A BENTHIC INVERTEBRATE MONITORING STUDY ON THE ATHABASCA RIVER, WHITECOURT, ALBERTA, 1991

MARCH 1992

SENTAR

FORMERLY Beak Associates Consulting Ltd.

March 25, 1992
File No.: 09-063-01-01

Mr. Brian Steinback
Alberta Newsprint Company
Postal Bag 9000
Whitecourt, Alberta
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Dear Brian:

Reference: 1991 Benthic Invertebrate Monitoring

SENTAR Consultants Ltd. (SENTAR) is pleased to submit six copies of our final report on the 1991 Benthic Invertebrate Monitoring Study on the Athabasca River. We have reviewed your comments on an earlier draft and have incorporated them in the final report, where appropriate.

We trust the report meets your requirements and fulfills the terms and conditions of Alberta Environment. Should you have any questions or would like to discuss any aspects of the report, please call the undersigned or Maire Luoma at (403) 291-5080.

Sincerely,

SENTAR CONSULTANTS LTD.

Bob Shelast, P.Biol.
Senior Aquatic Biologist

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ANC-BSL2

A BENTHIC INVERTEBRATE MONITORING STUDY ON THE ATHABASCA RIVER, WHITECOURT, ALBERTA 1991

Prepared for

ALBERTA NEWSPRINT COMPANY
WHITECOURT, ALBERTA

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TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

We would like to thank Mr. Brian Steinback of Alberta Newsprint Company for his assistance and cooperation during this study. We wish to thank Mr. Ken Duncan for providing jet boat transportation and Mr. Vern Albush for his assistance during the field surveys. We wish to acknowledge the assistance of Mr. John McCulloch and Mr. Greg Townsend for the sorting of the benthic invertebrate samples, and Mr. Bob Saunders for the identification of the benthic invertebrates.

EXECUTIVE SUMMARY

Alberta Newsprint Company (ANC) operates an integrated chemi-thermomechanical pulp (CTMP) and paper mill near Whitecourt, Alberta. A benthic invertebrate monitoring program is included as part of the environmental program for the mill, as required under the Clean Water Act, by Alberta Environment. Baseline benthic invertebrate monitoring programs were conducted during the spring and fall of 1989 and the spring of 1990 to establish pre-operational conditions in the Athabasca River (Beak 1990, 1991). The pulp and paper mill became operational in August 1990. Water is obtained from the Athabasca River for process use and following treatment, effluent is discharged to the Athabasca River at a rate of about 15,000 m^3/day. During the fall of 1990, a benthic monitoring program was conducted to establish start-up conditions in the Athabasca River (Beak 1991). The objective of the 1991 study was to assess the effects of the pulp and paper mill effluent on the benthic invertebrate community and water quality of the Athabasca River, by determining if there were any differences in benthic invertebrate community structure between sampling sites, by evaluating the general water quality conditions of the Athabasca River as reflected by the benthic invertebrate community structure, and by determining if there were any differences between pre-operational and post-operational conditions in the Athabasca River.

Benthic invertebrate sampling was conducted during the spring between 20 and 22 May, and during the fall between 1 and 3 October 1991, at seven sites, which were established in 1989. Sites 1 and 2 were located upstream of the ANC effluent outfall to provide information on the background benthic community structure of the river. Sites 3, 4 and 5 were located between the effluent outfall and the confluence of the McLeod River with the Athabasca River, as potential impact or recovery sites. Sites 6 and 7 were located approximately 13 and 33 km downstream of the effluent outfall, also as potential impact or recovery sites. These two sites were located downstream of the Millar Western Pulp Ltd. (Millar Western) effluent outfall, and Site 7 was also located downstream of the Whitecourt sewage treatment plant outfall.

Five replicate benthic samples were collected at each site using a modified Neill-Hess cylinder sampler enclosing an area of 0.0892 m^2. All sampling sites were in riffle/run areas and as similar as possible with regard to physical characteristics. Since it is not always possible to completely eliminate site variation, the physical characteristics of water velocity, depth and substrate composition were documented at each sampling location. An estimate of the amount of algal growth on the substrates was made at each site. Water quality sampling, consisting of standard field measurements, was conducted at each benthic site. Water samples were also collected at each site and analyzed by Alpha Laboratory Services Ltd. and Enviro-Test Laboratories of Edmonton for several parameters associated with the treated effluent discharge.

In the laboratory, each benthic sample was subsampled and sorted by the method of Wrona et al. (1982) and enumerated. All organisms were identified to the lowest practical taxonomic level (genus where possible).

The basic computations of total number of taxa, total number of organisms, standing crop (number/m^2) and Shannon-Weaver species diversity were calculated for each benthic sample. A mean standing crop (number/m^2) was also calculated for each major taxonomic group for each site. Statistical analyses were conducted using Analysis of Variance (ANOVA) to determine whether significant differences existed in the numbers of taxa and standing crops between sites during each sampling period. A benthic community analysis was conducted using reciprocal averaging ordination (RA), which groups samples into biological units (clusters) determined by faunal assemblages of highest similarity. A trophic guild (feeding group) analysis was used in conjunction with RA to determine the ecological implications of any noted differences in the benthic community structure between sites. The trophic guild analysis was intended only to provide a general indication of similarities and differences in feeding group structure between sites. A comparison was made between the pre-operational and post-operational surveys, to further assess the effects of pulp mill effluent on the benthic invertebrates.

The physical data indicated that there were some variations in mean water velocity, mean depth and substrate composition between sites and/or seasons. Seasonal differences in both water velocity and depth were the result of changes in the flow regime and water levels between spring and fall. Water velocity and depth differences between sites within a season were the result of hydraulic and other physical habitat differences between reaches of the river. Substrates at all sites consisted mainly of cobbles and pebbles, with a few gravels. In May, pebbles were the dominant substrate at all sites, except Sites 4 and 6 where cobbles were dominant, while in October, cobbles were the dominant substrate at all sites, except Site 1 where pebbles were dominant. No algal growth was obvious in May due to the high flows, which likely caused scouring of the substrate and/or increased water levels which would preclude sampling in areas that were underwater year-round. In

October, a moderate to heavy growth of algae was present at most downstream sites, compared to a light growth at background sites, as well as Site 7. The differences in physical characteristics, other than the presence of algae, did not likely cause any detectable differences in benthic community structure between sites within a season.

The water quality data indicated that the Athabasca River was a well oxygenated, alkaline stream during both the spring and fall surveys. Biochemical oxygen demand (BOD) concentrations in the river were low during both surveys and were not affected by treated effluent discharge from ANC, Miller Western and the Whitecourt sewage treatment plant. BOD concentrations were slightly higher in the spring than in the fall as a result of organic inputs associated with the spring freshet and a rainfall event. Total suspended solids (TSS) concentrations were high in the spring due to high flows and water levels. In the fall, treated effluent discharge from both ANC and Miller Western resulted in slight increases in TSS concentrations at sites immediately below the effluent outfalls. Total phosphorus concentrations were higher than at background sites at Site 6 in May and Site 7 in October, likely as a result of effluent inputs.

Detailed water quality analyses at Sites 2 and 3 indicated that many parameters were below detection limits and/or did not exceed provincial objectives or federal guidelines. In May, concentrations of cadmium, manganese, chromium, iron and silver exceeded guideline levels due to the high suspended sediment load during the spring freshet. Total resin and fatty acids concentrations were below the detection limit of 10 $\mu g/L$, except at Site 3 in May. However, the resin and fatty acids detected at this site were probably the result of glassware contamination since the total resin and fatty acids concentration in the sample exceeded the maximum concentration recorded in pure treated effluent. Chlorinated resin acids from an unknown source were also detected at Site 3. Chlorinated resin acids are produced only when chlorine is used in pulp bleaching. ANC does not use chlorine or chlorine-based compounds in any of its pulping processes. The presence of these chlorinated compounds also suggested sample contamination.

A total of 122 taxa of benthic invertebrates has been identified from the 1989 to 1991 samples collected from the Athabasca River. Of these, 45 taxa were identified from the May 1991 samples and 75 taxa from the October samples.

The mean numbers of taxa and mean standing crops during the May survey were low, probably due to the high flows encountered during the survey. There were no significant differences in the mean numbers of taxa between sites, but there were significant differences in mean standing crops between sites in May. The mean standing crops at all downstream sites were, however, similar to at least one of the background sites. The mean species diversity values in May also reflected the effects of the high flows. Ephemeroptera, Chironomidae and Oligochaeta were the dominant taxonomic groups at all sites during May.

In October, there were significant differences in the mean numbers of taxa and the mean standing crops between sites. The mean numbers of taxa at all downstream sites were similar to or intermediate to the background values, except at Site 7, where it was significantly greater than at background sites. The mean standing crops at all downstream sites were similar to at least one of the background sites, except at Site 4, where it was significantly greater than at background sites. The mean species diversity values at all downstream sites during October were similar to or slightly above background values. Ephemeroptera, Plecoptera and Chironomidae were the dominant taxonomic groups at all sites during October. The increases in mean standing crops at downstream sites during October were likely the result of organic loading from the ANC, the Millar Western and the Whitecourt sewage treatment effluents. Tolerant taxa, mainly Chironomidae, as well as intolerant taxa (Ephemeroptera and Plecoptera), increased in numbers at downstream sites, as a response to the organic enrichment. There were no clear relationships between algal density and the number of taxa and standing crop of benthic invertebrates at sites.

The RA analysis of the May benthic data indicated that most sample sites clustered in one main cluster. A few samples ordinated away from the main cluster. There was a fairly high degree of faunal homogeneity between most samples in May. A number of taxa have been found to respond to organic enrichment, by increasing in numbers, as a response to an increase in food availability, if oxygen is not limiting. The community analysis indicated that the dominant taxa characteristic of sites in May are suited to mild organic enrichment. However, the magnitude of increase of these taxa at downstream sites was small, when compared to mean standing crops found in the spring of previous years. Any potential organic enrichment effects in May may have been masked by substrate scour due to high flows and/or high water levels which caused sampling to be conducted in areas which may not have been underwater year-round.

The RA analysis of the October benthic data indicated that there were three sample clusters. Cluster I consisted of samples from Sites 1 and 5, Cluster II of samples from Sites

3 and 4, and Cluster III of samples from Sites 2, 6 and 7. A higher degree of faunal homogeneity existed within Cluster III than within Clusters I and II. During October, as in previous surveys, the dominant benthic community structure of the background sites indicated the presence of mild organic enrichment, especially at Site 2. The ANC effluent appeared to contribute some additional organic enrichment at downstream Site 4. Some recovery of the system, indicated by a decrease in the standing crop of dominant taxa, appeared to occur at Site 5. However, then the Millar Western and the Whitecourt sewage treatment effluents appeared to contribute further organic enrichment at Sites 6 and 7.

The trophic analysis showed that all sites during both the spring and fall surveys were dominated by detritivore/herbivores and detritivores, which is a common natural trait of most streams in North America. The third dominant group was carnivores in May. All sites in May had similar percent compositions of the dominant feeding groups, with the exception of a slight increase in detritivore/herbivores at Site 5. In October, the third and fourth dominant groups were the herbivores and carnivores, followed by omnivores which occurred mainly at downstream sites. The trophic analysis indicated that similar trends were apparent in the October benthic data, as was found by the RA analysis. Increases in the numbers of certain organisms and shifts in the feeding group structure occurred as a result of the change in the nature of the food supply caused by organic enrichment in the Athabasca River from the pulp mill and sewage effluents.

A general comparison was made of the pre-operational and post-operational surveys. In the spring of 1991, the mean number of taxa, mean standing crop and mean species diversity at most sites were lower than during the spring pre-operational surveys. In general, the benthic community structure of most sites in the spring of 1991 indicated a decrease in the number of dominant taxa present at each site, in comparison to pre-operational surveys. The high flows encountered during the spring 1991 survey likely caused these decreases.

In the fall of 1991, the mean number of taxa at all sites, except background Site 1 and downstream Site 3, was higher than during the 1989 fall pre-operational survey. The mean standing crop in the fall of 1991 at all sites was higher than during the 1989 pre-operational survey, and at all sites, except Sites 3 and 5, it was higher than during startup conditions in 1990. The mean species diversity in the fall of 1991 at all sites (including background sites), except Site 6, was lower than during the 1989 survey. However, the mean species diversity at all sites, except Sites 1 and 2, was higher in 1991 than during startup conditions in 1990. A low species diversity is typically the result of organic enrichment, where a few taxa, which are more suited to organic enrichment, increase in numbers, thus causing an uneven distribution. The dominant benthic community structure of downstream sites during the fall of 1991 was similar to the pre-operational surveys, except that some taxa increased in numbers as a response to organic loading from pulp mill and sewage effluents, causing a change in the sequence of the dominant taxa.

The benthic invertebrates of the Athabasca River at downstream sites responded to mild organic enrichment from the pulp mill and sewage treatment effluents by an increase in the populations of certain tolerant, as well as intolerant taxa. The benthic community structure also shifted to one of increasing proportions of tolerant taxa at downstream sites, which is a typical response to mild organic enrichment. The fall survey indicated some recovery of the system occurred downstream of the ANC mill site and just upstream of the Millar Western mill site.

1.0 INTRODUCTION

Alberta Newsprint Company (ANC) operates an integrated chemi-thermomechanical pulp (CTMP) and paper mill near Whitecourt, Alberta. A benthic invertebrate monitoring program is included as part of the environmental program for the mill, as required under the Clean Water Act, by Alberta Environment. Baseline benthic invertebrate monitoring programs were conducted during the spring and fall of 1989 and the spring of 1990 to establish pre-operational conditions in the Athabasca River (Beak 1990, 1991). The pulp and paper mill became operational in August 1990. Water is obtained from the Athabasca River for process use and following treatment, effluent is discharged to the Athabasca River at a rate of about 15,000 m^3/day. During the fall of 1990, the benthic monitoring program was conducted to establish start-up conditions in the Athabasca River (Beak 1991). The monitoring program was continued in 1991 to assess the effect of pulp and paper mill effluent on the benthic invertebrate community and water quality of the Athabasca River.

Benthic invertebrates are a useful monitoring tool since their community structure can reflect general water quality conditions over time. Benthic invertebrates are good indicators of disturbance primarily because of the long term stability of their populations and because they constitute an easily sampled community which is abundant and diverse enough to be responsive to both gross and subtle environmental changes (Hynes 1960, Gaufin 1973, Kovalak 1981). If the physical characteristics (substrate, water velocity and depth) of the sampling sites are standardized, then the water quality can be used to determine the potential causes for any changes in the benthic community structure.

The objective of the spring and fall 1991 benthic invertebrate monitoring program was to assess the effects of pulp and paper mill effluent on the benthic invertebrate community and water quality of the Athabasca River, specifically:

- to determine if there were any differences in benthic invertebrate community structure between sampling sites,
- to evaluate the general water quality conditions of the Athabasca River as reflected by the benthic invertebrate community structure, and
- to determine if there were any differences between pre-operational and post-operational conditions in the Athabasca River.

2.0 METHODOLOGY

2.1 SITE LOCATIONS

Seven sites which were established in 1989 (Beak 1990) on the Athabasca River were sampled for benthic invertebrates during the 1991 survey (Figure 1). Sites 1 and 2 were located upstream of the effluent outfall as background sites. Sites 3, 4 and 5 were located between the effluent outfall and the confluence of the McLeod River with the Athabasca River, as potential impact or recovery sites. Sites 3 and 4 were located on the north bank and Site 5 on the south bank of the river. Sites 6 and 7 were located approximately 13 and 33 km downstream of the effluent outfall, on the south bank, also as potential impact or recovery sites. These two sites were located downstream of the Millar Western Pulp Ltd. effluent outfall and Site 7 was also located downstream of the Whitecourt sewage treatment plant outfall.

2.2 BENTHIC INVERTEBRATE SAMPLING

Benthic invertebrate sampling was conducted during the spring between 20 and 22 May, and during the fall between 1 and 3 October 1991. Benthic samples were collected using a modified Neill-Hess cylinder sampler with a collecting net of 250 micrometre mesh and enclosing a surface area of 0.0892 m^2. During sampling, the sampler was forced into the substrate to a depth of 5 to 10 cm. Large substrates were removed and scraped into a bucket to ensure that attached organisms were collected. Smaller substrates were agitated in the sampler to the depth of sampler penetration to dislodge all other organisms which were then carried by the stream current into the collecting bottle. Samples consisting of organisms and detritus from the collecting bottle and bucket were concentrated over a 180 micrometre mesh standard sieve, stored in jars, and preserved in 10% formaldehyde for laboratory identification and enumeration. Five replicate samples were taken at each site to ensure that all representative benthic communities were assessed and to provide an acceptable level of confidence on the data (Needham and Usinger 1956, Wilhm and Dorris 1968, Crowther 1979).

2.3 PHYSICAL AND CHEMICAL SAMPLING

All sampling sites were in riffle/run areas and were as similar as possible with regard to water velocity, depth, and substrate composition to reduce inter-site variability. Since it is not always possible to completely eliminate natural site variation, the physical

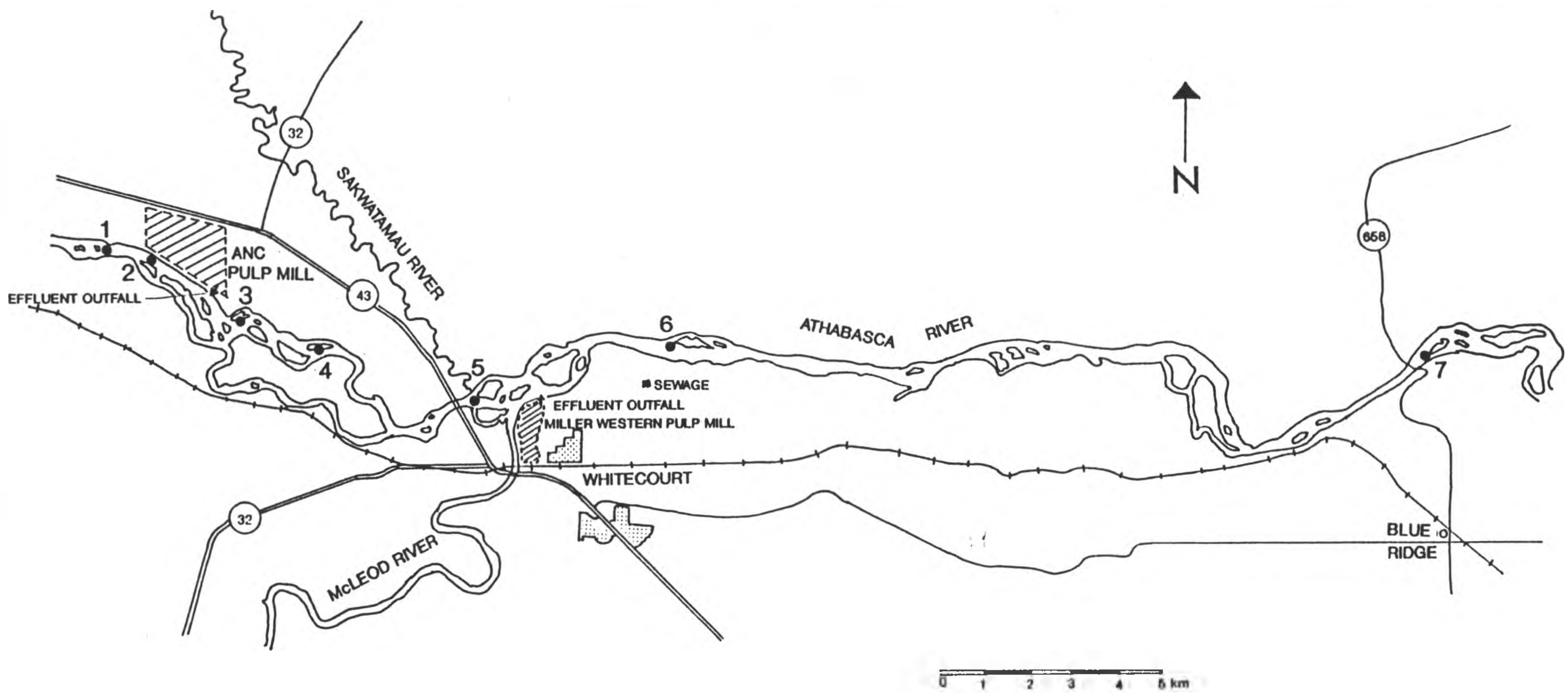

Figure 1. Benthic invertebrate sampling sites on the Athabasca River.

characteristics of each sampling location were documented. Any differences in habitat were then used in interpreting any naturally caused differences in benthic invertebrate distribution patterns and community structure between sites. Substrates at each sample location were classified using a modification of the Wentworth classification system (Cummins 1962). All loose substrates contained within the benthic sampler were removed, put into size categories using standard Tyler geologic screens, and weighed with a portable spring scale. These size category weights were then converted into percentages of the total substrate weight. Water velocity, taken 2 cm from the bottom with a Price AA current meter, and water depth were measured at each sample location. Three water velocity measurements were taken on a three point transect across each sample location, from which an average was then calculated for each sample. All sites were photographed.

An estimate of the amount of algal growth, based on the thickness on the substrate was made at each site. The algal growth was classified into three categories: light (<1 mm thickness), moderate (2 to 5 mm) and heavy (6 to 10 mm). The depth of algal growth was measured for three pebbles or cobbles with three readings for each rock at each site.

Water quality sampling, consisting of field measurements of pH using a pHep Hanna Instruments pH meter (± 0.1 unit), conductivity using a Hach Model 16300 portable conductivity meter (± 10 μmhos/cm), dissolved oxygen using a YSI Model 54A dissolved oxygen meter (± 0.2 ppm), and water temperature using a pocket thermometer (± 0.5 ^{O}C) was conducted at each benthic site. Water samples were also collected at each site, preserved by standard methods, and analyzed by Alpha Laboratory Services Ltd. of Edmonton for true color, total phosphorus, total Kjeldahl nitrogen, total suspended solids, and biochemical oxygen demand using standard methods (APHA-AWWA-WPCF 1985) and approved Alberta Environment methods (Alberta Environment 1987). A more detailed water chemistry analysis was conducted in both May and October for Site 2 (just upstream of the effluent outfall) and Site 3 (just downstream of the effluent outfall). Parameters analyzed for at these sites included total phenols, total organic carbon, total metals and resin acids. These parameters were analyzed using standard methods by Alpha Laboratories Services Ltd., except for resin acids which were analyzed by Enviro-Test Laboratories of Edmonton.

2.4 BENTHIC SAMPLE ANALYSIS

In the laboratory, each benthic sample was sorted either by a whole sort method or the subsampling method of Wrona et al. (1982). Subsampling was used when the samples contained a large portion of a homogeneous mixture and/or extremely large numbers of small benthic organisms which could not be feasibly counted. For subsampling, the benthic sample was initially sieved into coarse (>1 mm) and fine (0.180 to 1 mm) fractions. Organisms remaining in the coarse fraction were sorted and counted independently using a dissecting microscope. The fine fraction of homogeneously sized material was placed into the subsampling apparatus (an Imhoff cone) which was filled to a total volume of 1 L and agitated for five minutes to ensure thorough mixing. Five subsamples were removed from the agitated solution and organisms were sorted and counted using a dissecting microscope. The size of the subsamples varied (40 to 100 mL) for each site depending on the amount of fine material and numbers of organisms present in the samples. The numbers of each taxon occurring in the total fine fraction were then obtained by multiplying the respective counts by the volumetric proportion which the subsamples represented of the total fine fraction. These counts were then added to the counts obtained from the coarse fraction for each taxon. For samples which contained large amounts of algae, the coarse fraction was split into a coarse fraction (> 2 mm) and a mid-coarse fraction (1 to 2 mm). The mid-coarse fraction was then subsampled as described above for the fine fraction.

All organisms were identified to the lowest practical taxonomic level (genus where possible). These organisms were then stored in vials with 70% isopropyl alcohol. Samples of chironomid larvae (midges) were mounted on microscope slides using CMCP-9 mounting medium and identified to genus by mouth parts using a compound microscope. The commonest chironomid species were distinguishable on the basis of gross morphology, requiring only a few mounts (5 to 10) as checks, while mounts were made for all rare or less commonly occurring species. All taxa were identified using the keys from the following references:

General:	Clifford (1991), Merritt and Cummins (1984), Pennak (1978), Brooks and Kelton (1967), Usinger (1956)
Plecoptera:	Baumann et al. (1977), Stewart and Stark (1988)
Trichoptera:	Wiggins (1977)
Ephemeroptera:	Edmunds et al. (1976)

Diptera (Chironomidae):	Bode (1983), Oliver and Roussel (1983), Wiederholm (1983), Wiederholm (1986)
Diptera (others):	McAlpine et al. (1981)

2.5 DATA AND STATISTICAL ANALYSES

Benthic invertebrate community structure is known to differ between seasons which is caused by the reduction and/or addition of numbers and species of organisms through emergence and recruitment (Hynes 1972). When analyzing data from a benthic monitoring survey to detect water quality changes and resulting biological effects, it is essential to deal with comparable seasonal data sets. The basic computations, statistical analyses and reciprocal averaging ordination (RA) were therefore conducted separately for each data set (May and October).

All new taxa identified from the 1991 samples were added to the 1990 species list (Beak 1991). The basic computations of total number of taxa, total number of organisms, standing crop (number/m^2) and Shannon-Weaver species diversity were calculated for each benthic sample and means were calculated for each site. Confidence limits for all means were calculated at the 95% level. Species diversity (Shannon and Weaver 1949), which reflects both the number of taxa and the evenness of distribution of the individuals among the taxa, was calculated as follows:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

where "s" is the number of species, "p_i" is the proportion of the total number of individuals consisting of the ith species, and "ln" is the natural logarithm. A mean standing crop (number/m^2) of each major taxonomic group was also calculated for each site.

The initial basic computations were conducted on an IBM-PC compatible personal computer. The percent contribution of each taxon of the total numbers per sample was also calculated and these data set up in the Fortran format for input into RA (described below). All data were then transferred to the University of Calgary Honeywell Multics system for all other computer analyses. All input data were archived on a floppy disk.

Statistical analyses were conducted using one-way analysis of variance (ANOVA) to determine whether numbers of taxa and standing crops were significantly different between sites during May and October. A posteriori testing, using the Student-Newman-Keuls (SNK) procedure was then conducted for each ANOVA to determine which site means differed significantly (Sokal and Rohlf 1969).

Benthic invertebrate data are generally not normally distributed and rarely satisfy the basic assumptions of parametric statistics. However, violations of these assumptions, especially normality, do not necessarily invalidate the statistical test, since tests such as ANOVA are extremely robust (Glass et al. 1972, Green 1979). A robust statistical test preserves the validity of the probability statements applied to it, even though the assumptions upon which it is based are violated. Therefore, ANOVA will generally be valid, even on extremely non-normal populations, especially when there is equal and large sample sizes (Glass et al. 1972, Harris 1975, Green 1979).

The benthic data were also analyzed by RA, a pattern recognition technique (Hill 1973, Gauch et al. 1977) to determine the benthic invertebrate community structure of sites. RA will make use of the natural variability of benthic data, rather than try to impose uniformity on them. This technique utilizes sample by sample data, treating each individually such that the analysis is completed without the loss of any original biological information.

RA is a computer-assisted analysis technique which ordinates (aligns) sites on species by the method of successive approximation across environmental gradients (Hill 1973, Gauch et al. 1977). RA ranks species on a scale of 0 to 100 (ordination units) to approximate their positions along a species gradient. Site scores are produced by averaging the species scores which occur at each site. Species scores are recalculated from the initial site scores by averaging the scores of the sites which contain the species. This process is repeated for a maximum of 100 iterations or until site and species scores are stabilized. The result of this analysis is to group samples into biological units (clusters) determined by faunal assemblages of highest similarity.

RA can be used to relate changes in the physical and chemical environment to changes in the biotic community (Culp 1978, Crowther 1979, Culp and Davies 1980, Crowther and Luoma 1985). The separation and/or clustering of benthic communities indicated by RA is generally along the most significant environmental gradients. These environmental gradients are then used to interpret whether natural habitat differences or differences in water quality are causing the observed patterns in benthic community structure between sampling sites.

A trophic guild (feeding group) analysis was used in conjunction with RA to determine the ecological implications of any noted differences in the benthic community structure between sites. Each taxon was classified into a feeding group of either carnivore, detritivore, herbivore, detritivore/herbivore, herbivore/carnivore, carnivore/detritivore, or omnivore. This trophic classification depends on the dominant food consumed and/or feeding mechanisms of the species (Table 1) (modified from Merritt and Cummins 1984). The feeding group assigned to each taxon was determined from Merritt and Cummins (1984) for the insects and from the available literature (listed in Section 2.4) for all other organisms. The percent contribution of each feeding group of the total numbers per sample and site was calculated to determine any differences in benthic community feeding structure between sites. These differences were then compared to the separation of sites indicated by RA. The limited available literature and research to date does not allow the trophic guild analysis to be accurate at the species level or to take into account that organisms may change their feeding habits during their life history. The trophic guild analysis is intended only to provide a general indication of similarities and differences in feeding group structure between sites.

A comparison was made between the pre-operational and post-operational surveys, to further assess the effects of pulp and paper mill effluent on the benthic invertebrates of the Athabasca River. The mean number of taxa, mean standing crop, mean species diversity and the dominant taxa present at each site were compared to determine general trends between years.

Table 1. **Trophic classification of benthic invertebrates (modified from Merritt and Cummins 1984).**

Functional Feeding Group	Dominant Food	Feeding Mechanism
Carnivore (C)	Living animal tissue	Engulfers - whole animals or parts Piercers - attack prey and pierce tissues and cells and suck fluids
Detritivore (D)	Decomposing fine particulate organic matter	Collectors - filterers or suspension feeders-gatherers or deposit (sediment) feeders (includes surface film feeders)
	Decomposing coarse particulate organic matter or vascular plant tissue	Shredders - chewers and wood borers
Herbivore (H)	Living vascular hydrophyte plant tissue	Shredders - chewers and miners
	Periphyton - attached algae and associated material	Scrapers - grazing scrapers of mineral and organic surfaces
	Living vascular hydrophyte cell and tissue fluids or filamentous (macroscopic) algal cell fluids	Piercers - pierce tissues or cells and suck fluids
Detritivore/Herbivore (DH)	See above	See above
Herbivore/Carnivore (HC)	See above	See above
Carnivore/Detritivore (CD)	See above	See above
Omnivore (O)	All types - whatever is available	Various types

3.0 RESULTS AND DISCUSSION

3.1 PHYSICAL CHARACTERISTICS

River flow conditions and the physical characteristics of sites can influence the water and habitat quality of the river and therefore, the benthic invertebrate community. Mean daily discharge recorded for the Athabasca River near Windfall (Station No. 07AE001) during the 1989, 1990 and 1991 sampling surveys (Water Survey of Canada, unpublished data) ranged as follows:

	Spring Survey	Fall Survey
1989	367 - 429 m^3/s	234 - 258 m^3/s
1990	175 - 180 m^3/s	139 - 155 m^3/s
1991	? - 870 m^3/s	191 - 215 m^3/s

Recent historical mean daily discharge between 1980 and 1988 ranged from 84 to 1,250 m^3/s during May and from 74 to 361 m^3/s during October (Environment Canada 1981-1989).

The 1991 spring survey was conducted during much higher flows than in previous years. At the time of the scheduled spring field trip, the mean daily discharge in the Athabasca River near Windfall increased from an average of 264 m^3/s during the first week of May to a high of 647 m^3/s on 14 May, due to heavy precipitation in the area. The field trip was, therefore, delayed. The mean daily discharge then decreased to 493 m^3/s on 17 May, at which time the gauging station at Windfall malfunctioned for four days. Based on the assumption that the flows would continue to decrease, the field survey was re-scheduled for 20 to 22 May. However, during the sampling survey the flows in the Athabasca River increased again. The Windfall gauging station indicated a mean daily discharge of 870 m^3/s on 22 May.

The fall survey was conducted during flows typical for that time of year. In October, flows varied slightly between sampling years as a result of climatic conditions in the watershed.

The physical characteristics of water velocity, water depth and substrate composition were kept as similar as field conditions allowed between sample locations within a site, as well as between sites (Appendix A). There was some variation in mean water velocity between sites and seasons (Figure 2). In May, mean water velocity at the substrate surface between sites ranged from 53 to 71 cm/s, while in October, mean water velocity was less ranging from 33 to 65 cm/s. There was only a slight variation in mean water depth between sites, while there was a greater variation between seasons (Figure 2). In May, mean water depth between sites ranged from 43 to 47 cm, while in October, mean water depth was less ranging from 34 to 36 cm. Seasonal differences in both water velocity and depth were the result of changes in the flow regime and water levels between spring and fall. The greater water depths in May were the result of sampling in as deep water as possible to try to sample in areas which would have an established benthic community. Water velocity and depth differences between sites within a season were the result of hydraulic and other physical habitat differences between reaches of the river.

Substrates at all sites consisted mainly of cobbles and pebbles, with a few gravels (Figure 3). In May, pebbles were the dominant substrate at all sites, except Sites 4 and 6, where cobbles were dominant. Pebbles comprised between 61.5 and 71.3 % of the substrate at sites where they were dominant, while cobbles comprised between 28.7 and 38.5 % of the substrate composition. At Sites 4 and 6, the cobbles consisted of 60.3 and 61.7 % and pebbles of 37.9 and 38.1 % of the substrate composition, respectively. In October, cobbles were the dominant substrate at all sites, except Site 1 where pebbles were dominant. Cobbles comprised between 50.9 and 70.6 % of the substrate at sites where they were dominant, while pebbles comprised between 28.2 and 49.1 % of the substrate composition. At Site 1, pebbles comprised 56.0 % and cobbles 44.0 % of the substrate composition. Gravels comprised less than 3 % of the substrate composition during both May and October.

The seasonal difference in substrate was due to differences in sampling locations within a site during each season. In spring, when water levels were higher, samples were taken nearshore where the dominant substrate was pebbles. In the fall, when water levels had receded, samples were taken closer to mid-channel. This area of the river is subject to greater velocities during peak flows than nearshore areas. The resulting scour would tend to reduce the amount of smaller substrates found in mid-channel areas.

An estimate of the amount of algae found growing on the substrates indicated that no algal growth was obvious in May. The high flows encountered during the spring survey likely caused scouring of the substrate and therefore, a loss of the algal growth. Additionally, increased flows and the associated increase in water levels and depth would preclude

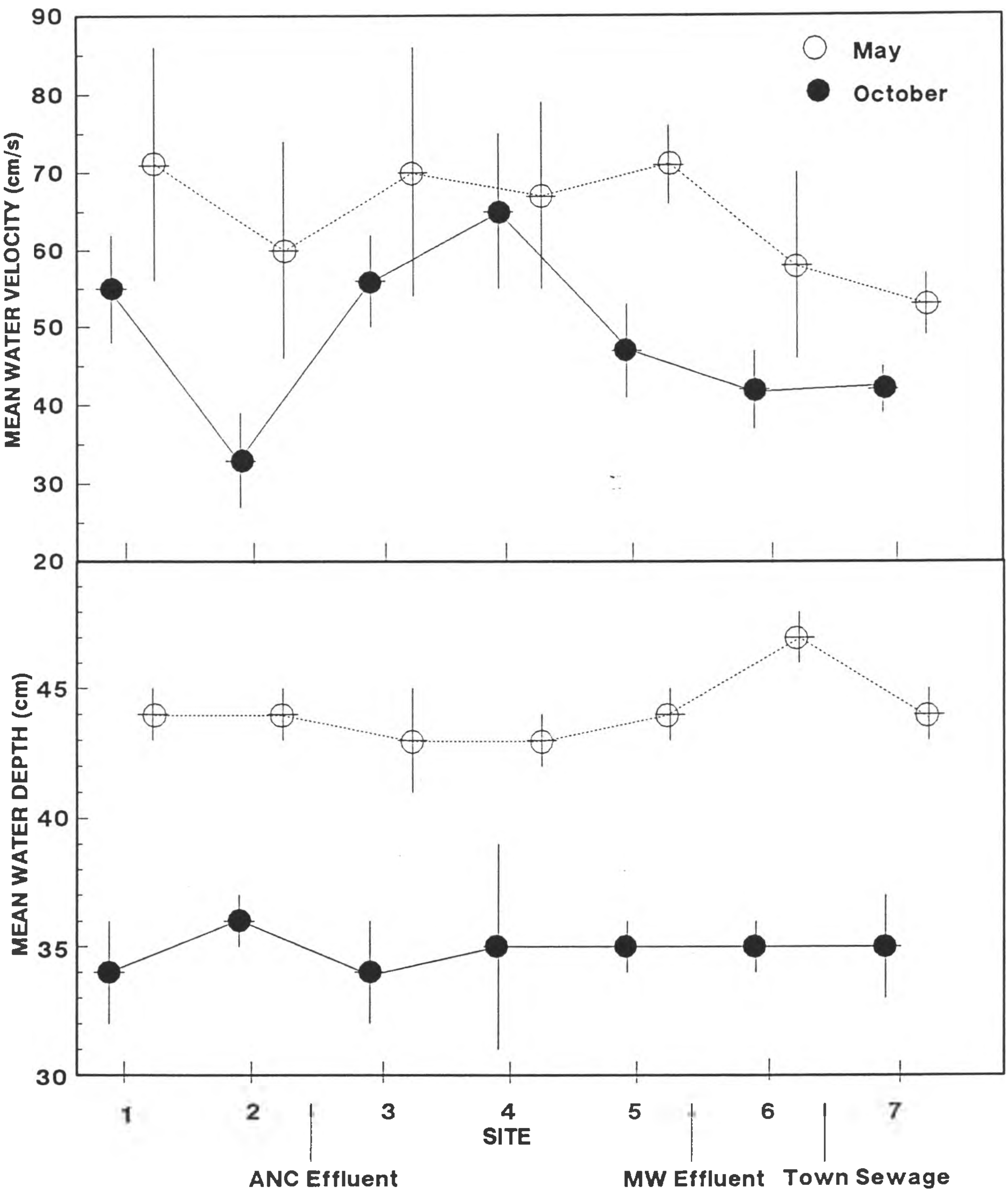

Figure 2. Mean water velocity and water depth with 95% confidence limits for sites on the Athabasca River, May and October 1991.

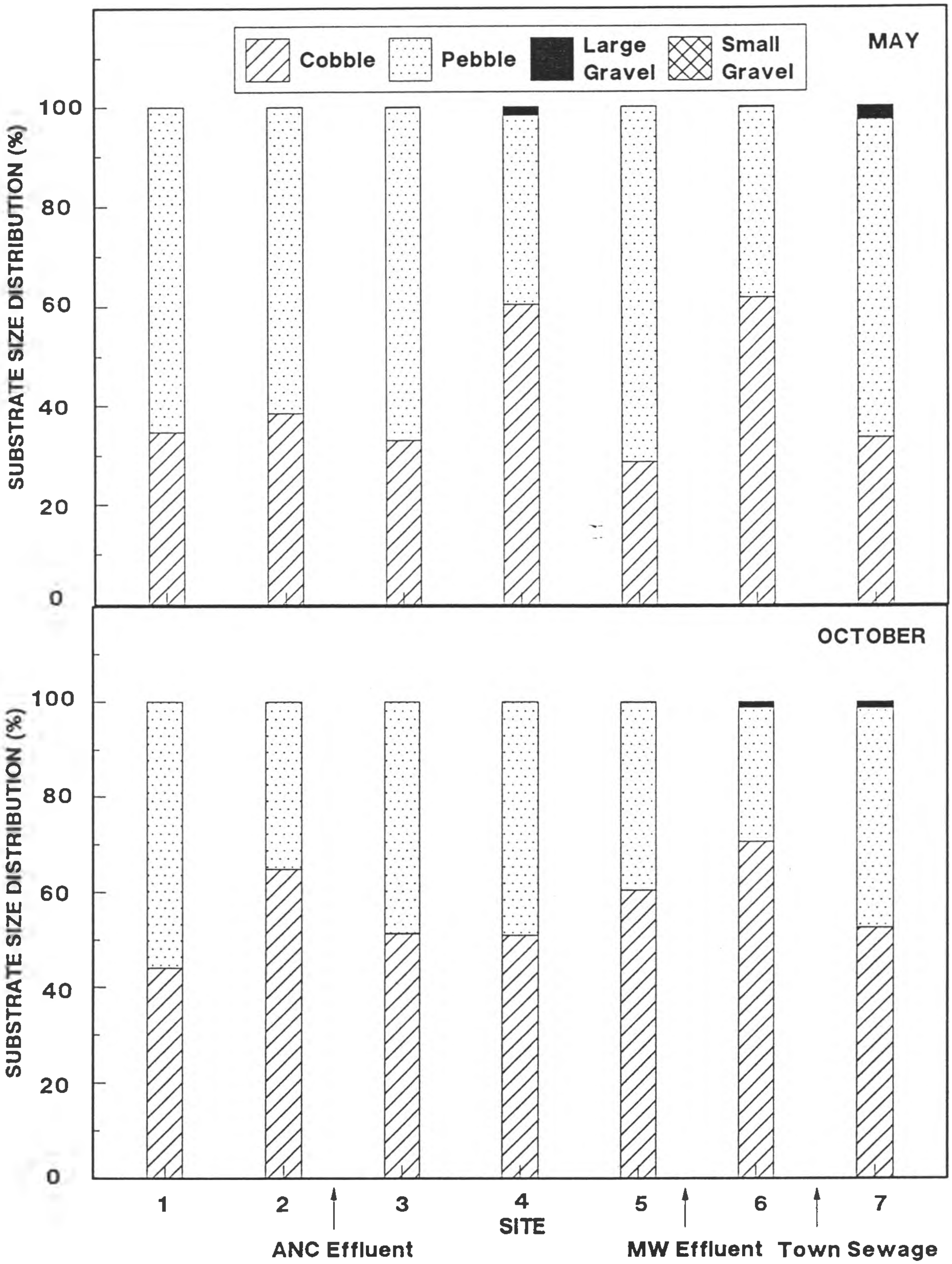

Figure 3. Mean percent of substrate size distribution (by weight) for sites on the Athabasca River, May and October 1991.

sampling in areas that were underwater year-round. Because the sample sites were only recently inundated with water, the absence of algal growth would be expected. In October, a light growth of algae was found on the substrates at Sites 1, 2 and 7, a moderate growth of algae at Sites 4 and 6, and a heavy growth of algae at Sites 3 and 5 (Appendix A-5).

The differences in physical characteristics, particularly water velocity and depth, did likely have an effect of benthic invertebrate standing crop and community structure between seasons. However, differences in physical characteristics, other than the presence of algae, did not likely cause any detectable differences in benthic community structure between sites within a season. Any habitat differences between sites within a season were, however, considered in the interpretation of the benthic invertebrate results.

3.2 WATER QUALITY

The results of the field and laboratory water quality analyses for the May and October 1991 surveys for all sites are presented in Tables 2 and 3. These data were based on single grab samples taken at each site and provide a description of water quality only at the time of sampling. ANC final treated effluent quality data for spring (March, April, May and fall (August, September, October) 1991 are shown in Table 4. Mean daily treated effluent discharge to the river ranged from 13,122 to 15,371 m^3/d in spring and 15,185 to 18,889 m^3/d in the fall. A summary of Millar Western effluent quality data is presented in Appendix B.

The pH values recorded during the surveys ranged from 8.1 to 8.3 in May and 8.5 and 8.7 in October. The difference in pH values between seasons was probably a reflection of differences in primary productivity. During periods of increased primary productivity and photosynthetic activity, pH values in natural waters tend to increase (Cole 1975, Wetzel 1975). Maximum primary productivity generally occurs in early spring. However, with the advent of the spring freshet, scour and decreased light penetration due to increased suspended sediment concentrations reduce the algal population, hence primary productivity. Water samples and field measurements were taken during the May survey at the onset of the spring freshet when both flows and suspended sediment concentrations were high. The pH values recorded at both background and downstream sites during the May survey were within both the Alberta Surface Water Quality Objective (ASWQO) of 6.5 to 8.5 and the Canadian Water Quality Guideline (CWQG) of 6.5 to 9.0 (Alberta Environment 1977, CCREM 1987). During the October survey, pH values at Sites 3 to 7

Table 2. Water quality results of samples collected from the Athabasca River, May and October 1991.

	SITE															
	1		2		3		4		5		6		7			
Parameter	21 May	3 Oct	21 May	3 Oct	21 May	3 Oct	21 May	3 Oct	20 May	2 Oct	22 May	2 Oct	22 May	1 Oct	ASWQO	CWQG
pH (units)*	8.1	8.5	8.2	8.5	8.2	8.6	8.3	8.6	8.3	8.6	8.2	8.7	8.2	8.6	6.5 - 8.5	6.5 - 9.0
Conductivity (μmhos/cm)*	260	300	260	300	260	300	260	300	280	300	230	310	240	310	-	-
Dissolved Oxygen (ppm)*	9.9	11.6	9.8	11.2	9.8	11.2	9.6	11.2	9.2	11.1	10.0	11.3	9.9	10.8	5.0	5.0 - 9.5
DO (percent saturation)*	101	105	98	101	98	104	96	104	101	103	98	105	97	103	-	-
Temperature (^{o}C)*	12.5	7.0	12.0	7.0	12.0	8.0	12.0	8.0	14.5	8.0	11.0	8.0	11.0	9.5	Increase of 3^{o}C	-
Biochemical Oxygen Demand (mg/L)	2	<1	2	1	2	1	2	1	2	<1	3	<1	3	<1	-	-
True Color (units)	40.0	15	32.5	10	37.5	15	37.5	10	25.0	15	35.0	15	42.5	15	Increase of 30 units	-
Total Suspended Solids (mg/L)	420	3	528	1	502	6	500	<1	160	<1	556	5	576	<1	Increase of 10 mg/L	Increase of 10 mg/L
Total Phosphorus (mg/L as P)	0.04	0.02	0.01	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.07	0.02	0.02	0.05	0.15	-
Total Kjeldahl Nitrogen (mg/L as N)	0.6	<0.1	0.7	<0.1	0.6	<0.1	0.8	<0.1	0.4	<0.1	0.7	<0.1	0.6	<0.1	1.0	-

* Measured in the field.
ASWQO Alberta Surface Water Quality Objectives (Alberta Environment 1977)
CWQG Canadian Water Quality Guidelines for Freshwater Aquatic Life (CCREM 1987)

Table 3. **Water quality results for selected parameters of samples collected at Sites 2 and 3 on the Athabasca River, May and October 1991. All values in mg/L unless otherwise stated.**

Parameter	Site 2 21 May	Site 2 3 Oct	Site 3 21 May	Site 3 3 Oct	ASWQO	CWQG
Total Phenols	0.002	<0.001	0.001	<0.001	0.005	0.001
Total Organic Carbon	4	3	4	3	-	-
Total Cadmium	<0.001	<0.001	<0.001	<0.001	0.01	0.0018*
Total Copper	0.007	0.002	0.007	0.002	0.02	0.006*
Total Nickel	0.009	<0.001	0.006	<0.001	-	0.15*
Total Lead	0.003	0.001	0.002	0.002	0.005	0.007*
Total Arsenic	<0.001	0.001	0.002	0.001	0.01	0.05
Total Mercury	<0.0005	<0.0005	<0.0005	<0.0005	0.0001	0.0001
Total Manganese	0.29	<0.5	0.31	<0.5	0.05	-
Total Cobalt	0.010	0.001	0.010	0.001	-	-
Total Chromium	0.011	0.002	0.010	0.002	0.05	0.002
Total Iron	5.3	0.08	5.4	0.08	0.30	0.30
Total Selenium	<0.001	<0.001	<0.001	<0.001	0.01	0.001
Total Silver	0.002	<0.001	0.002	<0.001	0.05	0.0001
Total Vanadium	0.025	0.010	0.024	0.006	-	-
Total Molybdenum	0.008	0.008	0.007	0.006	-	-
Total Resin and Fatty Acids (μg/L)					100	-
Oleic Acid	ND	ND	ND	ND	-	-
Linoleic Acid	ND	ND	40	ND	-	-
Pimaric Acid	ND	ND	12	ND	-	-
Sandaracopimaric Acid	ND	ND	14	ND	-	-
Palustric/Levopimaric Acid	ND	ND	ND	ND	-	-
Isopimaric Acid	ND	ND	ND	ND	-	-
Dehydroabietic Acid	ND	ND	37	ND	-	-
Abietic Acid	ND	ND	38	ND	-	-
Neoabietic Acid	ND	ND	26	ND	-	-
12-Chlorodehydroabietic Acid	ND	ND	17	ND	-	-
14-Chlorodehydroabietic Acid	ND	ND	15	ND	-	-
Dichlorodehydroabietic Acid	ND	ND	27	ND	-	-
Surrogate						
O-Methylpodocarpic Acid (%)	81	-	101	66	-	-
Tricosanoic Acid (I.S. #2) (%)	80	-	100	63	-	-

* At hardness > 180 mg/L ($CaCO_3$)

ASWQO Alberta Surface Water Quality Objectives (Alberta Environment 1977)

CWQG Canadian Water Quality Guidelines for Freshwater Aquatic Life (CCREM 1987)

ND Not Detected. Detection limit 10 μg/L in May and 0.63 μg/L in October for all target compounds.

Table 4. Average monthly concentrations of selected parameters for ANC final treated effluent, spring (March - May) and fall (August - October) 1991.

	Spring			Fall		
Parameter*	March	April	May	August	September	October
Discharge (m^3/d)	15,371	13,122	13,717	18,889	15,185	16,471
pH (units)	7.5	7.6	7.5	7.8	7.6	7.7
Dissolved Oxygen (mg/L)	7.6	7.7	7.6	6.6	6.5	7.6
Dissolved Oxygen (percent saturation)	99	101	104	96	89	100
Temperature (°C)	24.1	24.8	26.8	31.0	27.5	25.0
Biochemical Oxygen Demand (mg/L)	9	6	5	4	8	4
True Color (units)	189	146	153	151	162	196
Total Suspended Solids (mg/L)	11	12	8	24	34	6
Total Phosphorus (as P) (mg/L)	8.59	8.92	9.95	5.45	7.05	7.44
Total Kjeldahl Nitrogen (mg/L)	2.49	1.54	2.20	1.13	2.21	2.71
Total Phenols (mg/L)	0.100	0.020	0.027	0.050	0.023	0.068
Total Resin and Fatty Acids (μg/L)						
Oleic Acid	ND	ND	ND	38**	ND	ND
Linoleic Acid	ND	-	-	15	ND	ND
Pimaric Acid	ND	ND	ND	ND	ND	ND
Sandaracopimaric Acid	ND	ND	ND	ND	ND	ND
Palustric Acid	ND	ND	ND	ND	ND	ND
Levopimaric Acid	ND	ND	ND	ND	ND	ND

(continued)

Table 4. **(concluded)**

Parameter*	Spring			Fall		
	March	April	May	August	September	October
Isopimaric Acid	ND	ND	ND	ND	ND	ND
Dehydroabietic Acid	ND	ND	ND	ND	ND	ND
Abietic Acid	ND	ND	ND	ND	ND	ND
Neoabietic Acid	ND	ND	ND	ND	ND	ND

Source: Alberta Newsprint Company (unpublished data)

* All monthly averages were based on daily values, except for total phosphorus and total Kjeldahl nitrogen, which were weekly values, and total phenols and total resin and fatty acids which were monthly values.

** Oleic and linolenic combined result.

ND Not detected. Detection limit 10 $\mu g/L$.

slightly exceeded the ASWQO, but were within the CWQG. In the spring, the average monthly pH value of the ANC treated effluent ranged from 7.5 to 7.6, while in the fall, treated effluent pH ranged from 7.6 to 7.8. The pH of Millar Western's treated effluent was consistent during both spring and fall and ranged from 8.3 to 8.4. Effluent discharge from both ANC and Millar Western, however, did not affect pH values at any downstream sites.

Conductivity values varied seasonally and ranged from 230 to 280 μmhos/cm and 300 to 310 μmhos/cm during May and October, respectively. Conductivity values recorded in both May and October were not affected by discharge of treated effluent from ANC.

Dissolved oxygen concentrations during May ranged from 9.2 to 10.0 ppm, which represents 96 to 101% saturation. Dissolved oxygen concentrations were below background levels at Sites 4 and 5 during the May survey. However, a more appropriate comparison would be in saturation levels, since the solubility of oxygen in water is temperature dependent and there were water temperature differences between sites during field measurements for dissolved oxygen. When saturation levels are compared, only Site 4 was below background levels and the decrease between sites (98% cf. 96%) is considered marginal. In October, dissolved oxygen concentrations ranged from 10.8 to 11.6 ppm, which represents 101 to 105% saturation. Although dissolved oxygen concentrations were below background levels at two sites (Sites 5 and 7), saturation levels exceeded background values at all sites downstream of ANC. ANC treated effluent quality data indicated that in spring, monthly average dissolved oxygen concentrations ranged from 7.6 to 7.7 ppm and saturation levels from 99 to 104%. In the fall, dissolved oxygen concentrations and saturation levels of the treated effluent ranged from 6.5 to 7.6 ppm and 89 to 100%, respectively.

Biochemical oxygen demand (BOD), a measure of the amount of oxygen required to oxidize organic matter in water, exhibited little variation between sites and ranged from 2 to 3 mg/L in May and <1 to 1 mg/L in October. The slightly higher values during the spring survey were probably the result of organic inputs associated with the spring freshet. The average monthly BOD concentration in the ANC treated effluent ranged from 5 to 9 mg/L in the spring and 4 to 8 mg/L in the fall. Although these values were above background levels in the river, dissolved oxygen concentrations, as discussed previously, were not affected by these BOD inputs.

True color values recorded during the May survey ranged from 25.0 to 42.5 units, with the maximum value recorded at Site 7, the lowermost downstream site. In October, true color ranged from 10 to 15 units, with no discernible difference in values between background sites and sites downstream of the ANC effluent outfall. The monthly average true color value recorded for the ANC treated effluent ranged from 146 to 189 units in the spring and 151 to 196 units in the fall.

Total suspended solids concentrations exhibited extensive seasonal variations and in the spring, temporal variation due to differences in flows during the time of sampling. In May, total suspended solids concentrations were high, ranging from 420 to 576 mg/L at all sites, except Site 5. At this site, an anomalous value of 160 mg/L was recorded. As explained in Section 3.1, flow data for the Athabasca River at Windfall was not available for 20 May, the day sampling was conducted at Site 5. However, field observations indicated that flows in the river increased dramatically between the 20 and 22 May. This increase in flows and water levels resulted in an increase in the amount of suspended matter in the river due to erosion and substrate scouring. Maximum suspended solids concentrations were recorded at Sites 6 and 7; however, these higher values were associated with increased flows between sampling days rather than the results of any effluent discharges. In the spring, total suspended solids concentrations in ANC treated effluent ranged from 298 to 364 mg/L which is below the values recorded at the background sites during the May survey. Total suspended solids concentrations in October ranged from < 1 to 6 mg/L, with maximum values recorded at Site 3, 0.5 km below ANC's effluent outfall and at Site 6, 1 km below Millar Western's effluent outfall. Total suspended solids concentrations in ANC's final treated effluent averaged 6 mg/L in October, while Millar Western's treated effluent averaged 213 mg/L. Treated effluent discharge from both ANC and Millar Western were probably responsible for the slight increase in suspended solids concentrations above background levels in October.

Total phosphorus (as P) concentrations ranged from 0.01 to 0.07 mg/L in May and 0.02 to 0.05 mg/L in October. In May, the maximum total phosphorus concentration of 0.07 mg/L was recorded at Site 6 and exceeded the ASWQO of 0.05 mg/L total phosphorus. In October the maximum total phosphorus concentration was recorded at Site 7, with a concentration of 0.05 mg/L, which meets the ASWQO. The average total phosphorus concentration in the ANC treated effluent during May and October was 9.95 and 7.44 mg/L, respectively. As noted in Section 3.1, the amount of algae at sites downstream of the outfall has increased compared to the background sites, probably due to phosphorus inputs from the ANC effluent discharge, as well as inputs from the Millar Western mill and the Whitecourt sewage treatment plant. Phosphorus is generally regarded as the nutrient that limits productivity in freshwater ecosystems (Wetzel 1975). Since the 1990 survey (Beak 1991), mass loading of total phosphorus in the ANC treated effluent has been reduced by 50 to 75%, despite a 25% increase in mill production rate as compared to October 1990.

Total Kjeldahl nitrogen (TKN) concentrations in May ranged from 0.4 to 0.8 mg/L with little variation between background and downstream sites. In October, all TKN values were below the detection limit of 0.1 mg/L. The average monthly concentration of TKN in the ANC treated effluent in the spring ranged from 1.54 to 2.49 mg/L and 1.13 to 2.71 mg/L in the fall. However, it did not appear that effluent discharge had any significant affect on TKN concentrations in the Athabasca River. All TKN values recorded during both surveys were below the ASWQO of 1.0 mg/L.

The detailed water quality results for Sites 2 and 3 in May and October are presented in Table 3. Total phenol concentrations in May were 0.002 and 0.001 mg/L at Sites 2 and 3, respectively, while in October, concentrations at both sites were below the detection limit of 0.001 mg/L. In the spring, phenol concentrations in ANC's treated effluent ranged from 0.020 to 0.100 mg/L, while in the fall, concentrations ranged from 0.023 to 0.068 mg/L. Effluent discharge did not appear to affect total phenol concentrations in the Athabasca River. Phenolic compounds can occur naturally in the aquatic environment as decomposition products of aquatic plants and decaying vegetation (CCREM 1987). The total phenol values recorded during May and October at both sites were below the ASWQO of 0.005 mg/L, but were the same as, or exceeded the CWQG of 0.001 mg/L in May.

Total organic carbon concentrations showed little variation between sites and seasons. A total organic carbon value of 4 mg/L was recorded at Sites 2 and 3 in May and 3 mg/L at both sites in October.

Metal concentrations were substantially higher during the May survey than in October, primarily as a result of the high suspended sediment load during the spring. Metals such as copper, manganese and iron exhibit a strong affinity to adsorb to suspended particulate matter. In May, concentrations of cadmium, manganese, chromium, iron and silver exceeded either the CWQG or the ASWQO. In particular, manganese and iron concentrations were well above ASWQO levels. Soils and sediments are common sources of these two elements. Metals are not generally considered to be a major component of pulp mill effluent. The concentrations recorded in May are considered to be the result of natural processes. During October, metal concentrations were low and below both the ASWQO and CWQG.

Resin and fatty acids were detected only at Site 3 during the May survey. Several specific resin and fatty acids were detected in this sample; however, the source of these components is questionable. For example linoleic and oleic acids, which do occur in pulp mill effluents are also known ingredients of the soap typically used to wash the glassware used in the laboratory analyses (D. Birkholz per. comm.). Since all impurities cannot be removed from the glassware, residues of these compounds could contaminate the samples. Dehydroabietic, abietic pimaric, sandarcopimaric and neoabietic acids are commonly found in softwood pulp mill effluents (Taylor et al. 1988). Resin and fatty acids concentrations in ANC's treated effluent in October were below the detection limit of 10 μg/L . On one occasion in 1991 (June), these resin acids were detected in the treated effluent (ANC unpublished data). However, the maximum total resin acid concentration recorded in the treated effluent was lower than the concentration recorded at Site 3 in May, following dilution under high flows. Although the chlorinated resin acids were detected at Site 3 in May, the source of these compounds is unknown, since they are produced only when chlorine is used in pulp bleaching. The ANC mill does not use chlorine or chlorine-based compounds in any of its pulping processes. Therefore, the relatively high concentrations of resin and fatty acids and the presence of chlorinated resin acids suggested that sample contamination may have occurred in May.

3.3 BENTHIC INVERTEBRATES

3.3.1 Basic Computations

A total of 122 taxa of benthic invertebrates has been identified (most to the generic level) from the 1989 to 1991 samples collected from the Athabasca River (Table 5). Of these, 45 taxa were identified from May 1991 samples and 75 taxa from the October samples. A total of 12 new taxa was identified from the 1991 samples.

The raw benthic data showing taxa identified and the number of organisms per sample for all sites are presented in Appendix C. Summary tables of the basic computations for each sample are presented in Appendix D.

Table 5. **Benthic invertebrate species list with codes and functional feeding groups for the spring (S) and fall (F) 1991. Abbreviations for functional feeding groups as in Table 1.**

Species Code	Taxa	Functional Feeding Group	Season
	ARTHROPODA		
	INSECTA		
	Ephemeroptera (mayflies)		
	Ametropodidae		
001	*Ametropus neavei*	D	SF
	Baetidae		
002	*Baetis* spp.	DH	SF
003	*Acentrella insignificans*[a]	DH	F
	Ephemerellidae		
096	*Drunella coloradensis*	H	S
004	*Drunella doddsi*	H	SF
114	*Drunella grandis ingens*	H	F
005	*Ephemerella inermis*	DH	SF
	Ephemeridae		
006	*Ephemera* sp.	D	S
	Heptageniidae		
007	*Epeorus* sp.	DH	S
008	*Heptagenia* sp.	DH	SF
009	*Rhithrogena* sp.	DH	SF
010	*Stenonema* sp.	DH	F
011	Heptageniidae (early instar)*	DH	S
	Leptophlebiidae		
012	*Paraleptophlebia* sp.	DH	SF
	Metretopodidae		
013	*Metretopus borealis*	C	S
	Siphlonuridae		
014	*Ameletus* sp.	DH	SF
	Tricorythidae		
015	*Tricorythodes* sp.	D	SF
	Trichoptera (caddisflies)		
	Brachycentridae		
016	*Brachycentrus* sp.	O	SF
	Glossosomatidae		
115	*Glossosoma* sp.	H	F
	Hydropsychidae		
017	*Arctopsyche* sp.	O	SF
018	*Cheumatopsyche* sp.	O	SF
019	*Hydropsyche* spp.	O	SF

(continued)

Table 5. (continued)

Species Code	Taxa	Functional Feeding Group	Season
	Hydroptilidae		
020	*Hydroptila* sp.	H	SF
021	*Stactobiella* sp.	DH	S
	Lepidostomatidae		
022	*Lepidostoma* sp.	D	F
	Leptoceridae		
023	*Oecetis* sp.	HC	F
	Limnephilidae		
116	*Apatania* sp	DH	F
097	Limnephilidae (early instar)*	DH	F
	Polycentropodidae		
117	*Neureclipsis* sp.	O	F
	Psychomyiidae		
024	*Psychomyia* sp.	DH	SF
	Plecoptera (stoneflies)		
025	Capniidae[b]	D	SF
	Chloroperlidae		
	Chloroperlinae		
026	*Haploperla brevis*	HC	SF
098	*Triznaka* sp.	C	S
099	Chloroperlinae (early instar)*	C	SF
	Nemouridae		
100	*Nemoura sp.*	D	S
111	*Podmosta* sp.	D	S
027	*Zapada* sp.	D	S
	Perlidae		
028	*Claassenia sabulosa*	C	SF
101	*Hesperoperla pacifica*	C	F
	Perlodidae		
029	*Cultus* sp.	C	SF
030	*Isogenoides* sp.	C	SF
031	*Isoperla* sp.	C	SF
032	Perlodidae (early instar)*	C	SF
	Pteronarcyidae		
033	*Pteronarcella badia*	DH	SF
034	*Pteronarcys dorsata*	DH	SF
	Taeniopterygidae		
035	*Taenionema* sp.	H	SF
	Diptera (flies, midges)		
	Athericidae		
036	*Atherix* sp.	C	S

(continued)

Table 5. (continued)

Species Code	Taxa	Functional Feeding Group	Season
	Blephariceridae		
118	*Bibiocephala grandis*	H	F
	Ceratopogonidae		
037	*Bezzia/Palpomyia gp.*[b]	C	SF
	Empididae		
038	*Chelifera* sp.	CD	SF
039	*Hemerodromia* sp.	CD	SF
119	*Wiedemannia* sp.	C	F
	Simuliidae		
040	*Simulium* sp.	O	S
	Tanyderidae		
120	*Protanyderus* sp.	DH	F
	Tipulidae		
041	*Hexatoma* sp.	C	SF
042	*Limnophila* sp.	C	SF
043	Eriopterini Tribe	D	SF
	Chironomidae		
	Chironominae		
	Chironomini Tribe		
044	*Cryptochironomus* sp.	C	S
045	*Microtendipes* sp.	D	S
046	*Paracladopelma/Cyphomella* spp.[c]	D	SF
047	*Paralauterborniella nigrohalteralis*	D	S
112	*Paratendipes* sp.	D	S
048	*Polypedilum* spp.	DH	SF
049	*Robackia demeijerei*	D	SF
050	*Saetheria* sp.	D	S
051	Chironomini (early instar)*	D	SF
	Tanytarsini Tribe		
052	*Cladotanytarsus* sp.	D	SF
053	*Constempellina* sp.	D	S
054	*Micropsectra* sp.	D	SF
055	*Rheotanytarsus* spp.	D	SF
056	*Stempellinella* sp.	DH	S
057	*Sublettea* sp.	D	SF
058	*Tanytarsus* sp.	D	SF
059	Tanytarsini (early instar)*	D	S
	Diamesinae		
	Diamesini Tribe		
102	*Diamesa* sp.	D	SF
060	*Pagastia* sp.	D	F
061	*Potthastia gaedii* gp.	DH	SF
	Orthocladiinae		
103	*Brillia* sp.	D	F
062	*Cardiocladius* sp.	C	F

(continued)

Table 5. (continued)

Species Code	Taxa	Functional Feeding Group	Season
104	*Corynoneura* sp.	D	SF
063	*Cricotopus/Orthocladius* spp.	DH	SF
064	*Eukiefferiella* spp.	DH	SF
105	*Heleniella* sp.	D	F
106	*Heterotrissocladius* sp.	D	F
107	*Krenosmittia* sp.	D	SF
065	*Nanocladius* sp.	D	SF
108	*Orthocladius (Symposiocladius) lignicola*	D	F
066	*Paracladius* sp.	D	F
067	*Parakiefferiella* spp.	D	SF
068	*Parametriocnemus* sp.	D	SF
109	*Psectrocladius* sp.	DH	S
069	*Rheocricotopus* sp.	DH	SF
070	*Synorthocladius* sp.	D	SF
071	*Thienemanniella* sp.	D	SF
072	*Tvetenia* spp.	D	SF
073	Orthocladiinae (early instar)*	D	SF
	Prodiamesinae		
074	*Monodiamesa* sp.	D	SF
	Tanypodinae		
	Macropelopiini Tribe		
113	*Procladius* sp.	C	S
	Pentaneurini Tribe		
075	*Larsia* sp.	C	SF
076	*Nilotanypus* sp.	C	S
077	*Thienemannimyia* gp.	C	SF
078	Tanypodinae (early instar)*	C	F
	Coleoptera (beetles)		
	Dytiscidae		
079	*Oreodytes* sp.	C	F
	Elmidae		
080	*Optioservus* sp.	DH	S
121	Collembola (springtails)	DH	F
	Hemiptera		
	Corixidae (water boatmen)		
081	*Callicorixa audeni*	C	SF
122	*Hesperocorixa atopodonta*	C	F
082	*Sigara decoratella*	DH	F
083	*Sigara solensis*	DH	F

(continued)

Table 5. (continued)

Species Code	Taxa	Functional Feeding Group	Season
	Odonata (dragonflies)		
	Gomphidae		
084	*Ophiogomphus* sp.	C	S
	Megaloptera (alderflies)		
	Sialidae		
110	*Sialis* sp.	C	S
	ARACHNIDA		
085	Hydracarina (water mites)	C	SF
	CRUSTACEA		
	Podocopa (seed shrimps)		
	Candonidae[d]		
086	*Candona* sp.	O	SF
	ANNELIDA		
	OLIGOCHAETA (aquatic earthworms)		
	Haplotaxida		
087	Enchytraeidae	D	SF
088	Naididae	D	SF
089	Tubificidae	D	SF
	Lumbriculida		
090	Lumbriculidae	D	S
	HIRUDINEA (leeches)		
	Rhynchobdellida		
	Glossiphoniidae		
091	*Helobdella stagnalis*	C	F
092	**NEMATODA** (roundworms)	D	SF

(continued)

Table 5. (concluded)

Species Code	Taxa	Functional Feeding Group	Season
	MOLLUSCA		
	GASTROPODA (snails)		
	Basommatophora		
	Lymnaeidae		
093	*Lymnaea* sp.	O	SF
	PELECYPODA (clams)		
	Heterodonta		
	Sphaeriidae		
094	*Pisidium* sp.	O	S
	PLATYHELMINTHES		
	TURBELLARIA (flatworms)		
	Tricladida		
	Planariidae		
095	*Polycelis coronata*	CD	F

* The organisms indicated as early instars were too small to identify to the genus level.

a *Pseudocloeon* sp. has recently been placed into the *Acentrella* sp., along with the *Baetis* (*Laponica*) group (McCafferty and Waltz 1990).

b Definitive separation within the Capniidae family and the *Bezzia/Palpomyia* gp. is difficult with the keys presently available.

c *Cyphomella* sp. was previously (1989) identified as *Paracladopelma* sp. Definitive separation between these two genera is difficult with the present keys.

d *Candona* sp. has recently been moved from the Cypridae to the Candonidae family.

May

The mean number of taxa at sites during May ranged between 5 and 10 taxa (Figure 4). The mean number of taxa during the May 1991 survey was low at all sites, probably due to the high flows encountered during the survey.

The mean standing crop at sites during May ranged between 81 and 316 organisms/m^2 (Figure 5). The mean standing crop decreased slightly at Sites 3 and 4 from background values (Sites 1 and 2). At Sites 5, the mean standing crop increased slightly above background values, and at Sites 6 and 7, they were similar to background values. The mean standing crop at all sites during the May survey was low, also probably due to the high flows encountered during the survey.

High discharges, floods, ice and other physical disturbances which can scour the substrate, can reduce the abundance of benthic invertebrates in the benthos and increase their numbers in the drift (Hynes 1972, Waters 1972). High discharges increase the width, depth and velocity of the water and therefore, alter the habitat. For example, increased flow tends to flush out the accumulation of detritus that form the habitat of many species (Anderson and Lehmkuhl 1968). Sudden increased water levels can also make it difficult to sample in depths which have an established benthic community, since the Neill-Hess sampler is restricted to a maximum depth of about 50 cm.

The results of the one-way ANOVA's to determine whether numbers of taxa and standing crops varied between sites are presented in Appendix E. There were no significant differences during May in the mean numbers of taxa between sites ($p > 0.05$), but there were significant differences in the mean standing crops between sites ($p < 0.01$). A posteriori testing, using the SNK procedure showed that the groups of sites which did not have significantly different mean standing crops ($p > 0.05$) (Appendix E) were as follows:

<u>Mean Standing Crop</u>
Sites 1, 2, 3, 6, 7
Sites 1, 5, 7
Sites 2, 3, 4, 6, 7

Any two sites not within a group are considered significantly different. Often there are no clear boundaries between sets of means not significantly different from each other and

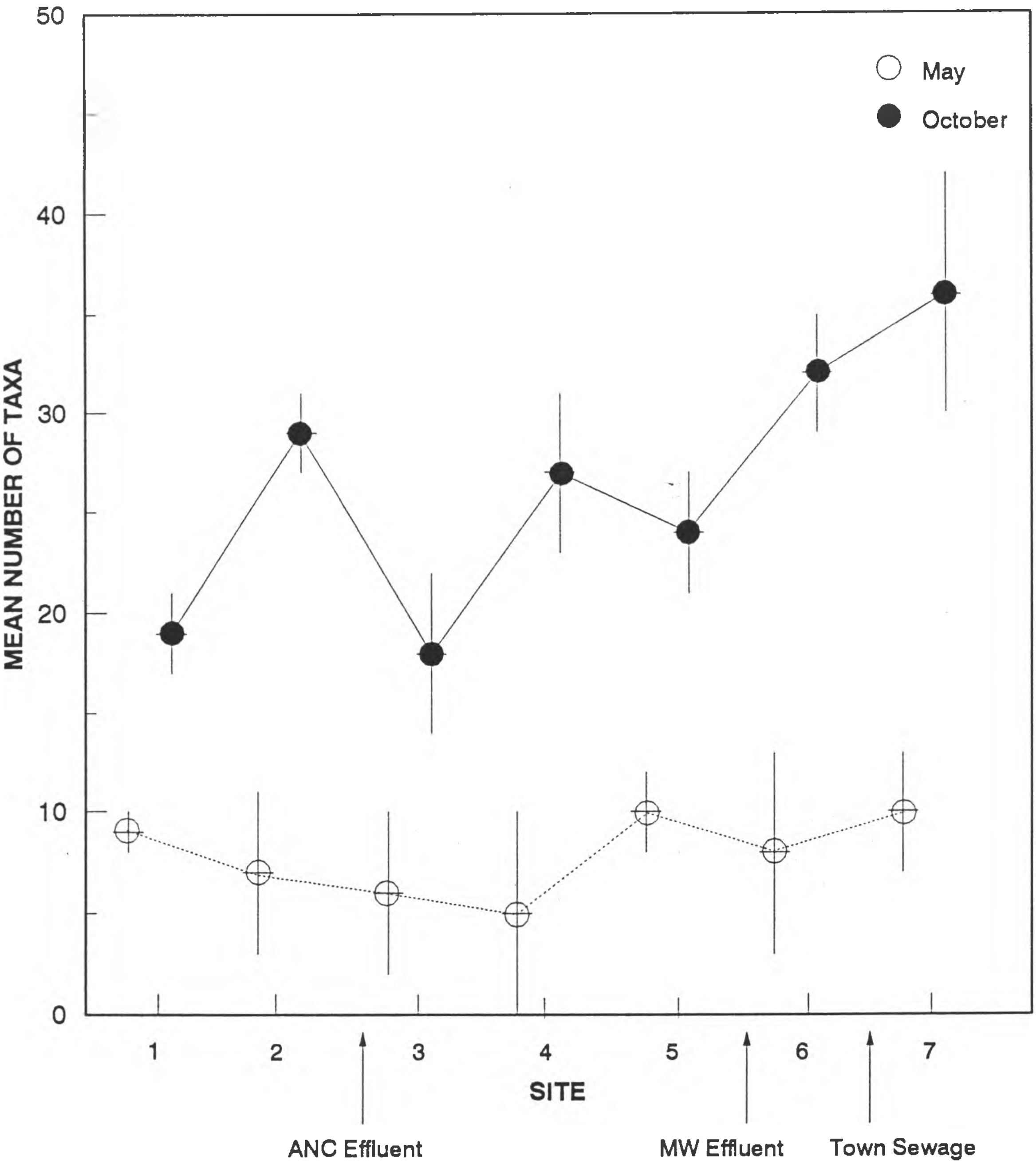

Figure 4. **Mean number of taxa with 95% confidence limits for sites on the Athabasca River, May and October 1991.**

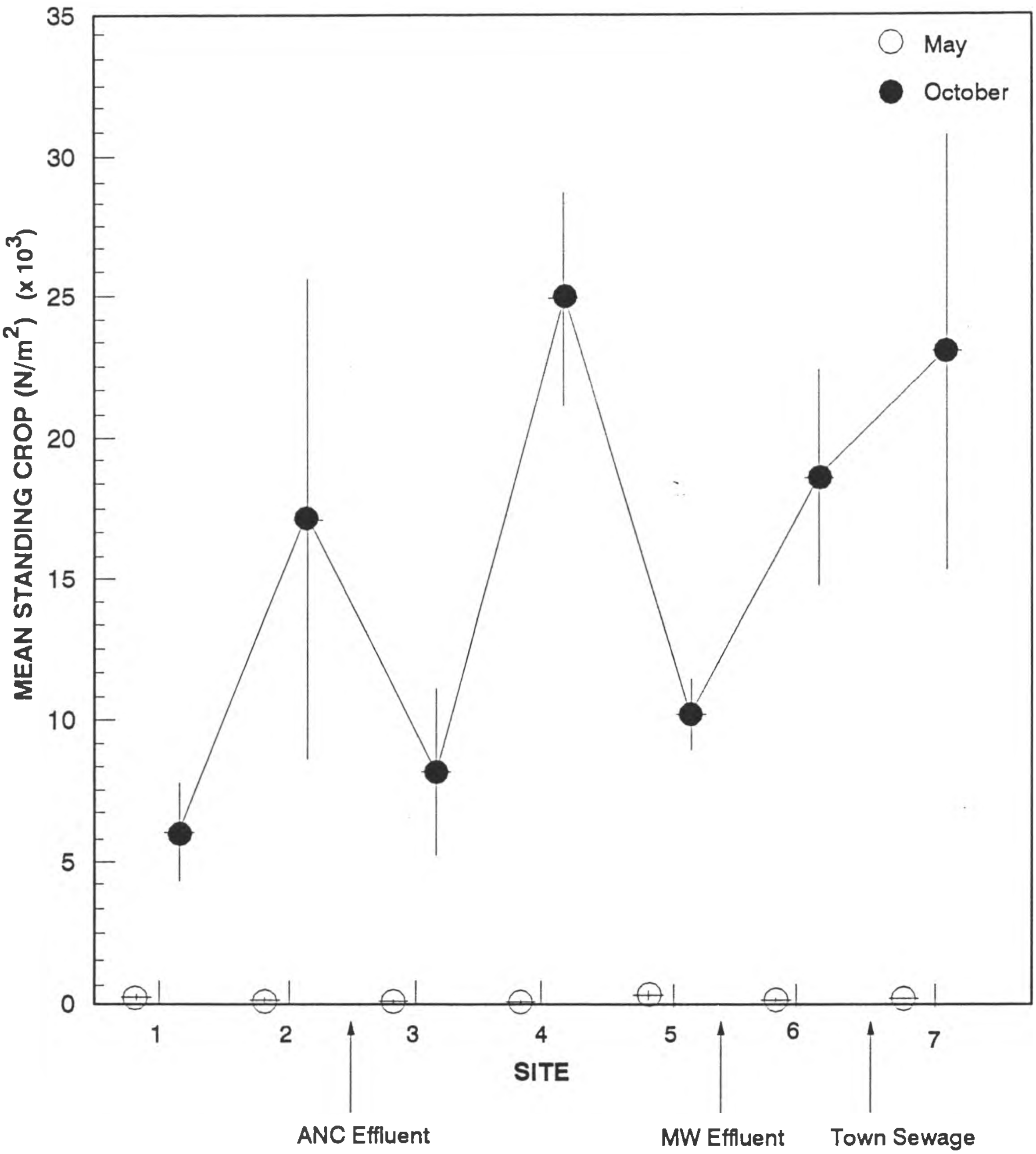

Figure 5. **Mean standing crop (number/m^2) with 95% confidence limits for sites on the Athabasca River, May and October 1991.**

therefore, sets overlap. The mean standing crop at Site 1 was significantly greater than at Site 4, at Sites 2, 3 and 4 less than at Site 5, and at Site 5 greater than at Site 6. The mean standing crops at all downstream sites were, however, similar to at least one of the background sites.

Species diversity reflects both the number of taxa and evenness of distribution of the organisms among the taxa. The mean species diversity at sites during May ranged between 1.31 and 2.12 (Figure 6). The mean species diversity decreased slightly at Site 4 from background values, with the confidence limits indicating a large amount of variability between samples. The mean species diversity then increased at downstream sites with Sites 5 and 6 being similar to background values and Site 7 having the highest value. A low species diversity indicates that the majority of organisms present belong to only a few taxa and that other fauna are low in numbers, thus causing an uneven distribution. Since both the number of taxa and the number of organisms appeared to be affected by the high flows, the species diversity values also reflected the effects of the high flows.

Ephemeroptera (mayflies), Chironomidae (midges) and Oligochaeta (aquatic worms) were the dominant taxonomic groups at all sites during May (Figure 7). Plecoptera (stoneflies) and the remaining groups were also present, but in smaller numbers and Trichoptera (caddisflies) was present only at Site 5. The mean standing crop of Chironomidae decreased at Sites 3 and 4, increased at Site 5 to the background Site 1 value and then decreased at Sites 6 and 7 to the background Site 2 value. The mean standing crop of Ephemeroptera fluctuated between sites, with the highest values occurring at Sites 3, 5 and 7 and values similar to background sites occurring at Sites 4 and 6. The mean standing crop of Oligochaeta was similar between all sites.

October

The mean number of taxa at sites during October ranged between 18 and 36 taxa (Figure 4). The mean numbers of taxa at Sites 3, 4 and 5 were similar to background values and at Sites 6 and 7, they increased slightly above background values. The mean number of taxa during October was higher than during May at all sites.

The mean standing crop at sites during October ranged between 6,045 and 24,922 organisms/m^2 (Figure 5). The mean standing crops at Sites 3 and 5 were similar to background values. At Sites 4, 6 and 7, the mean standing crops had increased above

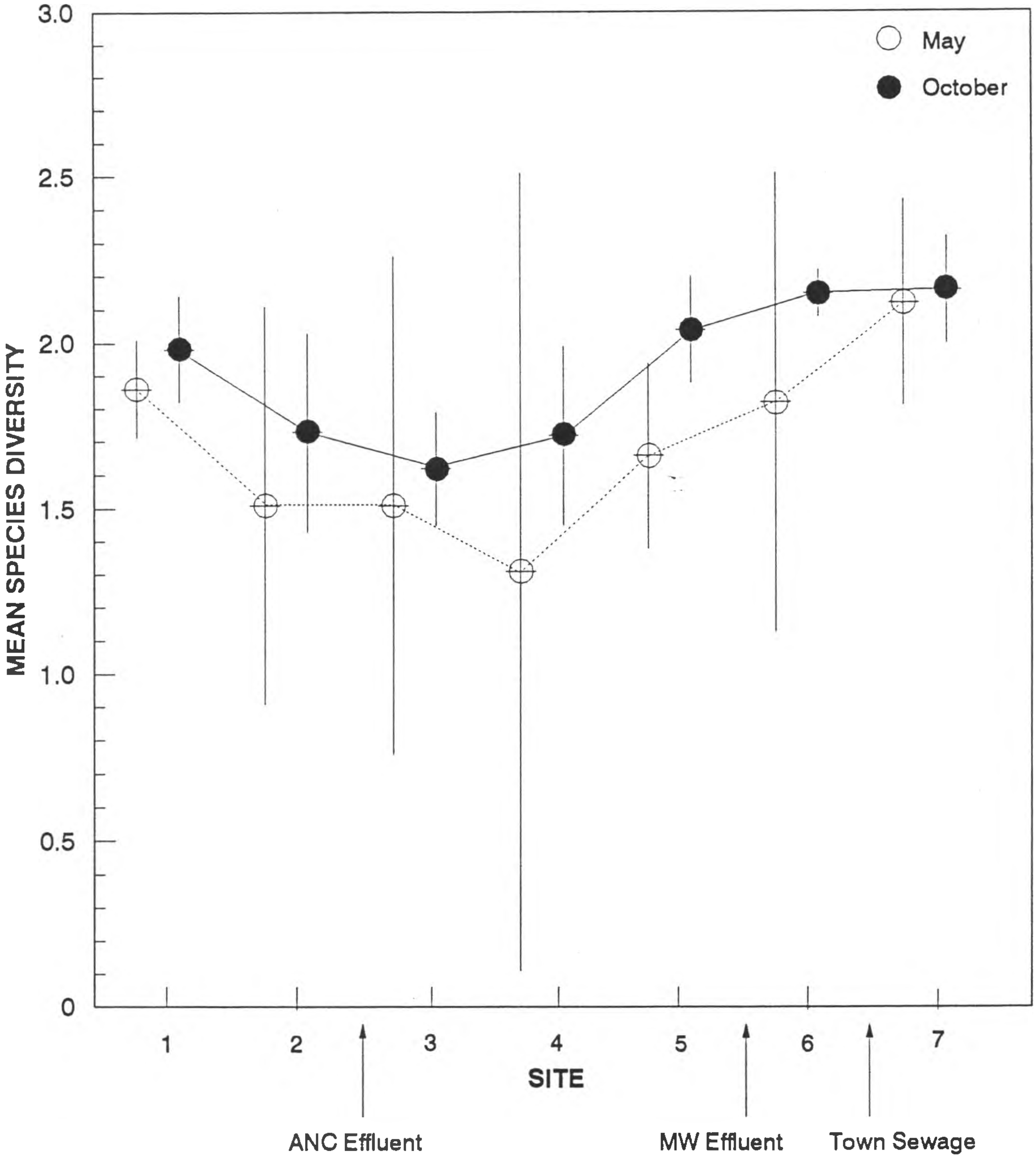

Figure 6. **Mean Shannon-Weaver species diversity with 95% confidence limits for sites on the Athabasca River, May and October 1991.**

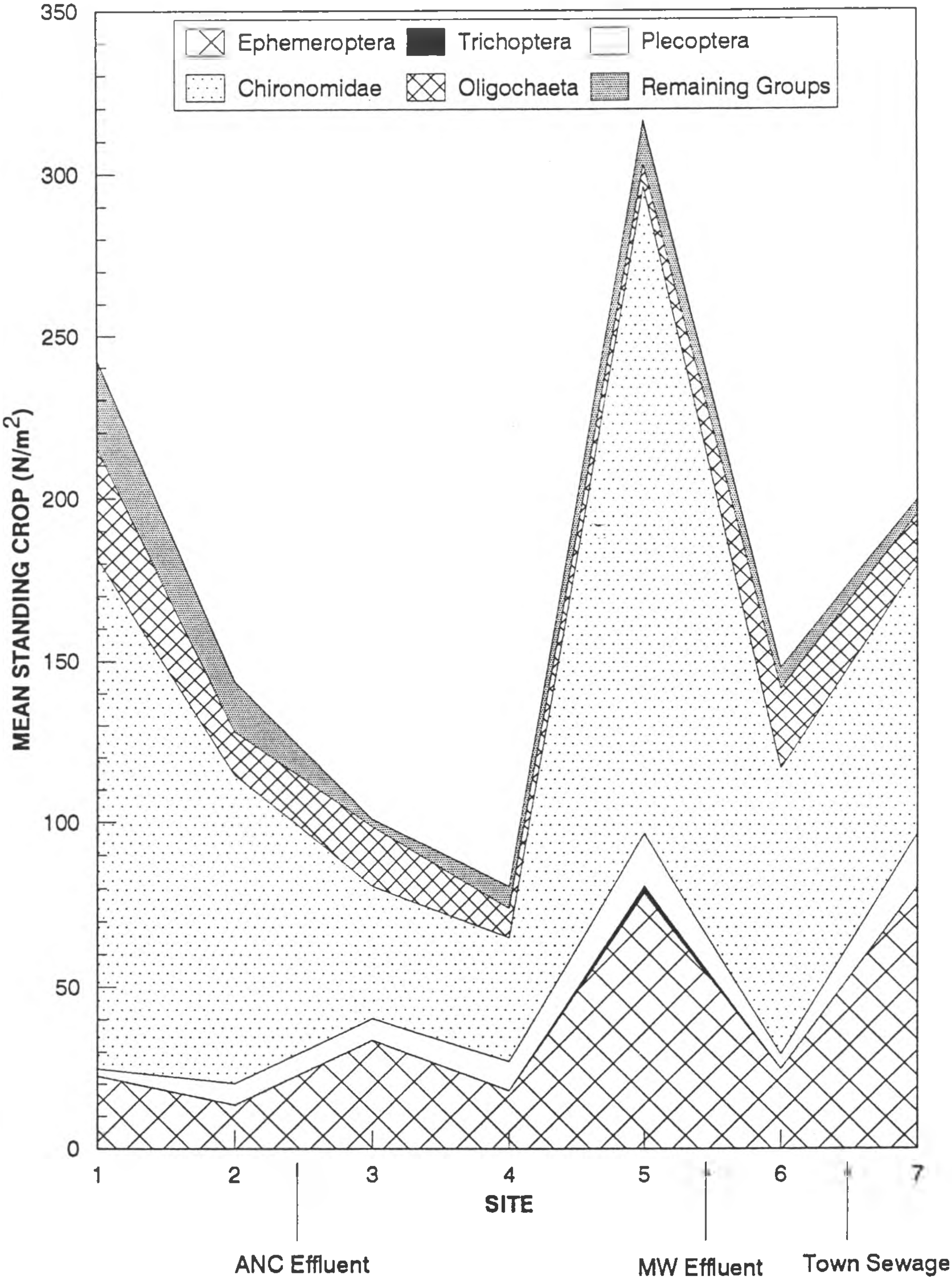

Figure 7. Mean cumulative standing crop (number/m^2) of the major taxonomic groups for sites on the Athabasca River, May 1991.

background values, with the highest value occurring at Site 4. The mean standing crop during October was higher than during May at all sites.

The results of the one-way ANOVA's showed that there were significant differences during October in the mean numbers of taxa between sites ($p < 0.01$) and in the mean standing crops between sites ($p < 0.01$) (Appendix E). The SNK procedure showed that the groups of sites which did not have significantly different mean numbers of taxa ($p > 0.05$) and mean standing crops ($p > 0.05$) (Appendix E) were as follows:

Mean Number of Taxa	Mean Standing Crop
Sites 1, 3	Sites 1, 3, 5
Sites 2, 4	Sites 2, 6, 7
Sites 2, 6	Sites 4, 7
Sites 4, 5	

The mean number of taxa at Site 1 was significantly less than at Sites 2, 4, 5, 6, and 7, at Site 2 greater than at Sites 3 and 5, at Site 2 less than at Site 7, at Site 3 less than at Sites 4, 5, 6 and 7, at Sites 4 and 5 less than at Sites 6 and 7, and at Site 6 less than at Site 7. The mean numbers of taxa at all downstream sites, except at Sites 5 and 7, were similar to at least one of the background sites. Although the mean number of taxa at Site 5 was not similar to either background site, it had an intermediate value between the two background values. The mean number of taxa at Site 7 was significantly greater than at background sites.

The mean standing crop at Site 1 was significantly less than at Sites 2, 4, 6 and 7, at Site 2 greater than at Sites 3 and 5, at Site 2 less than at Site 4, at Site 3 less than at Sites 4, 6, and 7, at Site 4 greater than at Sites 5 and 6, and at Site 5 less than at Sites 6 and 7. The mean standing crops at all downstream sites, except at Site 4, were similar to at least one of the background sites. The mean standing crop at Site 4 was significantly greater than at background sites.

The mean species diversity at sites during October ranged between 1.62 and 2.16 (Figure 6). The mean species diversities at Sites 3, 4 and 5 were similar to background values, and at Sites 6 and 7, they were slightly above background values. The mean species diversities at all sites during October were higher than during May.

Ephemeroptera, Plecoptera and Chironomidae were the dominant taxonomic groups at all sites during October (Figure 8). The mean standing crop of Chironomidae varied at background sites, ranging between 2,511 and 13,002 chironomids/m^2, while the mean standing crops of Ephemeroptera and Plecoptera were similar between the two background sites. The mean standing crop of Chironomidae at Sites 4 and 7, and to a lesser extent Ephemeroptera at Sites 4, 5 and 7, and Plecoptera at Sites 4, 6 and 7 were above the background values. Trichoptera, Oligochaeta and the remaining groups were present in smaller numbers. There was an increase in the mean standing crop of Trichoptera at downstream sites, compared to background values.

Environmental stress can affect entire groups of benthic invertebrates (major taxonomic groups). Somewhat arbitrarily, benthic invertebrates have been divided into two types: "tolerant taxa" such as Oligochaeta and Chironomidae, which can withstand relatively important changes in their habitat, and "intolerant taxa" such as Ephemeroptera, Plecoptera and Trichoptera, which can withstand minor changes only (Anderson 1989). Although these two types of benthic invertebrates commonly cohabit, a marked deterioration or a marked improvement in water quality will usually result in the numerical dominance of one type over the other. Although, the individual taxa from the same major group tend to respond relatively uniformly, exceptions are not uncommon and the intensity of response can vary considerably among taxa (Anderson 1989). Therefore, a community analysis of individual taxa is provided in Section 3.3.2.

Phosphorus is the nutrient that limits productivity in most freshwater ecosystems (Wetzel 1975). Increasing concentrations of phosphorus in streams often result in organic enrichment which increases biomass of algae, aquatic macrophytes and associated biota. Phosphorus inputs into the aquatic ecosystem can occur through either natural or anthropogenic sources. Natural sources of phosphorus include drainage from agricultural land, as well as leaching from soils that are high in phosphorus content (Hynes 1972). Effluents from pulp mills and sewage treatment plants can also elevate the phosphorus concentrations in receiving streams. Phosphorus is added to pulp mill effluents to enhance biological degradation of the pulping wastes. Benthic invertebrate enrichment has been reported downstream of pulp mills and sewage treatment plants as a result of organic loading from the effluents (Hynes 1972, Bothwell and Stockner 1980, Rabeni et al. 1985, Noton et al. 1989).

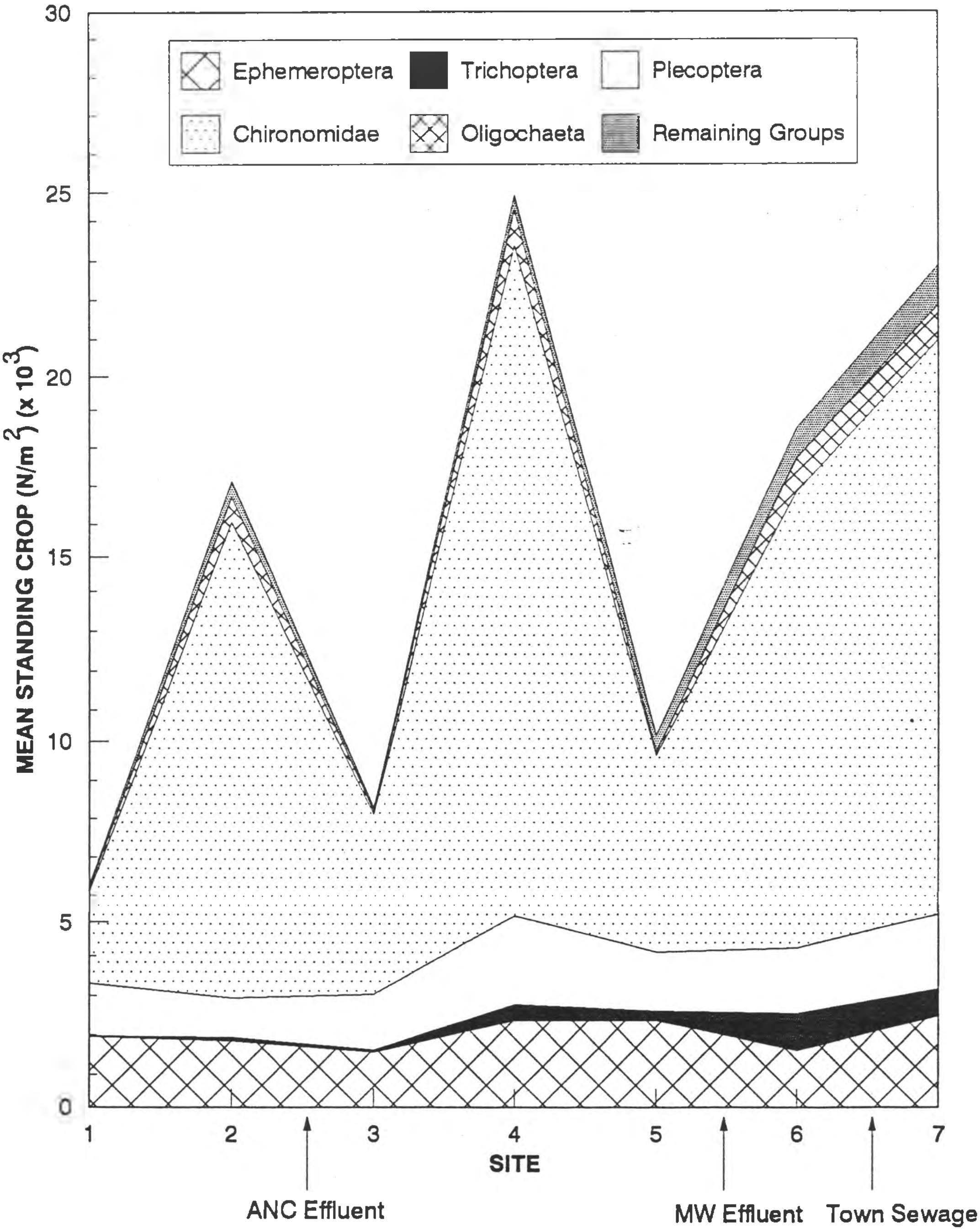

Figure 8. Mean cumulative standing crop (number/m^2) of the major taxonomic groups for sites on the Athabasca River, October 1991.

An increase in the amount of algal growth on the substrates was found at downstream sites during October. The increases in mean standing crops of benthic invertebrates at downstream sites (Sites 4, 6 and 7) during October, in comparison to background sites were likely the result of organic loading from the ANC, the Millar Western and the Whitecourt sewage treatment effluents. Tolerant taxa, mainly Chironomidae, as well as intolerant taxa (Ephemeroptera and Plecoptera), increased in numbers at downstream sites, as a response to the organic enrichment. There were no clear relationships between algal density and the number of taxa and standing crop of benthic invertebrates at sites. Future studies will attempt to investigate further the algal density and types present at each site.

3.3.2 Community Analysis

Reciprocal averaging ordination (RA) was conducted to analyze the data in terms of benthic invertebrate community structure. The results of the RA analysis are shown as a species dominance distribution matrix for each sample site for both May and October (Appendix F). These results were plotted as two-axes (X and Y) ordinations for both site and species scores on a scale of 0 to 100 (ordination units) on each axis. The species ordinations are shown in Appendix F. The taxa represented by the species codes in the matrices and species ordinations are listed in Table 5.

May

There was no distinct separation of sample clusters in May (Figure 9). Most samples clustered along the right Y-axis and a few samples ordinated away from the main cluster. A cluster of samples represents those which have similar benthic community assemblages. The degree of faunal homogeneity between samples within a cluster is represented by the closeness of the samples within the cluster. The May site ordination indicated that samples within the main cluster had a fairly high degree of faunal homogeneity.

Sample Sites 3-1, 3-2, 4-3 and 4-5 ordinated away from the main cluster. The dominant taxon which caused Sites 3-1 and 3-2 to ordinate away from the main cluster was Tubificidae (Oligochaeta), Site 4-3 *Isogenoides* sp. (Plecoptera) and *Cladotanytarsus* sp. (Chironominae-Tanytarsini), and Site 4-5 *Rhithrogena* sp. (Ephemeroptera).

The ordination indicated that most sample sites in May had a similar benthic community structure. The dominant benthic community assemblage characteristic of the main cluster,

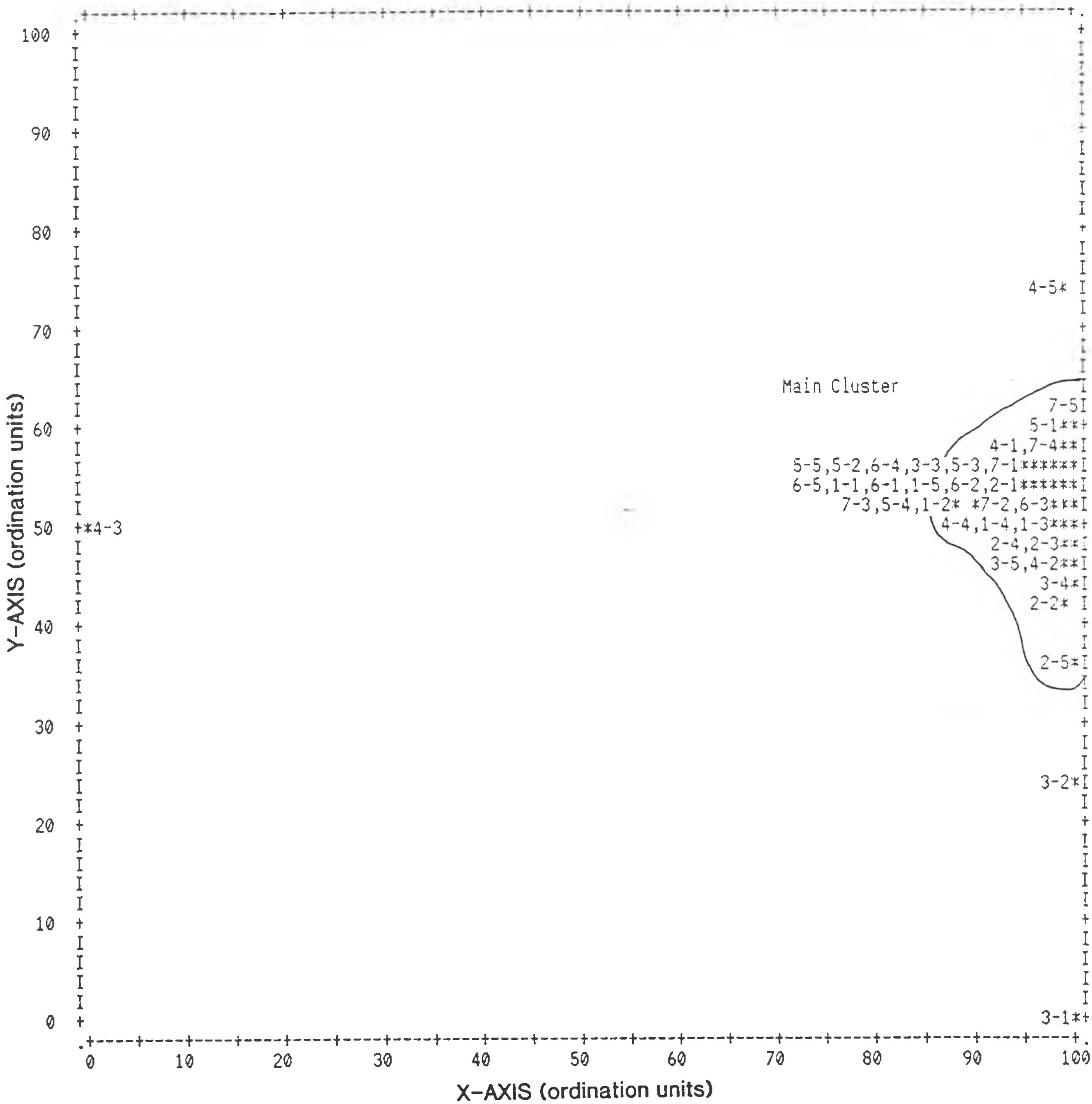

Figure 9. Reciprocal averaging ordination of site scores, May 1991.

in order of numerical dominance (Appendix F) was *Cricotopus/Orthocladius* spp., *Baetis* spp., *Rhithrogena* sp., *Ephemerella inermis* and *Polypedilum* spp. The mean standing crops (number/m^2) of the dominant taxa identified by RA for each site for May are shown in Figure 10.

A number of taxa have been found to respond to organic enrichment, by increasing in numbers, as a response to an increase in food availability, if oxygen is not limiting (Hynes 1960, Godfrey 1978). Three mayflies, *Baetis* spp., *Ephemerella inermis* and *Rhithrogena* sp. (Ephemeroptera), and one chironomid, *Cricotopus/Orthocladius* spp. (Orthocladiinae) increased slightly in mean standing crop at downstream sites. Most Ephemeroptera are grazers, feeding principally on algae and detrital materials (Merritt and Cummins 1984) and thus species, such as the dominant ones found in May, are suited to mild organic enrichment (Hynes 1960, Roback 1974). Orthocladiinae, such as *Cricotopus/Orthocladius* spp., have also been found to respond to mild organic enrichment (Hynes 1960).

It should, however, be noted that the magnitude of increase of these taxa at downstream sites was small, when compared to mean standing crops found in the spring in previous years. Although the dominant taxa found in May were ones which respond to organic enrichment, any potential effects may have been masked by substrate scour due to high flows and/or high water levels which caused sampling to be conducted in areas which may not have been underwater year-round.

October

The site ordination indicated three sample clusters in October (Figure 11). Cluster I consisted of samples from Sites 1 and 5, Cluster II of samples from Sites 3 and 4, and Cluster III of samples from Sites 2, 6 and 7. A higher degree of faunal homogeneity existed within Cluster III than within Clusters I and II.

The dominant benthic community assemblage characteristic of each cluster, in order of numerical dominance (Appendix F), was as follows:

Cluster I: *Cricotopus/Orthocladius* spp., *Baetis* spp., Capniidae, *Rhithrogena* sp., *Taenionema* sp.

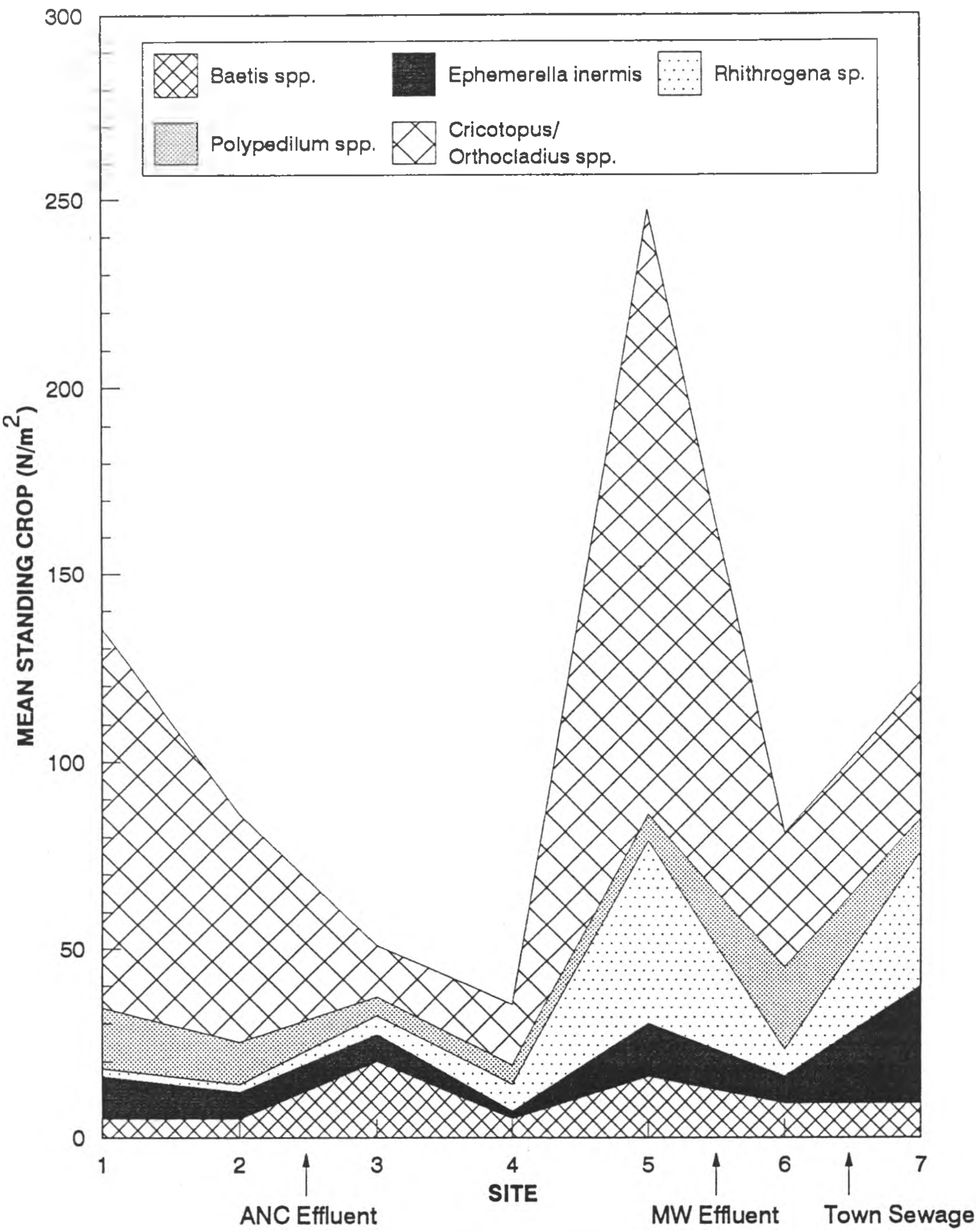

Figure 10. Mean cumulative standing crop (number/m^2) of the dominant taxa identified by RA for sites on the Athabasca River, May 1991.

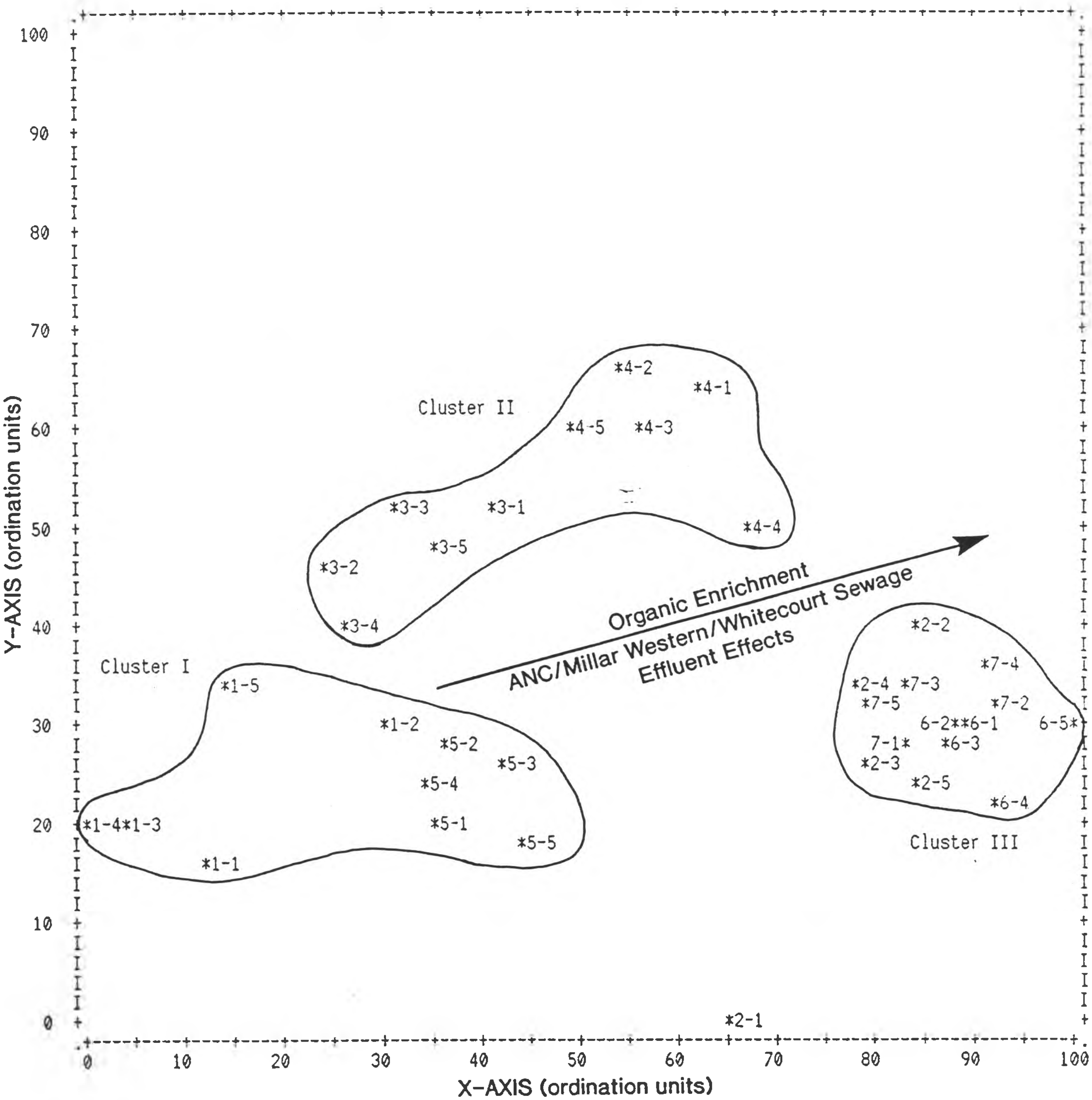

Figure 11. Reciprocal averaging ordination of site scores, October 1991.

Cluster II: *Cricotopus/Orthocladius* spp., *Baetis* spp., *Taenionema* sp., Capniidae

Cluster III *Cricotopus/Orthocladius* spp., *Rheotanytarsus* spp., *Ephemerella inermis*, Capniidae

The mean standing crops (number/m^2) of the dominant taxa identified by RA for each site for October are shown in Figure 12.

The dominant taxa within each cluster have been found to respond to organic enrichment from either natural or anthropogenic sources. A gradient of organic enrichment appeared to exist between Clusters I, II and III. This was shown by a chironomid, *Cricotopus/Orthocladius* spp. (Orthocladiinae), which was dominant in all three clusters. There were lower numbers of this taxon in samples of Cluster I and increasing numbers in Clusters II and III (Appendex F-3)

Cluster I indicated that the dominant community structure of downstream Site 5 was similar to background Site 1. Cluster I was dominated by *Cricotopus/Orthocladius* spp., two Ephemeroptera (*Baetis* spp. and *Rhithrogena* sp.) and two Plecoptera (Capniidae and *Taenionema* sp.). Cluster II (Sites 3 and 4), which ordinated away from Cluster I had the same dominant benthic community structure as Cluster I, except for *Rhithrogena* sp. which was not dominant in Cluster II. Cluster III indicated that the dominant benthic community structure of background Site 2 and downstream Sites 6 and 7 were similar in October. Cluster III was dominated by *Cricotopus/Orthocladius* spp. and Capniidae which were also dominant in both Clusters I and II. The other two dominant taxa in Cluster III were an Ephemeroptera (*Ephemerella inermis*) and a chironomid of the Tanytarsini Tribe (*Rheotanytarsus* spp.). These dominant taxa have been found to respond to mild organic enrichment, where oxygen levels are not seriously depressed (Hynes 1960, Roback 1974).

During October, as in previous surveys (Beak 1990, 1991), the dominant benthic community structures of the background sites indicated the presence of mild organic enrichment, especially at Site 2. The ANC effluent appeared to contribute some additional organic enrichment at downstream Site 4. Some recovery of the system, indicated by a decrease in the standing crop of dominant taxa appeared to occur at Site 5. However, then the Millar Western mill and/or the Whitecourt sewage treatment effluents appeared to contribute further organic enrichment at Sites 6 and 7.

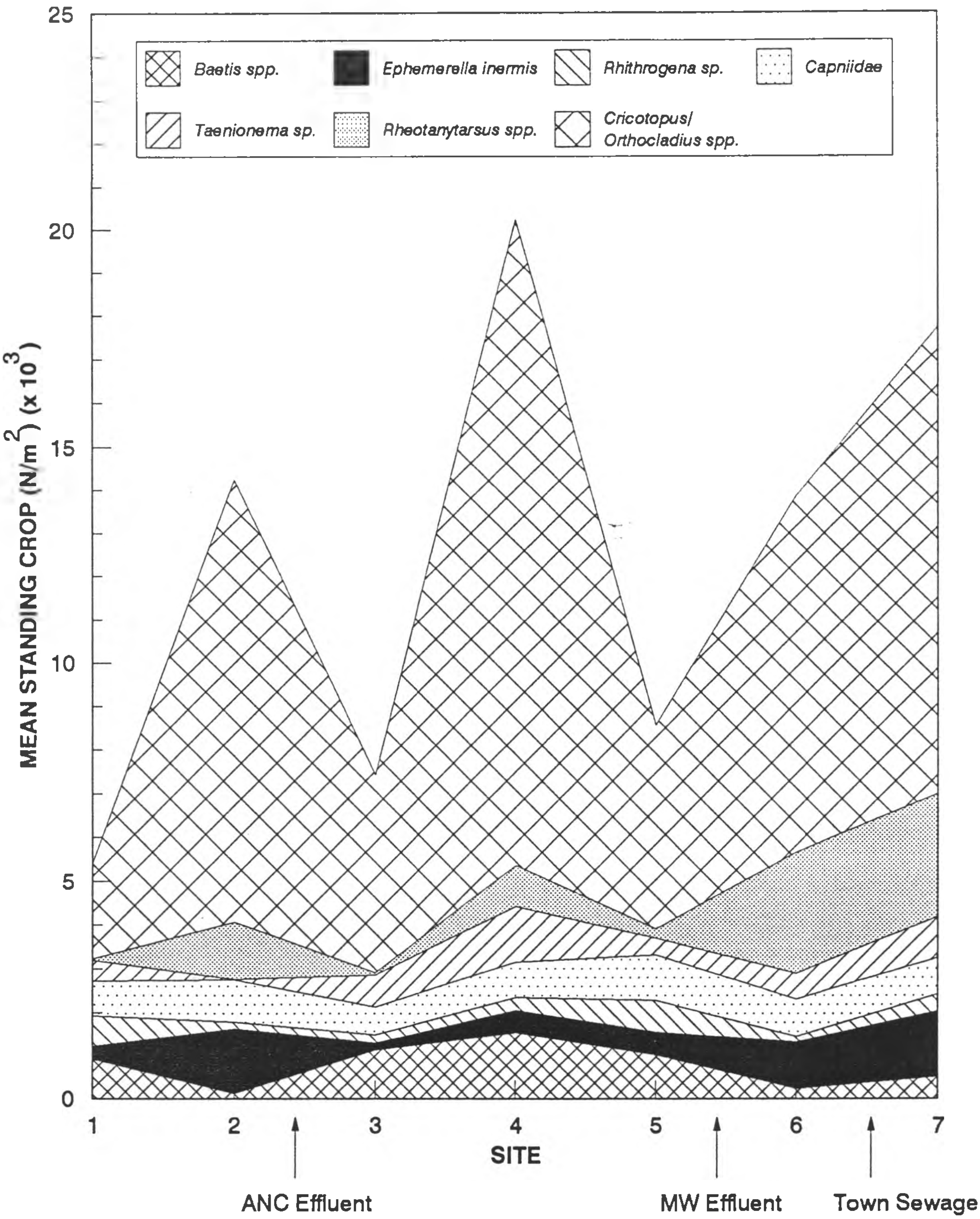

Figure 12. **Mean cumulative standing crop (number/m^2) of the dominant taxa identified by RA for sites on the Athabasca River, October 1991.**

3.3.3 Trophic Analysis

A trophic (feeding group) analysis of the benthic data was conducted to determine if there were any differences in benthic community trophic structure between sites for May and October. The availability of food is a factor which controls the occurrence and abundance of benthic invertebrates species (Hynes 1972). The percent contribution of each functional group for all samples sites for May and October are presented in Appendix C.

May

The trophic analysis showed that all sites were dominated by detritivore/herbivores, followed by detritivores, in May (Figure 13). The detritivore/herbivores formed 53.3 to 78.7% and the detritivores formed 12.8 to 39.4% of the total benthic fauna. A dominance of benthic detritivore/herbivores and detritivores is a common natural trait of streams in North America (Egglishaw 1964, Minshall 1967, Hynes 1972, Fisher and Likens 1972, Cummins et al. 1973). The third dominant group was the carnivores, which formed 2.8 to 8.9% of the total benthic fauna. All other feeding groups formed less that 3% of the total benthic fauna.

Since there was no distinct separation of sample clusters in May (Figure 9), all sample sites were within one main cluster. All sites had similar percent compositions of the dominant feeding groups, with the exception of a slight increase in the detritivore/herbivores at Site 5. This was the result of an increase in the numbers of *Cricotopus/Orthocladius* spp. and *Rhithrogena* sp., which are detritivore/herbivores, at Site 5 (Figure 10).

October

The trophic analysis showed that all the sites were dominated by detritivore/herbivores, followed by detritivores in October (Figure 14). The detritivore/herbivores formed 55.2 to 74.6 % and the detritivores formed 13.3 to 31.9 % of the total benthic fauna. The third and fourth dominant groups were the herbivores and carnivores, which formed 0.1 to 8.8 % and 1.8 to 5.3 %, respectively, of the total benthic fauna. The ominores also formed 0.2 to 5.3 % of the total benthic fauna, however they occurred mainly at downstream sites. All other feedings groups formed less than 1 % of the total benthic fauna.

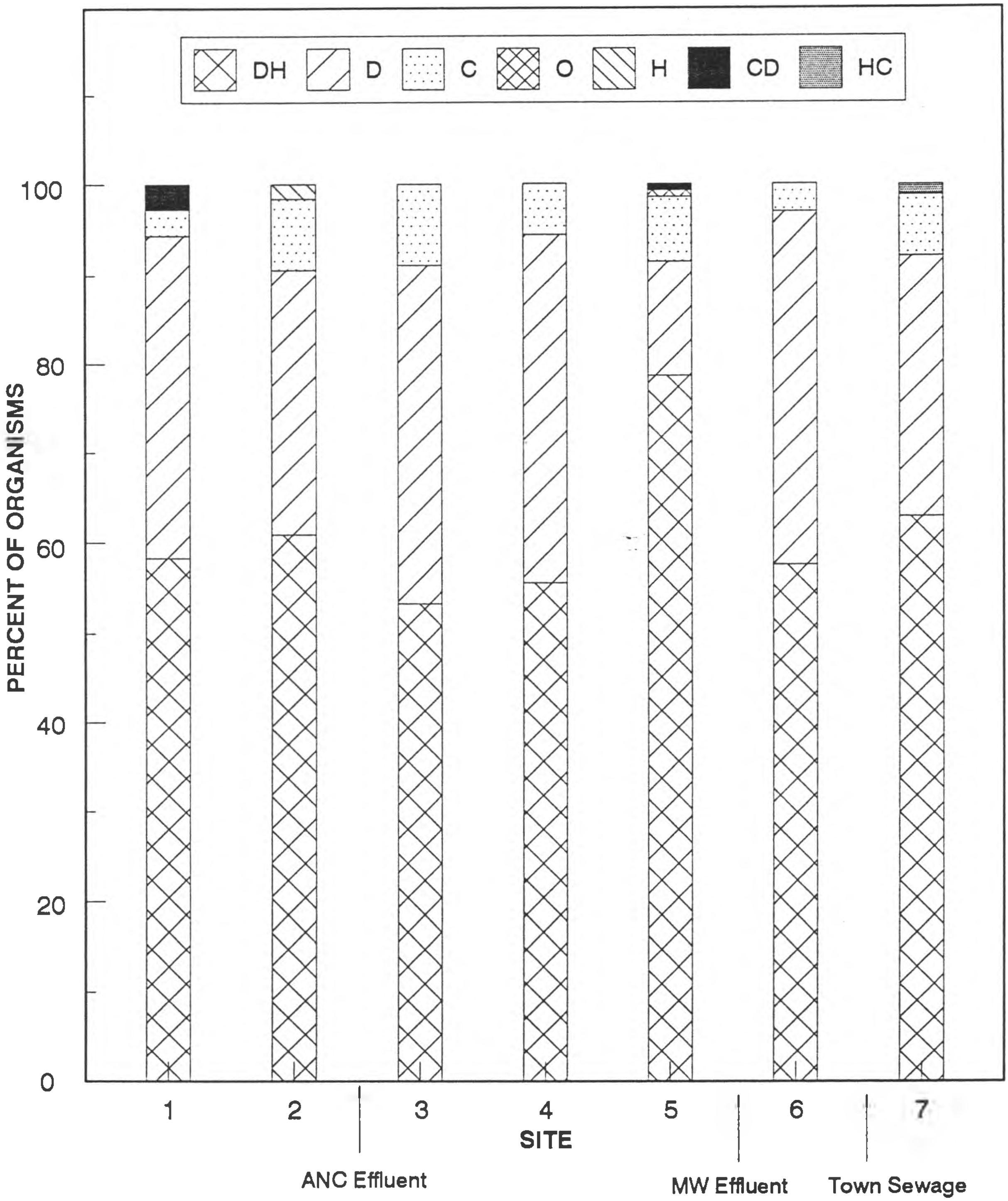

Figure 13. **Percent composition of benthic invertebrate functional feeding groups for sites on the Athabasca River, May 1991.**

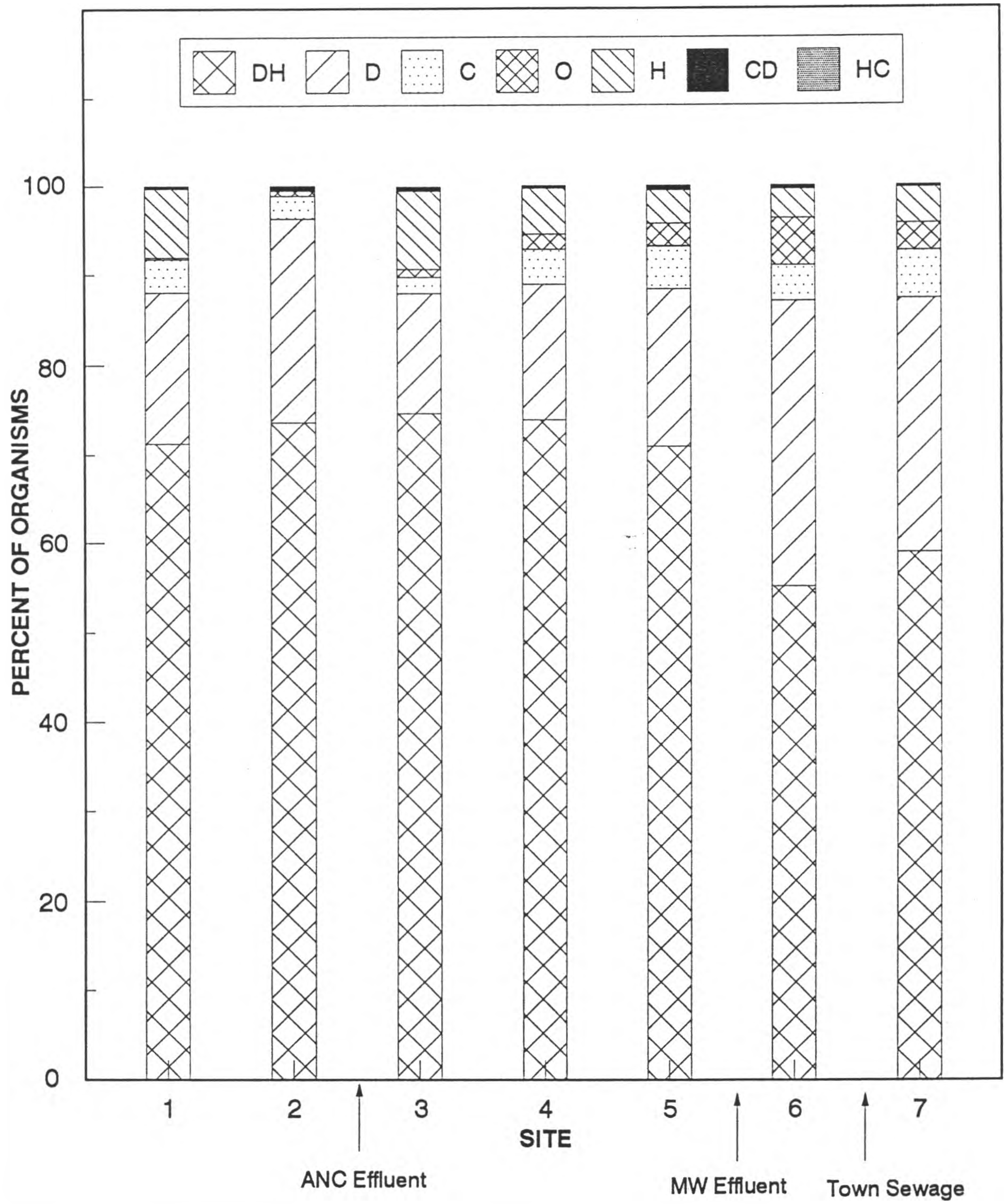

Figure 14. **Percent composition of benthic invertebrate functional feeding groups for sites on the Athabasca River, October 1991.**

The percent contribution of the dominant feeding groups for each cluster of sample sites (using individual samples) identified by RA for the October data was as follows:

Cluster	DH	D	H	C	O
I (Sites 1, 5)	64.6-77.4	12.2-20.9	2.9-11.5	2.2-6.0	0-4.9
II (Sites 3, 4)	66.5-81.2	7.7-19.6	3.8-11.6	0.5-4.6	0.1-1.9
III (Sites 2, 6, 7)	52.4-75.9	20.9-34.3	0-6.1	1.9-6.3	0.3-7.6

Cluster I had a high percentage of detritivore/herbivores, followed by detritivores and herbivores, and then similar percentages of carnivores and omnivores. Cluster II also had a high percentage of detritivore/herbivores, followed by detritivores, herbivores, carnivores and omnivores. Cluster II had a slightly higher percentage of detritivore/herbivores and a slightly lower percentage of carnivores and omnivores, compared to Cluster I. Cluster III had a high percentage of detritivore/herbivores, followed by detritivores and then omnivores, carnivores and herbivores. There was a lower percentage of detritivore/herbivores and a higher percentage of detritivores in Cluster III, compared to Clusters I and II. This was the result of an increase in the numbers of *Rheotanytarsus* spp. (a detritivore) in Cluster III. There was also a slightly higher percentage of omnivores in Cluster III, compared to Clusters I and II, as a result of the increase in the numbers of *Brachycentrus* sp. (Trichoptera). A slight decrease in the percentage of herbivores in Cluster III, compared to Clusters I and II, was caused by a decrease in the numbers of *Taenionema* sp.

The trophic analysis indicated that similar trends were apparent in the October benthic data, as was found by the RA analysis. Increases in the numbers of certain organisms and shifts in the feeding group structure occurred as a result of the change in the nature of the food supply caused by organic enrichment in the Athabasca River from the pulp mill and sewage effluents.

3.3.4 Comparison to Pre-Operational Surveys

To further assess the effects of pulp mill effluent on the benthic invertebrates of the Athabasca River, a comparison was made between the pre-operational and post-operational surveys. Pre-operational conditions existed in the spring and fall of 1989 and the spring of 1990, while start-up conditions existed in the fall of 1990. Post-operational conditions existed during 1991.

Benthic community structure is known to differ between seasons which is caused by the reduction and/or addition of numbers of species of organisms through emergence and recruitment (Hynes 1972). Similar to differences between seasons, the benthic community structure can differ between years, as a result of numerous factors, such as hydraulic and other physical habitat conditions in the river. It can therefore be difficult to make direct comparisons of benthic data between years. However, a comparison between pre-operational and post-operational data can be of importance in determining general trends in the benthic community structure.

In the spring of 1991, the mean number of taxa and the mean standing crop at all sites were lower than during the spring pre-operational surveys in 1989 and 1990 (Tables 6 and 7). The mean species diversity at all sites, except Sites 6 and 7, in the spring of 1991 was lower than during the spring pre-operational surveys (Table 8). The high flows encountered during the spring of 1991 likely caused these decreases.

In the fall of 1991, the mean number of taxa at all sites, except Sites 1 and 3, was higher than the values found during the pre-operational survey in 1989 (Table 6). A decrease in mean number of taxa occurred at both a background site (Site 1) and a downstream site (Site 3) in 1991. The mean standing crop in the fall of 1991 at all sites was higher than during the pre-operational survey in 1989, and at all sites, except Sites 3 and 5, it was higher than during startup conditions in 1990 (Table 7). The mean species diversity in the fall of 1991 at all sites, except Site 6, was lower than during 1989. This decrease occurred at background sites, as well as at downstream sites. However, the mean species diversity at all sites, except Sites 1 and 2, was higher in 1991 than during startup conditions in 1990 (Table 8). A low species diversity indicates that the majority of organisms present belong to only a few taxa and that other fauna are low in numbers, thus causing an uneven distribution. This is typically the result of organic enrichment, where a few taxa, which are more suited to organic enrichment, increase in numbers. Even though there was an increase in the numbers of taxa and standing crops at Sites 6 and 7 in 1991, the increase in standing crops did not occur equally among the taxa and therefore, the species diversity did not increase.

During the pre-operational surveys, the benthic community structure of Sites 1 to 5, upstream of the Millar Western pulp mill and Whitecourt sewage treatment plant indicated the presence of mild natural organic enrichment (Beak 1990, 1991). Effluents from the Millar Western pulp mill and Whitecourt sewage treatment plant appeared to contribute

Table 6. **Comparison of mean number of taxa between 1991 and pre-operational surveys (1989 - 1990)*.**

	Spring			Fall		
Site	**1989**	**1990**	**1991**	**1989**	**1990**	**1991**
1	21	14	9	24	21	19
2	25	19	7	26	29	29
3	23	18	6	25	23	18
4	22	31	5	23	23	27
5	20	11	10	21	24	24
6	32	12	8	24	21	32
7	32	13	10	27	26	36

* Pre-operational surveys included the spring and fall of 1989 and the spring of 1990, with startup conditions in the fall of 1990.

Table 7. Comparison of mean standing crop (number/m^2) between 1991 and pre-operational surveys (1989 - 1990)*.

Site	Spring 1989	Spring 1990	Spring 1991	Fall 1989	Fall 1990	Fall 1991
1	2,018	643	242	3,803	1,760	6,045
2	3,161	1,242	143	5,226	10,428	17,103
3	1,661	2,224	101	5,096	11,480	8,170
4	1,303	5,184	81	3,309	20,989	24,922
5	5,211	702	316	3,507	20,955	10,188
6	7,128	735	148	7,482	15,195	18,587
7	23,359	596	200	9,670	18,191	23,047

* Pre-operational surveys included the spring and fall of 1989 and the spring of 1990, with startup conditions in the fall of 1990.

Table 8. **Comparison of mean species diversity (Shannon-Weaver Index) between 1991 and pre-operational surveys (1989 - 1990)*.**

	Spring			Fall		
Site	**1989**	**1990**	**1991**	**1989**	**1990**	**1991**
1	2.46	1.90	1.86	2.54	2.42	1.98
2	2.70	2.09	1.51	2.17	2.17	1.73
3	2.67	1.57	1.51	2.29	1.15	1.62
4	2.68	1.97	1.31	2.37	1.33	1.72
5	1.95	1.72	1.66	2.29	1.11	2.04
6	2.57	1.18	1.82	2.15	1.18	2.15
7	1.83	2.00	2.12	2.37	1.75	2.16

* Pre-operational surveys included the spring and fall of 1989 and the spring of 1990, with startup conditions in the fall of 1990.

additional mild organic enrichment to downstream sites, especially at Site 7. This was indicated by several taxa which have been found to increase in organic loading, as long as oxygen is not limiting (Tables 9 and 10).

In the spring of 1991, the dominant benthic community structure of most sites indicated a decrease in the number of dominant taxa present at each site, in comparison to pre-operational surveys (Table 9). This was likely an effect of the high flows encountered during the spring survey.

In the fall of 1991, the dominant benthic community structure of background Site 1 and especially Site 2 indicated the presence of mild organic enrichment, similar to previous years. The dominant benthic community structure of downstream sites during the fall of 1991 was similar to the pre-operational surveys, except that some taxa increased in numbers as a response to organic loading from pulp mill and sewage effluents causing a change in the sequence of the dominant taxa (Table 10).

Table 9. **Comparison of dominant taxa in the spring between 1991 and the pre-operational surveys (1989-1990).**

Site	Year	Dominant Taxa
1	1989	*Isoperla* sp., *Cricotopus/Orthocladius* spp., *Rhithrogena* sp., *Eukiefferiella* spp., Naididae
	1990	*Cricotopus/Orthocladius* spp., Enchytraeidae, *Ephemerella inermis*
	1991	*Cricotopus/Orthocladius* spp., *Ephemerella inermis*
2	1989	*Cricotopus/Orthocladius* spp., *Eukiefferiella* spp., *Lymnaea* sp., *Rhithrogena* sp., Naididae, *Isoperla* sp.
	1990	*Cricotopus/Orthocladius* spp., *Ephemerella inermis,* Naididae
	1991	*Cricotopus/Orthocladius* spp., *Ephemerella inermis*
3	1989	*Cricotopus/Orthocladius* spp., *Brachycentrus* sp., Naididae, Tubificidae, *Baetis* spp., *Rhithrogena* sp., *Eukiefferiella* spp., *Hydropsyche* spp.
	1990	*Cricotopus/Orthocladius* spp., *Ephemerella inermis*, *Rhithrogena* sp.
	1991	*Baetis* spp., *Cricotopus/Orthocladius* spp.
4	1989	*Isoperla* sp., *Rhithrogena* sp., Heptageniidae, Naididae, Tubificidae, *Baetis* spp., *Brachycentrus* sp.
	1990	*Cricotopus/Orthocladius* spp., *Ephemerella inermis*
	1991	*Rhithrogena* sp., *Cricotopus/Orthocladius* spp.
5	1989	*Cricotopus/Orthocladius* spp., *Eukiefferiella* spp., *Baetis* spp.
	1990	*Cricotopus/Orthocladius* spp., *Rhithrogena* sp., Tubificidae, *Baetis* spp.
	1991	*Cricotopus/Orthocladius* spp., *Rhithrogena* sp.
6	1989	*Cricotopus/Orthocladius* spp., *Eukiefferiella* spp., *Hydropsyche* spp., *Baetis* spp., Naididae
	1990	*Cricotopus/Orthocladius* spp.
	1991	*Cricotopus/Orthocladius* spp., *Polypedilum* spp.
7	1989	*Cricotopus/Orthocladius* spp., *Eukiefferiella* spp., *Hydropsyche* spp.
	1990	*Cricotopus/Orthocladius* spp., Enchytraeidae, *Ephemerella inermis*, *Micropsectra* sp., Naididae
	1991	*Cricotopus/Orthocladius* spp., *Ephermerella inermis*, *Rhithrogena* sp.

Table 10. Comparison of dominant taxa in the fall between 1991 and the pre-operational surveys (1989 - 1990)*.

Site	Year	Dominant Taxa
1	1989	*Ephemerella inermis*, *Rhithrogena* sp., *Cricotopus/Orthocladius* spp., *Taenionema* sp., *Tvetenia* spp., *Baetis* spp., Hydracarina
	1990	*Cricotopus/Orthocladius* spp., *Rhithrogena* sp., *Ephemerella inermis*, Capniidae, *Taenionema* sp., Enchytraeidae
	1991	*Cricotopus/Orthocladius* spp., *Baetis* spp., Capniidae, *Rhithrogena* sp., *Taenionema* sp.
2	1989	*Ephemerella inermis*, *Micropsectra* sp., *Cricotopus/Orthocladius* spp., Hydracarina, *Rheotanytarsus* spp., *Tvetenia* spp.
	1990	*Cricotopus/Orthocladius* spp., *Rheotanytarsus* spp., *Ephemerella inermis*
	1991	*Cricotopus/Orthocladius* spp., *Ephemerella inermis*, Capniidae, *Rheotanytarsus* spp.
3	1989	*Ephemerella inermis*, *Micropsectra* sp., *Rhithrogena* sp., *Cricotopus/Orthocladius* spp., Hydracarina, *Tvetenia* spp.
	1990	*Cricotopus/Orthocladius* spp.
	1991	*Cricotopus/Orthocladius* spp., *Baetis* spp., *Taenionema* sp., Capniidae
4	1989	*Ephemerella inermis*, *Cricotopus/Orthocladius* spp., *Micropsectra* sp., *Taenionema* sp, Hydracarina, *Rhithrogena* sp., *Tvetenia* spp.
	1990	*Cricotopus/Orthocladius* spp., *Rheotanytarsus* spp., *Ephemerella inermis*
	1991	*Cricotopus/Orthocladius* spp., *Baetis* spp., *Taenionema* sp.
5	1989	*Rhithrogena* sp., *Ephemerella inermis*, Hydracarina, *Baetis* spp., *Taenionema* sp., *Tvetenia* spp., *Cricotopus/Orthocladius* spp., *Rheotanytarsus* spp.
	1990	*Cricotopus/Orthocladius* spp.
	1991	*Cricotopus/Orthocladius* spp., *Baetis* spp., Capniidae, *Rhithrogena* sp.
6	1989	*Micropsectra* sp., *Ephemerella inermis*, *Cricotopus/Orthocladius* spp., *Baetis* spp., *Taenionema* sp.
	1990	*Cricotopus/Orthocladius* spp., *Rheotanytarsus* spp.
	1991	*Cricotopus/Orthocladius* spp., *Rheotanytarsus* spp., *Ephemerella inermis*
7	1989	*Micropsectra* sp., *Ephemerella inermis*, *Cricotopus/Orthocladius* spp., Hydracarina, Naididae
	1990	*Cricotopus/Orthocladius* spp., *Rheotanytarsus* spp., *Ephemerella inermis*, *Taenionema* sp.
	1991	*Cricotopus/Orthocladius* spp., *Rheotanytarsus* spp., *Ephemerella inermis*

* Pre-operational surveys included the fall of 1989, with startup conditions in the fall of 1990.

4.0 SUMMARY AND CONCLUSIONS

There were some variations in the physical characteristics of water velocity, water depth and substrate composition between sites and seasons, which were the result of hydraulic and other physical habitat differences between reaches of the river and changes in flow regime between seasons. The spring survey was conducted during much higher flows than in previous surveys. The documented differences in physical characteristics, other than the presence of algae, did not likely cause any detectable differences in benthic community structure between sites within a season.

The water quality data indicated that the Athabasca River was a well oxygenated, alkaline stream during both the spring and fall surveys. Biochemical oxygen demand (BOD) concentrations in the river were low during both surveys and were not affected by treated effluent discharge from ANC, Miller Western and the Whitecourt sewage treatment plant. BOD concentrations were slightly higher in the spring than in the fall as a result of organic inputs associated with the spring freshet and a rainfall event. Total suspended solids (TSS) concentrations were high in the spring due to high flows and water levels. In the fall, treated effluent discharge from both ANC and Miller Western resulted in slight increases in TSS concentrations at sites immediately below the effluent outfalls. Total phosphorus concentrations were higher than at background sites at Site 6 in May and Site 7 in October, likely as a result of effluent inputs.

Detailed water quality analyses at Sites 2 and 3 indicated that many parameters were below detection limits and/or did not exceed provincial objectives or federal guidelines. In May, concentrations of cadmium, manganese, chromium, iron and silver exceeded guideline levels due to the high suspended sediment load during the spring freshet. Total resin and fatty acids concentrations were below the detection limit of 10 μg/L, except at Site 3 in May. However, the resin and fatty acids detected at this site were probably the result of glassware contamination since the total resin and fatty acids concentration in the sample exceeded the maximum concentration recorded in pure treated effluent. Chlorinated resin acids from an unknown source were also detected at Site 3. Chlorinated resin acids are produced only when chlorine is used in pulp bleaching. ANC does not use chlorine or chlorine-based compounds in any of its pulping processes. The presence of these chlorinated compounds also suggested sample contamination.

The mean number of taxa and mean standing crop during the May survey were low, probably due to the high flows encountered during the survey. There were no significant differences in the mean numbers of taxa between sites, but there were significant differences in mean standing crops between sites in May. The mean standing crops at all downstream sites were, however, similar to at least one of the background sites. The mean species diversity values in May also reflected the effects of the high flows. Ephemeroptera, Chironomidae and Oligochaeta were the dominant taxonomic groups at all sites during May.

In October, there were significant differences in the mean numbers of taxa and the mean standing crops between sites. The mean numbers of taxa at all downstream sites were similar to or intermediate to the background values, except at Site 7, where it was significantly greater than at background sites. The mean standing crops at all downstream sites were similar to at least one of the background sites, except at Site 4, where it was significantly greater than at background sites. The mean species diversity values at all downstream sites during October were similar to or slightly above background values. Ephemeroptera, Plecoptera and Chironomidae were the dominant taxonomic groups at all sites during October. The increases in mean standing crops at downstream sites during October were likely the result of organic loading from the ANC, the Millar Western and the Whitecourt sewage treatment effluents. Tolerant taxa, mainly Chironomidae, as well as intolerant taxa (Ephemeroptera and Plecoptera), increased in numbers at downstream sites, as a response to the organic enrichment. There were no clear relationships between algal density and the number of taxa and standing crop of benthic invertebrates at sites.

A number of taxa have been found to respond to organic enrichment, by increasing in numbers, as a response to an increase in food availability, if oxygen is not limiting. The community analysis indicated that the dominant taxa characteristic of sites in May are suited to mild organic enrichment. However, the magnitude of increase of these taxa at downstream sites was small, when compared to mean standing crops found in the spring of previous years. Any potential organic enrichment effects in May may have been masked by substrate scour due to high flows and/or high water levels which caused sampling to be conducted in areas which may not have been underwater year-round. During October, as in previous surveys, the dominant benthic community structure of the background sites indicated the presence of mild organic enrichment, especially at Site 2. The ANC effluent appeared to contribute some additional organic enrichment at downstream Site 4. Some recovery of the system, indicated by a decrease in the standing crop of dominant taxa, appeared to occur at Site 5. However, then the Millar Western and the Whitecourt sewage treatment effluents appeared to contribute further organic enrichment at Sites 6 and 7.

The trophic analysis showed that all sites during both the spring and fall surveys were dominated by detritivore/herbivores and detritivores, which is a common natural trait of most streams in North America. The third dominant group was carnivores in May. All sites in May had similar percent compositions of the dominant feeding groups, with the exception of a slight increase in detritivore/herbivores at Site 5. In October, the third and fourth dominant groups were the herbivores and carnivores, followed by omnivores which occurred mainly at downstream sites. The trophic analysis indicated that similar trends were apparent in the October benthic data, as was found by the RA analysis. Increases in the numbers of certain organisms and shifts in the feeding group structure occurred as a result of the change in the nature of the food supply caused by organic enrichment in the Athabasca River from the pulp mill and sewage effluents.

A general comparison was made of the pre-operational and post-operational surveys. In the spring of 1991, the mean number of taxa, mean standing crop and mean species diversity at most sites were lower than during the spring pre-operational surveys. In general, the benthic community structure of most sites in the spring of 1991 indicated a decrease in the number of dominant taxa present at each site, in comparison to pre-operational surveys. The high flows encountered during the spring 1991 survey likely caused these decreases.

In the fall of 1991, the mean number of taxa at all sites, except background Site 1 and downstream Site 3, was higher than during the 1989 fall pre-operational survey. The mean standing crop in the fall of 1991 at all sites was higher than during the 1989 pre-operational survey, and at all sites, except at Sites 3 and 5, it was higher than during startup conditions in 1990. The mean species diversity in the fall of 1991 at all sites (including background sites), except Site 6, was lower than during the 1989 survey. However, the mean species diversity at all sites, except Sites 1 and 2, was higher in 1991 than during startup conditions in 1990. A low species diversity is typically the result of organic enrichment, where a few taxa, which are more suited to organic enrichment, increase in numbers, thus causing an uneven distribution. The dominant benthic community structure of downstream sites during the fall of 1991 was similar to the pre-operational surveys, except that some taxa increased in numbers as a response to organic loading from pulp mill and sewage effluents, causing a change in the sequence of the dominant taxa.

The benthic invertebrates of the Athabasca River at downstream sites responded to mild organic enrichment from the pulp mill and sewage treatment effluents by an increase in the populations of certain tolerant, as well as intolerant taxa. The benthic community structure also shifted to one of increasing proportions of tolerant taxa at downstream sites, which is a typical response to mild organic enrichment. The fall survey indicated some recovery of the system occurred downstream of the ANC mill site and just upstream of the Millar Western mill site.

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APPENDICES

APPENDIX A

PHYSICAL CHARACTERISTICS (WATER VELOCITY, WATER DEPTH AND SUBSTRATE COMPOSITION) OF SAMPLE LOCATIONS, MAY AND OCTOBER 1991

Appendix A-1. **Water velocity and depth for each sample location with means and 95% confidence limits (CL) per site, May 1991.**

Site-Sample	Water Velocity* cm/s	Water Depth cm
1-1	55	44
1-2	67	43
1-3	78	44
1-4	87	45
1-5	70	43
Mean ± 95% CL	71 ± 15	44 ± 1
2-1	56	45
2-2	53	43
2-3	49	44
2-4	72	43
2-5	72	43
Mean ± 95% CL	60 ± 14	44 ± 1
3-1	52	45
3-2	77	42
3-3	78	43
3-4	82	42
3-5	63	42
Mean ± 95% CL	70 ± 16	43 ± 2
4-1	54	44
4-2	69	43
4-3	60	44
4-4	72	43
4-5	79	43
Mean ± 95% CL	67 ± 12	43 ± 1
5-1	72	45
5-2	77	44
5-3	68	43
5-4	72	43
5-5	66	43
Mean ± 95% CL	71 ± 5	44 ± 1
6-1	49	46
6-2	48	47
6-3	65	46
6-4	58	48
6-5	69	48
Mean ± 95% CL	58 ± 12	47 ± 1
7-1	53	43
7-2	56	45
7-3	50	45
7-4	56	44
7-5	50	45
Mean ± 95% CL	53 ± 4	44 ± 1

* Water velocity for each sample was an average of three measurements.

Appendix A-2. **Water velocity and depth for each sample location with means and 95% confidence limits (CL) per site, October 1991.**

Site-Sample	Water Velocity* cm/s	Water Depth cm
1-1	57	32
1-2	57	36
1-3	62	36
1-4	52	33
1-5	47	33
Mean ± 95% CL	55 ± 7	34 ± 2
2-1	27	35
2-2	36	36
2-3	37	36
2-4	36	38
2-5	28	37
Mean ± 95% CL	33 ± 6	36 ± 1
3-1	57	32
3-2	63	32
3-3	56	33
3-4	51	36
3-5	51	35
Mean ± 95% CL	56 ± 6	34 ± 2
4-1	66	31
4-2	71	32
4-3	60	34
4-4	55	39
4-5	74	37
Mean ± 95% CL	65 ± 10	35 ± 4
5-1	45	35
5-2	51	34
5-3	42	35
5-4	52	36
5-5	43	36
Mean ± 95% CL	47 ± 6	35 ± 1
6-1	42	35
6-2	42	35
6-3	49	36
6-4	40	35
6-5	39	36
Mean ± 95% CL	42 ± 5	35 ± 1
7-1	39	32
7-2	42	35
7-3	41	36
7-4	45	36
7-5	42	35
Mean ± 95% CL	42 ± 3	35 ± 2

* Water velocity for each sample was an average of three measurements.

Appendix A-3. Substrate size distribution (percentage by weight) for each sample location with means and 95% confidence limits (CL) per site, May 1991.

Site-Sample	Cobble 64-256 mm	Pebble 16-64 mm	Large Gravel 4-16 mm	Small Gravel 2-4 mm	Coarse Sand 0.5-2 mm
1-1	39.8	60.2	-	-	-
1-2	13.0	87.0	-	-	-
1-3	43.7	56.3	-	-	-
1-4	28.9	71.1	-	-	-
1-5	47.9	52.1	-	-	-
Mean ± 95% CL	34.7 ± 17.4	65.3 ± 17.4	-	-	-
2-1	50.1	49.9	-	-	-
2-2	43.1	56.9	-	-	-
2-3	45.4	54.6	-	-	-
2-4	13.5	86.5	-	-	-
2-5	40.4	59.6	-	-	-
Mean ± 95% CL	38.5 ± 17.9	61.5 ± 17.9	-	-	-
3-1	36.9	62.9	0.2	-	-
3-2	40.4	59.6	-	-	-
3-3	20.7	79.3	-	-	-
3-4	44.2	55.8	-	-	-
3-5	22.7	77.2	0.1	-	-
Mean ± 95% CL	33.0 ± 13.2	66.9 ± 13.2	0.1 ± 0.1	-	-
4-1	55.6	43.6	0.7	<0.1	-
4-2	54.8	42.0	3.2	-	-
4-3	69.8	28.4	1.8	-	-
4-4	65.1	33.3	1.6	-	-
4-5	56.2	42.4	1.4	-	-
Mean ± 95% CL	60.3 ± 8.4	37.9 ± 8.3	1.7 ± 1.1	<0.1 ± 0.1	-
5-1	38.1	61.9	-	-	-
5-2	26.6	73.4	-	-	-
5-3	16.2	83.8	-	-	-
5-4	35.3	64.7	-	-	-
5-5	27.2	72.8	-	-	-
Mean ± 95% CL	28.7 ± 10.7	71.3 ± 10.7	-	-	-
6-1	56.9	42.8	0.3	-	-
6-2	60.6	39.0	0.4	-	-
6-3	61.4	38.5	<0.1	-	-
6-4	52.2	47.7	0.1	-	-
6-5	77.5	22.4	<0.1	-	-
Mean ± 95% CL	61.7 ± 11.8	38.1 ± 11.8	0.2 ± 0.2	-	-
7-1	30.2	68.4	1.4	-	-
7-2	25.0	71.7	3.2	<0.1	-
7-3	33.0	63.9	3.0	<0.1	-
7-4	50.2	46.5	3.2	<0.1	-
7-5	29.2	67.9	2.8	<0.1	-
Mean ± 95% CL	33.5 ± 12.1	63.7 ± 12.4	2.7 ± 0.9	<0.1 ± 0.1	-

Appendix A-4. Substrate size distribution (percentage by weight) for each sample location with means and 95% confidence limits (CL) per site, October 1991.

Site-Sample	Cobble 64-256 mm	Pebble 16-64 mm	Large Gravel 4-16 mm	Small Gravel 2-4 mm	Coarse Sand 0.5-2 mm
1-1	59.6	40.4	-	-	-
1-2	40.3	59.7	-	-	-
1-3	46.4	53.6	-	-	-
1-4	24.1	75.9	-	-	-
1-5	49.4	50.6	-	-	-
Mean ± 95% CL	44.0 ± 16.3	56.0 ± 16.3	-	-	-
2-1	62.1	37.9	-	-	-
2-2	65.0	34.9	<0.1	-	-
2-3	67.1	32.9	-	-	-
2-4	58.1	41.8	<0.1	-	-
2-5	71.8	28.1	<0.1	-	-
Mean ± 95% CL	64.8 ± 6.4	35.1 ± 6.4	<0.1 ± 0.1	-	-
3-1	67.6	32.4	-	-	-
3-2	40.6	59.4	-	-	-
3-3	45.6	54.4	-	-	-
3-4	47.9	52.1	-	-	-
3-5	55.0	45.0	-	-	-
Mean ± 95% CL	51.3 ± 13.0	48.7 ± 13.0	-	-	-
4-1	73.3	26.7	-	-	-
4-2	49.2	50.8	-	-	-
4-3	32.0	68.0	-	-	-
4-4	48.5	51.5	-	-	-
4-5	51.6	48.4	-	-	-
Mean ± 95% CL	50.9 ± 18.3	49.1 ± 18.3	-	-	-
5-1	59.4	40.6	-	-	-
5-2	58.8	40.7	0.5	-	-
5-3	57.2	42.5	0.3	-	-
5-4	64.1	35.8	0.1	-	-
5-5	62.7	37.1	0.2	-	-
Mean ± 95% CL	60.4 ± 3.5	39.4 ± 3.5	0.2 ± 0.2	-	-
6-1	76.2	22.1	1.7	-	-
6-2	57.2	41.7	1.1	-	-
6-3	69.8	29.0	1.1	<0.1	-
6-4	67.9	31.0	1.1	-	-
6-5	82.2	17.2	0.6	-	-
Mean ± 95% CL	70.6 ± 11.7	28.2 ± 11.6	1.1 ± 0.5	<0.1 ± 0.1	-
7-1	30.7	68.2	1.1	-	-
7-2	77.0	20.3	2.3	0.4	-
7-3	54.1	44.0	1.8	0.1	-
7-4	60.9	38.0	1.1	-	-
7-5	39.7	60.3	-	-	-
Mean ± 95% CL	52.5 ± 22.5	46.2 ± 23.4	1.2 ± 1.1	0.1 ± 0.2	-

Appendix A-5. The thickness of algal growth on the substrate for each site, May and October 1991.

Site	Algal Thickness (mm)* Cobble 1	Cobble 2	Cobble 3	Mean	Algal Growth Category
May					
1	-	-	-	-	None**
2	-	-	-	-	None
3	-	-	-	-	None
4	-	-	-	-	None
5	-	-	-	-	None
6	-	-	-	-	None
7	-	-	-	-	None
October					
1	1, 1, <1	1, 1, <1	<1, <1, <1	<1	Light
2	<1, <1, <1	1, <1, <1	1, <1, <1	<1	Light
3	4, 5, 4	8, 8, 7	8, 9, 7	7	Heavy
4	2, 3, 3	4, 3, 3	4, 3, 4	3	Moderate
5	8, 6, 6	8, 7, 7	6, 5, 7	7	Heavy
6	2, 2, 2	3, 3, 2	2, 1, 2	2	Moderate
7	1, 1, 1	-	-	1	Light

* Three measurements were taken for each cobble.
** No algal growth was obvious.

APPENDIX B

AVERAGE MONTHLY CONCENTRATIONS OF SELECTED PARAMETERS FOR MILLAR WESTERN FINAL EFFLUENT, 1991

Appendix B. Average monthly concentrations of selected parameters for Millar Western final effluent, spring (March - May) and fall (August - October) 1991.

Parameter*	Spring			Fall		
	March	April	May	August	September	October
Discharge (m^3/d)	13,434	13,095	11,751	11,483	11,065	12,883
pH (units)	8.3	8.4	8.4	8.4	8.4	8.3
Dissolved Oxygen (mg/L)	4.1	3.6	3.2	4.1	5.8	6.0
Dissolved Oxygen (percent saturation)	59	54	46	61	83	86
Temperature (°C)	30.3	32.4	31.1	32.6	29.5	29.4
True Color (units)	892	763	734	954	782	624
Total Phosphorus (as P) (mg/L)	0.5	1.7	1.7	3.0	4.5	3.7
Total Kjeldahl Nitrogen (mg/L)	8.0	7.3	11.6	6.7	5.9	6.5
Total Suspended Solids (mg/L)	349	298	364	185	155	213
Biochemical Oxygen Demand (mg/L)	105	87	92	103	76	83

Source: Millar Western Pulp Ltd. (unpublished data)

* All monthly averages were based on daily values, except for total phosphorus and total Kjeldahl nitrogen, which were weekly values.

APPENDIX C

SPECIES IDENTIFICATIONS AND NUMBERS PER SAMPLE, MAY AND OCTOBER 1991

Site 1 - May 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp.	0	1	1	0	0
Ephemerellidae					
Ephemerella inermis	0	1	0	3	1
Heptageniidae					
Rhithrogena sp.	0	0	0	0	1
Siphlonuridae					
Ameletus sp.	0	1	0	0	1
Plecoptera					
Chloroperlidae					
Chloroperlinae					
Triznaka sp.	0	0	1	0	0
Diptera					
Empididae					
Chelifera sp.	1	1	0	0	0
Hemerodromia sp.	0	0	0	0	1
Tipulidae					
Hexatoma sp.	0	0	0	0	1
Chironomidae					
Chironominae					
Chironomini Tribe					
Paratendipes sp.	0	1	0	0	0
Polypedilum sp.	2	1	3	1	0
Tanytarsini Tribe					
Micropsectra sp.	1	0	0	0	0
Rheotanytarsus sp.	1	0	1	2	1
Orthocladiinae					
Corynoneura sp.	3	0	1	0	1
Cricotopus/Orthocladius spp.	15	12	8	5	5
Eukiefferiella sp.	1	0	0	0	0
Parakiefferiella sp.	1	1	0	0	0
Parametriocnemus sp.	0	0	0	0	1
Prodiamesinae					
Monodiamesa sp.	0	0	0	1	0
Tanypodinae					
Macropelopiini Tribe					
Procladius sp.	0	0	0	1	0
Haplotaxida					
Enchytraeidae	6	4	2	1	0
Naididae	0	0	0	0	1
Tubificidae	0	0	1	0	0
Nematoda	3	3	1	1	0

Site 2 - May 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp.	1	0	1	0	0
Ephemerellidae					
Ephemerella inermis	2	0	0	0	1
Heptageniidae					
Rhithrogena sp.	0	0	0	1	0
Plecoptera					
Capniidae	0	0	0	1	0
Perlodidae					
Isoperla sp.	0	0	1	0	0
Pteronarcyidae					
Taeniopterygidae					
Taenionema sp.	1	0	0	0	0
Diptera					
Tipulidae					
Hexatoma sp.	0	0	2	0	0
Chironomidae					
Chironominae					
Chironomini Tribe					
Paracladopelma/Cyphomella spp.	0	1	0	1	0
Polypedilum sp.	5	0	0	0	0
Tanytarsini Tribe					
Rheotanytarsus sp.	0	0	1	1	0
Orthocladiinae					
Cricotopus/Orthocladius spp.	8	6	5	6	2
Eukiefferiella sp.	0	0	0	1	0
Parakiefferiella sp.	0	0	0	1	0
Thienemanniella sp.	1	0	0	0	0
Tvetenia sp.	0	0	0	1	0
Tanypodinae					
Macropelopiini Tribe					
Procladius sp.	0	1	0	0	0
Pentaneurini Tribe					
Thienemannimyia gp.	1	0	0	0	0
Haplotaxida					
Enchytraeidae	0	0	0	1	0
Naididae	2	0	0	0	0
Tubificidae	0	1	0	1	1
Nematoda	1	0	3	1	0

Site 3 - May 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp.	1	0	1	4	3
Ephemerellidae					
Ephemerella inermis	0	1	0	0	2
Heptageniidae					
Rhithrogena sp.	0	0	2	0	0
Siphlonuridae					
Ameletus sp.	0	0	0	1	0
Plecoptera					
Chloroperlidae					
Chloroperlinae					
Triznaka sp.	0	1	1	0	0
Nemouridae					
Podmosta sp.	0	0	0	0	1
Diptera					
Tipulidae					
Hexatoma sp.	0	1	0	0	0
Chironomidae					
Chironominae					
Chironomini Tribe					
Polypedilum sp.	0	0	1	0	1
Tanytarsini Tribe					
Micropsectra sp.	0	0	0	0	1
Rheotanytarsus sp.	0	1	0	0	0
Orthocladiinae					
Cricotopus/Orthocladius spp.	0	2	2	1	1
Eukiefferiella sp.	0	0	0	1	0
Thienemanniella sp.	0	1	0	0	1
Tvetenia sp.	0	1	0	0	0
Prodiamesinae					
Monodiamesa sp.	0	1	0	1	1
Tanypodinae					
Macropelopiini Tribe					
Procladius sp.	0	1	0	0	0
Haplotaxida					
Tubificidae	3	5	0	0	0

Site 4 - May 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp.	0	1	0	1	0
Ephemerellidae					
Ephemerella inermis	1	0	0	0	0
Heptageniidae					
Rhithrogena sp.	1	0	0	0	2
Siphlonuridae					
Ameletus sp.	0	1	0	1	0
Plecoptera					
Capniidae	1	1	0	0	0
Perlodidae					
Isogenoides sp.	0	0	2	0	0
Diptera					
Chironomidae					
Chironominae					
Chironomini Tribe					
Polypedilum sp.	2	0	0	0	0
Tanytarsini Tribe					
Cladotanytarsus sp.	0	0	1	0	0
Tanytarsus sp.	1	0	0	0	0
Orthocladiinae					
Corynoneura sp.	1	0	0	0	0
Cricotopus/Orthocladius spp.	2	3	0	2	0
Eukiefferiella sp.	1	2	0	0	0
Nanocladius sp.	0	0	0	1	0
Thienemanniella sp.	1	0	0	0	0
Haplotaxida					
Enchytraeidae	0	1	0	1	0
Naididae	0	1	0	0	0
Tubificidae	0	1	0	0	0
Nematoda	2	1	0	0	0

Site 5 - May 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp.	1	1	2	2	1
Ephemerellidae					
Ephemerella inermis	0	1	1	4	0
Heptageniidae					
Rhithrogena sp.	7	2	6	2	5
Trichoptera					
Hydropsychidae					
Hydropsyche sp.	0	0	0	0	1
Plecoptera					
Perlodidae					
Isogenoides sp.	0	0	1	3	0
Isoperla sp.	0	0	1	1	1
Diptera					
Empididae					
Chelifera sp.	0	0	0	1	0
Tipulidae					
Limnophila sp.	0	0	0	0	1
Chironomidae					
Chironominae					
Chironomini Tribe					
Paracladopelma/Cyphomella spp.	0	1	0	0	0
Polypedilum sp.	1	0	1	1	0
Tanytarsini Tribe					
Rheotanytarsus sp.	0	1	2	1	2
Tanytarsus sp.	0	0	0	0	1
Orthocladiinae					
Cricotopus/Orthocladius spp.	7	4	22	13	26
Eukiefferiella sp.	1	0	0	0	0
Nanocladius sp.	0	0	1	0	0
Parakiefferiella sp.	0	0	1	0	0
Tvetenia sp.	0	0	0	0	1
Prodiamesinae					
Monodiamesa sp.	0	0	0	1	0
Tanypodinae					
Pentaneurini Tribe					
Thienemannimyia gp.	0	0	0	1	0
Hydracarina	0	0	0	0	1

(continued)

Site 5 - May 1991 (concluded)

Taxa	Sample 1	2	3	4	5
Haplotaxida					
Enchytraeidae	0	1	0	0	1
Naididae	1	0	0	0	0
Nematoda	1	1	1	0	0

Site 6 - May 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp.	1	0	1	1	1
Ephemerellidae					
Ephemerella inermis	0	1	0	1	1
Heptageniidae					
Rhithrogena sp.	0	0	0	2	1
Leptophlebiidae					
Paraleptophlebia sp.	0	0	0	0	1
Plecoptera					
Perlodidae					
Perlodidae (early instar)	0	0	0	1	1
Diptera					
Chironomidae					
Chironominae					
Chironomini Tribe					
Paracladopelma/Cyphomella spp.	1	0	0	0	1
Polypedilum sp.	3	3	1	1	2
Tanytarsini Tribe					
Rheotanytarsus sp.	1	0	0	1	0
Tanytarsus sp.	0	0	0	0	1
Orthocladiinae					
Cricotopus/Orthocladius spp.	6	0	2	5	3
Eukiefferiella sp.	0	0	0	0	1
Nanocladius sp.	2	0	0	0	1
Parametriocnemus sp.	0	0	0	0	1
Prodiamesinae					
Monodiamesa sp.	0	2	0	1	0
Haplotaxida					
Enchytraeidae	1	1	3	1	1
Naididae	0	0	0	1	3
Nematoda	2	0	0	1	0

Site 7 - May 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Ametropodidae					
Ametropus neavei	0	0	0	0	1
Baetidae					
Baetis sp.	1	0	1	0	2
Ephemerellidae					
Ephemerella inermis	2	6	0	4	2
Heptageniidae					
Rhithrogena sp.	1	3	3	4	5
Paraleptophlebiidae					
Paraleptophlebia sp.	0	0	0	0	1
Plecoptera					
Chloroperlidae					
Chloroperlinae					
Haploperla brevis	0	0	1	0	0
Triznaka sp.	0	0	1	0	0
Perlodidae					
Isogenoides sp.	0	0	2	0	0
Isoperla sp.	1	0	0	0	0
Perlodidae (early instar)	0	0	2	0	0
Diptera					
Chironomidae					
Chironominae					
Chironomini Tribe					
Paracladopelma/Cyphomella spp.	0	0	1	0	0
Paralauterborniella nigrohalteralis	1	0	0	0	1
Polypedilum sp.	1	1	1	0	1
Tanytarsini Tribe					
Micropsectra sp.	0	1	0	0	0
Rheotanytarsus sp.	1	0	0	2	0
Stempellinella sp.	1	0	0	0	0
Tanytarsus sp.	0	0	0	0	1
Orthocladiinae					
Corynoneura sp.	1	0	0	0	0
Cricotopus/Orthocladius spp.	5	2	3	4	2
Nanocladius sp.	0	1	0	0	0
Parakiefferiella sp.	0	0	1	0	0
Synorthocladius sp.	0	0	0	1	0
Thienemanniella sp.	0	2	0	0	1
Prodiamesinae					
Monodiamesa sp.	0	0	0	1	0

(continued)

Site 7 - May 1991 (concluded)

Taxa	Sample 1	2	3	4	5
Haplotaxida					
Enchytraeidae	1	0	0	1	2
Naididae	0	1	0	0	0
Tubificidae	0	1	1	0	0
Nematoda	0	0	1	0	1

Site 1 - October 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp.	63	49	143	68	85
Ephemerellidae					
Ephemerella inermis	30	17	46	20	28
Heptageniidae					
Rhithrogena sp.	48	46	93	80	42
Siphlonuridae					
Ameletus sp.	1	1	0	0	0
Trichoptera					
Brachycentridae					
Brachycentrus sp.	0	2	0	0	0
Hydropsychidae					
Hydropsyche sp.	0	0	0	3	0
Plecoptera					
Capniidae	82	53	99	71	47
Chloroperlidae					
Chloroperlinae (early instar)	1	3	0	1	1
Perlidae					
Claassenia sabulosa	1	0	3	0	1
Perlodidae					
Isogenoides sp.	3	5	8	10	1
Perlodidae (early instar)	4	6	12	6	6
Taeniopterygidae					
Taenionema sp.	23	26	67	57	38
Diptera					
Empididae					
Chelifera sp.	2	0	0	0	2
Hemerodromia sp.	0	2	0	2	0
Tipulidae					
Hexatoma sp.	0	1	0	1	0
Chironomidae					
Chironominae					
Chironomini Tribe					
Paracladopelma/Cyphomella spp.	0	0	0	0	1
Polypedilum sp.	6	10	8	6	2
Tanytarsini Tribe					
Rheotanytarsus sp.	0	6	4	4	2
Orthocladiinae					
Cricotopus/Orthocladius spp.	160	254	223	131	209
Eukiefferiella spp.	2	8	12	14	14
Parakiefferiella sp.	0	2	0	0	0

(continued)

Site 1 - October 1991 (concluded)

Taxa	Sample 1	2	3	4	5
Thienemanniella sp.	2	2	0	0	0
Tvetenia spp.	2	8	8	2	8
Prodiamesinae					
Monodiamesa sp.	0	0	0	2	2
Tanypodinae					
Pentaneurini Tribe					
Thienemannimyia gp.	0	0	4	0	2
Hydracarina	4	0	8	8	0
Haplotaxida					
Enchytraeidae	6	10	12	8	0
Naididae	0	0	4	0	0
Tubificidae	0	2	0	0	0
Nematoda	0	4	0	0	0

Site 2 - October 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Ametropodidae					
Ametropus neavei	0	0	1	0	0
Baetidae					
Baetis sp.	6	9	26	8	2
Ephemerellidae					
Drunella doddsi	1	0	0	0	0
Ephemerella inermis	96	108	198	129	145
Heptageniidae					
Heptagenia sp.	2	2	0	1	0
Rhithrogena sp.	8	13	23	11	17
Siphlonuridae					
Ameletus sp.	0	0	0	0	1
Trichoptera					
Brachycentridae					
Brachycentrus sp.	4	11	14	6	5
Hydropsychidae					
Arctopsyche sp.	0	0	0	0	1
Hydropsyche sp.	0	0	1	0	4
Plecoptera					
Capniidae	73	53	109	101	89
Chloroperlidae					
Chloroperlinae (early instar)	1	2	2	4	1
Perlidae					
Claassenia sabulosa	0	0	0	1	0
Perlodidae					
Isogenoides sp.	2	3	3	0	3
Isoperla sp.	0	0	0	1	0
Perlodidae (early instar)	5	2	0	5	6
Taeniopterygidae					
Taenionema sp.	2	2	0	0	0
Diptera					
Empididae					
Chelifera sp.	0	0	8	0	0
Hemerodromia sp.	2	10	12	0	1
Tipulidae					
Hexatoma sp.	0	2	6	1	2
Chironomidae					
Chironominae					
Chironomini Tribe					
Paracladopelma/Cyphomella spp.	8	10	12	4	12
Polypedilum sp.	2	25	61	24	95

(continued)

Site 2 - October 1991 (concluded)

Taxa	Sample 1	2	3	4	5
Robackia demeijerei	0	0	0	0	4
Tanytarsini Tribe					
Cladotanytarsus sp.	2	10	8	24	20
Micropsectra sp.	0	0	0	0	8
Rheotanytarsus sp.	13	221	136	100	115
Diamesinae					
Diamesini Tribe					
Pagastia sp.	0	5	0	0	0
Orthocladiinae					
Cardiocladius sp.	0	15	4	0	0
Corynoneura sp.	2	0	0	0	0
Cricotopus/Orthocladius spp.	178	1,326	912	1,178	947
Eukiefferiella spp.	4	15	24	12	4
Heterotrissocladius sp.	0	0	4	0	0
Krenosmittia sp.	0	0	0	0	4
Nanocladius sp.	0	0	0	4	4
Parakiefferiella sp.	2	10	4	8	8
Parametriocnemus sp.	0	5	0	0	0
Rheocricotopus sp.	0	0	4	0	0
Synorthocladius sp.	2	25	16	8	16
Thienemanniella sp.	2	1	4	16	8
Tvetenia spp.	0	27	21	12	22
Tanypodinae					
Pentaneurini Tribe					
Thienemannimyia gp.	0	1	6	1	10
Tanypodinae (early instar)	0	0	0	4	0
Hydracarina	7	15	12	40	29
Podocopa					
Candonidae					
Candona sp.	2	0	0	0	0
Haplotaxida					
Enchytraeidae	14	20	20	28	36
Naididae	6	15	64	52	48
Nematoda	4	11	2	19	18

Site 3 - October 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp.	45	109	158	108	86
Acentrella insignificans	0	0	1	0	0
Ephemerellidae					
Ephemerella inermis	14	15	9	20	15
Heptageniidae					
Heptagenia sp.	0	0	1	1	0
Rhithrogena sp.	6	32	18	17	13
Siphlonuridae					
Ameletus sp.	4	2	0	0	0
Trichoptera					
Brachycentridae					
Brachycentrus sp.	1	0	3	2	8
Hydropsychidae					
Arctopsyche sp.	1	1	0	6	0
Hydropsyche sp.	1	0	4	0	4
Plecoptera					
Capniidae	20	58	47	102	57
Chloroperlidae					
Chloroperlinae (early instar)	0	0	5	8	0
Perlidae					
Claassenia sabulosa	0	0	0	1	0
Perlodidae					
Isogenoides sp.	1	4	8	7	16
Pteronarcyidae					
Pteronarcella badia	0	0	0	0	4
Taeniopterygidae					
Taenionema sp.	33	90	75	79	45
Diptera					
Empididae					
Chelifera sp.	4	0	4	0	4
Hemerodromia sp.	0	0	4	4	0
Chironomidae					
Chironominae					
Chironomini Tribe					
Polypedilum sp.	0	8	0	4	0
Tanytarsini Tribe					
Micropsectra sp.	0	0	0	0	4
Rheotanytarsus sp.	8	4	0	0	13

(continued)

Site 3 - October 1991 (concluded)

Taxa	Sample 1	2	3	4	5
Orthocladiinae					
Brillia sp.	5	8	1	1	0
Cardiocladius sp.	4	0	0	0	0
Cricotopus/Orthocladius spp.	230	421	615	363	389
Eukiefferiella spp.	0	8	4	0	0
Thienemanniella sp.	0	0	0	4	0
Tvetenia spp.	13	12	4	24	37
Orthocladiinae (early instar)	4	0	4	0	0
Hydracarina	4	0	8	0	0
Haplotaxida					
Enchytraeidae	0	1	4	0	0
Naididae	8	0	16	20	0
Nematoda	2	4	0	0	0

Site 4 - October 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp.	69	121	173	95	228
Ephemerellidae					
Drunella doddsi	1	4	0	0	0
Ephemerella inermis	13	32	57	65	65
Heptageniidae					
Heptagenia sp.	1	0	0	0	0
Rhithrogena sp.	11	37	21	12	50
Trichoptera					
Brachycentridae					
Brachycentrus sp.	19	23	13	23	14
Hydropsychidae					
Arctopsyche sp.	1	2	1	1	1
Hydropsyche sp.	16	12	24	11	29
Limnephilidae					
Apatania sp.	0	2	0	0	0
Plecoptera					
Capniidae	43	72	59	92	90
Chloroperlidae					
Chloroperlinae (early instar)	6	4	0	17	5
Perlidae					
Claassenia sabulosa	0	0	4	0	4
Hesperoperla pacifica	0	0	0	1	0
Perlodidae					
Isogenoides sp.	6	3	9	4	8
Isoperla sp.	0	4	8	4	1
Perlodidae (early instar)	2	0	0	12	20
Pteronarcyidae					
Pteronarcella badia	1	3	0	0	5
Taeniopterygidae					
Taenionema sp.	94	140	93	90	153
Diptera					
Blephariceridae					
Bibiocephala grandis	0	0	0	0	1
Empididae					
Hemerodromia sp.	0	8	0	4	1
Wiedemannia sp.	0	4	0	0	0
Tanyderidae					
Protanyderus sp.	0	0	0	0	1
Tipulidae					
Hexatoma sp.	0	4	0	0	0

(continued)

Site 4 - October 1991 (concluded)

Taxa	Sample 1	2	3	4	5
Chironomidae					
Chironominae					
Chironomini Tribe					
Polypedilum sp.	0	0	0	12	8
Tanytarsini Tribe					
Cladotanytarsus sp.	0	0	0	8	0
Micropsectra sp.	0	0	4	0	0
Rheotanytarsus sp.	72	64	72	117	95
Sublettea sp.	0	0	0	8	0
Orthocladiinae					
Brillia sp.	1	0	8	0	0
Cardiocladius sp.	47	61	32	24	53
Cricotopus/Orthocladius spp.	1,302	1,091	1,473	1,453	1,312
Eukiefferiella spp.	56	116	108	37	189
Thienemanniella sp.	0	4	0	4	0
Tvetenia spp.	68	112	68	56	45
Orthocladiinae (early instar)	0	0	0	0	1
Prodiamesinae					
Monodiamesa sp.	0	4	0	0	0
Tanypodinae					
Pentaneurini Tribe					
Thienemannimyia gp.	0	0	0	8	14
Hydracarina	5	0	16	29	12
Haplotaxida					
Enchytraeidae	13	32	45	68	73
Naididae	23	28	36	64	37
Tubificidae	1	0	0	4	0
Nematoda	6	13	28	15	13
Tricladida					
Planariidae					
Polycelis coronata	0	4	0	12	4

Site 5 - October 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp.	99	74	68	121	93
Ephemerellidae					
Ephemerella inermis	66	11	44	53	66
Heptageniidae					
Heptagenia sp.	0	0	4	0	0
Rhithrogena sp.	62	68	57	47	87
Siphlonuridae					
Ameletus sp.	4	4	4	12	8
Trichoptera					
Brachycentridae					
Brachycentrus sp.	16	11	20	13	50
Hydropsychidae					
Arctopsyche sp.	0	0	1	1	0
Hydropsyche sp.	5	0	0	0	0
Plecoptera					
Capniidae	133	82	88	76	82
Chloroperlidae					
Chloroperlinae (early instar)	6	0	1	4	4
Perlidae					
Claassenia sabulosa	0	1	0	0	2
Perlodidae					
Isogenoides sp.	11	1	2	7	1
Isoperla sp.	1	0	0	0	0
Perlodidae (early instar)	0	4	5	11	5
Taeniopterygidae					
Taenionema sp.	29	44	32	26	41
Diptera					
Empididae					
Chelifera sp.	1	0	0	4	0
Hemerodromia sp.	4	0	5	8	0
Chironomidae					
Chironominae					
Chironomini Tribe					
Paracladopelma/Cyphomella spp.	4	4	0	0	4
Polypedilum spp.	8	12	12	12	36
Tanytarsini Tribe					
Micropsectra sp.	0	0	1	0	4
Rheotanytarsus sp.	13	20	14	25	21

(continued)

Site 5 - October 1991 (concluded)

Taxa	Sample 1	2	3	4	5
Diamesinae					
Diamesini Tribe					
Diamesa sp.	4	0	0	0	0
Orthocladiinae					
Brillia sp.	4	4	8	5	4
Cricotopus/Orthocladius spp.	434	412	443	360	429
Eukiefferiella spp.	4	0	4	0	4
Parakiefferiella spp.	8	12	0	0	4
Synorthocladius sp.	0	0	0	0	4
Thienemanniella sp.	4	4	0	0	0
Tvetenia spp.	8	12	8	12	8
Prodiamesinae					
Monodiamesa sp.	0	0	0	4	0
Tanypodinae					
Pentaneurini Tribe					
Thienemannimyia gp.	9	0	0	8	9
Hydracarina	30	21	32	21	18
Haplotaxida					
Enchytraeidae	4	5	9	0	9
Naididae	0	0	4	1	8
Nematoda	13	8	14	13	21

Site 6 - October 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp.	28	17	20	12	29
Ephemerellidae					
Drunella doddsi	1	0	4	0	1
Drunella grandis ingens	0	0	1	0	1
Ephemerella inermis	93	92	89	98	113
Heptageniidae					
Heptagenia sp.	5	5	3	0	2
Rhithrogena sp.	8	8	14	16	14
Siphlonuridae					
Ameletus sp.	9	4	4	0	4
Trichoptera					
Brachycentridae					
Brachycentrus sp.	87	31	114	32	115
Glossosomatidae					
Glossosoma sp.	0	0	0	4	0
Hydropsychidae					
Arctopsyche sp.	4	2	1	1	2
Hydropsyche sp.	5	5	5	0	35
Limnephilidae					
Apatania sp.	1	1	0	0	0
Plecoptera					
Capniidae	96	63	90	61	69
Chloroperlidae					
Chloroperlinae (early instar)	6	1	5	0	4
Perlidae					
Claassenia sabulosa	0	4	0	4	1
Perlodidae					
Isogenoides sp.	0	5	0	0	0
Isoperla sp.	0	4	0	0	0
Perlodidae (early instar)	25	14	23	13	33
Taeniopterygidae					
Taenionema sp.	90	54	73	20	21
Diptera					
Empididae					
Chelifera sp.	0	0	8	4	0
Hemerodromia sp.	4	4	4	12	0
Tipulidae					
Hexatoma sp.	0	0	0	2	0

(continued)

Site 6 - October 1991 (concluded)

Taxa	Sample 1	2	3	4	5
Chironomidae					
Chironominae					
Chironomini Tribe					
Paracladopelma/Cyphomella spp.	8	0	0	4	8
Polypedilum sp.	24	65	23	44	12
Tanytarsini Tribe					
Cladotanytarsus sp.	0	12	4	4	12
Micropsectra sp.	4	0	0	8	4
Rheotanytarsus sp.	267	207	222	162	380
Sublettea sp.	16	0	0	8	0
Tanytarsus sp.	0	0	4	0	0
Orthocladiinae					
Brillia sp.	9	0	12	0	4
Cardiocladius sp.	0	12	0	0	4
Corynoneura sp.	8	0	4	4	0
Cricotopus/Orthocladius spp.	799	751	683	580	848
Eukiefferiella spp.	12	0	4	8	28
Krenosmittia sp.	0	0	0	4	0
Nanocladius sp.	0	0	0	0	8
Parakiefferiella sp.	8	0	8	12	5
Thienemanniella sp.	4	20	12	8	4
Tvetenia spp.	50	33	52	20	45
Tanypodinae					
Pentaneurini Tribe					
Thienemannimyia gp.	4	4	0	4	0
Collembola	0	0	0	0	4
Hemiptera					
Corixidae					
Hesperocorixa atopodonta	0	0	0	1	0
Sigara decoratella	0	0	0	2	1
Hydracarina	37	36	33	5	40
Haplotaxida					
Enchytraeidae	12	38	12	37	23
Naididae	74	35	36	59	90
Tubificidae	0	0	0	0	4
Nematoda	47	35	37	30	28

Site 7 - October 1991

Taxa	Sample 1	2	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp.	17	20	27	87	77
Ephemerellidae					
Ephemerella inermis	84	127	129	191	154
Heptageniidae					
Heptagenia sp.	0	0	1	1	7
Rhithrogena sp.	19	32	33	24	62
Leptophlebiidae					
Paraleptophlebia sp.	0	0	4	0	0
Siphlonuridae					
Ameletus sp.	1	0	6	0	0
Tricorythidae					
Tricorythodes sp.	0	4	0	0	0
Trichoptera					
Brachycentridae					
Brachycentrus sp.	21	37	39	79	58
Hydropsychidae					
Arctopsyche sp.	0	0	2	3	3
Cheumatopsyche sp.	0	0	0	0	2
Hydropsyche spp.	0	0	2	3	3
Lepidostomatidae					
Lepidostoma sp.	0	1	0	0	1
Polycentropodidae					
Neureclipsis sp.	0	0	0	0	1
Psychomyiidae					
Psychomyia sp.	0	0	0	1	0
Plecoptera					
Capniidae	61	65	86	47	108
Chloroperlidae					
Chloroperlinae (early instar)	3	2	6	9	6
Perlidae					
Claassenia sabulosa	0	0	1	0	1
Perlodidae					
Isogenoides sp.	3	3	4	1	7
Isoperla sp.	0	1	1	2	1
Perlodidae (early instar)	5	1	11	11	22
Pteronarcyidae					
Pteronarcella badia	1	0	0	0	0
Pteronarys dorsata	0	0	0	2	1
Taeniopterygidae					
Taenionema sp.	44	29	96	105	147

(continued)

Site 7 - October 1991 (concluded)

Taxa	Sample 1	2	3	4	5
Diptera					
Empididae					
Chelifera sp.	0	4	0	0	0
Hemerodromia sp.	2	2	1	5	4
Tipulidae					
Hexatoma sp.	1	0	0	0	0
Chironomidae					
Chironominae					
Chironomini Tribe					
Paracladopelma/Cyphomella spp.	13	0	1	5	4
Polypedilum spp.	24	36	24	9	52
Robackia demeijerei	0	0	0	0	1
Tanytarsini Tribe					
Cladotanytarsus sp.	5	4	8	20	16
Micropsectra sp.	0	4	0	5	8
Rheotanytarsus sp.	111	255	209	377	301
Sublettea sp.	0	24	48	65	18
Orthocladiinae					
Brillia sp.	4	0	0	0	4
Cardiocladius sp.	20	38	10	65	46
Corynoneura sp.	0	4	4	0	4
Cricotopus/Orthocladius spp.	534	937	1,088	1,222	1,009
Eukiefferiella spp.	0	0	20	0	1
Nanocladius sp.	4	4	4	5	0
Parakiefferiella sp.	8	0	8	5	4
Synorthocladius sp.	0	12	0	0	5
Thienemanniella sp.	5	1	1	20	21
Tvetenia spp.	25	23	41	58	61
Prodiamesinae					
Monodiamesa sp.	4	0	0	0	5
Tanypodinae					
Pentaneurini Tribe					
Thienemannimyia gp.	5	18	11	23	10
Tanypodinae (early instar)	0	0	0	0	4
Hemiptera					
Corixidae					
Sigara decoratella	1	0	1	0	1
Sigara solensis	0	0	0	1	0
Hydracarina	24	27	53	56	37
Haplotaxida					
Enchytraeidae	57	45	43	35	19
Naididae	36	51	56	33	32
Tubificidae	10	1	1	0	2
Nematoda	50	56	59	61	38

APPENDIX D

BASIC COMPUTATIONS OF BENTHIC INVERTEBRATE SAMPLES, MAY AND OCTOBER 1991

Appendix D-1. Number (N) of taxa, number of organisms, standing crop and species diversity of benthic invertebrate samples with means and 95% confidence limits (CL) per site, May 1991.

Site-Sample	Number of Taxa	Number of Organisms	Standing Crop N/m^2	Species Diversity*
1-1	10	34	381	1.78
1-2	10	26	291	1.77
1-3	9	19	213	1.82
1-4	8	15	168	1.86
1-5	10	14	157	2.06
Mean ± 95% CL	9 ± 1	22 ± 10	242 ± 117	1.86 ± 0.15
2-1	9	22	247	1.84
2-2	4	9	101	1.00
2-3	6	13	146	1.59
2-4	11	16	179	2.10
2-5	3	4	45	1.04
Mean ± 95% CL	7 ± 4	13 ± 8	143 ± 95	1.51 ± 0.60
3-1	2	4	45	0.56
3-2	10	15	168	2.08
3-3	5	7	78	1.55
3-4	5	8	90	1.39
3-5	8	11	123	1.97
Mean ± 95% CL	6 ± 4	9 ± 5	101 ± 58	1.51 ± 0.75
4-1	10	13	146	2.25
4-2	9	12	135	2.09
4-3	2	3	34	0.64
4-4	5	6	67	1.56
4-5	1	2	22	0.00
Mean ± 95% CL	5 ± 5	7 ± 6	81 ± 71	1.31 ± 1.20
5-1	7	19	213	1.51
5-2	8	12	135	1.91
5-3	11	39	437	1.57
5-4	11	30	336	1.90
5-5	11	41	460	1.42
Mean ± 95% CL	10 ± 2	28 ± 16	316 ± 175	1.66 ± 0.28
6-1	8	17	191	1.84
6-2	4	7	78	1.28
6-3	4	7	78	1.28
6-4	11	16	179	2.18
6-5	14	19	213	2.52
Mean ± 95% CL	8 ± 5	13 ± 7	148 ± 80	1.82 ± 0.69
7-1	11	16	179	2.18
7-2	9	18	202	1.96
7-3	12	18	202	2.37
7-4	7	17	191	1.77
7-5	12	20	224	2.32
Mean ± 95% CL	10 ± 3	18 ± 2	200 ± 21	2.12 ± 0.31

* Shannon-Weaver Index

Appendix D-2. **Number (N) of organisms for major taxonomic groups for each sample with total number, mean number and mean standing crop (SC) per site, May 1991.**

	Number of Organisms					
Site-Sample	Ephemeroptera	Trichoptera	Plecoptera	Chironomidae	Oligochaeta	Others
1-1	-	-	-	24	6	4
1-2	3	-	-	15	4	4
1-3	1	-	1	13	3	1
1-4	3	-	-	10	1	1
1-5	3	-	-	8	1	2
Total Number	10	-	1	70	15	12
Mean Number	2.0	-	0.2	14.0	3.0	2.4
Mean SC (N/m^2)	22.4	-	2.2	157.0	33.6	26.9
2-1	3	-	1	15	2	1
2-2	-	-	-	8	1	-
2-3	1	-	1	6	-	5
2-4	1	-	1	11	2	1
2-5	1	-	-	2	1	-
Total Number	6	-	3	42	6	7
Mean Number	1.2	-	0.6	8.4	1.2	1.4
Mean SC (N/m^2)	13.5	-	6.7	94.2	13.5	15.7
3-1	1	-	-	0	3	-
3-2	1	-	1	7	5	1
3-3	3	-	1	3	-	-
3-4	5	-	-	3	-	-
3-5	5	-	1	5	-	-
Total Number	15	-	3	18	8	1
Mean Number	3.0	-	0.6	3.6	1.6	0.2
Mean SC (N/m^2)	33.6	-	6.7	40.4	17.9	2.2

(continued)

Appendix D-2. (concluded)

Site-Sample	Number of Organisms					
	Ephemeroptera	Trichoptera	Plecoptera	Chironomidae	Oligochaeta	Others
4-1	2	-	1	8	-	2
4-2	2	-	1	5	3	1
4-3	-	-	2	1	-	-
4-4	2	-	-	3	1	-
4-5	2	-	-	-	-	-
Total Number	8	-	4	17	4	3
Mean Number	1.6	-	0.8	3.4	0.8	0.6
Mean SC (N/m^2)	17.9	-	9.0	38.1	9.0	6.7
5-1	8	-	-	9	1	1
5-2	4	-	-	6	1	1
5-3	9	-	2	27	-	1
5-4	8	-	4	17	-	1
5-5	6	1	1	30	1	2
Total Number	35	1	7	89	3	6
Mean Number	7.0	0.2	1.4	17.8	0.6	1.2
Mean SC (N/m^2)	78.5	2.2	15.7	199.6	6.7	13.5
6-1	1	-	-	13	1	2
6-2	1	-	-	5	1	-
6-3	1	-	-	3	3	-
6-4	4	-	1	8	2	1
6-5	4	-	1	10	4	-
Total Number	11	-	2	39	11	3
Mean Number	2.2	-	0.4	7.8	2.2	0.6
Mean SC (N/m^2)	24.7	-	4.5	87.4	24.7	6.7
7-1	4	-	1	10	1	-
7-2	9	-	-	7	2	-
7-3	4	-	6	6	1	1
7-4	8	-	-	8	1	-
7-5	11	-	-	6	2	1
Total Number	36	-	7	37	7	2
Mean Number	7.2	-	1.4	7.4	1.4	0.4
Mean SC (N/m^2)	80.7	-	15.7	83.0	15.7	4.5

Appendix D-3. Number (N) of taxa, number of organisms, standing crop and species diversity of benthic invertebrate samples with means and 95% confidence limits (CL) per site, October 1991.

Site-Sample	Number of Taxa	Number of Organisms	Standing Crop N/m^2	Species Diversity*
1-1	18	440	4,933	1.91
1-2	22	517	5,796	1.91
1-3	17	754	8,453	2.08
1-4	19	494	5,538	2.16
1-5	18	491	5,504	1.85
Mean ± 95% CL	19 ± 2	539 ± 153	6,045 ± 1,716	1.98 ± 0.16
2-1	27	450	5,045	1.99
2-2	30	1,974	22,130	1.44
2-3	30	1,717	19,249	1.87
2-4	28	1,802	20,202	1.53
2-5	32	1,685	18,890	1.83
Mean ± 95% CL	29 ± 2	1,526 ± 759	17,103 ± 8,513	1.73 ± 0.30
3-1	20	408	4,574	1.72
3-2	16	777	8,711	1.58
3-3	21	993	11,132	1.41
3-4	18	771	8,643	1.76
3-5	14	695	7,791	1.61
Mean ± 95% CL	18 ± 4	729 ± 262	8,170 ± 2,936	1.62 ± 0.17
4-1	25	1,877	21,043	1.40
4-2	28	2,004	22,466	1.88
4-3	22	2,352	26,368	1.63
4-4	30	2,350	26,345	1.75
4-5	30	2,532	28,386	1.95
Mean ± 95% CL	27 ± 4	2,223 ± 338	24,922 ± 3,786	1.72 ± 0.27
5-1	27	984	11,031	2.07
5-2	21	814	9,126	1.87
5-3	24	880	9,865	1.94
5-4	23	844	9,462	2.11
5-5	26	1,022	11,457	2.19
Mean ± 95% CL	24 ± 3	909 ± 112	10,188 ± 1,254	2.04 ± 0.16
6-1	32	1,845	20,684	2.19
6-2	29	1,562	17,511	2.07
6-3	31	1,604	17,982	2.19
6-4	33	1,283	14,383	2.19
6-5	35	1,996	22,377	2.13
Mean ± 95% CL	32 ± 3	1,658 ± 341	18,587 ± 3,824	2.15 ± 0.07
7-1	33	1,204	13,498	2.27
7-2	33	1,877	21,043	2.02
7-3	37	2,154	24,148	2.09
7-4	34	2,649	29,697	2.13
7-5	44	2,395	26,850	2.32
Mean ± 95% CL	36 ± 6	2,056 ± 690	23,047 ± 7,731	2.16 ± 0.16

* Shannon-Weaver Index

Appendix D-4. Number (N) of organisms for major taxonomic groups for each sample with total number, mean number and mean standing crop (SC) per site, October 1991.

Site-Sample	Number of Organisms					
	Ephemeroptera	Trichoptera	Plecoptera	Chironomidae	Oligochaeta	Others
1-1	142	-	114	172	6	6
1-2	113	2	93	290	12	7
1-3	282	-	189	259	16	8
1-4	168	3	145	159	8	11
1-5	155	-	94	240	-	2
Total Number	860	5	635	1,120	42	34
Mean Number	172.0	1.0	127.0	224.0	8.4	6.8
Mean SC (N/m^2)	1,928.3	11.2	1,423.8	1,511.2	94.2	76.2
2-1	113	4	83	215	20	15
2-2	132	11	62	1,696	35	38
2-3	248	15	114	1,216	84	40
2-4	149	6	112	1,395	80	60
2-5	165	10	99	1,277	84	50
Total Number	807	46	470	5,799	303	203
Mean Number	161.4	9.2	94.0	1,159.8	60.6	40.6
Mean SC (N/m^2)	1,809.4	103.1	1,053.8	13,002.2	679.4	455.2
3-1	69	3	54	264	8	10
3-2	158	1	152	461	1	4
3-3	187	7	135	628	20	16
3-4	146	8	197	396	20	4
3-5	114	12	122	443	-	4
Total Number	674	31	660	2,192	49	38
Mean Number	134.8	6.2	132.0	438.4	9.8	7.6
Mean SC (N/m^2)	1,511.2	69.5	1,479.8	4,914.8	109.9	85.2

(continued)

Appendix D-4. (concluded)

Site-Sample	Number of Organisms					
	Ephemeroptera	Trichoptera	Plecoptera	Chironomidae	Oligochaeta	Others
4-1	95	36	152	1,546	37	11
4-2	194	39	226	1,452	60	33
4-3	251	38	173	1,765	81	44
4-4	172	35	220	1,727	136	60
4-5	343	44	286	1,717	110	32
Total Number	1,055	192	1,057	8,207	424	180
Mean Number	211.0	38.4	211.4	1,641.4	84.8	36.0
Mean SC (N/m^2)	2,365.5	430.5	2,370.0	18,401.3	950.7	403.6
5-1	231	21	180	500	4	48
5-2	157	11	132	480	5	29
5-3	177	21	128	490	13	51
5-4	233	14	124	426	1	46
5-5	254	50	135	527	17	39
Total Number	1,052	117	699	2,423	40	213
Mean Number	210.4	23.4	139.8	484.6	8.0	42.6
Mean SC (N/m^2)	2,358.7	262.3	1,567.3	5,432.7	89.7	477.6
6-1	144	97	217	1,213	86	88
6-2	126	39	145	1,104	73	75
6-3	135	120	191	1,028	48	82
6-4	126	37	98	870	96	56
6-5	164	152	128	1,362	117	73
Total Number	695	445	779	5,577	420	374
Mean Number	139.0	89.0	155.8	1,115.4	84.0	74.8
Mean SC (N/m^2)	1,558.3	997.8	1,746.6	12,504.5	941.7	838.6
7-1	121	23	117	762	103	78
7-2	183	47	101	1,360	97	89
7-3	200	58	205	1,477	100	114
7-4	303	99	177	1,879	68	123
7-5	300	95	293	1,574	53	80
Total Number	1,107	322	893	7,052	421	484
Mean Number	221.4	64.4	178.6	1,410.4	84.2	96.8
Mean SC (N/m^2)	2,482.1	722.0	2,002.2	15,811.7	943.9	1,085.2

APPENDIX E

ANALYSIS OF VARIANCE RESULTS, MAY AND OCTOBER 1991

One-way ANOVA on the Number of Taxa for Sites, May 1991.

DUE TO	DF	SS	MS	F-RATIO
Site	6	110.3	18.4	1.96 **
Error	28	262.4	9.4	
Total	34	372.7		

** Not Significant ($p > 0.05$) (Table $F_{(0.05;\ 6,28)} = 2.45$)

One-way ANOVA on the Standing Crop for Sites, May 1991.

DUE TO	DF	SS	MS	F-RATIO
Site	6	205,659	34,277	5.40 *
Error	28	177,624	6,344	
Total	34	383,283		

* Significant ($p < 0.01$) (Table $F_{(0.01;\,6,28)} = 3.53$)

SNK (a posteriori test) for the Standing Crop, May 1991.

MEAN	SITE	MEAN STANDING CROP	MEANS NOT SIGNIFICANTLY DIFFERENT ($p > 0.05$)
$\bar{Y}_1$	4	81	
$\bar{Y}_2$	3	101	
$\bar{Y}_3$	2	143	
$\bar{Y}_4$	6	148	
$\bar{Y}_5$	7	200	
$\bar{Y}_6$	1	242	
$\bar{Y}_7$	5	316	

k = 7	$\bar{Y}_7 - \bar{Y}_1 = 316 - 81$	= 235*	$LSR_7 = 159.935$
k = 6	$\bar{Y}_7 - \bar{Y}_2 = 316 - 101$	= 215*	$LSR_6 = 154.093$
	$\bar{Y}_6 - \bar{Y}_1 = 242 - 81$	= 161*	
k = 5	$\bar{Y}_7 - \bar{Y}_3 = 316 - 144$	= 172*	$LSR_5 = 146.862$
	$\bar{Y}_6 - \bar{Y}_2 = 242 - 101$	= 141**	
	$\bar{Y}_5 - \bar{Y}_1 = 200 - 81$	= 119**	
k = 4	$\bar{Y}_7 - \bar{Y}_4 = 316 - 148$	= 168*	$LSR_4 = 137.636$
k = 3	$\bar{Y}_7 - \bar{Y}_5 = 316 - 200$	= 116**	$LSR_3 = 124.706$

* Significant at $p < 0.05$
** Not significant at $p > 0.05$
k Number of groups over which the range is computed.
LSR_a Least significant range for 2, 3 ... a means.

One-way ANOVA on the Number of Taxa for Sites, October 1991.

DUE TO	DF	SS	MS	F-RATIO
Site	6	1,366.3	227.7	26.52 *
Error	28	240.4	8.6	
Total	34	1,606.7		

* Significant ($p < 0.01$) (Table $F_{(0.01;\ 6,28)} = 3.53$)

SNK (a posteriori test) for the Number of Taxa, October 1991.

MEAN	SITE	MEAN NUMBER OF TAXA	MEANS NOT SIGNIFICANTLY DIFFERENT ($p > 0.05$)
$\bar{Y}_1$	3	18	
$\bar{Y}_2$	1	19	
$\bar{Y}_3$	5	24	
$\bar{Y}_4$	4	27	
$\bar{Y}_5$	2	29	
$\bar{Y}_6$	6	32	
$\bar{Y}_7$	7	36	

k = 7	$\bar{Y}_7 - \bar{Y}_1 = 36 - 18$	= 18*	$LSR_7 = 5.885$
k = 6	$\bar{Y}_7 - \bar{Y}_2 = 36 - 19$	= 17*	$LSR_6 = 5.670$
	$\bar{Y}_6 - \bar{Y}_1 = 32 - 18$	= 14*	
k = 5	$\bar{Y}_7 - \bar{Y}_3 = 36 - 24$	= 12*	$LSR_5 = 5.404$
	$\bar{Y}_6 - \bar{Y}_2 = 32 - 19$	= 13*	
	$\bar{Y}_5 - \bar{Y}_1 = 29 - 18$	= 11*	
k = 4	$\bar{Y}_7 - \bar{Y}_4 = 36 - 27$	= 9*	$LSR_4 = 5.065$
	$\bar{Y}_6 - \bar{Y}_3 = 32 - 24$	= 8*	
	$\bar{Y}_5 - \bar{Y}_2 = 29 - 19$	= 10*	
	$\bar{Y}_4 - \bar{Y}_1 = 27 - 18$	= 9*	
k = 3	$\bar{Y}_7 - \bar{Y}_5 = 36 - 29$	= 7*	$LSR_3 = 4.589$
	$\bar{Y}_6 - \bar{Y}_4 = 32 - 27$	= 5*	
	$\bar{Y}_5 - \bar{Y}_3 = 29 - 24$	= 5*	
	$\bar{Y}_4 - \bar{Y}_2 = 27 - 19$	= 8*	
	$\bar{Y}_3 - \bar{Y}_1 = 24 - 18$	= 6*	

(continued)

SNK for the Number of Taxa, October 1991 (concluded)

k = 2	$\bar{Y}_7 - \bar{Y}_6$ = 36 - 32	= 4*	LSR_2 = 3.798
	$\bar{Y}_6 - \bar{Y}_5$ = 32- 29	= 3**	
	$\bar{Y}_5 - \bar{Y}_4$ = 29 - 27	= 2**	
	$\bar{Y}_4 - \bar{Y}_3$ = 27 - 24	= 3**	
	$\bar{Y}_3 - \bar{Y}_2$ = 24 - 19	= 5*	
	$\bar{Y}_2 - \bar{Y}_1$ = 19 - 18	= 1**	

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* Significant at $p < 0.05$

** Not significant at $p > 0.05$

k Number of groups over which the range is computed.

LSR_a Least significant range for 2, 3 ... a means.

One-way ANOVA on the Standing Crop for Sites, October 1991.

DUE TO	DF	SS	MS	F-RATIO
Site	6	1,646,000,000	274,286,440	16.98 *
Error	28	452,409,856	16,157,495	
Total	34	2,098,000,000		

* Significant ($p < 0.01$) (Table $F_{(0.01;\ 6,28)} = 3.53$)

SNK (a posteriori test) for the Standing Crop, October 1991.

MEAN	SITE	MEAN STANDING CROP	MEANS NOT SIGNIFICANTLY DIFFERENT ($p > 0.05$)
$\bar{Y}_1$	1	6,045	
$\bar{Y}_2$	3	8,170	
$\bar{Y}_3$	5	10,188	
$\bar{Y}_4$	2	17,103	
$\bar{Y}_5$	6	18,587	
$\bar{Y}_6$	7	23,047	
$\bar{Y}_7$	4	24,922	

k = 7	$\bar{Y}_7 - \bar{Y}_1$ = 24,922 - 6,045	= 18,877*	LSR_7 = 8,071.390
k = 6	$\bar{Y}_7 - \bar{Y}_2$ = 24,922 - 8,170	= 16,752*	LSR_6 = 7,776.578
	$\bar{Y}_6 - \bar{Y}_1$ = 23,047 - 6,045	= 17,002*	
k = 5	$\bar{Y}_7 - \bar{Y}_3$ = 24,922 - 10,188	= 14,734*	LSR_5 = 7,411.658
	$\bar{Y}_6 - \bar{Y}_2$ = 23,047 - 8,170	= 14,877*	
	$\bar{Y}_5 - \bar{Y}_1$ = 18,587 - 6,045	= 12,542*	
k = 4	$\bar{Y}_7 - \bar{Y}_4$ = 24,922 - 17,103	= 7,819*	LSR_4 = 6,946.070
	$\bar{Y}_6 - \bar{Y}_3$ = 23,047 - 10,188	= 12,859*	
	$\bar{Y}_5 - \bar{Y}_2$ = 18,587 - 8,170	= 10,417*	
	$\bar{Y}_4 - \bar{Y}_1$ = 17,103 - 6,045	= 11,058*	
k = 3	$\bar{Y}_7 - \bar{Y}_5$ = 24,922 - 18,587	= 6,335*	LSR_3 = 6,293.527
	$\bar{Y}_6 - \bar{Y}_4$ = 23,047 - 17,103	= 5,944**	
	$\bar{Y}_5 - \bar{Y}_3$ = 18,587 - 10,188	= 8,399*	
	$\bar{Y}_4 - \bar{Y}_2$ = 17,103 - 8,170	= 8,933*	
	$\bar{Y}_3 - \bar{Y}_1$ = 10,188 - 6,045	= 4,143**	

(continued)

SNK for the Standing Crop, October 1991 (concluded)

k = 2	$\bar{Y}_7 - \bar{Y}_6$ = 24,922 - 23,047 = 1,875**	LSR_2 = 5,209.552
	$\bar{Y}_4 - \bar{Y}_3$ = 17,103 - 10,188 = 6,915*	

* Significant at $p < 0.05$
** Not significant at $p > 0.05$
k Number of groups over which the range is computed.
LSR_a Least significant range for 2, 3 ... a means.

APPENDIX F

RESULTS OF RA ANALYSIS (SPECIES DOMINANCE DISTRIBUTION MATRICES AND SPECIES ORDINATIONS), MAY AND OCTOBER 1991

Appendix F-1. Species dominance distribution matrix for each sample site, May 1991.

Site	4	7	5	5	4	3	6	5	5	2	5	2	1	6	7	2	2	1	1	6	7	2	1	7	7	1	3	4	6	6	3	4	3	4	3
Species Code / Sample	3	3	4	3	5	3	4	1	2	4	5	2	2	5	4	1	3	1	3	1	1	5	4	5	2	5	2	1	3	2	4	4	5	2	1
052	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
030	6	1	1	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
026	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
032	-	1	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
077	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
067	-	+	-	+	-	-	-	-	-	+	-	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
038	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
098	-	+	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
031	-	-	+	+	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
046	-	+	-	-	-	-	-	-	+	+	-	1	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
009	-	1	+	1	9	2	1	3	1	+	1	-	-	+	2	-	-	-	-	-	+	-	-	2	1	+	-	+	-	-	-	-	-	-	-
063	-	1	4	5	-	2	3	3	3	3	6	6	4	1	2	3	3	4	4	3	3	5	3	1	1	3	1	1	2	-	1	3	+	2	-
092	-	+	-	+	-	-	+	+	+	+	-	-	1	-	-	+	2	+	+	1	-	-	+	+	-	-	-	1	-	-	-	-	-	+	-
005	-	-	1	+	-	-	+	-	+	-	-	-	+	+	2	+	-	-	-	-	1	2	2	1	3	+	+	+	-	1	-	-	1	-	-
055	-	-	+	+	-	-	+	-	+	+	+	-	-	-	1	-	+	+	+	+	+	-	1	-	-	+	+	-	-	-	-	-	-	-	-
002	-	+	+	+	-	1	+	+	+	-	+	-	+	+	-	+	+	-	+	+	+	-	-	1	-	-	-	-	1	-	5	1	2	+	2
048	-	+	+	+	-	1	+	+	-	-	-	-	+	1	-	2	-	+	1	1	+	-	+	+	+	-	-	1	1	4	-	-	+	-	-
085	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
042	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
019	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
074	-	-	+	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	+	-	-	2	1	-	+	-	-
112	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
089	-	+	-	-	-	-	-	-	-	+	-	1	-	-	-	-	-	-	+	-	-	2	-	-	+	-	3	-	-	-	-	-	-	+	7
070	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
035	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
012	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
088	-	-	-	-	-	-	+	+	-	-	-	-	-	1	-	+	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	+	-
065	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	1	-	-	-	-	+	-	-	-	-	-	-	1	-	-	-
072	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
056	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
113	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-
047	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-
058	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-
068	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
041	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-
001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	+	-	-	-	-	+	-	+	-	-	-	-	-	-	-
087	-	-	-	-	-	-	+	-	+	+	+	-	1	+	+	-	-	1	1	+	+	-	+	1	-	-	-	-	4	1	-	1	-	+	-
064	-	-	-	-	-	-	-	+	-	+	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	1	-	-	1	-
025	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-

(continued)

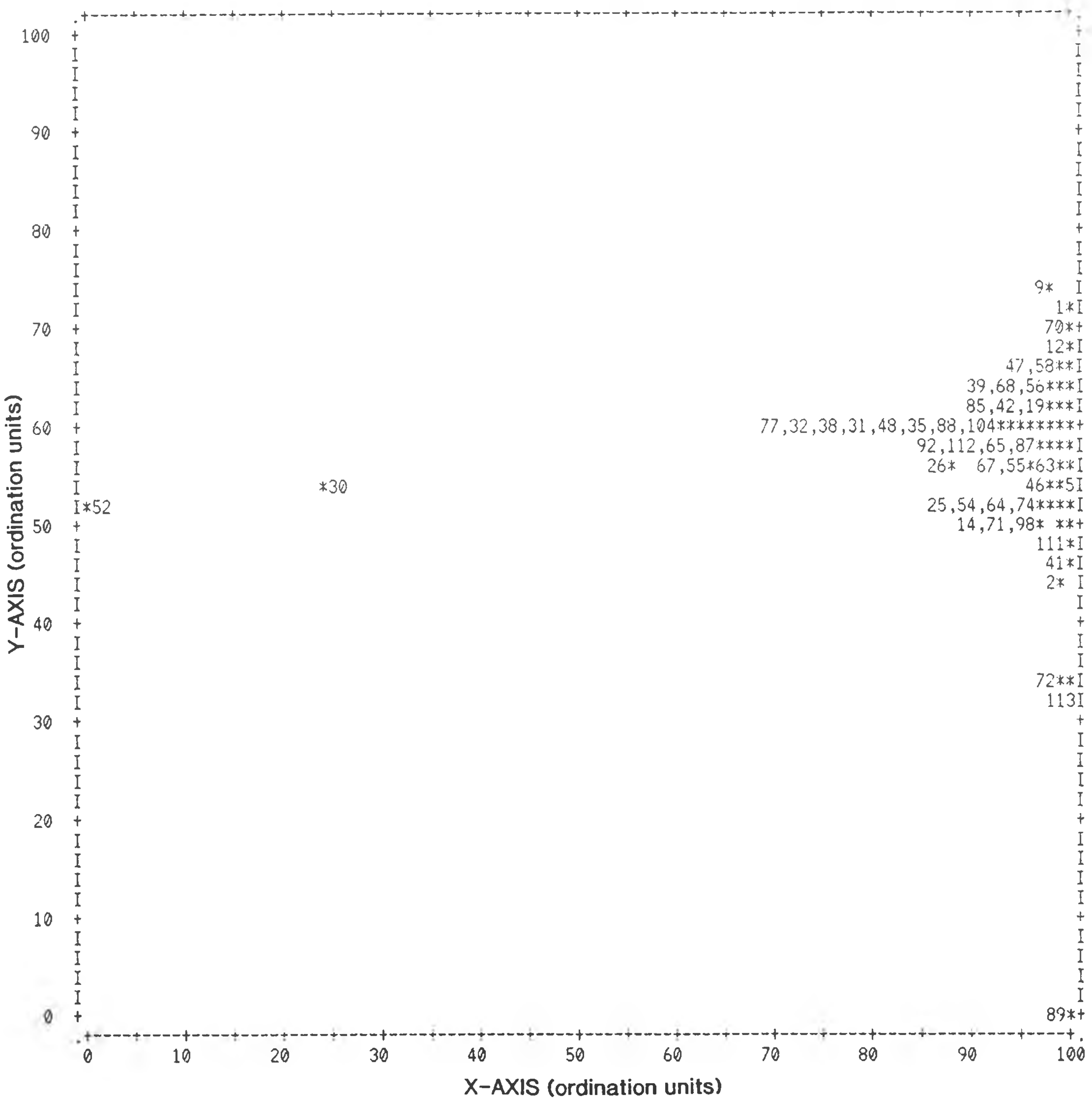
Appendix F-1. (concluded)

Species Code																																			
Site	4	7	5	5	4	3	6	5	5	2	5	2	1	6	7	2	2	1	1	6	7	2	1	7	7	1	3	4	6	6	3	4	3	4	3
Sample	3	3	4	3	5	3	4	1	2	4	5	2	2	5	4	1	3	1	3	1	1	5	4	5	2	5	2	1	3	2	4	4	5	2	1
071	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	1	-	+	+	-	-	-	-	+	-	-
039	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
054	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-
014	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	1	1	-	+	-
111	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-

\+ present

\- absent

1 to 9 weighted species abundance score



Appendix F-2. Reciprocal averaging ordination of species scores, May 1991.

Appendix F-3. Species dominance distribution matrix for each sample site, October 1991.

Site	1	1	1	1	3	3	1	3	5	3	5	5	3	5	5	4	4	4	4	2	4	2	7	2	7	7	2	2	6	6	6	7	6	7	6
Species Code / Sample	4	3	1	5	2	4	2	3	4	5	1	2	1	3	5	5	2	3	1	1	4	4	5	3	3	1	5	2	3	2	1	4	4	2	5
003	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
009	2	1	1	1	+	+	1	+	+	+	+	1	+	+	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
002	1	2	2	2	2	2	1	2	2	1	1	1	1	1	1	1	+	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
030	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	-	+	-	+	-	+	-
102	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
074	+	-	-	+	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-
073	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
035	1	1	+	1	1	1	+	1	+	+	+	+	1	+	+	+	1	+	+	+	+	-	+	-	+	+	-	+	+	+	+	+	+	+	+
025	2	1	2	1	1	1	1	+	1	1	1	1	+	1	1	+	+	+	+	2	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
033	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	+	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
028	-	+	+	+	-	+	-	-	-	-	-	+	-	-	+	+	-	+	-	-	-	+	+	-	+	-	-	-	-	+	-	-	+	-	+
038	-	-	+	+	-	-	-	+	+	+	+	-	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	-	+	+	-
014	-	-	+	-	+	-	+	-	+	-	+	+	+	+	+	-	-	-	-	-	-	-	-	-	+	+	+	-	+	+	+	-	-	-	+
064	+	+	+	+	+	-	+	+	-	-	+	-	-	+	+	1	+	+	+	+	+	+	+	+	+	-	+	+	+	-	+	-	+	-	+
118	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
120	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
103	-	-	-	-	+	+	-	+	+	-	+	+	+	+	+	-	-	+	+	-	-	-	+	-	-	+	-	-	+	-	+	-	-	-	+
099	+	-	+	+	-	+	+	+	+	-	+	-	-	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+
119	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
017	-	-	-	-	+	+	-	-	+	-	-	-	+	+	-	+	+	+	+	-	+	-	+	-	+	-	+	-	+	+	+	+	+	-	+
032	+	+	+	+	-	-	+	-	+	-	-	+	-	+	+	+	-	-	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+
063	3	4	5	6	7	6	7	8	6	8	6	7	8	7	6	7	7	9	9	5	8	9	6	7	7	6	8	9	6	6	6	6	6	7	6
039	+	-	-	-	-	+	+	+	+	-	+	-	-	+	-	+	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	-
072	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
041	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	+	-	+	+	+	-	-	-	-	+	-	-
095	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
085	+	+	+	-	-	-	-	+	+	-	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
077	-	+	-	+	-	-	-	-	+	-	+	-	-	-	+	+	-	-	-	-	+	+	+	+	+	+	+	+	-	+	+	+	+	+	-
005	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	3	+	1	+	1	+	1	1	+	+	+	+	1	1	+	+
086	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
087	+	+	+	-	+	-	+	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
048	+	+	+	+	+	+	+	-	+	-	+	+	-	+	+	+	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
019	+	-	-	-	-	-	-	+	-	+	+	-	+	-	-	+	+	+	+	-	+	-	+	+	+	+	+	-	+	+	+	+	-	+	+
031	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	+	+	-	-	+	+	+	-	+	-	-	-	-	+	-	+	-	+	-
067	-	-	-	-	-	-	+	-	-	-	+	+	-	-	+	-	-	-	-	+	-	+	+	+	+	+	+	+	+	-	+	+	+	-	+
101	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
008	-	-	-	-	-	+	-	+	-	-	-	-	-	+	-	-	-	-	+	+	-	+	+	-	+	-	-	+	+	+	+	+	-	-	+
062	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	+	+	+	-	+	-	+	+	+	+	-	+	-	+	-	+	-	+	+
071	-	-	+	-	-	+	+	-	-	-	+	+	-	-	-	-	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
046	-	-	-	+	-	-	-	-	-	-	+	+	-	-	+	-	-	-	-	+	-	+	+	+	+	+	+	+	-	-	+	+	+	-	+

(continued)

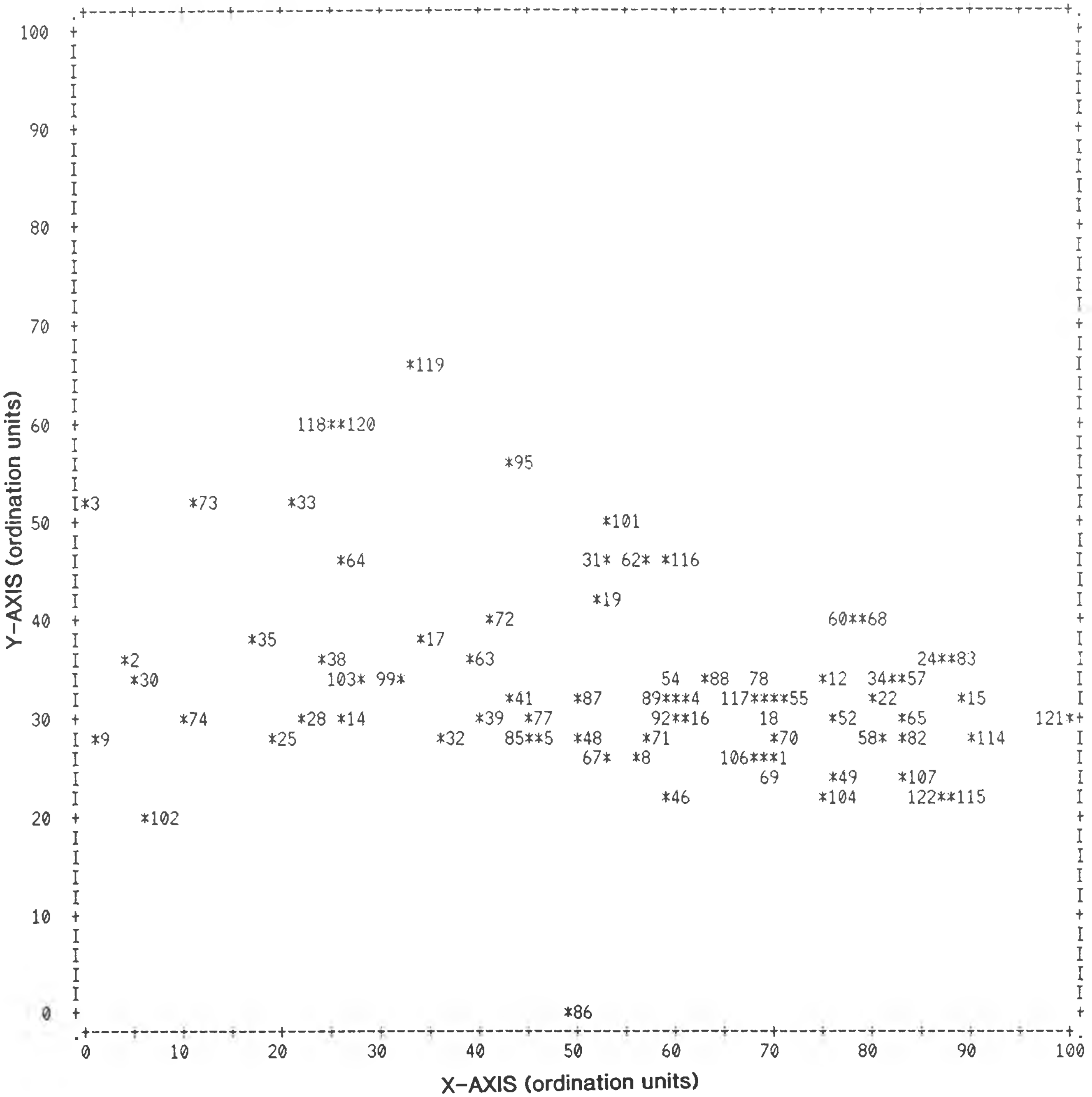
Appendix F-3. (concluded)

	Site																																		
	1	1	1	1	3	3	1	3	5	3	5	5	3	5	5	4	4	4	4	2	4	2	7	2	7	7	2	2	6	6	6	7	6	7	6
	Sample																																		
Species Code	4	3	1	5	2	4	2	3	4	5	1	2	1	3	5	5	2	3	1	1	4	4	5	3	3	1	5	2	3	2	1	4	4	2	5
116	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-
089	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	+	-	+	+	-	-	-	-	-	-	-	+	+
054	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+	-	-	+	-	-	-	-	+	-	-	-	+	-	-	-	+	+	+	+	+
004	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	+	-	-	-	-	-	-	-	-	+	-	+	-	-	-	+
092	-	-	-	-	+	-	+	-	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
016	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	1	+	+	+	+	+	+
088	-	+	-	-	-	+	-	+	+	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
078	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-
117	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
018	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
106	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
069	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
070	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	+	+	+	-	-	+	+	-	-	-	-	-	+	-
055	+	+	-	+	+	-	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	1	1	1	1	+	1	1	1	2	2	1	1	2
012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
104	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	+	-	-	-	+	-	+	-	+	+	-
049	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-
052	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+
060	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
068	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
022	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-
057	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	+	-	-	-	-	-	+	+	+	+	-
034	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-
058	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
065	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	+	+	-	-	-	-	+	-	+	+
107	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-
082	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	+	-	-	-	-	-	-	+	-	+
083	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
024	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
115	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
122	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
114	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+
121	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+

\+ present

\- absent

1 to 9 weighted species abundance score



Appendix F-4. Reciprocal averaging ordination of species scores,October 1991.

APPENDIX G

PERCENT COMPOSITION OF BENTHIC INVERTEBRATE FUNCTIONAL FEEDING GROUPS, MAY AND OCTOBER 1991

Appendix G-1. **Percent composition of benthic invertebrate functional feeding groups for each sample and site (pooled samples), May 1991.**

Site-Sample	Functional Feeding Group (percent) C	H	D	HC	DH	CD	O
1-1	-	-	44.1	-	52.9	2.9	-
1-2	-	-	34.6	-	61.5	3.8	-
1-3	5.3	-	31.6	-	63.2	-	-
1-4	6.7	-	33.3	-	60.0	-	-
1-5	7.1	-	28.6	-	57.1	7.1	-
Pooled Sample	2.8	-	36.1	-	58.3	2.8	-
2-1	4.5	4.5	18.2	-	72.7	-	-
2-2	11.1	-	22.2	-	66.7	-	-
2-3	23.1	-	30.8	-	46.2	-	-
2-4	-	-	50.0	-	50.0	-	-
2-5	-	-	25.0	-	75.0	-	-
Pooled Sample	7.8	1.6	29.7	-	60.9	-	-
3-1	-	-	75.0	-	25.0	-	-
3-2	20.0	-	60.0	-	20.0	-	-
3-3	14.3	-	-	-	85.7	-	-
3-4	-	-	12.5	-	87.5	-	-
3-5	-	-	36.4	-	63.6	-	-
Pooled Sample	8.9	-	37.8	-	53.3	-	-
4-1	-	-	46.2	-	53.8	-	-
4-2	-	-	41.7	-	58.3	-	-
4-3	66.7	-	33.3	-	-	-	-
4-4	-	-	33.3	-	66.7	-	-
4-5	-	-	-	-	100.0	-	-
Pooled Sample	5.6	-	38.9	-	55.6	-	-
5-1	-	-	10.5	-	89.5	-	-
5-2	-	-	33.3	-	66.7	-	-
5-3	5.1	-	12.8	-	82.1	-	-
5-4	16.7	-	6.7	-	73.3	3.3	-
5-5	7.3	-	12.2	-	78.0	-	2.4
Pooled Sample	7.1	-	12.8	-	78.7	0.7	0.7
6-1	-	-	41.2	-	58.8	-	-
6-2	-	-	42.9	-	57.1	-	-
6-3	-	-	42.9	-	57.1	-	-
6-4	6.3	-	31.3	-	62.5	-	-
6-5	5.3	-	42.1	-	52.6	-	-
Pooled Sample	3.0	-	39.4	-	57.6	-	-
7-1	6.3	-	25.0	-	68.8	-	-
7-2	-	-	33.3	-	66.7	-	-
7-3	27.8	-	22.2	5.6	44.4	-	-
7-4	-	-	29.4	-	70.6	-	-
7-5	-	-	35.0	-	65.0	-	-
Pooled Sample	6.7	-	29.2	1.1	62.9	-	-

Appendix G-2. **Percent composition of benthic invertebrate functional feeding groups for each sample and site (pooled samples), October 1991.**

Site-Sample	Functional Feeding Group (percent)						
	C	H	D	HC	DH	CD	O
1-1	3.0	5.2	20.9	-	70.5	0.5	-
1-2	2.9	5.0	16.8	-	74.5	0.4	0.4
1-3	4.6	8.9	16.8	-	69.6	-	-
1-4	5.3	11.5	17.6	-	64.6	0.4	0.6
1-5	2.2	7.7	12.2	-	77.4	0.4	-
Pooled Sample	3.7	7.8	16.8	-	71.2	0.3	0.2
2-1	3.3	0.7	28.4	-	65.8	0.4	1.3
2-2	2.0	0.1	20.9	-	75.9	0.5	0.6
2-3	1.9	-	23.4	-	72.7	1.2	0.9
2-4	3.2	-	20.9	-	75.6	-	0.3
2-5	3.0	-	24.5	-	71.9	0.1	0.6
Pooled Sample	2.6	0.1	22.7	-	73.6	0.4	0.6
3-1	2.2	8.1	14.7	-	73.3	1.0	0.7
3-2	0.5	11.6	11.2	-	76.6	-	0.1
3-3	2.1	7.6	7.7	-	81.2	0.8	0.7
3-4	2.1	10.2	19.6	-	66.5	0.5	1.0
3-5	2.3	6.5	16.0	-	72.9	0.6	1.7
Pooled Sample	1.8	8.8	13.3	-	74.6	0.5	0.9
4-1	3.5	5.1	12.1	-	77.4	-	1.9
4-2	4.0	7.2	16.4	-	70.0	0.6	1.8
4-3	2.9	4.0	13.6	-	77.9	-	1.6
4-4	4.2	3.8	18.6	-	71.2	0.7	1.5
4-5	4.6	6.1	14.0	-	73.4	0.2	1.7
Pooled Sample	3.9	5.2	15.0	-	73.9	0.3	1.7
5-1	5.8	2.9	19.8	-	68.8	0.5	2.1
5-2	3.3	5.4	18.6	-	71.4	-	1.4
5-3	4.5	3.6	16.6	-	72.3	0.6	2.4
5-4	6.0	3.1	16.1	-	71.7	1.4	1.7
5-5	3.8	4.0	16.5	-	70.7	-	4.9
Pooled Sample	4.7	3.8	17.5	-	70.9	0.5	2.6
6-1	3.9	4.9	32.7	-	53.1	0.2	5.2
6-2	5.1	3.5	28.4	-	60.4	0.3	2.4
6-3	3.8	4.9	30.7	-	52.4	0.7	7.5
6-4	2.3	1.9	32.8	-	59.2	1.2	2.6
6-5	4.1	1.2	34.3	-	52.9	-	7.6
Pooled Sample	3.9	3.3	31.9	-	55.2	0.4	5.3
7-1	5.1	3.7	32.6	-	56.6	0.2	1.9
7-2	4.8	1.5	29.5	-	61.4	0.3	2.5
7-3	4.5	4.5	26.4	-	61.9	<0.1	2.7
7-4	6.3	4.0	27.8	-	58.1	0.2	3.7
7-5	5.6	6.1	27.2	-	57.0	0.2	3.9
Pooled Sample	5.3	4.1	28.3	-	59.0	0.2	3.1