AQUATIC INVERTEBRATES OF THE MOOSE RIVER BASIN

AN INITIAL CHARACTERIZATION OF AQUATIC INVERTEBRATE COMMUNITY STRUCTURE IN THE MOOSE RIVER BASIN, ONTARIO

by

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Abstract

The Moose River Basin in northern Ontario is an important large river system, however very little is known about its aquatic invertebrate community. As macroinvertebrates are an integral part of river ecosystems, I conducted an initial assessment of the aquatic invertebrate community structure in the Moose River Basin, at both a fine, and a basin-wide, scale. The fine scale study used invertebrate data collected at five reaches within a 30km stretch of the Groundhog River. The examination of the invertebrate community at a basin-wide scale was accomplished using meta-analysis techniques on twenty-two studies conducted on various rivers within the Basin. The effect of the following factors on community structure were examined: i) the use of different sampling devices, ii) water depth, iii) substrate type, iv) sampling in two consecutive years, and v) spatial scale. I found that the use of various sampling devices resulted in significantly different estimates of community structure. This strongly suggests that consistent sampling protocols are necessary to effectively compare results within, and among, studies. The effect of water depth on community structure was inconclusive, as too few samples were collected to overcome the confounding effects of substrate type. Substrate type had a significant effect on community structure, with greater invertebrate richness and diversity found in fine substrate in the Groundhog River study, but with no consistent patterns at the basin-wide scale. Invertebrate richness and diversity did not differ significantly in the Groundhog River between two consecutive years. In both the

fine-scale and the basin-wide studies, the distribution of aquatic invertebrates varied among sites within a river reach, and among reaches within a river. To further examine the biological and physical processes affecting community structure at the fine-scale, consistent sampling protocols should be employed, which may also allow basin-wide trends to emerge.

Acknowledgments

Thank-you Jurek, for such a friendly work environment, for your insights and ideas, and for the many cups of tea and coffee.

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The person to whom I am most indebted, for her prayers to the gods of the outboard motor, for road-tripping and singing along with Indigo Girls, for swearing a blue streak with me, for being able to laugh, anytime, anyplace, in any situation, and for always, always being there, is Erin Fitzgerald. Erin, words can't express what we've been through together these last two years, and how much your friendship means to me. Thank-you.

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1.0 INTRODUCTION

1.1 General Introduction

Large rivers are important natural resources in Ontario, providing food, water, and shelter for wildlife, and providing transportation and recreation opportunities for humans. The impact of civilization, however, is often damaging to ecological systems. In order to assess human impact on large rivers, monitoring programs have been implemented to determine the state of both impacted and unimpacted regions, and to detect changes in these regions. In freshwater systems, macroinvertebrates have become useful in assessing the health of a river. The advantages in using macroinvertebrates are: i) they are ubiquitous, ii) their large number of species provide a spectrum of responses to environmental stresses, iii) their sedentary nature allows for spatial analysis for pollutant or disturbance effects, and iv) temporal changes caused by perturbations can be examined because of their relatively long life cycles compared to other groups (Rosenberg and Resh 1993). In order to use aquatic invertebrates as pollution indicators, baseline data on the existing taxa and how they respond to environmental variables within their habitat, must first be collected (Simpson et al. 1986, Lenat 1988). Also, the variable distribution of macroinvertebrates requires a high number of samples to estimate with precision the community structure (Rosenberg and Resh 1993).

The Moose River Basin in northern Ontario, an area of increasing industrialization, has been the site of very few scientific aquatic invertebrate studies. The Ontario Ministry of Natural Resources, however, obtained a number of aquatic invertebrate surveys conducted from the years 1967 to 1994. These studies varied widely in the season of sampling, the extent of sampling, the type of sampling device used, and the taxonomic resolution with which the results were reported. The MNR commissioned this project to extract information from these existing studies, and to conduct any additional field work to aid in the examination of the aquatic invertebrate community in the Moose River Basin.

There are many biotic and abiotic variables that effect invertebrate community structure. For this project, we focused on the effect of: i) substrate grain size, ii) water depth, iii) sampling device, iv) annual variation over two consecutive sampling years, and v) spatial variation between sites within a river reach, and among river reaches, to determine whether there were fine-scale effects, and to learn whether there exist basin-wide trends that could affect the interpretation of benthic community descriptors such as richness or diversity

River substrate is of prime importance to benthic invertebrates, as it provides a place for rest, refuge, food acquisition, reproduction, and development (Hynes 1970, Thorp and Covich 1991). In large rivers, the type of substrate varies from fine particles such as silt, clay, and sand, to very coarse grains such as gravel, cobble, and boulders. It is generally found that more coarse substrate types provide more diverse habitats, and so results in a more diverse aquatic invertebrate community (Hynes 1970, Minshall 1984, Quinn and Hickey 1990, Jowett et al. 1991).

The effect of depth in large rivers has not been completely elucidated as it is difficult to obtain a representative sample in deep or fast flowing waters (Mason et al. 1973). However, greater depths reduce the amount of light, resulting in a narrow photic zone (Thorp and Covich 1991), less productivity, and therefore, possibly fewer benthos.

The type of sampling devices used to sample aquatic invertebrates vary widely in both the scientific literature and in the surveys received from the MNR. However, studies often involve comparisons that require equivalent, quantitative sampling procedures throughout a range of habitats (Brooks 1994). If different sampling devices yield different community structure estimates, then their results are not directly comparable, and so may lead to erroneous inferences if they are directly compared. When more than one device is used in a study, it is thus important to determine whether they yield similar results in order to justify pooling the data for analysis.

Temporal variability of community structure can be addressed to a limited degree by sampling in two consecutive years. As invertebrate life histories are greatly effected by season (Hynes 1970), changes on a larger time scale can be examined by sampling in the same season but in different years.

It is also useful to determine the pattern of aquatic invertebrate distribution, at sites within a reach, and reaches within a river. If the distribution is not contiguous, then many samples must be taken to get a complete picture of the invertebrate community structure. A patchy dispersal also indicates that there are biotic or abiotic variables affecting the distribution (Weins 1989). For example, Legendre and Fortin (1989) have found that "spatial heterogeneity of the physical environment generates a diversity in communities, as

well as in the biological and ecological processes that can be observed at various points in space". The relative importance, however, of biotic and physical factors regulating patterns of community structure, appears to vary with spatial scale (Menge and Olson 1990). As there is a growing recognition of the need to determine how ecologically important processes at the fine-scale can be meaningfully aggregated to system-wide and global-scale responses (Sedell et al. 1989), this research presents a fine-scale and a basin-wide approach to the study of macroinvertebrates in this ecosystem.

The first paper, in preparation for the Journal of North American Benthological Society, focuses on a 30km stretch of the Groundhog River, a largely unimpacted river within the Moose River Basin. The objectives of this study were to determine the effect of: i) substrate grain size, ii) water depth, iii) two common sampling devices, iv) temporal variation between two consecutive sampling years, and v) spatial variation between sites within a river reach, and among river reaches. Effects of sampling effort, as illustrated by species-area curves, were also examined for the two sampling devices, for each substrate type, and for the five reaches sampled.

The second paper presents a meta-analysis of 22 studies on the Moose River Basin. This relatively new approach to synthesizing ecological data was used to investigate: i) whether there are differences in community structure at the fine scale, such as between reaches within one river, ii) what effect substrate grain size has on community structure, and iii) whether different sampling methods yield different assessments of community structure. This study is in preparation for the Canadian Journal of Fisheries

and Aquatic Sciences. The format of this thesis has been kept consistent for ease of reading, and is not in the format required for each journal.

1.2 Clarification of Contribution

Sections two and three of this thesis represent papers prepared for publication by Catrien Bouwman and Jurek Kolasa. The initial ideas for the work presented in these papers, and the data analysis, were developed by myself. Jurek Kolasa assisted with the sampling design, provided expertise and advice when requested, and edited the various drafts of the two papers. Field and laboratory work was carried out by myself, with the assistance of Erin Fitzgerald and two technicians.

2.0 A FINE-SCALE STUDY OF AQUATIC INVERTEBRATE COMMUNITY STRUCTURE IN THE GROUNDHOG RIVER

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Key words: benthos, aquatic invertebrate, river, ANOVA, MANOVA

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2.1 Abstract

A fine-scale study of aquatic invertebrate community structure was conducted on the Groundhog River, a large river within the Moose River Basin. Previous studies of this river basin were sporadic, with inconsistent sampling methodologies. Therefore, the goal of this research was to complement this data set with a more comprehensive study on a fine-scale. The effects of the following factors were investigated: i) substrate grain size, ii) water depth, iii) two common sampling devices, iv) annual variation between two consecutive sampling years, and v) spatial variation between sites within a river reach, and among river reaches. Effects of sampling effort, as illustrated by species-area curves, were also examined for the two sampling devices, for each substrate type, and for the five reaches sampled. Contrary to most of the previous findings reported in the scientific literature, it was found that fine substrate samples had a greater diversity, richness, and abundance of aquatic invertebrates than samples taken from coarser substrates. Several explanations of these results are discussed. The data also suggest that there are significant differences in community structure within areas, and

among areas, of the Groundhog River. The effect of water depth on community structure was inconclusive, as too few samples were collected to overcome the confounding effects of substrate type. The results of this study indicate that for fine-scale studies there is a need for a consistent sampling protocol.

2.2 Introduction

Large rivers represent ecosystems of great importance to humans and wildlife. A major component of river ecosystems is their macroinvertebrate fauna. Aquatic invertebrates provide food for fish, waterfowl, and other wildlife, breakdown organic matter, and can also be disease carriers (Reice and Wohlenberg 1993). Because of their diversity, life history, and place in the food chain, benthos may be used to assess the state of the river. Unfortunately there are relatively few published studies on macroinvertebrate fauna of large rivers, most likely due to the physical difficulties involved in sampling (Simpson et al. 1986, Thorp and Covich 1991). In deep or fast flowing waters it is difficult to obtain a representative sample, even within a limited area, because of shifting substrates, variable or high river flows, floating or submerged debris, and navigational traffic (Mason et al. 1973). Furthermore, studies often involve comparisons that require equivalent, quantitative sampling procedures throughout a range of habitats (Brooks 1994). Yet different sampling devices may yield different results. The use of different methods for different substrate types is sometimes unavoidable, but it should not be assumed that two samplers give directly comparable results without first validating this assumption. Sampling method should, therefore, be considered a factor when determining invertebrate community structure.

Other difficulties in characterizing a river system are associated with scale. Community structure can be measured along various temporal scales ranging from night/day, to month, season, year, decade, etc. Processes may also vary according to the

spatial scale. For example, in 4 hectare plots of north-eastern U.S. hardwood forests, the Least Flycatchers negatively influence the distribution of the American redstart, however these species are positively correlated at the regional scale (Weins 1989). Common spatial units in lotic ecology are sites, reaches, rivers, basins, and biomes. Habitat variables can include: bottom substrate type; water depth, velocity, pH, and temperature; canopy cover, and leaf litter. The effect of these abiotic variables on aquatic invertebrates often depends on the scale of measurement (Menge and Olson 1990). Patterns of community structure in a single river may be significantly different than the basin-wide patterns of which it is a part (Corkum 1991). These differences create difficulties in characterizing a river system. Consequently, Wohl et al. (1995) suggest that variation in community structure and function should be examined at several spatial scales.

Large rivers of northern Ontario, such as those in the Moose River Basin, have been studied sporadically, and over a coarse scale (Brousseau and Goodchild 1989). As basin-wide patterns derived from these results may obscure variations found within single rivers, there is a clear need to complement those studies with a fine scale, habitat-focused research. This research should also examine the potential biases introduced by using different sampling devices, as many samplers were used in the previous surveys. We conducted a study at a fine scale, using two common sampler types, to investigate how various methodological, temporal, spatial, and environmental factors effect aquatic invertebrate community structure, within one river, and one land use type. The specific aims were to determine the effects of: i) substrate grain size, ii) water depth, iii) sampling devices, iv) annual variation between two consecutive sampling years, v) spatial variation

among sites within a river reach, and among river reaches. Effects of the sampling effort, as illustrated by species-area curves, were also examined for the two sampling devices, for each substrate type, and for the five reaches sampled.

2.3 Method and Materials

2.3.1 Study area

The site of field work is a 30 km stretch of the Groundhog River, 5 km south to 25 km north of Fauquier, Ontario (Figures 1-3). The Groundhog River is a 5th order river within the Moose River Basin, located in Northern Ontario. The Moose River Basin is characterized by a modified continental climate influenced by the Hudson and James Bays to the north and the Laurentian Great Lakes to the south (Brousseau and Goodchild 1989). The Groundhog River is located within the Precambrian Shield, is approximately 363 km in length, and drains 12518 km^2 (Brousseau and Goodchild 1989). The study site is located downstream of the Carmichael Falls dam, but since this is a run-of-the-river facility it should not affect natural water levels. During its course, the Groundhog river crosses a number of geological faults where bedrock is exposed, usually resulting in the occurrence of rapids and falls. However the sampling sites were located in depositional areas, due to problems of access and sampling restrictions. The mean flow is 145 $m^3 \cdot s^{-1}$, with a minimum of 7 $m^3 \cdot s^{-1}$ and a maximum of 1810 $m^3 \cdot s^{-1}$ (Brousseau and Goodchild 1989). The Groundhog River watershed is heavily forested, with trees extending to the edge of the river, the banks of which are very stable, with little evidence of active erosion or slumping (Niblett et al. 1989). Within the study area there was a short stretch of river with land cleared to the river's edge, on which a few cottages were built.

Figure 1. Large scale map of the Moose River Basin, Ontario

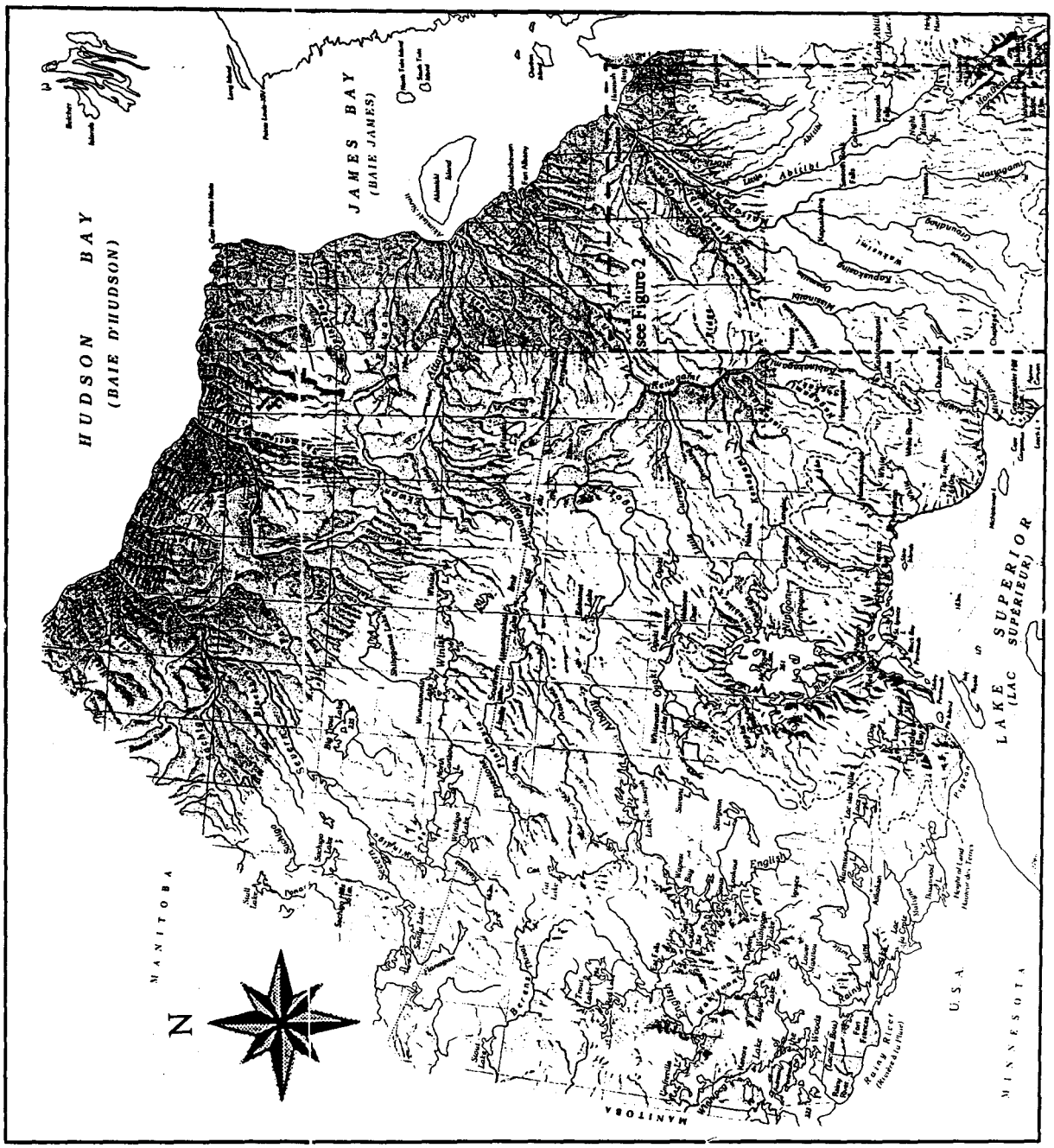


Figure 2. Map of the Moose River Basin, Ontario

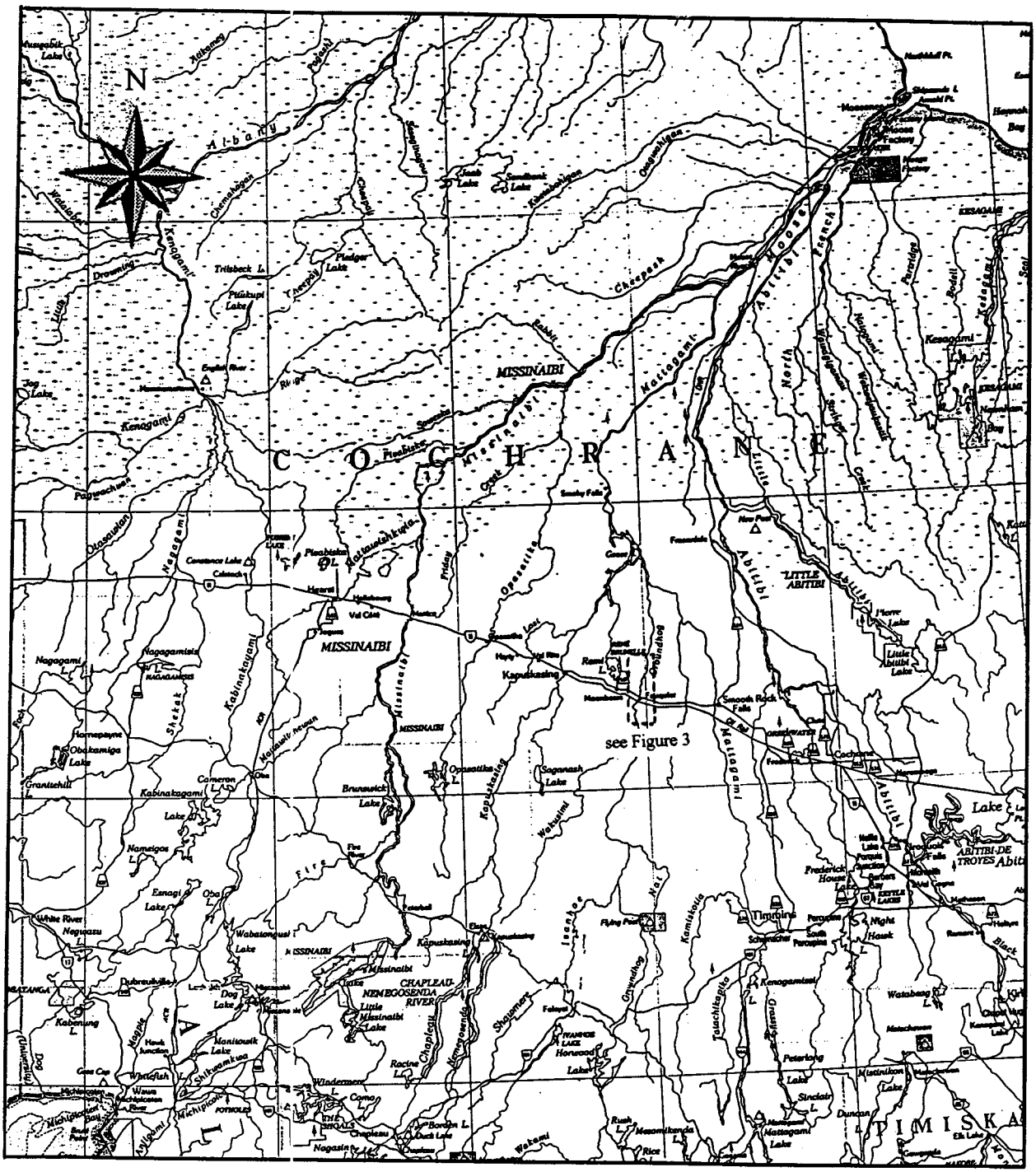
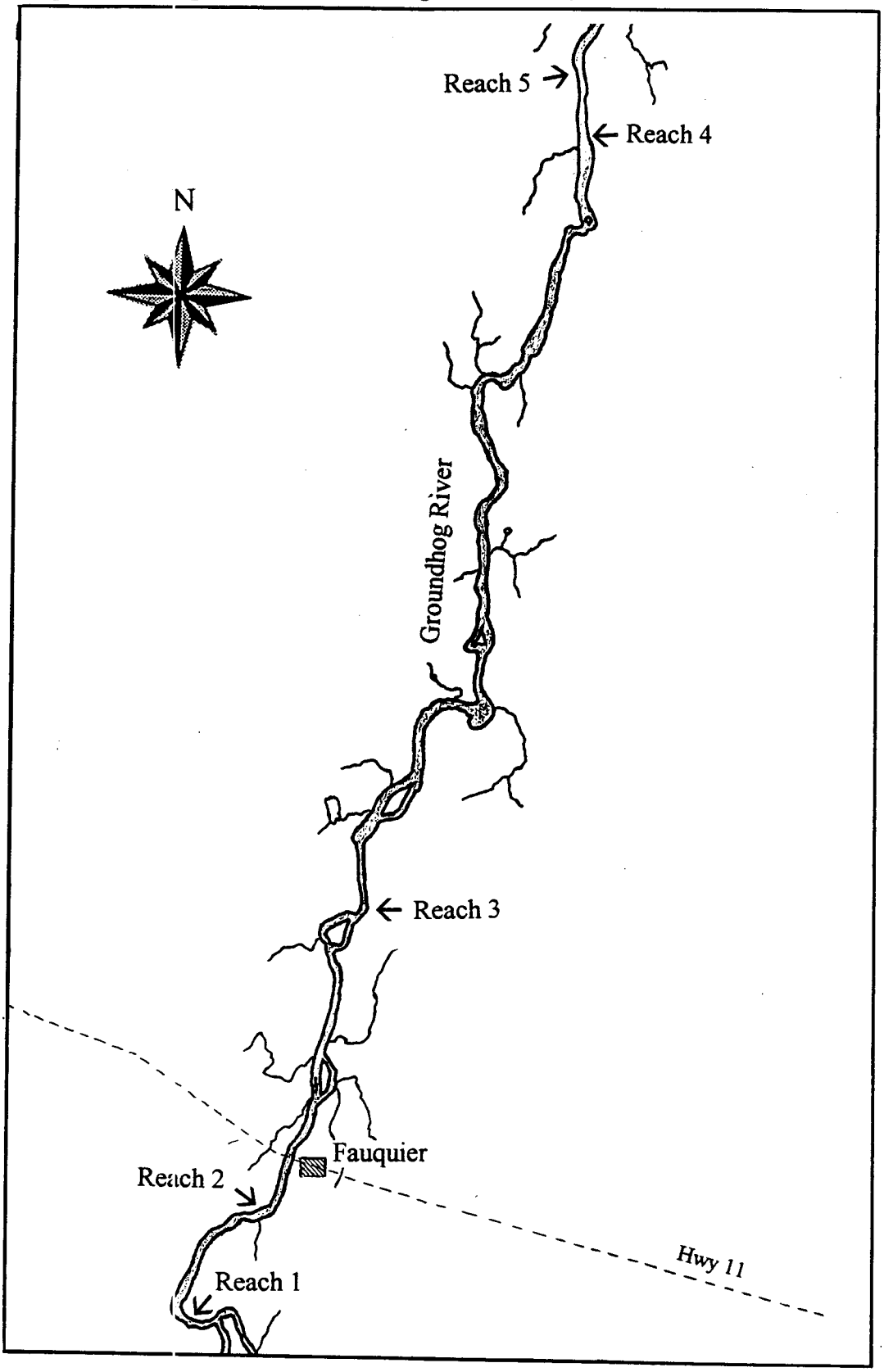


Figure 3. Map of the Groundhog River study site



The Groundhog River is still a clean (non-polluted) river in the Moose River Basin. Unpublished data from 1980 to 1988, from the Ontario Ministry of the Environment, shows that oxygen levels at Fauquier average 99% saturation (Niblett et al. 1989). These high levels are a result of very low biochemical oxygen demand in the river, and re-aeration at many places where the river passes over falls and rapids (Niblett et al. 1989). The Groundhog is a soft water river, with a neutral to slightly basic pH. The suspended solids are very low, with water transparency limited more by the very high colour (Niblett et al. 1989). This colour is natural, caused by tannins, and commonly found throughout Northern Ontario rivers. The sediment quality is also good, with phosphorus, carbon and nitrogen values all well below the Ministry of the Environment suggested values indicative of pollution: 389-483 ug/g phosphorus (< 10000 ug/g), 1.52%-2.65% carbon (< 6%), and 95-1649 ug/g nitrogen (< 20000) (Niblett et al. 1989).

2.3.2 Sampling

Temporal variation of aquatic invertebrate communities was addressed to some degree by sampling twice: mid-August in 1994 and in 1995. Prior to sampling, five reaches were randomly selected on a map along the 30 km section of the river. Once on the river, each area was visually inspected for substrate type. All different substrate types identified were sampled randomly, using two different types of gear: Ponar dredge (15cm x 15 cm), and corer (7.02 cm^2). The Surber sampler could not be used at any of the sampled reaches, as the water was either too deep or the current too slow. The Ponar

and corer were both used at most sites, however, only the Ponar was used at sites too rocky or too deep for the corer. Three replicates were taken with each type of gear at each site, and a fourth sample taken for further substrate analysis.

The invertebrate samples were sieved through a 500 µm mesh, preserved in 70% ethanol, and processed in the lab. The 219 samples processed contained a total of 10,371 individuals. Initial separation of animals and sediments involved sorting by hand under a dissecting microscope. Chironomids (keyed according to Oliver and Roussel 1983) and oligochaete worms (keyed using Brinkhurst 1986, and Stimpson et al. 1982) were mounted on slides and identified under 400x magnification using a compound microscope. Oligochaete worms were often found in fragments, therefore only pieces with the prostomium (anterior segments) intact were counted. Insects were identified to genus where possible, as were bivalves and gastropods, according to the respective keys (Merritt and Cummins 1984, Clarke 1981). Other non-insects were identified to family. Taxa were assigned to five functional groups based on Merritt & Cummins (1984).

2.3.3 Taxonomic Groups

Measurements such as diversity have the advantage of condensing large amounts of biological data into comprehensible and useful numbers, however, they do not take into consideration the taxonomic composition of the community (Godfrey 1978). For example, the presence of a species will depend on its environmental tolerance, but its abundance will be determined by the resources available to it (Godfrey 1978). Therefore the ten most abundant genera were analyzed to roughly ascertain the composition of the

community. Another approach in characterizing community structure is the classification of functional feeding groups. This classification links invertebrate food sources and morpho-behavioral adaptations (Merritt and Cummins 1984), and so aids in determining differences between communities and habitats.

Another taxonomic consideration is the level of identification. It is generally accepted that the species level contains the most amount of information, as the basic biological unit (Resh and McElravy 1993). Unfortunately, identification to species is difficult, time intensive, and costly, because of their small size, inadequate keys, and the need to rear certain immature taxa to their adult forms (Merritt et al. 1884). Identification at higher levels is a compromise between a loss of a portion of the information, and the feasibility of carrying out the study. In cases where the analysis includes diversity indices and other multiple taxa measures, which are less sensitive to information loss, the use of higher level identification has been justified (Resh and McElravy 1993). In this study, insects, bivalves, and gastropods were identified to the genus level, and other invertebrates to the family level.

2.3.4 Analysis

The analysis concentrated on diversity (Shannon-Weiner index) and richness calculations. Where warranted, functional feeding group abundance (FGA), and most abundant genera (MAG), were also analyzed.

We used a one way analysis of variance for each factor and variable, as there were too many missing cells to use a multi-way ANOVA. Multivariate statistics were used to

analyze functional group abundance (FGA) and most abundant genera (MAG), with the p values corresponding to the Wilk's lambda reported. Abundance was calculated as number of individuals per m^2. The FGA and MAG data were transformed to the power of 1/3 to normalize the data, and expressed as density (individuals per m^2).

Effects of sampling effort on richness values, as produced by various gear, river reach, or habitat, can be examined by comparing functions, commonly known as species area curves. The total richness (at the genus level) with each additional sample, was produced by first randomizing the data, and then evaluating richness for the first sample, for the first two samples combined, for the first three samples combined, and so on. A curve with the equation $y = ax^b$ was fitted to each data set. The genus - area curves were produced in a similar manner, using the area of each sampler in cm^2 instead of the number of samples.

2.4 Results

2.4.1 Year

There is no significant difference between sampling years for diversity and richness measurements as the means were similar and the variation large. The data, therefore, were pooled for further analysis.

2.4.2 Sampling Device

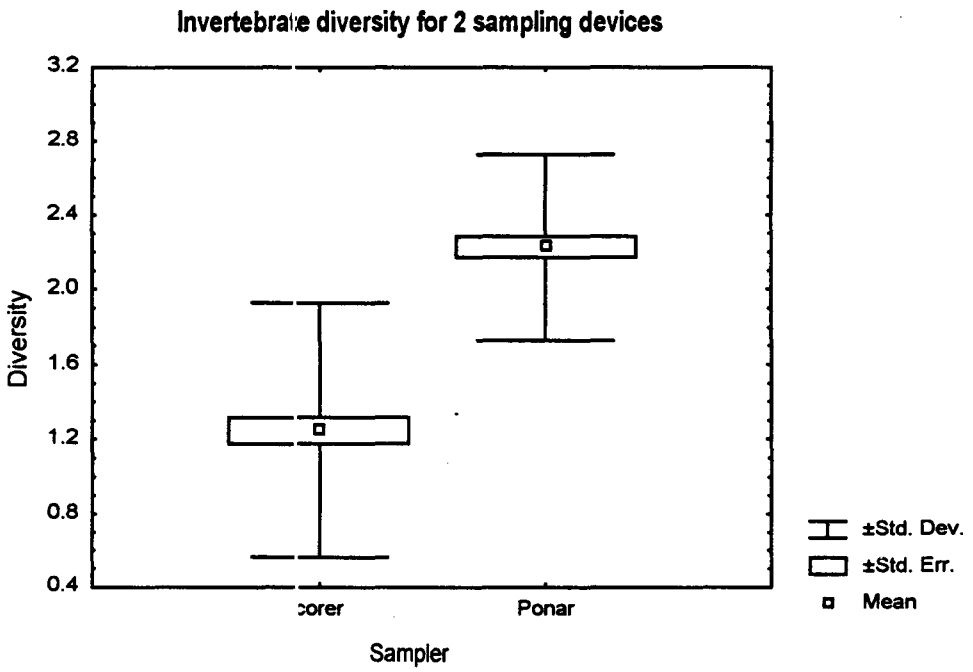


Figure 4. The mean, standard error, and standard deviation of invertebrate diversity from two sampling devices: corer and Ponar dredge.

There is a significant difference between the two sampling devices, corer and Ponar. Both diversity (ANOVA, $p < 0.0001$) and richness ($p < 0.0001$) differ, for all sites where both samplers were used. The Ponar sampler yields higher diversity and richness

than the corer (Figure 4). Of the 100 genera identified in the samples from all the sites where both corer and Ponar were used, only 4 were not found in the Ponar samples. However, 39 genera were not represented in the corer samples. When these samples were grouped according to substrate type, the Ponar missed 4 of the 97 genera (4%) in fine substrate, and the corer missed 36 genera (37%). In coarse substrate, only 39 genera were identified in samples from both devices. The Ponar missed 7 (18%), and the corer missed 18 genera (46%). The Ponar dredge consistently provided a greater percentage of the total richness, as well as higher diversity measures, and so these samples were used to analyze differences between substrate types, sites, reaches, and water depths. The Ponar provides a more complete picture of the actual community structure than the corer, and the exclusion of the corer reduces the within group variance. This allows for more sensitive analyses to detect differences between groups.

Corer and Ponar samples render different estimates of abundance, with opposite effects in fine and coarse substrate. The Ponar sampler yields significantly greater MAG abundance (MANOVA, $p = 0.032$) in fine substrate, while the corer has significantly higher MAG abundance in coarse substrate ($p = 0.025$). The trends for each of the most abundant genera are fairly consistent (Figures 5,6). In fine substrate, the abundance of *Amnicola* sp. (commonly known as spire snails) is significantly higher in the Ponar samples than the corer samples ($p = 0.00058$), as is the abundance of ceratopogonid midges ($p = 0.0069$). The remaining 8 genera also show a slightly higher abundance in the Ponar samples than the corer samples (Figure 5). In coarse substrate, the trend is reversed

(Figure 6), as the abundances of *Amnicola* sp., *Dubiraphia* sp., and *Procladius* sp. are all significantly lower in the Ponar samples than the corer samples (respectively, $p = 0.023$, $p = 0.032$, and $p = 0.024$). The remaining genera also are less abundant when sampled by the Ponar sampler than by the corer, except for *Cladotanytarsus* sp., whose abundance is greater, although not significantly, in the Ponar samples.

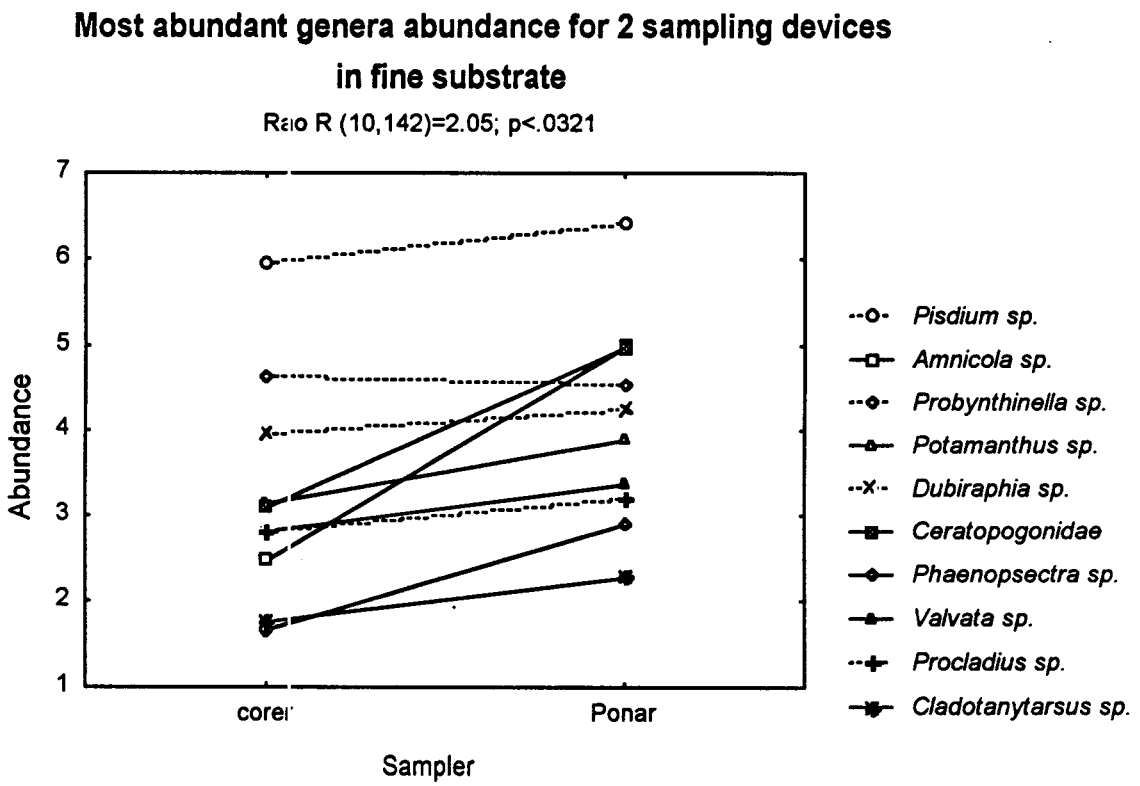


Figure 5. The mean abundance of each of the ten most abundant genera in fine substrate, reported as density (m^2), and transformed to the power of 1/3, for two sampling devices: corer and Ponar dredge.

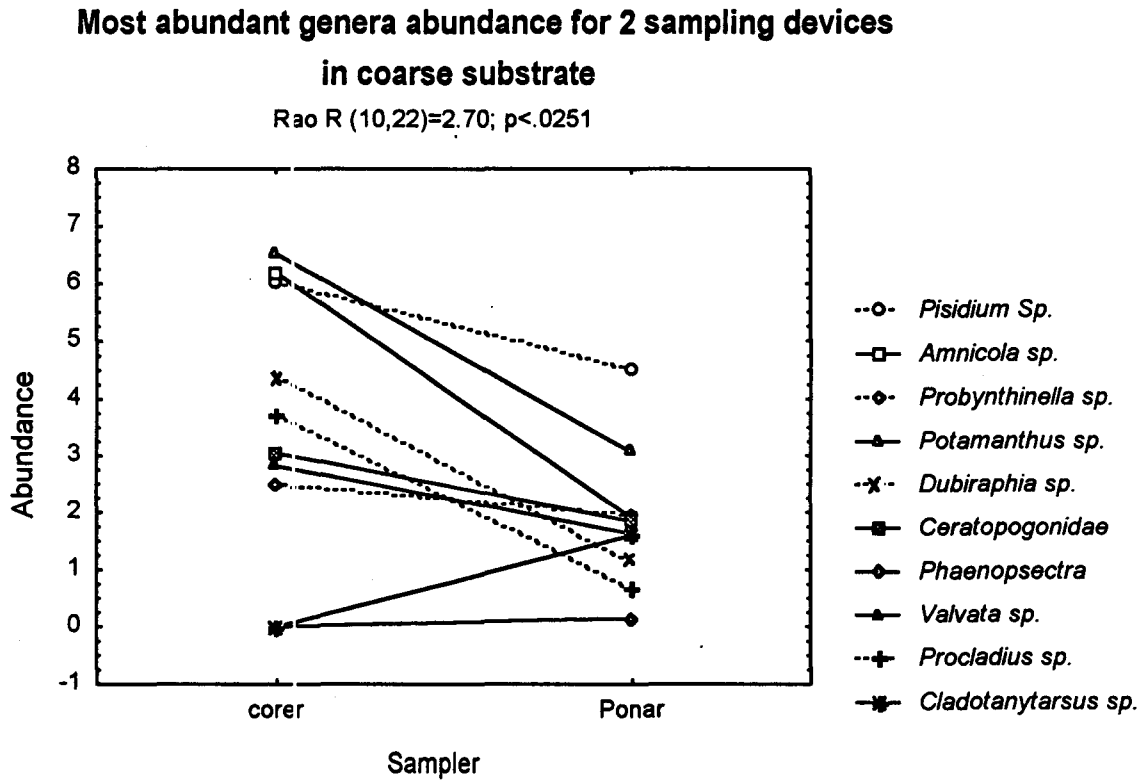


Figure 6. The mean abundance of each of the ten most abundant genera in coarse substrate, reported as density (m^2), and transformed to the power of 1/3, for two sampling devices: corer and Ponar dredge.

The rate at which richness increases with the number of samples taken is greater for the Ponar sampler than the corer sampler (Figure 7). However, when the number of samples taken is converted to the total area sampled (in cm^2), the rate of increase in richness is greater for the corer sampler than for the Ponar (Figure 8).

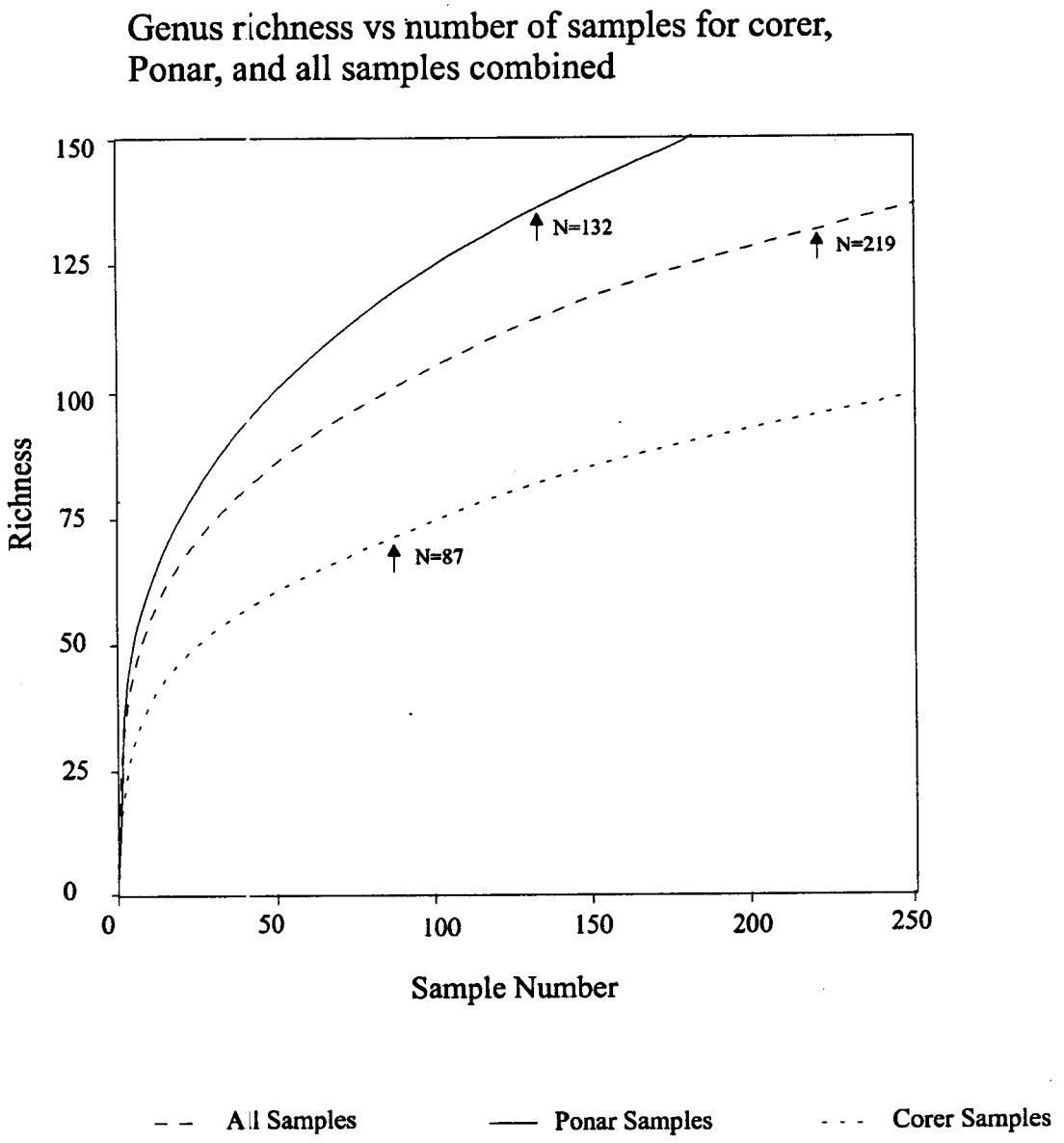


Figure 7. Total invertebrate richness (at the genus level) for each additional sample, for two sampling devices: corer and Ponar dredge, and for all samples combined. The ↑ indicates the number of samples taken in with each sampler, and in total.

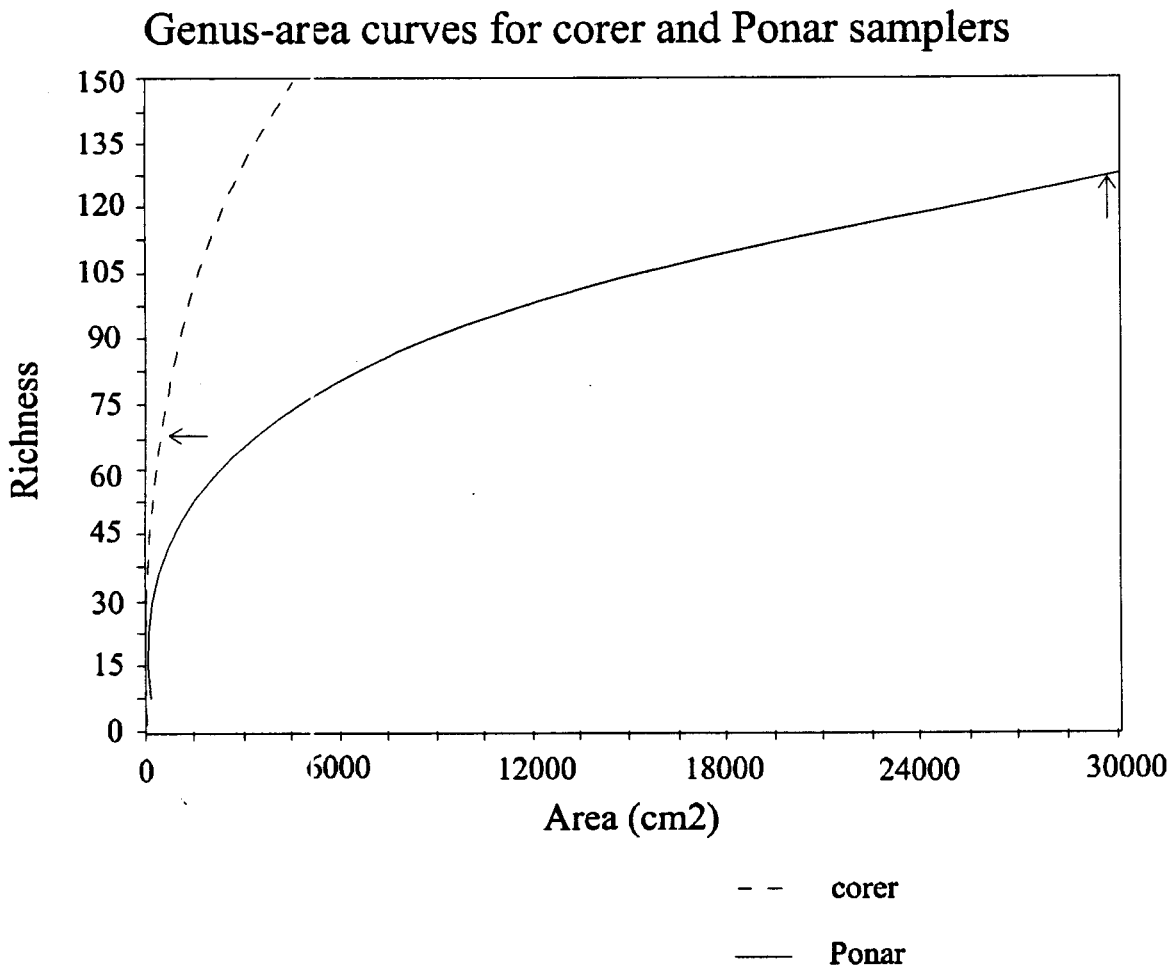


Figure 8. Total invertebrate richness (at the genus level) for each additional area sampled (cm^2), for two sampling devices: corer and Ponar dredge. The ↑ indicates the actual richness obtained by each sampler.

2.4.3 Substrate

Substrate type, as sampled by the Ponar, significantly affects invertebrate communities as measured by: i) diversity (ANOVA, $p < 0.0001$), ii) richness (ANOVA, $p < 0.0001$), iii) functional group abundance or FGA (MANOVA, $p < 0.0001$), and iv) most abundant genera or MAG, (MANOVA, $p < 0.0001$). The trend for all four community measurements shows that the greatest diversity, richness and abundance were found in fine substrate, and decreased as the substrate size increased. A planned comparison between each substrate group showed that there was a significant decrease between fine and coarse substrate samples in diversity ($p = 0.0017$), richness ($p = 0.0008$), functional group abundance ($p < 0.0001$), and MAG ($p < 0.0001$), and also between coarse and very coarse substrate in diversity ($p=0.0029$), richness ($p= 0.0041$), and MAG ($p = 0.0006$).

In fine substrate, the collectors is the most abundant functional group, followed by predators, shredders, scrapers, and piercers. The abundance of each group decreases with increasing substrate size, with scrapers and shredders switching relative positions of importance (Figure 9). The samples obtained by the corer were not significantly different among substrate types for any of the four community measures.

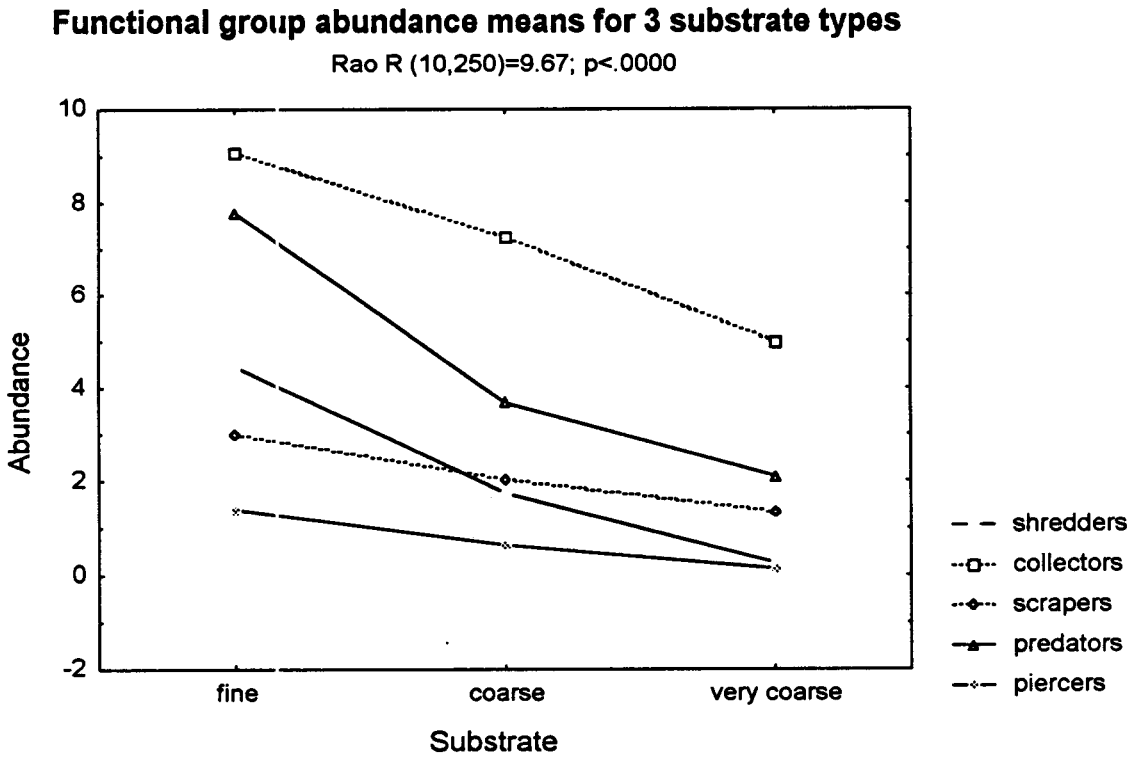


Figure 9. The mean abundance for each functional group, reported as density (m^2) and transformed to the power of 1/3, for each substrate type.

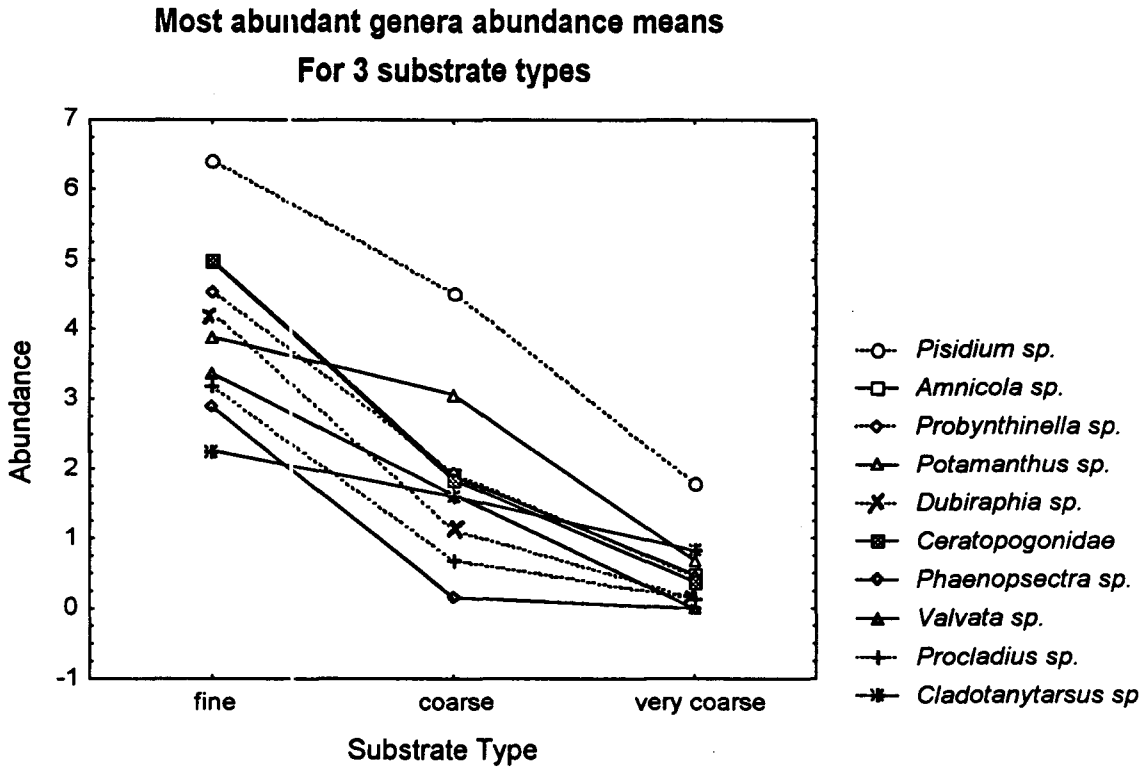


Figure 10. The mean abundance for each of the ten most abundant genera, reported as density (m^2) and transformed to the power of 1/3, for each substrate type.

Each of the most abundant genera decreases in abundance with larger substrate size (Figure 10). The rate of decrease from fine to very coarse is similar for all, except for *Pisidium* sp., *Potamanthus* sp., and *Cladotanytarsus* sp.

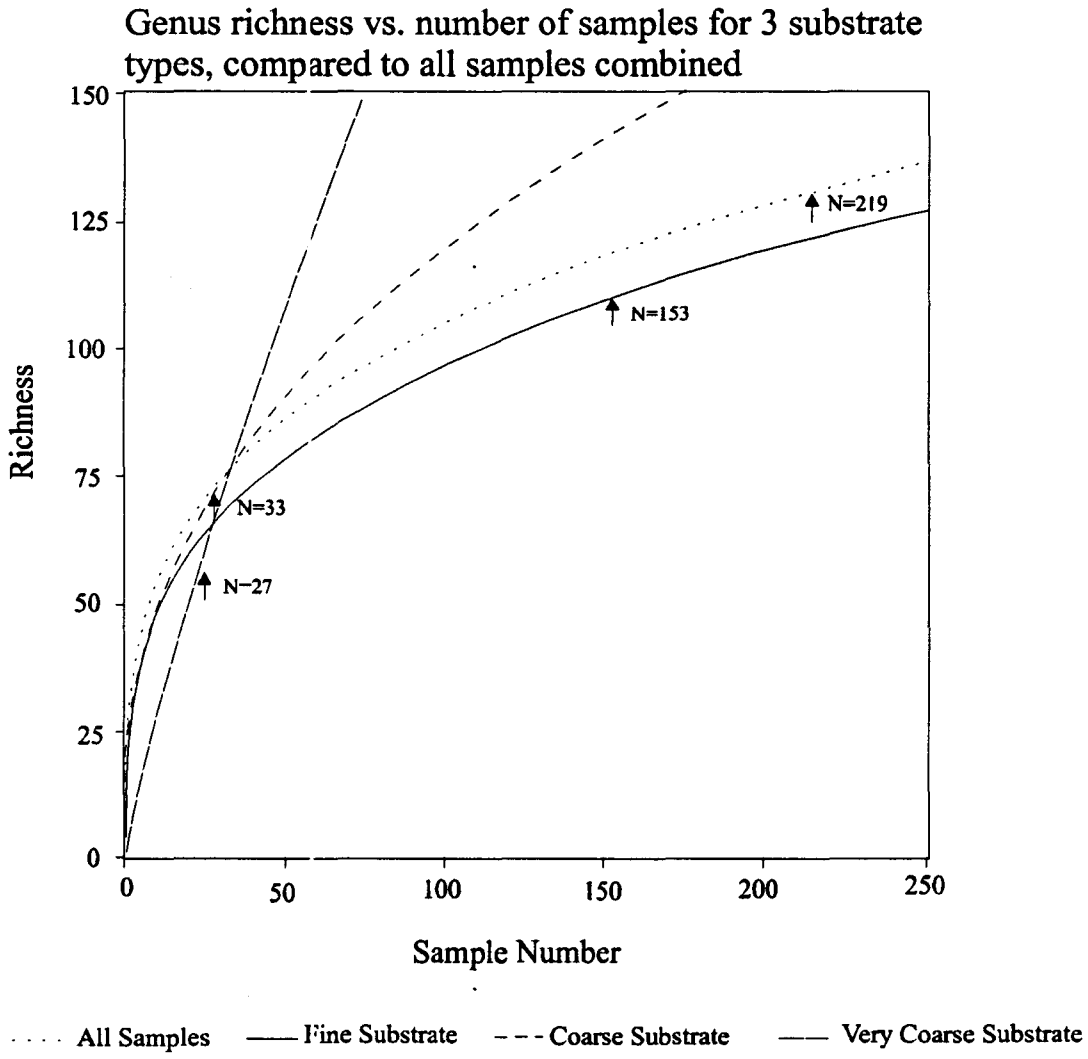


Figure 11. Total invertebrate richness (at the genus level) for each additional sample, for each substrate type, and for all samples combined. The ↑ indicates the number of samples taken for each substrate type and for all samples combined.

Although fine substrate has the greatest total richness and very coarse substrate has the least richness, the rate at which richness increases with the number of samples taken is greatest for very coarse substrate, followed by coarse substrate, and then fine substrate (Figure 11). To determine whether the slope of these curves was influenced by

sample size, richness was determined for a random set of 27 samples (the lowest sample size) for each substrate type. This was repeated ten times, and the average of these ten trials was graphed, and a curve with the equation $y = ax^b$ fitted, for each substrate type (Figure 12).

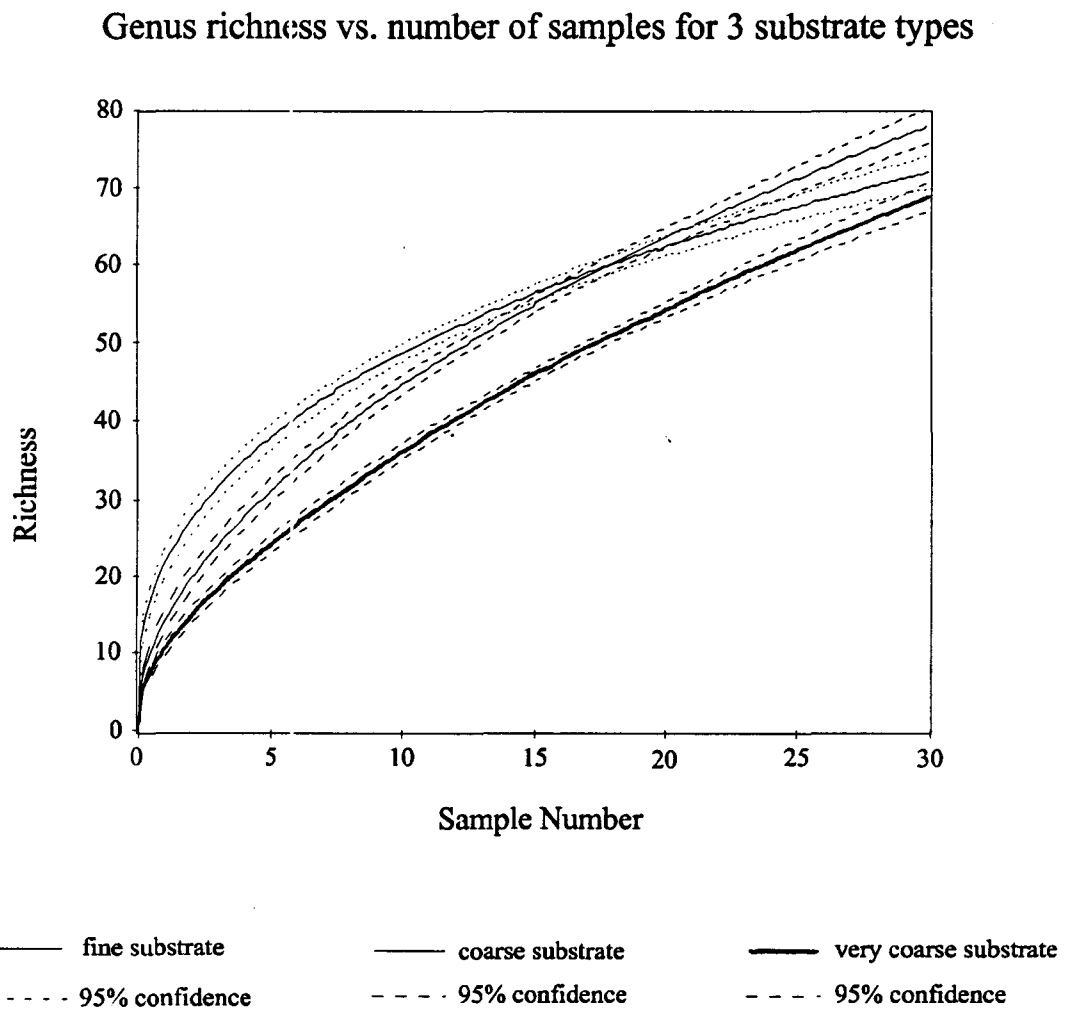


Figure 12. Average total invertebrate richness from ten random trials (at the genus level), for each additional sample, for each substrate type, as well as the 95% confidence limits for each.

The curves for each substrate type show a different rate of increasing richness, with fine substrate adding fewer genera per sample after about five samples than the coarse and very coarse substrates.

2.4.4 Area and Site

Diversity, richness, FGA and MAG differ among and within river reaches, but not for all substrate types (see Tables 1 and 2 for p values).

Table 1. Significance of differences within reaches (p values) for each substrate type

reach	diversity	richness	FGA	MAG	# of Sites
fine substrate					
1	NS	0.0078	0.0004	0.0003	7
2	0.0050	0.0026	0.0000	0.0146	7
3	0.0146	0.0002	0.0082	0.0168	6
4	< 0.0001	0.0001	0.0014	0.0011*	4
5	0.0392	0.0006	NS	0.0131*	3
coarse substrate					
5	0.0037	NS	NS	NS	4
very coarse substrate					
4	NS	NS	NS	NS	6
all substrates combined					
1	NS	0.0270	< 0.0001	< 0.0001	8
2	0.0157	0.0035	< 0.0001	< 0.0001	9
3	NS	0.0011	< 0.0001	< 0.0001	8
4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	11
5	0.0003	0.0002	0.0032	< 0.0001	8

*only 7 most abundant genera could be analyzed

- Diversity and richness analyzed by ANOVA, FGA and MAG by MANOVA

Table 2. Significance of differences among reaches (p values), for each substrate type

substrate type	diversity	richness	FGA	MAG	# of reaches
fine	0.0041	0.0014	< 0.0001	< 0.0001	5
coarse	NS	0.0389	0.0230	NS	4
v-coarse	0.0049	< 0.0001	0.0035	< 0.0001	4
all	< 0.0001	< 0.0001	< 0.0001	< 0.0001	5

NS = Not Significant

Samples from fine substrate, as well as from very coarse substrate, differed significantly among the five reaches for all four community measurements, while coarse substrate samples differed significantly among reaches for richness and FGA, but not for diversity and MAG (Table 2). The results are slightly different when comparing sites *within* each reach. Samples from fine substrate show significant differences between sites for at least four out five reaches for all community measurements (Table 1). Only reach 5 had enough sites with coarse substrate to analyze, and these sites were significantly different only for diversity, and not for richness, FGA or MAG (Table 1). While very coarse substrate samples were significantly different among reaches, this was not the case between sites within a river reach. In reach 4 (the only reach with more than two sites with this substrate type) there were no significant differences between the sites for any of the community measurements (Table 1). When all substrate types were combined, there were significant differences among reaches for all four community measurements (Table 2), and significant differences within each reach for at least 3 of the 4 community measures (Table 1). The trend that fine substrates have more spatial variation of invertebrate community structure than coarser substrates is evident among and within reaches.

The rate of increase for richness with each sample taken appears to be similar for each reach for the first fifty samples, except for reach 2, which has a higher rate than the others (Figure 13). This suggests that the sampling effort required to obtain a representative data set is approximately the same for each reach, however a greater samples size for each reach is needed to confirm this.

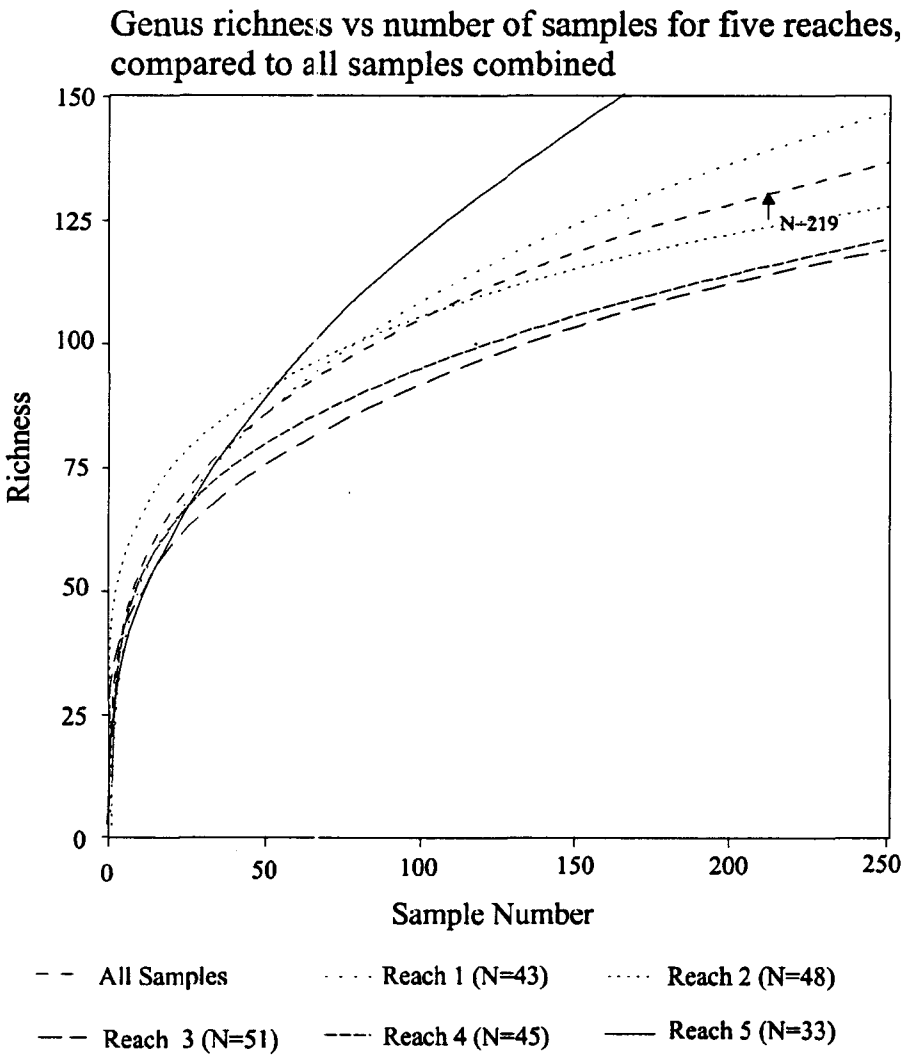


Figure 13. Total invertebrate richness (at the genus level) for each additional sample, for each river reach, and for all samples combined. The ↑ indicates the number of samples taken in all reaches combined.

2.4.5 Depth

There are significant differences among samples taken at different depths but not for all substrate types (see Table 3), with all measurements of community structure generally lower at greater depths. Again the differences in all community measurements between samples at different depths are significant for fine and coarse substrates (with the exception of MAG). There are no significant differences between depths for the samples in very coarse substrate. When all samples are combined there are significant differences for all community measures. It should be noted that these results are often based on only one site for a particular depth, and therefore the effect of depth cannot be isolated from the already determined differences between sites.

Table 3. Significance of differences between depths (p values) for each substrate type

substrate type	diversity	richness	FGA	MAG
fine	0.0000	0.0008	0.0178	0.0371
coarse	0.0055	0.0151	0.0227	NS
very coarse	NS	NS	NS	NS
all	0.0014	0.0470	< 0.0001	0.0017

2.5 Discussion

Our finding that an increase in substrate size results in a decrease in benthic diversity is in direct contrast to the patterns found in most other rivers that have been studied, where numbers and types of taxa increase with coarser substrate (Hynes 1970, Minshall 1984, Quinn and Hickey 1990, Jowett et al. 1991). Generally, coarse substrate provides a more diverse habitat, allowing for more types of invertebrate species to co-exist (Thorp and Covich 1991). If it is the case that in this river fine substrate provides a more suitable habitat, there must exist variables in this river that interact with substrate, to limit the number of invertebrates in coarser grain size, or to promote communities in fine substrate types. Further investigations would have to be conducted to determine what this variable might be, and whether it is biotic or abiotic.

Another explanation may be that this finding is due to an inadequate number of samples taken for each substrate type. The total invertebrate richness is greatest in finer substrate than in coarser substrate, however the rate of increase in richness with the addition of each sample is higher for coarser substrates than for finer substrates. This result suggests that, if more samples had been taken, total richness would have been highest in coarse substrate, followed by very coarse and then by fine substrate. This trend would most likely be reflected in the diversity and abundance measurements, as richness, diversity and abundance have generally followed the same patterns in this study. There were 153 samples taken in fine substrate types, while coarse and very coarse substrate types had 33 and 27 samples respectively. Increasing the number of samples taken in the

coarser substrates may yield results consistent with the scientific literature. In addition, the rate at which richness increases with the number of samples taken, indicates that new taxa continue to be added at approximately the same rate in coarser substrates, while the rate levels off more quickly in fine substrate. This suggests that in coarser substrates, representatives of many species may co-exist in close proximity, but at a scale larger than that of a sampler. This is likely because relatively higher substrate heterogeneity provides more effective and varied areas for attachment and shelter (Thorp and Covich 1991). Again, further work is needed to address these issues.

The results may also be due to a sampling artifact. Many workers have used methods other than the Ponar dredge to sample coarser substrates, and have obtained results that indicate benthic communities are more rich and diverse in larger substrate sizes (e.g.: Jowett et al. 1991, Miller 1985, Ormerod 1988, Quinn and Hickey 1990, Wohl 1995). It was noted during field work that the Ponar dredge sampler may sometimes scrape only the top layer of coarse substrate. In deep or highly coloured water it is difficult to determine whether the Ponar adequately sampled the bottom substrate. While the Ponar dredge seems to be efficient in finer substrates, it may be inferior to other sampling devices in coarse and very coarse substrate types. Further experimentation is necessary to determine whether this is indeed the case.

In this study, the corer sampler yielded significantly lower richness and diversity values than the Ponar dredge. This is most likely due to the size difference between the two samplers, and not in their efficiency per se. A larger device will sample a larger number of species, and so richness and diversity will be thus affected. There were also

significant differences in individual genus abundance between the two samplers. A possible explanation for differences in abundance may be the degree of patchiness in the distribution of certain genera. A larger sampler such as the Ponar dredge would have a greater chance of picking up patchily distributed taxa than a smaller sampler. This may be the case with *Amnicola* sp. and Ceratopogonidae, which have a greater abundance in the Ponar in fine substrate. It is interesting to note that *Amnicola* sp. are scrapers while Ceratopogonidae are predators. There may be a predator-prey interaction between these two genera, causing them to be aggregated together. However in coarse substrate, the density of *Amnicola* sp., *Dubiraphia* sp., and *Procladius* sp., were higher in the corer sampler than the Ponar, a result which is difficult to interpret. There may also be a predator-prey interaction between these three genera, as *Procladius* sp. are predators, *Amnicola* sp. are scrapers, and *Dubiraphia* sp. are collectors. Regardless of the processes effecting abundance, the two sampling devices yield different results, and community structure measurements would be confounded if both methods were used without accounting for these differences. Unfortunately, there are no standard sampling methods for different substrate types, and no calibrated means of comparing different methods.

There were significant differences in community structure among river reaches, and among sites within a reach. The patterns found in this study may indicate that fine substrate, as defined in this study, maintains benthic communities which are more diversified from one location to another, at two different scales. The reasons for this trend, and for the differences found in the other substrate types, have not yet been determined. As the factors such as sampling method, substrate type, season, pH, land-use,

and river were all constant, the change in community structure may be in response to another variable or group of variables. A possible contributor to these differences may be the presence or absence of macrophytes. Macrophytes can influence invertebrate microdistribution by reducing current velocities and by creating additional living spaces in the water column, where none would exist above unvegetated substrate (Gregg and Rose 1985). A related variable is the proximity of sites to the river bank. Cogerino et al. (1995) noted that several workers have estimated that production and retention of organic matter were several times higher in littoral biota than in mid-channel, and richness, diversity, density and biomass increased from mid-channel towards the banks. The availability of light is undoubtedly reflected in these findings. Sampling depth was analyzed in this study. However its effect on invertebrate community structure could not be determined with confidence as there were not enough samples taken at different depths for each substrate type. The number of samples taken at each site may also influence the results. Invertebrate richness in Reach 5 (33 samples) was lower than in Reach 2 (48 samples), but the rate with which richness increased with number of samples taken was greater for Reach 5. Until the patterns of community structure in this river are linked to specific and measurable variables, many areas and many sites within an area must be sampled in order get a complete picture of the distribution of aquatic invertebrates.

In conclusion, the patterns found in this study may indicate that fine substrate, as defined in this study of the Groundhog River, maintains benthic communities which are more diverse and rich than in coarser substrates. However, further work is necessary to support this finding. We found that two sampling devices, the corer and the Ponar dredge

yielded significantly different estimates of community structure. This brings up the question of whether these differences extend to other sampling devices as well. Further experimentation with many sampling methods, in different substrate types, is necessary to elucidate the extent of these differences, and perhaps quantify them. The number of samples taken for any particular variable is also an important factor to consider in the experimental design. Nevertheless, significant differences were detected between areas and sites within a 30 km stretch of the Groundhog River, suggesting that on small scale studies, many sites in many areas need to be sampled in order to get an accurate picture of the invertebrate community.

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3.0 A META-ANALYSIS OF AQUATIC INVERTEBRATE DIVERSITY IN THE MOOSE RIVER BASIN, ONTARIO

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Key words: meta-analysis, aquatic invertebrates, Moose River Basin, large rivers

3.0 A META-ANALYSIS OF AQUATIC INVERTEBRATE DIVERSITY IN THE MOOSE RIVER BASIN, ONTARIO

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3.1 Abstract

The Moose River Basin is an ecosystem for which little is known about the aquatic invertebrate community. The Ontario Ministry of Natural Resources acquired a large number of aquatic invertebrate surveys conducted on this river basin, which were never analyzed. The purpose of this study was to provide an initial assessment of the aquatic invertebrate community of this system. Twenty-two of the macroinvertebrate studies were analyzed using meta-analysis techniques, to determine: i) differences in macroinvertebrate diversity at the fine-scale, ii) the effect of substrate grain size on diversity, and iii) whether different sampling devices yield different values of diversity. We found significant differences in diversity between different reaches of a river. These differences at a fine scale are echoed by the absence of a basin-wide effect of substrate grain size on invertebrate diversity, but in spite of which, effects of substrate size on diversity were detected by individual studies. The type of sampling device used greatly influenced diversity values. This indicates that there is a need for consistent sampling protocols in future studies, in order for these studies to be comparable with each other.

3.2 Introduction

Determination of the structure and the dynamics of the benthic community is key to understanding the state of a freshwater ecosystem and how it works (Reice and Wohlenberg 1993). Aquatic invertebrates provide food for fish, waterfowl, and other wildlife, breakdown organic matter, and can also be disease carriers (Reice and Wohlenberg 1993). In a river ecosystem, macroinvertebrates have become useful in assessing the health of a river. The advantages in using macroinvertebrates are: i) they are ubiquitous, ii) their large number of species provide a spectrum of responses to environmental stresses, iii) their sedentary nature allows for spatial analysis for pollutant or disturbance effects, and iv) temporal changes caused by perturbations can be examined because of their relatively long life cycles compared to other groups (Rosenberg and Resh 1993). In order to use aquatic invertebrates as pollution indicators, baseline data on the existing taxa and how they respond to environmental variables within their habitat, must first be collected (Simpson et al. 1986, Lenat 1988). Diversity indices are commonly employed to quantify invertebrate survey data (Resh and McElravy). Norris and Georges (1993) note that it is generally accepted that diversity decreases with decreasing water quality.

The growing number of ecological studies has created a need to compare and summarize the results of related research. In the past, scientific information was synthesized through traditional literature reviews. These often suffered from selective inclusion of studies, and subjective weighting and interpretation of study results by the author of the review (Wolf 1986). This is especially true when there exist many studies

with conflicting data. Another method used to summarize studies was to count the number of statistically significant results in order to get an idea of the importance, frequency, and magnitude of an effect. However this "vote-counting" approach can have serious flaws, especially with small studies, as is usually the case in ecology (Gurevitch and Hedges 1993). Small studies are less likely to produce significant results, as they have low power, and therefore vote-counting is strongly biased toward finding no effect (Hedges and Olkin 1985). There is also the temptation, when the data is in a comparable format, to pool data directly, and then perform analyses. This too may underestimate the effect, as the different experimental designs and methods would add a large amount of variation into the data set. Pooling data from different studies is like comparing apples and oranges, which violates a "cardinal scientific prohibition"(Mann 1994), as comparing different entities may lead to erroneous inferences.

In recent years, another quantitative approach used to compare and combine results from similar studies, termed meta-analysis, has gained in popularity (Arnqvist and Wooster 1995). The application of meta-analysis techniques has become widespread in the medical and social sciences, but is not yet common in the field of biology (Fernandez-Duque and Valeggia 1994). One advantage that meta-analysis offers over the previously described methods is that it can detect effects that may not be statistically significant within an individual study, but which are nevertheless present overall. Such information should not be discarded only because individual studies failed to reject the null hypothesis (Fernandez-Duque and Valeggia 1994). This type of analysis is useful since it provides improved control of Type II statistical errors (accepting the null hypothesis when it should

be rejected) (Arnqvist and Wooster 1995). Making a Type II error may be serious when making conservation-related decisions, particularly when assessing the impact human activity may have in the environment (Fernandez-Duque and Valeggia 1994).

The Moose River Basin in northern Ontario is a system for which there is little known about its aquatic invertebrate community (Brousseau and Goodchild 1989). The Ontario Ministry of Natural Resources has conducted or received 31 macroinvertebrate surveys from as early as 1967, and all but one have never been statistically analyzed or published. The studies varied widely in the year, season, reach, and method of sampling. To characterize community structure in the Moose River Basin, some important factors to consider are: i) whether there are differences in community structure at the fine scale, such as between reaches within one river, ii) what the effect of substrate grain size has on community structure, and iii) whether different sampling methods yield different measures of community structure. A meta-analysis approach was applied to data from 22 studies on the Moose River Basin, to examine the effect these three factors on macroinvertebrate diversity.

3.3 Method

The Moose River Basin is situated in northern Ontario (Figures 1,2). Unpublished aquatic invertebrate surveys of the Moose River Basin were received from the Cochrane office of the Ontario Ministry of Natural Resources (see p. 74). The surveys were sorted into three sets, according to the type of data they contained, for three separate meta-analyses. A single study was used in more than one meta-analysis if it contained the necessary data.

The studies that had sampled in more than one reach of one river were used to determine whether fine scale differences in aquatic invertebrate diversity were evident across the Moose River Basin. If the distribution of macroinvertebrates is not contiguous, then many samples must be taken in future surveys to get a more precise estimate of the invertebrate community structure. A patchy dispersal also indicates that there are biotic or abiotic variables affecting the distribution (Weins 1989). For example, Legendre and Fortin (1989) have found that "spatial heterogeneity of the physical environment generates a diversity in communities, as well as in the biological and ecological processes that can be observed at various points in space". The relative importance, however, of biotic and physical factors regulating patterns of community structure, appears to vary with spatial scale (Menge and Olson 1990). There is a growing recognition of the need to determine how ecologically important processes at the fine-scale can be meaningfully aggregated to system-wide and global-scale responses (Sedell et al. 1989).

Figure 1. Large scale map of the Moose River Basin, Ontario

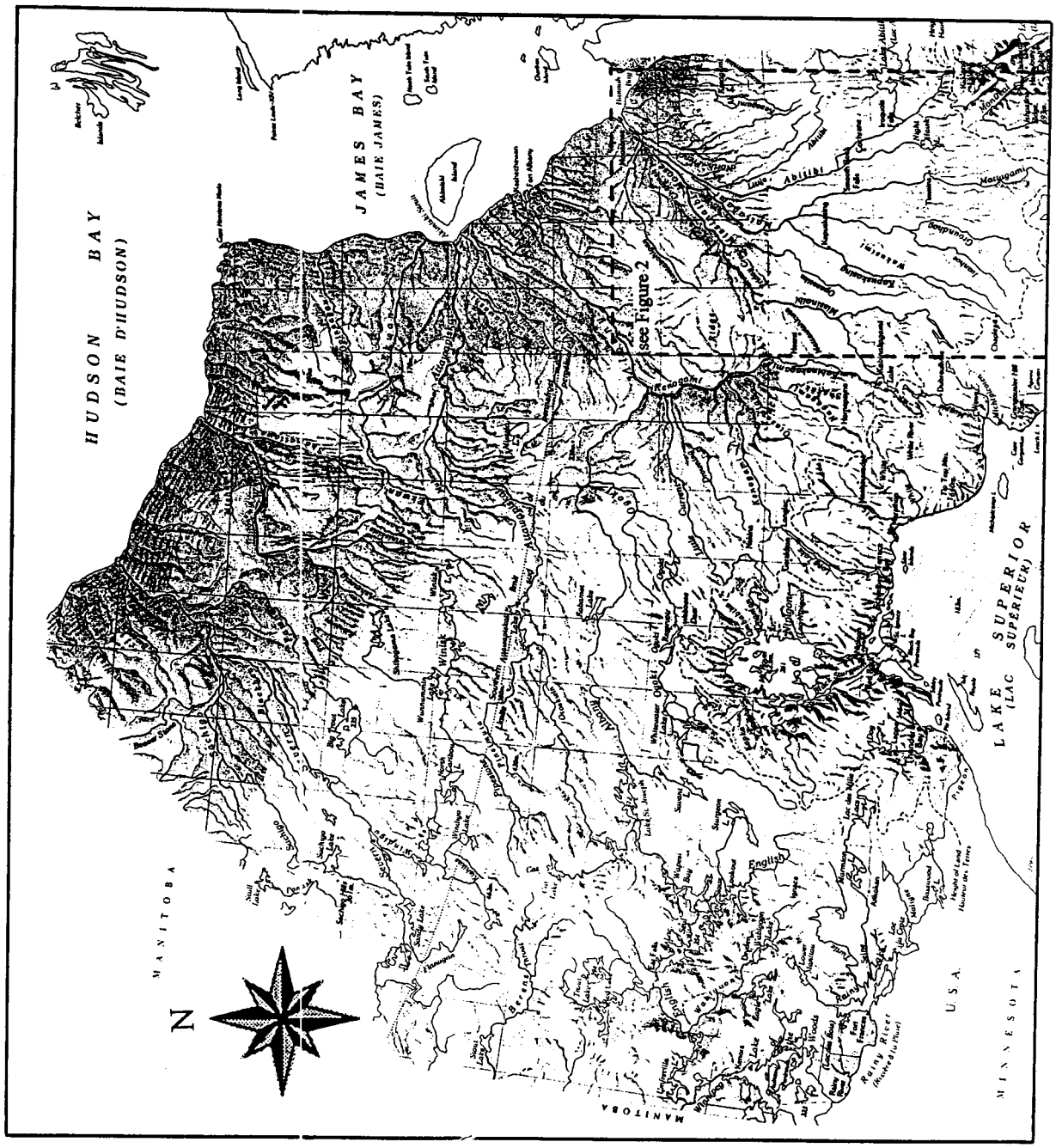
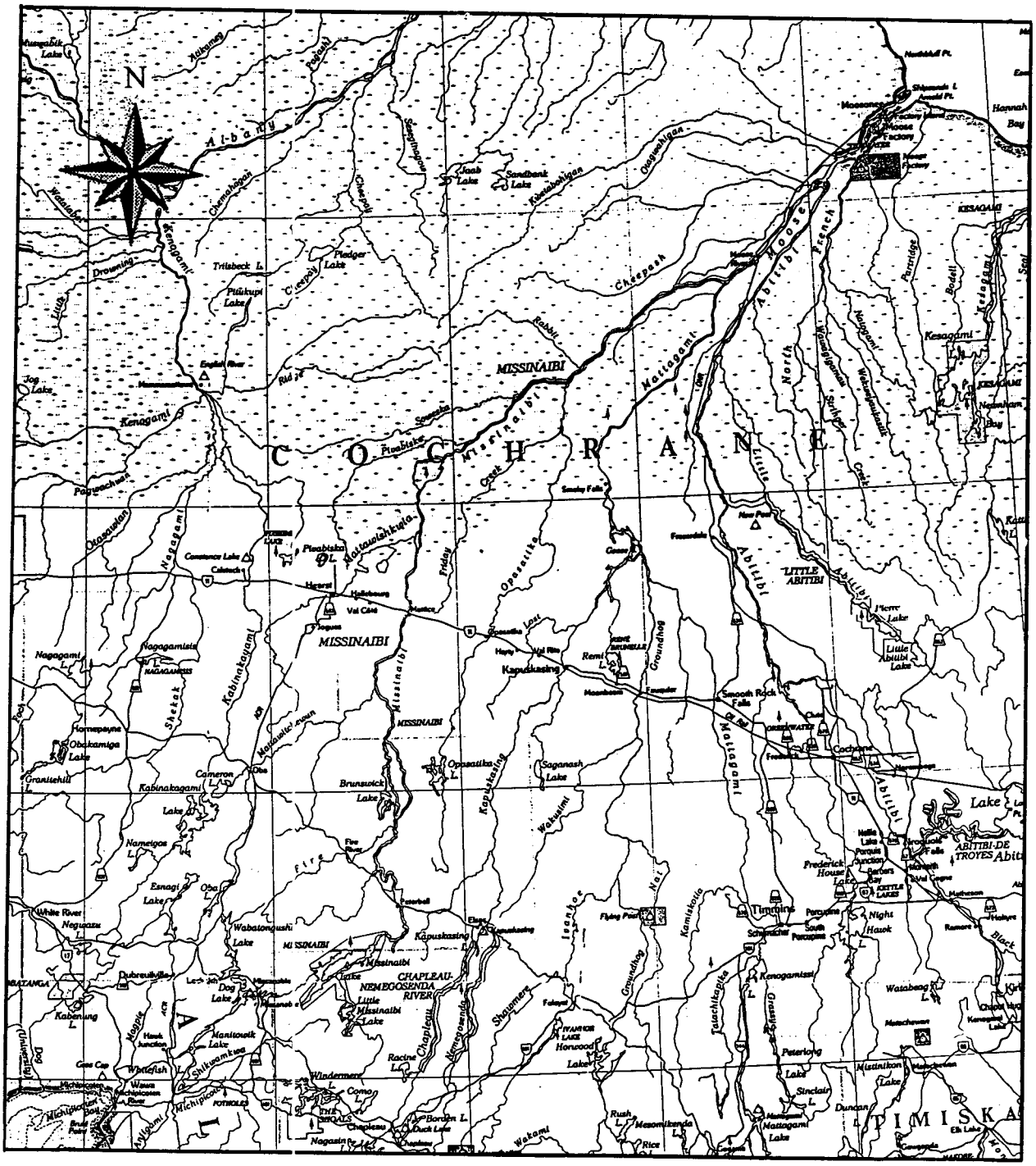


Figure 2. Map of the Moose River Basin, Ontario



The studies that used more than one sampling method or device were analyzed to assess whether the different devices yield comparable measures of diversity. The sampling devices used in this set of studies include Ekman and Ponar grabs, Surbers, drift nets, airlifters, seine nets, hand dips, scoops, and substrate cages. If different sampling devices yield different community structure estimates, then their results are not directly comparable, and so may lead to erroneous inferences if they are directly compared. When more than one device is used in a study, it is thus important to determine whether they yield similar results in order to justify pooling the data for analysis.

If a study reported the type of substrate encountered in the samples, this data was used to determine the fine-scale and basin-wide effects of substrate type on aquatic invertebrate diversity. River substrate is of prime importance to benthic invertebrates, as it provides a place for rest, refuge, food acquisition, reproduction, and development (Hynes 1970, Thorp and Covich 1991). In large rivers, the type of substrate varies from fine particles such as silt, clay, and sand, to very coarse grains such as gravel, cobble, and boulders. It is generally found that more coarse substrate types provide more diverse habitats, and so results in a more diverse aquatic invertebrate community (Hynes 1970, Minshall 1984, Quinn and Hickey 1990, Jowett et al. 1991). The substrates recorded in the MNR studies were classified into three types. "Fine" substrate included only silt, sand, clay, or muck, and did not contain grain sizes greater than 2 mm. Substrate that contained larger grain sizes, such as pebbles, gravel and cobble, as well as less then 50% fine substrate, was classified as "coarse". If the sample contained only larger grain sizes (over 2mm) and no fine substrate, then we classified it as "very coarse". Polluted river studies

were not included as they might distort baseline patterns of the Moose River Basin as a whole.

Of the thirty-one MNR studies received, twenty-one were used for at least one of the analyses, in addition to an unpublished study conducted by C. Bouwman. The Shannon-Weaver index was used as a measure of aquatic invertebrate diversity for all of the studies, for the lowest taxonomic groups reported. Nineteen studies were used to analyze differences between reaches of a river, seventeen were used to examine differences in sampling devices, and seven studies contained enough information to investigate the effect of substrate size.

The aim of the meta-analysis was to determine whether there were differences in aquatic invertebrate diversity between reaches of a river, and if different sampling devices yield different diversity values for all studies conducted. The nature of the data for individual river reaches and sampling devices precluded a two-group, directional test. There were too many different sampling devices used, with each represented in only a few studies, to compare all sampling device with one another. An Omnibus test, type of meta-analysis which uses only p-values, (Fernandez-Duque and Valeggia 1994), was used to analyze the results of the river reach studies and the sampling device studies. The methods used follow those described in Rosenthal (1987).

The studies containing substrate data were analyzed with a directional test. T-tests were conducted to determine differences in aquatic invertebrate diversity between: i) fine and coarse substrate, ii) coarse and very coarse substrate, and iii) fine and very coarse substrate. The size of the effect of substrate on diversity for each comparison, across all

the studies, was calculated using meta-analysis techniques as described in Gurevitch and Hedges (1993). The details of the omnibus tests and the meta-analysis are described in the sections that follow.

3.3.1 Omnibus Tests

A one-way analysis of variance was conducted for measurements of aquatic invertebrate diversity and sampling methods, and for diversity and river reach, for each study that contained adequate information. The resulting p-values were combined for each set of studies to determine whether there was an overall significant difference in diversity measurements between sampling devices used, and whether there were significant overall differences in diversity between reaches of a river. The results were also compared to determine whether the studies were heterogeneous. Studies are considered heterogeneous if their results are not uniform (Sokal and Rohlf 1981). If a series of studies provide a common (homogenous) estimate of the population, then it is more likely that the various studies are testing the same hypothesis (Wolf 1986). Otherwise it may not be appropriate to combine and synthesize the results, although hetereogeneity may also lead to increased understanding as to why studies differ (Wolf 1986).

To conduct the omnibus test, the normal standard deviate (Z) corresponding to each p value was recorded. The Z value from each study was used to test whether the null hypothesis, that there is no effect, can be rejected for all the studies combined.

An unweighted test (O') and a weighted test (O"), were calculated as follows:

$$O' = \frac{\sum Z_j}{[K]^{1/2}} \qquad O'' = \frac{\sum w_j Z_j}{\left[\sum w_j^2\right]^{1/2}}$$

where,

Z = the normal standard deviate corresponding to a p value

Z_j = the Z for the jth study

$\bar{Z}$ = the mean of all Z's

K = the number of studies

w_j = weight for the jth study (in this case the degrees of freedom for the jth study).

The result of each of the above equations is distributed as Z, to which a p-value can be attributed. If the p-value is ≤ 0.05, then the null hypothesis can be rejected. The heterogeneity (H) of the studies were tested using,

$$H = \sum \left(Z_j - \bar{Z} \right)^2$$

where the resulting H is distributed as χ^2 with K - 1 df.

3.3.2 Meta-Analysis

T-tests were performed for each study containing substrate information, to determine whether there were differences in aquatic invertebrate diversity for three sets of comparisons: between fine and coarse substrates, coarse and very coarse substrates, and between fine and very coarse substrates. For each study an effect size (d'), and an unbiased effect size (d^*) were calculated,

$$d'_j = \left(X_j^a - X_j^b\right)J \quad \text{and} \quad d_j^* = \frac{X_j^a - X_j^b}{s_j}J$$

where d' and d^* are calculated for the j^{th} study, and

$\bar{X}_j^a$ = mean of group a (one of three substrate types)

$\bar{X}_j^b$ = mean of group b (another of three substrate types)

s_j = the pooled standard deviation of groups a and b;

$$s_j = \sqrt{\frac{\left(N_j^a - 1\right)\left(s_j^a\right)^2 + \left(N_j^b - 1\right)\left(s_j^b\right)^2}{N_j^a + N_j^b - 2}}$$

where

N_j^a = the total number of samples in group a

N_j^b = the total number of samples in group b

s_j^a = the standard deviation of the samples in group a

s_j^b = the standard deviation of the samples in group b

J = corrective term for small sample size (as the sample size increases, J approaches 1):

$$J = 1 - \frac{3}{4\left(N_j^a + N_j^b - 2\right) - 1}$$

The variance for d' or d^* in each study can be approximated by,

$$v_j = \frac{N_j^a + N_j^b}{N_j^a N_j^b} + \frac{d_j^2}{2\left(N_j^a + N_j^b\right)}$$

The effect size of all the studies combined was calculated three different ways:

$$E_1 = \frac{\sum_{j=1} d_j'}{K}, \qquad E_2 = \frac{\sum_{j=1} d_j^*}{K}, \text{ and} \qquad E_3 = \frac{\sum_{j=1} w_j d_j^*}{\sum_{j=1} w_j},$$

where

K = total number of studies

w_j = weight $(1/v_j)$.

To determine the 95% confidence interval for any E_j, variance (s^2) was calculated,

$$s^2(E_j) = \frac{1}{\sum_{j=1} w_j}$$

from which the lower and upper limits were calculated as, respectively:

$$E_j^L = E_j - \left[Z_{\alpha/2} s(E_j)\right]$$
$$E_j^U = E_j + \left[Z_{\alpha/2} s(E_j)\right]$$

where Z is the two-tailed value of the standard normal distribution (1.96), and $s(E_j)$ is the square root of the variance of E_j.

The heterogeneity (H_j) of the studies was tested using,

$$H_1 = \sum\left(d'_j - E_1\right)^2, \qquad H_2 = \sum\left(d''_j - E_2\right)^2, \text{ and} \qquad H_3 = \sum w_j\left(d''_j - E_3\right)^2$$

where the resulting H_j's are distributed as χ^2 with K - 1 df.

3.4 Results

3.4.1 Omnibus Tests

The results of the ANOVA for each study (Table 1) were used in the omnibus tests as previously described.

Table 1. P-values for each ANOVA, for the set of studies analyzed for differences in diversity in river reaches, and for the set of studies analyzed for differences in sampling methods. The corresponding *Z* for each p-value, and the degrees of freedom for each study are also reported.

Reach study	ANOVA p level	*Z*	df	**Method** study	ANOVA p level	*Z*	df
1	0.0166	2.13	10	1	0.1945	0.86	9
2	*NA*	*NA*	*NA*	2	0.7025	0	9
3	0.3907	0.27	19	3	0.1367	1.09	9
4	0.0007	3.19	23	4	*NA*	*NA*	*NA*
5	0.0932	1.32	18	5	0.0197	2.06	17
6	0.9954	0	7	6	0.3040	0.51	7
8	0.0089	2.37	35	8	0.0001	3.8	35
9	0.9690	0	27	9	0.5147	0	27
10	0.0066	2.48	22	10	0.5148	0	27
12	0.3427	0.4	23	12	0.5671	0	23
13	0.5554	0	21	13	0.0607	1.55	20
14	0.1495	1.04	15	14	0.0262	1.93	12
15	0.0143	2.19	12	15	0.7529	0	11
16	0.5891	0	32	16	0.5057	0	31
17	0.4205	0.2	23	17	0.3891	0.28	23
18	0.0107	2.3	22	18	0.0617	1.54	22
19	0.6760	0	3	19	0.6715	0	3
20	0.2431	0.7	18	20	*NA*	*NA*	*NA*
21	0.1148	1.2	32	21	*NA*	*NA*	*NA*
22	0.0347	1.81	218	22	< 0.0001	4.4	218

NA - information not available

The omnibus tests (Table 2) reveal significant differences in aquatic invertebrate diversity between reaches of a river for the Moose River Basin as a whole. This is the case for both the unweighted test (*O'*, $p < 0.000001$), and the test weighted for study size (*O"*, $p = 0.0003$). There is also a significant difference in the diversity measurements

yielded by different sampling devices (O', $p < 0.00001$; O", $p < 0.0000001$). The test for heterogeneity reveals that the set of studies used to analyze river reaches are not significantly heterogeneous ($p = 0.3$), but that the set of studies used to analyze sampling method are heterogeneous ($p = 0.02$).

Table 2. Results of the omnibus and heterogeneity tests with the corresponding p-values, in addition to the mean Z and the number of studies used.

	$\bar{Z}$	K	O'	O''	H
Reach	1.137	19	4.955	3.433	20.314
p level			< 0.000001	0.0003	0.3
Method	1.06	17	4.370	5.350	29.708
p level			< 0.00001	< 0.0000001	0.02

3.4.2 Meta-analysis

The results of the t-tests performed on each study (Table 3) were used to calculate the variables used in the meta-analysis (Table 4).

Table 3. Results of t-tests for each study in each set of substrate comparisons; not every study contained all three substrate types

fine-coarse								Std.Dev.	Std.Dev.	F-ratio	p
study	$\bar{X}^F$	$\bar{X}^C$	t-value	df	p	N^F	N^C	fine	coarse	variance	variance
2	1.5527	1.3156	.8960	7	.399991	4	5	.4339	.3622	1.4355	.7141
3	.7632	.6841	.5232	6	.619613	5	3	.2329	.1420	2.6902	.5778
4	1.2749	2.0452	-3.664	22	.001364	10	14	.5854	.4462	1.7217	.3615
7	.4864	.4845	.0099	15	.992218	10	7	.3524	.4177	1.4054	.6199
11	.8583	.5643	1.0308	33	.310145	25	10	.8289	.5463	2.3024	.1940
22	1.7469	1.6135	.8854	184	.377093	153	33	.8089	.6619	1.4934	.1835
coarse-very coarse								Std.Dev.	Std.Dev.	F-ratio	p
study	$\bar{X}^C$	$\bar{X}^{VC}$	t-value	df	p	N^C	N^{VC}	coarse	v-coarse	variance	variance
2	1.3156	1.6480	-1.301	10	.222280	5	7	.3621	.4792	1.7511	.6116
3	.6841	.9920	-2.7912	3	.068347	3	2	.1420	.0590	5.7935	.5637
5	1.2622	1.2982	-.0977	6	.925356	4	4	.5655	.4741	1.4224	.7791
11	.5643	.7824	-.7622	18	.455835	10	10	.5463	.7217	1.7453	.4193
22	1.6135	1.0899	2.8203	58	.006556	33	27	.6619	.7762	1.3751	.3890
fine-very coarse								Std.Dev.	Std.Dev.	F-ratio	p
study	$\bar{X}^F$	$\bar{X}^{VC}$	t-value	df	p	N^F	N^{VC}	fine	v-coarse	variance	variance
2	1.5527	1.6480	-.3272	9	.751021	4	7	.4339	.4792	1.2199	.9427
3	.7632	.9920	-1.302	5	.249571	5	2	.2329	.0590	15.586	.3750
11	.8583	.7824	.2530	33	.801807	25	10	.8289	.7217	1.3192	.6909
22	1.7469	1.0899	3.9140	178	.000129	153	27	.8089	.7762	1.0860	.8413

Table 4. The variables as calculated for each study in each comparison, for the meta-analysis.

study	$\bar{X}^F - \bar{X}^C$	J	d'	Sp	d''	V	w	wd''
2	0.2371	0.8889	0.2108	0.3945	0.5342	0.4659	2.1466	1.1468
3	0.0791	0.8696	0.0688	0.2071	0.3321	0.5402	1.8511	0.6148
5	-0.7703	0.9655	-0.74371	0.5078	-1.4647	0.2161	4.6270	-6.7771
7	0.0019	0.9492	0.0018	0.3799	0.0047	0.2429	4.1176	0.0195
11	0.294	0.9771	0.2873	0.7623	0.3768	0.1420	7.0408	2.6533
22	0.1334	0.9959	0.1329	0.7853	0.1692	0.0369	27.0886	4.5827
study	$\bar{X}^C - \bar{X}^{VC}$	J	d'	Sp	d''	V	w	wd''
2	-0.3324	0.9231	-0.3068	0.4361	-0.7035	0.3635	2.7512	-1.9355
3	-0.3079	0.7273	-0.2239	0.1208	-1.8530	1.1767	0.8498	-1.5748
6	-0.036	0.8696	-0.0313	0.5218	-0.0600	0.5002	1.9991	-0.1199
11	-0.2181	0.9577	-0.2089	0.6400	-0.3264	0.2027	4.9343	-1.6104
22	0.5236	0.9870	0.5168	0.7154	0.7224	0.0717	13.9492	10.0768
study	$\bar{X}^F - \bar{X}^{VC}$	J	d'	Sp	d''	V	w	wd''
2	-0.0953	0.9143	-0.0871	0.4646	-0.1875	0.3945	2.5351	-0.4755
3	-0.2288	0.8421	-0.1927	0.2100	-0.9176	0.7601	1.3155	-1.2071
11	0.0759	0.9771	0.0742	0.8011	0.0926	0.14012	7.1366	0.6607
22	0.657	0.9958	0.6542	0.8042	0.8135	0.0454	22.0209	17.9142

Table 5. The meta-analysis for each set of substrate comparisons, with the corresponding 95% confidence intervals.

	E_1	$d_L : d_U$	E_2	$d_L : d_U$	E_3	$d_L : d_U$
fine-coarse	-0.0070	-0.2904 : 0.2763	-0.0079	-0.2942 : 0.2784	0.0478	-0.2385 : 0.3341
coarse-v.coarse	-0.0508	-0.4395 : 0.3379	-0.4441	-0.8402 : -0.0480	0.1975	-0.6930 : 1.0880
fine-v.coarse	0.1121	-0.2268 : 0.4511	-0.0498	-0.3909 : 0.2914	0.5118	0.0349 : 0.9886

Table 6. The tests for heterogeneity for each set of comparisons, with the corresponding p-values.

	H_1	p-value	H_2	p-value	H_3	p-value
fine-coarse	0.7022	> 0.5	2.7113	> 0.5	12.4114	< 0.05
coarse-v.coarse	0.4431	> 0.5	3.5745	> 0.5	11.1366	< 0.05
fine-v.coarse	0.4279	> 0.5	1.5376	> 0.5	7.1865	< 0.05

The first size effect (E_1), is based on d', a straight difference between the means of two substrate class groups, divided by the number of studies used (and corrected for

The first size effect (E_1), is based on d', a straight difference between the means of two substrate class groups, divided by the number of studies used (and corrected for small sample size bias). According to this calculation of size effect (see Table 5), invertebrate diversity is slightly lower in fine substrate than in coarse substrate (E_1 = -0.0070), and is slightly lower in coarse substrate than in very coarse substrate (E_1 = -0.0508). Interestingly, the comparison between fine and very coarse indicates that diversity is higher in fine substrate than in very coarse substrate (E_1 = 0.1121). However the upper and lower limits of the 95% confidence interval for each comparison encompasses 0 (see Table 5), and so the size of the effects are not significantly different from 0. According to the test for heterogeneity, the results for this set of comparisons are homogenous (see Table 6).

The second size effect (E_2) is also based on the difference between two substrate class groups, but this difference is divided by the pooled standard deviation to obtain d'', a standardized effect. Again, fine substrate has a slightly lower invertebrate diversity than coarse substrate (E_2 = -0.0079), and diversity in coarse substrate is lower than in very coarse substrate (E_2 = -0.4441, see Table 5). In contrast to the first size effect, fine substrate has lower diversity than very coarse substrate (E_2 = -0.0498). The 95% confidence limits encompass 0 for the fine-coarse and fine-very coarse comparisons, and so these two effects are not significantly different from zero (see Table 5). The difference in diversity between coarse and very coarse substrate is significant, and the size of the effect is considered small to medium according to Cohen's guidelines (1977). These studies are also homogenous (see Table 6).

The third size effect (E_3) is also based on d'', and is then weighted to account for differences in sample size. Large studies are weighed more heavily than smaller studies, on the assumption that larger studies will be more precise (Hedges and Olkin 1985). The result of this weighting produces size effects with the opposite direction than the previous two calculations (see Table 5). Fine substrate has higher invertebrate diversity than coarse substrate ($E_3 = 0.0478$), and coarse substrate has higher diversity than very coarse substrate ($E_3 = 0.1975$). Similarly, invertebrate diversity is higher in fine substrate than in very coarse substrate ($E_3 = 0.5118$). However, the upper and lower limit of the 95% confidence interval encompasses zero for the fine to coarse substrate, and for the coarse to very coarse substrate comparisons, indicating that the effects do not differ significantly from zero (see Table 5). The 95% confidence interval for the fine to very coarse substrate comparison does not encompass zero, and therefore the size effect is significant, and may be treated as a medium size effect according to Cohen (1977). The test of heterogeneity, using the weights for sample size, indicates that these studies are heterogeneous (see Table 6).

3.5 Discussion

The omnibus tests indicate significant differences in aquatic invertebrate diversity within each river studied. It is important to know whether these fine-scale differences within the Moose River Basin exist, especially for the initial characterization of the aquatic invertebrate community. Further investigation is needed to elucidate the nature of these differences in the invertebrate community, and the factors involved. Otherwise, basin-wide trends may obscure fine-scale processes, and would create a gap in our understanding of this ecosystem.

The result of the omnibus test also demonstrates the need for a consistent sampling methodology. As suggested by this study, different sampling devices yield different diversity values, and so their results are not directly comparable. Although it is usually not possible to use one sampling device in all river depths and substrate types, it may be possible to quantify their differences. A standardized protocol of river sampling is necessary to maximize the information that can be compared between studies. It should be noted that the results for this set of studies are heterogeneous, implying that the results of one, or each, of the studies is very different than the rest. This is not surprising as the types of sampling devices used were not consistent between studies. It is expected that the differences between certain samplers will be greater than the differences between other samplers. Again, further experimentation is necessary to determine the efficiency and practicality of any particular sampler.

The meta-analysis further indicates that substrate size has an effect on invertebrate diversity. However, the measure of the size and the direction of the effect depends on the type of meta-analysis used. The first size effect (E_1) is based on the straight difference between the means of two substrate type groups. This analysis gave somewhat inconsistent results. The second calculation of size effect (E_2) divides the difference between the means of two groups by the pooled standard deviation, which takes into account some of the variation within each study. As the E_2 size effects are all in the same direction, the inconsistency of the E_1 size effect calculations may be the result of not accounting for variation. When the studies are weighted by their sample size (E_3) , the results show an opposite direction of effect than the E_1 and E_2 analyses. The shift in the direction of the effect in the E_1 and E_2 analyses to the E_3 analysis is due to the weighting by study size. In the E_3 analysis there is one very large study whose data, when weighted by sample size, dominate the results. The test of heterogeneity indicates that in this meta-analysis, weighting the surveys by sample size yields heterogeneous results. The data for the E_1 and E_2 analysis, which were not weighted, were homogeneous. This suggests that one large study can dominate the data set and cause it to be heterogeneous when the studies are weighted by sample size.

How does one interpret the effect of substrate type on aquatic invertebrate diversity in the Moose River Basin when three different meta-analyses yield three different results? The inconsistent results seem to indicate that there is not a basin-wide trend with respect to substrate type, but that there are effects on a finer scale. It is also possible that the conditions of sampling for each study differed to the extent that they masked similar

processes. Again, further research, with a consistent sampling protocol, should be conducted to determine the local and the basin-wide effects of substrate type on aquatic invertebrate community structure.

It is worth noting that not all types of meta-analyses give similar results. The type of analysis conducted should depend on the purpose of the meta-analysis, and the quality of the studies used. If all the studies report results in the same format, such as diversity measurements, the size of the effect without standardizing may be useful. When studies report analyses that use different measures, then it is necessary to standardize the data using the pooled standard deviation to give a "unitless" effect. This may also be the desired procedure if the variation within studies is great. The weighting of studies for meta-analysis may be useful when there are studies with different sample sizes. This type of analysis gives larger studies more weight, under the assumption that they will be more precise (Hedges and Olkin 1985). Studies can also be weighted a priori according to scientific merit, if one is very familiar with how each study was conducted. Extreme care must be taken, however, to not introduce personal bias. If weighting is used in a meta-analysis, it is recommended that the unweighted results be reported as well (Wolf 1986). In this study, the weighting by study size in the E_3 analysis resulted in one large study overshadowing the rest. This may be appropriate if the large study was well conducted and representative of the set of studies as a whole. In the case of this meta-analysis, the large study was conducted on one stretch of one river, and the effect of substrate size on aquatic invertebrate diversity may not typify the Moose River Basin as a whole. For this data set, the E_2 meta-analysis seems to be the most suitable approach.

A common criticism of meta-analyses is referred to as the "file-drawer" problem (Rosenthal 1987). This refers to the tendency of journals to publish only significant results, while the studies showing insignificant results are hidden away in lab file drawers. Fortunately for this study, all the studies on the Moose River Basin (excepting one conducted by the author), was obtained from the Ministry of Natural Resources. As most of the studies had never been analyzed, there was no bias in the selection of studies for the meta-analysis, aside from discarding studies conducted on polluted rivers.

In conclusion, omnibus tests and meta-analysis techniques were useful in comparing and combining a large number of surveys conducted on the Moose River Basin. The omnibus tests suggest that there are fine-scale differences in aquatic invertebrate community structure, as macroinvertebrate diversity differed between river reaches. The finding that sampling devices yield different measures of diversity also demonstrates the need for consistent sampling protocols. The meta-analysis indicates that there do not exist basin-wide trends with respect to the effect of substrate type on macroinvertebrate diversity, but that there are effects of fine-scale processes that need to be further examined.

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4.0 CONCLUSION

The findings of this project, from both the fine-scale and the meta-analysis studies, illustrate the importance of consistent sampling methodologies for the collection and identification of aquatic invertebrates in large rivers. Various sampling devices yield significantly different estimates of community structure, and these differences must be addressed before their results can be combined or compared. This initial assessment of aquatic invertebrate communities in the Moose River Basin indicates that further work is necessary to elucidate the biological and physical processes at the fine-scale, as significant differences were found both in sites within a reach, and among reaches within a river. One of the factors found to have an effect on community structure was substrate type. In the Groundhog River study, the patterns detected may indicate that fine substrate, as defined in this study, maintains benthic communities which are more diverse and rich than in coarser substrates. This finding, however, may be due to insufficient sample sizes for each substrate type. The meta-analysis results support the existence of fine-scale effects of substrate types, but does not show basin-wide trends for the direction or size of the effect. It possible that the conditions of sampling for each study differed to the extent that they masked similar processes. Again, further research, with a consistent sampling protocol, should be conducted to determine the local and the basin-wide processes on aquatic invertebrate community structure in the Moose River Basin.

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6.0 APPENDIX: Total number of invertebrates reported in each study for each river

Study1 Aug-70

River	Kapuskasing	Mattagami
Hirudinea	4	21
Oligochaeta	1148	1153
Amphipoda	1	0
Diptera	136	64
Ephemeroptera	3	10
Megaloptera	1	1
Trichoptera	6	36
Gastropoda	0	25
Pelecypoda	3	89

Study 2 Aug-82

River	Kapuskasing
Hirudinea	4
Oligochaeta	188
Nematoda	3
Hyalella sp.	12
Decapoda	1
Elmidae	2
Optioservus sp.	1
Diptera	1
Pupae	1
Ceratopogonidae	27
Chironomidae	332
Chaoborus	1
Chrysops	1
Baetis sp.	31
Caenis	22
Hexagenia sp.	95
Stenonema sp.	14
Sialis	21
Boyeria sp.	1
Gomphus sp.	5
Oecetis sp.	2
Molanna sp.	3
Phylocentropus sp.	16
Polycentropus sp.	15
Amnicolidae	5
Gyraulus sp.	6
Sphaerium sp.	45
Unionidae	3

Study 3 Jul-85

River	Kapuskasing
Hirudinea	78
Tubificidae	8289
Dysticidae	6
Chironomidae	1943
pupae	5
Hexagenia sp.	5
Sialis	3
Trichoptera	1
Gastropoda	1
Physa sp.	8
Valvata sp.	73

Study 4 summer '83

River	Mattagami
Baetis sp.	29
Caenis	56
Isonychia sp.	10
Tricorythodes	7
Eurylophella sp.	28
Heptagenia sp.	943
Stenacron sp.	77
Stenonema sp.	58
Paraleptophlebia sp.	911
Leuctra sp.	66
Acroneuria sp.	159
Paragnetina sp.	12
Pteronarcys sp.	10
Hydrophyschidae	814
Hydropsyche sp.	1924
Mayatrichia	22
Mystacides sp.	2
Neureclipsis	218
· Nyctiophylax	11
Polycentropus sp.	712

Study 5 Sep-75

River	Mattagami	Poplar Rapids
Coelenterata	50	0
Hirudinea	2	0
Erpobdellidae	1088	0
Lumbriculus sp.	289	43
Stylodrilus sp.	1425	50
Nais	9681	43
Pristina sp.	2	0
Slavina	1000	0
Stylaria sp.	174	216
Limnodrilus sp.	8748	0
Rhyacodrilus sp.	508	0
Tubifex tubifex	435	0
immature with setae	207412	86
immature no setae	221677	3352
Nematoda	6508	392
Gammarus	3000	0

Study 5 Sep-75 (cont'd)		
River	Mattagami	Poplar Rapids
Pontoporeia sp.	87	0
Hyalella sp.	3879	5880
Cladocera	22634	1176
Copepoda	12000	0
Orconectes sp.	173	86
Ostracoda	12783	0
Dubiraphnia sp.	1568	2346
Optioservus sp.	0	1093
Stenelmis sp.	0	3498
Ceratopogonidae	348	0
Bezzia	2370	1152
Ablabesmyia	0	50
Brillia	5000	784
Chironomus sp.	2786	392
Coelotanypus	789	957
Conchapelopia	22600	50
Corynoneura	0	44
Crictopus	5709	907
Cryptochironomus	1774	304
Epoicocladius	0	44
Heterotrissocladius sp.	50	0
Micropsectra	0	174
Microtendipes	691	2618
Orthocladius	1355	0
Paracladopelma	2000	0
Polypedilum sp.	173	3179
Polypedilum fallax	5350	0
Procladius	10357	1045
Psectrocladius	311	218
Strictochironomus	0	4492
Tanytarsus	39423	216
Tribelos	3744	0
Zavreliella	0	44
Hydrophorus	200	0
Hemerodromia	108	0
Roederiodes	400	0
Atherix variegata	43	0
Simulium sp.	1350	0
Chrysops	0	44
Antocha	86	0
Tipula	11	0
Baetis sp.	0	217
Caenis	9444	0
Centroptilum	0	130
Ephemerella sp.	0	100
Ephemerella bicolor gr.	22	0
Ephemerella invaria gr	11	389
Tricorythodes	0	43
Ephemera sp.	0	1433
Hexagenia sp.	44	0
Heptagenia sp.	0	216
Stenacron sp.	0	173
Stenonema sp.	5411	389
Paraleptophlebia sp.	1501	43
Hemiptera	392	0
Gerris sp.	11	0
Sialis	3180	0
Aeshna sp.	0	43
Hetaerina	0	86
Ophiogomphus sp	1227	0
Taeniopteryx sp.	0	43
Acroneuria sp.	100	0
Acroneuria arida	0	259
Pteronarcys sp.	173	0
Cheumatopsyche	4337	5088
Helicopsyche sp.	0	216
Hydropsyche sp.	6863	43
Agraylea sp.	184	1512
Leucotrichia	3000	0
Leptoceridae	0	0
Mystacides sp.	6000	0
Oecetis sp.	4209	129
Neophylax	44	0
Molanna sp.	0	87
Odontoceridae	0	1000
Chimarra sp.	0	286
Neureclipsis	173	0
Polycentropus sp.	3500	435
Psychmyia sp.	195	0
Gastropoda	11	0
Amnicola sp.	15737	4629
Ancylidae	87	0
Ferrissia sp.	31607	1043
Physa sp.	2900	0
Promenetus sp.	10	0
Valvata sp.	2095	827
Pelecypoda	8	0
Pisidium sp.	126078	1784
Sphaerium sp.	1475	0
Elliptio sp.	0	43

Study 6 Aug-89	
River	Abitibi
Glossiphoniidae	53
Tubificidae	752
Nematoda	18
Gammaridae	1
Decapoda	23
Elmidae	20
Ceratopogonidae	1

Study 6 Aug-89 (cont'd)

River	Abitibi
Chironomidae	612
Culicidae	9
Tabanidae	3
Baetidae	417
Ephemiridae	22
Heptageniidae	222
Corixidae	2
Veliidae	31
Hydrophyschidae	72
Limnephilidae	2
Psychomyiidae	1
Rhyacophilidae	59
Lymnaeidae	1
Physidae	41
Sphaeriidae	118

Study 7 Jun-67

River	Abitibi	Frederick House
Hirudinea	68	0
Oligochaeta	24868	93
Amphipoda	2	0
Diptera	1336	10
Ephemeroptera	10	6
Megaloptera	2	0
Trichoptera	6	9
Gastropoda	12	0
Pelecypoda	445	18

Study 8 Jun-89

River	Groundhog
Helobdella sp.	2
Lumbriculus sp.	1
Stylodrilus sp.	14
Potamothrix sp.	3
Rhyacodrilus sp.	1
immature with setae	53
Hyalella sp.	5
Decapoda	2
Lirceus lineatus	1
Dubiraphnia sp.	1
Optioservus sp.	10
Stenelmis sp.	21
Gyrinus sp.	1
Psephenus sp.	1
Blepharocera	3
Palpomyia sp.	4
Ablabesmyia	8
Cladotanytarsus	3
Corynoneura	1
Demicryptochironomus	27
Eukiefferiella	4
Paralauterborniella	1
Paratendipes	12
Phaenopsectra	6
Polypedilum sp.	27
Procladius	32
Strictochironomus	35
Tanytarsus	4
Thienemannimyia	101
Xenochironomus sp.	1
Chaoborus	1
Atherix sp.	6
Simulium sp.	3
Chrysops	1
Dicranota sp	1
Ameletus	15
Baetis sp.	49
Isonychia sp.	17
Ephemerella sp.	81
Ephemera sp.	35
Eurylophella sp.	12
Hexagenia sp.	125
Rhithrogena	9
Stenacron sp.	4
Stenonema sp.	96
Leptophlebia	3
Paraleptophlebia sp.	57
Hesperocorixa sp.	7
Calopteryx	1
Gomphus sp.	8
Lanthus	1
Stylogomphus	1
Alloperla	120
Leuctra sp.	4
Acroneuria sp.	36
Agnetina sp.	1
Isoperla sp.	108
Cheumatopsyche	28
Hydropsyche sp.	125
Lepidostoma sp.	2
Mystacides sp.	1
Limnephilus	2
Pycnopsyche	2
Chimarra sp.	87
Nyctiophylax	3
Phylocentropus sp.	9
Polycentropus sp.	15
Rhyachophila sp.	6
Amnicola sp.	1
Valvata sp.	2

Study 8 Jun-89 (cont'd)

River	Groundhog
Musculium sp.	3
Pisidium sp.	8

Study 9 summer 90

River	Groundhog
Oligochaeta	43
Lumbriculus sp.	8
immature with setae	41
Nematoda	9
Amphipoda	5
Decapoda	1
Coleoptera	39
Dubiraphnia sp.	4
Optioservus sp.	11
Stenelmis sp.	4
Diptera	7
Ceratopogonidae	13
Palpomyia sp.	4
larvae	328
pupae	13
Chironomus sp.	6
Demicryptochironomus	15
Eukiefferiella	8
Paratendipes	38
Phaenopsectra	53
Procladius	41
Stempellina	2
Tanytarsus	35
Thienemannimyia	35
Simulium sp.	1
Chrysops	2
Dicranota sp	2
Ephemeroptera	614
Baetis sp.	61
Caenis	13
Ephemerella sp.	4
Ephemera sp.	21
Hexagenia sp.	209
Stenonema sp.	9
Paraleptophlebia sp.	1
Hesperocorixa sp.	2
Sialis	1
Odonata	28
Gomphus sp.	21
Plecoptera	19
Leuctra sp.	3
Acroneuria sp.	7
Agnetina sp.	1
Trichoptera	113
Helicopsyche sp.	25
Hydropsyche sp.	5
Lepidostoma sp.	6
Ceraclea	2
Pycnopsyche	3
Chimarra sp.	1
Phylocentropus sp.	5
Polycentropus sp.	2
Gastropoda	108
Pelecypoda	181
Sphaerium sp.	52

Study 10 Jun-92

River	Groundhog
Lumbriculus sp.	1
Nais	34
Limnodrilus sp.	3
immature with setae	24
immature no setae	188
Hyalella sp.	5
Agabus	2
Coptotomus sp.	2
Hydroporus	12
Dubiraphnia sp.	2
Optioservus sp.	1
Stenelmis sp.	18
Palpomyia sp.	4
Chironomus sp.	61
Crictopus	319
Cryptochironomus	7
Eukiefferiella	5
Orthocladius	25
Paratendipes	1
Phaenopsectra	51
Procladius	458
Tanytarsus	34
Thienemannimyia	376
Simulium sp.	18
Dicranota sp	1
Baetis sp.	55
Caenis	1
Siphlonurus sp.	136
Ephemerella sp.	45
Ephemera sp.	3
Hexagenia sp.	53
Stenonema sp.	23
Paraleptophlebia sp.	1
Corixidae	12
Hesperocorixa sp.	3
Ophiogomphus sp	2
Macromia sp.	3

Study 10 Jun-92 (cont'd)

River	Groundhog
Isoperla sp.	3
Cheumatopsyche	15
Helicopsyche sp.	68
Hydropsyche sp.	52
Lepidostoma sp.	2
Ceraclea	3
Pycnopsyche	4
Chimarra sp.	1
Polycentropus sp.	8
Valvata sp.	138
Pisidium sp.	74
Sphaerium sp.	1
Ligumia sp.	1

Study 11 Jun-81

River	Moose
Limnodrilus sp.	94
Potamothrix sp.	2
Tubifex sp.	22
mature with setae	3
mature no setae	11
immature no setae	42
Donacia	1
Elmidae	1
Limnius	1
Probezzia	68
Chironomus sp.	2
Cladotanytarsus	63
Cryptochironomus	5
Cryptotendipes	3
Dicrotendipes	2
Endochironomus	1
Eukiefferiella	1
Larsia	1
Micropsectra	5
Orthocladius	2
Paracladopelma	3
Paratendipes	1
Phaenopsectra	30
Polypedilum sp.	21
Psectrocladius	2
Pseudochironomus sp.	9
Rheotanytarsus	28
Robackia	11
Stempellina	12
Strictochironomus	2
anytarsus	21
Chaoborus	11
Empididae	3
Clinocera	1
Hemerodromia	2
Hexagenia sp.	3
Stenonema sp.	1
Ophiogomphus sp	1
Isogenus	1
Potamyia sp.	1
Oecetis sp.	2
Neophylax	1
Chimarra sp.	1
Psychmyia sp.	1
Probynthinella sp.	14
Valvata sp.	11
Musculium sp.	1
Pisidium sp.	57
Sphaerium sp.	3
Lasmigona sp.	1

Study 12 summer '85

River	Kapuskasing
Helobdella stagnalis	1
Placobdella ornata	3
Thermyzon biannulatum	1
Haemopsis sp.	1
Haemopsis marmorate	4
Hyalella azteca	177
Orconectes sp.	12
Orconectes propinquus	5
Orconectes virilis	4
Eurycercus lamellatus	1
Daphnia pulex	613
Daphnia rosea	9
Simocephalus vetulus	2
Polyphemus pediculus	365
Latona setifera	1
Sida crystallina	5
Coptotomus sp.	2
Coptotomus lenticus	29
Deronectes depressus	7
Hydroporus sp.	7
Dubiraphnia quadrinotata	1
Gyrinus sp.	2
Haliplus blanchardi	3
Chironomidae	1
Chironomus sp.	36
Conchapelopia sp.	7
Cryptochironomus sp.	2
Dicrotendipes sp.	3
Parachironomus sp.	5
Phaenopsectra sp.	1
Polypedilum sp.	3

Study 12 summer '85 (cont'd)	
River	Kapuskasing
Procladius sp.	5
Rheotanytarsus sp.	1
Tribelos sp.	1
Attenella sp.	2
Baetis sp.	25
Cloeon sp.	3
Baetisca sp.	2
Caenis sp.	1
Hexagenia limbata	18
Paraleptophlebia sp.	24
Siphlonurus sp.	6
Tricorythodes sp.	2
Corixidae	8
Sigara decoratella	13
Sigara grossolineata	1
Sigara solensis	2
Sigara trilineata	8
Gerris remigis	8
Notonectidae	2
Notonecta borealis	4
Rhagovelia obesa	10
Sialis sp.	5
Aeshna interrupta	4
Basiaeschna janata	12
Boyeria vinosa	2
Calopteryx aequabilis	13
Ischnura sp.	33
Gomphidae	3
Dromogomphus spinosus	1
Gomphus lividus	5
Hagenius brevistylus	2
Ophiogomphus carolus	1
Didymops transversa	9
Macromia illinoiensis	20
Molanna sp.	1
Phryganea sp.	20
Neureclipsis sp.	12
Phylocentropus sp.	3
Amnicola limosa	27
Lymnaeidae	3
Bulimnea megasoma	3
Lymnaea stagnalis	3
Physella gyrina	60
Gyraulus parvus	2
Helisoma anceps	3
Planorbula campanulata	5
Planorbula trivolis	3
Valvata sincera	1
Pisidium casertanum	3
Elliptio complanata	4
Lampsilis radiata	10

Study 13 summer '83	
River	Mattagami
Erpobdellidae	1
Placobdella ornata	1
Haemopsis grandis	1
Rhyacodrilus coccineus	1
Hyalella azteca	36
Orconectes sp.	5
Orconectes propinquus	5
Cladocera	100
Eurycercus lamellatus	59
Daphnia pulex	2
Daphnia rosea	2
Leptodora kindtii	1
Latona setifera	4
Sida crystallina	45
Diacyclops nanus	14
Eucyclops serrulatus	1
Macrocyclops fiwca	1
Potamocypris pallida	4
Hydrachnida	1
Eylais sp.	1
Ilybius biguttulus	1
Dubiraphnia quadrinotata	1
Dineutus maculiventris	1
Gyrinus sp.	1
Atherix lanthus	2
Conchapelopia sp.	5
Eukiefferiella sp.	1
Heterotrissocladius sp.	2
Microtendipes sp.	1
Polypedilum sp.	6
Polypedilum illinoiensis	1
Rheocricotopus sp.	1
Tanytarsus sp.	2
Tvetenia discoloripes	1
Xenochironomus festivus	15
Tanypodinae	1
Baetis flavistriga	3
Baetis pygmaeus	1
Centroptilum sp.	2
Cloeon sp.	19
Baetisca sp.	3
Caenis sp.	5
Ephemera sp.	1
Hexagenia munda	12
Heptagenia sp.	45
Stenacron interpunctatum	3

Study 13 summer '83 (cont'd)

River	Mattagami
Stenonema sp.	1
Stenonema vicarium	1
Paraleptophlebia sp.	1
Metretopus borealis	18
Isonychia sp.	1
Hesperocorixa minor	3
Sigara sp.	1
Sigara lineata	6
Sigara trilineata	3
Notonecta sp.	2
Sialis sp.	2
Basiaeschna janata	4
Boyeria vinosa	1
Calopteryx aequabilis	1
Enallagma sp.	1
Gomphus brevis	1
Ophiogomphus sp.	9
Libellulidae	1
Acroneuria carolinensis	1
Paragnetina media	1
Pteronarcys sp.	2
Cheumatopsyche sp.	42
Hydropsyche morosa	11
Hydropsyche recurvara/	2
Mystacides sepulchralis	1
Oecetis sp.	5
Phryganea cinerea	3
Cyrnellus fraternus	4
Phylocentropus sp.	1
Polycentropus sp.	3
Physella gyrina	5
Musculium transversum	8
Sphaerium simile	2

Study 14 spring '86

River	Mattagami
Rhynchobdellida	2
Placobdella ornata	1
Haemopsis grandis	2
Haemopsis lateromaculata	2
Naididae	1
Arcteonais lomondi	9
Aulodrilus americanus	1
Hyalella azteca	6
Orconectes sp.	5
Orconectes propinquus	6
Orconectes virilis	1
Bosmina longirostris	1
Eubosmina tubicens	1
Eurycercus lamellatus	11
Daphnia pulex	487
Daphnia rosea	50
Simocephalus serrulatus	4
Simocephalus vetulus	3
Polyphemus pediculus	127
Sida crystallina	42
Agabus sp.	2
Deronectes depressus	1
Hydroporus sp.	1
Gyrinus sp.	17
Gyrinus impressicallis	1
Haliplus sp.	1
Helophorus sp.	1
Chironomidae	37
Ablabesmyia sp.	1
Cardiocladius sp.	1
Chironomus sp.	7
Conchapelopia sp.	3
Crictopus sp.	8
Eukiefferiella sp.	9
Parachironomus sp.	1
Paracladopelma sp.	1
Polypedilum sp.	8
Procladius sp.	1
Psectrocladius sp.	1
Rheopelopia sp.	1
Tanytarsus sp.	6
Tribelos sp.	5
Empididae	5
Hemerodromia sp.	3
Simulium sp.	73
Antocha sp.	1
Attenella sp.	6
Baetis sp.	147
Cloeon sp.	7
Caenis sp.	9
Dannella simplex	1
Ephemera simulans	2
Hexagenia limbata	14
Heptagenia sp.	12
Stenonema sp.	8
Paraleptophlebia sp.	2
Siphlonurus sp.	12
Hemiptera	28
Lethocerus americanus	1
Corixidae	7
Palmacorixa gillettei	11
Sigara bicolorapennis	1
Sigara decoratella	4
Sigara trilineata	30

Study 14 spring '86 (cont'd)	
River	Mattagami
Trichocorixa borealis	4
Gerridae	3
Gerris remigis	14
Rhagovelia obesa	1
Aeshna interrupta	1
Gomphidae	5
Ophiogomphus carolus	3
Macromia illinoiensis	4
Alloperla sp.	12
Leuctra ferruginae	2
Pteronarcys sp.	1
Glossosoma sp.	1
Hydropsyche sp.	16
Lepidostoma sp.	1
Anabolia sp.	6
Limnephilus sp.	2
Molanna sp.	1
Neureclipsis sp.	2
Amnicola limosa	12
Physella gyrina	4
Gyraulus parvus	1
Valvata tricarinata	2
Pisidium casertanum	5

Study 15 summer '83	
River	Groundhog
Spongillidae	2
Planariidae	1
Nephelopsis obscura	1
Helobdella triserialis	2
Placobdella ornata	3
Haemopsis plumbea	1
Lumbriculus variegatus	1
Stylaria fossularia	1
Stylaria lacustris	5
Hyalella azteca	5
Orconectes virilis	1
Eurycercus lamellatus	8
Sida crystallina	45
Microcyclops sp.	3
Unionicola sp.	4
Elmidae	1
Crictopus bicinctus	1
Stenochironomus sp.	1
Tanytarsus sp.	1
Baetis sp.	8
Centroptilum sp.	7
Cloeon sp.	15
Ephemiridae	1
Hexagenia sp.	1
Heptageniidae	1
Heptagenia sp.	1
Leptophlebiidae	2
Siphloplecton sp.	7
Tricorythodes sp.	23
Corixidae	5
Cymatia americana	4
Hesperocorixa minor	2
Sigara lineata	10
Odonata	1
Basiaeschna janata	4
Boyeria grafiana	1
Enallagma sp.	38
Enallagma signatum	1
Gomphidae	1
Libellulidae	3
Didymops transversa	4
Ceraclea sp.	1
Oecetis sp.	2
Triaenodes sp.	14
Molanna sp.	3
Phryganea cinerea	11
Polycentropus sp.	7
Amnicola limosa	1
Lymnaea stagnalis	1
Physella gyrina	2
Planorbidae	1
Gyraulus circumstriatus	1
Planorbula armiger	6
Sphaeriidae	3
Anodonta sp.	1

Study 16 summer '85	
River	Groundhog
Placobdella montifera	1
Placobdella ornata	6
Haemopsis grandis	9
Hyalella sp.	20
Hyalella azteca	2
Orconectes sp.	40
Orconectes propinquus	31
Orconectes virilis	5
Sida crystallina	40
Eylais sp.	1
Deronectes depressus	1
Hydroporus sp.	1
Dubiraphnia sp.	1
Optioservus fastiditus	1
Stenelmis crenata	7
Gyrinus sp.	16

Study 16 summer '85 (cont'd)
River Groundhog

Haliplus leopardus	1
Atherix variegata	1
Probezzia sp.	4
Ablabesmyia sp.	5
Cryptochironomus sp.	5
Endochironomus sp.	2
Eukiefferiella sp.	3
Micropsectra sp.	1
Microtendipes sp.	3
Nanocladius sp.	5
Pagastiella sp.	2
Phaenopsectra sp.	2
Polypedilum sp.	20
Procladius sp.	8
Pseudochironomus sp.	1
Tanytarsus sp.	4
Thienemanniella sp.	3
Thienemannimyia sp.	3
Simulium vittatum	1
Hexatoma sp.	4
Baetis sp.	166
Baetis pygmaeus	3
Centroptilum sp.	41
Pseudocloeon sp.	41
Baetisca laurentina	62
Caenis sp.	40
Dannella simplex	2
Drunella walkeri	22
Ephemerella sp.	17
Ephemerella dorothea	3
Ephemerella subvaria	1
Eurylophella bicolor	257
Eurylophella temporalis	102
Serratella deficiens	44
Serratella serratoides	4
Ephemera simulans	5
Hexagenia sp.	3
Hexagenia limbata	42
Epeorus sp.	28
Heptagenia sp.	8
Rhithrogena sp.	9
Stenacron interpunctatum	17
Stenonema sp.	1
Stenonema luteum	1
Stenonema modestum	6
Stenonema pulchellum	3
Stenonema terminatum	4
Leptophlebia sp.	16
Paraleptophlebia sp.	41
Metretopus borealis	1
Isonychia sp.	31
Siphlonurus sp.	211
Corixidae	86
Hesperocorixa sp.	1
Hesperocorixa kennicotti	1
Sigara sp.	3
Gerris sp.	6
Gerris remigis	1
Ranatra fusca	1
Notonecta sp.	6
Rhagovelia obesa	50
Sialis sp.	2
Aeshna interrupta	1
Aeshna umbrosa	2
Boyeria vinosa	1
Calopteryx aequabilis	1
Cordulegaster maculatus	1
Somatochlora elongata	1
Gomphidae	6
Dromogomphus spinosus	6
Gomphus sp.	1
Gomphus scudderi	2
Hagenius brevistylus	1
Ophiogomphus sp	8
Ophiogomphus carolus	2
Macromia illinoiensis	28
Hastaperla sp.	2
Hastaperla brevis	2
Acroneuria sp.	7
Acroneuria abnormis	31
Acroneuria lycorlas	24
Paragnetina media	1
Isoperla sp.	4
Isoperla bilineata	34
Isoperla dicala	23
Isoperla frisoni	19
Pteronarcys sp.	6
Micrasema wataga	8
Helicopsyche borealis	3
Cheumatopsyche sp.	41
Hydropsyche sp.	47
Lepidostoma sp.	85
Oecetis sp.	15
Triaenodes sp.	3
Anabolia sp.	46
Pycnopsyche sp.	44
Chimarra sp.	27
Neureclipsis sp.	13
Protoptila sp.	2
Rhyachophila sp.	2

Study 16 summer '85 (cont'd)

River	Groundhog
Rhyachophila fuscala	2
Agarodes sp.	2
Amnicola limosa	52
Amnicola walkeri	54
Physella integra	5
Valvata tricarinata	1
Pisidium sp.	1
Pisidium idahoense	3
Pisidium variabile	4
Sphaerium sp.	7
Sphaerium rhomboideum	13
Elliptio sp.	1
Elliptio complanata	1
Lampsilis radiata	1

Study17 fall '81

River	Frederick House
Spongilla sp.	1
Turbellaria	1
Placobdella ornata	3
Haemopsis grandis	3
Haemopsis plumbea	3
Lumbriculidae	2
Tubificidae	31
Nematoda	2
Hyalella azteca	23
Orconectes sp.	5
Orconectes propinquus	9
Orconectes virilis	1
Eurycercus lamellatus	12
Daphnia pulex	7
Lebertia sp.	1
Unionicola sp.	1
Acilius semisulcatus	1
Agabus anthracinus	1
Bidessus fuscatus	3
Deronectes depressus	4
Dubiraphnia sp.	1
Dubiraphnia vittata	5
Gyrinus sp.	1
Hydrophilidae	1
Atherix sp.	3
Atherix lanthus	11
Ceratopogonidae	3
Chironomidae	4
pupae	5
Ablabesmyia sp.	3
Cardiocladius obscurus	1
Chironomus sp.	1
Conchapelopia sp.	59
Corynoneura taris	1
Crictopus sp.	129
Crictopus bicinctus	7
Crictopus trifascia	3
Cryptochironomus sp.	2
Demicryptochironomus sp	8
Dicrotendipes sp.	30
Epoicocladius sp.	10
Microtendipes sp.	36
Nanocladius rectinervis	1
Paratanytarsus sp.	2
Pentaneura sp.	6
Polypedilum sp.	2
Polypedilum convictum	2
Procladius sp.	8
Psectrocladius sp.	5
Rheotanytarsus sp.	3
Rheotanytarsus exiguus	3
Strictochironomus sp.	2
Tanytarsus sp.	4
Tribelos sp.	7
Tvetenia discoloripes	7
Xenochironomus sp.	1
Chelifera sp.	5
Hemerodromia sp.	11
Cnephia dacotensis	47
Chrysops furcatus	1
Tanypodinae	2
Hexatoma sp.	1
Baetis sp.	5
Baetis flavistriga	40
Baetis intercalaris	6
Pseudocloeon sp.	5
Baetisca sp.	1
Caenis sp.	5
Ephemerellidae	12
Ephemerella deficiens	4
Ephemerella invaria	26
Hexagenia bilineata	1
Hexagenia limbata	164
Hexagenia rigida	1
Epeorus sp.	2
Heptagenia sp.	50
Rhithrogena sp.	2
Stenacron interpunctatum	47
Stenonema femoratum	3
Stenonema terminatum	18
Stenonema vicarium	2
Leptophlebiidae	1
Leptophlebia sp.	78

Study17 fall '81	
River	Frederick House
Paraleptophlebia sp.	4
Metretopus borealis	1
Siphloplecton sp.	12
Isonychia sp.	1
Nymph	11
Hesperocorixa minor	3
Hesperocorixa minorella	16
Palmacorixa gillettei	13
Sigara lineata	18
Sigara trilineata	17
Gerris remigis	1
Mesovelia sp.	1
Aeshna tuberculifera	2
Gomphus brevis	6
Ophiogomphus sp.	14
Macromia illinoiensis	5
Hastaperla orpha*	1
Leuctra tenius	1
Leuctra truncata	3
Nemoura trispinosa	1
Acroneuria abnormis	36
Acroneuria carolinensis	2
Acroneuria lycorlas	83
Paragnetina immarginata	8
Paragnetina media	8
Pteronarcidae	3
Pteronarcys dorsata	9
Helicopsyche borealis	1
Cheumatopsyche sp.	666
Cheumatopsyche gracilis	1
Hydropsyche sp.	814
Hydropsyche bifida	87
Hydropsyche slossonae	12
Hydropsyche sparna	24
Hydropsyche walkeri	2
Hydroptila sp.	6
Leucotrichia pictipes	11
Lepidostoma sp.	8
Ceraclea sp.	1
Hydratophylax sp.	1
Pycnopsyche sp.	55
Molanna uniophila	1
Dolophilodes distinctus	1
Ptilostomis sp.	1
Phylocentropus sp.	1
Polycentropus sp.	19
Rhyachophila fuscala	2
Amnicola limosa	42
Physella gyrina	37
Gyraulus circumstriatus	13
Helisoma anceps	7
Helisoma corpulentum	2
Valvata tricarinata	35
Pisidium sp.	7
Sphaerium sp.	8
Sphaerium striatinum	7
Anodonta grandis	2
Lasmigona compressa	3

Study 18	fall '83
River	Frederick House
Placobdella ornata	2
Lumbriculus variegatus	1
Stylaria lacustris	1
Hyalella azteca	16
Orconectes sp.	2
Orconectes propinquus	14
Eurycercus lamellatus	1
Daphnia dubia	3
Leptodora kindtii	430
Sida crystallina	3
Copepoda	2
Unionicola sp.	37
Carabidae	1
Dubiraphnia quadrinotata	3
Haliplus blanchardi	1
Atherix lanthus	9
Ceratopogonidae	3
Chaoborus flavicans	9
Chaoborus punctipennis	8
Chironomus sp.	29
Conchapelopia sp.	1
Crictopus sp.	3
Dicrotendipes sp.	1
Epoicocladius sp.	6
Parachironomus sp.	1
Pentaneura sp.	7
Polypedilum convictum	2
Procladius sp.	45
Xenochironomus festivus	1
Simulium sp.	9
Tipulidae	1
Baetis brunneicolor	1
Baetis flavistriga	16
Baetis macdunnoughi	4
Pseudocloeon sp.	5
Caenis sp.	5
Ephemerella deficiens	4
Eurylophella temporalis	6
Ephemera sp.	7

Study 18 fall '83 (cont'd)

River	Frederick House
Hexagenia sp.	443
Heptagenia sp.	9
Rhithrogena sp.	1
Stenacron sp.	1
Stenacron interpunctatum	30
Stenonema femoratum	9
Stenonema terminatum	1
Stenonema vicarium	1
Leptophlebia sp.	6
Paraleptophlebia sp.	3
Siphlonurus sp.	2
Sigara lineata	18
Trichocorixa sp.	1
Sialis sp.	7
Basiaeschna janata	1
Gomphus brevis	13
Ophiogomphus sp.	2
Amphinemura delosa	1
Acroneuria abnormis	1
Acroneuria carolinensis	3
Phasganophora capitata	1
Pteronarcys sp.	2
Micrasema sp.	1
Cheumatopsyche sp.	42
Hydropsyche sp.	4
Hydropsyche morosa	49
Hydropsyche recurvara	23
Hydropsyche scalaris	48
Hydropsyche sparna	67
Leucotrichia pictipes	4
Ochrotrichia sp.	1
Lepidostoma sp.	3
Limnephilus sp.	1
Fabria sp.	1
Phryganea cinerea	3
Phylocentropus sp.	2
Polycentropus sp.	9
Amnicola limosa	1
Physella gyrina	2
Helisoma anceps	2
Musculium transversum	1
Sphaerium sp.	6

Study 19 summer '86

River	Missinaibi
Glossiphonia complanata	1
Placobdella ornata	2
Haemopsis grandis	1
Hyalella azteca	5
Orconectes propinquus	21
Eylais sp.	7
Deronectes depressus	1
Neoscutopterus sp.	1
Optioservus fastiditus	1
Stenelmis crenata	7
Gyrinus sp.	8
Psephenus herricki	1
Atherix variegata	12
Conchapelopia sp.	9
Polypedilum sp.	2
Rheotanytarsus sp.	2
Simulium sp.	16
Baetis sp.	7
Hexagenia limbata	2
Heptagenia sp.	2
Stenonema sp.	2
Paraleptophlebia sp.	3
Isonychia sp.	1
Siphlonurus sp.	2
Corixidae	9
Sigara bicolorapennis	1
Sigara decoratella	20
Sigara trilineata	2
Gerridae	6
Rhagovelia obesa	15
Aeshna interrupta	3
Boyeria vinosa	3
Calopteryx aequabilis	3
Ophiogomphus carolus	25
Macromia illinoiensis	1
Acroneuria sp.	10
Pteronarcys sp.	9
Helicopsyche borealis	1
Hydropsyche sp.	23
Pycnopsyche sp.	6
Chimarra sp.	35
Oligostomis sp.	8
Phryganea sp.	2
Neureclipsis sp.	1
Nectopsyche sp.	1
Amnicola limosa	4
Physella gyrina	8
Pisidium casertanum	3
Sphaerium striatinum	12
Lampsilis radiata	5

Study 20 summer '85

River	Chapleau
Erpobdellidae	1
Placobdella ornata	1

Study 20 summer '85 (cont'd)	
River	Chapleau
Haemopsis grandis	1
Gammarus lacustris	9
Hyalella azteca	57
Orconectes sp.	55
Orconectes propinquus	1
Orconectes virilis	12
Unionicola sp.	1
Coptotomus sp.	3
Deronectes depressus	7
Ilybius pleuriticus	1
Haliplus cribrarius	1
Ablabesmyia sp.	1
Cryptochironomus sp.	1
Dicrotendipes sp.	1
Micropsectra sp.	4
Polypedilum sp.	1
Procladius sp.	4
Cloeon sp.	2
Ephemera sp.	5
Hexagenia munda	10
Paraleptophlebia sp.	1
Siphlonurus sp.	3
Tricorythodes sp.	4
Nymph	12
Hesperocorixa minor	1
Sigara compressoidea	2
Notonecta sp.	5
Sialis sp.	3
Aeshna eremita	2
Aeshna umbrosa	3
Basiaeschna janata	8
Calopteryx aequabilis	6
Ischnura sp.	9
Neurocordulia sp.	1
Somatochlora sp.	4
Tetragoneuria spinigera	2
Dromogomphus spinosus	7
Gomphus lividus	10
Hagenius brevistylus	2
Ophiogomphus carolus	1
Ladona julia	2
Sympetrum vicinum	3
Macromia illinoiensis	6
Cheumatopsyche sp.	14
Hydropsyche sp.	10
Agrypnia sp.	3
Polycentropus sp.	2
Lymnaea stagnalis	5
Physella gyrina	8
Helisoma anceps	2
Sphaeriidae	3

Study 21 summer '85	
River	Ivanhoe
Placobdella papillata	1
Haemopsis sp.	1
Haemopsis grandis	1
Tubificidae	5
Hyalella azteca	11
Orconectes sp.	6
Orconectes propinquus	27
Orconectes virilis	4
Holopedium gibberum	4
Arrenurus sp.	1
Sperchon sp.	1
Coptotomus lenticus	2
Deronectes depressus	2
Hydroporus sp.	9
Dubiraphnia sp.	2
Dubiraphnia vittata	2
Gyrinus sp.	4
Gyrinus analis	3
Gyrinus fraternus	3
Haliplus cribrarius	3
Psephenus herricki	3
Ceratopogonidae	5
Ablabesmyia sp.	1
Brillia sp.	1
Chironomus sp.	3
Cryptochironomus sp.	1
Diamesa sp	1
Micropsectra sp.	3
Orthocladius sp.	5
Paracladopelma sp.	2
Polypedilum sp.	3
Procladius sp.	35
Thienemannimyia sp.	6
Hemerodromia sp.	1
Simulium sp.	2
Simulium pictipes	2
Simulium venestum	3
Tipulidae	1
Attenella attenuata	1
Baetis brunneicolor	2
Baetis propinquus	3
Cloeon sp.	4
Pseudocloeon sp.	3
Baetisca laurentina	9
Caenis sp.	1
Drunella walkeri	1

Study 21 summer '85 (cont'd)	
River	Ivanhoe
Eurylophella sp.	3
Eurylophella temporalis	1
Ephemera sp.	16
Hexagenia sp.	2
Hexagenia munda	3
Arthroplea bipunctata	2
Heptagenia sp.	3
Stenacron interpunctatum	2
Stenonema terminatum	3
Isonychia sp.	1
Siphlonurus sp.	12
Nymph	55
Hesperocorixa minor	5
Sialis sp.	7
Aeshna umbrosa	2
Basiaeschna janata	5
Boyeria vinosa	1
Calopteryx sp.	1
Calopteryx maculata	3
Helocordulia uhleri	2
Somatochlora elongata	1
Gomphus brevis	3
Gomphus lividus	2
Gomphus scudderi	4
Hagenius brevistylus	2
Ophiogomphus carolus	3
Stylogomphus albistylus	1
Macromia illinoiensis	10
Acroneuria sp.	1
Isoperla sp.	10
Isoperla marlynia	1
Pteronarcys sp.	10
Cheumatopsyche sp.	3
Hydropsyche sp.	3
Lepidostoma sp.	1
Anabolia sp.	15
Pycnopsyche sp.	6
Neureclipsis sp.	45
Amnicola limosa	10
Lymnaea stagnalis	1
Physella gyrina	9
Helisoma sp.	2
Promenetus exacuous	1
Sphaeriidae	7
Pisidium sp.	1
Pisidium variabile	2
Anodonta grandis	1

study 22 Aug '94 & '95	
river	Groundhog
Nematoda	24
Hirudinea	5
Limnodrilus hoffmeisteri	3
immature tubifex	193
Arachnida	44
Decapoda	3
Shrimp	1
Gammarus	11
Cladocera	1342
Copepoda	2
Ostracoda	109
unident	3
C1	4
Dubiraphnia sp.	533
Gyrinus	1
Atherix	1
Ceratopogonidae	450
Ablabesmyia	89
Apsectrotanypus	4
Cladotanytarsus	252
Cladopelma	1
Corynoneura	6
Crictopus	181
Cryptochironomus	20
Cryptotendipes	10
Cyphomella	2
Demicrytpochironomus	16
Dicrotendipes	33
Endochironomus	3
Epoicocladius	6
Eukiefferiella	1
Glyptotendipes	4
Heterotanytarsus	9
Heterotrissocladius sp.	11
Krenopelopia	1
Larsia	2
Lauterborniella	1
Micropsectra	92
Microtendipes	39
Monodiamesa	19
nilothauma	6
Orthocladius	5
Parachironomus	1
Paracladius	12
Paracladopelma	30
Paracricotopus	8
Parakiefferiella	1
Paralauterborniella	1
Paratanytarsus	4

study 22 Aug '94 & '95 (cont'd)
river Groundhog

Paratendipes	11
Phaenopsectra	436
Polypedilum sp.	216
Procladius	306
Psectrocladius	5
Pseudochironomus sp.	55
Rheocricotopus	2
Rheotanytarsus	76
Robackia	2
Saetheria	1
Stempellina	104
Stempellinella	35
Stenochironomus	9
Strictochironomus	78
Stylaria	6
Tanypus	2
Tanytarsus	138
Thienemanniella	5
Xenochironomus sp.	62
Unknown a	5
unknown b	4
unknown C	14
unident	133
Hemerodromia	5
Tabanus	112
unident	7
Baetis	1
Baetisca sp.	17
Caenis	227
Centroptilum	30
Drunella sp.	67
Stenonema sp.	22
Paraleptophlebia sp.	46
Isoperla	14
Potamanthus	527
Glaenocorisa	4
Sigara sp.	74
Notonecta sp.	1
Bactra	1
Sialis	110
Odonata	1
Boyeria	1
Somatochlora	2
unident	3
Hagenius	1
Ophiogomphus	1
Stylarus	15
unident	11
Glossosoma	4
Helicopsyche	8
Cheumatopsyche	117
Agraylea	1
Lepidostoma	10
Ceraclea	2
Mystacides	1
Oecetis	175
Setodes	3
Molanna sp.	1
Mollanodes	9
Psilotreta	1
Chimarra	19
Cernotina	39
Phylocentropus sp.	157
Polycentropus	16
Neureclipsis	5
pupae	102
larvae	12
unident	1
Amnicola sp.	711
Ferrissia sp.	37
Probynthinella sp.	624
Stagnicola sp.	1
Physa sp.	42
Planorbidae	3
Gyraulus deflectus	62
Helisoma sp.	9
Planorbula	2
Valvata sp.	398
Pelecypoda	15
Pisidium sp.	1180