CAN A NATURALLY IMPOVERISHED BOREAL EPHEMEROPTERA, PLECOPTERA, AND TRICHOPTERA (EPT) FAUNA SERVE AS AN INDICATOR OF WATER QUALITY?

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Can a naturally impoverished boreal Ephemeroptera, Plecoptera, and Trichoptera (EPT) fauna serve as an indicator of water quality?

by

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ABSTRACT

Biomonitoring of small boreal water-catchments has become increasingly important for small human communities in Newfoundland, Canada. Benthic macroinvertebrate fauna are commonly used to assess conditions of water-catchments. However, Newfoundland has a very impoverished freshwater fauna due to isolation of the island from the mainland (faunal source), reduced habitat diversity and recent glaciation of the island. Questions addressed by the study were: how sensitive is this fauna to different environmental gradients, and will the fauna be useful in biomonitoring programs on the island?

The study examined the relative diversity and abundance of the Ephemeroptera, Plecoptera and Trichoptera (EPT) component of the benthic macroinvertebrate fauna in 23 lake-outlets in six water-catchments of northeastern Newfoundland. Faunal composition and structure were related to gradients of natural and human impacted environmental variables of the sites sampled. Sixteen environmental variables were measured during May and July 1995, and May and July 1996 collection trips.

Principal Components Analysis (PCA) of the environmental data indicated that the 23 sites represented a broad range of stream and drainage basin characteristics. This was expected from sites that ranged from highly urbanized sites to sites with little human disturbance. Concentrations of several chemicals,

conductivity, and pH were correlated with disturbance on axis one.

Analysis of the EPT data showed shifts in community structure related to chemical variables, disturbance level, and study area. Generally, EPT diversity and abundance were lower in the physically disturbed and polluted urban sites, and were highest in physically disturbed but relatively unpolluted rural sites. Principle Components Analysis also showed trends in taxa diversity and abundance. Taxa correlated with presence-absence PC-I included *B. pygmaeus*, *B. macdunnoughi*, *E. prudentalis*, *Paraleptophlebia spp.*, *S. vicarium*, *Leuctra spp.*, *Polycentropus spp.* and *Platycentropus sp.*, which occur in a wide variety of running water habitats, but have low tolerances of disturbance (Edmunds *et al.* 1976; Larson and Colbo 1983; Lenat 1993; Lang and Reymond 1995). These taxa tended to be absent from the highly disturbed St. John's sites, but present at most remaining sites. Taxa correlated with relative abundance PC-II were *H. sparna* and *Chimarra sp.*, which have low tolerances to pollution (Bargos *et al.* 1990; Lenat 1993). These taxa had low abundances at St. John's sites. Therefore, it was concluded that the impoverished EPT fauna of Newfoundland can serve as an indicator of water quality.

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Eco-Research project

Cold-coastal ocean human communities in Newfoundland and elsewhere are in economic crisis due to the depletion of groundfish stocks. Other contributory factors include the depletion of mineral resources, deterioration of forests and technological change, and globalization of the economy, which have rendered a variety of resource extraction industries uneconomic (Ommer 1993). The purpose of the Eco-Research project was to examine the sustainability of these cold-coastal communities.

Ommer (1993) provided an extensive report presenting objectives that were then used as goals for the project. To summarize, the objective of the project was to identify the central components required to achieve sustainability for cold-coastal ocean human communities, such that environmental quality in the system could be balanced with economic development. To assess the implications for sustainability, the project proposed to identify the elements which have constituted sustainability in the past, and where, when and how those have been disturbed. Overall, the project proposed to suggest guidelines for future policy with respect to regional sustainability. To identify the inter-relationships that underlie the current crisis, inter-disciplinary analysis was required. Thus, the project brought together researchers from the Social, Health, and Natural Sciences. The central interdisciplinary question was "To what extent can human practices and the use of environmental resources be flexibly organized to sustain cold coastal assemblages, given current threats to the integrity of the ecosystem?" (Ommer 1993).

A goal of the natural sciences component of the project was to evaluate the effects of natural and human-induced environmental changes on the water-catchments associated with these cold-coastal human communities (Ommer 1993). Human disturbance of the water-catchment can alter the cycling of nutrients in both terrestrial and marine ecosystems (Ommer 1993). By determining those effects caused by local anthropogenic disturbances, future responses of the water-catchments can be predicted, and data can be used to assess the sustainable nature of various economic uses of the environment. Studies in this component included water chemistry, lake palynology, vegetation cover and studies on benthic stream flora and fauna.

The present study was included in the stream-biology portion of the natural science component of the project. It involved the biomonitoring of small water-catchments through examination of the composition and structure of the benthic macroinvertebrate community in relation to abiotic and biotic characteristics of the sites. The goal was to evaluate the use of characteristics of the benthic fauna for monitoring existing environmental conditions and changes in these conditions over time.

Chapter 1. Overview of study

1.1 HISTORY OF BIOMONITORING

Monitoring of freshwater systems has become increasingly important because increased human activities such as agriculture, urban land use and industrial activities tend to alter freshwater systems through chemical contamination and habitat alteration. Thus, the results of human disturbances need to be assessed and controlled.

There are several methods used to monitor freshwater systems. These include traditional chemical evaluation, and biological methods using fish, plants, algae, microinvertebrates and benthic macroinvertebrates. This study focused on the use of biological methods, in particular, macroinvertebrates as biological indicators of water quality. Freshwater macroinvertebrates are most often recommended for biological monitoring (Hellawell 1986).

Biological monitoring is "the surveillance using the responses of living organisms to determine whether the environment is favourable to living material" (Rosenberg and Resh 1993). This often involves the use of indicator species. An indicator species is a species (or species assemblage) that has particular requirements for a known set of physical or chemical variables (Johnson *et al.* 1993). Changes in presence/absence, numbers, morphology, physiology or behaviour of the indicator species show when the given physical or chemical variables are outside its preferred range. According to Rosenberg and Wiens (1976), cited by Johnson *et al.* (1993), an ideal indicator should have the following characteristics: narrow and specific environmental tolerances; taxonomic soundness and easy recognition by the nonspecialist; cosmopolitan distribution; high numerical abundance; low genetic and ecological variability; large body size; limited mobility and relatively long life history; well known ecological characteristics; and suitability for use in laboratory studies.

Benthic macroinvertebrates have been widely used as biological indicators for assessing water quality (e.g., Hynes 1970; James and Evison 1979; Bargos *et al.* 1990; Rosenberg and Resh 1993; Barbour *et al.* 1996; Hauer and Lamberti 1996). There are several advantages in using macroinvertebrates for biomonitoring (Rosenberg and Resh 1993; Resh *et al.* 1996): they occur in all types of waters and habitats; being sedentary, they act as continuous monitors of the water flowing over them allowing for effective spatial analyses of pollutant or disturbance effects; they reflect episodic and cumulative pollution and habitat alteration; they integrate the effects of, and respond relatively quickly to environmental changes; the responses of many common species to different types of pollution are known; the large number of species offers a wide range of responses to environmental stresses; and the taxonomy of many groups is well known.

However, there are several disadvantages to using macroinvertebrates as biomonitors. They do not respond directly to all types of impacts; their distribution and abundance can be affected by factors other than water quality (e.g., climatic events); their abundance and distribution vary seasonally, and dispersal abilities may carry aquatic insects into areas where they normally do not occur (Rosenberg and Resh 1993; Resh *et al.* 1996).

Hellawell (1986), Rosenberg and Resh (1993) and Hauer and Lamberti (1996) provide excellent reviews of the history of biomonitoring. Individual organisms, populations and multispecies communities can be used as biomonitors. There are numerous methods available tc analyze populations and species assemblages used as biomonitors. Some commonly used univariate analyses, often used for rapid assessment, include: richness measures (e.g. number of taxa, number of EPT (Ephemeroptera, Plecoptera, and Trichoptera) taxa); enumerations (e.g. number of individuals, % dominant taxa, ratio of EPT abundance to Chironomidae abundance); community diversity and similarity indices (e.g. Shannon's (1948) Index, Jaccard (1912) Coefficient); biotic indices (e.g. Biotic Index (Hilsenhoff 1987), BMWP (Biological Monitoring Working Party) Score (Wright *et al.* 1988), Saprobien System (Kolkwitz and Marsson 1909)); and functional feeding group measures (e.g. ratio of shredders to total number of individuals, ratio of trophic specialists to generalists). Taxa richness measures are most commonly used to describe macroinvertebrate communities (Plafkin *et al.* 1989; Rosenberg and Resh 1993). Functional feeding group measures are also common because they measure a functional aspect of the macroinvertebrate community, rather than just the structure (Rosenberg and Resh 1993).

Several studies have focused on Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa only (e.g. Harper 1990, Bournaud *et al.* 1996). These orders are valuable because most taxa in these orders are sensitive to pollution and therefore a loss of taxa is an indication of perturbation (Lenat 1988; Plafkin *et al.* 1989; Heliövaara and Väisänen 1993), and they are often easier to identify than many other aquatic insects (Resh and Rosenberg 1993).

It is advantageous to use indicator species rather than chemical and physical measurements. Chemical measurements are instantaneous and describe conditions that existed when the sample was taken, whereas macroinvertebrates add a temporal component because they reflect past conditions. However, it is optimal to use both approaches (James 1979; Rosenberg and Resh 1993). Biological indicators show the ecological imbalance that has been caused and chemical methods measure the concentration of pollutant(s) responsible (James 1979) assuming they are still present at the time of sampling.

1.2 THE PRESENT STUDY

The present study used the EPT component of the benthic macroinvertebrate community as a measure of the health of 23 lake outlets in six small water-catchments throughout the northeastern portion of the Island of Newfoundland, Canada. The aquatic insect fauna of Newfoundland has an essentially boreal aspect (Larson and Colbo 1983). However, the fauna is naturally impoverished when compared to the mainland. Larson and Colbo (1983) identified 28 species of Ephemeroptera in Newfoundland compared to 160 species in Maine (Burian and Gibbs 1991) and 126 in Illinois (Burks 1975). There are 13 species of Plecoptera in Newfoundland (Larson and Colbo 1983) compared to 36 species in Illinois (Frison 1975), 20 species in Labrador and 58 species in Nova Scotia (Hitchcock 1974, cited by Larson and Colbo 1983). Marshall and Larson (1982) recorded 124 species of Trichoptera in Newfoundland, which is low compared to richness in the eastern North American deciduous biome (Wiggins and Mackay 1978). Peterson and Eeckhaute (1990) studied two streams in Nova Scotia and one stream in New Brunswick. More than 90 species of Trichoptera were recorded in the New Brunswick stream, and in the two Nova Scotian streams combined.

The numerical reduction in fauna richness of Newfoundland can be attributed to several factors: Newfoundland is isolated from the mainland (faunal source) by salt water creating an effective dispersal barrier, particularly for plecopteran taxa; Newfoundland has reduced habitat diversity; and much of the fauna is of relatively recent (< 10,000 years) post-glacial recruitment from the mainland (Prest 1970, cited by Larson and Colbo 1983). In addition, many of these Newfoundland species are generalists, occurring in many types of freshwater habitats (Larson and Colbo 1983). Thus a reduced fauna consisting primarily of generalists may pose problems for biomonitoring because shifts in community composition and structure may be difficult to define and interpret.

Therefore the aim of this study was to compare the EPT communities of 23 lake outlets in northeastern Newfoundland and determine whether any identified patterns between communities and environmental variables can be used to assess water quality in the study area given the depauperate fauna. The study examined the impact of human activity and chemical/physical gradients on the composition and structure of the stream EPT communities of 23 lake outlet sites. EPT community composition and structure were expected to change in a predictable manner in relation to human disturbance. Generally, taxa richness and abundance were expected to be low at high levels of human disturbance (e.g., Benke *et al.* 1981; Pitt and Bozeman 1983; Duda *et al.* 1982). However, a reduced level of disturbance may enhance EPT diversity (number of taxa) and abundance (number of individuals).

Broad regional lake-outlet studies comparing various human impacts have been carried out elsewhere on this scale (e.g. Corkum 1990; Bournaud *et al.* 1996; Fore *et al.* 1996). However, most previous studies concentrated on lakes, or on basins that were not interrupted by lakes, and the studies were not in areas with naturally impoverished fauna (e.g., Wiederholm and Eriksson 1977; Corkum 1989, 1990; Bargos *et al.* 1990; Whitehurst and Lindsey 1990; Barbour *et al.* 1996;

Bournaud *et al.* 1996). Studies on this scale have not been previously carried out in Newfoundland.

The remainder of this thesis is divided into four sections: Chapter 2 describes the chemical/physical characteristics and human disturbances of sites sampled; Chapter 3 compares and contrasts sites based on chemical/physical characteristics and human disturbances described in Chapter 2; Chapter 4 describes the EPT fauna of the 23 lake outlet sites and relates the composition and structure of fauna to the chemical/physical characteristics and human disturbances of the sites sampled (Chapter 2); and Chapter 5 provides concluding remarks on the success of the study and its relevance to the Eco-Research project.

Chapter 2. Location and description of study areas and sites

2.1 STUDY LOCATION

The natural sciences component of the Eco-Research project focused on water-catchments that were in the areas where social and health studies were underway and thus in areas settled and influenced directly by human activity. Therefore, all sites selected for sampling had some degree of human influence. In order to provide data relevant to the marine natural science studies, all water-catchments flowed into Bonavista Harbour or Trinity Bay. The Eco-Research project selected different areas for sampling to enable broad comparisons of the effects of anthropogenic and natural factors on the whole water-catchment physiology (Ommer 1993).

Twenty-three lake outlet sites were studied in four areas of northeastern Newfoundland (Figure 1). The Eco-Research studies primarily focused on two areas: i) the Bonavista Peninsula, from Bonavista to the mouth of Trinity Bay (Figure 2), and ii) the Isthmus of the Avalon at Come-by-Chance (Figure 3) including both headland and bay aspects (Ommer 1993). The original proposal intended to study the Come-by-Chance River, which flows into Placentia Bay on the southern shore of Newfoundland, to evaluate the impact of airborne pollutants from the nearby refinery on freshwater systems. However, a small water-catchment that drained into Trinity Bay was studied instead. This system was also near the Come-by-Chance oil refinery. An additional study was conducted on Random Island, Trinity Bay (Figure 4), to associate terrestrial studies with the marine natural science studies and to obtain data from a water-catchment within a commercially harvested forest.

Originally, fourteen outlets from three water-catchments were sampled. Six sites were in the headwaters of the Bonavista catchment (Figure 2), four were located on the Isthmus of the Avalon (Figure 3), and four were on Random Island (Figure 4). In April 1996, seven additional sites in the St. John's area were sampled (Figure 5), as well as an additional site at Bonavista and Random Island. St. John's sites were included as representatives of highly disturbed, urbanized water-catchments. The additional sites at Bonavista (B18) and Random Island (R19) were included as further representatives of relatively undisturbed areas.

Sampling concentrated on low-order streams, which by definition tend to be small and numerous. This allowed for site replication based on stream size, and limited variation associated with stream size. Sampling was also restricted to lentic outlets, with sample sites located within 1 to 10 m of where the water surface breaks at the transition from lentic to lotic. Outlets are unique because they represent the area where the biological and physical characteristics of lotic and lentic habitats merge (Genge 1985). The fauna of outlets differs in composition and numerical density from downstream sites in that outlets tend to have enhanced benthic macroinvertebrate fauna production, with communities dominated by filter-feeders such as net-spinning caddisflies (Hydropsychidae, Polycentropodidae, Philopotamidae) and blackflies (Simuliidae) (Richardson and Mackay 1991).

Larson and Colbo (1983) provide an extensive description of Newfoundland hydrology, and the following is a summary. The Newfoundland climate is cool and humid with a strong seasonal lag in temperature. Precipitation exceeds evapotranspiration across the entire island. On the Avalon Peninsula, annual precipitation varies between 1200 and 1700 mm. The boreal landscape consists of a mixture of barren areas (mainly dwarf shrub heaths, bogs, and shallow fens) and forest sections dominated by balsam fir (*Abies balsamea*). Other common trees include white birch (*Betula papyrifera*), white pine (*Pinus strobus*), mountain alder (*Alnus crispa*), black spruce (*Picea mariana*), white spruce (*Picea glauca*) and red maple (*Acer rubrum*). There are a large number of bodies of standing water due to low relief and irregularly glaciated topography. Pools, bogs and fens are abundant. Thus, most water-catchments are small, have a low gradient over most of their length and plunge rapidly into the sea. Newfoundland streams are oligotrophic with expected low biomass, except at lake outlets (Genge 1985). Most aquatic habitats have cool temperatures, which only occasionally exceed 25°C in the shallowest pools and streams and for only short periods of time (Larson and Colbo 1983). Waters are generally acidic with low levels of dissolved materials. Low pH and limited buffering capacity of the water make the aquatic systems especially susceptible to degradation by even small amounts of pollution.

This chapter describes the chemical composition and physical characteristics of the 23 lake outlets studied.

2.2 MATERIALS AND METHODS

Nineteen environmental variables were measured at 23 lake outlet sites (Table 1). Eleven of these were continuous chemical variables including concentrations of various chemicals, pH, conductivity and temperature. Chemical analysis was performed by Dr. Peter Davenport, Department of Mines and Energy, Newfoundland. Attempts were made to measure phosphorus, however levels were too low to be detected with the analytical methods used. pH and conductivity were measured using a combined pH-conductivity meter. pH was measured to the nearest 0.5 and conductivity was measured to the nearest 1.0 μS/cm. Water temperature were measured to the nearest 1.0 °C using a hand-held thermometer. Values for separate sampling dates were averaged for each site to obtain a single measurement of temperature.

Eight categorical physical variables were measured (Table 1). Stream order was determined using topographic maps with a scale of 1:50,000. Stream width at the sample sites was measured to the nearest 0.1 m using a measuring tape or meter stick. Water velocity was measured using an Ott Current Meter held ca. 2.5 cm above the substrate. Three measures of revolutions/15sec were taken at each site. These were converted to revolutions/min and current velocity was read from calibration plots and recorded to the nearest 0.5 m/s. Mean width and mean velocity for all sampling dates were calculated and categorized to obtain single velocity and width measurements for each site relative to each other (refer to Table 1 for categories of physical variables).

Substrate type was estimated visually, and classified based on size (diameter) of the predominant particle type (Table 2). Three 1-m transects (unless site was less than 1 m wide) of substrate type were taken at each site. The mean of the three transects was calculated for each substrate type recorded and substrate was categorized as that type which accounted for the largest portion of the total. Substrate ranged from mud to boulder. A category of wood was included to accommodate site C14 where the artificial substrates (see Chapter 4) were placed on branches due to the slow current velocity and vegetation which choked the channel at this site. Overhanging vegetation, surrounding cover, and percentage cover of aquatic vegetation were determined visually and categorized. Overhanging vegetation was scored as present or absent. Present overhanging vegetation was taken to be vegetation along the bank (within 1-2 m from the bank) that overhung the sample site such that the site was partially or completely covered. Surrounding cover was taken to be the dominant vegetation in the area visible beyond 1-2 m from the bank. It was scored as being open or forest. Level of disturbance was ranked from low (1) to high (5) and assigned to each site based on the condition of the site relative to all other sites (similar to Fore *et al.* 1996). A disturbance included any known present and past, human and natural, physical and chemical disturbance (e.g., urbanization, nearby roads, road runoff, waste discharge, channelization, recreational use). A score of 1 was assigned to a site influenced by few-to-none of these disturbances, whereas a score of 5 was assigned to a site influenced by most or all of these disturbances.

Continuous physical variables were categorized to maintain consistency between these and other categorically measured variables. The categorization of variables is justified because not enough sites were sampled to provide trends in measures such as velocity and width. Furthermore, variables were measured twice a year only, therefore intended only to reflect gross differences between sites.

2.3 SITE DESCRIPTIONS

Chemical data are presented in Table 3. All chemical concentrations were low and fell within the range of typical values for "healthy" waters in Newfoundland (Peter Davenport, personal communication). Most sites were only slightly acidic with pH values no lower than 5.63. Temperatures were cool to warm.

Categorized physical data are provided in Table 4. Sites ranged from low (1) to mid-order (4), with most sites being narrow, low-order streams. Substrate was dominated by cobbles and boulders at most sites and most sites were in forest areas. Come-by-Chance sites were the least disturbed and St. John's sites were the most disturbed. Brief descriptions of study areas and sites follow below.

2.3.1 Bonavista

The Bonavista headland includes the town of Bonavista and several small surrounding settlements. Bonavista is a relatively large fishing settlement with a fish plant and which is also a regional service centre (Ommer 1993). The urbanized area is limited to the mouth of the water-catchment with no current waste-water input, but several parts are disturbed by abandoned railbed right-of-ways, roads and gravel pits (Colbo, personal communication). Bonavista is a naturally harsh environment. The Peninsula extends into the ocean and is exposed to cold, high winds. The area is a heathland and the terrain is covered by stunted forest growth (Meade 1993). Seven sites in the Bonavista area were sampled (Figure 2).

Site B1 (48°39'N, 53°05'W) (Figure 6a). Located in the town of Bonavista. The outlet was ca. 600 m from Bonavista Harbour. The bankside and surrounding area were cleared and covered by heath, grass or low lying shrubs. Aquatic vegetation was dominated by pondweed (*Potamogeton natans*). There was also algae on the substrate surface. Blue flag (*Iris versicolor*) and sedges (*Carex spp.*) trailed into the stream from the banks. Disturbances resulting from urbanization were vegetation clearance and replacement by introduced species (Colbo, personal communication), road construction and solid urban and industrial waste. The pond above the outlet was divided by the railroad in the early 1900s and sewage from the hospital was dumped into one section in the past (Colbo, personnel communication). The site was assigned a disturbance value of 4.

Site B2 (48°37'N, 53°05'W). About 3000 m upstream of B1. The outflowing pond is the water supply for the town of Bonavista. The site was located in a stunted conifer forest of balsam fir and spruce but the outlet itself was clear of trees. Bankside vegetation was dominated by bog myrtle (*Myrica gale*), mountain holly (*Nemopanthus mucronata*) and meadowsweet (*Spiraea latifolia*). The pond was isolated from the residential area, and the only apparent disturbance was the old railroad, abandoned in the early 1980s, and water main right-of-way which ran nearby. The site was assigned a disturbance value of 2.

Site B3 (48°37'N, 53°05' W) (Figure 6b). Near highway 230 on the outskirts of Bonavista immediately upstream (ca. 500 m) of B7. The stream had been channelized a few decades before the present, when the site was in a gravel pit which is now abandoned (Colbo, personal communication). Aquatic vegetation included bur reed (*Sparganium angustifolium*), grasses, shrubs and algae. Bankside vegetation was dominated by meadowsweet, mountain alder, bog myrtle, grasses and sedges. The outlet was directly beneath an abandoned cement bridge. The site had obviously been highly disturbed in the past, but is now naturally revegetating as indicated by abundant 2-3 m alder regrowth and the aquatic vegetation (Colbo, personal communication). The site was assigned a disturbance value of 3.

Site B6 (48°37'N, 53°06'W). Located ca. 1500 m upstream of B2 on a tributary in an open wetland. The surrounding area had been highly disturbed but is now vegetated by a shrub forest. Bankside vegetation was dominated by sedges, bulrush (*Scirpus cyperinus*) and marsh cinquefoil (*Potentilla palustris*). The outlet had been channelized in the past, running under an old railroad bridge, through a small wetland, and then under the highway. The channel between the railroad bridge and highway was about 20 m long. Sampling was carried out about 8 m downstream from the bridge. The site was assigned a disturbance value of 3.

Site B7 (48°37'N, 53°05'W). About 1500 m upstream of B2 on the main stream. The outlet stream ran 30 to 50 m between the pond and a large pool. The surrounding area was heathland and stunted conifer forest with an open stream channel. Bankside vegetation was dominated by bog myrtle, meadowsweet, sedges, meadow rue (*Thalictrum polygamum*)and stunted black spruce. The only apparent disturbance was the old gravel pit along the tributary from the pond (B3). The site was assigned a disturbance value of 2.

Site B8 (48°37'N, 53°05'W). On a tributary ca. 1700 m upstream of B2. The surrounding area was coniferous forest, but the stream had been cleared and channelized and is now revegetated by shrubs which semi-overgrow the channel. Bankside vegetation was dominated by bog myrtle, meadowsweet, sedges and meadow rue. The outlet was ca. 10 m from highway 230, and there was a woods access road and abandoned railroad along the shore of the pond. Beaver had created a small dam at the outlet. The site was assigned a disturbance value of 3.

Site B18 (48°37'N, 53°07W). About 1300 m upstream of B6 on its inlet stream. The surrounding area was stunted coniferous forest, but the outlet itself was in an open wetland-shrub area. Bankside vegetation was dominated by sedges and bog myrtle with a small clump of black spruce trees (ca. 5-6 m tall) also present. The site was located about 50 m from highway 235, an old abandoned roadbed used for camping, and a powerline. Beaver had dammed the outlet in the past leaving much decaying wood at the outlet. The site was assigned a disturbance value of 3.

2.3.2 Random Island

Random Island is a large (ca. 35 km long) sheltered island in Trinity Bay, surrounded by two narrow inlets. The water-catchment sampled flows into Hickmans Harbour. The water-catchment was sheltered within a narrow, heavily forested valley. Most sites were in rural areas used for forestry and limited farming.

All sites were disturbed, but without direct point source pollutant inputs (Colbo, personal communication). Five sites were sampled on Random Island (Figure 4).

Site R9 (48°06N, 53°46'W) (Figure 7a). About 2500 m upstream of R13 on a tributary. The surrounding area was a coniferous spruce-fir forest, but the stream itself was open in a ditch beside highway 231. The site had been recently channelized. The banks were primarily gravel and cobble just beginning to revegetate. A recreational park was located at the opposite end of the pond, and the outlet was ca. 3 m from the highway. The site was assigned a disturbance value of 4.

Site R10 (48°07'N, 53°43'W). About 1300 m upstream of R11 on a tributary of R13. The outlet was located in a spruce-fir forest and the stream channel was overgrown by speckled alder (*Alnus rugosa*) and mountain maple (*Acer spicatum*) (ca. 4-5 m tall). There were many branches and small logs in the outlet. Bankside vegetation was dominated by speckled alder and dogberry (*Sorbus sp.*), with some sedges and buttercups (*Ranunculus sp.*). The site was located near highway 231, and a dairy farm was located on the opposite side of the road. There was a wood-hauling trail through the outlet, and the site was used for recreational activities as evidenced, for example, by a row boat beached near the outlet. The site was assigned a disturbance value of 4.

Site R11 (48°07'N, 53°44W). About 1700 m upstream of R13. The surrounding area was coniferous forest and the outlet was overgrown by speckled alder. There was a large accumulation of branches and tree trunks in the stream. Surrounding vegetation was dominated by 3 to 5 m tall speckled alder, with an understorey dominated by meadow rue, dogberry and goldenrod (*Solidago rugosa*). This site was within 30 m of highway 231 and there were several houses at the opposite end of the pond. In 1995 the outlet flowed through an old beaver dam. This was rebuilt by beavers in 1996 flooding the sampling site which was consequently moved further downstream. The site was assigned a disturbance value of 2.

Site R13 (48°06'N, 53°44'W) (Figure 7b). About 1000 m upstream from Hickmans Harbour. The surrounding area was a coniferous forest. Bankside vegetation was sparse and dominated by mountain alder and goldenrod. The site was in the town of Hickman's Harbour and was located near a small Salvation Army Cemetery. The outlet flowed through two large culverts under a gravel road to the cemetery. The site was assigned a disturbance value of 4.

Site R19 (48°06'N, 53°43'W). About 1800 m upstream from Hickmans Harbour on a tributary. The surrounding area was fir-spruce-larch forest and the sample site was overgrown by conifers. Surrounding vegetation was dominated by alders, larch (*Larix laricina*), grasses and meadow rue, with the stream flowing through a 10 m sedge wetland from the pond. The outlet was located within 30 m of a water supply and a gravel access road to the town of Hickman's Harbour. There had been some limited recreational use and some wood cutting. The site was assigned a disturbance value of 2.

2.3.3 Come-by-Chance

The area studied was a relatively undisturbed fen with some patches of stunted coniferous trees. There was no urbanization in the area, and the highway was 200 - 500 m from the sites. There are two industrial projects in the area which directly and indirectly impact the environment. These are the construction of the gravity-based structure at Bull Arm/Sunnyside to be used to extract oil from the offshore Hibernia field 6 to 7 km east of the water-catchment, and the Come-by-Chance Oil Refinery constructed in the late 1960's which is 5 to 6 km south southwest of the water-catchment. The Oil Refinery has been the object of considerable environmental concern due to the waste and air pollution (Ommer 1993). The four sites sampled in this area (Figure 3) were all downwind of the oil refinery air pollution.

Site C14 (47°50'N, 53°57'W) (Figure 8a). About 2000 m from Bull Arm. The outlet and surrounding area were open wetland with patches of stunted coniferous forest. The site was located in a fen area. There was much woody debris in the outlet.

Bankside vegetation was dominated by sedges, Canada burnet (*Sanguisorba canadensis*), bog aster (*Aster nemoralis*) and bog myrtle. Apart from the oil refinery air pollution, there was no apparent physical disturbance in the area of the pond or outlet, although an abandoned railway bed lay on the edge of the water-catchment. The site was assigned a disturbance value of 1.

Site C15 (47°50N, 53°56'W). About 500 m upstream of C17. The surrounding area was an open wetland with stunted clumps of conifers, but the outlet itself was semi-overgrown by low shrubs. There was extensive algal growth on the substrate. Bankside vegetation was dominated by low growing bog myrtle, mountain alder, grasses and sedges. The only obvious disturbance was the air pollution of the oil refinery. The site was assigned a disturbance value of 1.

Site C16 (47°50'N, 53°56'W). About 200 m upstream of C15. The surrounding area was shrub coniferous forest and heathland, but the outlet was semi-covered by low alder bushes. Bankside vegetation was dominated by low growing speckled alder, bog myrtle and sedges. This site was immediately under a cleared transmission line and downwind of the oil refinery air pollution. The site was assigned a disturbance value of 2.

Site C17 (47°50'N, 53°57'W) (Figure 8b). About 1800 m from the sea in Bull Arm. The surrounding area was stunted coniferous forest and heathland. Surrounding vegetation was dominated by bog myrtle, Canada burnet and meadow rue. This site also had no apparent disturbances apart from the air pollution of the oil refinery. The site was assigned a disturbance value of 2.

2.3.4 St. John's area

Seven sites in two water-catchments were sampled in Paradise, Mount Pearl and the city of St. John's (Figure 5). All are highly disturbed urbanized basins. S20, S21 and S22 drain into the Waterford River which flows into St. John's Harbour. S23, S24, S25 and S26 are on a different catchment that drains into Quidi Vidi Lake which releases into Quidi Vidi Harbour.

Site S20 (47°32'N, 52°50'W) (Figure 9a). Head of the Waterford River, in Paradise, ca. 12000 m from St. John's Harbour. The surrounding area was coniferous forest and hay fields, with the outlet overgrown by shrubs. A large dead fir tree had fallen across the stream 2 m above the sampling area. Bankside vegetation was dominated by meadow rue, bog myrtle and grasses. The pond was urbanized along about one quarter of the shoreline and hay fields covered another quarter of the shoreline. An abandoned railbed lay along one shoreline, ca. 100 m downstream, as did highway 60 and a power corridor. Although the outlet was not highly disturbed, the pond above the site had a considerable amount of disturbance. The site was assigned a disturbance value of 5.

Site S21 (47°31'N, 52°49'W). On a tributary, in Mount Pearl, about 900 m from the main Waterford River and drains into the river about 2500 m downstream of S20. The surrounding area was coniferous forest with urban housing, but the outlet itself was an open, dug channel with mown grass along the banks. There was ca. 5% algal cover on the substrate. Bankside vegetation was dominated by grasses and rush (*Juncus sp.*). This site was located in an urban local park with heavily used walking trails. There were houses 10 m from the stream and pond. The first 6 m of the stream were channelized with concrete. The site was assigned a disturbance value of 5.

Site S22 (47°31'N, 52°47'W). On a tributary, in Mount Pearl, about 900 m from the main Waterford River and drains into the river about 4000 m downstream from where S21 drains into the river. The drainage from S22 is about 7000 m upstream from where the river flows into St. John's Harbour. The surrounding area was coniferous forest, abandoned fields and urbanized housing development. The outlet was semi-overgrown by bushes and trees. Bankside vegetation was dominated by balsam fir, sedges, grasses and bog myrtle. This site was located behind a shopping centre and beside a cemetery in a clump of forest in the Mount

Pearl area. The site was channelized at least 40 years ago but 30-40 year old trees grow along the present channel (Colbo, personal communication). The outlet was isolated from the residential area. The site was assigned a disturbance value of 3.

Site S23 (47°34'N, 52°43'W) (Figure 9b). In St. John's about 2800 m from Quidi Vidi Lake. The outlet and surrounding area were in an open urbanized park, located between major streets and government buildings. There was a scattering of fir and shrubs in the surrounding area. There was extensive algal growth on the substrate. Bankside vegetation was dominated by grasses and meadowsweet. The pond was adjacent to the university buildings and a recreational area. The upstream section was highly channelized through commercial and urban developments. A side channel from S24 flowed into the stream immediately above the area sampled. The site was assigned a disturbance value of 5.

Site S24 (47°35'N, 52°43'W). On a tributary, in St. John's, about 700 m upstream of S23. The surrounding area was coniferous forest and the outlet was semi-overgrown by trees. There was also some fallen wood in the stream. Bankside vegetation was dominated by balsam fir, bog myrtle, white spruce and alders. This site was located in a local park with heavily used walking trails. The pond was adjacent to a major street, housing development, government buildings and institutions. The site was assigned a disturbance value of 5.

Site S25 (47°36'N, 52°42'W). On Virginia River, in St. John's, about 3000 m from Quidi Vidi Lake. The surrounding area was coniferous forest and the outlet was semi-overgrown by bushes. Bankside vegetation was dominated by mint (*Mentha sp.*) and balsam fir. The pond was located within a residential area in the city of St. John's. The outlet had been dammed and channelized several years ago (Colbo, personal communication). The sample site was in a side channel which still showed active erosion. There was garbage (e.g., milk crate, plastic bag) in and around the outlet and nearby trail. There was a trail cut through the vegetation leading to the outlet. The site was assigned a disturbance value of 5.

Site S26 (47°34'N, 52°41'W). On a small tributary flowing from Signal Hill in St. John's about 1000 m from Quidi Vidi Lake. The surrounding area was open heath but the outlet stream was in a deep channel overgrown by small trees and bushes. Bankside vegetation was dominated by alders and mountain ash. This site was located below the Cabot Tower on Signal Hill, St. John's. The area had been deforested and used for military purposes at least 200 years ago (Colbo, personal communication). The pond served as the first water supply for the city. A gravel road ran over the stream ca. 20 m below the outlet. There was a path crossing the outlet, and garbage in the outlet (e.g., plastic bags, road sign). The site was assigned a disturbance value of 5.

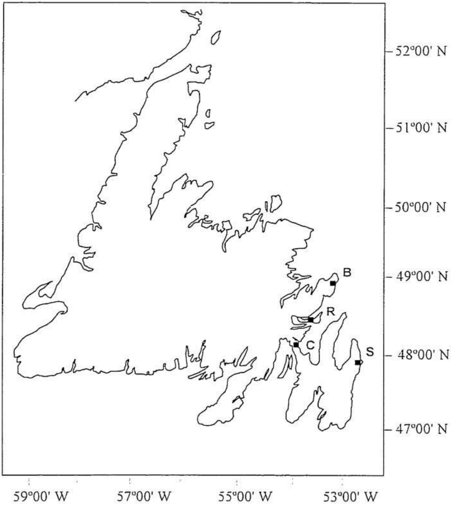

Figure 1. Map of Newfoundland indicating location of the four study areas (B = Bonavista, R = Random Island, C = Come-by-Chance, S = St. John's).

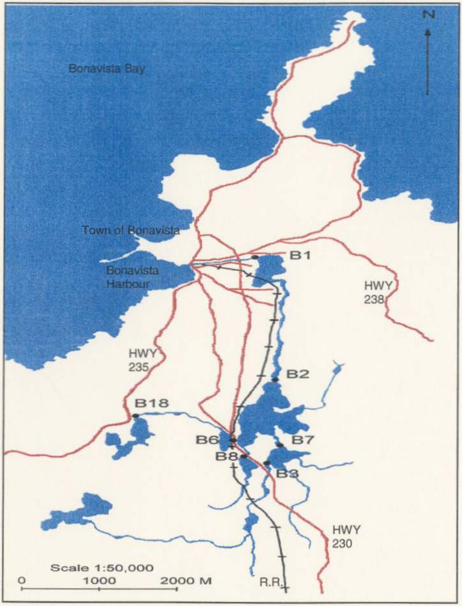

Figure 2. Map of Bonavista, Newfoundland, indicating location of sites sampled (R.R. = Railroad).

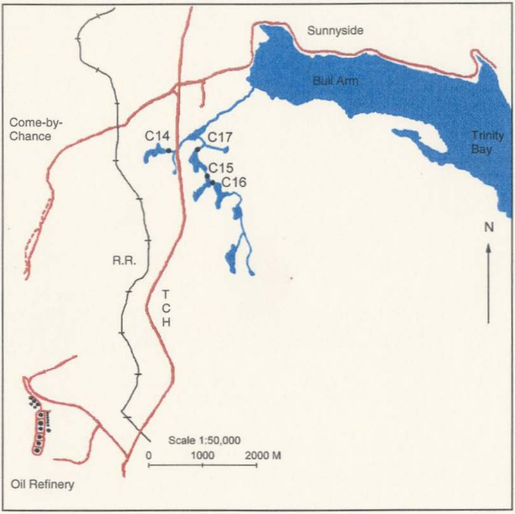

Figure 3. Map of the Isthmus of the Avalon, Newfoundland, indicating location of sites sampled near Come-by-Chance, Newfoundland.

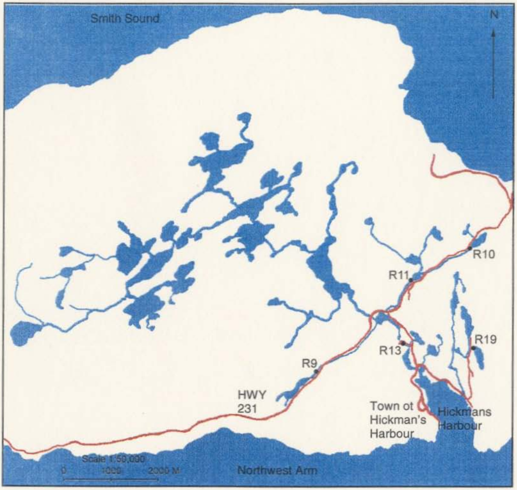

Figure 4. Map of Random Island, Newfoundland, indicating location of sites sampled.

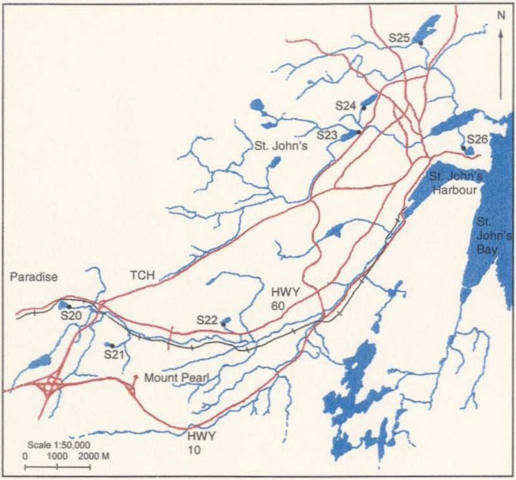

Figure 5. Map of St. John's area, Newfoundland, indicating location of sites sampled.

Table 1. Chemical and physical characteristics of 23 lake outlet sites, their codes, and notes on measurement.

Variables	Code	Measurement Units	Notes
Chemical			
Sulphate	SO4	mg/l	
Magnesium	Mg	mg/l	
Zinc	Zn	µg/l	
Aluminium	Al	µg/l	
Calcium	Ca	mg/l	
Potassium	K	mg/l	
Sodium	Na	mg/l	
Copper	Cu	µg/l	
pH	pH		
Conductivity	Cond	µS/cm	
Temperature	Temp	°C	
Physical			See Note
Stream order	ORDER	Four categories	1
Stream width (m)	WIDTH	Two categories	2
Substrate type	SUBST	Five categories	3
Mean velocity (m/s)	AVVEL	Two categories	4
Aquatic vegetation (%)	AQVEG	Two categories	5
Immediate cover	IMMCOV	Two categories	6
Surrounding cover	SURCOV	Two categories	7
Disturbance	PHYDIS	Five categories	8

1. Stream order was determined using maps with scales of 1:50,000. Stream order ranged from first to fourth order.
2. Stream width categories were: 1 (3.3 m), 2 (> 3.3 m).
3. Substrate type categories were: 1 (mud), 2 (small stone), 3 (wood), 4 (cobble), 5 (boulder).
4. Average velocity categories were: 1 (< 50 m/s), 2 (> 50 m/s).
5. Aquatic vegetation categories were: 1 (< 5 %), 2 (> 5 %).
6. Immediate cover categories were: 1 (absent), 2 (present).
7. Surrounding cover categories were: 1 (open), 2 (forest).
8. Disturbance categories ranged from 1 (low) to 5 (high).

Table 2. Classification of stream bed particles (adapted from McCreadie (1991)).

Category	Particle diameter (mm)
Mud	< 2
Small stone	2 - 32
Cobble	33 - 256
Boulder	> 256

Table 3. Chemical characteristics of 23 lake outlets in Bonavista, Random Island, Come-by-Chance and St. John's, NF, recorded during May and July 1995, and May and July 1996 (mean values of 4 sampling dates).

	Environmental site											
	Bonavista							Random Island				
Variables	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
SO4 (mg/l)	38.72	23.46	54.91	30.40	48.00	62.09	3.65	15.69	10.86	12.24	14.09	3.05
Mg (mg/l)	1.01	0.74	0.75	0.94	0.75	0.83	0.97	0.98	1.45	1.12	0.61	0.81
Zn (μg/l)	5.83	5.28	6.15	4.56	4.59	4.16	1.95	2.28	2.19	3.39	4.25	2.05
Al (μg/l)	55.63	58.13	108.38	103.13	126.38	75.50	59.25	26.25	18.00	15.63	44.88	15.50
Ca (mg/l)	1.89	4.00	1.06	1.33	1.04	1.01	1.97	4.88	3.30	7.65	2.92	3.63
K (mg/l)	0.34	0.31	0.23	0.26	0.25	0.30	0.35	0.49	0.71	0.38	0.26	0.25
Na (mg/l)	12.39	8.02	6.97	8.88	7.68	6.47	13.65	9.70	9.77	6.43	3.49	3.21
Cu (μg/l)	3.50	4.63	7.55	7.50	6.63	5.13	1.75	4.50	5.63	2.63	2.38	1.50
pH	6.65	5.88	5.63	6.25	6.10	5.93	6.80	7.35	6.98	7.25	6.93	7.10
Cond (μS/cm)	99.38	60.70	54.38	67.45	55.95	49.90	99.30	89.15	89.00	86.88	41.15	45.25
Temp (°C)	14.75	14.22	13.00	14.78	12.78	14.57	13.00	13.63	14.45	14.28	13.97	15.00

Table 3 continued. Chemical characteristics of 23 lake outlets.

	Environmental site										
	Come-by-Chance				St. John's						
Variables	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
SO4 (mg/l)	58.66	32.75	28.31	24.41	7.10	12.13	4.28	7.05	19.88	9.90	6.60
Mg (mg/l)	0.60	0.66	0.62	0.64	1.19	1.29	1.23	1.03	9.20	4.28	2.29
Zn (µg/l)	12.10	3.90	3.15	3.43	4.15	22.15	4.53	17.80	5.20	9.55	4.50
Al (µg/l)	118.33	78.88	90.88	80.88	39.50	39.00	32.50	74.00	0.00	26.00	23.25
Ca (mg/l)	2.04	2.81	2.50	2.55	4.62	7.67	4.40	5.18	16.80	7.26	3.45
K (mg/l)	0.21	0.26	0.25	0.26	0.75	0.95	0.48	0.93	2.10	1.08	0.80
Na (mg/l)	3.43	4.95	3.38	4.79	38.51	87.01	29.26	43.82	109.70	53.16	50.05
Cu (µg/l)	9.17	3.25	3.63	3.63	2.25	3.75	2.00	4.00	3.00	3.00	3.50
pH	6.30	6.53	6.55	6.45	6.65	6.75	6.55	6.80	7.30	7.10	6.60
Cond (µS/cm)	33.80	46.38	37.38	45.70	211.50	407.50	178.00	238.00	1081.00	287.50	279.00
Temp (°C)	12.97	14.40	14.82	13.68	15.00	16.00	15.50	13.50	15.50	14.00	14.50

Table 4. Physical characteristics of 23 lake outlets in Bonavista, Random Island, Come-by-Chance and St. John's, NF, recorded during May and July 1995, and May and July 1996.

	Environmental site											
	Bonavista							Random Island				
Variables	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
Stream order	3	3	2	1	3	1	1	1	1	2	4	1
Stream width (m)	2	2	1	1	2	1	1	1	1	1	2	1
Substrate type	4	5	5	2	5	4	4	4	1	4	5	2
Mean velocity (m/s)	2	1	2	1	2	1	2	2	1	1	2	2
Aquatic vegetation (%)	2	1	2	2	1	1	1	1	2	1	1	2
Immediate cover	1	1	2	1	1	2	1	1	2	2	1	2
Surrounding cover	1	2	2	2	2	2	2	2	2	2	2	2
Disturbance	4	2	3	3	2	3	2	4	4	2	4	2

	Environmental site										
	Come-by-Chance				St. John's						
Variables	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
Stream order	1	2	2	2	1	1	1	3	1	3	1
Stream width (m)	1	1	1	1	1	1	1	2	1	2	1
Substrate type	3	5	4	4	2	4	2	5	4	5	2
Mean velocity (m/s)	1	1	2	2	1	2	1	2	1	2	1
Aquatic vegetation (%)	2	2	2	1	1	1	2	2	1	2	1
Immediate cover	1	2	2	2	2	1	2	1	2	2	2
Surrounding cover	1	1	2	2	2	2	2	1	2	2	1
Disturbance	1	1	2	1	5	5	3	5	5	5	5

a)

b)

Figure 6. Sites B1 (a) and B3 (b), Bonavista, Newfoundland.

a)

b)

Figure 7. Sites R9 (a) and R13 (b), Random Island, Newfoundland.

a)

b)

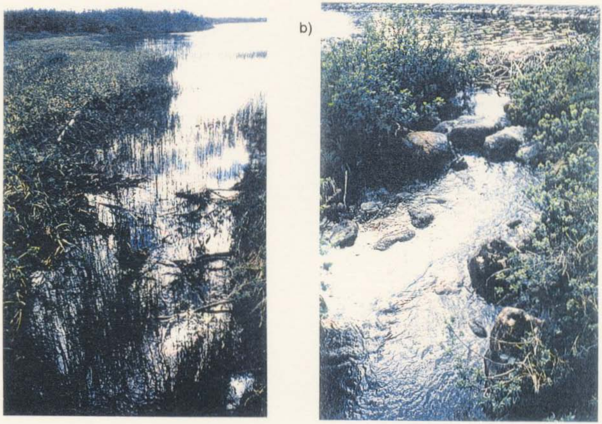

Figure 8. Sites C14 (a) and C17 (b), near Come-by-Chance, Newfoundland.

a)

b)

Figure 9. Sites S20 (a) and S23 (b), St. John's area, Newfoundland.

Chapter 3. Comparison of 23 lake outlet sites of four study areas in northeastern Newfoundland based on chemical/physical characteristics and human disturbance.

3.1 INTRODUCTION

The condition of a water-catchment is influenced by many factors, both natural and human. Naturally, water quality is influenced by ecological, hydrological and geomorphological processes such as the nature of the bedrock, the geological history and climate of the catchment and the biotic community found in the catchment. For example, the type of bedrock, climate, precipitation and biota present influence the availability of metals and the rate at which they are leached into the water through weathering. The soil type, topography, climate and biota help determine the amount of particulate matter present in the water. In areas with fine substrates, little vegetation, and heavy rain storms, erosion of sediment into the streams and wetlands may produce a high input of particulate matter. Water velocity determines sediment transport, resulting in areas of erosion and deposition, which are reflected in the substrates found in streams. Water velocity is determined by relief and water depth which reflects past geological and geomorphological processes. Surrounding and overhanging vegetation influence the amount and type of organic material entering the system. Other natural occurrences that may alter the condition of a water-catchment include floods, storms and animal activity (e.g. beaver dams). Extensive ecological reviews of rivers and streams (e.g. Hynes

1970; Vannote *et al.* 1980; Minshall 1988; Calow and Petts 1992; Hauer and Lamberti 1996) provide considerable insight into natural processes that influence the structure and function of running water systems.

Human activity also has a tremendous impact on freshwater systems. Areas with slowly weathering bedrock and poorly buffered soils tend to be more sensitive to disturbances, particularly chemical disturbances (Wiederholm 1984). Human activity may influence water quality indirectly by altering the nature of the catchment. Activities such as logging, clearcutting, farming and channelization may result in heavy erosion of slopes, siltation of streams, piling up of slash in streams, increased current velocity, elevated water temperatures and decreased allochthonous organic inputs (Heliövaara and Väisänen 1993). The addition of suspended particulate material may reduce plant growth by reducing the availability of light and may alter the substrate by filling interstices and smothering hard surfaces (Wiederholm 1984). Removal of riparian vegetation and channelization may change the mean temperature and the diurnal and seasonal pattern of temperature fluctuation (Wiederholm 1984). Disturbance of the soil and removal of vegetation disrupt the mineral and nutrient cycles by accelerating natural weathering, mineralization and leaching processes.

Land use such as farming, forestry, urbanization, industrial development and road and dam construction, results in contaminated runoff, which changes the physical and chemical nature of streams. Agriculture activities may result in the runoff of nutrients, pesticides and increased turbidity (Wiederholm 1984). Industrial wastes, surface runoff from paved roads and accidental spills may add oil to streams (Wiederholm 1984). Combustion of fossil fuels creates acid precipitation. Temperature may also be affected by industrial discharges, agricultural, forestry and urbanization activities.

Two types of chemical pollution that result from human activity are organic pollution and eutrophication. Organic pollution may reduce the availability of oxygen as the organic matter is decomposed (Heliövaara and Väisänen 1993). Therefore organism biomass may be reduced. Eutrophication results from the addition of large quantities of nutrients, mainly phosphorus and nitrogen compounds. This causes excessive growth of algae and aquatic plants, which provides food and substratum for organisms. (Heliövaara and Väisänen 1993; Dojlido and Best 1993). Excessive plant and algal growth also alters nutrient concentrations and dissolved oxygen levels, can secrete toxins, affect light penetration, and alter the nature of the substratum. Plants and algae reduce water movement which allows sedimentation of particulate mineral and organic matter. Eventually, the excess vegetation dies and falls to the bottom where a build up of organic matter increases decomposition and creates anaerobic conditions.

The following sections use data from Chapter 2 to compare concentrations of selected chemical variables between the study areas, levels of disturbance, sites which are open and covered, and sites in open and forest areas. Sites are grouped based on similar physical and chemical characteristics using multivariate statistics. All statistical analysis were performed using Minitab Release 11. Sites are hypothesized to differ significantly based on level of disturbance and associated chemical composition. St. John's sites are hypothesized to differ significantly from remaining sites in terms of chemical composition, which tends to be influenced by disturbance.

3.2 ANALYTICAL METHODS

3.2.1 Univariate Analysis

The General Linear Model (GLM) was used to perform Model II Analysis of Variance (ANOVA) to test for significant differences in the values of each chemical variable between study areas, levels of disturbance, open and covered outlets, and outlets in open and forest areas (Chapter 2). ANOVA is used to test for significant differences between two or more sample means using variances to measure the differences between means (Sokal and Rohlf 1995). ANOVA is commonly used to analyse data from benthic studies (Rosenberg and Resh 1993).

For each test, residuals were examined to determine whether they met the assumptions of the ANOVA model. When the residuals did not meet the assumptions of the ANOVA model, randomization tests were performed. Unlike ANOVA, randomization requires no assumptions of the error distribution, except for random selection (Manly 1991).

Fisher's pairwise comparisons were used to determine which study areas and which disturbance levels were significantly different from the others for those chemical variables that were significantly different between study areas and disturbance levels. Fisher's pairwise comparisons provide confidence intervals for all pairwise differences between level means using Fisher's LSD procedure (Minitab reference manual 1993). This allows one to assess the practical significance of differences among means.

3.2.2 Multivariate Analysis

Principal Components Analysis (PCA) using the correlation matrix was used to group similar sites based on the chemical and physical environmental variables (Chapter 2). Principal Components Analysis is a type of ordination. According to Rosenberg and Resh (1993), "ordination is used to reduce the dimensionality of a complex multivariate data set with minimal loss of information, and to extract a set of uncorrelated variables from a set of correlated variables." In ecological studies, environmental variables measured are often correlated. Principal Components Analysis is commonly used to reduce the data-set to a smaller number of statistically independent variables (e.g., Green and Vascotto 1978; Ciborowski and Alder 1990).

Physical variables measured only once were assumed not to change (or change very little) between sampling dates. The variables were ranked into two or more categories and a single category was assigned to each site. The mean of those physical variables measured during each sampling date (or more than once) was calculated before categories were assigned. All chemical variables, including temperature, were measured during each sampling date (or more than once) and the mean was calculated (Griffith *et al.* 1995; Bournaud *et al.* 1996; Guerold *et al.* 1995). Before the analysis was carried out, all variables not categorized (i.e., chemical variables excluding pH) were transformed using the natural logarithem (ln(X)).

Spearman's Rank Correlation Coefficients were calculated between each environmental variable loaded on the Principal Components axis (PC-axis) and PC-scores to determine the degree of association between the original variables and the derived PC-axis (Ciborowski and Adler 1990).

ANOVA was used to test for significant differences in PC-scores between study areas. Fisher's pairwise comparisons were used to determine which study areas were significantly different from the others if the ANOVA indicated a significant difference between study areas.

3.3 RESULTS

3.3.1 Univariate Analysis

The residuals of most tests did not meet the assumptions of the ANOVA model (Table 5) (see Appendix 1 for sample of ANOVA output and examination of residuals). Randomization tests were performed for those tests which had a p-value less than 0.300 but greater than 0.015 (Table 6) (see Appendix 2 for sample randomization test). Remaining p-values were accepted as they would not change significantly after randomization.

Overall, there was a significant difference in most chemical values (except Cu and temperature) between study areas (Table 5 and 6). Results of Fisher's pairwise comparisons are given in Table 7 (see Appendix 3 for sample Fisher's pairwise comparisons output). Most significant differences were between St. John's and the remaining three areas. Concentrations of Ca, K, Mg and Na, and conductivity were significantly higher at St. John's than at Bonavista and Come-by-Chance sites, whereas concentrations of Al and SO_4 were significantly lower at St. John's than at Bonavista and Come-by-Chance sites. pH was also higher at St. John's than at Bonavista sites. Concentrations of K, Na and Zn, and conductivity were significantly higher at St. John's than at Random Island sites. There were few significant differences amongst the remaining three areas.

Chemical variables which differed significantly between levels of disturbance were concentrations of Ca, K, Mg, Na and SO_4, and pH and conductivity (Table 5 and 6). Most significant differences were between level 5 and the remaining 4 levels (Table 8). Concentrations of Ca, K and Na, and conductivity were higher at level 5 disturbance than at the remaining four levels. Concentrations of Mg were higher at level 5 than at levels 1 and 2 disturbance, whereas concentrations of SO_4 were lower at level 5 than at levels 1 and 2 disturbance. pH was lower at level 3 than at levels 2, 4 and 5 disturbance.

Only Zn concentrations were significantly different between open and covered sites. Concentrations tended to be higher at open sites. There were no other significant differences in chemical variables between open and covered sites or between sites in open and forest areas.

3.3.2 Multivariate Analysis

Results of the Principal Components Analysis are given in Tables 9 and 10. Environmental variables with a score $\geq$ 0.650 or $\leq$ -0.650 were considered to be correlated with PC-axes. Since most environmental variables were loaded on the first two PC-axes, only these will be discussed further. The first principal component described 35.3% of the variation among sites. Seven variables were positively correlated with PC-I. These were concentrations of Ca, K, Mg and Na, and pH, conductivity and disturbance. Al concentration was negatively correlated with PC-I. PC-I described the chemical composition of the outlets. Sites with high

PC-I values had high concentrations of Ca, K, Mg and Na, low concentrations of Al, and high values of pH, conductivity and disturbance.

The second principal component described 17.8% of the variation. Four variables were negatively correlated with PC-II. These were Zn concentration, substrate type, stream order, and stream width. Therefore, PC-II tended to describe physical characteristics of the sites. Sites with high PC-II scores had low Zn concentrations, small substrate, and were narrow, low-order streams.

PC-I was plotted against PC-II, and a general grouping of sites was produced based on the four quadrants of the plot (Figure 10). St. John's sites had positive scores on PC-I indicating that these sites had low concentrations of Al, high concentrations of Ca, K, Mg and Na, and high pH, conductivity and disturbance. Random Island sites, excluding R13, also had positive scores on PC-I, however the values were closer to zero than those for St. John's sites. Bonavista and Come-by-Chance sites had negative scores on PC-I indicating that these sites had lower chemical concentrations and disturbance. Sites showed a broad range of characteristics on PC-II. However, Come-by-Chance sites had only positive scores on PC-II indicating that all of these outlets were narrow, low-order streams with small substrate and low concentrations of Zn.

Results of the ANOVA tests indicated that study areas differed significantly on PC-I (Table 11). Fisher's pairwise comparisons indicated a significant difference between Bonavista and Random Island sites, and a significant difference between St. John's sites and sites of the remaining three study areas.

3.4 DISCUSSION

Nine chemical variables were selected for analysis in the present study. K, Ca, Mg and Na were selected because their salts occur naturally in waters in such proportions to produce a physiologically balanced solution (Hawkes 1979). When an anthropogenic discharge increases the concentration of one of these ions, it upsets the balance and may create toxic conditions. High concentrations of the remaining chemicals, Al, Cu, SO_4 and Zn, are often associated with human disturbance (e.g., discharge of industrial and municipal wastes, road runoff, and drainage water from agricultural land), and may be toxic at high concentrations.

Most significant differences in chemical variables were between highly disturbed St. John's sites and other study areas and/or levels of disturbance. Most chemical concentrations and conductivity were highest at St. John's sites. This was expected since urbanized areas receive high levels of road salts and municipal and industrial wastes, which alter the chemical composition of the water (Heliövaara and Väisänen 1993). Chemically, the remaining three study areas were relatively similar to each other. However, even at St. John's, no chemical values were beyond normal ranges for "healthy" waters in Newfoundland (Peter Davenport, Department of Energy and Mines, Newfoundland, personal communication).

Environmental variables important in distinguishing between sites were Al, Ca, K, Mg, Na and Zn concentrations, pH, conductivity, disturbance, substrate type, stream order and stream width. Remaining variables were not useful in separating sites in the present study. Various chemical concentrations and conductivity were positively correlated with disturbance. These chemical variables tend to be associated with human disturbance and urbanization (Heliövaara and Väisänen 1993; Dojlido and Best 1993).

PC-I was useful in distinguishing between sites based on disturbance and chemical concentrations. As expected, highly disturbed sites tended to have high concentrations of Ca, K, Mg and Na, and high conductivity. Highly urbanized disturbed sites also had high pH values, probably because of the high salt input resulting from road runoff. Al concentrations tend to be negatively correlated with pH values (Dojlido and Best 1993), thus low concentrations of Al occurred at the highly urbanized, disturbed sites, which had high pH values. There was much overlap among the remaining three study areas in terms of scores on PC-I. However, there was a significant difference between Bonavista and Random Island sites. Random Island sites tended to be intermediate in terms of disturbance and chemical concentrations with values near zero on PC-I. Bonavista sites tended to have low disturbance and chemical concentrations. Only values of the more disturbed Bonavista sites were near zero on the negative side of PC-I. All Come-by-Chance sites had low values on PC-I, indicating their low disturbance and chemical concentrations.

PC-II distinguished between sites based on physical characteristics. Substrate, stream order and stream width were correlated on PC-II. These variables were expected to be correlated since higher order streams tend to be wide and therefore have large substrate size (Hynes 1970). There was no significant difference between study areas on PC-II, indicating that sites of each study area included a broad range of physical characteristics.

Sites B1, B2, B3, B7 and R13 were grouped as having negative values on both PC-scores. Most of these sites were wide outlets, with large substrate size, high current velocity, and low levels of disturbance and chemical concentrations. B1 and R13 had relatively high levels of disturbance. However, their scores were near zero on the negative side of PC-I. Unlike the urbanized St. John's sites, these sites occurred in rural areas and received less chemical input from road runoff and municipal and industrial wastes (Colbo, personal communication). B3 had a negative score on PC-II even though it was a narrow, low-order stream. However, B3 did have large substrate and a high Zn concentration which are characteristic of sites with negative scores on PC-II.

Sites B6, B8, B18, C14, C15, C16 and C17 were grouped as having negative values on PC-I and positive values on PC-II. These sites tended to have low disturbance and chemical concentrations, small substrate size and low stream order and width. B6 and B8 had moderate levels of disturbance (level 3), however the disturbance was primarily physical with little chemical pollution. Although there was much variation in substrate size (ranging from small stone to boulder), sites had positive scores on PC-II because of low values of the remaining three variables correlated with PC-II. However, all values were near zero (i.e., < 1).

Sites S21, S23, S24 and S25 were grouped as having high disturbance and chemical concentrations, large substrate, and high stream order and width. These sites were St. John's sites, expected to have high levels of physical and chemical disturbance. S21 was a narrow low-order stream. However, a high Zn concentration and large substrate size gave it a negative score on PC-II. S24 was also a narrow low-order stream and also had a low Zn concentration. However, large substrate size gave it a negative score near zero on PC-II.

Sites R9, R10, R11, R19, S20, S22 and S26 were grouped as having high disturbance and chemical concentrations, small substrate size, and low stream order and width. Random Island sites had values near zero on PC-I due to low chemical concentrations relative to St. John's sites. S22 had a moderate level of disturbance due to little physical disturbance. However, high chemical concentrations gave it a positive score on PC-I. R9 and R11 had large substrate size, but low stream order and width gave them positive scores on PC-II.

Results of this study indicate that sites studied covered a broad range of physical characteristics (e.g., narrow to wide, open to covered, small to large substrate, slow to fast current velocity). PC-I was useful in separating sites based on disturbance and chemical concentrations. There was clear separation of St. John's sites from sites of the remaining three areas. Come-by-Chance sites, which were least disturbed, had the lowest values on PC-I. There was some overlap between Bonavista, Random Island and Come-by-Chance sites. This overlap was probably due to minor differences in levels of disturbance between the three areas.

Chemical data indicate that the streams studied were not adversely affected by human activity. The water catchments of the study areas are healthy in terms of chemical composition. However, as expected, St. John's sites did contain higher concentrations of many chemicals that are associated with human disturbance. Because the values are within typical ranges, these data provide a baseline measure for future water quality assessment of the catchments studied.

Table 5. Results of ANOVA (using GLM command) to test for significant differences in chemical variables with respect to various environmental variables for 23 lake outlet sites. Values in bold indicate those tests for which the residuals met the assumptions of the ANOVA model. Values underlined indicate those tests re-run using randomization. Remaining p-values were accepted as they would not change significantly after randomization.

Variables	Study area p-value	Disturbance level p-value	Immediate cover p-value	Surrounding cover p-value
Al (µg/l)	<0.001*	<u>0.058</u>	<u>0.117</u>	**0.374**
Ca (mg/l)	0.012*	<u>0.051</u>	0.341	0.468
Cu (µg/l)	**0.134**	**0.311**	<u>0.165</u>	0.483
K (mg/l)	0.001*	**<0.001***	0.369	0.900
Mg (mg/l)	<u>0.090</u>	<u>0.113</u>	<u>0.190</u>	0.633
Na (mg/l)	<0.001*	<0.001*	0.670	0.992
SO4 (mg/l)	0.002*	<u>0.079</u>	0.624	0.440
Zn (µg/l)	<u>0.087</u>	<u>0.088</u>	<u>0.076</u>	<u>0.154</u>
pH	<0.001*	**0.024***	0.686	0.788
Cond (µS/cm)	0.008*	0.013*	0.456	0.820
Temp (°C)	<u>0.161</u>	0.448	**0.133**	**0.484**

* significant at 0.05 significance level

Table 6. Results of randomizations (using Mean Square of Error) to test for significant differences in chemical variables with respect to various physical environmental variables for 23 lake outlet sites. Randomization tests were carried out only for those tests for which the residuals did not meet the assumptions of the ANOVA model.

Variables	Study area p-value	Disturbance level p-value	Immediate cover p-value	Surrounding cover p-value
Al (µg/l)	-	0.056	0.093	-
Ca (mg/l)	-	0.027*	-	-
Cu (µg/l)	-	-	0.130	-
K (mg/l)	-	-	-	-
Mg (mg/l)	0.030*	0.037*	0.166	-
Na (mg/l)	-	-	-	-
SO4 (mg/l)	-	0.049*	-	-
Zn (µg/l)	0.047*	0.063	0.047*	0.066
pH	-	-	-	-
Cond (µS/cm)	-	-	-	-
Temp (°C)	0.153	-	-	-

* significant at 0.05 significance level

Table 7. Results of Fisher's pairwise comparisons for those chemical environmental variables that were significantly different between study areas (B = Bonavista, R = Random Island, C = Come-by-Chance, S = St. John's). Areas with same letters are not significantly different.

Al

Area	N	Mean	StDev	
B	7	83.77	28.62	A
R	5	24.05	12.44	B
C	4	92.24	18.17	A
S	7	33.46	22.33	BC

Mg

Area	N	Mean	StDev	
B	7	0.86	0.11	A
R	5	0.99	0.32	AB
C	4	0.63	0.03	A
S	7	2.93	2.99	B

ZN

Area	N	Mean	StDev	
B	7	4.65	1.39	AB
R	5	2.83	0.96	A
C	4	5.64	4.32	AB
S	7	9.70	7.37	B

Ca

Area	N	Mean	StDev	
B	7	1.76	1.07	A
R	5	4.48	1.92	AB
C	4	2.48	0.32	A
S	7	7.05	4.56	B

Na

Area	N	Mean	StDev	
B	7	9.15	2.77	A
R	5	6.52	3.19	A
C	4	4.14	0.85	A
S	7	58.79	28.88	B

pH

Area	N	Mean	StDev	
B	7	6.18	0.42	A
R	5	7.12	0.18	B
C	4	6.46	0.11	AC
S	7	6.82	0.28	BC

K

Area	N	Mean	StDev	
B	7	0.29	0.05	A
R	5	0.42	0.19	A
C	4	0.25	0.02	A
S	7	1.01	0.52	B

SO4

Area	N	Mean	StDev	
B	7	37.32	20.05	A
R	5	11.18	4.90	B
C	4	36.03	15.47	A
S	7	9.56	5.20	BC

Conductivity

Area	N	Mean	StDev	
B	7	69.60	21.10	A
R	5	70.30	24.80	A
C	4	40.80	6.20	A
S	7	383.20	316.30	B

Table 8. Results of Fisher's pairwise comparisons for those chemical environmental variables that were significantly different between levels of disturbance (1 = low, 5 = high). Disturbance levels with same letters are not significantly different.

Ca

Level	N	Mean	StDev	
1	3	2.47	0.39	A
2	6	3.47	2.32	A
3	4	1.95	1.64	A
4	4	3.25	1.24	A
5	6	7.50	4.83	B

K

Level	N	Mean	StDev	
1	3	0.24	0.03	A
2	6	0.30	0.06	A
3	4	0.32	0.11	A
4	4	0.45	0.20	A
5	6	1.10	0.50	B

Mg

Level	N	Mean	StDev	
1	3	0.63	0.03	A
2	6	0.83	0.18	A
3	4	0.94	0.21	AB
4	4	1.01	0.34	AB
5	6	3.21	3.18	B

Na

Level	N	Mean	StDev	
1	3	4.39	0.84	A
2	6	7.06	3.83	A
3	4	12.89	10.96	A
4	4	8.84	3.78	A
5	6	63.71	28.24	B

SO4

Level	N	Mean	StDev	
1	3	38.61	17.86	A
2	6	19.79	17.20	AB
3	4	37.92	26.21	A
4	4	19.84	12.75	AB
5	6	10.44	5.09	B

Conductivity

Level	N	Mean	StDev	
1	3	42.00	7.10	A
2	6	64.20	24.10	A
3	4	87.40	60.80	A
4	4	79.70	26.10	A
5	6	417.40	332.00	B

pH

Level	N	Mean	StDev	
1	3	6.43	0.11	AB
2	6	6.61	0.55	A
3	4	6.09	0.40	B
4	4	6.98	0.29	A
5	6	6.87	0.28	A

Table 9. Principal components analysis of the mean chemical and physical characteristics of lake-outlet sites around Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S). Spearman's rank correlation (r_s) was used to assess the relationship among the PC-Scores and the environmental variables.

Score	Site characteristics and range of values			Interpretation of scores		Correlation among variables and PC-Scores	Percent explained variation
	VARIABLE	MINIMUM	MAXIMUM	LOW	HIGH		
I	Mg (mg/l)	0.60	9.20	Low	High	0.908	
	Al (µg/l)	0.00	126.38	High	Low	-0.828	
	Ca (mg/l)	1.01	16.80	Low	High	0.792	
	K (mg/l)	0.21	2.10	Low	High	0.912	
	Na (mg/l)	3.21	109.70	Low	High	0.785	
	pH	5.63	7.35	Low	High	0.684	
	Cond (µS/cm)	33.80	1081.00	Low	High	0.852	
	Disturbance	1	5	Low	High	0.785	35.3
II	Zn (µg/l)	1.00	23.0	High	Low	-0.693	
	Substrate	1	5	Boulder	Mud	-0.751	
	Stream order	1	4	Fourth	First	-0.690	
	Stream width	1	2	Wide	Narrow	-0.746	17.8
Total							53.1

Table 10. Interpretation of the principal components analysis of the average chemical and physical characteristics of lake-outlet sites around Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S).

Score I	Score II	Sites	I	II
Negative	Negative	B1, B2, B3, B7, R13	[Mg]: low; [K]: low; [Ca]: low, intermediate; [Al]; intermediate, high; [Na]: low, intermediate; pH: low, intermediate, high; Cond: low; Dist: low-intermediate, intermediate, intermediate-high	[Zn]: low, intermediate Substrate: cobble, boulder Stream order: 2, 3, 4 Stream width: wide
Negative	Positive	B6, B8, B18, C14, C15, C16, C17	[Mg]: low; [K]: low; [Ca]: low, intermediate; [Al]: intermediate, high; [Na]: low, intermediate; pH: low, Intermediate, high; Cond: low, Dist: low to intermediate	[Zn]: low, intermediate, high Substrate: sand, wood, cobble, boulder Stream order: 1, 2 Stream width: narrow
Positive	Negative	S21, S23, S24, S25	[Mg]: low, high; [K]: intermediate; [Ca]: intermediate, high; [Al]: low, Intermediate; [Na]: high; pH: high; Cond: intermediate, high; Dist: high	[Zn]: intermediate, high Substrate: cobble, boulder Stream order: 1, 3 Stream width: narrow, wide
Positive	Positive	R9, R10, R11, R19, S20, S22, S26	[Mg]: low, intermediate; [K]: low, intermediate; [Ca]: intermediate, high; [Al]: low, intermediate; [Na]: low, Intermediate, high; pH: intermediate, high; Cond: low, intermediate; Dist: low-intermediate to high	[Zn]: low, intermediate Substrate: mud, sand, cobble Stream order: 1, 2 Stream width: narrow

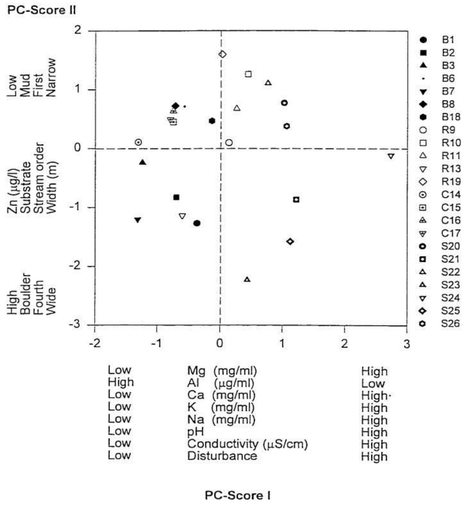

Figure 10. PC-I relative to PC-II for the principal components analysis of mean chemical and physical characteristics of 23 lake outlets in Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S), NF, during May and July 1995, and May and July 1996.

Table 11. Results of ANOVA (using GLM command) and Fisher's pairwise comparisons to test for significant differences in environmental PC-I and PC-II between study areas (B = Bonavista, R = Random Island, C = Come-by-Chance, S = St. John's). Areas with same letters are not significantly different.

ANOVA

PC-axes	Study area
PC-I	0.001*
PC-II	0

Environmental PC-I

Area	N	Mean	StDev	
B	7	-0.7190	0.4324	A
R	5	0.0543	0.3962	B
C	4	-0.8984	0.2752	AB
S	7	1.1936	0.7290	C

Chapter 4. Comparison of the benthic Ephemeroptera, Plecoptera and Trichoptera (EPT) fauna of 23 lake outlet sites with different chemical and physical characteristics and levels of human disturbance.

4.1 INTRODUCTION

Benthic macroinvertebrate community composition and structure are influenced by biotic and abiotic environmental factors. Biotic factors include aquatic vegetation, and canopy cover. Abiotic factors include physical factors such as stream size and order, nature of the substratum, current velocity, discharge and flow pattern, and chemical factors (Bargos *et al.* 1990; Rosenberg and Resh 1993; Heliövaara and Väisänen 1993; Hauer and Lamberti 1996). Species assemblages respond to these factors, and changes therein, by their occurrences and relative abundances (Vannote *et al.* 1980).

Both natural and human-induced environmental disturbances can significantly alter environmental characteristics, thus indirectly alter the benthic macroinvertebrate community composition and structure. This section outlines the response of the benthic EPT fauna to the various environmental factors, and provides an extensive literature review of previous studies that used benthic macroinvertebrate communities as bioindicators of running water conditions.

4.1.1 Literature review

Water temperature affects oxygen concentration and photoperiod and may account for a large percentage of variation of benthic macroinvertebrate community composition (Rossaro 1991). The oxygen requirements of some species may confine them to certain temperatures (Hynes 1970). In an Ontario study, Sprules (1947) found that the number of plecopteran species that emerged as adults decreased as the temperature increased from 13 to 20°C, whereas the number of ephemeropteran and trichopteran species emerging increased (Hynes 1970).

Current velocity determines sediment transport and substratum size. High velocity erosional zones generally have coarser substratum, whereas low velocity results in increased deposition and fine substrates. Generally, the larger and more complex the substratum, the more diverse the fauna (Hynes 1970). The addition of sediment fills interstices and reduces both the diversity and density of organisms (Wiederholm 1984).

Tolerance to salinity varies amongst freshwater invertebrates (Hawkes 1979). Ephemeropteran, plecopteran and trichopteran species are generally intolerant of salinity. Of the Ephemeroptera, the Baetidae are the most tolerant family (Hawkes 1979). The net-spinning, caseless caddis are more tolerant than other trichopterans. Generally, plecopterans are not found in waters of high salinity (Hawkes 1979).

At high levels, turbidity, colour and suspended solids reduce light penetration, which reduces primary production (Hawkes 1979). Benthic macroinvertebrates, which are directly or indirectly dependent on plants for food, are suppressed or eliminated. The overall effect is a change in species composition and in abundance of some species.

Canopy cover influences production through the amount of light energy reaching streams. Several studies have examined the effects of canopy cover on macroinvertebrate communities (e.g., Murphy *et al.* 1981; Towns 1981; Silsbee and Larson 1983; Corkum 1990). Open areas tend to have increased aquatic production at all trophic levels.

Associated with the degree of canopy cover is the presence of aquatic vegetation (macrophytes and periphyton) which affects the faunal composition. Vegetation increases the amount of shelter resulting in enrichment of the fauna (Heliövaara and Väisänen 1993). Extensive growth of aquatic vegetation may be induced by deforestation (Heliövaara and Väisänen 1993). However, Murphy *et al.* (1981) and Power *et al.* (1988) suggest that removal of an existing canopy may initially increase the amount of accumulated sediment and the transport of sediment, adversely affecting the stream habitat. This may result in a decrease in benthic biomass and diversity.

pH tends to have little direct effect on faunal composition within the range of 5 to 9 (Hawkes 1979). Many studies have been conducted to assess the effects of acidification on benthic macroinvertebrate communities (e.g., Weiderholm and Eriksson 1977; Hall 1994; Griffith *et al.* 1995; Guerold *et al.* 1995). Generally, low pH values reduces the diversity and abundance of benthic macroinvertebrate species. Ephemeropterans are among the most sensitive (Wiederholm 1984; Heliövaara and Väisänen 1993). Some plecopterans and trichopterans are tolerant of high pH values (Hawkes 1979; Heliövaara and Väisänen 1993). Griffith *et al.* (1995) studied the effects of acidification on macroinvertebrate communities in headwater streams in West Virginia. *Leuctra sp.* (Plecoptera) and *Eurylophella funeralis* (Ephemeroptera) had high numbers at pH 4.3, whereas *Baetis sp.* and *Ephemerella dorothea* (Ephemeroptera) had high numbers at pH 7.5. Guerold *et al.* (1995) studied streams in northeastern France. Relative abundance and diversity of benthic macroinvertebrates were significantly lower in the acid streams. Acidified streams were dominated by plecopterans (*Leuctra sp.*) and/or oligochaetes. Mollusca and ephemeropterans were the most sensitive to acidification.

Toxic discharges reduce the diversity and abundance of faunal species present (Hawkes 1979; Beckett and Keyes 1983). However, there may be an initial increase in the population of the more tolerant species as the less tolerant species are eliminated and competition and predation are reduced. Trichopterans tend to be more tolerant of heavy metal pollution than ephemeropterans (Heliövaara and Väisänen 1993). The toxic effects of heavy metals are influenced by their chemical properties and habitat variables such as temperature, pH, oxygen content, alkalinity or hardness, and the amount of complexing substances in the water (Dojlido and Best 1993). For example, low pH increases solubility, and dissolved metals are generally the most toxic.

Oil pollution results in decreased faunal diversity. Initially, low or moderate levels may increase the abundance of the more tolerant species as the density of attached algae which serves as food and substrate increases (Heliövaara and Väisänen 1993). However, the abundance will then decrease from oil residues on the substrate and the large amount of organic matter resulting from the algal growth (Heliövaara and Väisänen 1993).

Mild eutrophication favours grazing ephemeropterans, filter-feeding black flies and hydropsychid caddisflies, and deposit feeding chironomids (Wiederholm 1984). Higher levels may have adverse effects on the insect fauna as oxygen levels decrease (Wiederholm 1984; Heliövaara and Väisänen 1993). Eutrophication may also increase silt levels which fills interstices and smothers hard surfaces. Therefore the effects are similar to those of organic pollution (Wiederholm 1984). Bargos *et al.* (1990) used 92 benthic macroinvertebrate taxa to ordinate 175 sites from main water courses of Biscay, Spain. Macroinvertebrate community structure differed between rivers due to differences in natural eutrophication and the combined effects of industrial and urban sewage. Three groups of taxa were observed that represented headwater reaches, moderately eutrophic waters, and polluted waters.

The discharge of organic matter such as sewage or wastes from the processing of biological materials reduces faunal diversity (Hynes 1960; Heliövaara and Väisänen 1993). The depletion of oxygen, brought about by the oxidation of the wastes, eliminates the more sensitive species. Diversity is reduced, whereas the abundance of species more tolerant of low oxygen conditions increases (Hynes 1960; Heliövaara and Väisänen 1993). Most species of Ephemeroptera, Plecoptera, and Trichoptera are intolerant of low levels of dissolved oxygen (Heliövaara and Väisänen 1993). However, even within these groups many species can tolerate reduced oxygen levels. Of the Plecoptera, the families Leuctridae, Capniidae and Nemouridae contain the more tolerant species (Hawkes 1979). Generally, collectors and filterers, which are generalists, are more tolerant of pollution (Plafkin *et al.* 1989). Scrapers, piercers and shredders are specialists and tend to be more sensitive. Therefore, they are more common in healthy waters (Plafkin *et al.* 1989). Whitehurst and Lindsey (1990) studied the effects of organic pollution on macroinvertebrate communities in a lowland river in England. The number of taxa decreased, whereas abundance of the more tolerant taxa increased with increasing organic pollution. Bournaud *et al.* (1996) related macroinvertebrate communities and sixteen environmental features of the Rhone River, France. The Upper Rhone was of relatively good quality, whereas the Lower Rhone received domestic and industrial inputs, resulting in higher mineralization, increased pollution, and greater flow regulation. There was a good correlation between the fauna and the environmental variables. The fauna became poorer downstream, as ephemeropterans and trichopterans were replaced by molluscs and lentic groups. Barbour *et al.* (1996) studied the effects of pollution on the benthic macroinvertebrates of Florida streams. They measured 32 macroinvertebrate metrics, eight of which were used to create the SCI index (Stream Condition Index). The number of taxa, number of EPT taxa, number of Chironomidae taxa, % filterers, and % gatherers decreased with increasing perturbation, whereas % dominant taxon and % Diptera increased with increasing perturbation. Palmer *et al.* (1996) studied the use of functional feeding groups as indicators of water quality in the Buffalo River, South Africa. Downstream reaches received industrial and urban pollution, however relative species abundance was unrelated to water quality. Sites were ranked sequentially downstream regardless of water quality. Functional feeding groups had weak relations with water quality changes and were not useful as indicators of water quality in the Buffalo River.

Urbanization of a water-catchment may significantly alter stream water quality even in the absence of direct industrial and municipal discharges (Heliövaara and Väisänen 1993). Suspended sediment loads from streams draining urban areas are often greater than those from nearby forested water-catchments. Increased loads can eliminate habitats or interfere with feeding under lower levels of stress. Many studies have assessed the impact of urbanization on freshwater benthic communities (e.g., Benke *et al.* 1981; Pitt and Bozeman 1983; Duda *et al.* 1982). Generally, diversity and abundance have a negative relationship with the degree of urbanization of the water-catchment. Jones and Clark (1987) found that *Hydropsyche spp.* (Trichoptera) and *Stenonema spp.* (Ephemeroptera) were virtually absent from all moderately-to-highly urbanized streams.

Various types of land use also influence macroinvertebrate assemblages (Dance and Hynes 1980; Corkum 1990). Dance and Hynes (1980) studied the effects of agricultural land use on stream insect communities of two similar basins with different land use intensities in southwestern Ontario. The west basin had intermittent flow, heavier sediment and nutrient loads, and higher summer temperatures. Fauna consisted of 98 taxa, 40 of which were chironomids, two plecopteran species, and seven species of Trichoptera. Shredders were absent and the fauna consisted mainly of grazers and detrivores. The east basin contained 110 taxa, 36 of which were chironomids, eight species were plecopterans, and 15 species were trichopterans. Fauna at this basin consisted of shredders, detrivores and carnivores. Corkum (1990) studied three rivers in southwestern Ontario. Macroinvertebrate composition and total density was associated with land use type. Forests had the lowest number of individuals and were characterized by taxa of Hydropsychidae (Trichoptera) (filterers and/or predators) and Leptophlebiidae (Ephemeroptera) (gatherers and/or shredders), which cling to rocky substrates in lotic erosional areas (Merritt and Cummins 1996). These areas had fast flow and little benthic detritus. Farmlands had the highest number of individuals. These areas were slow flowing and had high levels of detritus. However, ephemeropterans, plecopterans and trichopterans were not characteristic of these enriched areas. Mixed land use areas had intermediate numbers of individuals and were characterized by the ephemeropteran families Baetidae (scrapers) and Heptageniidae (gatherers) which cling to substrate and can be found in lotic and lentic erosional sites. Fore *et al.* (1996) found that plecopteran taxa were more sensitive to human disturbance than were ephemeropteran and trichopteran taxa in southwestern Oregon. All three orders decreased in number with increasing disturbance. Functional feeding groups were not useful in distinguishing between disturbed and undisturbed sites.

4.1.2 Review of benthic macroinvertebrate studies in Newfoundland

Larson and Colbo (1983) described the benthic macroinvertebrate fauna of Newfoundland relating the overall environment to characteristics of the organisms. Colbo (1985) looked at the variation in larval black fly populations at three sites in a stream system in Newfoundland over five years. There was a marked annual variation in black fly populations partly due to changing water levels. Larson and House (1990) studied the macroinvertebrate fauna of a series of bog pools on the Avalon Peninsula, Newfoundland. Diversity and abundance increased with an increase in pool size. Oligochaetes, beetles and mosquito larvae were dominant in small, astatic pools, whereas odonates, chironomids, and trichopterans were dominant in large, stable vegetated pools.

Ryan *et al.* (1993) monitored four Newfoundland lakes to evaluate the effects of reduced concentrations of sulphur dioxide emissions. Benthic macroinvertebrate catches declined with increasing lake acidity. Two years after the initiation of a lake fertilization experiment, short-lived benthic macroinvertebrates (e.g. chironomids) showed a rapid increase in population, however longer-lived benthic invertebrates (e.g. ephemeropterans) did not show a significant response in the second year (Ryan *et al.* 1993).

Pickavance (1971) examined the effects of pollution on the invertebrate fauna of a polluted stream located in the city of St. John's, Newfoundland. Domestic waste and road drainage were the sources of pollution due to the close proximity of roads and houses. As pollution increased downstream, fewer planarians, crustaceans and non-dipterous insects were present, and more leeches, chironomids and worms were present. The station furthest downstream had a high percentage of worms and a small percentage of chironomids, which is typical of grossly-polluted habitats. Meade (1993) studied the same area as Pickavance (1971) to determine any change in the condition of the river with time. There was a decrease in the proportion of oligochaetes and an increase in the proportion of non-dipterous insects at all sites, consistent with a reduction in organic pollution.

However, the species present were those more tolerant of organic or heavy metal pollution. Colbo (1993) also noted a marked reduction in the number of families and genera of five orders of benthic insects in St. John's city rivers compared to two rivers outside the city.

4.1.3 The present study

The aim of this study was to evaluate the use of a naturally impoverished fauna for biomonitoring freshwater systems. Questions addressed in the study were (i) does the composition of the Ephemeroptera, Plecoptera, and Trichoptera communities of 23 lake outlets (Chapter 2) vary between water catchments in northeastern Newfoundland (ii) can the presence-absence or relative abundance of these three insect orders be used to predict environmental conditions at the above sites, and (iii) can any identified patterns between communities and environmental variables be effective in assessing human impacts on freshwater systems in the study area given the depauperate fauna?

It was hypothesized that similar sites in terms of physical and chemical characteristics and levels of disturbance would have similar macroinvertebrate community composition and structure. Also, EPT diversity and abundance were expected to change along a disturbance gradient in a predictable manner.

4.2 MATERIALS AND METHODS

4.2.1 Field Methods

Benthic macroinvertebrate samples were collected from 23 lake outlet sites in four study areas of northeastern Newfoundland (Chapter 2).

4.2.1 a) Qualitative data

Qualitative data were collected during May and July 1995, and May and July 1996, using a triangular D-frame dip net (area ca. 265 cm^2; mesh size ca. 1 mm). Kick net samples (Bargos *et al.* 1990; Whitehurst and Lindsey 1990) were taken in the area of highest current velocity at each site 2 meters above and below the location of the substrate samplers. The collector rested the net on the bottom of the stream and disturbed the upstream substrate in front of the net by kicking. Sampling time was about 2 minutes. A general sweep sample (Pickavance 1971) around the edge of the stream was also taken to obtain macroinvertebrates present in areas of low current velocity. The net was swept about the stream edges 2 meters above and below the location of the substrate samplers to obtain a single sample. Sampling time was about 5 minutes. Samples were rinsed through a 250 μm sieve to remove the water, then stored in plastic bags with 95% ethanol for preservation.

4.2.1 b) Quantitative data

Artificial substrate samplers were used to collect quantitative data (Ryan *et al.* 1993). Artificial substrate samplers are useful in comparative studies because they present a uniform substrate for colonization at each sampling site (Beak *et al.* 1973), thus eliminating variation due to differences in the nature of the substratum between sites. Other advantages include the ability to sample areas that otherwise would be difficult to sample (e.g. boulders, deep water, areas of high current velocity) and a standardized sampling effort at each site (Plafkin *et al.* 1989). Disadvantages of artificial substrate samplers include the additional trip required to place the samplers, the long exposure period required for colonization, which makes them inappropriate for rapid bioassessment and the possible loss or disturbance of the samplers during the colonization period (Plafkin *et al.* 1989). Also, artificial substrate samplers often select certain taxa and may misrepresent their abundance, and the sample may not be representative of the macroinvertebrate community if the artificial substrate is very different from the natural substrate. Plafkin *et al.* (1989) suggest that artificial substrate samplers may be more indicative of colonization potential, which may actually be an advantage in isolating the effects on water quality on benthic macroinvertebrate communities from substrate and other microhabitat effects.

Artificial substrate samplers used in this study were made of crab net bags (ca. 30 cm long, mesh size ca. 1.5 cm in diameter) containing one litre of roadside gravel (ca. 2.5 cm in diameter) with no attached organic material. Four samplers were placed in close proximity at each site in areas of high current velocity, as measured using the Ott Current Meter, to compare similar habitats at each site. Samplers were placed in each outlet in June 1995 and collected in July 1995, and May and July 1996. During collection, samplers were removed from the outlet and placed in a wash pan with water. The samplers were shaken in the pan for several minutes to remove macroinvertebrates, and the water and contents were run through a 250 µm sieve. This was repeated several times until the sampler appeared clean. The sampler then was examined visually to remove any macroinvertebrates remaining, and the sampler was replaced in the water. Although controlled sampling to test the efficiency of the procedure for removing macroinvertebrates was not performed, all material was removed until samplers were clean, therefore it was easy to determine visually whether all organisms were removed. The sample was placed in a plastic bag with 95% ethanol.

4.2.2 Laboratory methods

In the laboratory, both artificial substrate sampler (only 3 were processed for each site) and sweep net samples were washed through a series of sieves to remove large stones and debris. Portions of the sample on each sieve were placed in separate petri dishes. Gridded petri dishes were used to section the sample into portions. Each dish was examined several times, using a Wild Heerbrugg binocular dissection microscope (magnification from 6.4 to 40 X), to ensure that all organisms had been removed. Macroinvertebrates collected from the artificial substrate samplers were identified and counted. The sweep net samples were examined quickly to identify any macroinvertebrates present at the outlet that were not collected from the artificial substrate samplers. Since there were no artificial substrate sampler samples for May 1995, all organisms were removed from the sweep net samples and identified. Macroinvertebrates were identified to the lowest taxonomic level possible (preferably species) using the dissecting microscope and various published keys (Flint 1962; Wiggins 1977; Morihara and McCafferty 1979; Marshall and Larson 1982; Peckarsky *et al.* 1990; Merritt and Cummins 1996; Larson, unpublished manuscripts). Taxa were assigned to functional feeding groups using Merritt and Cummins (1996). Taxa identifications were made by the author with assistance and verification by Murray H. Colbo (Department of Biology, Memorial University of Newfoundland) as needed. Voucher specimens are archived at the Department of Biology, Memorial University of Newfoundland. Taxa were compiled into lists consisting of benthic macroinvertebrates identified at various taxonomic levels, but the level of identification for each taxon is consistent between sites. Data from three artificial substrate samplers were pooled for each site (Corkum 1989) and recorded as quantitative data: abundance (as number of individuals) and relative abundance(% of total). Qualitative data (presence-absence) were derived from both the artificial substrate sampler data and the sweep net data.

Two data sets were used for statistical analysis: (i) a combined qualitative data set (presence-absence or diversity) for all four sampling dates indicating if taxa were recorded at each site at any time during the study, and (ii) a quantitative data set consisting of means of the three sampling dates (Griffith *et al.* 1995; Guerold *et al.* 1995). Quantitative data are expressed as abundance (# of individuals) and relative abundance (% of total). Data were combined over sampling dates to obtain a large data set and because new taxa continued to be recorded during each sampling date (Table 12).

4.2.3 Statistical analyses of qualitative data

4.2.3 a) Univariate Analysis

4.2.3 a) i) <u>Presence-absence of EPT taxa at 23 lake outlets</u>

Combined EPT presence-absence data were tabulated for 23 lake outlets. A summary table is provided indicating total and mean number of taxa in each study area. This allows for a comparison of EPT community composition between sites and study areas.

4.2.3 a) ii) EPT diversity (number of taxa) at 23 lake outlets

A histogram indicating the total number of ephemeropteran, plecopteran and trichopteran taxa recorded at each site is given. This allows for a quick comparison of EPT diversity between sites.

4.2.3 a) iii) EPT diversity versus levels of disturbance

The response of EPT taxa diversity to levels of disturbance (Chapter 2) is indicated in an interval plot.

4.2.3 a) iv) EPT diversity measures compared to measured physical environmental variables

GLM was used to perform Model II ANOVA to test for significant differences in EPT diversity measures with respect to physical environmental variables (Chapter 2). For each test, residuals were examined to determine whether they met the assumptions of the ANOVA model. When the residuals did not meet the assumptions of the ANOVA model, randomization tests were performed. Fisher's pairwise comparisons was used to determine which study areas, disturbance levels, substrate types and stream orders were significantly different from the others for those EPT diversity measures that were significantly different between categories of these environmental variables.

4.2.3 a) v) Correlation of EPT diversity measures with environmental principal components (PC) I and II

Total diversity and diversities of ephemeropteran, plecopteran and trichopteran taxa were correlated with environmental PC-I and PC-II (Chapter 3) using Spearman's Rank Correlation Coefficients.

4.2.3 a) vi) Functional feeding group (FFG) diversity at 23 lake outlets

A histogram indicating the relative proportion of the total number of taxa belonging to each feeding group for each site is given. This allows for a quick comparison of dominant feeding groups (in terms of diversity) between sites.

4.2.3 a) vii) FFG diversities compared to measured physical environmental variables

GLM was used to perform Model II ANOVA to test for significant differences in FFG diversities with respect to physical environmental variables (Chapter 2). Residuals were examined to determine whether they met the assumptions of the ANOVA model. When the residuals did not meet the assumptions of the ANOVA model, randomization tests were performed. Fisher's pairwise comparisons was used to determine which study areas, disturbance levels, substrate types and stream orders were significantly different from the others for those FFG diversity measures that were significantly different between categories of these environmental variables.

4.2.3 a) viii) Correlation of FFG diversities with environmental principal components I and II

The number of taxa belonging to each feeding group was correlated with environmental PC-I and PC-II (Chapter 3) using Spearman's Rank Correlation Coefficients.

4.2.3 b) Multivariate analysis

4.2.3 b) i) Grouping of 23 lake outlet sites based on presence-absence of EPT taxa

Principal Components Analysis was used to group sites that were similar based on EPT diversity. Multivariate analysis is commonly used to group sites based on taxa presence and/or taxa abundance, or to relate biological data to environmental variables (Rosenberg and Resh 1993). Many argue that multivariate analyses are more useful than univariate analysis for detecting and understanding spatial and temporal trends in benthic fauna because many environmental problems involve multiple variables (e.g. Green 1979; Rosenberg and Resh 1993).

In this analysis, 21 taxa were selected for analysis. All taxa could not be included in the analysis because number of variables could not exceed number of observations (23 sites). Taxa were examined individually, and only those taxa which showed obvious variations in occurrence in relation to one or more physical variables were included in the analysis. This included the removal of both rare and widespread taxa. Taxa selection was purely subjective.

Model II ANOVA was used to test for significant differences in PC-scores with respect to physical environmental variables (Chapter 2). Fisher's pairwise comparisons tests were used to determine which study areas, disturbance levels, substrate types and stream orders were significantly different from the others if the ANOVA indicated a significant difference between categories of these environmental variables.

4.2.3 b) ii) Correlation of EPT presence-absence principal components and environmental principal components

Presence-absence PC-I and PC-II were correlated with environmental PC-I and PC-II (Chapter 3) using Spearman's Rank Correlation Coefficients. Those which had significant correlations were plotted.

4.2.4 Statistical analyses of quantitative data

4.2.4 a) Univariate analysis

4.2.4 a) i) Abundance of EPT taxa at 23 lake outlets

Relative abundance (%) of ephemeropteran, plecopteran and trichopteran taxa were recorded for each site for sampling dates combined. A summary table is provided indicating total and mean abundance of taxa in each study area. This allows for a comparison of EPT community composition between sites and study areas.

4.2.4 a) ii) EPT abundance at 23 lake outlets

A histogram is provided indicating the relative abundance (%) of each insect order for each site. This allows for a quick comparison of relative abundance of EPT orders among sites.

4.2.4 a) iii) EPT abundance versus levels of disturbance

The response of taxa abundance to levels of disturbance (Chapter 2) is plotted as an interval plot.

4.2.4 a) iv) EPT abundance measures compared to measured physical environmental variables

GLM was used to perform Model II ANOVA to test for significant differences in the EPT abundance measures with respect to physical environmental variables (Chapter 2). Residuals were examined to determine whether they met the assumptions of the ANOVA model. When the residuals did not meet the assumptions of the ANOVA model, randomization tests were performed. Fisher's pairwise comparisons tests were used to determine which study areas, disturbance levels, substrate types and stream orders were significantly different from the others for those EPT abundance measures that were significantly different between categories of these environmental variables.

4.2.4 a) v) Correlation of EPT abundance measures with environmental principal components I and II

Spearman's Rank Correlation Coefficients were used to correlate total abundance and abundances of ephemeropteran, plecopteran and trichopteran taxa with environmental PC-I and PC-II (Chapter 3).

4.2.4 a) vi) Functional feeding group abundance at 23 lake outlets

A histogram indicating the relative abundance (%) of each feeding group at each site is provided.

4.2.4 a) vii) FFG abundance measures compared to measured physical environmental variables

GLM was used to perform Model II ANOVA to test for significant differences in FFG abundance measures with respect to physical environmental variables (Chapter 2). Residuals were examined to determine whether they met the assumptions of the ANOVA model. When the residuals did not meet the assumptions of the ANOVA model, randomization tests were performed. Fisher's pairwise comparisons tests were used to determine which study areas, disturbance levels, substrate types and stream orders were significantly different from the others for those FFG abundance measures that were significantly different between categories of these environmental variables.

4.2.4 a) viii) Correlation of FFG abundance measures with environmental principal components I and II

Relative abundance (%) of each feeding group was correlated with environmental PC-I and PC-II (Chapter 3) using Spearman's Rank Correlation Coefficients.

4.2.4 b) Multivariate Analysis

4.2.4 b) i) Grouping of 23 lake outlet sites based on relative abundance of EPT taxa

Relative abundance (%) was coded using octaves and logarithmically transformed ($Y' = 2.25 + \ln(Y)$) (Gauch 1982). Principal Components Analysis was performed using 22 selected taxa. Taxa which occurred at eight or more sites were included in the analysis. Although this excludes taxa that occurred in 30% or less of the sites, a number of taxa had to be removed such that the number of variables (taxa) did not exceed the number of observations (23 sites).

Model II ANOVA was used to test for significant differences in PC-scores with respect to physical environmental variables (Chapter 2). When the residuals did not meet the assumptions of the ANOVA model, randomization tests were performed. Fisher's pairwise comparisons was used to determine which study areas, disturbance levels, substrate types and stream orders were significantly different from the others for those PC scores that were significantly different between categories of these environmental variables.

4.2.4 b) ii) Correlation of EPT abundance principal components and environmental principal components

Biological PC-I and PC-II were correlated with environmental PC-I and PC-II (Chapter 3) using Spearman's Rank Correlation Coefficients. Those with significant correlations were plotted.

4.3 RESULTS

4.3.1 Statistical analyses of qualitative data

4.3.1 a) Univariate analysis

4.3.1 a) i) Presence-absence of EPT taxa at 23 lake outlets

Table 13 presents the EPT taxa presence-absence data for sampling dates combined (see Appendix 4 for a complete taxa list, and Appendix 5 for presence-absence data for individual sampling dates). A total of 14 ephemeropteran taxa, three plecopteran taxa and 34 trichopteran taxa were recorded. Generally, St. John's sites had the lowest total diversities, whereas Random Island sites had high total diversities, as did C15 and C17 at Come-by-Chance. *Leptophlebia cupida* (Ephemeroptera) was the only taxa recorded at all sites. *Hydropsyche betteni*

(Trichoptera) was recorded at all but one site (S26). Several taxa were recorded at all or most sites in Bonavista, Random Island and Come-by-Chance, but were less common at St. John's sites. These included the ephemeropteran taxa *Paraleptophlebia spp.* and *Eurylophella prudentalis*, the plecopteran genus *Leuctra* and the trichopteran taxa *Lepidostoma spp.*, *Oxytheria spp.*, *Hydropsyche sparna*, *Hydroptila metoeca*, *Polycentropus spp.* and *Platycentropus sp.*. *Baetis tricaudatus* (Ephemeroptera) was more common at St. John's sites. On the other hand, *Caenis simulans* (Ephemeroptera) was recorded only at St. John's sites.

Table 14 provides a summary of the presence-absence data. Random Island had the highest diversity and mean diversity for all three insect orders. St. John's had the lowest diversity and mean diversity for all three insect orders.

4.3.1 a) ii) EPT diversity at 23 lake outlets

There was little variation in total diversity between Bonavista sites. B8 had the highest diversity (25 taxa), whereas B6 had the lowest diversity (16 taxa) (Figure 11). Of the Random Island sites, R13 had the highest diversity with 36 taxa. Remaining Random Island sites had similar diversities, with R9 having the lowest diversity (25 taxa). Come-by-Chance sites had the greatest range of diversity from fourteen taxa at C14 to 32 taxa at C17. St. John's sites also had a wide range in diversity. S20 had the highest diversity with nineteen taxa and S22 had the lowest diversity with only six taxa. Overall, site R13 had the highest diversity, followed by

C17 and C15. S22 and S26 had the lowest diversities. All sites were dominated by trichopteran taxa. Ephemeropteran taxa were present at all sites. Plecopteran taxa were never recorded at S24 or S26.

4.3.1 a) iii) EPT diversity plotted against levels of disturbance

Taxa diversity was lowest at sites with the highest level of disturbance (Figure 12). Generally, taxa diversity decreased with increasing levels of disturbance, except at level 4 disturbance which had the highest taxa diversity.

4.3.1 a) iv) EPT diversity measures compared to measured physical environmental variables

Residuals did not meet the assumptions of the ANOVA model for most tests (Table 15). Of these, randomization tests were carried out for those tests that had p-values between 0.015 and 0.300 (Table 16). Remaining p-values were accepted as they would not change significantly after randomization.

Total diversity and diversities of ephemeropteran, plecopteran and trichopteran taxa differed significantly between study areas (Tables 15 and 16). Results of the Fisher's pairwise comparisons tests are given in Table 17. Most significant differences in diversity measures were between St. John's sites and the remaining three study areas. Total diversity, diversity of plecopteran and diversity of trichopteran taxa were significantly lower at St. John's sites than at sites in the remaining three study areas. Diversity of ephemeropterans was significantly lower at St. John's sites than at Random Island and Come-by-Chance sites. Total diversity and diversity of trichopterans were significantly higher at Random Island sites than at Bonavista sites.

Total diversity, diversity of ephemeropterans and diversity of plecopterans were significantly different between levels of disturbance (Tables 15 and 16). Results of Fisher's pairwise comparisons tests are given in Table 18. Most significant differences were between level 5 disturbance and the remaining four levels of disturbance. Total diversity was significantly lower at level 5 disturbance than at levels 1, 2 and 4. Total diversity was also significantly lower at level 3 disturbance than at level 4. Diversity of ephemeropterans was significantly higher at levels 1 and 4 disturbance than at levels 3 and 5. Diversity of plecopteran taxa was significantly lower at level 5 than at levels 2 and 4 disturbance.

Total diversity and diversity of ephemeropterans were significantly different between stream orders (Tables 15 and 16). Total diversity was significantly higher at order 4 than at orders 1 and 3 (Table 19). Diversity of ephemeropterans was significantly higher in order 2 than order 1 streams, and significantly higher at order 4 than at order 1, 2 and 3 streams. Only diversity of ephemeropterans was significantly different between streams of high and low current velocity. Diversity was significantly higher at streams with high current velocity. There were no other significant differences in EPT diversity measures in terms of mean velocity, immediate cover, surrounding cover, stream width, stream order, substrate type or percent aquatic vegetation.

4.3.1 a) v) Correlation of EPT diversity measures with environmental principal components I and II

Diversity of ephemeropterans and diversity of plecopterans were negatively correlated with environmental PC-I (Table 20). Diversities tended to be lower at sites with low concentrations of Al, high concentrations of Mg, Ca, K and Na, and high pH, conductivity and disturbance.

Diversity of ephemeropterans and diversity of plecopterans were then correlated with chemical variables loaded on environmental PC-I (Table 20). Diversity of ephemeropterans and diversity of plecopterans were negatively correlated with concentrations of K, Mg and Na, and conductivity.

4.3.1 a) vi) Functional feeding group (FFG) diversity at 23 lake outlets

Filterers and/or shredders dominated at most sites, except R13, C14, C15, C17 and S21, where gatherers dominated (Figure 13) (see Appendix 4 for FFG classifications of taxa). Predators were recorded at all sites except S22. Piercers were recorded at all but 3 sites (S23, S25 and S26). Scrapers were recorded at all Random Island sites, all but one (C16) Come-by-Chance site and only one site at Bonavista (B3) and St. John's (S20).

4.3.1 a) vii) FFG diversity measures compared to measured physical environmental variables

Residuals did not meet the assumptions of the ANOVA model for most tests (Table 21). Randomization tests were carried out for those tests which had p-values between 0.015 and 0.300 (Table 22). Remaining p-values were accepted as they would not change significantly after randomization.

There was a significant difference in the diversities of gatherers, predators, scrapers and shredders between study areas (Tables 21 and 22). Results of Fisher's pairwise comparisons are given in Table 23. Diversity of gatherers and diversity of predators were significantly higher at Random Island and Come-by-Chance sites than at St. John's sites. Diversity of scrapers was significantly higher at Random Island sites than at sites in the remaining three study areas. Diversity of shredders was significantly higher at Bonavista and Random Island sites than at Come-by-Chance and St. John's sites.

Diversities of gatherers, predators and shredders were significantly different between levels of disturbance. Results of Fisher's pairwise comparisons are given in Table 24. Diversity of gatherers was significantly higher at levels 1 and 4 disturbance than at levels 3 and 5. Diversity of predators was significantly higher at levels 1 and 4 disturbance than at levels 2, 3 and 5. Diversity of shredders was significantly lower at level 5 than at levels 2, 3 and 4 disturbance.

Diversity of gatherers was significantly different between streams with high and low current velocity. Diversity was higher at streams with high current velocity. Diversity of gatherers was also significantly different between stream orders. Diversity was significantly higher at stream order 2 than order 1, and significantly higher at stream order 4 than at orders 1, 2 and 3 (Table 25). Diversity of piercers was significantly different between streams in open and forest areas. Diversity was higher in streams in forested areas. Diversity of filterers was significantly different between substrate types. Diversity was significantly higher at substrates 4 (cobble) and 5 (boulder) than at substrates 2 (small stone) and 3 (wood) (Table 26). There were no other significant differences in FFG diversity measures in terms of mean velocity, immediate cover, surrounding cover, stream width, stream order, substrate types or percent aquatic vegetation.

4.3.1 a) viii) Correlation of FFG diversity measures with environmental principal components I and II

Results of Spearman's Rank Correlation Coefficients indicate that the number of gatherers was negatively correlated with environmental PC-I (Table 27). Sites with high numbers of gatherers tended to have high concentrations of Al, low concentrations of Mg, Ca, Na and K, and low pH, conductivity and disturbance.

When diversity of gatherers was compared to environmental variables loaded on PC-I, the number of gatherers was negatively correlated with concentrations of Mg and Na and conductivity.

4.3.1 b) Multivariate analysis

4.3.1 b) i) Grouping of 23 lake outlet sites based on presence-absence of EPT taxa

Results of the principal components analysis on presence-absence data are summarized in Tables 28 and 29 and Figure 14. PC-I explained 25.2% of the variation in the data. Eight taxa were negatively loaded on PC-I. These were the ephemeropteran species, *Paraleptophlebia spp.*, *E. prudentalis*, *B. pygmaeus*, *B. macdunnoughi* and *S. vicarium*, the plecopteran genus *Leuctra* and the trichopteran genera *Polycentropus* and *Platycentropus*. Sites with negative scores on PC-I tended to have these taxa present.

PC-II explained 16.8% of the variation in the data. Four taxa were positively loaded on PC-II. These included *B. tricaudatus* (Ephemerotpera), *I. transmarina* (Plecoptera) and the trichopteran species *R. fuscula* and *H. slossonae*. Sites with positive scores on PC-II tended to have these taxa present.

There was a significant difference in PC-I scores between study areas and between levels of disturbance (Table 30 and 31). Fisher's pairwise comparisons indicate that PC-I scores were significantly higher at St. John's sites than at sites in the remaining three study areas (Table 32). PC-I scores were significantly higher at level 5 disturbance than each of the remaining four disturbance levels. PC-I scores were also significantly higher at level 3 than levels 1 and 4 disturbance. PC-II was significantly different between stream orders (Tables 30 and 31). PC-II scores were significantly higher at stream orders 1 and 3 than at order 2 (Table 33).

4.3.1 b) ii) Correlation of EPT presence-absence principal components and environmental principal components

Biological PC-I was positively correlated with environmental PC-I (Table 34, Figure 15). Sites with negative values on biological PC-I tended to have negative values on environmental PC-I. Sites that had *Paraleptophlebia spp.*, *E. prudentalis*, *B. pygmaeus*, *B. macdunnoughi*, *S. vicarium*, *Leuctra spp.*, *Polycentropus spp.* and *Platycentropus sp.* present, tended to have high concentrations of Al, low concentrations of Mg, Ca, K and Na, and low pH, conductivity and disturbance. These taxa tend to be absent from St. John's sites.

Biological PC-II had a weak negative correlation with environmental PC-II (Figure 16). *B. tricaudatus*, *I. transmarina*, *H. slossonae* and *R. fuscula* tend to be present at wide, high-order outlets with large substrate size and high concentrations of Zn.

4.3.2 Statistical analyses of quantitative data

4.3.2 a) Univariate analysis

4.3.2 a) i) Abundance of EPT taxa at 23 lake outlets

Table 35 presents the relative abundance (%) of EPT taxa collected at 23 lake outlet sites (see Appendix 6 for relative abundance data for individual sampling dates). Most sites were dominated by hydropsychids (Trichoptera). Of those not dominated by hydropsychids, most were dominated by Philopotamidae (Trichoptera) (e.g. B3, B7 and S25 were dominated by *Chimarra sp.*, and R13 was dominated by *Dolophilodes distinctus*).

Of the Bonavista sites, B6 and B7 had low total abundances. R11 on Random Island had a relatively low total abundance compared to other Random Island sites. All Come-by-Chance sites had relatively low total abundances. Of the St. John's sites, S22, S23, S24 and S26 had relatively low total abundances. Overall, Random Island sites tended to have the highest mean total abundance. Come-by-Chance and St. John's sites generally had the lowest mean total abundances.

Bonavista had the highest total abundance, abundance of Plecoptera and abundance of Trichoptera (Table 36). Abundance of ephemeropterans was highest at Random Island and lowest at St. John's. Abundance of plecopterans, abundance of trichopterans and total abundance were highest at Bonavista and lowest at Come-by-Chance. Random Island had the highest mean abundance of all measures. Lowest mean abundance of ephemeropterans and lowest mean abundance of plecopterans were recorded at St. John's, whereas lowest mean abundance of trichopterans and total abundance were at Come-by-Chance.

4.3.2 a) ii) <u>EPT abundance at 23 lake outlets</u>

Figure 17 shows the relative abundances of ephemeropteran, plecopteran and trichopteran taxa at each site. All sites were dominated by trichopteran taxa.

4.3.2 a) iii) <u>EPT abundance versus levels of disturbance</u>

Abundance increased with intermediate levels of disturbance (Figure 18). Abundance was highest at level 4 disturbance and lowest at level 1.

4.3.2 a) iv) <u>EPT abundance measures compared to measured physical environmental variables</u>

Residuals did not meet the assumptions of the ANOVA model for all tests (Table 37). Randomization tests were carried out for those tests which had a p-value less than 0.300 but greater than 0.015 (Table 38). Remaining p-values were accepted as they would not change significantly after randomization.

Total abundance was significantly different between study areas. Results of Fisher's pairwise comparisons are given in Table 39. Total abundance was significantly higher at Random Island sites than at Come-by-Chance and St. John's sites. Total abundance was also significantly higher at Bonavista sites than at Come-by-Chance sites.

Total abundance, abundance of plecopterans and abundance of trichopterans were significantly different between levels of disturbance. Results of Fisher's pairwise comparisons are given in Table 40. Total abundance, abundance of plecopterans and abundance of trichopterans were significantly higher at level 4 than at levels 1, 2 and 5 disturbance. Abundance of plecopterans was also significantly higher at level 3 disturbance than at level 5.

Abundance of ephemeropterans was significantly different between stream orders and substrate types (Table 41). Abundance was significantly higher at stream order 2 than order 1, and significantly higher at stream order 4 than orders 1, 2 and 3. Abundance was significantly higher at substrate type 5 (boulder) than at types 2 (small stone) and 4 (cobble). There were no other significant differences in EPT abundance measures in terms of mean current velocity, immediate cover, surrounding cover, stream width, stream order, substrate type or percent aquatic vegetation.

4.3.2 a) v) Correlation of EPT abundance measures with environmental principal components I and II

Ephemeropteran abundance had a weak negative correlation with environmental PC-I (Table 42). When ephemeropteran abundance was correlated with variables on environmental PC-I, ephemeropteran abundance was negatively correlated with concentrations of Na.

4.3.2 a) vi) Functional feeding group abundance at 23 lake outlets

A histogram indicating the relative abundance (%) of each functional feeding group at each site is provided (Figure 19). Filterers dominated at all sites, except S26 which was dominated by gatherers.

4.3.2 a) vii) Functional feeding group abundance measures compared to measured physical environmental variables

Residuals did not meet the assumptions of the ANOVA model for all tests (Table 43). Randomization tests were carried out for those tests which had a p-value less than 0.300 but greater than 0.015 (Table 44). Remaining p-values were accepted as they would not change significantly after randomization.

Abundance of filterers and abundance of scrapers were significantly different between study areas. Results of Fisher's pairwise comparisons tests are given in Table 45. Abundance of filterers was significantly higher at Random Island sites than at Come-by-Chance and St. John's sites. Abundance of filterers was also significantly higher at Bonavista sites than at Come-by-Chance sites. Abundance of scrapers was significantly higher at Random Island sites than at each of the remaining three areas.

Abundances of filterers, scrapers and shredders were significantly different between levels of disturbance. Results of Fisher's pairwise comparisons tests are given in Table 46. Abundance of filterers was significantly higher at level 4 than at levels 1, 2 and 5 disturbance. Abundance of scrapers was significantly higher at level 4 than at levels 2, 3 and 5 disturbance. Abundance of shredders was significantly higher at level 4 than level 5 disturbance, and higher at level 3 than at levels 1 and 5 disturbance.

Abundance of gatherers and abundance of predators were significantly higher at wide streams than narrow streams. Abundance of gatherers was also significantly different between stream orders and substrate types. Abundance was significantly higher at stream order 2 than order 1, and significantly high at order 4 than orders 1, 2 and 3 (Table 47). Abundance was significantly higher at substrate type 5 (boulder) than at substrate types 2 (small stone), 3 (wood) and 4 (cobbles). There were no other significant differences in FFG abundance measures in terms of mean current velocity, immediate cover, surrounding cover, stream width, stream order, substrate type or percent aquatic vegetation.

4.3.2 a) viii) Correlation of functional feeding group abundance measures with environmental principal components I and II

Abundance of piercers was negatively correlated with environmental PC-I (Table 48). When abundance of piercers was correlated with environmental variables on PC-I, abundance was negatively correlated with concentrations of Ca and K and pH.

4.3.2 b) Multivariate Analysis

4.3.2 b) i) Grouping of 23 lake outlet sites based on relative abundance of EPT taxa

Results of the PCA on abundance data are summarized in Tables 49 and 50 and Figure 20. PC-I explained 27.2% of the variation. Six taxa were heavily loaded in PC-I. The ephemeropteran species *B. tricaudatus* and the trichopteran species *H. alternans*, *H. slossonae* and *R. fuscula* were positively loaded on PC-I. *L. cupida* (Ephemeroptera) and *C. pettiti* (Trichoptera) were negatively loaded on PC-I. Sites with positive scores on PC-I tended to have high relative abundances of *B. tricaudatus*, *H. alternans*, *H. slossonae* and *R. fuscula*, and low relative abundances of *L. cupida* and *C. pettiti*.

PC-II explained 17.0% of the variation. *Chimarra sp.* and *H. sparna* (Trichoptera) were negatively loaded on PC-II. Sites with negative scores on PC-II tended to have high abundances of these two taxa.

PC-I scores were significantly different between mean current velocity, stream width and stream orders (Tables 51 and 52). Scores were significantly higher at streams with high current velocity and at wide streams. Scores were significantly higher at stream orders 3 and 4 than at order 1 (Table 53). PC-II scores were significantly different between study areas and levels of disturbance. PC-II scores were significantly higher at St. John's sites than sites in the remaining three study areas (Table 54). PC-II scores were also significantly higher at level 5 disturbance than at each of the remaining four levels of disturbance.

4.3.2 b) ii) Correlation of EPT abundance principal components and environmental principal components

Biological PC-II was positively correlated with environmental PC-I (Table 55, Figure 21). Sites with low abundances of *H. sparna* and *Chimarra sp.* tended to have low concentrations of Al, high concentrations of Ma, Na, Ca and K, and high pH, conductivity and disturbance.

When taxa on biological PC-II were correlated with chemical variables on environmental PC-I, *Chimarra sp.* was positively correlated with Al and negatively correlated with pH.

4.4 DISCUSSION

Taxa diversity was generally low and dominated by trichopteran taxa at all sites. In terms of functional feeding group diversity, sites were dominated by filterers, shredders and gatherers. The most abundant groups were also trichopteran taxa, particularly hydropsychids. Most sites (except S26) were dominated by filterers in terms of relative abundance of functional feeding groups. This is typical of lake outlets which tend to be dominated by filter feeders such as hydropsychids (Richardson and Mackay 1991). Shredders also are common in heterotrophic headwater communities (Cummins 1992).

There were few plecopteran taxa recorded and abundance was relatively low. Therefore, the order Plecoptera was of little use as a biological indicator in the present study, although *Leuctra spp.* were absent from all city sites. Plecopteran taxa tend to be most sensitive to pollution and disturbance (Heliövaara and Väisänen 1993). In southwestern Oregon, Fore *et al.* (1996) found that plecopteran taxa were more sensitive to human disturbances than ephemeropterans or trichopterans. Hilsenhoff (1987) studied Wisconsin streams in an attempt to improve the existing index of organic stream pollution. *Leuctra spp.* were found to be intolerant of pollution. Of the aquatic insects, plecopterans are most restricted to cool, clean, well-oxygenated water (Heliövaara and Väisänen 1993).

In studies of this type, a certain number of taxa will be of no use as biological indicators (Bargos *et al.* 1990). Bargos *et al.* 1990 selected 92 taxa of 139 to ordinate 175 sites from main water courses of Biscay, Spain. Taxa for analyses were selected based on frequency, abundance and relevance. In the present study, several taxa (e.g. *Hydropsyche betteni*) were more or less ubiquitous, thus diversities of these taxa were of no use for biomonitoring. However, these taxa were of use quantitatively as dominance and frequency distributions shift between sites (Jackson and Waide 1982). Rare taxa also are of limited use, both qualitatively and quantitatively, as they will not show patterns associated with environmental conditions. Therefore in the present study the number of taxa useful as biological indicators was further limited.

Overall, Random Island sites had the highest faunal diversity. R13 had the highest diversity of all sites. Most Random Island sites also had high fauna abundance. R9 had the highest abundance of all sites. Although most Random Island sites were relatively disturbed by channelization, road construction, low levels of road runoff and recreational use, there was little chemical input into the system. Also, most sites had large stable substrates with clean surfaces, creating a favourable habitat for many EPT taxa (Hynes 1960).

Come-by-Chance sites were the least disturbed sites. Even so, taxa abundance was relatively low at all sites. C14 had the lowest taxa abundance and diversity (excluding St. John's sites). This site had a low current velocity, with a muddy substrate covered by fallen vegetation, creating a very turbid habitat with no clean surfaces for organisms to attach. This type of environment is unfavourable to most EPT taxa. Taxa diversity was relatively high at C15 and C17 which had fast current velocities and large substrate size with clean surfaces for attachment.

There was little variation in taxa diversity between Bonavista sites. B6 had the lowest diversity of Bonavista sites. Although only moderately disturbed, B6 had an unfavourable habitat for most EPT taxa. The outlet tended to partially dry out in the summer. During July 1996 many of the artificial substrate samplers were no longer submerged. When the outlet was in high flow, there was considerable movement of the smaller gravel and mud substrate, clogging the samplers. All but one site (B18) had high taxa abundances. Overall, Bonavista had the highest taxa abundance.

All St. John's sites had relatively low EPT diversities. St. John's sites were highly disturbed urbanized sites expected to have low diversities. S22 had the lowest diversity of all sites. Although only moderately disturbed, S22 had a low current velocity, small substrate size and dense growth of sedges in the outlet creating a less favourable environment for EPT taxa. Abundance was low at most St. John's sites.

Most diversity and abundance measures were significantly different between the highly disturbed St. John's sites and the remaining study areas and/or disturbance levels. Diversity and abundance measures were always lowest at St. John's sites. This is not surprising since St. John's sites were significantly different from the remaining sites in terms of disturbance, conductivity and chemical concentrations (Chapter 3). These results are comparable to previous studies. For example, Colbo (1993) found a reduction in the number of families and genera of five orders of benthic insects in St. John's city rivers compared to two rivers outside the city. Fore *et al.* (1996) found that total number of taxa and number of ephemeropteran, plecopteran and trichopteran taxa were useful in distinguishing between most and least disturbed sites in southwestern Oregon. Bournaud *et al.* (1996) also found that ephemeropterans and trichopterans decreased with increasing pollution and water mineralization when they compared macroinvertebrate communities to 16 environmental variables of the Rhone River, France.

Previous studies have indicated that numerical density and biomass are often greater in open unshaded areas than in forested areas (e.g. Murphy *et al.* 1981; Towns 1981; Silsbee and Larson 1983; Corkum 1990). However, Hawkes (1988) found no relations between riparian vegetation and macroinvertebrate communities. In the present study, only diversity of piercers was significantly different between streams in open and forested areas, being higher in forested areas. This result is difficult to interpret since piercers included only two taxa and only five of the 23 sites sampled were not in forest areas.

Only diversity of ephemeropterans was significantly different between streams with high and low current velocity. Diversity was higher at streams with high current velocity. This is not surprising since many ephemeropteran taxa favour habitats with high current velocity which creates clean substrate surfaces for attachment (Hynes 1960).

Minshall *et al.* (1985) found that species richness varied with stream size. Species richness was maximum in mid-order streams and decreased in very large streams. In the present study, there was a limited range of streams sampled, from narrow to mid-order. However, significant differences in diversity and abundance measures between stream widths and stream orders were detected. Total diversity,

diversity of ephemeropterans, diversity of gatherers, abundance of gatherers and abundance of predators were higher at mid-order streams.

Fauna tend of to be more diverse in streams with larger and more complex substratum (Hynes 1970). Diversity of filterers, abundance of ephemeropterans and abundance of gatherers were significantly different between substrate types. Diversity of filterers was highest at streams with substrates dominated by cobbles or boulders. Abundance of ephemeropterans and abundance of gatherers were significantly higher at streams with substrates dominated by boulders.

Overall, there were few significant differences in diversity and abundance measures with respect to physical environmental variables (excluding study areas and levels of disturbance). Two possible reasons for this were the narrow range of some environmental variables (e.g. current velocity, stream width and order) and most taxa in the present study were generalists which occur in a wide variety of running water habitats (Larson and Colbo 1983; Lenat 1993; Lang and Reymond 1995).

Functional feeding groups were not very useful in distinguishing between sites in the present study. This is comparable to previous studies. Palmer *et al.* (1996) found that functional feeding groups had weak correlations with water quality changes and were not useful as indicators of water quality in the Buffalo River, South Africa. Fore *et al.* (1996) found that feeding groups were not useful in distinguishing between disturbed and undisturbed sites in southwestern Oregon.

Minshall (1988) suggested that functional feeding groups may not be ecologically meaningful, and that information is lost when the entire community is collapsed into 3-6 composite groups. Of the functional feeding group measures, diversity and abundance of gatherers was most useful in the present study. However, this was because most gatherers were ephemeropteran taxa which were very useful in distinguishing between sites with respect to environmental variables.

Comparison of EPT diversities and abundances between the four areas illustrates that low disturbance does not necessarily produce high faunal diversity or abundance, and high disturbance does not necessarily insure low faunal diversity and abundance. Suitability of the habitat is also an important determining factor. C14 is a relatively undisturbed site, but it had a very low faunal diversity and abundance because of the low current velocity and small silty substrate which create an unfavourable environment. C13, an outflow from two culverts, was relatively disturbed, but it had a fast current velocity and large substrate size which was stable and had clean surfaces, creating a favourable habitat for many EPT taxa. Therefore it is important to have some knowledge of the nature of the habitat and life histories of the organisms studied.

Comparison of EPT diversities and abundances also illustrates that a moderate degree of disturbance tends in increase faunal diversity and abundance. Rather than decrease with increasing disturbance, diversity and abundance showed parabolic relations to disturbance, increasing at intermediate levels of disturbance.

This corresponds to predictions of the intermediate disturbance hypothesis which states that a certain degree of disturbance will enhance stream ecosystems (Connell 1978). This hypothesis suggests that small spatial disturbance enhances ecological features such as species diversity and trophic structure. Communities are enhanced when disturbances are intermediate in intensity, frequency or size, and decrease when disturbances are at either extreme. Disturbances keep local assemblages in a nonequilibrium state by interrupting the process of competitive elimination, or removing taxa that are competitively excluding further invaders (Connell 1978).

In light of the intermediate disturbance hypothesis, one would expect sites with level 3 disturbance to have higher diversities and abundances. However, two sites in this group, B6 and S22, had low diversities and abundances. B6 had an unfavourable habitat for most EPT taxa due to the small silty substrate, turbid water and partial drying during summer. S22 was assigned a level 3 disturbance even though it occurred in the city of St. John's. The site was isolated from residential areas and had not been disturbed recently, indicated by the high numbers of *Simulium* (Perez, unpublished data). However, S22 had high chemical concentrations similar to other highly disturbed St. John's sites. Therefore, there may be an effect due to area or S22 should have been assigned level 5 disturbance. Another possible cause of the low abundance and diversity at S22 is the unique characteristics of the site (Colbo, personal communication). The stream was channelized in the past, lowering the level of the pond, and there was a dense sedge reach between the pond and stream site where sampling was conducted.

Taxa correlated with presence-absence PC-I included *B. pygmaeus*, *B. macdunnoughi*, *E. prudentalis*, *Paraleptophlebia spp.*, *S. vicarium*, *Leuctra spp.*, *Polycentropus spp.* and *Platycentropus sp.* which occur in a wide variety of running water habitats, but have low tolerances of disturbance (Edmunds *et al.* 1976; Larson and Colbo 1983; Lenat 1993; Lang and Reymond 1995). These taxa tended to be absent from the highly disturbed St. John's sites, but present at most remaining sites. In terms of disturbance, there was clear separation of level 5 from the remaining four levels of disturbance, with some overlap between levels 3 and 5 on presence-absence PC-I. There was much overlap between levels 2, 3 and 4. Of the taxa correlated with presence-absence PC-I, only *Leuctra spp.* and *Polycentropus spp.* were recorded at B6. B6 had an unfavourable environment for most EPT taxa because of the muddy substrate, turbid water and drying out during summer. R10 had a positive score near zero on PC-I indicating an intermediate diversity of the taxa correlated with PC-I. Four of the eight taxa correlated with PC-I were present at R10. These were *Paraleptophlebia spp.*, *Leuctra spp.*, *Polycentropus spp.* and *Platycentropus sp.* Although this site had an intermediate level of disturbance, the substrate was muddy and the water was turbid, creating a less favourable habitat for many EPT taxa. C16 also did not have many of the taxa correlated with PC-I present, although it was relatively undisturbed. Those present were *Paraleptophlebia spp.*, *E. prudentalis* and *Leuctra spp*.

There was no separation of sites on presence-absence PC-II with respect to study area or disturbance level. Taxa correlated with presence-absence PC-II included *B. tricaudatus*, *I. transmarina*, *H. slossonae* and *R. fuscula* which are moderately tolerant to disturbance (Bargos *et al.* 1990; Lenat 1993). These taxa tended to be present at large high-order outlets with large substrate size. This is not surprising since fauna tend to be more diverse in streams with larger and more complex substrates (Hynes 1970) and at mid-order streams (Minshall *et al.* 1985). Taxa loaded on presence-absence PC-II were present at R9 and R11 (except *B. tricaudatus* at R11) even though these sites had positive scores on environmental PC-II. However, the sites did have large substrate size and favourable habitats due to intermediate disturbance levels. The taxa were also present at C16 (except *R. fuscula*), C17 and S20 (except *H. slossonae*) even though these sites had positive scores on environmental PC-II. However, these sites did have large substrate size. Although S24 had a negative score on environmental PC-II, S24 did not have any of the taxa correlated with presence-absence PC-II present. This is probably because of the high level of chemical disturbance indicated by the high conductivity and chemical concentrations. Also, despite the negative score on environmental PC-II, this site was a narrow low-order stream. Only *H. slossonae* was present at B7, even though this site was a wide outlet with large substrate size and low disturbance. *Isoperla transmarina* was the only taxon present at B3 which was a narrow low-order stream despite the negative score on environmental PC-II.

Taxa positively correlated with relative abundance PC-I included *B. tricaudatus*, *H. alternans*, *H. slossonae* and *R. fuscula*. These taxa tended to have high abundances at wide mid-order streams with high current velocity. Taxa negatively correlated with PC-I were *L. cupida* and *C. pettiti*. These taxa tended to have high abundances at narrow low-order streams with low current velocity. Most taxa correlated with PC-I were more tolerant of pollution and disturbance (Larson and Colbo 1983; Bargos et al. 1990; Lenat 1993). Bonavista sites and sites with level three disturbance had negative scores only on PC-I. Scores were near zero indicating intermediate to high abundances of *L. cupida* and *C. pettiti*, and low abundances of *B. tricaudatus*, *H. alternans*, *H. slossonae* and *R. fuscula*.

Study areas and levels of disturbance were significantly different on relative abundance PC-II which was positively correlated with environmental PC-I. St. John's sites had low abundances of *H. sparna* and *Chimarra sp.* which have low tolerances to pollution (Bargos *et al.* 1990; Lenat 1993). S25 had a negative score near zero on PC-II because of a high relative abundance of *Chimarra sp.*. S20 and S21 had positive scores near zero on PC-II indicating intermediate relative abundances of *Chimarra sp.* The remaining three areas tended to have negative scores on PC-II indicating high relative abundances of *H. sparna* and *Chimarra sp.*. B1, R10 and R11 had intermediate relative abundances of *H. sparna* and *Chimarra* *sp.*, even though they had positive scores on environmental PC-I. These sites had intermediate levels of disturbance which enhance fauna communities. C14 had low relative abundances of *H. sparna* and *Chimarra sp.*, even though C14 had a negative score on environmental PC-I. C14 had a low level of disturbance, but the site had an unfavourable habitat for most EPT taxa. B2 and B18 had positive scores on relative abundance PC-II, however their scores were very close to zero. These sites had high relative abundances of *H. sparna*, but low relative abundances of *Chimarra sp.*. R19 had a positive score near zero on relative abundance PC-II. R19 had a high relative abundance of *Chimarra sp.*, but a low relative abundance of *H. sparna*. R19 had a positive score near zero on environmental PC-I due to high pH and low concentration of Al.

Site groupings of the two biological PCAs were similar. Of the highly disturbed St. John's sites, S20, S21 and S23 formed one group. These sites had low diversities of taxa correlated with presence-absence PC-I and low abundances of taxa correlated with relative abundance PC-II. However, the sites tended to have high diversities of taxa correlated with presence-absence PC-II and high relative abundances of taxa correlated with relative abundance PC-I. These sites had large substrate size which is more favourable to EPT taxa. S22, S24 and S26 formed another group. These sites had low diversities and abundances of all taxa correlated with biological PC-scores.

Of the remaining sites, R9, R11, R13 and C17 grouped together. These sites had high diversities and abundances of all taxa correlated with biological PC-scores. These sites had low to intermediate levels of disturbance and large substrate size with clean surfaces favourable to most EPT taxa. B18, R19 and C14 formed a group. These sites had high diversities of taxa correlated with presence-absence PC-I, but low diversities and abundances of taxa on remaining biological PC-scores. These sites had low levels of disturbance, but were narrow low-order streams with small substrate size. B3, B7, B8 and C15 also formed a group. These sites had high diversities of taxa correlated with presence-absence PC-I and high abundances of taxa correlated with relative abundance PC-II. The sites had low diversities and abundances of taxa correlated with the remaining biological PC-scores. These sites had low to intermediate levels of disturbance and large substrate size.

Since presence-absence and relative abundance principal components analysis gave similar results, presence-absence data may be sufficient for rapid biomonitoring studies in the study area (Wright *et al.* 1995; Furse *et al.* 1984). However, both sets of data are recommended for a clearer understanding of the overall EPT community composition and structure.

4.5 CONCLUSIONS

Identified patterns in the composition of an impoverished EPT fauna were associated with environmental conditions in the study area. Therefore, it was concluded that an impoverished EPT fauna can be used as an indicator of water quality. Ephemeropterans were most useful in terms of diversity, and trichopterans were most useful in terms of abundance. This is consistent with the current opinion that lake outlets are dominated by filter feeding trichopterans (Richardson and Mackay 1991), thus trichopterans would be expected to occur at all sites, therefore shifts in abundance of these taxa would be more useful than diversity in biomonitoring studies.

Range of disturbance was narrow in the present study. However, significant differences and patterns related to human disturbance were still detectable. This is similar to results reported by Fore *et al.* (1996) who also detected patterns within a narrow range of disturbance.

A moderate degree of disturbance was favourable. Generally, EPT diversity and abundance were lower in the physically disturbed and polluted urban sites, and were highest in physically disturbed but relatively unpolluted rural sites. This is consistent with the intermediate disturbance hypothesis of Connell (1978) which suggests that a certain degree of disturbance will enhance stream ecosystems.

Conductivity and concentrations of Mg, Na and K, were positively correlated with human disturbance on environmental PC-I. These factors tend to have a negative effect on EPT diversity and abundance.

Table 12. Diversity of EPT taxa collected at 23 lake outlet sites in Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S), NF, during May and July 1995, and May and July 1996. Numbers of new taxa recorded at site during each sampling date are indicated in parentheses.

Site	May 1995	July 1995	May 1996	July 1996	Total
B1	14	9 (3)	20 (6)	9 (1)	24
B2	10	6 (1)	15 (8)	12 (3)	22
B3	14	7 (1)	13 (1)	10 (2)	18
B6	10	8 (1)	15 (4)	10 (1)	16
B7	10	7 (4)	16 (5)	11 (2)	21
B8	11	8 (3)	16 (6)	14 (5)	25
B18	-	-	19 -	12 (2)	21
R9	17	10 (0)	23 (8)	10 (0)	25
R10	13	11 (3)	22 (10)	8 (1)	27
R11	10	6 (3)	23 (12)	10 (1)	26
R13	20	4 (2)	31 (13)	18 (1)	36
R19	-	-	20 -	13 (6)	26
C14	10	5 (1)	8 (2)	6 (1)	14
C15	16	13 (5)	17 (5)	15 (2)	28
C16	11	5 (1)	14 (4)	9 (3)	19
C17	19	11 (4)	23 (7)	11 (2)	32
S20	-	-	17 -	8 (2)	19
S21	-	-	12 -	7 (2)	14
S22	-	-	5 -	3 (1)	6
S23	-	-	11 -	6 (0)	11
S24	-	-	11 -	8 (3)	14
S25	-	-	15 -	12 (3)	18
S26	-	-	4 -	4 (3)	7

Table 13. Presence-absence of EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa collected at 23 lake outlet sites in Bonavista, Random Island, Come-by-Chance and St. John's, NF, during May and July 1995, and May and July 1996.

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
EPHEMEROPTERA												
Leptophlebia cupida	+	+	+	+	+	+	+	+	+	+	+	+
Paraleptophlebia spp.		+	+		+	+	+	+	+	+	+	+
Eurylophella prudentalis	+	+	+		+	+	+	+		+	+	
Ephemerella subvaria	+	+			+		+		+	+	+	
Baetis tricaudatus	+							+			+	
Baetis pygmaeus	+	+	+				+				+	
Habrophlebia vibrans			+								+	+
Baetis macdunnoughi	+									+	+	+
Stenonema vicarium								+			+	+
Drunella cornuta								+			+	+
Caenis simulans												
Baetis flavistriga											+	
Epeorus pleuralis											+	
Heptogenia hebe											+	
PLECOPTERA												
Nemoura macdunnoughi	+	+	+	+	+	+	+	+	+	+	+	+
Leuctra spp.	+	+	+	+	+	+	+	+	+	+	+	+
Isoperla transmarina	+	+	+			+		+		+	+	
TRICHOPTERA												
Hydropsyche betteni	+	+	+	+	+	+	+	+	+	+	+	+
Pycnopsyche spp.	+	+	+	+	+	+	+	+	+	+	+	+
Chimarra sp.	+	+	+	+	+	+	+	+	+	+	+	+
Cheumatopsyche pettiti	+	+	+	+	+	+	+	+	+	+		+
Lepidostoma spp.	+	+	+	+	+	+	+	+	+	+	+	+
Oxytheria sp.	+	+	+	+	+	+	+	+	+		+	+
Hydropsyche sparna	+	+	+	+	+	+	+	+	+	+	+	+
Hydroptila metoeca	+	+		+	+	+	+	+	+	+	+	+
Polycentropus spp.	+	+	+	+	+	+	+	+	+	+	+	+
Nemotaulius hostilis	+	+		+	+	+	+	+	+	+	+	
Hydropsyche alternans					+	+	+	+		+	+	+

Table 13 continued. Presence-absence of EPT taxa collected at 23 lake outlet sites.

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
Platycentropus sp.	+	+	+		+	+	+	+	+	+		+
Limnephilus spp.	+	+		+	+				+		+	
Rhyacophila fuscula	+	+						+		+	+	
Ceraclea spp.	+			+	+	+		+	+			+
Hydropsyche slossonae		+			+		+	+		+	+	
Mystacides sepulchralis						+			+	+	+	
Neophylax spp.			+						+	+	+	+
Oecetis sp.						+		+	+		+	
Dolophilodes distinctus						+				+	+	
Rhyacophila invaria									+			+
Rhyacophila carolina									+		+	
Rhyacophila vibox												+
Banksiola sp.						+	+					
Rhyacophila minora									+	+		
Rhyacophila melita										+	+	
Molanna sp.									+			+
Beothicus complicata	+					+						
Glyphopsyche irrorata				+		+						
Psilotreta frontalis									+			+
Triaenodes injusta									+			
Glossosoma sp.											+	
Oligostomis sp.												+
Rhyacophila nigrita												
Taxa diversity	24	22	18	16	21	25	21	25	27	26	36	26

Table 13 continued. Presence-absence of EPT taxa collected at 23 lake outlet sites.

	Come-by-Chance						St. John's				
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
EPHEMEROPTERA											
Leptophlebia cupida	+	+	+	+	+	+	+	+	+	+	+
Paraleptophlebia spp.	+	+	+	+						+	
Eurylophella prudentalis	+	+	+	+							
Ephemerella subvaria				+		+		+		+	
Baetis tricaudatus			+	+	+	+		+		+	
Baetis pygmaeus		+		+							
Habrophlebia vibrans	+	+		+			+				
Baetis macdunnoughi		+		+							
Stenonema vicarium	+	+		+							
Drunella cornuta				+							
Caenis simulans						+			+		
Baetis flavistriga											
Epeorus pleuralis											
Heptogenia hebe											
PLECOPTERA											
Nemoura macdunnoughi		+	+	+	+	+	+			+	
Leuctra spp.	+	+	+	+							
Isoperla transmarina		+	+	+	+	+		+		+	
TRICHOPTERA											
Hydropsyche betteni	+	+	+	+	+	+	+	+	+	+	
Pycnopsyche spp.	+	+	+	+	+		+			+	+
Chimarra sp.		+	+	+	+	+		+	+	+	
Cheumatopsyche pettiti	+	+	+	+	+	+			+	+	+
Lepidostoma spp.		+	+	+	+	+			+	+	
Oxytheria sp.	+	+	+	+	+	+	+		+		
Hydropsyche sparna		+	+	+	+			+		+	
Hydroptila metoeca		+	+	+	+	+			+		
Polycentropus spp.	+	+							+		
Nemotaulius hostilis		+			+					+	+
Hydropsyche alternans		+	+	+	+			+	+	+	
Platycentropus sp.	+	+		+							
Limnephilus spp.			+		+	+			+	+	+

Table 13 continued. Presence-absence of EPT taxa collected at 23 lake outlet sites.

	Come-by-Chance				St. John's						
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
Rhyacophila fuscula				+	+	+		+		+	
Ceraclea spp.		+		+						+	
Hydropsyche slossonae			+	+				+		+	
Mystacides sepulchralis			+					+	+		+
Neophylax spp.					+						
Oecetis sp.									+		+
Dolophilodes distinctus		+		+					+		
Rhyacophila invaria	+	+		+							
Rhyacophila carolina		+		+							
Rhyacophila vibox	+	+		+							
Banksiola sp.					+						
Rhyacophila minora				+							
Rhyacophila melita				+							
Molanna sp.					+						
Beothicus complicata											
Glyphopsyche irrorata											
Psilotreta frontalis											
Triaenodes injusta											
Glossosoma sp.											
Oligostomis sp.											
Rhyacophila nigrita		+									
Taxa diversity	14	28	19	32	19	14	5	10	14	18	7

Table 14. Summary of total diversity and mean diversity of EPT taxa collected at 23 lake outlet sites in Bonavista, Random Island, Come-by-Chance and St. John's, NF, during May and July 1995, and May and July 1996.

	Total EPT diversity (mean EPT diversity) (one standard error)			
Area	Ephemeroptera	Plecoptera	Trichoptera	Total diversity
Bonavista	8 (4.14) (0.63)	3 (2.57) (0.20)	23 (14.29) (1.02)	34 (21.00) (1.19)
Random Island	13 (6.60) (1.69)	3 (2.60) (0.25)	30 (18.80) (1.02)	46 (28.00) (2.03)
Come-by-Chance	10 (6.50) 1.33)	3 (2.50) (0.50)	24 (14.25) (2.60)	37 (23.25) (4.11)
St. John's	6 (2.57) (0.43)	2 (1.14) (0.34)	22 (9.14) (1.55)	29 (12.71) (1.90)

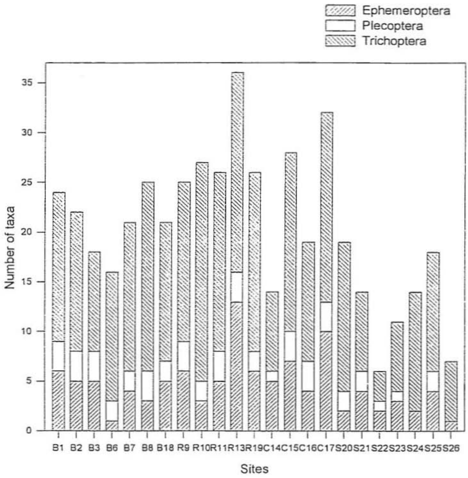

Figure 11. EPT diversity recorded at 23 lake outlet sites in Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S), NF, during May and July 1995, and May and July 1996.

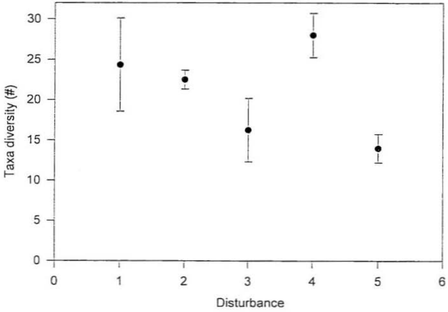

Figure 12. Response of EPT taxa diversity to levels of disturbance (1 = low, 5 = high) for 23 lake outlet sites. Dots represent means and bars represent one standard error above and below the mean.

Table 15. Results of ANOVA (using GLM command) to test for significant differences in EPT diversity measures with respect to physical environmental variables for 23 lake outlet sites. Values in bold indicate tests for which the residuals did meet the assumptions of the ANOVA model. Values underlined indicate tests re-run using randomization. Remaining p-values were accepted as they would not change significantly after randomization.

Variables	Study area p-value	Disturbance level p-value	Mean velocity p-value	Immediate cover p-value	Surrounding cover p-value
Total diversity	**0.001***	0.010*	0.243	**0.996**	0.233
Ephemeroptera	0.023	0.013*	0.022	0.380	**0.853**
Plecoptera	0.006*	0.050	0.142	0.770	0.171
Trichoptera	**0.002***	0.059	0.827	0.619	0.168

Variables	Stream width p-value	Stream order p-value	Substrate type p-value	Aquatic vegetation p-value
Total diversity	0.511	0.043	0.246	0.346
Ephemeroptera	0.213	< 0.001*	0.279	0.490
Plecoptera	0.563	0.040	0.211	0.856
Trichoptera	0.864	0.445	0.178	0.331

* significant at 0.05 significance level

Table 16. Results of randomizations (using Mean Square of Error) to test for significant differences in EPT diversity measures with respect to physical environmental variables for 23 lake outlet sites. Randomization tests were carried out only for those tests for which the residuals did not meet the assumptions of the ANOVA model.

Variables	Study area p-value	Disturbance level p-value	Mean velocity p-value	Immediate cover p-value	Surrounding cover p-value
Total diversity	-	-	0.189	-	0.226
Ephemeroptera	0.007*	-	0.007*	-	-
Plecoptera	-	0.033*	0.150	-	0.133
Trichoptera	-	0.080	-	-	0.133

Variables	Stream width p-value	Stream order p-value	Substrate type p-value	Aquatic vegetation p-value
Total diversity	-	0.047*	0.206	-
Ephemeroptera	0.249	-	0.279	-
Plecoptera	-	0.056	0.243	-
Trichoptera	-	-	0.100	-

* significant at 0.05 significance level

Table 17. Results of Fisher's pairwise comparisons for those EPT diversity measures that were significantly different between study areas (B = Bonavista, R = Random Island, C = Come-by-Chance, S = St. John's). Areas with same letters are not significantly different.

Total diversity

Area	N	Mean	StDev	
B	7	21.00	3.16	A
R	5	28.00	4.53	B
C	4	23.00	8.60	AB
S	7	12.86	4.98	C

Plecoptera

Area	N	Mean	StDev	
B	7	2.57	0.53	A
R	5	2.60	0.55	A
C	4	2.50	1.00	A
S	7	1.14	0.90	B

Ephemeroptera

Area	N	Mean	StDev	
B	7	4.14	1.68	AB
R	5	6.60	3.78	A
C	4	6.50	2.65	A
S	7	2.57	1.13	B

Trichoptera

Area	N	Mean	StDev	
B	7	14.29	2.69	A
R	5	18.80	2.28	B
C	4	14.25	5.19	AB
S	7	9.14	4.10	C

Table 18. Results of Fisher's pairwise comparisons for those EPT diversity measures that were significantly different between levels of disturbance (1 = low, 5 = high). Disturbance levels with same letters are not significantly different.

Total diversity

Level	N	Mean	StDev	
1	3	24.33	10.02	AB
2	6	22.50	2.88	AB
3	4	16.25	7.85	BC
4	4	28.00	5.48	A
5	6	14.00	4.34	C

Ephemeroptera

Level	N	Mean	StDev	
1	3	7.33	2.52	A
2	6	4.83	0.75	AB
3	4	2.75	1.71	B
4	4	7.00	4.24	A
5	6	2.67	1.21	B

Plecoptera

Level	N	Mean	StDev	
1	3	2.33	1.15	AB
2	6	2.50	0.55	A
3	4	2.25	0.96	AB
4	4	2.75	0.50	A
5	6	1.17	0.98	B

Table 19. Results of Fisher's pairwise comparisons for those EPT diversity measures that were significantly different between stream orders. Orders with same letters are not significantly different.

Total diversity

Order	N	Mean	StDev	
1	12	17.75	7.25	A
2	5	24.60	5.98	AB
3	5	19.40	4.67	A
4	1	36.00	0.00	B

Ephemeroptera

Order	N	Mean	StDev	
1	12	3.33	1.83	A
2	5	6.20	2.39	B
3	5	4.40	1.14	AB
4	1	13.00	0.00	C

Table 20. Spearman's Rank Correlation Coefficients to evaluate the relation between EPT diversity measures and environmental PC-I and PC-II (Chapter 3) and chemical variables correlated with environmental PC-I for 23 lake outlet sites.

Diversity	Environmental PC-scores and chemical variables								
variables	PC I	PC II	Al (µg/l)	Ca (mg/l)	K (mg/l)	Mg (mg/l)	Na (mg/l)	pH	Cond (µS/cm)
Total diversity	-0.366	0.194	-	-	-	-	-	-	-
Ephemeroptera	-0.499*	-0.222	0.145	-0.148	-0.467*	-0.613*	-0.598*	0.077	-0.552*
Plecoptera	-0.522*	-0.024	0.262	-0.317	-0.425*	-0.528*	-0.558*	-0.199	-0.518*
Trichoptera	-0.277	0.293	-	-	-	-	-	-	-

* significant correlation (critical value: +/- 0.413)

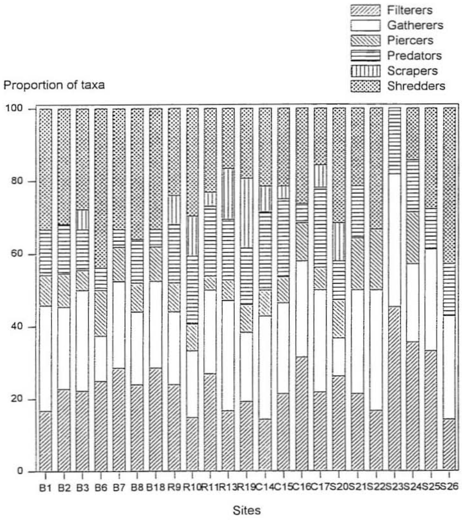

Figure 13. Relative diversity of functional feeding groups recorded at 23 lake outlet sites in Bonavista (B), Random Island (R), Come-by-Chance (C) and St.John's (S), NF, during May and July 1995, and May and July 1996.

Table 21. Results of ANOVA (using GLM command) to test for significant differences in functional feeding group diversity measures with respect to physical environmental variables for 23 lake outlet sites. Values in bold indicate tests for which the residuals met the assumptions of the ANOVA model. Values underlined indicate tests re-run using randomization. Remaining p-values were accepted as they would not change significantly after randomization.

Variables	Study area p-value	Disturbance level p-value	Mean velocity p-value	Immediate cover p-value	Surrounding cover p-value
Filterers	0.235	0.343	0.107	0.844	0.079
Gatherers	**0.023***	**0.014***	0.030	0.590	0.899
Piercers	0.095	0.201	0.904	0.449	0.047
Predators	**0.002***	0.006*	0.823	0.645	0.709
Scrapers	<0.001*	0.194	0.428	0.596	0.335
Shredders	<0001*	0.036	0.837	0.799	0.156

Variables	Stream width p-value	Stream order p-value	Substrate type p-value	Aquatic vegetation p-value
Filterers	0.369	0.108	0.021	0.175
Gatherers	0.101	<0.001*	0.063	0.571
Piercers	0.376	0.632	0.429	0.211
Predators	0.899	0.076	0.427	0.661
Scrapers	0.765	0.018	0.633	1.000
Shredders	0.767	0.977	0.540	0.480

* significant at 0.05 significance level

Table 22. Results of randomizations (using Mean Square of Error) to test for significant differences in FFG diversity measures with respect to physical environmental variables for 23 lake outlet sites. Randomization tests were carried out only for those tests for which the residuals did not meet the assumptions of the ANOVA model.

Variables	Study area p-value	Disturbance level p-value	Mean velocity p-value	Immediate cover p-value	Surrounding cover p-value
Filterers	0.243	-	0.070	-	0.100
Gatherers	-	-	0.010*	-	-
Piercers	0.060	0.150	-	-	0.027*
Predators	-	-	-	-	-
Scrapers	-	0.133	-	-	-
Shredders	-	0.010*	-	-	0.110

Variables	Stream width p-value	Stream order p-value	Substrate type p-value	Aquatic vegetation p-value
Filterers	-	0.163	0.023*	0.156
Gatherers	0.076	-	0.103	-
Piercers	-	-	-	0.136
Predators	-	0.140	-	-
Scrapers	-	0.063	-	-
Shredders	-	-	-	-

* significant at 0.05 significance level

Table 23. Results of Fisher's pairwise comparisons for those FFG diversity measures that were significantly different between study areas (B = Bonavista, R = Random Island, C = Come-by-Chance, S = St. John's). Areas with same letters are not significantly different.

Gatherers

Area	N	Mean	StDev	
B	7	4.86	1.46	AB
R	5	6.40	2.61	A
C	4	6.25	2.22	A
S	7	3.14	1.22	B

Scrapers

Area	N	Mean	StDev	
B	7	0.14	0.38	A
R	5	3.20	1.79	B
C	4	1.00	0.82	A
S	7	0.29	0.76	A

Predators

Area	N	Mean	StDev	
B	7	4.14	1.68	AB
R	5	6.60	3.78	A
C	4	6.50	2.65	A
S	7	2.57	1.13	B

Shredders

Area	N	Mean	StDev	
B	7	7.14	1.22	A
R	5	6.20	1.10	AB
C	4	4.75	1.26	BC
S	7	3.00	2.00	C

Table 24. Results of Fisher's pairwise comparisons for those FFG diversity measures that were significantly different between levels of disturbance (1 = low, 5 = high). Disturbance levels with same letters are not significantly different.

Gatherers

Level	N	Mean	StDev	
1	3	6.67	2.52	A
2	6	5.17	0.41	AB
3	4	3.50	1.73	B
4	4	7.00	2.83	A
5	6	3.33	1.21	B

Predators

Level	N	Mean	StDev	
1	3	5.33	2.08	A
2	6	2.50	1.76	B
3	4	1.50	1.29	B
4	4	4.50	1.29	A
5	6	2.00	0.63	B

Shredders

Level	N	Mean	StDev	
1	3	4.67	1.53	AB
2	6	6.17	0.98	A
3	4	5.75	2.99	A
4	4	7.00	1.16	A
5	6	3.17	2.14	B

Table 25. Results of Fisher's pairwise comparisons for diversity of gatherers which was significantly different between stream orders. Orders with same letters are not significantly different.

Gatherers

Order	N	Mean	StDev	
1	12	3.67	1.37	A
2	5	6.40	1.67	B
3	5	5.20	1.10	AB
4	1	11.00	0.00	C

Table 26. Results of Fisher's pairwise comparisons for diversity of filterers which was significantly different between substrate types (1 = mud, 2 = small stone, 3 = wood, 4 = cobble, 5 = boulder). Substrate types with same letters are not significantly different.

Filterers

bstrate ty	N	Mean	StDev	
1	1	4.00	0.00	AC
2	5	3.20	2.05	A
3	1	2.00	0.00	A
4	9	5.56	1.33	C
5	7	5.43	0.79	C

Table 27. Spearman's Rank Correlation Coefficients to evaluate the relation between FFG diversity measures and environmental PC-I and PC-II (Chapter 3) and chemical variables loaded on environmental PC-I for 23 lake outlet sites.

Diversity	Environmental PC-Score and chemcial variables								
Variables	PC I	PC II	Al (µg/l)	Ca (mg/l)	K (mg/l)	Mg (mg/l)	Na (mg/l)	pH	Cond (µS/cm)
Gatherers	-0.481*	-0.186	0.114	-0.251	-0.375	-0.489*	-0.557*	0.060	-0.507*
Scrapers	-0.158	0.349	-	-	-	-	-	-	-
Shredders	-0.347	0.165	-	-	-	-	-	-	-
Piercers	-0.224	0.236	-	-	-	-	-	-	-
Filterers	-0.291	-0.042	-	-	-	-	-	-	-
Predators	-0.201	0.014	-	-	-	-	-	-	-

* significant correlation (critical value: +/- 0.413)

Table 28. Principal components analysis of EPT presence-absence data of 23 lake outlet sites in Bonavista, Random Island, Come-by-Chance and St. John's, NF, during May and July 1995, and May and July 1996

Score	Taxa and range of values			Interpretation of scores		Percent explained variance
	Variable	Minimum	Maximum	Low score	High score	
I	*Paraleptophlebia spp.*	0	1	High	Low	
	E. prudentalis	0	1	High	Low	
	B. pygmaeus	0	1	High	Low	
	B. macdunnoughi	0	1	High	Low	
	S. vicarium	0	1	High	Low	
	Leuctra spp.	0	1	High	Low	
	Polycentropus spp.	0	1	High	Low	
	Platycentropus sp.	0	1	High	Low	25.2%
II	*B. tricaudatus*	0	1	Low	High	
	I. transmarina	0	1	Low	High	
	R. fuscula	0	1	Low	High	
	H. slossonae	0	1	Low	High	16.8%
III	*H. vibrans*	0	1	High	Low	
	N. hostilis	0	1	Low	High	11.4%
Total						53.4%

Table 29. Interpretation of the principal components analysis of EPT presence-absence data for 23 lake outlet sites in Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S), NF, during May and July 1995, and May and July 1996

Score I	Score II	Sites	I	II
Negative	Negative	B3, B7, B8, B18, R19, C14, C15	*Paraleptophlebia* spp., *E. prudentalis*, *B. pygmaeus*, *B. macdunnoughi*, *S. vicarium*, *Leuctra* spp., *Polycentropus* spp., and *Platycentropus* sp. present	*B. tricaudatus*, *I. transmarina*, *R. fuscula*, and *H. slossonae* absent
Negative	Positive	B1, B2, R9, R11, R13, C17	*Paraleptophlebia* spp., *E. prudentalis*, *B. pygmaeus*, *B. macdunnoughi*, *S. vicarium*, *Leuctra* spp., *Polycentropus* spp., and *Platycentropus* sp. present	*B. tricaudatus*, *I. transmarina*, *R. fuscula*, and *H. slossonae* present
Positive	Negative	B6, R10, S22, S24, S26	*Paraleptophlebia* spp., *E. prudentalis*, *B. pygmaeus*, *B. macdunnoughi*, *S. vicarium*, *Leuctra* spp., *Polycentropus* spp., *Platycentropus* sp. absent	*B. tricaudatus*, *I. transmarina*, *R. fuscula*, and *H. slossonae* absent
Positive	Positive	C16, S20, S21, S23, S25	*Paraleptophlebia* spp., *E. prudentalis*, *B. pygmaeus*, *B. macdunnoughi*, *S. vicarium*, *Leuctra* spp., *Polycentropus* spp., *Platycentropus* sp. absent	*B. tricaudatus*, *I. transmarina*, *R. fuscula*, and *H. slossonae* present

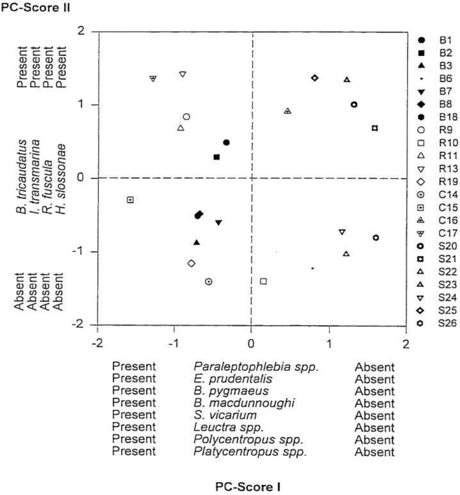

Figure 14. PC-I relative to PC-II for the principal components analysis of EPT presence-absence data collected at 23 lake outlet sites in Bonavista (B), Random Island (R), Come-byChance (C) and St. John's (S), NF, during May and July 1995, and May and July 1996.

Table 30. Results of ANOVA (using GLM command) to test for significant differences in presence-absence (P-A) PC-I and PC-II scores with respect to physical environmental variables for 23 lake outlet sites. Underlined values indicate those tests re-run using randomization. Remaining p-values were accepted as they would not change significantly after randomization.

Variables	Study area p-value	Disturbance level p-value	Mean velocity p-value	Immediate cover p-value	Surrounding cover p-value
P-A PC-I	<0.001*	<0.001*	0.302	0.921	0.701
P-A PC-II	0.581	0.265	0.188	0.141	0.519

Variables	Stream width p-value	Stream order p-value	Substrate type p-value	Aquatic vegetation p-value
P-A PC-I	0.943	0.214	0.373	0.557
P-A PC-II	0.088	0.042	0.464	0.636

* significant at 0.05 significance level

Table 31. Results of randomizations (using Mean Square of Error) to test for significant differences in presence-absence (P-A) PC-I and PC-II scores with respect to physical environmental variables for 23 lake outlet sites. Randomization tests were carried out only for those tests with p-values between 0.015 and 0.300.

Variables	Study area p-value	Disturbance level p-value	Mean velocity p-value	Immediate cover p-value	Surrounding cover p-value
P-A PC-I	-	-	-	-	-
P-A PC-II	-	0.239	0.156	0.103	-

Variables	Stream width p-value	Stream order p-value	Substrate type p-value	Aquatic vegetation p-value
P-A PC-I	-	0.249	-	-
P-A PC-II	0.053	0.043*	-	-

* significant at 0.05 significance level

Table 32. Results of Fisher's pairwise comparisons for presence-absence PC-I which was significantly different between study areas (B = Bonavista, R = Random Island, C = Come-by-Chance, S = St. John's) and levels of disturbance. Areas and levels of disturbance with same letters are not significantly different.

PC-I

Area	N	Mean	StDev	
B	7	-0.3630	0.5251	A
R	5	-0.6639	0.4619	A
C	4	-0.7482	0.9092	A
S	7	1.2647	0.2738	B

PC-I

Level	N	Mean	StDev	
1	3	-1.0932	0.4343	A
2	6	-0.3566	0.6088	AB
3	4	0.1503	0.9919	B
4	4	-0.7057	0.2653	A
5	6	1.2735	0.2989	C

Table 33. Results of Fisher's pairwise comparisons for presence-absence PC-II which was significantly different between stream orders. Orders with same letters are not significantly different.

PC-II

Order	N	Mean	StDev	
1	12	0.1266	0.9956	A
2	5	-1.0222	0.4637	B
3	5	0.5823	0.8158	A
4	1	0.6807	0	AB

Table 34. Spearman's Rank Correlation Coefficients to evaluate the relation between presence-absence PC-scores and environmental PC-scores (Chapter 3) for 23 lake outlet sites.

	Environmental PC axes	
Biological PC axes	PC-I	PC-II
PC I	0.631*	-0.097
PC II	0.118	-0.440*

* significant result (critical value: +/- 0.413)

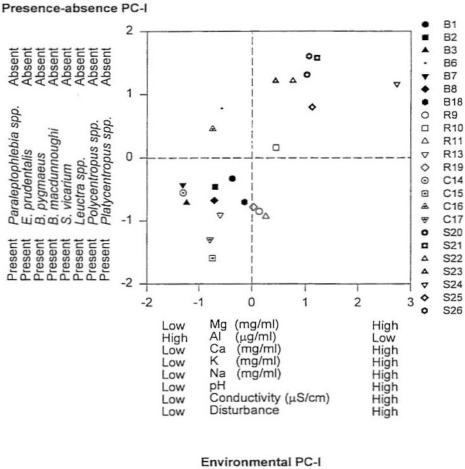

Figure 15. Presence-absence PC-I relative to environmental PC-I (Chapter 3) for 23 lake outlet sites in Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S), NF.

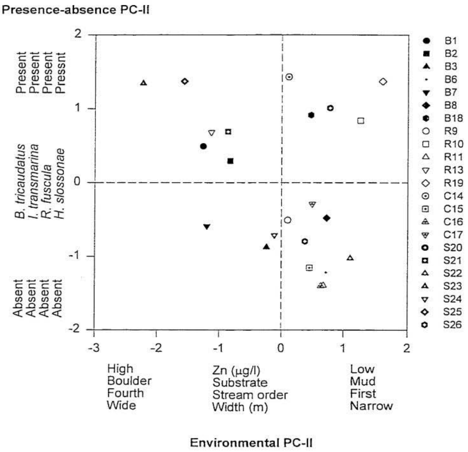

Figure 16. Presence-absence PC-II relative to environmental PC-II (Chapter 3) for 23 lake outlet sites in Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S), NF.

Table 35. Relative abundance of EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa collected at 23 lake outlet sites in Bonavista, Random Island, Come-by-Chance, and St. John's, NF, during July 1995, and May and July 1996.

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
EPHEMEROPTERA												
Baetis flavistriga											0.925	
Baetis macdunnoughi	0.034									0.368	0.063	0.419
Baetis pygmaeus	0.169	0.377	0.158				0.490				1.492	
Baetis tricaudatus	0.017							0.010			5.296	
Baetis spp.	0.135							0.291				
Caenis simulans												
Drunella cornuta								0.221			0.147	0.105
Ephemerella subvaria	0.169				0.028		0.061			0.920	0.063	
Eurylophella prudentalis	0.135	0.146			0.084	0.027	0.184				0.189	
Epeorus pleuralis												
Hetagenia hebe											0.231	
Stenonema vicarium								0.020			0.021	0.052
Habrophlebia vibrans			0.198									0.157
Leptophlebia cupida	0.490	0.042	0.139	1.091	0.281	0.122	0.061	0.020	1.273	0.092		2.410
Paraleptophlebia spp.		0.188	5.027		0.028	0.150	0.123	0.010	0.208	7.544	1.177	0.838
Leptophlebiidae spp.	0.389		1.682	0.324	3.205	0.054	0.123	0.080	0.282		0.315	
PLECOPTERA												
Leuctra spp.	1.757	0.042	2.355	1.091	0.056	0.054	0.306	0.241	0.392	4.784	0.525	
Nemoura macdunnoughi	0.389		0.020	8.078	0.253		1.164	0.331		0.092	1.723	
Isoperla transmarina	0.473		0.435			0.014		0.221		1.012	0.946	
Unidentified Plecoptera								1.637				

Table 35 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

				Bonavista						Random Island		
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
TRICHOPTERA												
Cheumatopsyche pettiti	67.472	61.184	1.662	23.349	2.980	11.696	6.679	46.280	44.123	13.983		11.996
Hydropsyche alternans					0.084	0.068	0.306	2.249		0.460	1.429	0.419
Hydropsyche betteni	10.595	14.815	7.837	13.355	6.354	25.133	36.458	9.599	6.232	6.440		8.119
Hydropsyche slossonae					0.056		0.061	0.251		0.460	0.084	
Hydropsyche sparna	1.808	12.806	0.613	1.651	7.478	8.269	4.596	0.532	1.861	0.644	0.673	1.257
Hydropsychidae spp.	12.842	9.856	5.977	5.896	2.755	27.785	48.836	33.879	31.476	55.198	6.536	
Chimarra sp.	0.135	0.021	70.790	44.310	59.938	21.352		3.846	12.365	4.784	18.138	68.360
Dolophilodes distinctus										0.552	58.092	
Philopotamidae spp.						3.305						
Polycentropus spp.	0.997	0.021	0.139	0.295	0.112	0.041	0.061		0.196	0.368	0.021	
Lepidostoma spp.						0.122			0.049	0.092		0.367
Ceralcea spp.	0.051			0.088	2.080	0.014		0.010	0.012			0.052
Mystacides sepulchralis									0.110			
Oecetis sp.									0.098		0.084	
Limnephilus spp.									0.098			
Nemotaulius hostilis						0.014			0.024			
Neophylax spp.									0.233	0.092		1.048
Platycentropus sp.												
Pycnopsyche spp.			0.079	0.236		0.014	0.123		0.355	0.276	0.021	3.405
Limnephilidae spp.												
Molanna sp.												
Psilotreta spp.									0.024			
Banksiola sp.												
Glossosoma sp.											0.021	
Hydroptila metoeca	0.017	0.063		0.059	0.084	0.150	0.184	0.050	0.294	0.276		0.419
Oxytheria sp.	1.893	0.398	2.889	0.177	14.141	1.618	0.184	0.221	0.282		0.399	0.105
Rhyacophila carolina												
Rhyacophila fuscula	0.034	0.042								0.736	1.366	

Table 35 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
Rhyacophila invaria									0.012			0.419
Rhyacophila melita										0.184	0.021	
Rhyacophila minora										0.092		
Rhyacophila nigrita												
Rhyacophila vibox												0.052
Rhyacophila spp.										0.552		
TOTAL ABUNDANCE	5918	4779	5053	3392	3557	7353	1632	9959	8168	1087	4758	1909

Table 35 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

	Come-by-Chance				t. John's						
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
EPHEMEROPTERA											
Baetis flavistriga											
Baetis macdunnoughi		9.250		1.180							
Baetis pygmaeus		1.059		0.655							
Baetis tricaudatus			0.071	3.014	0.184	0.030		33.889		5.015	
Baetis spp.											
Caenis simulans									0.157		
Drunella cornuta				1.835							
Ephemerella subvaria				0.131		0.300		1.111		0.271	
Eurylophella prudentalis	0.521		0.071								
Epeorus pleuralis											
Hetagenia hebe											
Stenonema vicarium		0.122		0.131							
Habrophlebia vibrans		0.733		1.180			0.167				
Leptophlebia cupida	5.990	1.059	1.203	0.393	0.023		2.667		0.157		43.590
Paraleptophlebia spp.	1.042	0.407	0.071	0.655							
Leptophlebiidae spp.	1.042	0.041		0.262					2.358		
PLECOPTERA											
Leuctra spp.	0.781	1.222	0.071								
Nemoura macdunnoughi		0.204	0.071		0.230	0.060	0.500			0.058	
Isoperla transmarina		0.896	0.071	0.786	0.414	0.120		0.556		1.143	
Unidentified Plecoptera											

Table 35 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

	Come-by-Chance				St. John's						
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
TRICHOPTERA											
Cheumatopsyche pettiti	43.229	17.400	46.285	7.995	72.859	16.557			66.038	1.995	25.641
Hydropsyche alternans		0.407	0.071	2.097	0.368			4.444		15.666	
Hydropsyche betteni	5.469	20.660	16.631	2.490	14.618	2.130	23.833	5.000	0.157	4.880	
Hydropsyche slossonae			0.142	0.131				3.889		4.493	
Hydropsyche sparna		6.357	2.689	1.048	0.322			1.667		1.878	
Hydropsychidae spp.	17.188	11.654	30.502	65.924		66.587	68.167	47.222	22.956	6.642	
Chimarra sp.		6.683	0.637	0.786	10.750	13.287				51.569	
Dolophilodes distinctus		0.081		0.786							
Philopotamidae spp.											
Polycentropus spp.	0.781								3.459		
Lepidostoma spp.			0.566		0.023	0.060					
Ceralcea spp.		0.122		0.262							
Mystacides sepulchralis									1.572		2.564
Oecetis sp.									0.157		2.564
Limnephilus spp.						0.030					
Nemotaulius hostilis					0.023						
Neophylax spp.					0.023						
Platycentropus sp.											
Pycnopsyche spp.					0.069						25.641
Limnephilidae spp.			0.071								
Molanna sp.											
Psilotreta spp.											
Banksiola sp.											
Glossosoma sp.											
Hydroptila metoeca		3.871	0.071	0.262	0.046	0.120			0.157		
Oxytheria sp.	23.958	17.441	0.708	0.524	0.023	0.690	4.667		2.830		

Table 35 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

	Come-by-Chance				St. John's						
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
Rhyacophila carolina				0.786							
Rhyacophila fuscula				3.277	0.023	0.030		1.667		0.794	
Rhyacophila invaria		0.204		0.262							
Rhyacophila melita				0.393							
Rhyacophila minora				1.311							
Rhyacophila nigrita		0.081									
Rhyacophila vibox		0.041		0.131							
Rhyacophila spp.				1.311				0.556		5.596	
TOTAL ABUNDANCE	384	2454	1413	763	4344	3334	600	180	636	5164	39

Table 36. Summary of total abundance and mean abundance of EPT taxa collected at 23 lake outlet sites in Bonavista, Random Island, Come-by-Chance, and St. John's, NF, during July 1995, and May and July 1996.

Area	Total EPT abundance (mean abundance) (one standard error)											
	Ephemeroptera			Plecoptera			Trichoptera			Total abundance		
Bonavista	711	(101.57)	(122.31)	650	(92.86)	(116.39)	30323	(4331.86)	(1870.25)	31684	(4526.29)	(1865.10)
Random Island	854	(170.80)	(171.08)	490	(98.00)	(98.45)	24537	(4907.40)	(3805.51)	25881	(5176.20)	(3853.48)
Come-by-Chance	436	(109.00)	(136.47)	69	(17.25)	(26.54)	4509	(1127.25)	(772.67)	5014	(1253.50)	(906.14)
St. John's	407	(58.14)	(96.53)	100	(14.29)	(23.26)	13790	(1970.00)	(2099.17)	14297	(2042.43)	(2169.89)

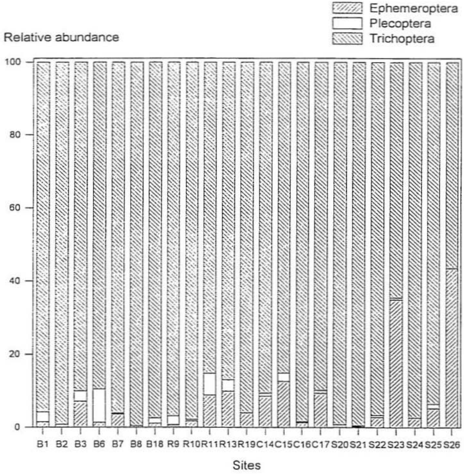

Figure 17. EPT relative abundance recorded at 23 lake outlet sites in Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S), NF, during July 1995, and May and July 1996.

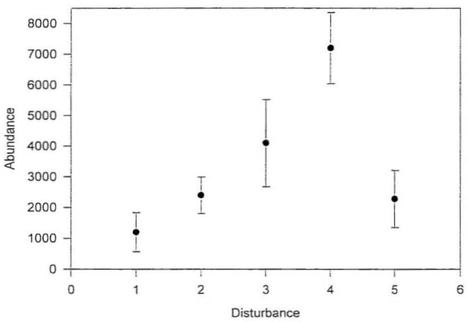

Figure 18. Response of EPT taxa abundance to levels of disturbance (1 = low, 5 = high) for 23 lake outlet sites. Dots represent means and bars represent one standard error above and below the mean.

Table 37. Results of ANOVA (using GLM command) to test for significant differences in EPT abundance measures with respect to physical environmental variables for 23 lake outlet sites. Values underlined indicate tests re-run using randomization. Remaining p-values were accepted as they would not change significantly after randomization.

Variables	Study area p-value	Disturbance level p-value	Mean velocity p-value	Immediate cover p-value	Surrounding cover p-value
Total abundance	0.047	0.007*	0.640	0.508	0.160
Ephemeroptera	0.542	0.526	0.200	0.793	0.974
Plecoptera	0.174	0.036	0.568	0.098	0.696
Trichoptera	0.055	0.010*	0.650	0.522	0.153

Variables	Stream width p-value	Stream order p-value	Substrate type p-value	Aquatic vegetation
Total abundance	0.471	0.724	0.245	0.755
Ephemeroptera	0.105	0.001*	0.009*	0.356
Plecoptera	0.824	0.752	0.972	0.499
Trichoptera	0.511	0.708	0.242	0.700

* significantly different at 0.05 significance level

Table 38. Results of randomizations (using Mean Square of Error) to test for significant differences in EPT abundance measures with respect to physical envirnonmental variables for 23 lake outlet sites. Randomization tests were carried out only for tests which had p-values between 0.015 and 0.300.

Variables	Study area p-value	Disturbance level p-value	Mean velocity p-value	Immediate cover p-value	Surrounding cover p-value
Total abundance	0.030*	-	-	-	0.159
Ephemeroptera	-	-	0.216	-	-
Plecoptera	0.146	0.020*	-	0.100	-
Trichoptera	0.056	-	-	-	0.140

Variables	Stream width p-value	Stream order p-value	Substrate type p-value	Aqautic vegetation p-value
Total abundance	-	-	0.213	-
Ephemeroptera	0.073	-	-	-
Plecoptera	-	-	-	-
Trichoptera	-	-	0.219	-

* significant at 0.05 significance level

Table 39. Results of Fisher's pairwise comparisons for total abundance which was significantly different between study areas (B = Bonavista, R = Random Island, C = Come-by-Chance, S = St. John's). Areas with same letters are not significantly different.

Total abundance

Area	N	Mean	StDev	
B	7	4526	1865	AB
R	5	5176	3853	B
C	4	1254	906	C
S	7	2042	2170	AC

Table 40. Results of Fisher's pairwsie comparisons for those EPT abundance measures that were significantly different between levels of disturbance (1 = low, 5 = high). Disturbance levels with same letters are not significantly different.

Total abundance

Level	N	Mean	StDev	
1	3	1200	1102	A
2	6	2396	1451	A
3	4	4099	2843	AB
4	4	7201	2321	B
5	6	2283	2273	A

Plecoptera

Level	N	Mean	StDev	
1	3	22	30.35	AC
2	6	17.33	24.51	AC
3	4	115.25	145.82	AB
4	4	145.25	86.27	B
5	6	16.17	24.89	C

Trichoptera

Level	N	Mean	StDev	
1	3	1040	922	A
2	6	2316	1459	A
3	4	3871	2822	AB
4	4	6862	2444	B
5	6	2202	2199	A

Table 41. Results of Fisher's pairwise comparisons for abundance of Ephemeroptera which was significantly different between stream orders and substrate types (1 = mud, 2 = small stone, 3 = wood, 4 = cobble, 5 = boulder). Orders and substrate types with same letters are not significantly different.

Ephemeroptera

Order	N	Mean	StDev	
1	12	40.00	39.27	A
2	5	172.80	154.04	B
3	5	118.40	93.04	AB
4	1	472.00	0.00	C

Ephemerotpera

Substrate type	N	Mean	StDev	
1	1	144.00	0.00	AB
2	5	33.40	28.11	A
3	1	33.00	0.00	AB
4	9	46.22	34.72	A
5	7	235.43	163.53	B

Table 42. Spearman's Rank Correlation Coefficients to evaluate the relation between EPT abundance measures and environmental PC-I and PC-II (Chapter 3) and chemical variables loaded on PC-I for 23 lake outlet sites.

Abundance	Environmental PC-scores and chemical variables								
Variables	PC-I	PC-II	Al (µg/l)	Ca (mg/l)	K (mg/l)	Mg (mg/l)	Na (mg/l)	pH	Cond (µS/cm)
Total abundance	-0.107	-0.083	-	-	-	-	-	-	-
Ephemeroptera	-0.416*	-0.266	0.128	-0.239	-0.373	-0.321	-0.434*	0.026	-0.409
Plecoptera	-0.174	-0.119	-	-	-	-	-	-	-
Trichoptera	-0.080	-0.081	-	-	-	-	-	-	-

* significant correlation (critical value: +/- 0.413)

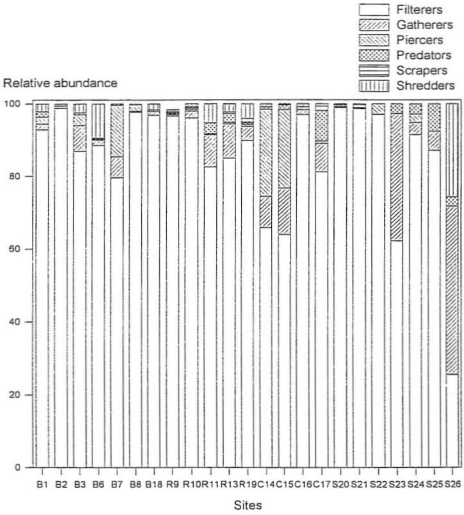

Figure 19. Relative abundance of functional feeding groups recorded at 23 lake outlet sites in Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S), NF, during July 1995, and May and July 1996.

Table 43. Results of ANOVA (using GLM command) to test for significant differences in FFG abundance measures with respect to physical environmental variables for 23 lake outlet sites. Values underlined indicate tests re-run using randomization. Remaining p-values were accepted as they would not change significantly after randomization.

Variables	Study area p-value	Disturbance level p-value	Mean velocity p-value	Immediate cover p-value	Surrounding cover p-value
Filterers	0.051	0.007*	0.669	0.508	0.138
Gatherers	0.602	0.648	0.202	0.839	0.956
Piercers	0.218	0.439	0.912	0.865	0.233
Predators	0.798	0.639	0.171	0.531	0.703
Scrapers	<0.001*	0.023	0.228	0.891	0.244
Shredders	0.084	0.068	0.918	0.280	0.687

Variables	Stream width p-value	Stream order p-value	Substrate type p-value	Aquatic vegetation p-value
Filterers	0.566	0.691	0.253	0.660
Gatherers	0.069	0.001*	0.003*	0.367
Piercers	0.516	0.455	0.312	0.691
Predators	0.026	0.170	0.578	0.406
Scrapers	0.667	0.192	0.437	0.830
Shredders	0.848	0.810	0.733	0.141

* significant at 0.05 significance level

Table 44. Results of randomizations (using Mean Square of Error) to test for significant differences in FFG abundance measures with respect to physical environmental variables for 23 lake outlet sites. Randomization tests were carried out for those tests which had p-values between 0.015 and 0.300.

Variables	Study area p-value	Disturbance level p-value	Mean velocity p-value	Immediate cover p-value	Surrounding cover p-value
Filterers	0.037*	-	-	-	0.173
Gatherers	-	-	0.219	-	-
Piercers	0.116	-	-	-	0.103
Predators	-	-	0.119	-	-
Scrapers	-	0.023*	0.319	-	0.329
Shredders	0.053	0.027*	-	0.309	-

Variables	Stream width p-value	Stream order p-value	Substrate type p-value	Aquatic vegetation p-value
Filterers	-	-	0.292	-
Gatherers	0.047*	-	-	-
Piercers	-	-	-	-
Predators	0.010*	0.153	-	-
Scrapers	-	0.299	-	-
Shredders	-	-	-	0.140

* significant at 0.05 significance level

Table 45. Results of Fisher's pairwise comparisons for those FFG abundance measures that were significantly different between study areas (B = Bonavista, R = Random Island, C = Come-by-Chance, S = St. John's). Areas with same letters are not significantly different.

Filterers

Area	N	Mean	StDev	
B	7	4171	1870	AB
R	5	4826	3802	B
C	4	949	615	C
S	7	1903	2032	AC

Scrapers

Area	N	Mean	StDev	
B	7	0.00	0.00	A
R	5	17.80	9.52	B
C	4	4.50	7.14	A
S	7	0.14	0.38	A

Table 46. Results of Fisher's pairwise comparisons for those FFG abundance measures that were significantly different between levels of disturbance (1 = low, 5 = high). Disturbance levels with same letters are not significantly different

Filterers

Level	N	Mean	StDev	
1	3	808	670	A
2	6	2187	1395	A
3	4	3781	2765	AB
4	4	6752	2474	B
5	6	2128	2129	A

Scrapers

Level	N	Mean	StDev	
1	3	6.00	7.94	AB
2	6	4.00	9.32	A
3	4	0.00	0.00	A
4	4	16.25	10.97	B
5	6	0.17	0.41	A

Shredders

Level	N	Mean	StDev	
1	3	12.67	19.40	AC
2	6	29.83	28.34	ABC
3	4	115.25	146.33	B
4	4	91.75	31.60	AB
5	6	5.50	5.96	C

Table 47. Results of Fisher's pairwise comparisons for abundance of gatherers which was significantly different between stream orders and substrate types (1 = mud, 2 = small stone, 3 = wood, 4 = cobble, 5 = boulder). Orders and substrate types with same letters are not significantly different.

Gatherers

Order	N	Mean	StDev	
1	12	40.00	40.46	A
2	5	170.20	156.26	B
3	5	133.80	100.41	AB
4	1	453.00	0.00	C

Gatherers

Substrate type	N	Mean	StDev	
1	1	154.00	0.00	AB
2	5	33.80	27.65	A
3	1	33.00	0.00	A
4	9	43.78	32.61	A
5	7	243.29	153.36	B

Table 48. Spearman's Rank Correlation Coefficients to evaluate the relation between FFG abundance measures and environmental PC-I and PC-II (Chapter 3) and chemical variables loaded on environmental PC-I for 23 lake outlet sites.

Abundance	Environmental PC-scores and chemical variables								
Variables	PC-I	PC-II	Al (µg/l)	Ca (mg/l)	K (mg/l)	Mg (mg/l)	Na (mg/l)	pH	Cond (µS/cm)
Filterers	-0.048	-0.049	-	-	-	-	-	-	-
Gatherers	-0.382	-0.326	-	-	-	-	-	-	-
Piercers	-0.523*	-0.032	0.388	-0.493*	-0.466*	-0.362	-0.298	-0.441*	-0.369
Predators	0.037	-0.256							
Scrapers	0.000	0.376	-	-	-	-	-	-	-
Shredders	-0.198	0.238	-	-	-	-	-	-	-

* significant correlation (critical value: +/- 0.413)

Table 49. Principal components analysis of EPT relative abundance data for 23 lake outlet sites in Bonavista, Random Island, Come-by-Chance and St. John's, NF, during July 1995, and May and July 1996

Score	Taxa and range of values			Interpretation of scores		Correlation among variables and PC-scores	Percent explained variance
	Variable	Minimum	Maximum	Low score	High score		
I	*B. tricaudatus*	0	33.889	Low	High	0.810	
	L. cupida	0	17.000	High	Low	-0.820	
	C. pettiti	0	72.859	High	Low	-0.409	
	H. alternans	0	15.666	Low	High	0.764	
	H. slossonae	0	4.493	Low	High	0.779	
	R. fuscula	0	3.277	Low	High	0.766	27.2%
II	*H. sparna*	0	12.806	High	Low	-0.553	
	Chimarra sp.	0	70.790	High	Low	-0.618	17.0%
III	*Hydropsychidae*[1]	0	68.167	Low	High	0.517	
	Pycnopsyche spp.	0	10.000	High	Low	-0.663	14.4%
Total							58.6%

[1] Includes only unidentified Hydropshchidae taxa

Table 50. Interpretation of the principal components analysis of EPT abundance data for 23 lake outlet sites in Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S), NF, during July 1995, and May and July 1996

Score I	Score II	Sites	I	II
Negative	Negative	B1, B3, B6, B7, B8, R10, C15, C16	Low relative abundance of *B. tricaudatus*, *H. alternans*, *H. slossonae*, and *R. fuscula*. High relative abundance of *L. cupida*, and *C. pettiti*.	High relative abundance of *H. sparna*, and *Chimarra sp.*
Negative	Positive	B2, B18, R19, C14, S22, S24, S26	Low relative abundance of *B. tricaudatus*, *H. alternans*, *H. slossonae*, and *R. fuscula*. High relative abundance of *L. cupida*, and *C. pettiti*.	Low relative abundance of *H. sparna*, and *Chimarra sp.*
Positive	Negative	R9, R11, R13, C17, S25	High relative abundance of *B. tricaudatus*, *H. alternans*, *H. slossonae*, and *R. fuscula*. Low relative abundance of *L. cupida*, and *C. pettiti*.	High relative abundance of *H. sparna*, and *Chimarra sp.*
Positive	Positive	S20, S21, S23 C17, S25	High relative abundance of *B. tricaudatus*, *H. alternans*, *H. slossonae*, and *R. fuscula*. Low relative abundance of *L. cupida*, and *C. pettiti*.	Low relative abundance of *H. sparna*, and *Chimarra sp.*

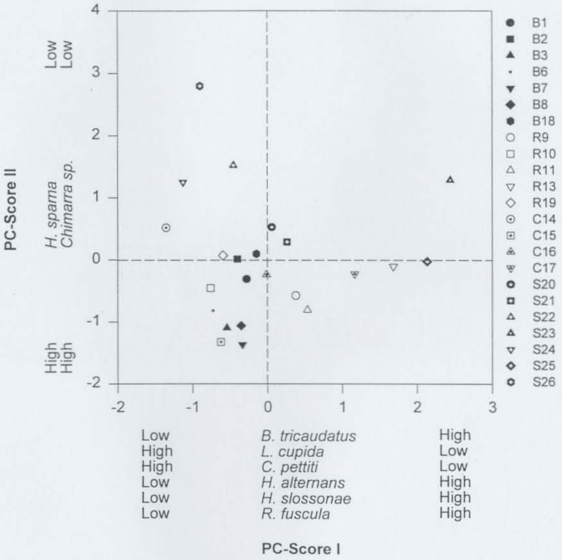

Figure 20. PC-I relative to PC-II for the principal components analysis of EPT relative abundance data collected ar 23 lake outlet sites in Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S), NF, during July 1995, and May and July 1996.

Table 51. Results of ANOVA (using GLM command) to test for significant differences in relative abundance PC-I and PC-II scores with respect to physical environmental variables for 23 lake outlet sites. Bold values indicate tests for which the residuals met the assumptions of the ANOVA model. Underlined values indicate tests re-run using randomization. Remaining p-values were accepted as they would not change significantly after randomization.

Variables	Study area p-value	Disturbance level p-value	Mean velocity p-value	Immediate cover p-value	Surrounding cover p-value
Abundance PC-I	0.517	0.581	0.007*	0.540	0.723
Abundance PC-II	0.001*	<u>0.056</u>	0.376	0.699	**0.136**

Variables	Stream width p-value	Stream order p-value	Substrate type p-value	Aquatic vegetaion p-value
Abundance PC-I	0.009*	<u>0.029</u>	<u>0.155</u>	0.748
Abundance PC-II	0.819	<u>0.247</u>	<u>0.288</u>	0.732

* significant at 0.05 significance level

Table 52. Results of randomizations (using Mean Square of Error) to test for significant differences in relative abundance PC-I and PC-II with respect to physical environmental variables for 23 lake outlet sites. Randomization tests were carried out only for those tests for which the residuals did not meet the assumptions of the ANOVA model.

Variables	Study area p-value	Disturbance level p-value	Mean velocity p-value	Immediate cover p-value	Surrounding cover p-value
Abundance PC-I	-	-	-	-	-
Abundance PC-II	-	0.037*	-	-	-

Variables	Stream width p-value	Stream order p-value	Substrate type p-value	Aquatic vegetaion p-value
Abundance PC-I	-	0.040*	0.189	-
Abundance PC-II	-	0.326	0.269	-

* significant at 0.05 significance level

Table 53. Results of Fisher's pairwise comparisons for relative abundance PC-I which was significantly different between stream orders. Orders with same letters are not significantly different.

PC-I

Order	N	Mean	StDev	
1	12	-0.4787	0.5415	A
2	5	0.1026	0.7548	AB
3	5	0.7101	1.4443	B
4	1	1.6812	0.0000	B

Table 54. Results of Fisher's pairwise comparisons for relative abundance PC-II which was significantly different between study areas (B = Bonavista, R = Random Island, C = Come-by-Chance, S = St. John's) and levels of disturbance (1 = low, 5 = high). Areas and disturbance levels with same letters are not significantly different.

PC-II

Area	N	Mean	StDev	
B	7	-0.6469	0.5803	A
R	5	-0.3716	0.3548	A
C	4	-0.3166	0.7590	A
S	7	1.0933	0.9451	B

PC-II

Level	N	Mean	StDev	
1	3	-0.3434	0.9272	A
2	6	-0.3698	0.5933	A
3	4	-0.3609	1.2625	A
4	4	-0.3592	0.2018	A
5	6	0.0216	1.0142	B

Table 55. Spearman's Rank Correlation Coefficients to evaluate the relation between relative abundance PC-scores and environmental PC-scores (Chapter 3) for 23 lake outlet sites.

	Environmental PC axes	
Biological PC axes	PC I	PC II
PC I	0.104	-0.374
PC II	0.609*	-0.020

* significant result (critical value: +/- 0.413)

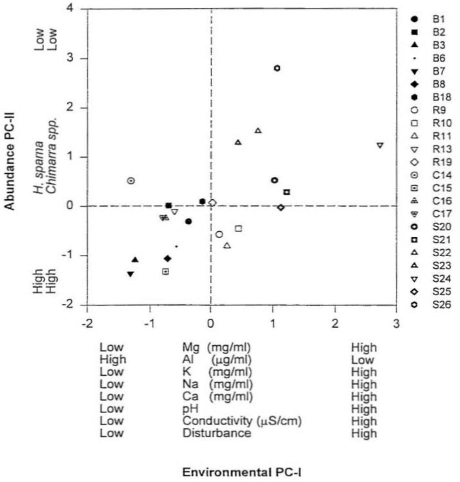

Figure 21. Relative abundance PC-II relative to environmental PC-I (Chapter 3) for 23 lake outlet sites in Bonavista (B), Random Island (R), Come-by-Chance (C) and St. John's (S), NF.

Chapter 5. Concluding remarks

The present study examined the use of an impoverished benthic Ephemeroptera, Plecoptera, and Trichoptera (EPT) fauna as an indicator of water quality in Bonavista, Random Island, Come-by-Chance, and St. John's, NF. The study was a portion of the Eco-Research program developed to examine the sustainability of cold coastal communities in Newfoundland. The aim of the present study was to evaluate environmental conditions of the freshwater systems studied, and to assess the use of the benthic EPT fauna as a predictor of these conditions. Although EPT diversities and abundances were low and dominated by generalists (Table 13 and 35, Chapter 4), significant differences were found between faunal communities of 23 lake outlets in relation to levels of disturbance (Tables 15, 16, 18, 37, 38, and 40, Chapter 4). EPT diversity and abundance had a parabolic relation with disturbance, decreasing with high and low levels of disturbance and increasing at intermediate levels (Figures 12 and 18, Chapter 4). This is consistent with the intermediate disturbance hypothesis (Cornell 1978). It is therefore concluded that an impoverished EPT fauna was useful as an indicator of water quality in the present study.

A major difficulty in the present study was the assignment of levels of disturbance (Chapter 2). Disturbance type, frequency, intensity and time scale are important factors determining level of disturbance. However, these factors are difficult to quantify. A separate study examining disturbances on physical, chemical, and temporal scales would be required to properly evaluate disturbance quantitatively. Assignment of disturbance levels may not be accurate in the present study. However, sites assigned level 4 disturbance were definitely more disturbed than those sites assigned a 1, 2 or 3, and less disturbed than those assigned level 5 disturbance, suggesting a possible combination of levels 1, 2 and 3.

Most significant differences in EPT diversities and abundances were between St. John's sites and the remaining three study areas, or between level 5 disturbance and the remaining four levels (Tables 17, 18, 39, and 40, Chapter 4). Therefore the range of disturbance in the present study may have been too narrow to provide more distinct site separations. In fact, chemical analysis indicated that waters examined in the present study were relatively healthy (Davenport, personal communication). Newfoundland waters, even those most disturbed within St. John's, are relatively uncontaminated compared to larger urbanized areas which have higher levels of industrial and municipal wastes. Most previous studies of this type compared macroinvertebrate communities between areas with more pronounced differences in terms of disturbance and pollution (e.g., Whitehurst and Lindsey 1990; Barbour *et al.* 1996; Bournaud *et al.* 1996). These results suggest that combining disturbance levels 1, 2 and 3, therefore leaving only 3 levels of disturbance, may have provided more distinct site groupings.

During the present study, samples were collected only at lake outlets which tend to be dominated by filter feeders. Fauna communities at the outlet may not be representative of overall stream communities. Therefore, another possible means to improve upon the present study would be to collect additional samples further downstream at each site. Also, biogeographic features such as altitude, latitude, slope, site distance from source, drainage basin size, and bedrock geology should be included as environmental variables, particularly if results are to be generalized for the whole of Newfoundland. Corkum (1989) found these features to be more important than ecological features in determining invertebrate distributions.

This study was a preliminary study of an exploratory nature to examine the composition of a naturally impoverished EPT fauna in relation to environmental conditions and disturbances. Overall, the study was successful in identifying patterns in the faunal distribution that were associated with environmental conditions and disturbance, suggesting that a naturally impoverished EPT fauna can be used as an indicator of water quality in the study area. An interesting area of further investigation would be to examine the distribution of individual taxa at these outlets.

The study provides information useful to the original Eco-Research project. The study indicates that human activity has not adversely affected the water systems studied and provides a useful baseline measure of EPT communities of the systems studied. This baseline data will be useful for future biomonitoring studies in the study area to identify changes in EPT communities which may reflect changes in human activity.

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Appendix 1

1) Sample ANOVA output

Table 1. Analysis of Variance to test for a significant difference in Mg concentrations between study areas.

Factor	Levels	Values
AREA	4	1 2 3 4

Source	DF	Seq SS	Adj SS	Adj MS	F	P
AREA	3	21.486	21.486	7.162	2.51	0.090
Error	19	54.257	54.257	2.856		
Total	22	75.743				

2) Examination of residuals.

2) i) The ANOVA model assumes that the residuals (error) have a normal distribution.

Character histogram of residuals of the ANOVA testing for a significant difference in Mg concentrations between study areas.

```
Histogram of RESIDUALS   N = 23
Midpoint  Count
   -2      4  ****
   -1      1  *
    0     16  ****************
    1      1  *
    2      0
    3      0
    4      0
    5      0
    6      1  *
```

Residuals do not have a normal distribution, therefore they do not meet the assumptions of the ANOVA model.

ii) The ANOVA model assumes that the Normal probability plot of the residuals is a straight line.

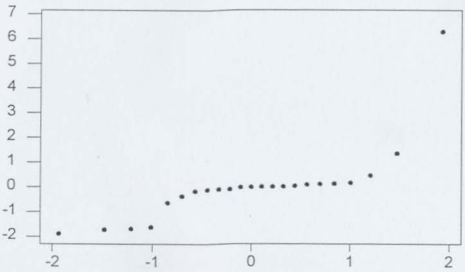


Figure 2. Normal probability plot for the ANOVA testing for a significant difference in Mg concentrations between study areas. The plot is not a straight line, therefore the residuals do not meet the assumptions of the ANOVA model.

iii) The plot of residuals versus fitted values should not show a pattern such as an arc or a funnel.

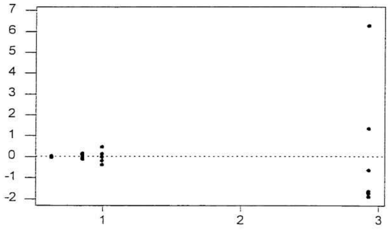


Figure 3. Plot of residuals versus fitted values for the ANOVA testing for a significant difference in Mg concentrations between study areas. Plot shows a funnel pattern, therefore the residuals do not meet the assumptions of the ANOVA model.

Appendix 2

Sample randomization of Mean Square (Adj MS) Error as calculated in an ANOVA table.

Randomization program used to generate 300 random Mean Square of Error values for study areas (c1) and Mg concentration (c2).

```
MTB> store 'random.ctl'
stor> sample 23 c2 into c3
stor> unstack c3 into c4 c5 c6 c7;
stor> subscripts c1.
stor> let k1=sum (c4)
stor> let k2=sum (c5)
stor> let k3=sum (c6)
stor> let k4=sum (c7)
stor> let k5=mean (c4)
stor> let k6=mean (c5)
stor> let k7=mean (c6)
stor> let k8=mean (c7)
stor> let k9=count(c4)
stor> let k10=count(c5)
stor> let k11=count(c6)
stor> let k12=count(c7)
stor> let k13=mean(c3)
stor> let k14=(k9*(k5-k13)**2)+(k10*(k6-k13)**2)+(k11*(k7-k13)**2)+
          (k12*(k8-k13)**2)
stor> let k15=(c4(1)-k5)**2+(c4(2)-k5)**2+(c4(3)-k5)**2+(c4(4)-k5)**2+
          (c4(5)-k5)**2+(c4(6)-k5)**2
stor> let k16=k15+(c4(7)-k5)**2+(c5(1)-k6)**2+(c5(2)-k6)**2+
          (c5(3)-k6)**2+(c5(4)-k6)**2+(c5(5)-k6)**2
stor> let k17=k16+(c6(1)-k7)**2+(c6(2)-k7)**2+(c6(3)-k7)**2+
          (c6(4)-k7)**2+(c7(1)-k8)**2+(c7(2)-k8)**2
stor> let k18=k17+(c7(3)-k8)**2+(c7(4)-k8)**2+(c7(5)-k8)**2+
          (c7(6)-k8)**2+(c7(7)-k8)**2
stor> let k19=k14/(4-1)
stor> let k20=k18/(23-4)
stor> name k1='Sum-Level1'
stor> name k2='Sum-Level2'
stor> name k3='Sum-Level3'
stor> name k4='Sum-Level4'
```

```
stor> name k5='Mean-Level1'
stor> name k6='Mean-Level2'
stor> name k7='Mean-Level3'
stor> name k8='Mean-Level4'
stor> name k9='n-Level1'
stor> name k10='n-Level2'
stor> name k11='n-Level3'
stor> name k12='n-Level4'
stor> name k13='Grand mean'
stor> name k14='SSQ-Among groups'
stor> name k15='SSQ-Within groups (partial 1)'
stor> name k16='SSQ-Within groups (partial 2)'
stor> name k17='SSQ-Within groups (partial 3)'
stor> name k18='SSQ-Within groups (complete)'
stor> name k19='MSE-Among groups'
stor> name k20='MSE-Within groups'
stor> let c9(1)=k20
stor> stack c9 k20 c9
stor> end
MTB> execute 'random.ctl' 299
```

Divide the number of randomized Mean Square of Error values less than the original Mean Square of Error value from the ANOVA table by the total number of randomized values to obtain the p-value.

For study areas and Mg concentration, $p = 9/300 = 0.030$.

Therefore, $p = 0.030$, which is significant at $\alpha = 0.05$ significance level. The decision changed when the p-value was calculated more accurately, without assumptions of normal, homogeneous error.

Appendix 3

Sample Fisher's Pairwise Comparisons output

Testing for significant differences in Mg concentration between study areas (1 = Bonavista, 2 = Random Island, 3 = Come-by-Chance, 4 = St. John's).

```
                         Individual 95% CIs For Mean
                         Based on Pooled StDev
Level    N    Mean    StDev  --------+---------+---------+---------+-------
1        7   0.855   0.114     (--------*-------)
2        5   0.994   0.319     (----------*---------)
3        4   0.630   0.026  (----------*-----------)
4        7   2.928   2.994             (--------*-------)
                             --------+---------+---------+--------
Pooled StDev =   1.690               0.0       1.5       3.0
```

Fisher's pairwise comparisons

```
  Family error rate = 0.191
Individual error rate = 0.0500

Critical value = 2.093

Intervals for (column level mean) - (row level mean)

            1          2          3

  2     -2.210
         1.932

  3     -1.992     -2.009
         2.441      2.736

  4     -3.964     -4.005     -4.515
        -0.183      0.137     -0.081
```

Intervals that do not contain zero indicate significant differences between study areas. In this case, St. John's is significantly different from the remaining three study areas in terms of Mg concentrations.

Appendix 4

Complete EPT taxa list and FFG classification of taxa for the present study

Ephemeroptera	Feeding group
Baetidae	
Baetis flavistriga McDunnough	Gatherer
Baetis macdunnoughi Ide	Gatherer
Baetis pgymaeus Hagen	Gatherer
Baetis tricaudatus Dodds	Gatherer
Baetis Leach	Gatherer
Caenidae	
Caenis simulans McDunnough	Gatherer
Ephemerellidae	
Drunella cornuta Morgan	Scraper
Ephemerella subvaria McDunnough	Gatherer
Eurylophhella prudentalis McDunnough	Gatherer
Heptageniidae	
Epeorus pleuralis Banks	Gatherer
Hetagenia hebe McDunnough	Scraper
Stenonema vicarium Walker	Scraper
Leptophlebiidae	
Habrophlebia vibrans Needham	Gatherer
Leptophlebia cupida Say	Gatherer
Paraleptophlebia spp. McDunnough	Gatherer
Leptophlebiidae	Gatherer
Plecoptera	
Leuctridae	
Leuctra spp. Stephens	Shredder
Nemouridae	
Nemoura macdunnoughi Ricker	Shredder

Perlodidae	
Isoperla transmarina Newman	Predator
Trichoptera	
Hydropsychidae	
Cheumatopsyche pettiti Banks	Filterer
Hydropsyche alternans Walker	Filterer
Hydropsyche betteni Ross	Filterer
Hydropsyche slossonae Banks	Filterer
Hydropsyche sparna Ross	Filterer
Hydropsychidae	Filterer
Philopotamidae	
Chimarra sp. Stephens	Filterer
Dolophilodes distinctus Walker	Filterer
Philopotamidae	Filterer
Polycentropodidae	
Polycentropus spp. Curtis	Predator
Lepidostomatidae	
Lepidostoma spp. Rambur	Shredder
Leptoceridae	
Ceraclea spp. Stephens	Gatherer
Mystacides sepulchralis Walker	Gatherer
Oecetis sp. McLachlan	Predator
Triaenodes injusta Hagen	Shredder
Limnephilidae	
Glyphopsyche irrorata Fabricius	Shredder
Limnephilus spp. Leach	Shredder
Nemotaulius hostilis Hagen	Shredder
Neophylax spp. McLachlan	Scraper
Platycentropus sp. Ulmer	Shredder
Pycnopsyche spp. Banks	Shredder
Limnephilidae	

Molannidae	
Molanna sp. Curtis	Scraper
Odontoceridae	
Psilotreta frontalis Banks	Scraper
Phryganeidae	
Banksiola sp. Martynov	Shredder
Fabria complicata Banks	Shredder
Oligostomis sp. Kolenati	Predator
Glossosomatidae	
Glossosoma sp. Curtis	Scraper
Hydroptilidae	
Hydroptila metoeca Blickle and Morse	Piercer
Oxytheria sp. Eaton	Piercer
Rhyacophilidae	
Rhyacophila carolina Banks	Predator
Rhyacophila fuscula Walker	Predator
Rhyacophila invaria Walker	Predator
Rhyacophila melita Ross	Predator
Rhyacophila nigrita Banks	Predator
Rhyacophila vibox Milne	Predator
Rhyacophila spp. Pictet	Predator

Appendix 5

Table 2. Presence/absence data for EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa collected at 23 lake outlet sites in Bonavista, Random Island, Come-by-Chance and St. John's, NF, during May and and July 1995, and May and July 1996.

May 1995

	Bonavista						Random Island				Come-by-Chance			
	B1	B2	B3	B6	B7	B8	R9	R10	R11	R13	C14	C15	C16	C17
EPHEMEROPTERA														
Leptophlebia cupida	+		+	+	+	+	+	+	+	+	+	+	+	+
Eurylophella prudentalis	+	+	+		+		+		+	+	+	+	+	+
Habrophlebia vibrans			+							+	+	+		+
Baetis tricaudatus	+						+			+				
Stenonema vicarium							+			+	+			
Paraleptophlebia spp.							+			+				+
Baetis spp.			+											+
PLECOPTERA														
Nemoura macdunnoughi	+	+	+	+	+	+	+	+	+	+		+	+	+
Isoperla transmarina	+	+	+							+		+		+
Leuctra spp.	+		+	+				+		+				+
TRICHOPTERA														
Cheumatopsyche pettiti	+	+	+	+	+	+	+	+	+		+	+	+	+
Oxytheria sp.	+	+	+	+	+	+	+	+		+	+	+	+	+
Pycnopsyche spp.	+	+	+	+	+	+		+	+	+	+	+	+	+
Hydropsyche betteni	+	+	+	+		+	+	+	+	+	+	+	+	+

Table 2 continued. Presence-absence data for EPT taxa collected at 23 lake outlet sites.

May 1995

	Bonavista						Random Island				Come-by-Chance			
	B1	B2	B3	B6	B7	B8	R9	R10	R11	R13	C14	C15	C16	C17
Hydroptila metoeca	+	+		+	+	+	+	+		+		+	+	
Lepidostoma spp.			+	+	+		+		+	+		+	+	+
Platycentropus sp.	+	+	+		+		+	+	+		+			
Polycentropus spp.	+		+	+	+	+	+				+	+		
Chimarra sp.			+			+	+	+	+	+				
Hydropsyche slossona		+					+			+			+	+
Mystacides sepulchralis						+			+	+			+	
Hydropsyche alternans							+			+		+		+
Rhyacophila fuscula							+			+				+
Rhyacophila carolina								+				+		+
Ceraclea spp.	+													+
Rhyacophila invaria												+		+
Rhyacophila vibox												+		+
Nemotaulius hostilis						+								
Rhyacophila minora								+						
Triaenodes injusta								+						
Rhyacophila melita										+				
Taxa diversity	14	10	15	10	10	11	17	13	10	20	10	16	11	20

Table 2 continued. Presence-absence data for EPT taxa collected at 23 lake outlet sites.

July 1995

	Bonavista						Random Island				Come-by-Chance			
	B1	B2	B3	B6	B7	B8	R9	R10	R11	R13	C14	C15	C16	C17
EPHEMEROPTERA														
Paraleptophlebia spp.			+		+	+		+	+		+	+	+	
Leptophlebia cupida	+			+			+	+						
Eurylophella prudentalis		+	+				+						+	
Habrophlebia vibrans												+		+
Stenonema vicarium												+		+
Baetis macdunnoughi												+		+
Baetis pygmaeus	+													
Baetis spp.							+							
PLECOPTERA														
Leuctra spp.	+		+	+				+	+	+				
Isoperla transmarina			+											
Unidentified plecoptera							+							
TRICHOPTERA														
Hydropsyche betteni	+	+	+	+		+	+	+	+		+	+	+	+
Cheumatopsyche pettiti	+	+		+		+	+	+	+		+	+	+	+
Oxytheria sp.	+	+		+	+	+	+				+	+	+	+
Chimarra sp.	+		+	+	+	+	+	+		+		+		
Pycnopsyche spp.			+	+	+	+		+	+			+		
Polycentropus spp.	+			+	+		+			+	+			
Hydropsyche alternans						+	+		+			+		+

Table 2 continued. Presence-absence data for EPT taxa collected at 23 lake outlet sites.

July 1995

	Bonavista						Random Island				Come-by-Chance			
	B1	B2	B3	B6	B7	B8	R9	R10	R11	R13	C14	C15	C16	C17
Hydroptila metoeca		+						+				+		+
Limnephilus spp.		+			+			+						
Ceraclea spp.						+						+		+
Nemotaulius hostilis					+			+						
Hydropsyche slossonae										+				+
Lepidostoma spp.	+													
Triaenodes injusta								+						
Rhyacophila carolina										+				
Rhyacophila vibox												+		
Rhyacophila minora														+
Taxa diversity	9	6	7	8	7	8	10	11	6	4	5	13	5	11

Table 2 continued. Presence-absence data for EPT taxa collected at 23 lake outlet sites.

May 1996

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
EPHEMEROPTERA												
Leptophlebia cupida	+	+	+	+	+	+	+	+	+	+	+	+
Eurylophella prudentalis	+	+	+		+		+	+		+	+	
Ephemerella subvaria	+	+			+		+		+	+	+	
Paraleptophlebia spp.							+	+	+	+	+	+
Baetis tricaudatus	+										+	
Baetis pygmaeus	+										+	
Drunella cornuta								+			+	+
Baetis macdunnoughi	+									+	+	
Habrophlebia vibrans			+									+
Stenonema vicarium								+			+	+
Baetis spp.												
Baetis bileneate											+	
Epeorus pleuralis											+	
Heptagenia hebe											+	
Caenis simulans												
PLECOPTERA												
Nemoura macdunnoughi	+	+	+	+	+		+	+		+	+	+
Isoperla transmarina	+		+			+		+		+	+	
Leuctra spp.	+		+	+			+	+	+	+	+	+

Table 2 continued. Presence-absence data for EPT taxa collected at 23 lake outlet sites.

May 1996

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
TRICHOPTERA												
Hydropsyche betteni	+	+	+	+	+	+	+	+	+	+		+
Cheumatopsyche pettiti	+	+	+	+	+	+	+	+	+	+		+
Oxytheria sp.	+	+	+	+	+	+	+	+	+		+	+
Hydropsyche sparna	+	+	+	+	+	+	+	+	+	+	+	+
Pycnopsyche spp.	+	+	+	+	+		+	+	+	+	+	+
Chimarra sp.		+	+	+	+	+	+	+	+		+	+
Lepidostoma spp.		+		+	+	+	+		+	+	+	+
Polycentropus spp.	+	+	+	+	+	+	+	+	+	+	+	+
Hydroptila metoeca	+	+		+	+	+	+	+	+	+		
Nemotaulius hostilis	+	+		+	+	+	+	+		+	+	
Rhyacophila fuscula	+	+						+		+	+	
Limnephilus spp.	+			+					+		+	
Hydropsyche alternans					+		+	+			+	
Hydropsyche slossonae					+			+		+	+	
Mystacides sepulchralis						+			+	+	+	
Platycentropus sp.						+	+	+		+		+
Ceraclea spp.	+			+		+		+	+			
Neophylax spp.									+	+	+	+
Rhyacophila invaria									+			
Rhyacophila vibox												+
Oecetis sp.						+		+			+	
Rhyacophila melita										+	+	

Table 2 continued. Presence-absence data for EPT taxa collected at 23 lake outlet sites.

May 1996

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
Rhyacophila minora									+	+		
Banksiola spp.						+	+					
Dolophilodes distinctus											+	
Molanna spp.									+			+
Rhyacophila carolina									+			
Psilotreta frontalis									+			+
Taxa diversity	20	15	13	15	16	16	19	23	22	23	31	20

Table 2 continued. Presence-absence data for EPT taxa collected at 23 lake outlet sites.

May 1996

	Come-by-Chance						St. John's				
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
EPHEMEROPTERA											
Leptophlebia cupida	+	+	+	+	+	+	+	+	+	+	+
Eurylophella prudentalis	+	+	+								
Ephemerella subvaria				+		+		+		+	
Paraleptophlebia spp.				+							
Baetis tricaudatus						+		+		+	
Baetis pygmaeus		+		+							
Drunella cornuta				+							
Baetis macdunnoughi											
Habrophlebia vibrans				+							
Stenonema vicarium											
Baetis spp.			+								
Baetis bileneate											
Epeorus pleuralis											
Heptagenia hebe											
Caenis simulans									+		
PLECOPTERA											
Nemoura macdunnoughi		+	+		+	+	+			+	
Isoperla transmarina		+	+	+	+	+		+		+	
Leuctra spp.		+									

Table 2 continued. Presence-absence data for EPT taxa collected at 23 lake outlet sites.

May 1996

	Come-by-Chance						St. John's				
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
TRICHOPTERA											
Hydropsyche betteni	+	+	+	+	+	+	+	+	+	+	
Cheumatopsyche pettiti	+	+	+	+	+	+			+	+	
Oxytheria sp.	+	+	+	+	+	+	+		+		
Hydropsyche sparna		+	+	+	+			+		+	
Pycnopsyche spp.			+	+	+		+			+	+
Chimarra sp.		+			+	+		+	+	+	
Lepidostoma spp.		+	+	+	+	+				+	
Polycentropus spp.	+								+		
Hydroptila metoeca		+			+	+			+		
Nemotaulius hostilis					+						
Rhyacophila fuscula				+	+	+		+		+	
Limnephilus spp.			+		+				+	+	+
Hydropsyche alternans			+	+				+		+	
Hydropsyche slossonae			+					+		+	
Mystacides sepulchralis								+	+		+
Platycentropus sp.		+		+							
Ceraclea spp.				+							
Neophylax spp.					+						
Rhyacophila invaria	+	+		+							
Rhyacophila vibox	+	+		+							
Oecetis sp.									+		
Rhyacophila melita				+							

Table 2 continued. Presence-absence data for EPT taxa collected at 23 lake outlet sites.

May 1996

	Come-by-Chance				St. John's						
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
Rhyacophila minora				+							
Banksiola spp.					+						
Dolophilodes distinctus		+		+							
Molanna spp.					+						
Rhyacophila carolina				+							
Psilotreta frontalis											
Taxa diversity	8	17	14	23	17	12	5	11	11	15	4

Table 2 continued. Presence-absence data for EPT taxa collected at 23 lake outlet sites.

July 1996

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
EPHEMEROPTERA												
Paraleptophlebia spp.		+	+			+				+	+	+
Baetis tricaudatus								+			+	
Baetis pygmaeus		+	+				+				+	
Eurylophella prudentalis		+			+	+	+				+	
Leptophlebiidae spp.				+			+		+			
Habrophlebia vibrans											+	
Leptophlebia cupida	+				+			+				
Heptogenia hebe											+	
Baetis macdunnoughi												+
Stenonema vicarium												
Caenis simulans												
PLECOPTERA												
Leuctra spp.	+	+	+	+	+	+	+	+	+	+	+	
Nemoura macdunnoughi											+	
TRICHOPTERA												
Cheumatopsyche pettiti	+	+	+	+	+	+	+	+	+	+		+
Hydropsyche betteni	+	+	+	+	+	+	+	+	+	+		+
Oxytheria spp.	+	+	+	+	+	+		+			+	
Chimarra spp.			+	+	+	+		+	+	+	+	+
Pycnopsyche spp.		+	+	+	+	+	+		+	+	+	+

Table 2 continued. Presence-absence data for EPT taxa collected at 23 lake outlet sites.

	July 1996											
	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
Hydroptila metoeca		+		+	+		+					+
Hydropsyche alternans							+	+			+	+
Ceraclea spp.	+				+	+		+				+
Polycentropus spp.	+	+	+		+		+					
Hydropsyche sparna		+		+			+				+	
Nemotaulius hostilis						+		+				
Limnephilus spp.	+	+							+			
Dolophilodes distinctus						+				+	+	
Lepidostoma spp.						+					+	+
Hydropsyche slossonae							+			+		
Rhyacophila fuscula										+	+	
Oecetis spp.									+		+	
Beothicus complicata	+					+						
Glyphopsyche irrorata				+		+						
Mystacides sepulchralis												
Neophylax spp.			+									
Rhyacophila melita										+		
Glossosoma spp.											+	
Molanna spp.												+
Oligostomis spp.												+
Rhyacophila invaria												+
Rhyacophila nigrita												
Rhyacophila spp.												
Taxa diversity	9	12	10	10	11	14	12	10	8	10	18	13

Table 2 continued. Presence-absence data for EPT taxa collected at 23 lake outlet sites.

	July 1996										
	Come-by-Chance				St. John's						
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
Hydroptila metoeca		+	+			+					
Hydropsyche alternans					+			+	+	+	
Ceraclea spp.		+								+	
Polycentropus spp.		+							+		
Hydropsyche sparna			+							+	
Nemotaulius hostilis		+			+					+	+
Limnephilus spp.			+			+					
Dolophilodes distinctus				+					+		
Lepidostoma spp.									+		
Hydropsyche slossonae								+		+	
Rhyacophila fuscula				+						+	
Oecetis spp.											+
Beothicus complicata											
Glyphopsyche irrorata											
Mystacides sepulchralis								+	+		
Neophylax spp.											
Rhyacophila melita											
Glossosoma spp.											
Molanna spp.											
Oligostomis spp.											
Rhyacophila invaria											
Rhyacophila nigrita		+									
Rhyacophila spp.								+			
Taxa diversity	6	15	9	11	8	7	3	6	8	12	4

Appendix 6

Table 3. Relative abundance of EPT (Ephemeroptera, Plecoptera, and Trichoptera) taxa collected at 23 lake outlet sites in Bonavista, Random Island, Come-by-Chance and St. John's during July 1995, and May and July 1996.

July 1995

	Bonavista						Random Island			Come-by-Chance			
	B1	B2	B3	B6	B7	B8	R9	R10	R11	C14	C15	C16	C17
EPHEMEROPTERA													
Baetis macdunnoughi											35.86		3.42
Baetis pygmaeus	0.76												
Baetis spp.							0.50						
Stenonema vicarium											0.32		0.38
Habrophlebia vibrans											2.69		3.04
Leptophlebia cupida				2.70									
Paraleptophlebia spp.			4.27		0.10	0.14		0.39	3.64	2.94		0.28	
Eurylophella prudentalis												0.28	
PLECOPTERA													
Leuctra spp.	1.34		1.99	1.23				0.21	2.08				
Isoperla transmarina			0.30										
Plecoptera spp.							2.83						
TRICHOPTERA													
Cheumatopsyche pettiti	20.39	10.92		1.96		3.73	27.75	8.45	10.65		0.95	6.20	3.42
Hydropsyche alternans						0.18	2.50		0.65		1.58		0.38
Hydropsyche betteni	11.07	0.57	4.57	32.35		4.13	1.67	1.40	5.06	1.47	5.06	0.85	0.38

Tabl(3 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

July 1995

	Bonavista						Random Island			Come-by-Chance			
	B1	B2	B3	B6	B7	B8	R9	R10	R11	C14	C15	C16	C17
Hydropsyche slossonae													0.38
Hydropsychidae spp.	63.76	88.22	5.40	35.29	3.95	52.97	58.63	66.88	77.92	77.94	45.18	91.83	84.41
Hydroptila metoeca		0.29						0.26			5.37		0.76
Oxytheria sp.	1.93			0.25	2.39	0.83				17.65	2.53	0.56	0.38
Ceraclea spp.						0.04					0.32		0.38
Nemotaulius hostilis								0.05					
Pycnopsyche spp.				1.47		0.04							
Chimarra sp.	0.67		83.43	24.26	93.24	37.94	6.12	22.35			0.16		
Polycentropus spp.	0.08		0.04	0.49	0.31								
Rhyacophila minora													2.66
Total abundance	1192	348	2668	408	962	2762	5755	3844	770	68	633	355	263

Table 3 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

May 1996

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
EPHEMEROPTERA												
Baetis bileneate											5.31	
Baetis macdunnoughi	0.16									3.01	0.36	
Baetis pygmaeus	0.08										4.95	
Baetis tricaudatus	0.08										1.09	
Baetis spp.	0.62											
Epeorus pleuralis												
Heptagenia hebe											0.36	
Stenonema vicarium								0.14			0.12	0.42
Habrophlebia vibrans			1.60									1.26
Leptophlebia cupida	2.26	0.05	1.12	3.06	1.02	0.26	0.30		4.52	0.75		19.25
Paraleptophlebia spp.							0.60	0.07	0.09	30.08	6.76	0.42
Drunella cornuta								1.50			0.85	0.84
Ephemerella subvaria	0.78				0.10		0.30			7.52	0.36	
Eurylophella prudentalis	0.62						0.60				0.12	
Caenis simulans												
PLECOPTERA												
Leuctra spp.	2.11		7.20	0.71			0.89	0.61	0.70	3.76	0.24	
Nemoura macdunnoughi	1.79		0.16	32.27	0.92		5.65	2.25		0.75	0.72	2.09
Isoperla transmarina	2.18		2.24			0.03		1.50		8.27	5.43	

Table 3 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

May 1996

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
TRICHOPTERA												
Cheumatopsyche pettiti	60.69	66.44	7.68	24.15	5.29	20.09	16.37	31.77	60.94	20.30		15.90
Hydropsyche alternans					0.31		1.19	2.86			0.85	
Hydropsyche betteni	16.15	16.68	30.08	27.80	20.04	44.12	62.50	51.87	18.14	3.01		23.43
Hydropsyche slossonae					0.20			1.70		3.01	0.48	
Hydropsyche sparna	8.35	16.31	4.96	6.60	27.06	17.48	10.42	3.61	6.61	5.26	1.09	10.04
Hydroptila metoeca	0.08			0.12	0.31	0.32	0.30	0.34	0.61	2.26		
Oxytheria sp.	2.73	0.43	6.88	0.24	23.19	2.36	0.89	1.30	1.00		1.33	0.84
Lepidostoma spp.						0.23			0.17	0.75		2.93
Ceraclea spp.	0.23			0.35				0.07	0.04			
Mystacides sepulchralis									0.39			
Oecetis sp.											0.48	
Limnephilus spp.												
Nemotaulius hostilis						0.03						
Neophylax spp.									0.83	0.75		8.37
Platycentropus sp.												
Pycnopsyche spp.			0.48	0.12					0.57	0.75	0.12	1.67
Molanna sp.												
Psilotreta frontalis									0.09			
Chimarra sp.		0.03	36.80	3.65	21.46	15.00		0.41	4.57		2.29	12.13

Table 3 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

May 1996

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
Dolophilodes distinctus											64.98	
Banksiola sp.												
Polycentropus spp.	0.94		0.80	0.94	0.10	0.09			0.70	3.01	0.12	
Rhyacophila carolina												
Rhyacophila fuscula	0.16	0.05								5.26	1.45	
Rhyacophila invaria									0.04			
Rhyacophila melita										0.75	0.12	
Rhyacophila minora										0.75		
Rhyacophila nigrita												
Rhyacophila vibox												0.42
Total abundance	1282	3728	625	849	983	3479	336	1467	2299	133	828	239

Table 3 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

May 1996

	Come-by-Chance				St. John's						
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
EPHEMEROPTERA											
Baetis bileneate											
Baetis macdunnoughi											
Baetis pygmaeus		1.40		3.05							
Baetis tricaudatus						0.43		4.55		1.19	
Baetis spp.											
Epeorus pleuralis											
Heptagenia hebe											
Stenonema vicarium											
Habrophlebia vibrans				0.76							
Leptophlebia cupida	9.70	1.65	2.97	2.29	0.14		30.77		3.33		77.27
Paraleptophlebia spp.				3.82							
Drunella cornuta				10.69							
Ephemerella subvaria				0.76		4.27		9.09		1.85	
Eurylophella prudentalis											
Caenis simulans									3.33		
PLECOPTERA											
Leuctra spp.		1.72									
Nemoura macdunnoughi		0.13	0.17		1.38	0.85	5.77			0.40	
Isoperla transmarina		1.40	0.17	4.58	2.49	1.71	0.00	4.55		7.81	

Table 3 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

May 1996

	Come-by-Chance				St. John's						
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
TRICHOPTERA											
Cheumatopsyche pettiti	69.20	23.55	60.31	22.90	36.05	71.79			6.67	4.64	
Hydropsyche alternans			0.17	11.45				18.18		11.52	
Hydropsyche betteni	8.02	29.22	26.92	4.58	54.01	14.96	40.38	9.09	3.33	9.27	
Hydropsyche slossonae			0.35					27.27		25.56	
Hydropsyche sparna		9.93	6.64	6.11	1.93			13.64		4.77	
Hydroptila metoeca		0.57			0.28	0.85			3.33		
Oxytheria sp.	11.81	23.11	0.87	1.53	0.14	2.56	23.08		20.00		
Lepidostoma spp.			1.40		0.14	0.85					
Ceraclea spp.				0.76							
Mystacides sepulchralis									6.67		4.55
Oecetis sp.									3.33		
Limnephilus spp.											
Nemotaulius hostilis					0.14						
Neophylax spp.					0.14						
Platycentropus sp.											
Pycnopsyche spp.					0.41						18.18
Molanna sp.											
Psilotreta frontalis											
Chimarra sp.		6.81			2.62	1.28			3.33	27.68	

Table 3 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

May 1996

	Come-by-Chance				St. John's						
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
Dolophilodes distinctus		0.13		0.76							
Banksiola sp.											
Polycentropus spp.	1.27								46.67		
Rhyacophila carolina				4.58							
Rhyacophila fuscula				14.50	0.14	0.43		13.64		5.30	
Rhyacophila invaria		0.32		1.53							
Rhyacophila melita				2.29							
Rhyacophila minora				2.29							
Rhyacophila nigrita											
Rhyacophila vibox		0.06		0.76							
Total abundance	237	1571	572	131	724	234	52	22	30	755	22

Table 3 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

July 1996

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
EPHEMEROPTERA												
Baetis macdunnoughi												0.48
Baetis pygmaeus		2.56	0.45				0.62				0.76	
Baetis tricaudatus								0.04			6.18	
Hetagenia hebe											0.20	
Stenonema vicarium												
Habrophlebia vibrans												
Leptophlebia cupida								0.07				
Paraleptophlebia spp.		1.28	7.95			0.63				7.61		0.90
Leptophlebiidae spp.	0.67		4.83	0.52	7.07	0.36	0.15	0.29	1.14		0.38	
Eurylophella prudentalis		1.00			0.19	0.18	0.08				0.20	
PLECOPTERA												
Leuctra spp.	1.77	0.28	1.19	1.22	0.12	0.36	0.15	0.55	0.40	16.85	0.59	
Nemoura macdunnoughi											1.93	
TRICOPTERA												
Glossosoma sp.											0.03	
Cheumatopsyche pettiti	86.30	58.18	2.05	27.12	3.35	5.22	4.17	93.02	92.74	23.37		11.40
Hydropsyche alternans							0.08	1.39			1.55	0.48
Hydropsyche betteni	8.36	11.95	4.89	3.98	1.80	17.90	29.71	3.62	1.88	14.67		5.91
Hydropsyche slossonae							0.08			0.54		
Hydropsyche sparna		0.57					3.09				0.59	

Table 3 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

July 1996

	Bonavista							Random Island				
	B1	B2	B3	B6	B7	B8	B18	R9	R10	R11	R13	R19
Hydropsychidae spp.		23.33	8.98	2.62	3.72	52.16	61.50				7.91	
Hydroptila metoeca		0.28		0.05			0.15					0.48
Oxytheria sp.	1.57	0.43	5.85	0.14	15.63	1.26		0.11			0.20	
Lepidostoma spp.						0.09						
Ceralcea spp.					4.59							0.06
Mystacides sepulchralis												
Oecetis sp.									0.40			
Limnephilus spp.									0.40			
Pycnopsyche spp.			0.06	0.05			0.15		0.79	1.09		3.64
Limnephilidae spp.												
Chimarra sp.			63.69	64.31	63.52			0.91	2.27	28.26	21.48	76.18
Dolophilodes distinctus										3.26	56.64	
Philopotamidae spp.						21.85						
Polycentropus spp.	1.34	0.14	0.06				0.08					
Rhyacophila fuscula										0.54	1.35	
Rhyacophila invaria												0.48
Rhyacophila melita										0.54		
Rhyacophila nigrita												
Rhyacophila spp.										3.26		
Total abundance	3444	703	1760	2135	1612	1112	1296	2737	2025	184	3930	1675

Table 3 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

July 1996

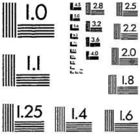
	Come-by-Chance						St. Johns'				
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
EPHEMEROPTERA											
Baetis macdunnoughi											
Baetis pygmaeus		1.60		0.27							
Baetis tricaudatus			0.21	6.23	0.22			37.97		5.67	
Hetagenia hebe											
Stenonema vicarium		0.40									
Habrophlebia vibrans		0.40					0.18				
Leptophlebia cupida											
Paraleptophlebia spp.	2.53	4.00									
Leptophlebiidae spp.	5.06	0.40		0.54					1.93		
Eurylophella prudentalis	2.53										
PLECOPTERA											
Leuctra spp.	3.80	1.20	0.21								
Nemoura macdunnoughi		1.20									
TRICOPTERA											
Glossosoma sp.											
Cheumatopsyche pettiti	2.53	20.40	59.05	5.96	80.22	12.39			53.73	1.54	58.82
Hydropsyche alternans					0.44			2.53		16.38	
Hydropsyche betteni	1.27	6.40	16.05	3.25	6.74	1.16	22.26	4.43		4.13	
Hydropsyche slossonae								0.63		0.88	
Hydropsyche sparna										1.38	

Table 3 continued. Relative abundance of EPT taxa collected at 23 lake outlet sites.

July 1996

	Come-by-Chance							St. Johns'			
	C14	C15	C16	C17	S20	S21	S22	S23	S24	S25	S26
Hydropsychidae spp.	16.46		21.60	76.15		71.61	74.64	53.80	18.77	7.78	
Hydroptila metoeca		20.80	0.21			0.06					
Oxytheria sp.	65.82	19.60	0.62	0.27		0.55	2.92		1.54		
Lepidostoma spp.											
Ceralcea spp.		0.40									
Mystacides sepulchralis									1.03		
Oecetis sp.											5.88
Limnephilus spp.						0.03					
Pycnopsyche spp.											35.29
Limnephilidae spp.			0.21								
Chimarra sp.		22.40	1.85	1.63	12.38	14.19				55.66	
Dolophilodes distinctus				1.36					3.86		
Philopotamidae spp.									18.12		
Polycentropus spp.									1.03		
Rhyacophila fuscula				1.63						0.02	
Rhyacophila invaria											
Rhyacophila melita											
Rhyacophila nigrita		0.80									
Rhyacophila spp.				2.71				0.63		6.55	
Total abundance	79	250	486	369	3620	3100	548	158	778	4409	17

IMAGE EVALUATION
TEST TARGET (QA-3)



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