tended to have high alkalinity and bicarbonate readings. Quite high chlorophyll *a* and dissolved oxygen readings were found in group E, while group F had high invertebrate diversity and low turbidity (Table 3.1).

The seven TWINSPAN groups identified correspond to different periphyton communities. Community A was dominated by filamentous algae, although two of the sites in this group were dominated by a diatom species.

All of the sites in community B are dominated by one of the Green algae species, *Stigeoclonium* sp., *Spirogyra* sp. or *Ulothrix* sp.

There is no clear dominance by any one diatom or filamentous algae species or group in communities C, F and G, although of the five sites in community G, two of them are dominated by the diatom *Cymbella kappii*.

All but two of the sites in community D are dominated by *Cladophora glomerata* and even at those two sites where another algal species is dominant, *C. glomerata* is still a major part of the community.

Community E is dominated by three main species, these being the filamentous Green algae *C. glomerata*, and the diatoms *Gomphoneis herculeana* and *Gomphoneis angustatum*.

Unlike the macroinvertebrate data (see chapter 2) no geographical patterns were evident with the TWINSPAN groupings derived from the periphyton data. There does not appear to be any correlation or relationship between macroinvertebrate community composition and periphyton community composition, for example, neither axis of the periphyton ordination (Fig. 3.1) is correlated with any of the invertebrate indices such as MCI or diversity.

## 3.5. DISCUSSION

From the 47 sites sampled in Hawkes Bay, it appears that diatoms are the most diverse part of the periphyton community, however it is the multicellular Green algae that most often dominate the communities. This dominance by the filamentous taxa has been found to be a common feature of New Zealand rivers with gravel beds in late summer (Biggs and Price, 1987). These algal growths can often be so prolific that problems such as clogging of abstraction structures, degradation of water

quality through diel fluctuations in dissolved oxygen, and degradation of aesthetic values have been identified (Biggs, 1985)

*Cladophora glomerata* appears to be the main component of algal proliferations in North America and European rivers (Whitton, 1970; Pitcairn and Hawkes, 1973). Biggs and Price (1987) also found this species dominated a significant number of proliferations in New Zealand after surveying 378 sites. In this study, *Cladophora glomerata* was dominant at 11 of the 47 sites. *Stigeoclonium* sp., *Spirogyra* sp. and *Gomphoneis herculeana* were each dominant at six sites. The bloom-forming green algae *Rhizoclonium* sp. has often been found to be one of the dominant taxa in New Zealand rivers (Biggs et al., 1990; Biggs, 1990; Biggs and Price, 1987). Surprisingly, this taxa was not identified at any of the sites in this study.

The TWINSPAN analysis identified seven different periphyton communities in the 47 rivers. Biggs (1990) identified eight periphyton communities from 91 rivers in the "100 Rivers Project". All but two of the eight periphyton communities in Biggs (1990) study were dominated by filamentous taxa. However, in this study, only three of the seven communities were dominated by filamentous algae, these being communities A, B and D. Diatoms were found to be most dominant in community E. There was an approximately equal dominance by filamentous taxa and diatoms in communities C, F and G.

Only pH was found to be significantly correlated with Axis 1 in the DECORANA analysis. Chessman (1986) also found pH was an important factor in distinguishing between different diatom communities. The predominant geology of an area is expected to have a major effect on the periphyton community through the weathering of bedrock and the subsequent input of various dissolved ions into the water (Close and Davies-Colley, 1990; Biggs and Gerbeaux, 1993; Biggs, 1995). However, those factors that are strongly related to geology, such as bicarbonate levels, are not significantly correlated with Axis 1. Flow characteristics of rivers were not measured in this study but have also been shown to have some influence over periphyton communities (Biggs and Gerbeaux, 1993). Conductivity, which is

also related to geology, has been found to be the most important factor related to the composition and biomass of periphyton communities (Biggs, 1990). Other environmental factors found to have significant associations with periphyton community type were low-flow stream power, temperature and some nutrients (Biggs, 1990).

This study indicated that periphyton ash-free dry mass (AFDM) and chlorophyll *a* (chl *a*) concentration, percentage leaf litter and G440 are all secondary determinants of periphyton community composition. As AFDM and chl *a* are measures of periphyton abundance, this suggests that they may be important determinants of community structure through competitive exclusion. That is, species that form proliferations (have high AFDM and chl *a* measurements) are probably more aggressive competitors for nutrients and light and can therefore dominate the community at the expense of poorer competitors (McCormick and Stevenson, 1991; Stevenson et al., 1991; Biggs, 1995). Percentage leaf litter cover also increases significantly along Axis 2 of the DECORANA analysis. This is possibly due to more leaf litter being caught up amongst proliferations of periphyton.

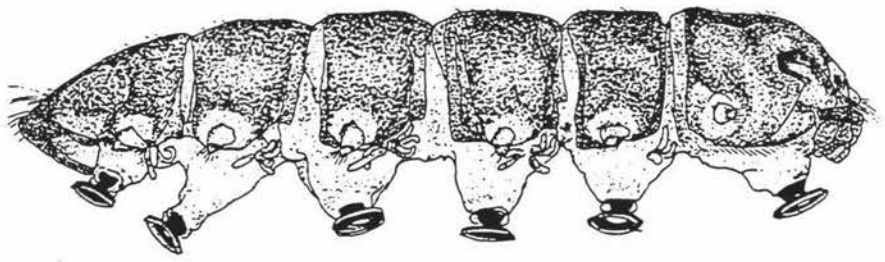
Unlike the macroinvertebrate data (see chapter 2) it was not possible to distinguish any clearly defined bioregions. This was also the case for Biggs (1990), although he did find that some community types were not found over large areas, e.g. no *Cladophora glomerata/Rhizoclonium* sp. or *Spirogyra* sp. dominated sites were found in the South Island. Common periphyton species such as *C. glomerata*, *Fragilaria vaucheriae* and *Ulothrix zonata* have cosmopolitan distributions (Chessman, 1986; Biggs and Price, 1987). Because of this there is unlikely to be any restriction in any periphyton taxa's distribution within an area the size of Hawkes Bay.

Invertebrates have been shown to be an important factor in controlling periphyton biomass (Lamberti and Resh, 1983; McAuliffe, 1984; Biggs and Close, 1989; Horner

et al., 1990; Winterbourn, 1990). In this study it appears that periphyton production often exceeded invertebrate grazing because many of the sites have moderate (>20mg/$m^2$) and high (>40mg/$m^2$) (Biggs, 1990) periphyton biomass.

# CHAPTER 4:

# COMPOSITION AND DISTRIBUTION OF BENTHIC MACROINVERTEBRATES ALONG TWO LARGE HAWKES BAY RIVERS



# CHAPTER 4:

# COMPOSITION AND DISTRIBUTION OF BENTHIC MACROINVERTEBRATES ALONG TWO LARGE HAWKES BAY RIVERS

## 4.1. INTRODUCTION

There have been many attempts to produce a characterisation or classification for rivers (Whittier et al., 1988). A brief history of lotic system classifications, especially as related to zonation studies, is given by Hawkes (1975). The attempt that has gained most attention is the River Continuum Concept (RCC) (Vannote et al., 1980) which proposes stream ecosystems are predictably organised units, and attempts to produce a conceptual framework of their organisation. Community structure and function are seen as adjusting to changes in certain geomorphic, physical and biological variables, such as stream flow, channel morphology, detritus loading and thermal regime, to achieve a state of dynamic equilibrium. Downstream communities are considered to be dependent on those upstream for part of their energy income and therefore will structure themselves in a predictable manner to efficiently utilise this material.

The concept of a predictable continuum within streams is not universally accepted (Barmuta & Lake, 1982). Winterbourn et al. (1981) provided evidence against the RCC by reporting that physical conditions in geologically young streams, such as those found in New Zealand, may be unpredictable and regulated primarily by random events. Therefore the benthic invertebrate communities could not be accounted for by a system as predictable as the continuum of Vannote et al. (1980).

Ormerod & Edwards (1987) and Bournaud et al. (1996) also failed to find support for the RCC in large river systems. Because the longitudinal patterns of macroinvertebrate fauna is closely related to the environment, local human influences, such as impoundments or water pollution have been found to create discontinuities (Bournaud et al., 1996).

There have also been studies, however, that do provide some support for the RCC (e.g. Crunkilton & Duchrow, 1991; Hawkins & Sedell, 1981; Minshall et al., 1982), although its proponents do accept the need for a modification which would allow for multiple gradients (e.g. effects of different types of vegetation at headwater sites on the continuum)(Minshall et al., 1985).

There have been few studies of longitudinal macroinvertebrate variation in New Zealand. Towns (1979) studied a small forested catchment and found the trophic structure of the macroinvertebrates closely resembled the change from autotrophic to heterotrophic conditions. A study of a small South Island river by Cowie (1985) failed to find any support for the RCC due to the unstable nature of the stream. Likewise, Ryder and Scott (1988) also found that the RCC cannot be applied to New Zealand rivers because macroinvertebrate distribution did not conform to any RCC prediction.

This study aims to characterise longitudinal variation in benthic macroinvertebrates along the main branch of two large rivers from the coast to within a few kilometres of the source. This chapter also aims to find out whether there are predictable longitudinal gradients or zones in the two rivers, and if so, if these gradients or zones are similar for the two rivers.

## 4.2. STUDY SITES

Nine sites were sampled on both the Tukituki River and the Ngaruroro River. Fig. 2.1 shows the location of the sites. Sites T1 and N1 were located closest to the coast, with site number increasing upstream. The sites on each river ranged from lowland sites near the river mouth to high altitude(>700m) headwater sites.

The main part of the Tukituki River catchment is located west of the towns of Waipawa and Waipukurau. Many rivers and streams drain into the central area of the catchment from the Ruahine and Wakarara Ranges in the west and a few streams drain the hill country to the east. From this broad basin the Tukituki River drains northward, through a narrow valley and into the sea 12 km south of Napier. The catchment area is 2500 square kilometres, with a main river length of 126 km. Most of the Tukituki catchment is high producing pasture, although the eastern hill country and western foothills contain large areas of low producing pasture. Indigenous forest, shrubland and alpine grassland cover approximately 10% of the catchment area (Hawkes Bay Regional Council and Regional Water Board, 1987). Much of the main branch of the river is braided. Sites T5 to T9 of this study are located on the Waipawa River which is one of the main tributaries of the Tukituki River.

The Ngaruroro River catchment has its headwaters located in the Kaimanawa and Kaweka Ranges. It flows in a predominantly southerly direction through the ranges but once it reaches the foothills, flows in a generally easterly direction and drains into the sea a few kilometres south of Napier. The small percentage of the catchment located in the Kaimanawa Ranges is high altitude native tussocklands and beech forest. Within the Kaweka Ranges indigenous forest predominates while the foothills of the ranges contain a mixture of indigenous forest, scrub, exotic forest and low producing pasture. About half of the catchment is high producing pasture. The catchment area is about 2500 square kilometres with a main river length of 169 km. On the lowlands the main branch of the Ngaruroro River can become braided.

## 4.3. METHODS

### 4.3.1. Data Collection

*Invertebrates*

Sites were sampled between 19th January 1995 and 4th April 1995 except sites N6 to N9 which were sampled on 8th June 1995. Five 0.1 $m^2$ Surber samples (250μm mesh net) were taken in a transect across the river. If the river was too dangerous to cross to the other side for sampling, then the replicates were taken progressively up the river. Samples were taken from riffle habitat with a sampling duration of 2 minutes and were preserved in 70 % ethanol.

*Periphyton and Environmental Data*

Refer to chapter 2.

### 4.3.2. Laboratory Procedures

Laboratory procedures are as described in chapter 2.

### 4.3.3. Data Analysis

For ease of analysis, the five replicates for each site were combined to give a total area sampled at each site of 0.5$m^2$. The sites were classified into groups based on macroinvertebrate taxonomic composition by two-way indicator species analysis

(TWINSPAN) (Hill, 1979a). Pseudo-species cut levels were set at 1, 10, 100 and 1000 per $0.5m^2$ sample. Rare taxa were downweighted to reduce their influence in the classifications and ordinations.

## 4.4. RESULTS

### 4.4.1. Tukituki River

A summary of the environmental variables recorded for each site on the Tukituki river is shown in Table 4.1. As expected, gradient, altitude and substrate size all increased with distance from the coast, while there was a general decrease in average depth, average width, conductivity and percentage periphyton cover. Current velocity peaked at Site T7. Temperature was lowest in the upper reaches of the Tukituki river and varied between 18.7°C and 22.4°C along the rest of the river. There was little leaf litter found at any point on the river and dissolved oxygen and chlorophyll *a* were variable over the whole river. Moderate levels of periphyton AFDW were recorded between Sites T1 to T5, with the upper reaches having little or no periphyton.

Forty seven macroinvertebrate taxa were identified from the Tukituki river with a total of 54434 individuals. The number of taxa found at each site varied between 14 (Site T8) and 19 (Sites T2, T4, T5 and T7) (Fig. 4.1). Greatest invertebrate abundance occurred in the middle reaches of the river with the highest density being found at Site T3 where there were 30354 individuals $m^{-2}$ (Fig. 4.2). Sites T2 to T6 all contained densities of greater than 10000 individuals $m^{-2}$ (Fig. 4.2). Lowest invertebrate densities were recorded at site T9 ($328m^{-2}$) with Site T8 also having a relatively low density ($1008m^{-2}$).

The TWINSPAN analysis classified sites T1, T2 and T3 together after the first level of division with *Oxyethira albiceps*(1) being the indicator species (Fig. 4.3a). The

Table 4.1. Environmental variable measurements for the Tukituki river. T = trace amounts, F = farmland, NF = native forest, DO = Dissolved Oxygen, MCI = Macroinvertebrate Community Index.

| | Site | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 |
| Dist. from Coast (km) | 1.2 | 15.3 | 27.1 | 60.8 | 77.3 | 89.8 | 105.8 | 119.3 | 121.8 |
| River Order | 7 | 7 | 7 | 7 | 6 | 5 | 4 | 4 | 3 |
| Altitude(m) | 1 | 20 | 40 | 100 | 140 | 210 | 310 | 585 | 740 |
| Gradient(°) | 0.09 | 0.07 | 0.08 | 0.14 | 0.25 | 0.36 | 0.57 | 1.76 | 6.24 |
| Current Velocity (m/s) | 0.47 | 0.40 | 0.64 | 0.78 | 1.11 | 1.07 | 1.45 | 0.98 | 0.74 |
| Average Depth (cm) | 42.2 | 45.2 | 66 | 44.3 | 39 | 34.2 | 28 | 21 | 19.8 |
| Average Width (m) | 30 | 55 | 35 | 32 | 14.9 | 8.2 | 8.9 | 4.8 | 2.9 |
| Canopy Cover (%) | 10 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 |
| Conductivity (mS/cm) | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 | 0.11 | 0.11 | 0.11 | 0.09 |
| Temperature (°C) | 22.4 | 20.2 | 19.1 | 20.7 | 18.7 | 20.7 | 15.8 | 14.2 | 13.2 |
| Leaf Litter (%) | T | 3 | 2 | 2 | 1 | T | 2 | 2 | 1 |
| DO (mg/l) | - | 13.1 | 13.2 | 10.6 | 10.3 | 8.9 | 10.5 | 12.8 | 10.2 |
| Land Use | F | F | F | F | F | F | F | F, NF | NF |
| Periphyton Cover (%) | 90 | 55 | 90 | 15 | 15 | 15 | 15 | 4 | 0 |
| Periphy. AFDW ($g/m^2$) | 17.7 | 26.7 | 13.6 | 11.6 | 19.9 | - | 1.8 | 2.6 | 0.6 |
| Chl. *a* conc. ($mg/m^2$) | 56.2 | 136.3 | 56.7 | 7.3 | 82.8 | 7.9 | 8.7 | 14.6 | 0.4 |
| Stability | 75 | 61 | 61 | 59 | 65 | 71 | 71 | 51 | 47 |
| Substrate Index | 5.1 | 5.16 | 5.5 | 5.4 | 5.3 | 5.85 | 6.05 | 5.8 | 6.95 |
| MCI | 74 | 72 | 77 | 100 | 106 | 112 | 129 | 132 | 140 |

number after the species name refers to the pseudo-species cut level. The next division separated Sites T4 to T7 from Sites T8 and T9. *Aoteapsyche*(2) was the indicator species for this division. Thus, the TWINSPAN analysis classified the Tukituki river into three groups of adjacent sites.

The first group is composed of the three sites that are located nearest the coast (Sites T1 - T3). This group is dominated by Molluscs (Fig. 4.4). Hemiptera and Crustacea were found in this group but only rarely, if at all, in the other two groups. Minor groups consisting of Oligochaetes, Polychaetes, Planarians and Hirudinea

were also found in greatest numbers in this group. No Plecopterans and only a single Ephemeropteran species were found. MCI scores in this group were well below 100 (Table 4.1).

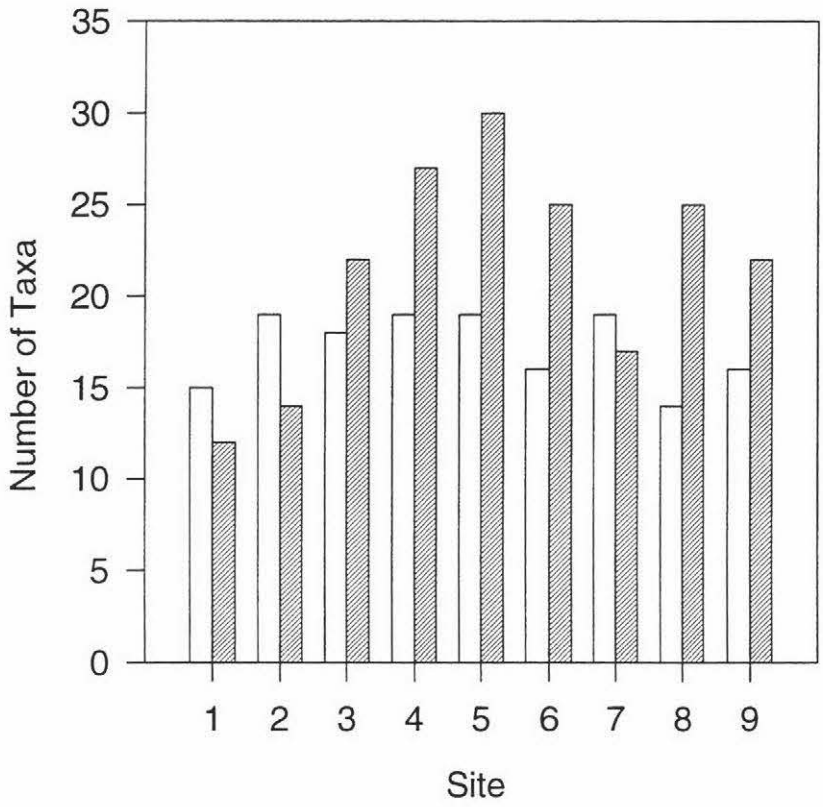



Fig. 4.1. Number of taxa identified at each site along the two rivers. Open bars = Tukituki river, shaded bars = Ngaruroro river. Site 1 refers to sites T1 and N1, site 2 to T2 and N2, etc.

The four sites that comprised of the second group were located in the middle reaches of the Tukituki and Waipawa rivers (Sites T4 - T7). Four insect orders dominated this group (Fig. 4.4). Coleoptera made up 36% of the invertebrate composition while Diptera, Ephemeroptera and Trichoptera made up the rest in approximately equal amounts. Molluscs, Crustacea and Other are effectively absent

from this group after being such a major component of Group 1. The large increase in Ephemeroptera (almost all *Deleatidium* spp.) reflects an improvement in water quality as the distance from coast increases. In site T7, the most headwater site in Group 2, less common Ephemeroptera such as *Coloburiscus* and *Neozephlebia scita* were present. The Trichopteran community also shows a shift from more tolerant taxa to cleaner water taxa. Site N7, which is located closest to the Ruahine ranges where the river originates, shows the first signs of Plecoptera, with *Zelandoperla* and *Zelandobius* being present.

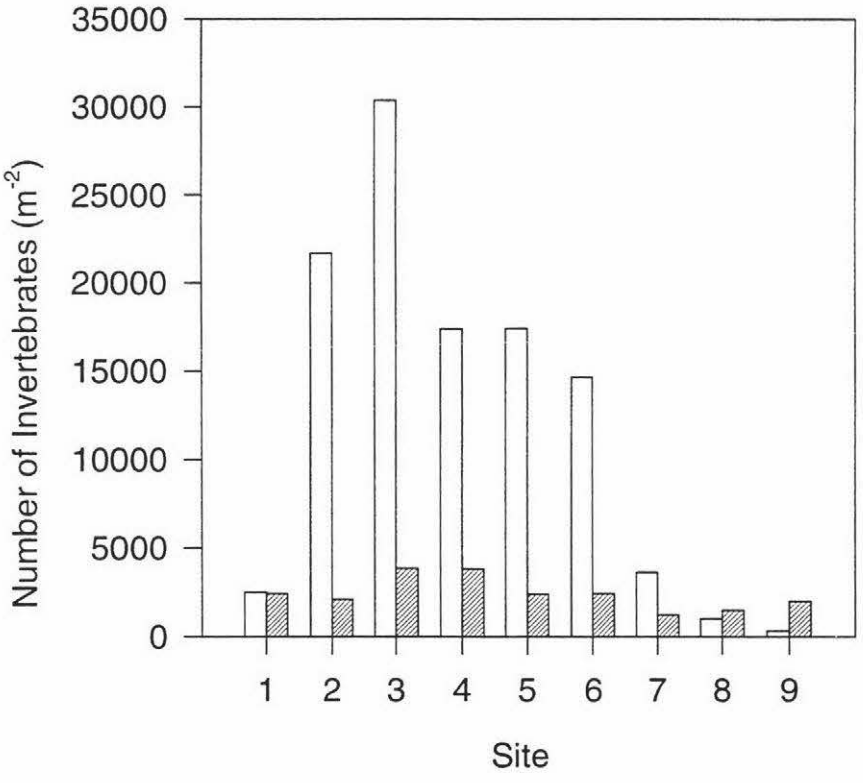



Fig. 4.2. Number of invertebrates found at each site along the two rivers. Open bars = Tukituki river, shaded bars = Ngaruroro river. Site 1 refers to sites T1 and N1, Site 2 to T2 and N2, etc.

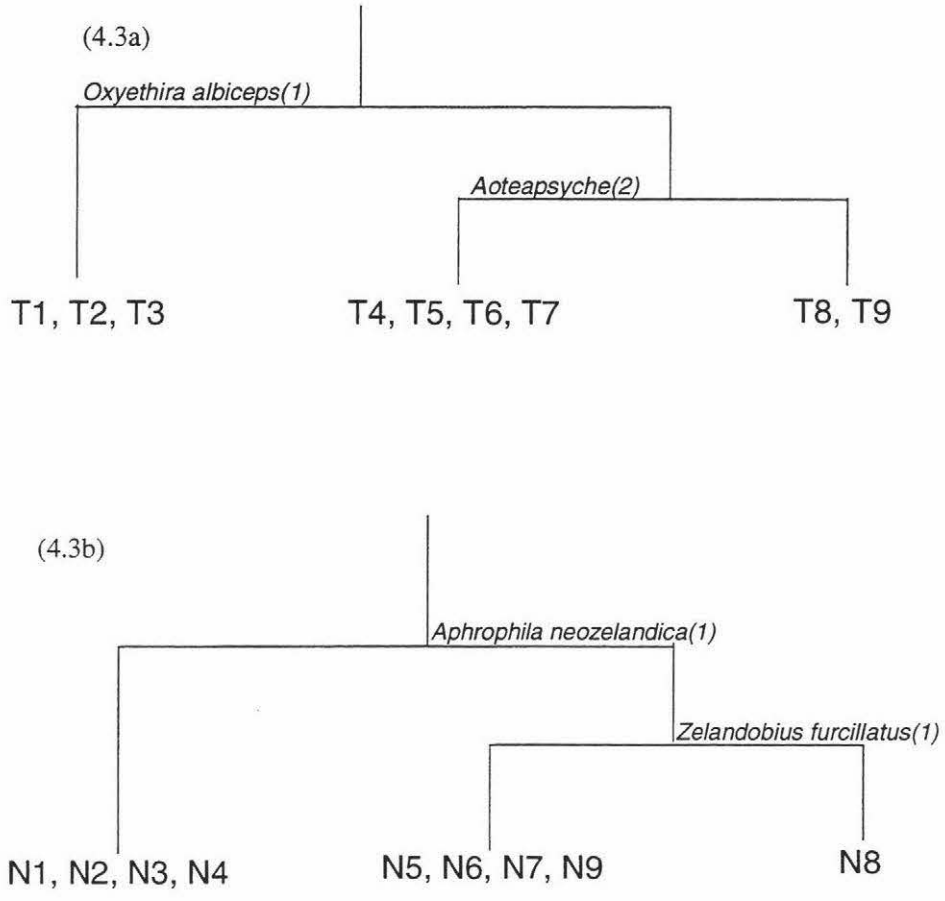



Fig. 4.3. Dendrogram showing the results of the TWINSPAN analysis on the (a) Tukituki River and (b) the Ngaruroro River.

The third group consisted of the two most upstream sites on the Tukituki river (Sites T8 and T9). These sites are upstream of farmland in areas dominated by native vegetation. Plecoptera was found to be the most dominant order, with Ephemeroptera and Coleoptera making up most of the rest of the community composition (Fig. 4.4). Crustacea and the minor classes were completely absent and there was only a single Mollusc specimen collected. This third group had a much lower density of invertebrates than the other two groups. Group 3 had a mean of 668 individuals $m^{-2}$, as compared with means of 18162 and 13262 individuals $m^{-2}$ for

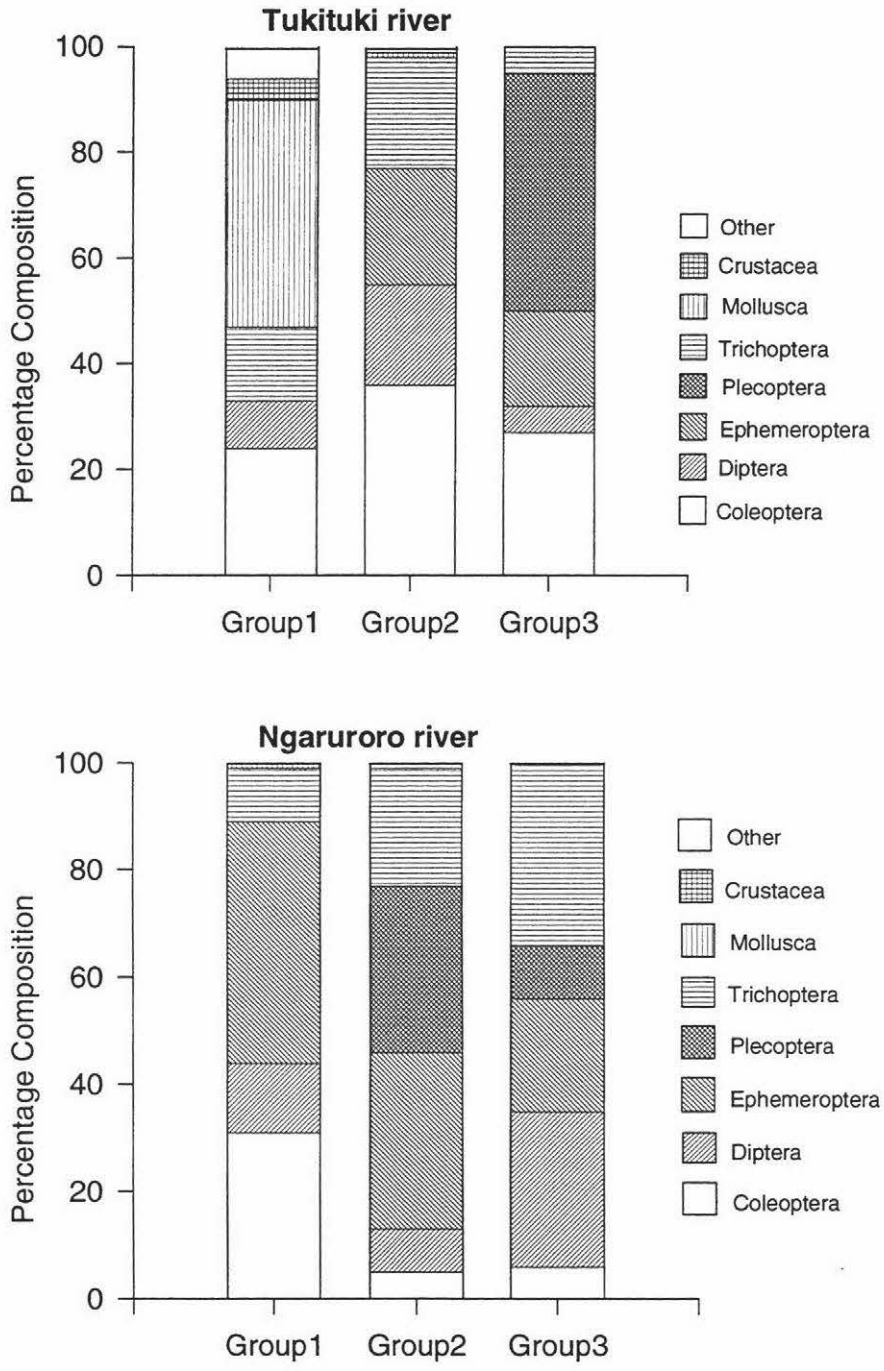



Fig. 4.4. Percentage composition by Order of macroinvertebrate communities in the Tukituki river and Ngaruroro river. The group refers to the grouping derived from the TWINSPAN analysis (see Fig. 4.3).

Group 1 and Group 2, respectively. Both sites in Group 3 had MCI scores greater than 130, indicating no pollution.

### 4.4.2. Ngaruroro River

A summary of the environmental variable measurements recorded for each site on the Ngaruroro river is shown in Table 4.2. Gradient increased up to site N6 but then decreased at site N7 before increasing again. Width and conductivity both decreased, while substrate size showed a general increase upstream. Sites N1 and N2 were very deep (>1m) but in general depth showed little pattern. For the four sites where current velocity was recorded, a pattern similar to the Tukituki river was found, with velocity increasing up to N7 and then decreasing. Farmland was the dominant landuse at Sites N1 to N4. Forest, both native and exotic, dominated the next two sites before tussockland becomes the dominant vegetation at the three most upstream sites. The forested and tussockland sites were most physically stable, while the highest canopy cover was recorded at the forested sites. Temperature was lowest in the four most headwater sites but this would be largely because they were sampled in winter as opposed to late summer and early autumn. Dissolved oxygen concentration generally increased from Sites N1 to N5 where it was sampled. Little leaf litter or periphyton was found at any point sampled on the Ngaruroro River, although there was about a 10% covering of moss at site N8. Fifty invertebrate taxa were identified from the Ngaruroro River with a total of 10822 individuals. Thus, while there were more taxa identified from the Ngaruroro river than the Tukituki river, only about a fifth of the number of individuals were collected. Site N1 contained the fewest number of taxa (12) while Site N5 had the most (30)(Fig. 4.1).

Macroinvertebrate diversity was generally highest from Sites N3 to N6 and Sites N8 and N9. Abundance was highest at Site N3 where 3820 invertebrates $m^{-2}$ were recorded. The lowest abundance was 1218 invertebrates $m^{-2}$ at site N7 (Fig. 4.2).

Table 4.2. Environmental variable measurements for the Ngarururo river. T = trace amounts, F = farmland, NF = native forest, EF = exotic forest, Tuss = tussockland, DO = Dissolved Oxygen, MCI = Macroinvertebrate Community Index.

| | Site | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | N1 | N2 | N3 | N4 | N5 | N6 | N7 | N8 | N9 |
| Dist. from Coast (km) | 18.0 | 24.6 | 54.9 | 61.9 | 100.1 | 128.7 | 148.7 | 160.5 | 160.8 |
| River Order | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5 | 4 |
| Altitude(m) | 20 | 50 | 145 | 180 | 480 | 705 | 910 | 970 | 970 |
| Gradient(°) | 0.13 | 0.18 | 0.23 | 0.27 | 0.34 | 0.5 | 0.31 | 0.49 | 0.49 |
| Current Velocity (m/s) | - | - | - | - | - | 0.67 | 1.28 | 1.06 | 0.81 |
| Average Depth (cm) | 100+ | 100+ | 36.6 | 42.2 | 46.8 | 40.6 | 29.8 | 36.6 | 26.6 |
| Average Width (m) | 50 | 32 | 40 | 21 | 19.4 | 20 | 16.7 | 10.5 | 9.5 |
| Canopy Cover (%) | 0 | 0 | 0 | 0 | 5 | 10 | 1 | 0 | 0 |
| Conductivity (mS/cm) | 0.12 | 0.11 | 0.1 | 0.08 | 0.08 | 0.06 | 0.04 | 0.03 | 0.03 |
| Temperature (°C) | 18.1 | 17.1 | 15.9 | 17.1 | 17.7 | 4.9 | 5.4 | 7 | 6.6 |
| Leaf Litter (%) | T | 1 | 2 | T | 2 | 0 | T | T | T |
| DO (mg/l) | 8.65 | 9.65 | 10.84 | 10.56 | 11.3 | - | - | - | - |
| Land Use | F | F | F | F | EF,NF,F | NF | Tuss | Tuss | Tuss |
| Periphyton Cover (%) | 5 | 0 | T | T | 2 | T | 0 | 0* | T |
| Periphy. AFDW ($g/m^2$) | 5.0 | 2.3 | 1.4 | 16.5 | 4.5 | 3.3 | 1.4 | 2.3 | 4.3 |
| Chl. *a* conc. ($mg/m^2$) | 2.0 | 1.9 | 0.1 | 79.7 | 0 | 0 | 0.4 | 0 | 3.9 |
| Stability | 49 | 36 | 37 | 51 | 69 | 87 | 78 | 82 | 58 |
| Substrate Index | 5.06 | 5.35 | 5.60 | 5.70 | 6.43 | 6.15 | 6.06 | 6.16 | 5.75 |
| MCI | 98 | 87 | 114 | 119 | 134 | 134 | 133 | 128 | 135 |

*10% moss was found at site N8

The TWINSPAN analysis classified sites N1 to N4 together at the first level of division with *Aphrophila neozelandica*(1) being the indicator species for sites N5 to N9 (Fig. 4.3b). Site N8 was separated from N5, N6, N7 and N9 at the next division with *Zelandobius furcillatus*(1) being the indicator species for N8.

Like the Tukituki river, the sites that are located closest to the coast were classified together (N1 - N4). However, in contrast to the Tukituki River, Ephemeroptera were found to be the most dominant Order in this grouping, with Coleoptera also

making up a large percentage of the community (Fig. 4.4). Diptera and Trichoptera made up most of the rest of the community in this group. Unlike the Tukituki River where Molluscs made up over 40% of the macroinvertebrate community in this coastal grouping, in the Ngarururoro river they were only rarely found. Plecoptera, Crustacea and "Other" only made up very small percentages of Group 1 on the Ngarururoro river.

The second group consisted of all the sites on the rest of the river that were sampled, except Site N8. The Orders Ephemeroptera and Plecoptera were roughly equally dominant in this group, but Trichoptera was also a major component (Fig. 4.4). Coleoptera and Diptera effectively made up the rest of the community in this group.

The third group, which consisted of just Site N8, was dominated by Trichopterans and Dipterans. Ephemeroptera made up 21% of the community, while Plecoptera made up 11% and Coleoptera 6% (Fig. 4.4).

### 4.4.3. Tukituki River and Ngarururoro River Combined

The results of a TWINSPAN analysis carried out on all 18 sites from the two rivers is shown in Fig. 4.5. Sites T1 to T3 are separated from the rest of the sites at the first division with *Paroxyethira hendersoni*(1) being the indicator species. *Zelandoperla*(1) was the indicator species for the second division which separated Sites T4 to T6 and N1 to N3 from the remaining sites. Sites T4 to T6 are then separated from N1 to N3 by the presence of Chironomidae(3). *Aoteapsyche*(1) is the indicator for the next division that separated Site T9. The final division separated Sites N4 and N8 from sites N5, N6, N7, N9, T7 and T8 on the presence of *Zelandobius*(1). This dendrogram is divided into three main zones (Fig. 4.5). Zone 1 consists of the three most coastal Tukituki river sites. The middle Tukituki River sites and three most coastal Ngarururoro sites make up Zone 2, while Zone 3 contains the headwater sites of both rivers.

## 4.5. DISCUSSION

In both the Tukituki and Ngaruroro rivers, longitudinal changes in the macroinvertebrate community composition were evident. However, the two rivers showed several differences from each other, both in terms of community composition and taxa richness and abundance.

The sites near the coast on the Tukituki river were dominated by taxa that have either broad habitat tolerance levels (e.g. Elmidae larvae), or are more characteristically found in areas of reasonably high organic enrichment e.g. Chironomidae, Mollusca and other minor groups (Oligochaetes, Planarians and

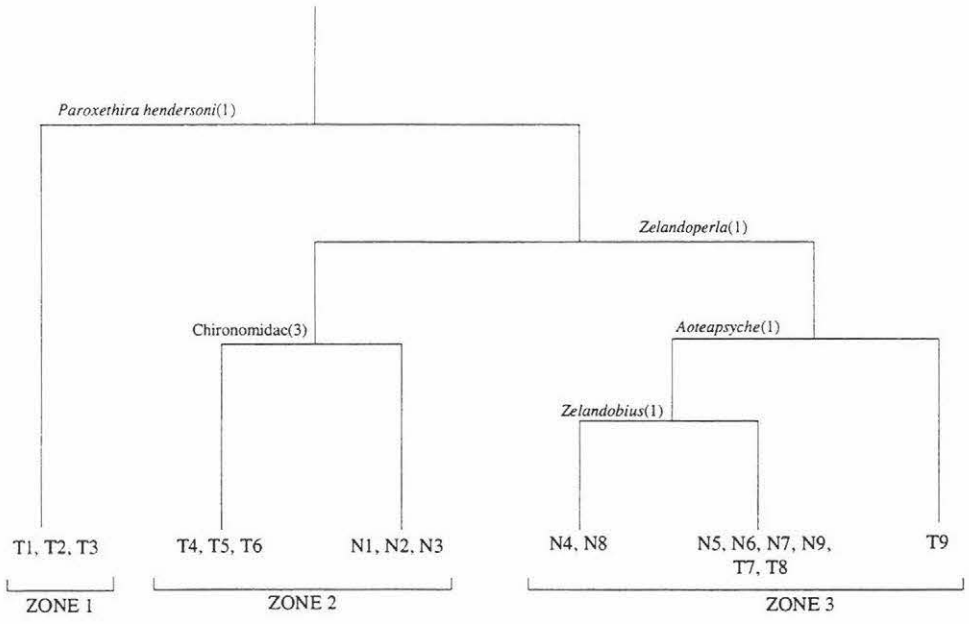



Fig. 4.5. Dendrogram showing the results of a TWINSPAN analysis on all 18 sites from the two study rivers. The three main zones identified are shown.

Hirudinea, in particular). Even the Trichopteran larvae that were found in Group 1 on the Tukituki river generally consisted of taxa that show high tolerance levels to enrichment such as Hydroptilidae larvae (*Oxyethira albiceps* and *Paroxyethira* spp.), and *Aoteapsyche*. This observation is supported by the Macroinvertebrate Community Index (MCI) scores recorded at these sites which were all well below 100, indicating low water quality.

The sites in Group 2 on the Tukituki river show quite a large change in community composition from the sites lower down the river. Group 2 sites are situated on a part of the river that has broad floodplains and often has freshes (Hawkes Bay Regional Council and Regional Water Board, 1987), making it unsuitable for invertebrates such as Molluscs and Crustacea. This may explain why they are almost absent from this zone.

As expected, the two most headwater sites on the Tukituki river in Group 3 were dominated by taxa characteristically found in high water quality, such as Plecopterans and Ephemeropterans. Little or no modification was indicated by the high MCI scores.

To understand why particular invertebrate communities are found where they are on a river, it is important to understand how particular land use practices could affect invertebrates. For example, farmland releases more nutrients, which means higher organic enrichment/pollution in the waterways through runoff and groundwater seepage. Only certain invertebrates can live and thrive in these enriched waters. Forest sites generally had greater habitat heterogeneity (e.g. wider range of substrate sizes), so higher diversity would be expected. The Tukituki river contained exceptionally high densities of invertebrates in Sites T2 to T6. All of these sites are located amongst high producing farmland and probably experience high levels of organic enrichment from fertilisers. It has been found that organic enrichment often results in large increases in invertebrate biomass or density, although there is also a corresponding decrease in number of taxa (Welch, 1980; Mason, 1981; Penny, 1985). Although no decrease in taxa richness was detected, it is probable that

organic enrichment is causing the high densities of invertebrates in the Tukituki river. Because Site T1 is also situated on high producing farmland near the coast, it too would be expected to have extremely high densities of invertebrates, but this was not the case. T1 is located just a few hundred meters from the coast and is subject to tidal influence. Therefore, this site is probably effected to some extent by such factors as salt spray, which would in turn effect the invertebrates. A shingle extraction site was also located a few hundred meters upstream and disturbance from the associated activities may also be adversely effecting the invertebrates.

The Ngaruroro river shows a small increase in macroinvertebrate abundance once the river flows out of the ranges onto farmland, but the increase is far less marked than that seen on the Tukituki river. This perhaps indicates that organic enrichment is not as severe on the Ngaruroro river as it is on the Tukituki river, and the changes observed in the community composition between Group 1 and Group 2 on the Ngaruroro river are probably due to habitat related influences such as stability (Group 1 has lower stability than Group 2) or substrate size (gravel and small cobbles were the dominant substrate size in Group 1, as opposed to a predominance of large cobble in Group 2).

Surprisingly, Group 1 on the Ngaruroro river is unlike Group 1 on the Tukituki River. In fact, it is almost analogous to Group 2 on the Tukituki river by having very few Molluscs, Crustacea and Other, but high numbers of Coleoptera and Ephemeroptera (with nearly all of the Ephemeroptera being *Deleatidium* spp.). This close relationship is shown in Fig. 4.5 with these two groups being clustered close together in Zone 2. This may reflect low to medium levels of organic pollution, similar to levels on the Tukituki river where Group 2 is located. These sites also have low stability and little periphyton, perhaps making them unsuitable for such macroinvertebrates as mollusc grazers.

Since sites in Group 2 on the Ngaruroro river have cool water temperatures, and native vegetation surrounding them, it would be expected to be dominated by

Ephemeropterans and Plecopterans, and indeed, this was the case. Trichopterans characteristic of high water quality (Stark, 1985, 1993) were also quite common.

Group 3, consisting of site N8, would be expected to be clustered in with Group 2 because it has very similar environmental measurements. The only major difference is site N8 had about 10% moss in the river. This moss may have resulted in the different community composition, with species such as *Zelolessica cheira* which are associated with moss (Cowie and Winterbourn, 1979) being present only at this site.

Although the Ngarururoro and Tukituki river's are of similar catchment size, they vary in a number of ways that have effects on the invertebrate communities. Perhaps the most important difference between the two rivers is how much of their length flows through native vegetation. The Tukituki river is modified to some extent for over 90% of its length, whereas the Ngarururoro river has only 40% of its main river length flowing through land that has been modified for human uses. The effect of this can be seen with the invertebrates, with species that are associated more with "cleaner" water, such as Plecopterans, being absent much earlier on the Tukituki river. Taxa that are much more prevalent in modified rivers such as chironomids, Hydroptilidae larvae, and oligochaetes, are also far more abundant in the Tukituki river than the Ngarururoro river. Some of the differences between the Tukituki River and the Ngarururoro River could be due to river depth. Rivers that are more shallow have been found to have greater macroinvertebrate abundance (Jowett et al., 1991) and over much of the length of the two rivers, the Ngarururoro River is both wider and deeper than the Tukituki River.

This study indicates that the differences between rivers are not necessarily bigger than the difference in zonation pattern within rivers. This is most obvious with the similarities in community composition between Group 2 on the Tukituki River and Group 1 on the Ngarururoro River shown in Fig. 4.4 and Fig. 4.5 (Zone 2). Zone 3 of Fig. 4.5 also identifies the headwater sites of the two rivers as being quite similar. Therefore, it appears likely that different rivers still contain similar zones. These zones appear to correspond well with water quality, i.e. Zone 1 contains sites that

score very low on the MCI, Zone 2 sites have low to medium MCI scores, and Zone 3 contains high MCI scoring sites (see Tables 1 and 2). Because sampling on the Ngaruroro River didn't extend right to the coast, it is possible that there are areas on this river that would cluster with the Tukituki River sites in Zone 1. Corkum (1989) also suggested that there are similar zones of macroinvertebrate assemblages along different rivers. She related these zones to uniformity of landscape or biome.

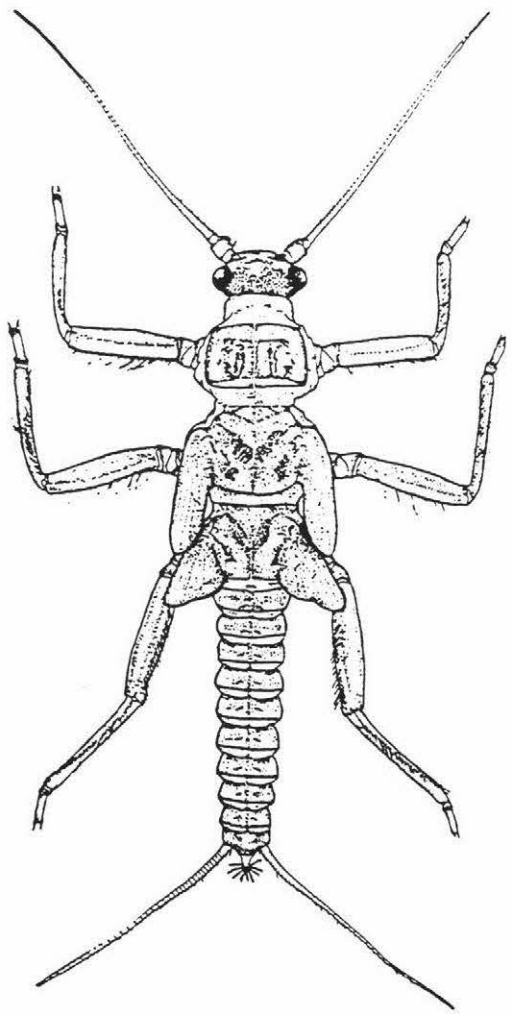
I have not attempted to describe the invertebrate communities in terms of functional feeding groups in this chapter. This is because the dominance of collector/browser on most parts of the river means that there is very little discernible pattern in functional feeding groups from the headwaters to the coast. The only sites where there wasn't a major dominance by collector/browsers was on the lower parts of the Tukituki river where *Potamopyrgus*, a mollusc grazer, was present in higher numbers. This conflicts with the River Continuum Concept which predicts other functional feeding groups to play a large role on the various parts of the rivers (Vannote et al., 1980; Minshall et al., 1985). Other problems with this type of classification are that many invertebrates span more than one functional feeding group eg. collector/browser or collector/filterer, and some invertebrates change their grouping as they mature from early instar to later instars. Most larvae of New Zealand aquatic insects also show little evidence of food specialisation (Winterbourn et al., 1981).

This study provides some support for the contention that longitudinal changes in invertebrate communities may be due to local human influences which create discontinuities (Bournaud et al., 1996; Crunkilton and Duchrow, 1991). Findings in this study indicate that invertebrates do not distribute themselves to utilise food/resources at the optimum level as proposed by Vannote et al. (1980), but are determined by the degree and type of human disturbance predominating in that section of the river. Invertebrate communities can be predicted to a certain extent as distance from coast increases, but this change is more likely to be due to changes in water quality from human influences than any predictable change to utilise resources. The RCC would predict a gradual and predictable change in macroinvertebrate

community to occur on both rivers. However, both rivers show a rapid change over to more pollution tolerant macroinvertebrates as soon as they flow out of the ranges, which indicates a human influence. The RCC was developed for natural stream systems (Vannote et al., 1980). However, there are very few stream systems that are not modified to some extent. It could be that rivers have a continuum, but disturbances and local impacts on the rivers overrides this continuum of invertebrate communities and causes a clustering of sites, or zonation effect on the rivers. This has led to attempts to clarify, expand, and refine the concept to encompass broader spatial and temporal scales, including climatic and geology, tributaries, location-specific lithology and geomorphology, and long term changes imposed by man (Minshall et al., 1985). Despite this, a number of studies still fail to support the RCC. For example, Bournaud et al. (1996) study of the Rhône River found that longitudinal changes in macroinvertebrates were not continuous. The differences were related to human disturbance such as regulation or pollution and to the effect of a main confluence. Similarly, Cowie (1985) failed to find support for the concept in a southern New Zealand montane stream, stating that the concept disregards the fundamental role played by physical instability in determining faunal characteristics and cannot realistically be applied to unstable stream systems.

# CHAPTER 5:

# ASSESSMENT OF WATER QUALITY IN RIVERS: COMPARING BIOTIC INDICES AND CANONICAL CORRESPONDENCE ANALYSIS



# CHAPTER 5:

# ASSESSMENT OF WATER QUALITY IN RIVERS: COMPARING BIOTIC INDICES AND CANONICAL CORRESPONDENCE ANALYSIS

## 5.1. INTRODUCTION

Benthic macroinvertebrates are normally abundant and important components of lotic systems (Quinn and Hickey, 1990a) and are easily the most commonly used group of freshwater organisms for the assessment of water quality (Rosenberg and Resh, 1993; Resh et al., 1995). This is because of their relatively sedentary nature and long life spans, ease of sampling, inability to easily avoid harmful environmental changes, and varying tolerance to pollution (Lenat, 1988; Quinn and Hickey, 1990a; Crunkilton and Duchrow, 1991).

There are very few rivers that remain in their natural state, and changes in macroinvertebrate community composition due to human effects on water quality, such as sewage input or habitat destruction, are the norm on most river systems (Zamora-Muñoz and Alba-Tercedor, 1996). Because of this, the use of macroinvertebrates as bioindicators of water quality, through indices such as the MCI (Stark, 1985, 1993), EPT (Lenat, 1988), and BMWP (Armitage et al., 1983; Wright et al., 1988), has become well established. In addition, the use of multivariate analysis such as Two Way INdicator SPecies ANalysis (TWINSPAN), DEtrended CORrespondence ANAlysis (DECORANA) and Canonical Correspondence Analysis (CCA), which classify and

ordinate sites on the basis of macroinvertebrate composition (e.g.; Moss et al., 1987; Whittier et al., 1988; Wade et al., 1989; Quinn and Hickey, 1990a; Rutt et al., 1990; Richards et al., 1993; Gower et al., 1994; Collier, 1995) are commonly used in studies of lotic systems (Zamora-Muñoz and Alba-Tercedor, 1996).

The most commonly used biotic index for monitoring freshwater ecosystems in New Zealand is the Macroinvertebrate Community Index (MCI)(Stark, 1985) and variations of this index such as the Quantitative Macroinvertebrate Community Index (QMCI). The MCI was developed from the British Biological Monitoring Working Party Score System (BMWP)(Armitage et al., 1983; Stark, 1993) and in New Zealand was first applied to streams in the Taranaki region. It relies on prior allocation of scores (between 1 and 10) to taxa of freshwater macroinvertebrates based upon their pollution tolerances. Tolerant taxa score lower than taxa more characteristic of pristine conditions. The main problem with the MCI is that it was developed only for stony streams. When applied to streams that have a sandy or silty bottom, MCI scores for sites are often inaccurate. This is because these types of habitat support quite different macroinvertebrate communities from stony streams, comprising, on average, lower scoring taxa (Stark, 1993).

Another index for assessing water quality is the number of Ephemeropteran, Plecopteran and Trichopteran taxa (EPT) (Lenat, 1988). This index has been used in a number of New Zealand studies (e.g. Quinn and Hickey, 1990a, 1990b; Collier, 1995), as well as overseas (e.g. Richards et al., 1993). The EPT score is derived simply by summing the number of Ephemeropteran, Plecopteran and Trichopteran taxa found at each site. The rationale behind this is that these Orders of insects are generally only found in water of high quality, so a high EPT score indicates high water quality, whereas a low score would indicate high levels of pollution. This index could also suffer from the same problem as the MCI, as many taxa in these Orders favour coarse substrates. Another problem is that taxonomic revisions can alter the EPT score, e.g. a new key allowing identification of taxa to a lower level will inflate future EPT scores.

In chapter 2, two multivariate techniques, TWINSPAN and DECORANA, were used to characterise and classify 52 sites in Hawkes Bay. In this chapter I will use a related multivariate technique, Canonical Correspondence Analysis (CCA), which examines relationships between sites, species and environmental variables directly to determine the main environmental factors affecting macroinvertebrate distribution. It does this by escaping the assumption of linearity and is able to detect unimodal relationships between taxa and external variables. If water quality is a major influence on macroinvertebrate communities in the sites studied, this should be evident from the CCA ordination diagram. The effectiveness of the MCI and EPT biotic indices can then be tested by comparing them with the environmental axes derived from CCA.

## 5.2. METHODS

Apart from the data analysis, the study sites and methods are as described in chapter 2.

### 5.2.1. Data Analysis

The MCI is a simple index that requires only presence/absence data. A site score is obtained by summing the individual taxa scores and dividing this total by the number of taxa present at the site. Taxa scores were obtained from Stark (1993). However, nine of the less common taxa did not have MCI scores allocated to them by Stark (1993) they were omitted. Because chironomids were not identified below family level, they were assigned an MCI score of 3 (Stark, 1985). The site score is then multiplied by 20 to give a value between 0 and 200. A site score of less than 100 indicates a high level of pollution. A score of 100 to 120 indicates a moderate level of pollution, while slightly enriched or pristine sites are indicated by scores over 120 (Stark, 1985).

Eight sites were excluded because there was no data for most of the environmental variables (sites 16, 17, 18, 52, 53, 54, 56 and 57). This reduced the number of sites analysed to 44.

Canonical Correspondence Analysis was performed using CANOCO version 3.12 (ter Braak, 1986, 1988). This ordination technique detects the patterns of variation in community composition that can be best explained by the environmental variables. Two CCAs were performed, one which used semi-quantitative data, and because the two community indices require only presence/absence information, another CCA was performed that was based only upon presence/absence data. The option of downweighting rare species was applied when using the semi-quantitative data (Hill, 1979a).

A Monte Carlo permutation test was used to test the significance of the first canonical axis (ter Braak, 1988). This non-parametric test compares the actual ordination with a set based on a simulated distribution derived from random permutations of the environmental variables with placement in the 95th percentile or above indicating a significant ordination of the first axis (Richards et al., 1993).

Pearson correlations between the MCI and EPT scores and the first two axes scores from the CCA were also calculated.

## 5.3. RESULTS

Macroinvertebrate community characteristics of the sites are described in chapter 2.

### 5.3.1. Ordination of Semi-Quantitative Data

Initially, a total of 28 environmental factors were used for the CCA's. However, eight of these were found to have variance inflation factors greater than 20 (indicating strong multicollinearity) and were therefore removed from the analysis (ter Braak, 1988). These were alkalinity, chloride, hardness, magnesium, calcium, sodium, ammonia, and bicarbonate. All these variables were highly correlated with each other, and with conductivity which remained in the analysis.

Table 5.1 shows the summary statistics of the CCA ordination. The species-environment correlation coefficients were high indicating that the environmental variables were able to explain much of the variation in community composition. The Monte Carlo permutation test indicated that the first axis was significant ($p<0.05$).

The results of the CCA ordination for the semi-quantitative taxa data are displayed in Fig. 5.1. The orientation and length of the line for each environmental factor reflects the direction of maximum change and relative importance of that environmental factor on community composition. The longer the line the more influence that environmental factor has over community composition. Therefore, if Fig. 5.1c was superimposed over Fig. 5.1a or Fig. 5.1b, those species or sites that have positions close to the end of a line will be strongly positively correlated with and influenced by the environmental variable represented by that line. Species or sites that lie near the origin will have intermediate levels of all environmental factors. The relative contribution of each environmental variable to the first two axes is reflected in their weighted intraset correlations (Table 5.2).

Three main groupings of environmental variables can be seen in Fig. 5.1c and these are summarised in Fig. 5.1d. The variables most strongly positively correlated with Axis 1 are measures of chemical composition, in particular $SO_4$, K and conductivity (Table 5.2). The environmental factors that were removed because of high inflation factors

were strongly correlated with conductivity and so these too would have strong positive correlations with Axis 1. Substrate related factors have a strong negative correlation with Axis 1 (i.e. substrate size, gradient and to a lesser extent stability), but they also have a reasonably strong positive relationship with Axis 2 (Table 5.2). The environmental variables found to be most strongly correlated with Axis 2 were pH, leaf litter, AFDW and chl *a* (Table 5.2). The last three of these are macroinvertebrate food sources (Biggs, 1990, 1995; McAuliffe, 1984; Cummins, 1974) so Fig. 5.1d identifies these variables under "food". Taxa located on the far right of Fig. 5.1a, consisting predominantly of Crustacea, Mollusca, Odonata and Hemiptera, were tolerant of high

Table 5.1. Results of canonical correspondence analysis (CCA) using semi-quantitative and presence/absence taxa data.

| Axes | 1 | 2 | 3 | 4 | Total Inertia |
|---|---|---|---|---|---|
| **Semi-Quantitative** | | | | | |
| Eigenvalues | 0.358 | 0.146 | 0.127 | 0.100 | 2.055 |
| Species-environment correlations | 0.902 | 0.951 | 0.947 | 0.905 | |
| Cumulative percentage variance | | | | | |
| of species data | 17.4 | 24.5 | 30.7 | 35.6 | |
| of species-environment relation | 28.9 | 40.7 | 50.9 | 59.0 | |
| Sum of all unconstrained eigenvalues | | | | | 2.055 |
| Sum of all canonical eigenvalues | | | | | 1.239 |
| **Presence/Absence** | | | | | |
| Eigenvalues | 0.476 | 0.289 | 0.213 | 0.186 | 4.308 |
| Species-environment correlations | 0.944 | 0.914 | 0.946 | 0.941 | |
| Cumulative percentage variance | | | | | |
| of species data | 11.1 | 17.8 | 22.7 | 27.0 | |
| of species-environment relation | 20.0 | 32.1 | 41.1 | 48.9 | |
| Sum of all unconstrained eigenvalues | | | | | 4.308 |
| Sum of all canonical eigenvalues | | | | | 2.381 |

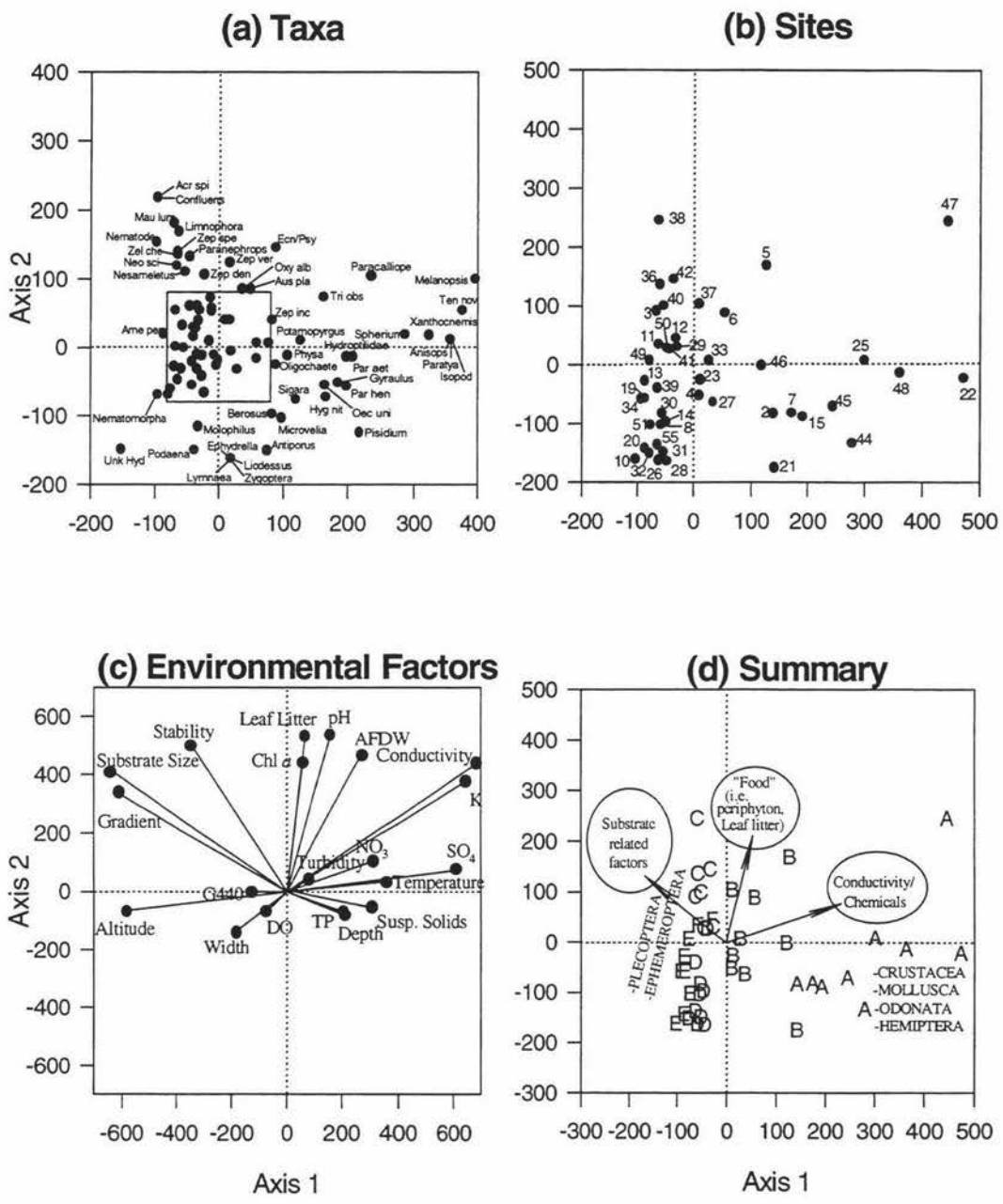



Fig. 5.1. CCA ordination using semi-quantitative taxa data. (a) Ordination of taxa. See appendix 1 for names of abbreviated taxa. Unnamed taxa within the central box include taxa that are generally widely distributed and show little effect from either axis or their optima in conditions may be represented by the middle of the diagram. (b) Ordination of sites. See Fig. 2.1 for river names. (c) Ordination of environmental variables. (d) Summary of the three previous graphs. Letters refer to the bioregions identified in chapter 2.

Table 5.2. Weighted intraset correlations of environmental variables with the first two axes of canonical correspondence analysis (CCA) for semi-quantitative taxa data. Asterisks refer to log transformed variables. † refers to arcsine transformation.

| Variable | Axis 1 | Axis 2 |
|---|---|---|
| Conductivity ($\mu S\ cm^{-1}$)* | 0.684 | 0.438 |
| K ($mg\ L^{-1}$)* | 0.645 | 0.377 |
| $SO_4$ ($mg\ L^{-1}$)* | 0.612 | 0.076 |
| Temperature (°C) | 0.360 | 0.031 |
| $NO_3$ ($mg\ L^{-1}$)* | 0.313 | 0.103 |
| Total phosphorus ($mg\ L^{-1}$)* | 0.309 | -0.055 |
| AFDW ($g\ m^{-2}$)* | 0.275 | 0.464 |
| Depth (cm)* | 0.214 | -0.081 |
| Suspended Solids ($mg\ L^{-1}$)* | 0.208 | -0.070 |
| pH | 0.159 | 0.536 |
| Turbidity (NTU)* | 0.084 | 0.040 |
| Leaf Litter (%)† | 0.067 | 0.531 |
| Chl a ($mg\ m^{-2}$)* | 0.060 | 0.439 |
| Dissolved Oxygen (ppm) | -0.075 | -0.070 |
| G440* | -0.129 | -0.004 |
| Width (m)* | -0.182 | -0.142 |
| Stability | -0.345 | 0.498 |
| Altitude (m)* | -0.583 | -0.071 |
| Gradient (degrees)* | -0.613 | 0.338 |
| Substrate Index | -0.641 | 0.406 |

levels of dissolved minerals, small substrate sizes and low gradients. These taxa and environmental conditions are characteristic of the sites located to the far right of Fig. 5.1b (e.g. sites 47, 48, 22, 25). The unnamed taxa located in the central box of Fig. 5.1a consist predominantly of Ephemeroptera, Plecoptera and some Trichoptera. All of these

taxa show a preference for lower chemical concentrations, but a wider range of preference to "food", stability and pH. In the summary graph of Fig. 5.1d the bioregions identified in chapter 2 from a TWINSPAN analysis have been substituted for the appropriate site. Sites in bioregion A have the highest chemical concentrations, followed by sites in bioregion B. Although bioregions C, D and E all show little variation along Axis 1, they show quite wide preferences along Axis 2. Bioregion C sites are more stable with larger substrate sizes and may contain, large amounts of "food". Bioregions D and E generally have low amounts of "food". Bioregion F showed little relationship to either axis.

Pearson correlations between the MCI score for each site and the two axes of the site ordination indicated a strong negative correlation with axis 1 ($r=-0.88$, $p<0.0001$) but no relationship with Axis 2 ($r=0.049$, $p=0.752$). This indicates that MCI has an inverse relationship with chemical concentration. The EPT index had a negative relationship with Axis 1 ($r=-0.65$, $p<0.0001$) and a positive relationship with Axis 2 ($r=0.434$, $p<0.01$). This also indicates a negative correlation with mineral concentrations and chemicals but there is an even closer relationship between EPT and substrate related factors.

The correlation between MCI scores for each taxon (ranging from 1 for pollution tolerant taxa to 10 for taxa that require high water quality) and the Axis 1 score for that taxon indicates a significant negative relationship ($r=-0.452$, $p<0.0001$).

### 5.3.2. Ordination of Presence/Absence Data

A total of 28 environmental factors were investigated initially in the presence/absence CCA, however nine of these were found to have inflation factors greater than 20 and were therefore removed from the analysis. These included the same eight removed from the semi-quantitative CCA, plus potassium.

The summary statistics for the CCA ordination on the presence/absence data is shown in Table 5.1. Species-environment correlation coefficients were high indicating that the environmental variables could explain a lot of the variation in community composition. The Monte Carlo permutation test indicated the first axis was significant ($p<0.05$).

Fig. 5.2 displays the results of the CCA ordination for the presence/absence data. Interpretation of these graphs is as described for Fig. 5.1. The relative contribution of each environmental variable to the first two axes is reflected in their weighted intraset correlations (Table 5.3). Two main groupings of environmental variables have been identified. The variables with most influence on Axis 1 are conductivity and $SO_4$. The environmental variables removed because of high inflation factors were highly correlated with conductivity and so would have a high correlation with Axis 1 as well. Like the semi-quantitative data, substrate related factors such as gradient, altitude and substrate size were negatively correlated with Axis 1. Gradient was also the most significantly correlated variable with Axis 2 (Table 5.3).

The presence/absence data resulted in a higher degree of clumping of taxa within the central box of Fig. 5.2a than was found with the semi-quantitative data. Taxa located to the right of the diagram in Fig. 5.2a are increasingly tolerant of high levels of chemicals. Sites scoring high on Axis 1 of Fig. 5.2b are characterised by high levels of chemicals. Sites to the top right of Fig. 5.2b typically are at low altitude and have low gradients and small substrate sizes. When sites are labelled by bioregions, a similar pattern to the semi-quantitative data is found with bioregion A scoring highest on Axis 1, followed by bioregion B. Bioregions C, D, E and F are not effectively distinguished by either axis.

Pearson correlations carried out between MCI and Axis 1 and Axis 2 of the site ordination indicated strong negative relationships with both Axis 1 and Axis 2 ($r=-0.737$, $p<0.0001$ for Axis 1; $r=-0.472$, $p<0.01$ for Axis 2). EPT was found to have a negative relationship with Axis 1 ($r=-0.58$, $p<0.0001$) but no correlation with Axis 2

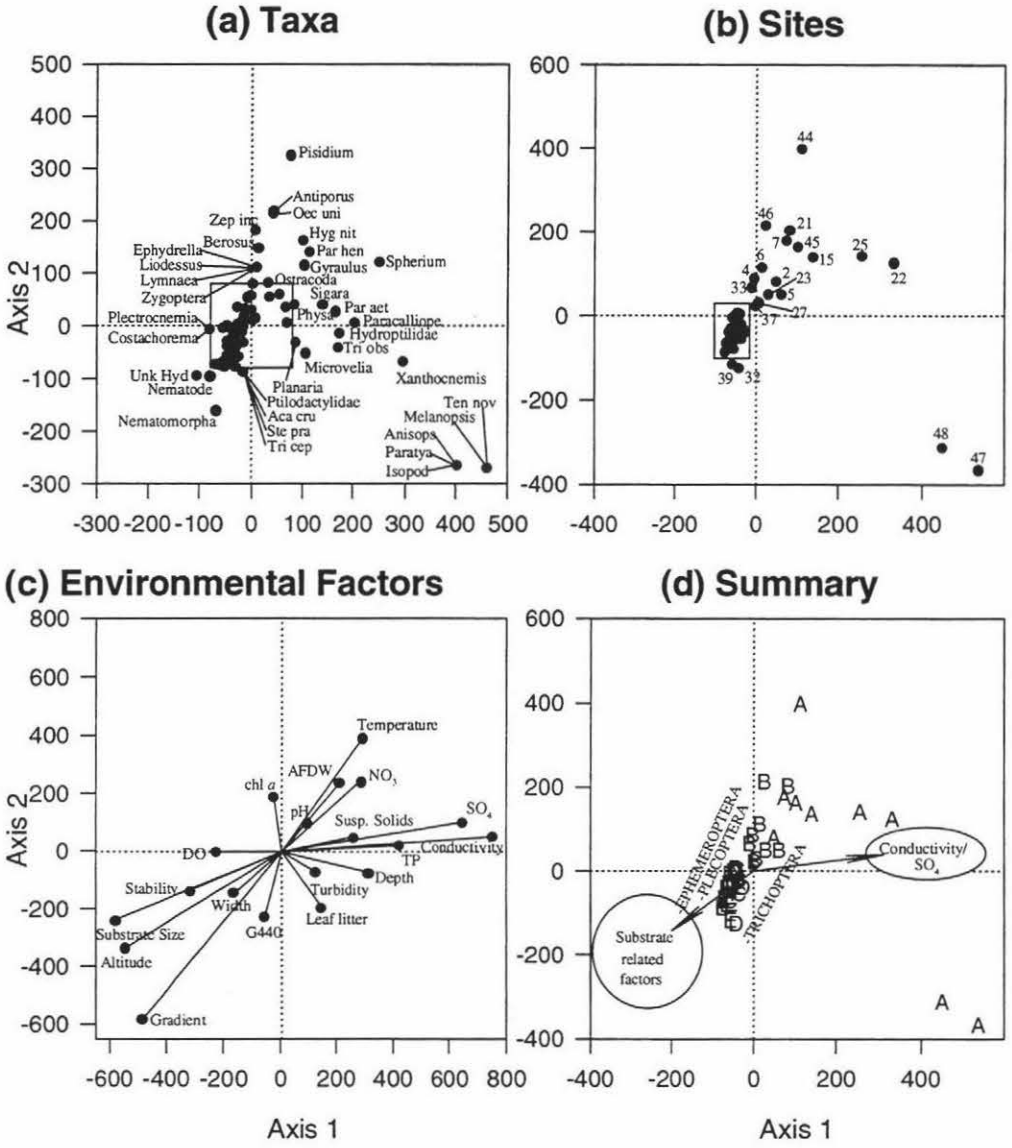



Fig. 5.2. CCA ordination using presence/absence taxa data. (a) Ordination of taxa data. See appendix 1 for names of abbreviated taxa. Unnamed taxa within the central box include taxa that are generally widely distributed and show little effect from either axis or their optima in conditions may be represented by the middle of the diagram. (b) Ordination of sites. See Fig. 2.1 for river names. Sites enclosed in the box, with decreasing score on Axis 2, are 30, 29, 28, 40, 14, 26, 42, 41, 50, 3, 19, 55, 12, 8, 31, 51, 11, 38, 49, 34, 36, 13, 20, and 10. (c) Ordination of environmental variables. (d) Summary of the three previous graphs. Letters refer to the bioregions identified in chapter 2.

(r=-0.253, p=0.098). These results also indicate there is an inverse relationship between MCI and EPT, and levels of chemicals, but there is also a strong influence from substrate related factors. In other words, water quality is not fully explained by either Axis 1 or Axis 2, but has instead a diagonal orientation on the axes. The correlation of MCI with the two axes almost exactly follows this diagonal. This shows that water

Table 5.3. Weighted intraset correlations of environmental variables with the first two axes of canonical correspondence analysis (CCA) for presence/absence data. Asterisks refer to log transformed variables. † refers to arcsine transformation.

| Variable | Axis 1 | Axis 2 |
|---|---|---|
| Conductivity (μS $cm^{-1}$)* | 0.751 | 0.048 |
| $SO_4$ (mg $L^{-1}$)* | 0.649 | 0.097 |
| Total Phosphorus (mg $L^{-1}$)* | 0.421 | 0.015 |
| Depth (cm)* | 0.317 | -0.080 |
| Temperature (°C) | 0.297 | 0.385 |
| $NO_3$ (mg $L^{-1}$)* | 0.293 | 0.235 |
| Suspended Solids (mg $L^{-1}$)* | 0.266 | 0.044 |
| AFDW (g $m^{-2}$)* | 0.214 | 0.233 |
| Leaf Litter (%)† | 0.147 | -0.200 |
| Turbidity (NTU)* | 0.127 | -0.076 |
| pH | 0.096 | 0.094 |
| Chl a* (mg $m^{-2}$) | -0.022 | 0.183 |
| G440* | -0.054 | -0.231 |
| Width (m)* | -0.164 | -0.146 |
| Dissolved Oxygen (ppm) | -0.222 | -0.007 |
| Stability | -0.313 | -0.142 |
| Gradient (degrees)* | -0.482 | -0.584 |
| Altitude (m)* | -0.543 | -0.340 |
| Substrate Index | -0.577 | -0.244 |

quality is confounded with physical factors, which is evidenced by the physical factors generally being opposite to the chemical factors in Fig. 5.2c.

Like the semi-quantitative data, a significant negative relationship between a taxa's MCI score and the taxa's Axis1 score was indicated ($r=-0.405$, $p<0.0001$).

## 5.4. DISCUSSION

Environmental variables indicative of water chemistry (such as conductivity, sulphate and potassium concentrations), as well as physical variables like substrate size, altitude and gradient, all play a major role in determining the distribution pattern of macroinvertebrates in Hawkes Bay rivers. These two sets of variables (physical and chemical) were inversely related to one another, so when a site or species was positively correlated with the chemical variables there also tended to be a negative correlation with the physical. This would be expected as sites located at higher altitudes tend to be close to, or within, hill country or mountain ranges and so have high gradients and large substrate sizes. These sort of sites usually have little or no agricultural or urban development and therefore don't receive much nutrient input in the form of fertilisers or other pollutants, and the type of geology the rivers flow over is predominantly hard igneous or metamorphic rock rather than soft sedimentary rock (Eyles et al., 1993) so less ions are dissolved in the water, and therefore lower conductivity is recorded. Hence, the 1st canonical axis, which explained the greatest amount of variation in the data, represented the change from high altitude and gradient with low conductivity and nutrient content, to lowland sites with conductivity and nutrient levels. This is similar to the findings in chapter 4 and by Zamora-Muñoz and Alba-Tercedor (1996). The major difference between the findings from this study and other studies is that physical and chemical variables explained approximately equal amounts of the variation in the macroinvertebrate data, whereas other studies have found either nutrients to explain most of the variation (e.g. Gower et al., 1994; Zamora-Muñoz and Alba-Tercedor,

1996) or nutrients were found to be of secondary importance to factors representing the quality of physical habitat (Richards et al., 1993).

The second canonical axis for the semi-quantitative data was related mainly to the amount of "food" present, although stability, pH and conductivity also had an influence. Stable sites would allow the build-up of large amounts of periphyton over time and allow the accumulation of leaf litter. It would be expected that sites with high periphyton levels would also have high nutrient levels, as nitrates, phosphorus and other nutrients have been demonstrated as playing an important role in both periphyton community structure and abundance (Chessman, 1986; Biggs, 1990; Biggs, 1995). However, in Hawkes Bay it appears that physical stability is more important in controlling periphyton abundance. Biggs and Close (1989) found that hydrological factors contribute at least equally with nutrients to differences in periphyton biomass.

Axis 2 of the presence/absence analysis indicated gradient as having most influence. Although water velocity wasn't measured, I suspect it too would come out highly correlated with Axis 2 as the higher gradients may be affecting water flow, which would have some effect on macroinvertebrate community composition.

The findings of the CCA analysis of the semi-quantitative data is quite similar to those found in the DECORANA analysis of chapter 2. That is, both analyses found Axis 1 to be highly correlated with chemicals and a number of physical variables, with measures of periphyton playing a secondary role. Perhaps the most obvious difference between the two analyses is more environmental factors are identified as playing a secondary role in determining community composition (i.e. stability, percentage leaf litter and pH) in the CCA than in the DECORANA.

It has been observed by Bargos et al. (1990) that rivers that are less perturbed showed no correlation between ordination scores and the BMWP biotic index. This was because when the main environmental variables influencing the species distributions are other

than pollution, values of this index do not change between the sites. In my study, both biotic indices were strongly correlated with the first canonical axis and are related to pollution.

Taxa scores on each canonical axis may be used to assess how well the tolerance values to water pollution given for invertebrate taxa in the MCI, fit to the measured environmental variables in the sites where taxa were found. Taxa that have low MCI scores would be expected to have high positive scores on Axis 1 of the CCA, while taxa that score high should have increasing negative scores on Axis 1. To test this, each species MCI score was correlated with Axis 1 score of that species. The results of this showed that there was a high correlation between the two for both the semi-quantitative analysis and the presence absence analysis, and this indicates that, in general, the MCI score assigned to taxa based on their tolerance to chemical pollution is correct. The MCI is intended as a measure of organic pollution (Stark, 1985), so nitrate and phosphorus, two of the main organic pollutants, would be expected to be correlated with it. However, these two factors appeared to have little effect on the CCA ordination. Instead it was the measures of chemical concentration such as potassium and conductivity that were effected most by Axis 1 and therefore MCI. Interpretation of what MCI is actually measuring is further confounded by the substrate related factors which also have a high correlation with Axis 1. All this seems to indicate that MCI is a measure of chemical and physical factors rather than organic enrichment as is intended. However, it should be noted that because the MCI was developed for stony bottomed rivers, a number of sites in this study may have distorted the results somewhat since they had silty or sandy bottoms.

CCA could perhaps be used as a technique for assigning MCI scores to taxa that don't as yet have one, by determining their position along the canonical axis most strongly related to water quality. Thus in this study, if the taxon scores high on Axis 1 then it should be assigned a low MCI score. A negative score on Axis 1 indicates a low tolerance to pollution and therefore a high MCI score should be assigned. Table 5.4

Table 5.4. Ranking of some of the common taxa by decreasing semi-quantitative CCA Axis 1 score. MCI scores in bold are approximate scores that could be assigned based on the position of the taxa in the Table.

| CCA Axis 1 Score | Taxa Name | MCI Score |
|---|---|---|
| 199 | *Paroxyethira* | 2 |
| 186 | *Gyraulus* | 3 |
| 127 | *Potamopyrgus* | 4 |
| 107 | *Physa* | 3 |
| 87 | Oligochaete | 1 |
| 76 | Ostracoda | 3 |
| 58 | Planaria | 3 |
| 36 | *Oxyethira albiceps* | 2 |
| -1 | Chironomidae | **4** |
| -3 | Elmidae | 6 |
| -7 | *Zelandobius furcillatus* | 5 |
| -11 | *Austroclima sepia* | 9 |
| -12 | *Hudsonema* | 6 |
| -14 | *Pycnocentria* | 7 |
| -15 | *Pycnocentrodes* | 5 |
| -22 | *Zephlebia dentata* | 7 |
| -26 | Eriopterini | 9 |
| -26 | *Hydrobiosis parumbripennis*-group | 5 |
| -27 | *Aoteapsyche* | 4 |
| -30 | *Archichauliodes diversus* | 7 |
| -32 | *Aphrophila neozelandica* | 5 |
| -34 | *Austrosimulium* | 3 |
| -34 | *Austroclima jollyae* | 9 |
| -34 | *Deleatidium* | 8 |
| -35 | *Orchymontia* | 8 |
| -40 | *Olinga* | 9 |
| -41 | *Psilochorema* | 8 |
| -52 | *Nesameletus* | 9 |
| -57 | *Coloburiscus* | 9 |
| -62 | *Limnophora* | **9** |
| -63 | *Austroperla cyrene* | 9 |
| -66 | *Neozephlebia scita* | 7 |
| -69 | *Zelandoperla* | 10 |

demonstrates this procedure. Some of the common taxa are listed in order of Axis 1 score in the semi-quantitative analysis. The MCI score for each of these taxa is also shown. As expected, taxa with low MCI scores generally have high Axis 1 scores, while high negative scores on Axis 1 are generally associated with taxa with high MCI scores. Two of these taxa, Chironomidae and *Limnophora*, do not have scores assigned to them by Stark (1993). From their Axis 1 scores and positions in Table 5.4, Chironomidae should be assigned an MCI score of 4 (so the score of 3 used initially when working out

MCI's appears reasonably accurate), while *Limnophora* could be assigned a score of 9. This could also be used for other taxa without MCI scores. However, this method should only be used on taxa that have been found at a number of sites because the presence of a taxon at one site could be an anomaly, it may not normally be found there, but if it is found at a number of sites then its requirements and tolerance will be well represented. Table 5.4 also suggests some existing MCI scores could be modified - at least for Hawkes Bay rivers. If the taxa are ranked by Axis 1 score and by MCI score, the obvious outliers are *Austroclima sepia*, Eriopterini and *Austrosimulium* (see Fig. 5.3). Of these three taxa, it appears that Austrosimulium should be assigned a higher MCI score, while the other two should be given lower scores.

Because the EPT index and MCI were strongly correlated with Axis 1, these two indices are confirmed as good measures of water quality, although the influence of substrate related factors is problematic. It seems that the EPT index and MCI are as much a measure of these substrate related factors as they are of water quality. This is expected to a large extent because of the strong inverse correlation between these physical and chemical variables. This relationship is a feature of my data set - it would be interesting to find streams with low gradient and altitude but high water quality, but none appear to exist in Hawkes Bay.

Semi-quantitative and presence/absence data produced similar results, especially for Axis 1. However, there does appear to be slightly better discrimination along Axis 2 when the semi-quantitative data is used. The semi-quantitative analysis is also able to identify more environmental factors as having a significant effect of community composition, with perhaps the most important discovery being AFDW, chl *a*, pH, leaf litter, stability and conductivity all having a significant secondary influence on the macroinvertebrate communities. The higher degree of clumping of taxa within the central box for the presence/absence data than the semi-quantitative data could be expected because presence/absence data is less discriminating - for a species to have any influence on the ordination it has to be completely absent from a site, not just rare,

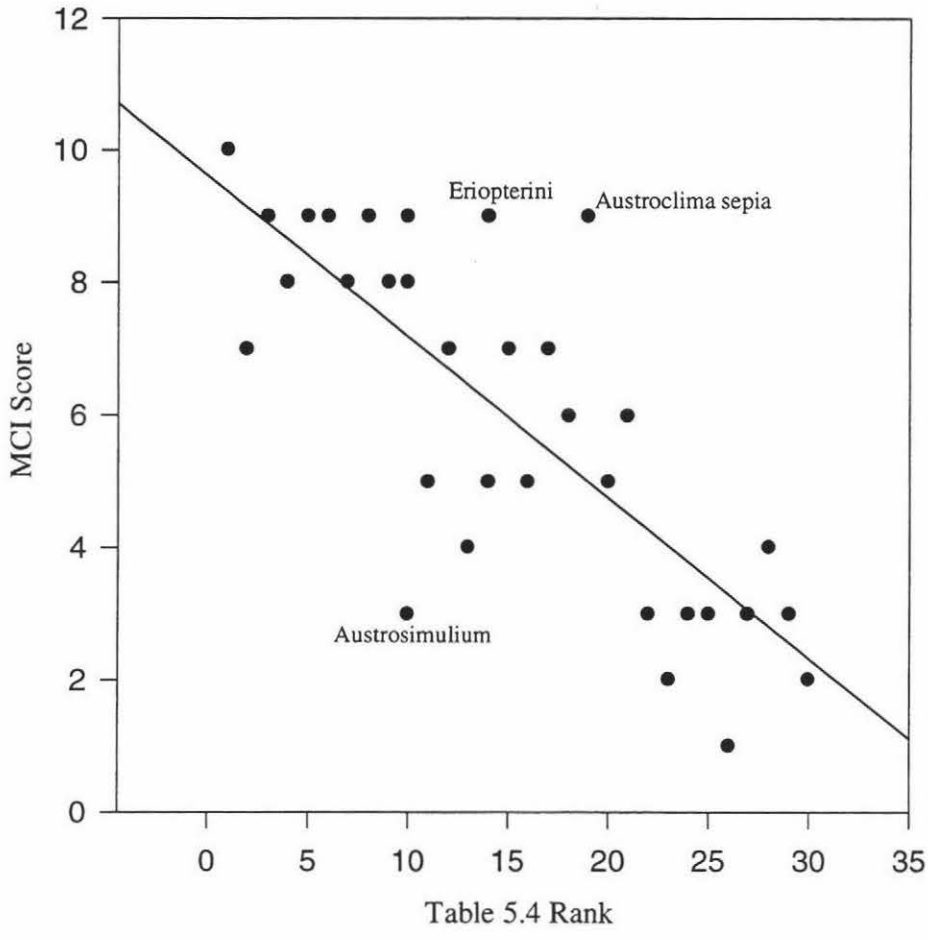



Fig. 5.3. Ranking of taxa from Table 5.4 by Axis 1 score and by MCI score. Most obvious outliers are labelled.

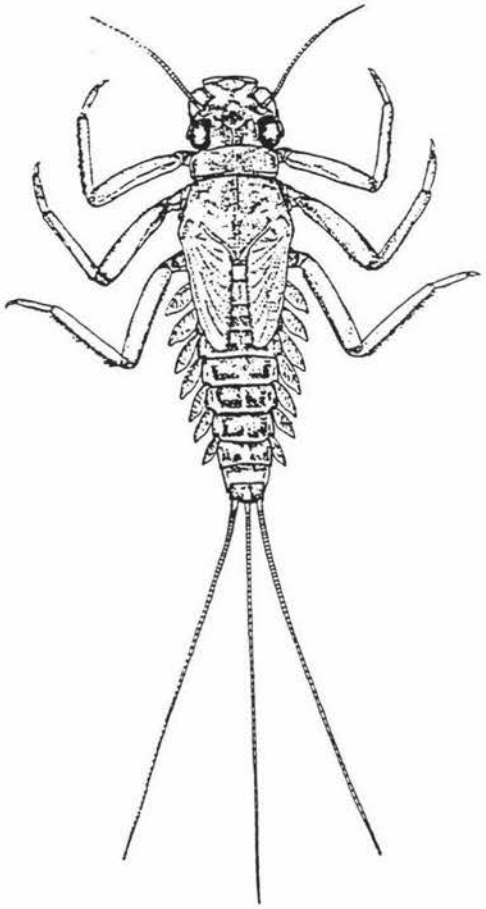
so a taxon such as *Potamopyrgus*, which shows great variation in abundance but can be present just about anywhere, appears on the semi-quantitative ordination but not the presence/absence.

Results from the CCA's indicate that this multivariate analysis technique is effective for interpretation of site and species distributions according to a range of environmental

factors in Hawkes Bay. The analyses also show that the principle biomonitoring index used in New Zealand, the MCI, as well as the EPT index, are effective in predicting the level of pollution in Hawkes Bay rivers and streams.

# CHAPTER 6:

# LOTIC ECOREGIONS OF HAWKES BAY



# CHAPTER 6:

# LOTIC ECOREGIONS OF HAWKES BAY

## 6.1. INTRODUCTION

Over the last decade, numerous studies have looked to provide a classification scheme for large geographical areas based on the relative homogeneity of several physical and/or biological components of that area (e.g. Biggs et al., 1990; Corkum, 1989; Barbour et al., 1996). These areas have become known as ecoregions and can be useful for providing a basis for the understanding of the components and processes that go on within ecosystems. Ecoregions allow us to assess the effect of changes to the habitat that occur over large geographical areas as well as investigate how biological communities interact with their environments (Harding, 1994). This is important to ecologists and water managers because by knowing what is appropriate for an ecoregion they can aim their management towards restoring or improving a site within an ecoregion if it has been adversely effected.

Past biogeographic conditions which may preclude the presence of a taxa from a region can complicate attempts to associate the distributions of macroinvertebrates with regional environmental conditions. Events such as climatic changes, alterations in sea level, or volcanic activity may result in local extinctions or areas of isolated endemism. It is often difficult to obtain evidence of the influence of these sorts of events, although in North America stream invertebrate communities have been shown to vary between biogeographic regions (Minshall et al., 1985; Corkum, 1989).

In New Zealand, several classifications have been suggested for elements of the biota. These include the proposition of regional ecological frameworks based on vegetation, geological and climatic features by Simpson (1982) and McEwen (1987), as well as

Crosby et al. (1976) proposing 29 regions for entomological locality data. The first attempt to classify New Zealand rivers using a wide range of biological and environmental variables was by Biggs et al. (1990). They proposed dividing New Zealand up into five ecoregions, however large areas of the country were not sampled, particularly in the South Island.

Two main methods have been adopted to identify aquatic ecoregions. The first method involves collecting and analysing a large amount of biological, chemical and hydrological data. Analysis of this large data set then seeks to identify patterns in distribution, which form the basis of ecoregions (e.g. Biggs et al., 1990; Quinn and Hickey, 1990a; Corkum, 1989; chapter 2). The main problems identified with this method are that to be effective this approach requires large data bases, and it can be difficult to extrapolate results to other geographical regions (Harding, 1994). However, because this method usually involves sampling a greater variety of river types and the formation of ecoregions is independent of physical data, the ecoregions formed for an area would be more robust. This method is also more likely to identify human effects structuring the biological communities. To help remove any confusion in later sections, I will call the areas identified by this technique bioregions rather than ecoregions, as it is principally biological distribution that determines where the bioregions are distributed.

Catchment characteristics of geology and climate have been described as the principle "driving" factors that influence lotic systems. These two factors, in turn, have a major influence over topography, land use, vegetation, hydrology and water quality, which all effect lotic biota (Biggs et al., 1990). Lotspeich (1980) also suggested that stream communities evolve in response to climatic conditions acting on the geological landscape. For this reason, ecoregions can be defined by clustering a number of geomorphological and climatic variables that are considered most likely to influence stream biota. The second method involves developing ecoregions by correlating a number of macro-environmental factors such as bedrock geology, soils, vegetation and climate (e.g. Harding, 1994; Omernik, 1987; Omernik and Griffith, 1991; Lotspeich,

1980; Whittier et al., 1988). Each of these ecoregions can then be tested by surveying the communities of streams considered to be characteristic of the ecoregions to see if the community from one ecoregion is distinct from the community occurring in other ecoregions. This strategy is described as providing a more holistic perspective on aquatic ecosystems, as broad scale patterns in climatic and geomorphological data are used to explain patterns (Lotspeich, 1980; Harding, 1994). This approach assumes that ecosystems and their components show regional patterns that are reflected in combinations of different biogeographical conditions (Omernik, 1987; Harding, 1994). The ecoregion maps compiled for the United States used this method (Bailey, 1983; Omernik, 1987).

The aim of this chapter is to develop ecoregions for Hawkes Bay based on a range of climatic and geomorphological factors found at the 52 sites sampled in chapter 2. The ecoregions found using this technique will then be compared with the bioregions found and described in chapter 2 based on benthic macroinvertebrates to see if the two different methods produce similar results for Hawkes Bay. In addition, the bioregions I have described in chapter 2 will be compared with the ecoregions that Harding (1994) described for Hawkes Bay.

## 6.2. METHODS

### 6.2.1. Identification of Hawkes Bay Ecoregions

Six parameters were used to identify and establish boundaries for the ecoregions. These were geology (New Zealand Geological Survey, 1972), soils (New Zealand Geological Survey, 1973), vegetation, rainfall (New Zealand Meteorological Service, 1979a, 1979b), relief (altitude)(NZ Lands and Survey, 1989), and New Zealand Climatic Regions (New Zealand Meteorological Service, 1983). These are the same parameters

used by Harding (1994). Bedrock geology is measured because it has an effect on water chemistry and catchment morphology. Soil type gives an idea of past regional climate, topography, vegetation and bedrock materials. Vegetation class was determined at the site and was used as a indicator of what the present land use patterns are. Rainfall normals represented the mean annual rainfall over a 30 year period (1941-1970) and indicate the potential differences in stream flows between rivers in each ecoregion. The Climatic Regions provide an indication of comparable hydrological, temperature and climatic extremes (Harding, 1994). Climatic Region descriptions are:

C1 - Very warm summers; day temperatures occasionally greater than $30^0$C; dry fohn wind; annual rainfall 1000-1500mm; moderate winter temperatures with maximum rainfall at this time.

C2 - Drier than C1; rainfall 600-1000mm; summer droughts common.

C3 - Cooler and wetter than C1; annual rainfall 1500-2500mm.

M - High rainfall, mountain climates. Conditions vary greatly with altitude and exposure.

Table 6.1 shows the broad categories for the climatic or geomorphological factors used.

Table 6.1. The broad categories of climatic and geomorphological variables used in the cluster analysis to develop ecoregions.

| **Variable** | **Categories** |
|---|---|
| Climatic Region | C1, C2, C3, M |
| Elevation (m) | 0-99, 100-350, 351+ |
| Vegetation | Farmland, Scrub, Forest |
| Soil | Yellow-brown and yellow-grey earths, Yellow brown loams and pumice, Recent alluvial/volcanic |
| Geology (Time period) | Quaternary, Tertiary, Cretaceous, Jurassic |
| Rainfall (mm) | 0-599, 600-1199, 1200-2000, 2000+ |

A cluster analysis was used with average linkage on percentage similarity measures to construct the Hawkes Bay ecoregion map. This method differs from that used by Harding (1994). For the South Island he used a Geographic Information System (GIS) to overlay a series of maps of each of the six climatic and geomorphological variables measured, and eventually "merged" these maps to form his ecoregions. He used the same protocol for the North Island but instead of using GIS he merged the six maps by hand (see Fig. 6.1). The method used to define bioregions from the macroinvertebrate data is explained in chapter 2.

## 6.3. RESULTS

The main groupings of sites from the cluster analysis of climatic and geomorphological variables are shown in Fig. 6.2. If the cut-off level is taken at 0.5 so that members of each cluster share, on average, 50% of the variables, four main groupings of sites are identified, with one outlier. Their distribution over Hawkes Bay is shown in Fig. 6.3. The four ecoregions correspond to Northern Hawkes Bay (NHB), Central Hawkes Bay (CHB), Southern Hawkes Bay (SHB) and Inland Hawkes Bay (IHB). Each ecoregion was identified by having a set of characteristic conditions associated with the climatic and geomorphological variables (Table 6.2). The IHB ecoregion is dominated by forested, cool, wet mountains with hard Mesozoic rocks and thin soils. Northern Hawkes Bay contained a geology of predominantly Cretaceous age and soils were thin yellow-brown and yellow-grey earths. The SHB ecoregion was mostly warm, low altitude farmland, while CHB was medium altitude farmland with a Quaternary geology. The outlying site 18 is on the boundary between CHB, NHB and SHB and shares some features of all of these ecoregions.

A visual assessment was used to see how similar the ecoregions found in the cluster analysis compare to those described in chapter 2 and to the ecoregion boundaries around Hawkes Bay found by Harding (1994).

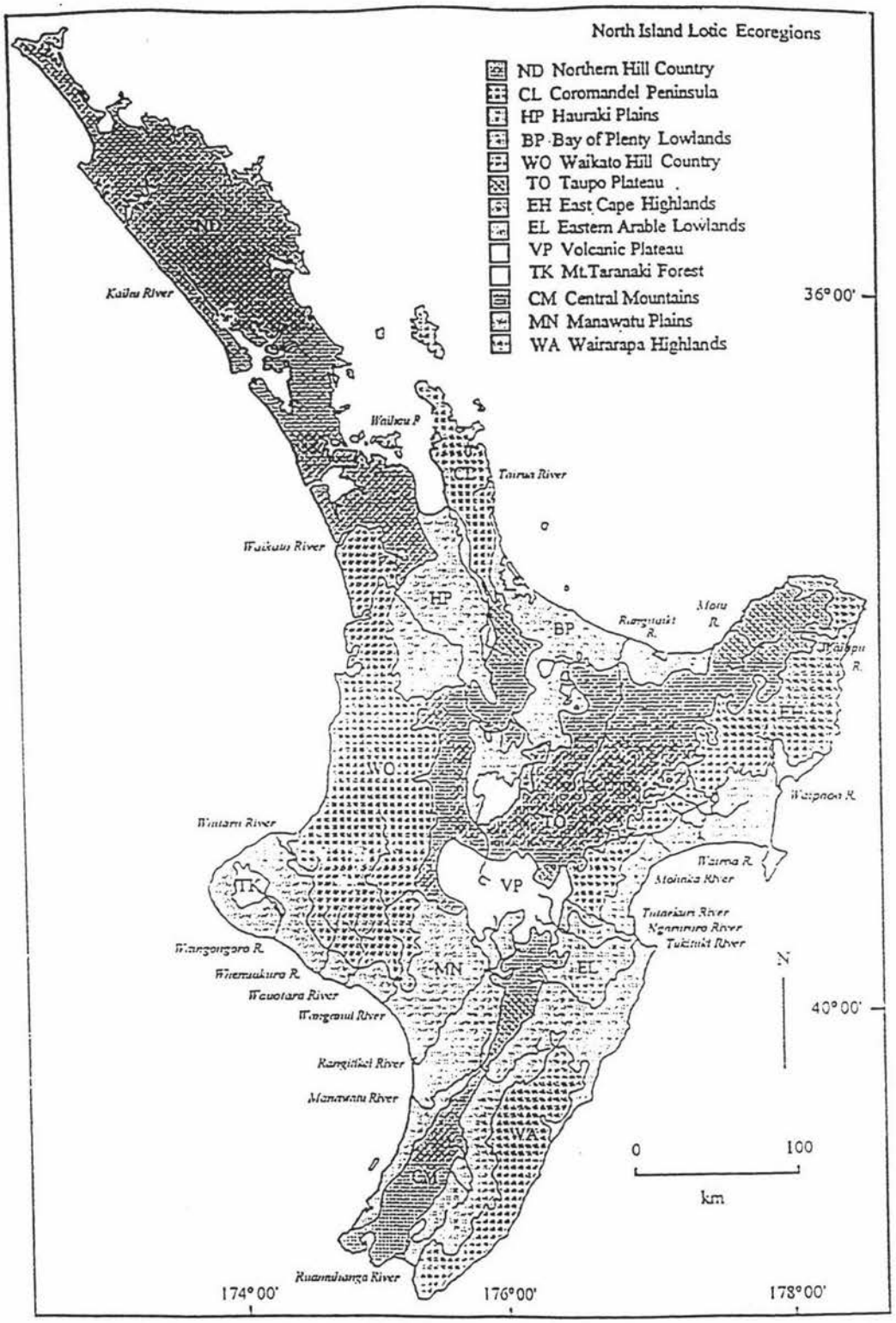



Fig. 6.1. Ecoregion classification for the North Island, New Zealand derived from merging six climatic and geomorphological variables (from Harding, 1994, reproduced with permission).

Table 6.2. Characteristic features of the six climatic and geomorphological variables for the four ecoregions derived from the cluster analysis.

| Code | Area | Climatic Region | Elevation (m) | Vegetation Class | Soil Class | Geology | Rainfall (mm) |
|---|---|---|---|---|---|---|---|
| NHB | Northern Hawkes Bay | Variable | Variable | Variable | Yellow-brown & yellow-grey earths | Cretaceous | 1200-2000 |
| CHB | Central Hawkes Bay | C3 | 100-350 | Farmland | Variable | Quaternary | 1200-2000 |
| SHB | Southern Hawkes Bay | C1 | 0-350 | Farmland | Variable | Variable | 600-1199 |
| IHB | Inland Hawkes Bay | M | 351+ | Forest | Yellow-brown & yellow-grey earths | Mesozoic | 1200-2000+ |

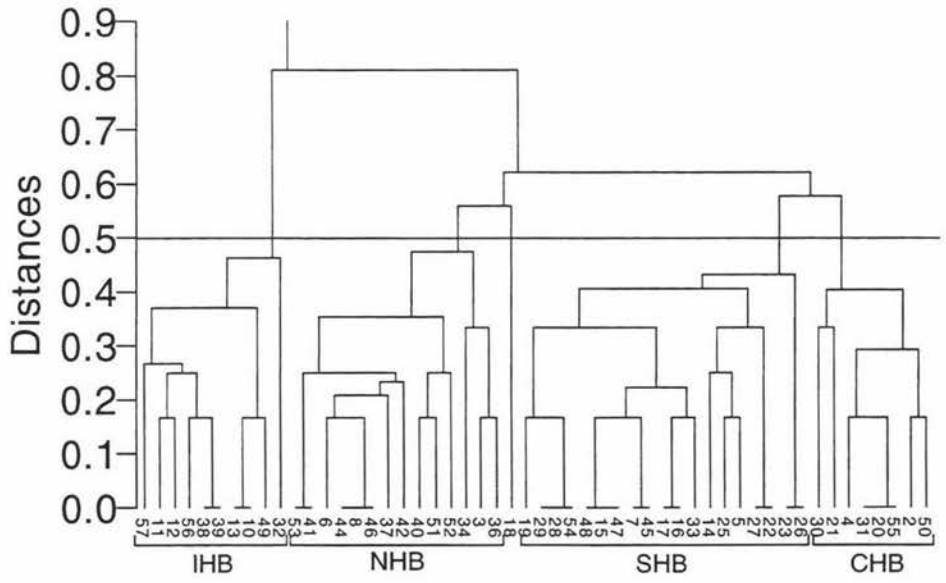



Fig. 6.2. The groupings of sites found with the cluster analysis. The ecoregion codes and line showing cutoff level are shown. See Fig. 6.3 for each ecoregions distribution over Hawkes Bay.

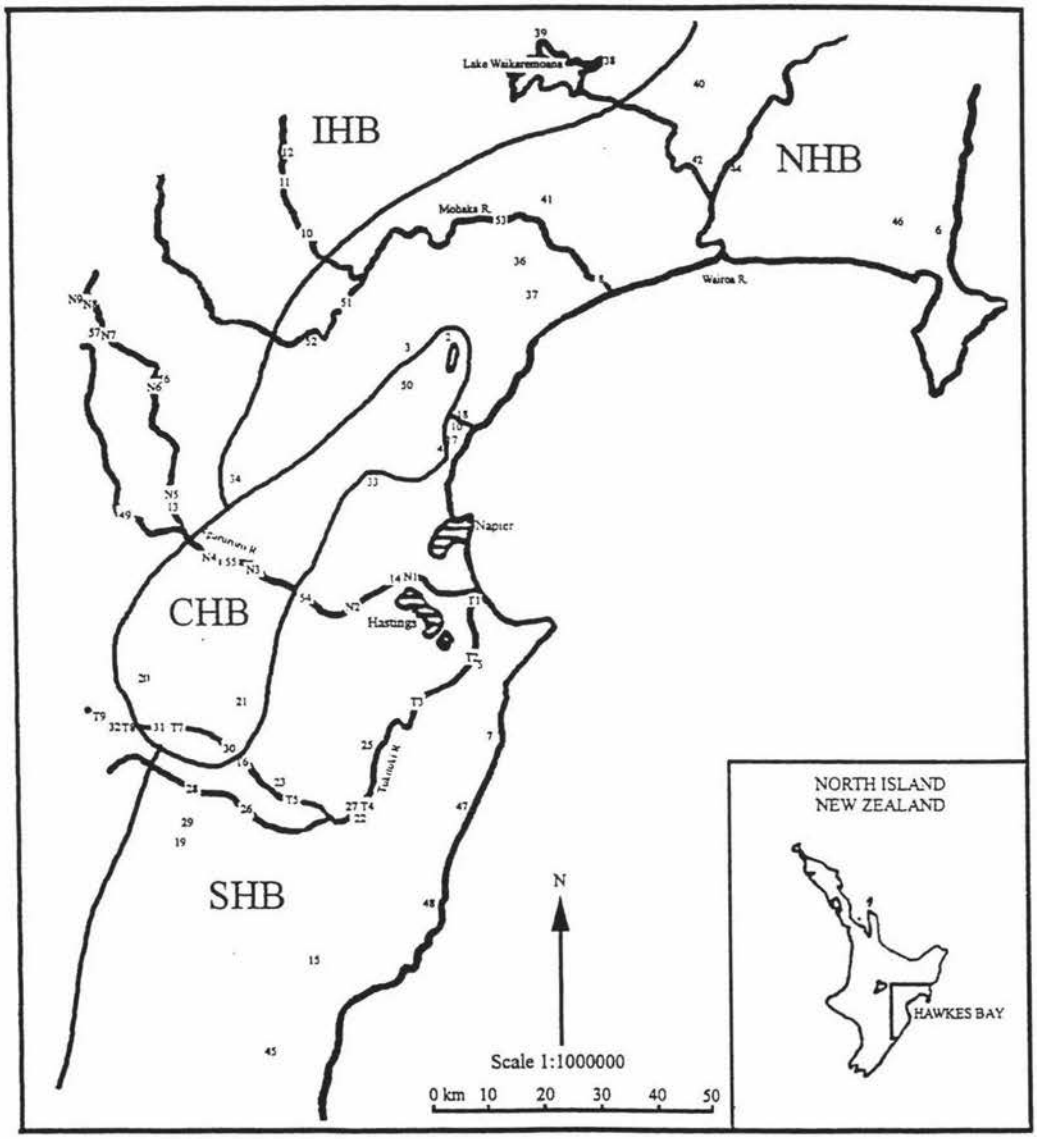



Fig. 6.3. Ecoregion classification derived from a cluster analysis of six climatic and geomorphological variables.

### 6.3.1. Cluster Analysis Ecoregions versus Chapter 2 Bioregions

The best correspondence between boundaries was between bioregion E from chapter 2 and IHB from the cluster analysis. Both of these areas encompass the inland ranges of Hawkes Bay. Bioregion F, which occupies a pumice infilled valley, was not distinguished by the cluster analysis. The rest of the bioregions do not show much correspondence with the cluster analysis ecoregions. The cluster analysis fails to distinguish between the coastal and near coastal bioregions that were distinctive in chapter 2, but instead divided Hawkes Bay into a northern and a southern ecoregion, with a smaller central ecoregion, none of which match very well with the bioregions derived from the TWINSPAN analysis in chapter 2.

### 6.3.2. Cluster Analysis Ecoregions versus Hardings (1994) Ecoregions

There also appeared to be little correspondence between the ecoregions identified from the cluster analysis and those found by Harding (1994). His Eastern Arable Lowlands ecoregion encompasses all of the coastal areas of Hawkes Bay and extends well inland in places, so it overlays large parts of NHB, SHB and CHB. Inland Hawkes Bay includes parts of three of Harding's (1994) ecoregions, these being the Taupo Plateau, Volcanic Plateau and Central Mountains.

### 6.3.3. Hardings (1994) Ecoregions versus Chapter 2 Bioregions

This appeared to produce the best correspondence between bioregions and ecoregions using the two different strategies. If bioregions A, B and C are combined, then the inland border of this grouping corresponds well with Hardings (1994) Eastern Arable Lowlands. Bioregion C appears to occupy the same area as the East Cape Highlands, while E and F, if combined, overlay the Taupo Plateau, Volcanic Plateau and Central Mountains ecoregions.

## 6.4. DISCUSSION

The results for the ecoregion boundaries using the different techniques are quite different and not as predicted. The ecoregions identified in the cluster analysis would be expected to be reasonably similar to those reported by Harding (1994) because the same climatic and geomorphological variables were used. However, this was not the case. This is probably due to how each method used the variables to define the boundaries. With the cluster analysis I could only record the variables as they were found at each of the 52 sites, so any differences in climatic or geomorphological variables that occur between sites would not show up when the boundaries are drawn. Harding's (1994) method of merging the variables by hand isn't limited to discrete points in the region and so may provide a more realistic representation of the ecoregions. Another reason could be that although both Harding (1994) and I used the same variables, the Hawkes Bay region is a much smaller scale than what Harding (1994) was working on so there was less variability for some climatic or geomorphological factors. For example, Harding (1994) dealt with eight Climatic Regions, whereas I only needed to consider four. Also, for elevation and rainfall, the cut-off points for each category within that variable was altered to a more appropriate level for the scale I was working on.

If catchment characteristics of climatic and geomorphology are the principle factors influencing lotic systems, then it would be expected that the cluster analysis would produce ecoregions similar to the bioregions found in chapter 2, but, in general, this was not the case. The only boundary with a reasonable match between the two methods is the IHB ecoregion with bioregion E in chapter 2. It appears as though collecting a large biological and chemical database identifies land use, modification, and small to moderate scale effects such as nutrient levels, much more readily than using climatic and geomorphological variables. This is shown with the change in bioregions as distance from the coast increases shown in Fig. 2.4. Coastal sites showed the most modification and usually had more extreme values for water chemisry than sites associated with the inland bioregions, and this effect on the macroinvertebrates is picked up with the

technique used in chapter 2. However, the cluster analysis was only able to distinguish broad scale changes in vegetation, altitude and climatic regions, such as those that occur between the ranges of the IHB ecoregion and the rest of the ecoregions. It fails to pick up any smaller scale effects (e.g. substrate size, nutrient levels) on macroinvertebrates. It could be that the ecoregions based on climatic and geomorphological variables tell us what should be present, but the bioregions show what happens with human impacts. Large scale factors have been identified as being important in influencing lotic systems (e.g. Biggs and Gerbeaux, 1993) but they can be obscured by small scale or regional characteristics that are relevant to stream management and have been identified in numerous studies as having a major influence over macroinvertebrate community composition (e.g. Tate and Heiny, 1995; Collier, 1995; Ormerod and Edwards, 1987; Gower et al., 1994).

The small to medium scale effects are not distinguished in Hardings (1994) ecoregions. Instead, three quite distinct bioregions identified in chapter 2 correspond approximately with his Eastern Arable Lowland ecoregion. However, because the inland borders of bioregion B and D correspond reasonably well with the border of the Eastern Arable Lowland, and bioregion C appears to be equivalent to Hardings (1994) East Cape Highlands, it may be appropriate to say that these bioregions, at least, identified in chapter 2, are "subecoregions" of the ecoregions defined by Harding (1994). The practice of having subecoregions with broader ecoregions has been found to be useful for Florida (Barbour et al., 1996) and other areas of the United States of America (Omernik, 1995).

Bioregion E (and F) from chapter 2 occupy the same area as three of Hardings (1994) ecoregions. These three ecoregions, consisting of the Taupo plateau, Volcanic Plateau and Central Mountains, are all relatively homogenous over the Hawkes Bay region in terms of vegetation cover, rainfall and altitude and, indeed, sites located in these areas are classed together in the cluster analysis. Macroinvertebrates appear to find these high

altitude forested ranges more homogenous than is indicated by Hardings (1994) ecoregions, despite difference in geology.

In this chapter I have compared the results from the different strategies for identifying ecoregions and bioregions, and have discussed what the possible causes for the differences between the strategies could be. Although forming ecoregions from a range of climatic and geomorphological variables can provide useful broad scale information, I believe that from a management point of view, the best and most informative method is the one used in chapter 2. There are a number of reasons for this. Firstly, the findings in this chapter indicate that collecting extensive biological and chemical databases allows the identification of the small to medium scale factors that have an important role in determining the biotic community. It is these factors, such as physical aspects of the stream or chemical levels, that cause the greatest change in biotic communities, and this method allows the factor causing the change to be identified and an appropriate management strategy can be planned. Secondly, the method employed in chapter 2 involves *directly* studying the biotic communities to find patterns - if a distributional pattern doesn't exist, then it won't find one (cf. Quinn and Hickey, 1990a). However, even if no geographic pattern is found, it can still be used to identify different types of community (Quinn and Hickey, 1990a; Biggs, 1990; Zamora-Muñoz and Alba-Tercedor, 1996; Wade et al., 1989; Wright et al., 1984). Thirdly, because forming ecoregions from climatic and geomorphological variables involves using only large scale factors that effectively don't change, any subsequent change in, for example, land use practices, will not result in a reevaluation of ecoregion boundaries. Regular monitoring of the biotic communities within ecoregions formed from large databases can detect both positive and negative changes occurring in the community of an ecoregion, and boundaries can be redrawn to take these changes into account. For example, if management practices have resulted in an improvement of habitat for macroinvertebrates at certain sites, it may be appropriate to redraw bioregion boundaries to take into account the change in community composition. This would allow water managers to set realistic goals and easily evaluate their progress in trying to

reach these goals, i.e. it may be the managers goal to change some of the sites in bioregion D in Fig. 2.4 to be more like bioregion E because bioregion E is seen as being more "pristine".

There are also some disadvantages to using large databases, the most obvious being it is very labour and time intensive. The other major disadvantage is it is difficult to extrapolate results to other regions (Harding, 1994). One factor that should be taken into consideration when using this method is what the intensity of sampling should be. If the distance between sites is too far apart, then there may be too much variation in environmental factors between the sites and patterns will either fail to be found, or will be false. This I believe was the main problem with the studies by Biggs et al. (1990) and Quinn and Hickey (1990a). Conversely, if sites are too close together, then little valuable information is gained for a large increase in effort.

Taxa which have limited geographical distribution but are locally abundant could have their distribution explained by past biogeographical events (Harding, 1994; Michaelis, 1973; Cowley, 1978). For example, it has been noted that locally endemic Trichopteran distributions are congruent with palaeographical events such as the presence of a Pliocene sea barrier in the Manawatu region (Henderson, 1983). The distribution of some Blephariceridae species provided further support for this hypothesis (Craig, 1969). Several workers have found support for the hypothesis that the high diversity of particular regions today may have been caused by the creation of refugia from Pleistocene glaciations (Fleming, 1962, 1979; McLellan, 1977; Cowley, 1978; Rogers, 1989), however this doesn't adequately account for the lack of dispersal of these species after the glacial retreat (Henderson, 1983). In Hawkes Bay, some species had restricted distributions. The freshwater polychaete worm *Namalycastis tiriteae* was found in central and southern areas of Hawkes Bay. Other specimens have been collected in northern Wairarapa (Reece Fowler, pers. comm) and Manawatu (Dr Ian Henderson, pers comm; Winterbourn, 1969). All records of this species are associated with recently uplifted marine sediments, suggesting an origin from marine ancestors by rapid tectonic

ancestors by rapid tectonic uplift of this part of New Zealand. Other species with restricted distributions are the mayfly *Austronella planulata* and the cased caddisfly *Confluens*. Both of these species are absent in southern Hawkes Bay, which might be due to biogeographical rather than ecological factors.

In summary, the findings of this chapter indicate that in Hawkes Bay ecoregions can be identified using any of the techniques described, but results can vary widely. Since this thesis focuses on macroinvertebrates, I believe that the best technique for identifying ecoregions is the one employed in chapter 2 as it looks directly at the macroinvertebrate community. This method also allows the water managers to identify and manage the factors that are influencing the community structure at a local level and permits much more flexibility in reevaluating ecoregion boundaries once management goals have been attained.

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# APPENDIX 1

Invertebrate taxa collected and abbreviations (if used in chapter 5) for the 52 Hawkes Bay sites.

| Taxa | Abbreviation | Taxa | Abbreviation |
|---|---|---|---|
| **COLEOPTERA** | | *Austroclima sepia* | |
| *Antiporus* sp. | Antiporus | *Austronella planulata* | Aus pla |
| *Berosus* sp. | Berosus | *Coloburiscus humeralis* | |
| Elmidae | | *Deleatidium* spp. | |
| *Ephydrella* sp. | Ephydrella | *Ichthybotus hudsoni* | |
| *Liodessus* sp. | Liodessus | *Mauiulus luma* | Mau lum |
| *Orchymontia* sp. | | *Neozephlebia scita* | Neo sci |
| *Podaena* sp. | Podaena | *Nesameletus* sp. | Nesameletus |
| Ptilodactylidae | Ptilodactylidae | *Rallidens mcfarlanei* | |
| Scirtidae | | *Zephlebia dentata* | Zep den |
| Staphylinidae | | *Zephlebia inconspicua* | Zep inc |
| **DIPTERA** | | *Zephlebia spectabilis* | Zep spe |
| *Aphrophila neozelandica* | | *Zephlebia versicolor* | Zep ver |
| Chironomidae | | **PLECOPTERA** | |
| Empididae/Dolichopodidae | | *Acroperla spiniger* | Acr spi |
| Eriopterini | | *Austroperla cyrene* | |
| Eriopterini "Molophilus" | Molophilus | *Megaleptoperla diminuta* | |
| Muscidae "Limnophora" | Limnophora | *Megaleptoperla grandis* | |
| *Paralimnophila skusei* | | *Spaniocerca* sp. | |
| *Austrosimulium australense*-group | | *Stenoperla prasina* | Ste pra |
| Stratiomyidae | | *Zelandobius furcillatus* | |
| Tabanidae | | *Zelandoperla* sp. | |
| Zelandotipula sp. | | **TRICHOPTERA** | |
| **EPHEMEROPTERA** | | *Aoteapsyche* sp. | |
| *Acanthophlebia cruentata* | Aca cru | *Beraeoptera roria* | |
| *Ameletopsis perscitus* | Ame per | *Confluens hamiltoni* | Confluens |
| *Ataloplebioides cromwelli* | | *Costachorema* sp. | Costachorema |
| *Austroclima jollyae* | | Ecnomidae/Psychomyiidae | Ecn/Psy |

| | |
|---|---|
| *Helicopsyche* sp. | |
| *Hudsonema amabilis* | |
| *Hydrobiosella mixta* | |
| Hydrobiosidae (unknown) | Unk Hyd |
| *Hydrobiosis clavigera*-group | |
| *Hydrobiosis parumbripennis*-group | |
| Hydroptilidae | Hydroptilidae |
| *Neurochorema* sp. | |
| *Oecetis unicolor* | Oec uni |
| *Olinga feredayi* | |
| *Oxyethira albiceps* | Oxy alb |
| *Paroxyethira eatoni/kimminsi* | Par aet |
| *Paroxyethira hendersoni* | Par hen |
| *Plectrocnemia maclachlani* | Plectrocnemia |
| *Polyplectropus* sp. | |
| *Psilochorema* sp. | |
| *Pycnocetrella eruensis* | |
| *Triplectrides cephalotes* | Tri cep |
| *Triplectides obsoleta/dolichos* | Tri obs |
| *Zelolessica cheira* | Zel che |
| **MEGALOPTERA** | |
| *Archicauliodes diversus* | |
| **HEMIPTERA** | |
| *Anisops* sp. | Anisops |
| *Microvelia* sp. | Microvelia |
| *Sigara* sp. | Sigara |
| **LEPIDOPTERA** | |
| *Hygraula nitens* | Hyg nit |
| **ODONATA** | |
| *Xanthocnemis* sp. | Xanthocnemis |
| Zygoptera | Zygoptera |
| **MOLLUSCA** | |
| *Gyraulus* sp. | Gyraulus |
| *Lymnaea tomentosa* | Lymnaea |
| *Melanopsis trifasciata* | Melanopsis |
| *Potamopyrgus* sp. | Potamopyrgus |
| *Physa* sp. | Physa |
| *Pisidium casertanum* | Pisidium |
| *Sphaerium* sp. | Sphaerium |
| **CRUSTACEA** | |
| Ostracoda | Ostracoda |
| *Paracalliope* sp. | Paracalliope |
| *Paranephrops planifrons* | Paranephrops |
| *Paratya curvirostrum* | Paratya |
| *Tenagomysis novaezealandiae* | Ten nov |
| Isopod | Isopod |
| **NEMATOMORPHA** | Menatomorpha |
| **NEMATODA** | Nematode |
| **OLIGOCHAETA** | Oligochaete |
| **PLATYHELMINTHES** | Planaria |
| **POLYCHAETA** | |
| *Namalycastis tiriteae* | |