Benthic Macroinvertebrates in Freshwaters-
Taxa Tolerance Values, Metrics, and Protocols

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June 2002

It is my belief that the philosophy of "Think Globally, Act Locally" has been adhered to in this worthwhile project!

Dedication

This is dedicated to my father:

M.R. Rao BSc(Hons), D.I.I.Sc.

.... a practical, at the same time, a telecommunications research engineer in his time, now in his 80s, and still living in India

.... my father imparted to all of us as children a keen desire of scientific and technical goals/curiosity, and among the favourite discussions at our daily meals were the works and achievements of: Albert Einstein, the 1921 Nobel Laureate in Physics; Rabindranath Tagore, the 1913 Nobel Laureate in Literature; P.G. Wodehouse, especially his Jeeves character; Sir Arthur Conan Doyle; Bertrand Russell, the 1950 Nobel Laureate in Literature; Leo Tolstoy; Sir. C.V. Raman, the 1930 Nobel Laureate in Physics; Dr. Albert Schweitzer; the Nova Scotia world famous Pugwash conferences and the Antigonish Coady Institute for self-help; among others!

Foreword

Biomonitoring is now recognized as one of the most valuable tools available in the arsenal of environmentalists. In order to achieve and maintain the highest water quality in lakes, rivers, and streams, environmental advocates are using the resident organisms living in these waters as sensitive indicators of change. Biomonitoring is based on the straightforward premise that living organisms are the ultimate indicators of environmental quality.

People who experience for the first time the diversity of life in a stream are invariably moved to a wider awareness of what is at stake in the protection of water quality. Thus biomonitoring has the secondary benefit of inspiring and stimulating individuals, especially the young, toward science and the study of nature. Few disciplines exist in which the study of nature can offer so much direct benefit toward the preservation of the very habitat being studied.

Having been involved in stream biomonitoring for 30 years, I have witnessed the maturing of this most interesting branch of science. New York State undertook biomonitoring in 1972, as an alternative method of monitoring and assessing its streams and rivers. Since that time it has surpassed chemical monitoring in its capability of screening water quality in a maximum number of waterbodies statewide. Biomonitoring has also proved invaluable in tracking water quality trends over time, and is now contributing to a compilation of 30-year water quality trends.

The focus of this work is providing tolerance values for some of the many species of aquatic macroinvertebrates. As is cautioned in the text, these values are intended to reflect tolerance to organic and decomposable wastes, those that exert a biological oxygen demand. Stating this fact highlights the acute ongoing need for developing tolerance values for the many other classes of contaminants and pollutants, such as metals, pesticides, and acidity. Much work remains to be done in this area.

Another facet of biomonitoring highlighted by this tolerance list is the value of species identifications in biomonitoring. One has only to scan the list to find many examples of differing tolerance values within the same genus. More differences will undoubtedly emerge as more work is done in this area. It seems an inescapable conclusion that the advancement of biomonitoring will necessitate also the concurrent refinement in taxonomy, leading to a greater resolution capability of this science.

The highly commendable endeavor of Shalom Mandaville in this publication constitutes a positive step toward facilitating and promoting water quality biomonitoring by Government agencies, non-governmental groups and individuals who have an active interest in protecting one of our most precious resources.

January, 2002

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Preface

This report, a result of intense volunteerism, is focused principally on tolerances of individual taxa. Also refer to our various related web pages and formalised reports as referenced below:

- Freshwater Benthic Ecology and Aquatic Entomology Homepage:
  - http://chebucto.ca/Science/SWCS/ZOOBENTH/BENTHOS/benthos.html
- Taxa Tolerance Values:
  - http://chebucto.ca/Science/SWCS/ZOOBENTH/BENTHOS/tolerance.html
- Paleolimnology Homepage:
  - http://chebucto.ca/Science/SWCS/PALEO/paleo.html
- Master Homepage:
  - http://chebucto.ca/Science/SWCS/SWCS.html
- Studies/Reports:
  - http://chebucto.ca/Science/SWCS/studies.html

The references section in this report lists not only the literature used in this report but also the related bibliography of considerable value.

Acknowledgements

I herewith gratefully acknowledge Robert Bode, Senior Scientist, New York State Department of Environmental Conservation, for his consistent advice and encouragement. Mr. Bode is an unquestioned world-class leader in Freshwater Benthic Ecology and has been quoted extensively by numerous leading researchers. The handbooks prepared under the scientific supervision of Mr. Bode are an unparalleled treasure in the exciting and fascinating domain of Biodiversity and Benthic Ecology overall!

I also thank Prof. Dr. Gerrie Mackie of the University of Guelph for sharing his insight into biotic indices with me and his confidence in the various tolerance values published by Robert Bode.

The printing/binding costs of this report are being met through the kind partnership of Geoff Howell, Manager, Integration and Interpretation Section, Ecosystems Sciences Division, Environmental Conservation Branch of Environment Canada.

Thanks are herewith expressed to Kelly Marney, Webmaster, Halifax Regional Municipality (HRM) for her assistance in several of our projects.

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Chapter I: Introduction

Biomonitoring is the systematic use of living organisms or their responses to determine the quality of the environment. Water pollution is essentially a biological problem. Chemical measurements are like taking snapshots of the ecosystem, whereas biological measurements are like making a videotape. The ultimate purpose of environmental assessment and regulation is the maintenance of biological integrity, so setting water- and sediment- quality objectives should involve biological criteria as well as chemical surrogates.

.... Prof. David M. Rosenberg PhD, University of Manitoba and the DFO, Winnipeg. (*cf.* Bull. Entomol. Soc. Can. 1998. 30(4):144-152)

Extracts from Rosenberg (1998)

The history of biomonitoring can be traced back to Aristotle, who placed freshwater fish into seawater to observe their reactions. The first toxicity experiments were published in 1816, and described longer survival of several species of freshwater molluscs in 2% than 4% saline solutions. Studies of the survival of freshwater invertebrates exposed to metals and organic compounds appeared in the mid-1890s. The use of community structure of freshwater organisms for biomonitoring can be traced back to the pioneering work of two German scientists, R. Kolkwitz and M. Marsson, in the early 1900s. Their publication on saprobity (degree of pollution) led to the development of indicator organisms. Today, indicators are much sought after as magic bullets to summarize a wide variety of states - from biological health to economics.

A wide variety of biotic groups is used for biomonitoring. A search of the database from 1993 to July 1998 carried out by Vincent Resh and Norma Kobzina at the University of California, Berkeley confirmed that macroinvertebrates are the most popular group.

There are compelling reasons for the apparent popularity of freshwater macroinvertebrates in current biomonitoring practice; they offer a number of advantages:

1) they are ubiquitous, so they are affected by perturbations in many different habitats,
2) they are species rich, so the large number of species produces a range of responses,
3) they are sedentary, so they stay put, which allows determination of the spatial extent of a perturbation,
4) they are long-lived, which allows temporal changes in abundance and age structure to be followed, and
5) they integrate conditions temporally, so like any biotic group, they provide evidence of conditions over long periods of time (the videotape referred to above).

To be fair, macroinvertebrates also have disadvantages, but these can be mostly overcome by proper experimental design. For example, macroinvertebrates do not respond to all impacts; the distribution and abundance of macroinvertebrates may be affected by factors in addition to the perturbation in question; and the distribution and abundance of macroinvertebrates vary seasonally.

There has been a melding of quantitative and qualitative approaches known **as rapid assessment** or **rapid biomonitoring**. These approaches are meant to provide an initial screening of water bodies for possible further investigation.

Chapter II: Overview and Background

Diversity and Biotic Indices

(Also *cf*.:
Mandaville, S.M. 1999. Bioassessment of Freshwaters Using Benthic Macroinvertebrates-A Primer. First Ed. Project E-1, Soil & Water Conservation Society of Metro Halifax. Chapters I-XXVII, Appendices A-D. 244p., and

Mandaville, S.M. 2000a. Limnology- Eutrophication and Chemistry, Carrying Capacities, Loadings, Benthic Ecology, and Comparative Data. Project F-1, Soil & Water Conservation Society of Metro Halifax. Synopses 1, 2, 3, 13, and 14. 210p.)

Benthic macroinvertebrate species are differentially sensitive to many biotic and abiotic factors in their environment. Consequently, macroinvertebrate community structure has commonly been used as an indicator of the condition of an aquatic system (Armitage *et al.*, 1983; Ohio Department of Natural Resources, unpublished; Rosenberg and Resh, 1993). Biotic index systems have been developed which give numerical scores to specific "indicator" organisms at a particular taxonomic level (Armitage *et al.*, 1983; Ohio Department of Natural Resources, unpublished). Such organisms have specific requirements in terms of physical and chemical conditions. Changes in presence/absence, numbers, morphology, physiology or behaviour of these organisms can indicate that the physical and/or chemical conditions are outside their preferred limits (Rosenberg and Resh, 1993). Presence of numerous families of highly tolerant organisms usually indicates poor water quality (Hynes, 1998).

RBPs—Biotic Indices—Rapid Bioassessment Protocols

(Barbour *et al.*, 1999; Bode *et al.*, 1991, 1996; David *et al.*, 1998; Gaertner, 1999, Gerritsen *et al.*, 1998; Hynes, 1998; Kirsch, 1999, Klemm *et al.*, 1990; Mackie, 2001; Novak and Bode, 1992; Plafkin *et al.*, 1989; Reid *et al.*, 1995; Rosenberg and Resh, 1993; Rosenberg *et al.*, 1997; Somers, 1997a,b; Somers *et al.*, 1998)

The numbers of indices based on the benthic macroinvertebrate communities is probably about five times that of any of the other groups, with about fifty indices currently in existence, and the number is still growing. Some of the benthic indices are based on species identification, the species assemblages being analyzed by a range of mathematical models, from a fairly straightforward species diversity index to more complex multivariate analyses. Bioassessment methods such as these are based on numerous quantitative samples (e.g. with Ekman/Ponar grabs, T-samplers, Surber samplers, etc.) that require a great deal of time to sort and separate all the invertebrates, and more time and expertise (and money) to identify all the organisms.

So recent trends have been towards more **rapid bioassessment techniques**, such as using semi-quantitative collecting methods (e.g. kick-and-sweep) and selecting at random and identifying only the first 100 organisms in the sample. To help ensure unbiased selection of organisms, it is recommended that a subsampling procedure be used. This entails evenly distributing the composite sample into a gridded pan with a light coloured bottom. Then all organisms are removed from a set of randomly selected grids until atleast 100 animals are picked. Once identified, the functional feeding behaviour of each species is determined from tables (Barbour *et al.*, 1999; Bode *et al.*, 1991, 1996; Klemm *et al.*, 1990; Mackie, 2001; Plafkin *et al.*, 1989). **A CPOM** (coarse particulate organic matter, such as leaf litter) sample is also required from each site. This sample is used for determining the numbers of shredders present.

RBPs (Rapid Bioassessment Protocols)

Some of these rapid bioassessment techniques have been standardized so that water quality comparisons can be made between streams and lakes. These standardized methods are in common use today and are termed **RBPs** (Rapid Bioassessment Protocols). The U.S. EPA has developed 5 RBPs, the first three being based on benthic macroinvertebrates and the fourth and fifth on fish (Plafkin *et al.,* 1989). The complexity of the protocol increases with the RBP number, RBP I being less complex than RBP II and so on. RBP I is used to discriminate obviously impacted and non-impacted areas from potentially affected areas requiring further investigation. It allows rapid screening of a large number of sites. Areas identified for further study can be rigorously evaluated using RBP II, III and V (IV is a questionnaire survey).

RBP II is based on family level identification and RBP III on a species level identification.

Metrics- Protocols for Use in Wadeable Streams and Rivers

(Barbour *et al.*, U.S. EPA, 1999; http://www.epa.gov/owow/monitoring/rbp/)

Metrics (or indices) allow the investigator to use meaningful indicator attributes in assessing the status of assemblages and communities in response to perturbation. For a metric to be useful, it must have the following technical attributes:

(1) ecologically relevant to the biological assemblage or community under study and to the specified program objectives;

(2) sensitive to stressors and provides a response that can be discriminated from natural variation.

The purpose of using multiple metrics to assess biological condition is to aggregate and convey the information available regarding the elements and processes of aquatic communities.

It is cautioned that all the published metrics inclusive of the ones discussed here have been developed from extensive field data from rivers and not from lakes, hence may or may not be totally applicable in the case of lakes, especially larger and deeper lakes. Caution should be exercised and the indiscriminate use of the metrics without supporting chemical and other related field data should be avoided. Further, none of the indices originate from the Atlantic Provinces of Canada, especially from Nova Scotia.

To date though, we found reasonable correspondence even in lakes (Hynes, 1998; Gaertner, 1999; Kirsch, 1999; and a few other studies underway).

Reference sites

Because species assemblages differ naturally among different regions (ecoregions) in North America and even between stream orders in the same ecoregion, many metrics require a reference site for each evaluation. The reference can be an unaffected reach in the same stream or in a neighbouring stream of the same order. Many of the indices in the protocols use **`tolerance scores'** that were derived from large data bases of both published and unpublished studies of experts for all the major groups of taxa. Colonial taxa, like Porifera (sponges) and Bryozoa (moss animals), are not included in the scoring systems (Mackie, 2001).

Lake and Reservoir Bioassessment and Biocriteria

(Gerritsen *et al.*, U.S. EPA, 1998; http://www.epa.gov/owow/monitoring/tech/lakes.html)

Benthic invertebrate assemblages in lakes correspond to particular habitat types and can be classified according to the three basic habitats of lake bottom: littoral, sublittoral, and profundal.

Littoral habitat

The littoral habitat of lakes usually supports larger and more diverse populations of benthic invertebrates than do the sublittoral and profundal habitats. The vegetation and substrate heterogeneity of the littoral habitat provide an abundance of microhabitats occupied by a varied fauna, which in turn enhances invertebrate production. The littoral habitat is also highly variable due to seasonal influences, land use patterns, riparian variation, and direct climatic effects producing high-energy areas. The epifauna species composition, number of individuals, areal extent, and growth form vary with the species composition of the macrophyte beds, making it difficult to determine the benthic status accurately.

Sublittoral habitat

The sublittoral habitat, below the area of dense macrophyte beds, but above typical thermoclines, lacks the heterogeneity of the littoral habitat; However it is also less subject to littoral habitat variables and influences. The sublittoral habitat is rarely exposed to severe hypoxia but might also lack the sensitivity to toxic effects that is found in the profundal habitat. The sublittoral habitat supports diverse infaunal populations, and standardized sampling is easy to implement because a constant depth and substrate can be selected for sampling. Therefore, the sublittoral habitat is the preferred habitat for surveying the benthic assemblage in most regions.

Profundal habitat

The profundal habitat, in the hypolimnium of stratified lakes, is more homogeneous due to a lack of habitat and food heterogeneity, and hypoxia and anoxia in moderately to highly productive lakes are common. The profundal habitat is usually dominated by three main groups of benthic organisms including chironomid larvae, oligochaete worms, and phantom midge larvae (*Chaoborus*). Many species of chironomids and tubificid oligochaetes are tolerant to low dissolved oxygen, such that these become the dominant profundal invertebrates in lakes with hypoxic hypolimnia. As hypoxia becomes more severe tubificids can become dominant over chironomids. In cases of prolonged anoxia, the profundal assemblage might disappear entirely. If hypoxia is rare in reference lakes of the region, and if toxic sediments are suspected to occur in some lakes, then the profundal habitat sampling might be preferred for the region.

Benthic macroinvertebrates are moderately long-lived and are in constant contact with lake sediments. Contamination and toxicity of sediments will therefore affect those benthic organisms which are sensitive to them. Acidification of lakes is accompanied by shifts in the composition of benthic assemblages to dominance by species tolerant of acidic conditions. Effects of rapid sedimentation are less well-known but appear to cause shifts toward lower abundances and oligotrophic species assemblages as well as more motile species.

Benthic macroinvertebrates are present year-round and are often abundant, yet not very motile. However, the benthos integrate environmental conditions at the sampling point.

Reference lakes/sites

The recommended empirical approach is to use a population of reference lakes to establish conditions that will be used to identify and calibrate metrics.

Reference sites must be carefully selected because they will be used as a benchmark against which test sites will be compared. The conditions at reference sites should represent the best range of minimally impaired conditions that can be achieved by similar lakes within the region. The reference sites must be representative of the region, and relatively least impacted compared to other lakes of the region.

Sites that are undisturbed by human activities are ideal reference sites. However, land use practices and atmospheric pollution have so altered the landscape and quality of water resources nationally that truly undisturbed sites are rarely unavailable.

Stringent criteria might require using park or preserve areas for reference lakes. Criteria for reference lakes will also pertain to the condition of the watershed, as well as the lake itself.

If relatively unimpaired conditions do not occur in the region, the selection process could be modified to be more realistic and reflect attainable goals, such as the following:

- Land use and natural vegetation- Natural vegetation has a positive effect on water quality and hydrological response of streams. Reference lakes should have at least some percentage of the watershed in natural vegetation.
- Riparian zones- Zones of natural vegetation alongside the lakeshore and streams stabilize shorelines from erosion and contribute to the aquatic food source through allochthonous input. They also reduce nonpoint pollution by absorbing and neutralizing nutrients and contaminants. Watersheds of reference lakes should have at least some natural riparian zones regardless of land use.
- Best management practices- Urban, industrial, suburban, and agricultural nonpoint source pollution can be reduced with successful best management practices (BMPs). Watersheds of reference lakes should have BMPs in place provided that the efficacy of the BMPs have been demonstrated.

- Discharges- Absence or minimal level of permitted discharges (NPDES) into surface waters.
- Management- Management actions, such as extreme water level fluctuations for hydropower or flood control, can significantly influence lake biota. Reference lakes should be only minimally impacted by management activities.

Paleolimnology

(http://chebucto.ca/Science/SWCS/PALEO/paleo.html)

An alternative to characterizing present-day reference conditions is to estimate historic or prehistoric pristine conditions. In many lakes, presettlement conditions can be inferred from fossil diatoms, chrysophytes, midge head capsules, cladoceran carapaces, and other remains preserved in lake sediments. Fossil diatoms are established indicators of historical lake alkalinity, salinity, and trophic state. Diatom frustules, composed of silica, are typically well preserved in lake sediments and easy to identify. However, remains of other organisms are problematic because of incomplete preservation.

Protocols for Measuring Biodiversity: Benthic Macroinvertebrates in Fresh Waters- EMAN (Ecological Monitoring and Assessment Network)

(Rosenberg *et al*., Environment Canada and DFO, 1997; http://eqb-dqe.cciw.ca/eman/ecotools/protocols/freshwater/benthics/)

Introduction

Benthic macroinvertebrates are common inhabitants of lakes and streams where they are important in moving energy through food webs. The term "benthic" means "bottom-living", so these organisms usually inhabit bottom substrates for at least part of their life cycle; the prefix "macro" indicates that these organisms are retained by mesh sizes of ~200-500 mm (Rosenberg and Resh, 1993).

The most diverse group of freshwater benthic macroinvertebrates is the aquatic insects, which account for ~70% of known species of major groups of aquatic macroinvertebrates in North America. More than 4000 species of aquatic insects and water mites have been reported from Canada. Thus, as a highly diverse group, benthic macroinvertebrates are excellent candidates for studies of changes in biodiversity.

However, benthic macroinvertebrates can be difficult to work with unless the proper study design is used (Rosenberg and Resh, 1993). For example:

(1) quantitative sampling is difficult because the contagious (i.e. clumped or patchy) distribution of benthic macroinvertebrates requires large numbers of samples to achieve reasonable precision in estimating population abundance. The resulting processing and identification requirements for samples can be costly and time consuming. An alternative would be to use rapid assessment procedures;
(2) the distribution and abundance of benthic macroinvertebrates are affected by a large number of natural factors, which have to be accounted for to determine changes in biodiversity; and
(3) some groups of benthic macroinvertebrates are taxonomically difficult, although the development of new and improved keys is a high priority in research.

The collection of benthic macroinvertebrates from lakes and streams is usually a straightforward procedure using standard equipment. However, the removal of organisms from background material can be tedious and time-consuming unless available labor-saving strategies are used (see below) and the identification of organisms to the species level, when possible, requires substantial training and skill. The processing of samples can be successfully accomplished by non-specialists, but the involvement of systematists is recommended for species-level identifications. Data-analysis procedures are standard, and can be done by anyone trained in elementary statistics.

Frequency and timing of sampling

In addition to using standard methods, it is important to establish the frequency and timing of sampling. Freshwater communities are non-equilibrium systems that are maintained by a flow-through of energy and materials. Interannual variability of benthic communities is high because of the many physical, chemical, and biotic factors that impinge on these communities. For example, weather, nutrient supply, and interspecific interactions all serve to regulate the benthos. For this reason, a single survey is usually insufficient to fully characterize an aquatic system; several years of data may be required to establish adequately the range of variation in community structure and productivity.

Seasonal variability of community structure and productivity is high because many species of benthic macroinvertebrates have annual (or shorter) life cycles, which culminate in an adult phase during the open-water period. Thus, the presence of mature larvae, pupae, or adults (the life stages most useful for taxonomic work) may be short-lived and easily missed if seasonal development rates differ from year to year and mid-summer survey dates are chosen.

It is best to sample either just after ice-out in the spring when late-stage larval forms are present but have not yet begun their final maturation, or in late fall after most species have mated and the immatures have had a chance to develop throughout the summer in preparation for over-wintering.

Subsampling

Samples are usually subsampled to save processing time because either the samples are excessively large or there are large numbers of them. Thus, the sample is quantitatively reduced, the invertebrates from a known portion of the sample are counted, and these counts are extrapolated back to the entire sample. Samples need to be homogeneous, so large organisms or pieces of debris should be removed prior to subsampling. Several methods are available; for example, the volumetric method of Wrona *et al.*, the weight-based method of Sebastien *et al.*, and the spatial (sample-splitting) method of Marchant have proven reliable. In the Marchant method, a predetermined number of invertebrates (100, 200, or 300) is removed from a box subdivided into 100 cells and then counting stops. No matter what method is used, precision and accuracy need to be assessed initially by comparing selected subsamples to the total sample. Subsampling error should be estimated in at least 10% of the samples being processed by sorting another subsample of equal size (Environment Canada and Department of Fisheries and Oceans, 1993); allowable deviations between counts should be set at a reasonable but consistent level.

Rare species may be missed by subsampling, which is an important concern in biodiversity studies. Thus, rare species deserve special consideration when selecting a subsampling method; alternatively, avoid subsampling completely.

Data Analysis

Four different types of biodiversity studies may be undertaken: (1) pilot or reconnaissance studies at the beginning of a full-fledged program; (2) descriptions of population or community characteristics; (3) detection of differences in populations or communities between or among sites; and (4) initiation of a long-term, rapid-assessment program. Each of these studies has its own data-analytical requirements, so it is important to decide the objective of a biodiversity study at the outset.

A new approach called the "reference condition" (Reynoldson *et al.*, 1995, 1997), which uses qualitative sampling and multivariate statistics, circumvents many of the problems inherent in quantitative, inferential approaches (Reynoldson *et al.*, 1997).

Quality Assessment/Quality Control (QA/QC)

Roughly 20% of program resources should be devoted to QA/QC, although more will be required if the results are intended for legal or policy use. Investigators should be able to design the QA/QC procedures that are best suited to their needs and available resources.

Identification of Specimens

The sweep-net collections of adult insects along shorelines are valuable to the identification of immature aquatic forms. Another, more time-consuming endeavor is to establish rearing programs to provide associated stages. The taxonomy of aquatic insects is based mainly on the adult form, although the immatures are the forms most frequently collected in aquatic sampling. If the adult, cast pupal skin, and cast last larval skin are available for holometabolous insects (i.e. those with complete metamorphosis such as midge flies), or the adult and a series of cast nymphal skins are available for hemimetabolous insects (i.e. those with incomplete metamorphosis such as mayflies), then the immature forms can often be identified by working backward from the adult. Merritt and Cummins (1996) review field-based and laboratory rearing methods for major insect groups.

The specimens sorted into major taxa and stored in 10-ml glass vials can be identified to lower levels by using two excellent, North American texts: Thorp and Covich (1991) for non-insect benthic macroinvertebrates and Merritt and Cummins (1996) for the insects. Both texts provide keys to genera and references to the more specialized literature for species-level determinations. An excellent overall reference is Peckarsky *et al* (1990).

Once identified, specimens belonging to the same taxon should be stored in their own vial or in a group of shell (tiny) vials plugged with cotton and placed together in a larger vial. Accurate labeling is essential.

Non-specialists may find it difficult to identify most benthic invertebrates to the species level. Hence, it is wise to send representative, identified material to qualified systematists for verification or get the systematists directly involved in the study. A voucher collection of identified/verified material should be prepared (and curated) for future reference. Curation is important because vials containing alcohol will dry out over time. Voucher collections often prove invaluable in rechecking data, and in taxonomic revisions.

Ontario Ministry of the Environment- (subsampling 100 animals is sufficient)

(David *et al.*, 1998; Reid *et al.*, 1995; Somers *et al.*, 1998)

Conclusions of Somers *et al* (1998):

1) Subsampling 100 animals is sufficient for rapid bioassessments. The results of the ANOVAs and associated power calculations revealed only modest gains in our ability to distinguish lakes using subsamples of 200 or 300 animals. The only exceptions to this conclusion are studies that use indices based on richness measures and rare taxa, where larger counts are necessary to adequately census rare individuals.
2) Multivariate indices should be used in addition to simple indices to interpret rapid bioassessment data. Two simple metrics (% amphipods and % insects) and a multivariate metric (CA axis 1) were the best indices for distinguishing our 5 lakes.
3) Variance components (i.e., r_i) and MDCs should be used in comparative studies to provide guidance for making unbiased decisions. Intraclass correlations and power calculations complement simple ANOVAs and provide useful tools to evaluate competing methods. Without objective criteria, these types of comparative studies often produce inconclusive results.

Exceptions (Bode *et al.*, 1996)

Characteristics of headwater stream sites

Headwater stream sites are defined as first-order or second-order stream locations close to the stream source, usually less than three miles. The natural characteristics of headwaters may sometimes result in an erroneous assessment of impacted water quality.

Headwater sites have reduced upstream recruitment resource populations to provide colonization by drift, and may have reduced species richness. Headwater sites usually are nutrient-poor, lower in food resources, and less productive. The reduced, simplified fauna of headwater sites may result in a community in which a few intolerant species may be very abundant. The dominant species could average 37% of the total fauna.

Corrective action for data judged to be affected by headwater conditions is the adjustment of the water quality assessment up one category (e.g., slightly impacted to non-impacted) to reflect genuine water quality. Alternative corrective action for non-representative indices from headwater sites is to apply a correction factor of 1.5 to species richness, EPT richness, and percent model affinity.

Effects of lake outlets and impoundments on aquatic invertebrate communities

Species richness is nearly always lower below lake outlets. Due primarily to the lack of upstream communities to provide a resource for colonization and drift, lake outlet communities often have only about 60% of the number of species found in comparable non-impacted segments. EPT richness is often only 30% of that found at non-impacted sites. Biotic index values and percent model affinity values are also depressed.

A marked succession of species often occurs over a short distance. Productivity may be initially high below the lake, but usually decreases a short distance downstream. Lakes with cold-water hypolimnion releases limit the fauna additionally by interference with life cycles of aquatic insects such as mayflies, stoneflies, and caddisflies. Because the temperature of hypolimnetic releases is usually very cold, the downstream communities are often limited to midges, worms, black flies, snails, and sowbugs.

Corrective action for data judged to be affected by lake outlets is the adjustment of the water quality assessment up one category (e.g., slightly impacted to non-impacted) to reflect genuine water quality. However, faunal effects caused by hypolimnion releases should be considered temperature-related and anthropogenic.

Chapter III: The Nova Scotia experience-representative lakes in the Halifax Regional Municipality (HRM)

(Gaertner, 1999; Hynes, 1998; Kirsch, 1999; and Mandaville, 1999; other studies under progress; http://chebucto.ca/Science/SWCS/ZOOBENTH/BENTHOS/benthos.html)

While much of the discussion in this chapter is based on experience with family-level identification, nevertheless, somewhat the same arguments may also apply with genus/species level Ids. Indeed, the metrics discussed here were based mostly on species-level indices, for e.g., the family-level RBP II was derived from the species-level RBP III.

Field Protocol

Because of the weather conditions, it is best to sample lake sublittoral stations in late Fall. The perimeter of each lake was measured from bathymetric maps. For a given lake, the perimeter was evenly divided into approximately 50 survey sites. The distance between these sites along the shoreline varies with the size of the lake. The survey sites were accessed by boat and estimates of substrate composition were made. 5 sampling sites were then chosen which included the substrate types in the same proportions as they had been observed in the whole lake survey. For example, if 80% of the survey sites contained sand then 80%, or 4 of the 5 sampling sites chosen should contain sand. In this way, the sampling sites can be representative of the variety of benthic habitats found in the entire lake per David *et al.* (1998).

Following the combined protocols outlined from the pre-existing methods for measuring biodiversity as already discussed, it was determined that a kick and sweep collection method of the sublittoral zone was preferable. The kick and sweep was standardized to 5 minutes at each site. Starting at a depth of 1-metre, the kicker would slowly walk towards the shore and back out to the same spot kicking up the substrate. If time permitted, another transect was completed immediately adjacent to the first and the process was repeated until 5 minutes were up. A second kick and sweep replicate was also completed, this would start immediately adjacent to the last transect of the first kick and sweep.

Following behind the kicker, the sweeper would gather the sample into the net. A seine net with a mesh of 280μm size was used to insure that most macroinvertebrates would be captured. The sample was then emptied into a large bucket and water was used to rinse the net off completely into the bucket. In order to avoid adding any extra sample into the collected substrate, water was poured over the back of the net.

To avoid biased picking of the more easily visible large individuals, the collectors focused on looking for movement in the water, picking out anything that caught the eye. The collected organisms were placed into a container of 95% ethanol (which was subsequently diluted by some lake water sucked up into the droppers with the organisms) for preservation and transportation to the lab. If a picked subsample contained a large amount of plant material, a portion of this was also taken. The remaining water and material from the picked sample was returned to the lake.

Data transformation

The raw data for site replicates for each lake were combined. All branchiopods and copepods were subsequently removed since they are not benthic organisms. The counts for each site were **weighted to 100** to provide a total count of 100 organisms per site as well as per lake.

Representative reference collections were isolated for future more detailed analyses and study, and for genus/special level Ids when imperative.

The following indices were computed:

Biological Indices

(Kirsch, 1999; Mandaville, 1999)

(a) Simpson's Diversity Index (D)

Diversity within the benthic macroinvertebrate community was described using the Simpson's diversity index ("D"), which was calculated as:

$$D = 1 - \sum_{i=1}^{s} (p_i)^2$$

where "p_i" is the proportion of individuals in the "i^{th}" taxon of the community and "s" is the total number of taxa in the community. This index places relatively little weight on rare species and more weight on common species (Krebs, 1994). Its values range from 0, indicating a low level of diversity, to a maximum of 1-1/s.

(b) Shannon-Wiener Diversity Index (H)

Used by the Gerritsen *et al* (1998), the Shannon-Wiener Diversity index (H) is commonly used to calculate aquatic and terrestrial biodiversity. This index was calculated as:

$$H = -\sum_{i=1}^{s} (p_i)(\log_2 p_i)$$

where "p_i" is the proportion of individuals in the "i^{th}" taxon of the community and "s" is the total number of taxa in the community. As the number and distribution of taxa (biotic diversity) within the community increases, so does the value of "H" (Gerritsen *et al.*, 1998).

(c) Family Biotic Index (FBI, Metric 2- RBP II)

The Biotic Index was originally developed by Hilsenhoff (1982) to provide a single 'tolerance value' which is the average of the tolerance values of all species within the benthic arthropod community. The Biotic Index was subsequently modified to the family-level with tolerance values ranging from 0 (very intolerant) to 10 (highly tolerant) based on their tolerance to organic pollution (Chapter IV, this report), creating the Family Biotic Index (FBI). FBI was further developed by the State of New York to include other macroinvertebrates for the use of the U.S. EPA Rapid Bioassessment Protocol II (Plafkin *et al.*, 1989; Bode *et al*., 1991). FBI was calculated as:

$$FBI = \sum \frac{x_i \; t_i}{n}$$

where "x_i" is the number of individuals in the "i^{th}" taxon, "t_i" is the tolerance value of the "i^{th}" taxon, and "n" is the total number of organisms in the sample. The FBI was then used to evaluate the water quality of each lake (Tables 1 & 2, Chapter IV, this report).

(d) Biological Monitoring Working Party (BMWP)

The Biological Monitoring Working Party score (BMWP) provides single values, at the family level, representative of the organisms' tolerance to pollution. The greater their tolerance towards pollution, the lower the BMWP score. To reflect conditions within North America, Mackie (2001) has modified this index. BMWP was calculated by adding the individual scores of all families, and order Oligochaeta (Friedrich *et al*., 1996), represented within the community (*cf*. Table-6, Appendix B this report).

(e) Average Score Per Taxon (ASPT)

The Average Score Per Taxon (ASPT) represents the average tolerance score of all taxa within the community, and was calculated by dividing the BMWP by the number of families represented in the sample (Friedrich *et al*., 1996). From this value, the water quality of each lake was assessed (Mackie, 2001; *cf*. Table-5, Appendix B this report).

(f) Taxa Richness (TR, Metric 1- RBP II)

Taxa Richness (TR) indicates the health of the community through its' diversity, and increases with increasing habitat diversity, suitability, and water quality (Plafkin *et al*., 1989). TR equals the total number of taxa represented within the sample. The healthier the community is, the greater the number of taxa found within that community

(g) Ratio of Scraper and Filtering Collector Functional Feeding Groups (scr/f-c, Metric 3- RBP II)

The Scraper and Filtering Collector index (scr/f-c) is calculated by dividing the total number of individuals classified as scrapers by the total number of individuals classified as filtering collectors within the sample. This index is independent of taxonomy, since some families may represent several functional feeding groups (Plafkin *et al*., 1989). When compared to a reference site, shifts in the dominance of a particular feeding group corresponds to the abundance of a particular food source, which reflects a specific type of impact on the community (Plafkin *et al*., 1989).

(h) EPT Index (Metric 6- RBP II)

The Ephemeroptera, Plecoptera, and Trichoptera (EPT) index displays the taxa richness within the insect groups which are considered to be sensitive to pollution, and therefore should increase with increasing water quality. Initially developed for species-level identifications, this index is valid for use at the family-level (Plafkin *et al*., 1989). The EPT index is equal to the total number of families represented within these three orders in the sample.

(i) Ratio of EPT and Chironomidae (EPT/C, Metric 4- RBP II)

The abundance of EPT and Chironomidae indicates the balance of the community, since EPT are considered to be more sensitive and Chironomidae less sensitive to environmental stress (Plafkin *et al*., 1989). A community considered to be in good biotic condition will display an even distribution among these four groups, while communities with disproportionately high numbers of Chironomidae may indicate environmental stress (Plafkin *et al*., 1989). The EPT/C index is calculated by dividing the sum of the total number of individuals classified as Ephemeroptera, Plecoptera, and Trichoptera by the total number of individuals classified as Chironomidae.

(j) ETO Index

The Ephemeroptera, Trichoptera, and Odonata (ETO) index represents the taxa richness of these groups (Gerritsen *et al.,* 1998). The ETO index is equal to the total number of families represented within these three orders in the sample. Ephemeroptera, Trichoptera and Odonata are considered to be sensitive to pollution. This index has no reference, but provides a comparison of the abundance of these groups within one study site over time.

(k) Percent Contribution of Dominant Family (%DF, Metric 5- RBP II)

The Percent Contribution of Dominant Family or percent dominance (%DF) equals the abundance of the numerically dominant family relative to the total number of organisms in the sample. This index indicates the present state of the community balance at the family level. For example, a community dominated by relatively few families would have a high %DF value, thus indicating the community is under the influence of environmental stress (Plafkin *et al*., 1989).

(l) Community Loss Index (CLI, Metric 7- RBP II)

The Community Loss Index (CLI) measures the loss of benthic taxa in a study site with respect to a reference site. Values range from 0 to "infinity" and increase as the degree of dissimilarity between the sites increases (Plafkin *et al*., 1989). CLI was calculated as:

$$Community\ Loss = \frac{d - a}{e}$$

where "a" is the number of taxa common to both sites, "d" is the total number of taxa present in the reference site, and "e" is the total number of taxa present in the study site. In this study, CLI was determined by comparing the total number of taxa present in each study lake ("e") to the number of taxa present in each site of the reference lake ("d"). This was done to account for the variation that occurs under natural conditions.

(m) Ratio of Shredder Functional Feeding Group and Total Number of Individuals Collected- CPOM Sample (shredders/total, Metric 8- RBP II)

Also based on the Functional Feeding Group Concept, the abundance of the Shredder Functional Group relative to the abundance of all other Functional Groups allows evaluation of potential impairment as indicated by the CPOM-based Shredder community. Shredders are sensitive to riparian zone impacts and are particularly good indicators of toxic effects when the toxicants involved are readily adsorbed to the CPOM and either affect microbial communities colonizing the CPOM or the Shredders directly.

The degree of toxicant effects on Shredders versus Filterers depends on the nature of the toxicants and the organic particle adsorption efficiency. Generally, as the size of the particle decreases, the adsorption efficiency increases as a function of the increased surface to volume ratio. Because water-borne toxicants are readily adsorbed to FPOM, toxicants of a terrestrial source (e.g., pesticides, herbicides) accumulate on CPOM prior to leaf fall thus having a substantial effect on Shredders.

The focus of this approach is on a comparison to the reference community which should have a reasonable representation of Shredders as dictated by seasonality, region, and climate.

This allows for an examination of Shredder or Collector "relative" abundance as indicators of toxicity (Plafkin *et al.*, 1989).

(n) Percent Similarity Comparisons (PSC- RBP II)

Several of the aforementioned indices (TR, FBI, scr/f-c, EPT, EPT/C, % DF, CLI, and shredders/total) are used by the RBP-II to assess the biological condition of study sites (Plafkin *et al*., 1989). Referring to this, the indices were given scores depending on whether the actual values indicated the community to be non-impaired (score = 6), moderately impaired (score = 3), or severely impaired (score = 0) by pollution. The biological condition scores for each site were summed and divided by the total indices score for the reference site, e.g. for each index the reference site would receive a score of 6, to provide a percent comparison between the reference and study sites. Among the indices used, scr/f-c regularly produced no measurable values due to the absence of scrapers in the reference lake (Dollar Lake), i.e. the dividend had a value of 0 and the index was not computable. In the sites where scr/f-c did not produce a numeric value, this index was not included in the calculation of percent comparison.

For FBI, scr/f-c, and EPT/C, the "average" indices for each study lake were compared to the indices for each site of the reference lake, while the TR and EPT values, based on total representation within each study lake, were compared to the indices for each site of the reference lake. Actual % DF values for each site of the study lakes were used and not compared to the reference lake. As well, actual CLI values for each study lake (total) were used, since comparison to the reference lake was incorporated into its calculation.

In addition, the ratio of shredders/total was not used since no plant material was collected to determine the presence of organisms classified as shredders.

Finally, the percent comparisons were averaged to provide an overall percent comparison of each lake to the reference lake.

(o) Percent Model Affinity (PMA)

Percent Model Affinity (PMA) is used to compare how similar a study site is with respect to a model non-impacted community, and is based on the percent abundance of seven major macroinvertebrate groups (Novak and Bode, 1992). From this, the biological effects of pollutants on an existing community can be measured. For the kick samples obtained for this study, the model non-impacted community consisted of 40% Ephemeroptera, 5% Plecoptera, 10% Trichoptera, 10% Coleoptera, 20% Chironomidae, 5% Oligochaeta, and 10% Others (Novak and Bode, 1992). The percent contributions for each of the seven groups at each site (summing 100) of the study lakes were determined and compared with those of the model community. PMA was calculated by summing the lesser of the two values (actual and model values) for each site of the study lakes, and used to assess water quality.

(p) Additional Indices

In accordance with the recommendations of the Ontario Ministry of the Environment (Somers *et al*., 1998), the following indices were also included in the present study. These indices were calculated as their proportional abundance relative to the total number of organisms in the sample: <u>% Oligochaetes</u>, <u>% Amphipods</u>, <u>% EPT</u>, <u>% Insects</u>, <u>% Non-Dipteran Insects</u>, <u>%Dipteran Insects</u>, <u>% Gastropods</u>, and <u>% Pelecypods</u>.

Statistical Analysis

To determine if differences exist between the lakes, one-way ANOVA was performed on each index. This analysis was performed on the data for the five lakes (Wrights, Springfield, McGrath, Kearney, and Morris Lakes), as well as the combination of these lakes plus those analyzed by Gaertner (1999; Dollar, Russell, Stillwater, Papermill, and Kinsac Lakes). Correlation analysis was performed on transformed (log (X+1)) index data to determine if any repetition existed between individual indices. CLI, PSC, and PMA were not included in the correlation analysis since their calculations involved comparing the study lakes to a reference or model lake.

To further examine the differences between the ten lakes, Correspondence Analysis (CA; K. Somers) was performed using a modified program provided to us by Keith Somers of the Dorset Research Centre, Ontario Ministry of the Environment. Prior to performing this analysis, in order to be consistent with the rapid-bio taxonomic levels, the abundance data was modified by rolling up some of the identifications to coarser levels. Individual taxa were summed across all lakes and sites, and taxa which accounted for less than 0.1% of all taxa present (i.e. rare species) were removed from the database. The remaining abundance data was then transformed (log (X+1)) and analyzed. Taxa were also identified as being present (1) or absent (0), and a second CA was performed. Finally, the indices were transformed (log (X+1)) to perform a third CA. CLI and PSC were not included in this analysis since comparisons of the study lakes to the reference lake (Dollar Lake) were incorporated in the calculation, resulting in no CLI or PSC values for Dollar Lake. The resulting CA scores for the transformed abundance, presence/absence, and transformed indices data were analyzed using ANOVA.

Analysis of Indices

(Kirsch, 1999)

By performing CA analysis on the lakes and indices, Kirsch hoped to get a better understanding of which indices would be most appropriate, and which would be futile, in analyzing and comparing lakes of this region. However, according to the CA analysis, the indices were not significantly different (p=0.105). With regards to % gastropods and % pelecypods, visual outliers, these macroinvertebrates were either absent or present in very small numbers within the lakes. This would account for their separation from the other indices. Without considering these two indices, all indices were significantly different between the lakes, with the exception of % amphipods (p=0.091). Based on these results, Kirsch was unable to suggest which indices would be most appropriate in analyzing the lakes of this region, and hesitated to recommend the disqualification of % amphipods based on its' relatively low p-value.

There remains the question of whether the inclusion of certain indices would be repetitive, or if there are certain indices that are better able to determine differences than others. For example, Novak and Bode (1992) found PMA to be closely correlated with EPT and Biotic Index (both at species level), and more accurately able to determine water quality changes resulting from non-organic pollutants. Within the current study, several indices also proved to be strongly correlated; TR and BMWP (0.955), % EPT and % non-dipteran insects (0.970), D and H (0.924), EPT and ETO (0.916), EPT and BMWP (0.909), EPT and TR (0.902), D and % DF (-0.905). With regards to detecting differences among lakes in this region, it may be suggested that some of these indices are repetitive.

In the case of the two highly correlated diversity indices, D and H, it was suggested that H would be a more suitable index since it provides equal weight to rare and common species. In addition, within this study, among the first five lakes H was significantly different (p=0.005) but D was not (p=0.159). Hence, H may be more sensitive towards differences in diversity. TR and BMWP were also strongly correlated, and in view of these two indices it is suggested that it would be more appropriate to calculate BMWP since it accounts for the tolerance of individual organisms towards pollution. Unfortunately, TR does indicate the health of a community through its diversity, but does not take into consideration whether the taxa present are tolerant or intolerant towards pollution. In addition, TR is necessary in the calculation of the PSC.

Among the indices analyzed, EPT was found to be highly correlated with several other indices, including ETO. Kirsch felt that the removal of ETO would be appropriate for several reasons. First, the ETO index has no reference and is solely used as a comparison over time for the same study site. EPT could also be analyzed in this way. Second, like EPT, this index provides the taxa richness of several groups of macroinvertebrates which are considered to be sensitive to pollution and, therefore, repetitive. Furthermore, both ETO and EPT include the taxa richness of Ephemeroptera and Trichoptera and only differ in one group (Odonata vs. Plecoptera).

The strongest correlation occurred between % EPT and % non-dipteran insects. Among the indices % insects and % dipteran insects are also included, and since % insects equals the sum of % dipteran and % non-dipteran insects, it would not be necessary to include % non-dipteran insects. It is suggested that including the index % non-dipteran may be repetitive, and therefore easily excluded.

Even though it did not show strong correlation with any other indices, Kirsch questions the reliability of ASPT. This index displays the average tolerance of all taxonomic groups represented within the study site, but does not take into consideration their relative amounts. Within the first study, ASPT classified all lakes (Wrights, Springfield, McGrath, Kearney, and Morris Lakes) as having probable moderate pollution. However, the benthic macroinvertebrate communities of McGrath, Kearney, and Morris Lakes were clearly dominated by pollution sensitive families, while pollution tolerant families dominated those of Wrights and Springfield Lakes, differences which were not apparent through ASPT analysis. However, ASPT did provide varying classifications among the lakes studied by Gaertner (1999), as well as between the sites within each of the ten lakes. Regardless, the author questions the reliability of this index to detect differences between lakes within this region. At this point, removal of this index would not be recommended unless further analyses of lakes in this region deem it to be appropriate.

Although correlation analysis only resulted in the removal of 4 of the original 20 'simple' indices, Kirsch felt that more data from lakes within this region would be necessary to justify the removal of any more indices, unlike Somers *et al*. (1998) who concluded the five lakes in their study could be easily distinguished by two 'simple' indices (% amphipods and % insects) along with a multivariate index. As well, Somers *et al*. (1998) strongly suggested that multivariate indices should be used, in conjunction with a few 'simple' indices, to interpret rapid bioassessment data. However, the comparison of lakes within a given region through the analysis of several indices would be beneficial, since various indices are designed to measure different aspects of the community or system. Plafkin *et al*. (1989) reported that the evaluation of a variety of indices would provide greater assurance of a valid assessment, ensuring the deficiency of any one index would not invalidate the entire approach.

Conclusion

From further analysis of the diversity and biotic indices used to assess the water quality and macroinvertebrate communities of these lakes, Kirsch was able to suggest and justify the removal of four indices (D, TR, ETO, and % non-dipteran insects) deemed to be repetitive. Although derived from stream and river data, all indices (except % amphipods and % pelecypods) were successful in detecting differences between the lakes. It is cautioned that these results are derived from and should only be used for the study of lakes in this geographical area. Despite the low numbers of pelecypods and the large variability of % amphipods within the lakes, as well as the questionable reliability of ASPT, Kirsch felt that the removal of more indices could only be justified through the analysis of more lakes within this region. Classifications based on the analysis of several indices would, however, decrease the probability of misclassification due to the inaccuracy of any one index.

At this point, it is suggested using the following indices to study lakes within this region: D, H, FBI, BMWP, ASPT, TR, scr/f-c, % DF, EPT, EPT/C, % EPT, % oligochaetes, % amphipods, % insects, % dipteran insects, % gastropods, and % pelecypods. In addition, PSC, CLI, shredders/total, and PMA would also be recommended (modified from Kirsch, 1999).

Chapter IV: Tolerances- Family level

Modified Family Biotic Index, RBP II (Plafkin *et al*., 1989)

Tolerance values (Table-2) range from 0 to 10 for families and increase as water quality decreases. The index was developed by Hilsenhoff (Hilsenhoff, 1988) to summarize the various tolerances of the benthic arthropod community with a single value. The Modified Family Biotic Index (FBI) was developed to detect organic pollution and is based on the original species-level index (BI) of Hilsenhoff (Table-3, Chapter V of this report). Tolerance values for each family were developed by weighting species according to their relative abundance in the State of Wisconsin.

In unpolluted streams the FBI was higher than the BI, suggesting lower water quality, and in polluted streams it was lower, suggesting higher water quality. These results occurred because the more intolerant genera and species in each family predominate in clean streams, whereas the more tolerant genera and species predominate in polluted streams. Thus the FBI usually indicates greater pollution of clean streams by overestimating BI values and usually indicates less pollution in polluted streams by underestimating BI values. The FBI is intended only for use as a rapid field procedure. It should not be substituted for the BI; it is less accurate and can more frequently lead to erroneous conclusions about water quality (Hilsenhoff, 1988).

The family-level index has been modified for the RBP II to include organisms other than just arthropods using the genus and species-level tolerance values adopted by the State of New York (Bode *et al*., 1991, 1996, 2002; *cf.*, Table-4, Appendix A of this report). Although the FBI may be applicable for toxic pollutants, it has only been evaluated for organic pollutants. The formula for calculating the Family Biotic Index is:

$$FBI = \frac{\sum x_i t_i}{n}$$

where
x_i = number of individuals within a taxon
t_i = tolerance value of a taxon
n = total number of organisms in the sample (100)

Table-1: Evaluation of water quality using the family-level biotic index (Hilsenhoff, 1988)

Family Biotic Index	Water Quality	Degree of Organic Pollution
0.00-3.75	Excellent	Organic pollution unlikely
3.76-4.25	Very good	Possible slight organic pollution
4.26-5.00	Good	Some organic pollution probable
5.01-5.75	Fair	Fairly substantial pollution likely
5.76-6.50	Fairly poor	Substantial pollution likely
6.51-7.25	Poor	Very substantial pollution likely
7.26-10.00	Very poor	Severe organic pollution likely

Hilsenhoff's family-level tolerance values may require modification for some regions.

Table-2 : Tolerance Values for macroinvertebrates for application in the Modified Family Biotic Index and other metrics

Bode *et al*. (1996); Hauer and Lamberti (1996); Hilsenhoff (1988); Plafkin *et al*. (1989)

Plecoptera		**Trichoptera**		**Amphipoda**	
Capniidae	1	Brachycentridae	1	Gammaridae	4
Chloroperlidae	1	Calamoceratidae	3	Hyalellidae	8
Leuctridae	0	Glossosomatidae	0	Talitridae	8
Nemouridae	2	Helicopsychidae	3		
Perlidae	1	Hydropsychidae	4	**Isopoda**	
Perlodidae	2	Hydroptilidae	4	Asellidae	8
Pteronarcyidae	0	Lepidostomatidae	1		
Taeniopterygidae	2	Leptoceridae	4	**Decapoda**	6
		Limnephilidae	4		
Ephemeroptera		Molannidae	6	**Acariformes**	4
Baetidae	4	Odontoceridae	0		
Baetiscidae	3	Philpotamidae	3	**Mollusca**	
Caenidae	7	Phryganeidae	4	Lymnaeidae	6
Ephemerellidae	1	Polycentropodidae	6	Physidae	8
Ephemeridae	4	Psychomyiidae	2	Sphaeridae	8
Heptageniidae	4	Rhyacophilidae	0		
Leptophlebiidae	2	Sericostomatidae	3		
Metretopodidae	2	Uenoidae	3		
Oligoneuriidae	2				
Polymitarcyidae	2				
Potomanthidae	4				
Siphlonuridae	7				
Tricorythidae	4				

(Table-2 continued)

		Diptera			
		Athericidae	2		
		Blephariceridae	0		
		Ceratopogonidae	6		
		Blood-red Chironomidae (Chironomini)	8		
Odonata		Other Chironomidae (including pink)	6		
Aeshnidae	3	Dolochopodidae	4		
Calopterygidae	5	Empididae	6		
Coenagrionidae	9	Ephydridae	6		
Cordulegastridae	3	Muscidae	6		
Corduliidae	5	Psychodidae	10	**Oligochaeta**	8
Gomphidae	1	Simuliidae	6		
Lestidae	9	Syrphidae	10	**Hirudinea**	
Libellulidae	9	Tabanidae	6	Bdellidae	10
Macromiidae	3	Tipulidae	3	*Helobdella*	10
Megaloptera		**Coleoptera**		**Polychaeta**	
Corydalidae	0	Dryopidae	5	Sabellidae	6
Sialidae	4	Elmidae	4		
		Psephenidae	4		
Lepidoptera				**Turbellaria**	4
Pyralidae	5	**Collembola**		Platyhelminthidae	4
		Isotomurus sp.	5		
Neuroptera				**Coelenterata**	
Sisyridae				Hydridae	
Climacia sp.	5			*Hydra* sp.	5

Chapter V: Tolerances- Species level

Taxa List in Table-4 (Appendix A) includes macroinvertebrates, principally collected in water quality surveys of New York State streams by the Stream Biomonitoring Unit since 1972 as well as from other literature. These are listed primarily in phylogenetic order. Classification included for most organisms are phylum, class, order, family, genus, and species. Genera are arranged alphabetically within each family (subfamily for Chironomidae).

Tolerance is a listing of tolerance values for each taxon used in the calculation of the Hilsenhoff species-level Biotic Index and the Family Biotic Index. Tolerance values range from 0 for organisms very intolerant of organic wastes to 10 for organisms very tolerant of organic wastes. Most of these values were taken from Hilsenhoff (1987). For species not included in Hilsenhoff's listing, such as Oligochaeta, values were assigned based on water quality data from the Stream Biomonitoring Unit surveys of New York and from other literature references. Values taken from survey data were assigned by taking the mean of the tolerance values of other species in the sample. The Hilsenhoff tolerance values were derived from more than 53 Wisconsin streams.

Feeding Habit lists the primary feeding habit for each species, using the following abbreviations:

c-f: collector-filterer
c-g: collector-gatherer
prd: predator
scr: scraper
shr: shredder
par: parasite
omn: omnivore
pir: piercer

Most of these designations were taken from Merritt and Cummins (1996). In cases where more than one feeding habit is listed, the first listing was selected. For species not listed in Merritt and Cummins, other references were consulted, primarily Pennak (1978).

Modified Hilsenhoff Biotic Index, RBP III (Plafkin *et al.*, 1989)

(based on species level identification of most taxa)

The index has been modified to include non-arthropod species as well on the basis of the biotic index used by the State of New York (Bode *et al*., 1991, 1996, 2002). Although the BI may be applicable for other types of pollutants, it has only been evaluated for organic pollutants. The formula for calculating the Biotic Index is:

$$BI = \frac{\sum x_i t_i}{n}$$

where
x_i = number of individuals within a species
t_i = tolerance value of a species
n = total number of organisms in the sample (100)

The following table is a general guide to the water quality of streams. Replicate samples, or both spring and fall samples, will add to the confidence of the evaluation.

Table-3: Evaluation of water quality using biotic index values of samples collected in March, April, May, September, and early October (Hilsenhoff, 1987)

Biotic Index	Water Quality	Degree of Organic Pollution
0.00-3.50	Excellent	No apparent organic pollution
3.51-4.50	Very good	Possible slight organic pollution
4.51-5.50	Good	Some organic pollution
5.51-6.50	Fair	Fairly significant organic pollution
6.51-7.50	Fairly Poor	Significant organic pollution
7.51-8.50	Poor	Very significant organic pollution
8.51-10.00	Very Poor	Severe organic pollution

Hilsenhoff's biotic index (1987) may require regional modification in some instances.

The detailed Macroinvertebrate Species List, Tolerance Values and Feeding Habits is given as Table-4 in Appendix A.

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Appendix A

Tolerance is a listing of tolerance values for each taxon used in the calculation of the Hilsenhoff species-level Biotic Index (*cf*. Chapter V, pg. 39) and the Family Biotic Index (*cf*. Chapter IV, pg. 35). Tolerance values range from 0 for organisms very intolerant of organic wastes to 10 for organisms very tolerant of organic wastes.

Modified Hilsenhoff Biotic Index, RBP III:

$$BI = \frac{\sum x_i t_i}{n}$$

Biotic Index	Water Quality	Degree of Organic Pollution
0.00-3.50	Excellent	No apparent organic pollution
3.51-4.50	Very good	Possible slight organic pollution
4.51-5.50	Good	Some organic pollution
5.51-6.50	Fair	Fairly significant organic pollution
6.51-7.50	Fairly Poor	Significant organic pollution
7.51-8.50	Poor	Very significant organic pollution
8.51-10.00	Very Poor	Severe organic pollution

Table-4: Macroinvertebrate Species List, Tolerance Values and Feeding Habits

Taxa	Tolerance	Feeding Habit	Reference
COELENTERATA			
HYDROZOA			
HYDROIDA			
Hydridae			
Hydra sp.	5	prd	Bode *et al*, 1996
NEMERTEA (ribbon worms)			
ENOPLA			
HOPLONEMERTEA			
Tetrastemmatidae			
Prostoma graecense	8	prd	Bode *et al*., 1996
PLATYHELMINTHES			
TURBELLARIA (planarians/dugesia)	4	prd	Barbour *et al*, 1999
TRICLADIDA	4	c-g	Barbour *et al*, 1999
Planariidae	1	omn	Barbour *et al*., 1999
Dugesia tigrina	6	prd	Bode *et al*., 1996
Dugesia sp.	6	prd	Bode *et al*., 1996
Undetermined Turbellaria	6	c-g	Bode *et al*., 1996

DUGESIA	4	omn	Barbour *et al.*, 1999
Platyhelminthidae	4	---	Hauer & Lamberti, 1996

Taxa	Tolerance	Feeding Habit	Reference
ANNELIDA (true worms)			
POLYCHAETA (freshwater tube worms)			
Undetermined Polychaeta	6	c-g	Bode *et al*., 2002
SABELLIDA			
Sabellidae			
Manayunkia speciosa	6	c-g	Bode *et al*., 1996
OLIGOCHAETA (aquatic worms)	5	c-g	Barbour *et al*., 1999
HAPLOTAXIDA			
Haplotaxidae			
Undetermined Haplotaxidae	5	prd	Bode *et al*., 1996
LUMBRICIDA			
Undetermined Lumbricina	6	c-g	Bode *et al*., 2002
LUMBRICULIDA			
Lumbriculidae			
Eclipidrilus sp.	5	c-g	Bode *et al*., 2002
Stylodrilus heringianus	5	c-g	Bode *et al*., 1996
Undetermined Lumbriculidae	5	c-g	Bode *et al*., 2002
TUBIFICIDA			
Enchytraeidae			
Undetermined Enchytraeidae sp. 1	10	c-g	Bode *et al*., 1996
Undetermined Enchytraeidae sp. 2	10	c-g	Bode *et al*., 1996
Undetermined Enchytraeidae	10	c-g	Bode *et al*., 1996
Tubificidae	10	c-g	Barbour *et al*, 1999
Aulodrilus americanus	7	c-g	Bode *et al*., 2002
Aulodrilus limnobius	7	c-g	Bode *et al*., 2002
Aulodrilus piqueti	7	c-g	Bode *et al*., 2002
Aulodrilus pluriseta	7	c-g	Bode *et al*., 2002
Aulodrilus sp.	7	c-g	Bode *et al*., 2002
Bothrioneurum vejdovskyanum	7	c-g	Bode *et al*., 2002
Branchiura sowerbyi	6	c-g	Bode *et al*., 2002
Ilyodrilus templetoni	10	c-g	Bode *et al*., 1996
Isochaetides freyi	8	c-g	Bode *et al*., 2002
Limnodrilus cervix	10	c-g	Bode *et al*., 1996
Limnodrilus claparedeianus	10	c-g	Bode *et al*., 1996
Limnodrilus hoffmeisteri	10	c-g	Bode *et al*., 1996
Limnodrilus profundicola	10	c-g	Bode *et al*., 1996
Limnodrilus udekemianus	10	c-g	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
ANNELIDA (contd.)			
OLIGOCHAETA (contd.)			
TUBIFICIDA (contd.)			
Tubificidae (contd.)			
Potamothrix moldaviensis	8	c-g	Bode *et al*., 2002
Potamothrix vejdovskyi	8	c-g	Bode *et al*., 2002
Quistadrilus multisetosus	10	c-g	Bode *et al*., 1996
Rhyacodrilus sp.	10	c-g	Bode *et al*., 2002
Spirosperma ferox	6	c-g	Bode *et al*., 2002
Tubifex	10	c-g	Barbour *et al*., 1999
Tubifex tubifex	10	c-g	Bode *et al*., 1996
Undetermined Tubificidae w/ capillary setae	10	c-g	Bode *et al*., 1996
Undetermined Tubificidae w/o capillary setae	10	c-g	Bode *et al*., 1996
Naididae			
Amphichaeta americana	6	c-g	Bode *et al*., 1996
Arcteonais lomondi	6	c-g	Bode *et al*., 1996
Chaetogaster diaphanus	7	prd	Bode *et al*., 1996
Chaetogaster diastrophus	7	prd	Bode *et al*., 1996
Chaetogaster limnaei	7	prd	Bode *et al*., 1996
Chaetogaster setosus	7	prd	Bode *et al*., 1996
Chaetogaster sp.	7	prd	Bode *et al*., 1996
Derodigitata	10	c-g	Bode *et al*., 1996
Dero furcata	10	c-g	Bode *et al*., 1996
Dero nivea	10	c-g	Bode *et al*., 1996
Dero obtusa	10	c-g	Bode *et al*., 1996
Dero sp.	10	c-g	Bode *et al*., 1996
Haemonais waldvogeli	8	c-g	Bode *et al*., 1996
Nais barbata	8	c-g	Bode *et al*., 1996
Nais behningi	6	c-g	Bode *et al*., 1996
Nais bretscheri	6	c-g	Bode *et al*., 1996
Nais communis	8	c-g	Bode *et al*., 1996
Nais elinguis	10	c-g	Bode *et al*., 1996
Nais pardalis	8	c-g	Bode *et al*., 1996
Nais simplex	6	c-g	Bode *et al*., 1996
Nais variabilis	10	c-g	Bode *et al*., 1996
Nais sp.	8	c-g	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
ANNELIDA (contd.)			
OLIGOCHAETA (contd.)			
TUBIFICIDA (contd.)			
Naididae (contd.)			
Ophidonais serpentina	6	c-g	Bode *et al*., 1996
Paranais frici	10	c-g	Bode *et al*., 2002
Piguetiella michiganensis	6	c-g	Bode *et al*., 2002
Pristina aequiseta	8	c-g	Bode *et al*., 1996
Pristina breviseta	8	c-g	Bode *et al*., 1996
Pristina leidyi	8	c-g	Bode *et al*., 1996
Pristina synclites	8	c-g	Bode *et al*., 1996
Pristina sp.	8	c-g	Bode *et al*., 1996
Pristinella jenkinae	8	c-g	Bode *et al*., 2002
Pristinella osborni	8	c-g	Bode *et al*., 2002
Pristinella sp.	8	c-g	Bode *et al*., 2002
Ripistes parasita	8	c-f	Bode *et al*., 1996
Slavina appendiculata	6	c-g	Bode *et al*., 1996
Specaria josinae	6	c-g	Bode *et al*., 1996
Stylaria lacustris	6	c-g	Bode *et al*., 2002
Vejdovskyella comata	6	c-g	Bode *et al*., 2002
Vejdovskyella intermedia	6	c-g	Bode *et al*., 2002
Vejdovskyella sp.	6	c-g	Bode *et al*., 2002
Undetermined Naididae	8	c-g	Bode *et al*., 2002
Undetermined Oligochaeta	8	c-g	Bode *et al*., 2002

Taxa	Tolerance	Feeding Habit	Reference
ANNELIDA (contd.)			
HIRUDINEA (leeches and bloodsuckers)	10	prd	Barbour *et al*, 1999
RHYNCHOBDELLIDA			
Bdellidae	10	---	Hauer & Lamberti, 1996
Glossiphoniidae			
Batracobdella phalera	8	prd	Bode *et al.*, 2002
Helobdella	6	par/prd	Barbour *et al.*, 1999
Helobdella elongata	8	prd	Bode *et al.*, 2002
Helobdella stagnalis	8	prd	Bode *et al.*, 2002
Helobdella triserialis	8	prd	Bode *et al.*, 2002
Helobdella sp. 1	8	prd	Bode *et al.*, 2002
Placobdella montifera	8	prd	Bode *et al.*, 2002
Undetermined Hirudinea	8	prd	Bode *et al.*, 2002
APHANONEURA			
AEOLOSOMATIDA			
Aeolosomatidae			
Aeolosoma headleyi?	8	c-f	Bode *et al.*, 1996
Aeolosoma leidyi?	8	c-f	Bode *et al.*, 1996
Aeolosoma quarternarium	8	c-f	Bode *et al.*, 1996
Aeolosoma tenebrarum?	8	c-f	Bode *et al.*, 1996
Aeolosoma travancorense	8	c-f	Bode *et al.*, 1996
Undetermined Aeolosomatidae	8	c-f	Bode *et al.*, 1996
BRANCHIOBDELLIDA (leech-like ectosymbionts)		---	Thorp & Covich, 1991
BRANCHIOBDELLIDA			
Branchiobdellidae			
Branchiobdella sp.	6	c-g	Bode *et al.*, 1996
Undetermined Branchiobdellidae	6	c-g	Bode *et al.*, 1996

Taxa	Tolerance	Feeding Habit	Reference
MOLLUSCA			
GASTROPODA (snails and limpets)	7	scr	Barbour *et al*., 1999
BASOMMATOPHORA (pulmonates)			
Physidae	8	scr	Barbour *et al*., 1999
Physella ancillaria	8	c-g	Bode *et al*., 1996
Physella gyrina	8	c-g	Bode *et al*., 1996
Physella heterostropha	8	c-g	Bode *et al*., 1996
Physella integra	8	c-g	Bode *et al*., 1996
Physella sp.	8	c-g	Bode *et al*., 1996
Undetermined Physidae	8	c-g	Bode *et al*., 1996
Lymnaeidae	6-6.9	scr	Barbour *et al*., 1999
Fossaria sp.	6	c-g	Bode *et al*., 1996
Lymnaea stagnalis	6	c-g	Bode *et al*., 1996
Pseudosuccinea columella	6	c-g	Bode *et al*., 1996
Radix auricularia	6	c-g	Bode *et al*., 1996
Stagnicola catascopium	6	c-g	Bode *et al*., 1996
Stagnicola elodes	6	c-g	Bode *et al*., 1996
Undetermined Lymnaeidae	6	c-g	Bode *et al*., 1996
Planorbidae	7	scr	Barbour *et al*., 1999
Gyraulus circumstriatus	8	scr	Bode *et al*., 1996
Gyraulus deflectus	8	scr	Bode *et al*., 1996
Gyraulus parvus	8	scr	Bode *et al*., 1996
Helisoma anceps	6	scr	Bode *et al*., 1996
Helisoma campanulata	6	scr	Bode *et al*., 1996
Helisoma trivolvis	6	scr	Bode *et al*., 1996
Helisoma sp.	6	scr	Bode *et al*., 1996
Micromenetus dilatatus	6	scr	Bode *et al*., 1996
Undetermined Planorbidae	6	scr	Bode *et al*., 1996
Ancylidae			
Ferrissia parallela	6	scr	Bode *et al*., 1996
Ferrissia rivularis	6	scr	Bode *et al*., 1996
Ferrissia walkeri	6	scr	Bode *et al*., 1996
Ferrissia sp.	6	scr	Bode *et al*., 1996
Undetermined Ancylidae	6	scr	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
MOLLUSCA (contd.)			
GASTROPODA (contd.)			
MESOGASTROPODA (prosobranches)			
Viviparidae	6	scr	Barbour *et al*., 1999
Campeloma decisum	6	scr	Bode *et al*., 1996
Viviparus georgianus	6	scr	Bode *et al*., 1996
Pleuroceridae			
Goniobasis livescens	6	scr	Bode *et al*., 1996
Goniobasis virginica	6	scr	Bode *et al*., 1996
Goniobasis sp.	6	scr	Bode *et al*., 1996
Pleurocera acuta	6	scr	Bode *et al*., 1996
Undetermined Pleuroceridae	6	scr	Bode *et al*., 1996
Bithyniidae			
Bithynia tentaculata	8	scr	Bode *et al*., 1996
Hydrobiidae	7	scr	Barbour *et al*., 1999
Amnicola decepta	5	scr	Bode *et al*., 1996
Amnicola grana	5	scr	Bode *et al*., 1996
Amnicola limosa	5	scr	Bode *et al*., 1996
Amnicola sp.	5	scr	Bode *et al*., 1996
Cincinnatia cincinnatiensis	5	scr	Bode *et al*., 1996
Pomatiopsis lapidaria	8	scr	Bode *et al*., 1996
Probythinella lacustris	8	scr	Bode *et al*., 1996
Undetermined Hydrobiidae	8	scr	Bode *et al*., 1996
Valvatidae			
Valvata lewisi	8	scr	Bode *et al*., 1996
Valvata piscinalis	8	scr	Bode *et al*., 1996
Valvata sincera	8	scr	Bode *et al*., 1996
Valvata tricarinata	8	scr	Bode *et al*., 1996
Undetermined Valvatidae	8	scr	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
MOLLUSCA (contd.)			
PELECYPODA/BIVALVIA (clams and mussels)	8	c-f	Barbour *et al*, 1999
UNIONIDA			
Unionidae (native to N. America; freshwater pearly mussel, Mackie, 2001)	8	c-f	Barbour *et al.*, 1999
Anodonta implicata	6	c-f	Bode *et al.*, 1996
Elliptio complanata	8	c-f	Bode *et al.*, 1996
Lampsilis radiata	6	c-f	Bode *et al.*, 2002
Pyganodon cataracta	6	c-f	Bode *et al.*, 2002
Undetermined Unionidae	6	c-f	Bode *et al.*, 1996
VENEROIDEA			
Corbiculidae (Asian clams)			
Corbicula fluminea	6	c-f	Bode *et al.*, 1996
Dreisseniidae (zebra and quagga mussels)			
Dreissena polymorpha	8	c-f	Bode *et al.*, 1996
Sphaeriidae (native to North America; fingernail or pea clams, Peckarsky *et al.*, 1990)	8	c-f	Barbour *et al.*, 1999
Musculium partumeium	6	c-f	Bode *et al.*, 1996
Musculium transversum	6	c-f	Bode *et al.*, 1996
Musculium sp.	6	c-f	Bode *et al.*, 1996
Pisidium amnicum	6	c-f	Bode *et al.*, 1996
Pisidium casertanum	6	c-f	Bode *et al.*, 1996
Pisidium compressum	6	c-f	Bode *et al.*, 1996
Pisidium variabile	6	c-f	Bode *et al.*, 1996
Pisidium sp.	6	c-f	Bode *et al.*, 1996
Sphaerium corneum	6	c-f	Bode *et al.*, 1996
Sphaerium striatinum	6	c-f	Bode *et al.*, 1996
Sphaerium sp.	6	c-f	Bode *et al.*, 1996
Undetermined Sphaeriidae	6	c-f	Bode *et al.*, 1996
Pisidiidae	8	c-g	Barbour *et al.*, 1999

Taxa	Tolerance	Feeding Habit	Reference
ARTHROPODA (jointed-legged metazoan animals, Williams & Feltmate, 1992)			
CRUSTACEA	8	c-g	Barbour *et al*., 1999
ISOPODA (sow bugs)	8	c-g	Barbour *et al*., 1999
Anthuridae			
Cyathura polita	5	c-g	Bode *et al*., 1996
Idoteidae			
Chiridotea almyra	5	c-g	Bode *et al*., 1996
Edotea sp.	5	c-g	Bode *et al*., 1996
Asellidae			
Caecidotea communis	8	c-g	Bode *et al*., 1996
Caecidotea racovitzai	8	c-g	Bode *et al*., 1996
Caecidotea racovitzai racovitzai	8	c-g	Bode *et al*., 1996
Caecidotea nr. *Racovitzai*	8	c-g	Bode *et al*., 1996
Caecidotea sp.	8	c-g	Bode *et al*., 1996
Lirceus sp.	8	c-g	Bode *et al*., 1996
AMPHIPODA (scuds; side swimmers)	4	c-g	Barbour *et al*., 1999
Crangonyctidae			
Crangonyx sp.	6	c-g	Bode *et al*., 1996
	4, 8	c-g	Barbour *et al*., 1999
Gammaridae	4	---	Hauer & Lamberti, 1996
Gammarus fasciatus	6	c-g	Bode *et al*., 1996
Gammarus pseudolimnaeus	4	c-g	Bode *et al*., 1996
Gammarus tigrinus	6	c-g	Bode *et al*., 1996
Gammarus sp.	6	c-g	Bode *et al*., 1996
Oedicerotidae			
Monoculodes edwardsi	5	c-g	Bode *et al*., 1996
Talitridae	8	c-g	Barbour *et al*., 1999
Hyalella azteca	8	c-g	Bode *et al*., 1996 Barbour *et al*., 1999
CUMACEA			
Almyracuma proximoculi	5	c-g	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
ARTHROPODA (contd.)			
CRUSTACEA (contd.)	8	c-g	Barbour *et al*., 1999
DECAPODA (crayfish)	8	shr	Barbour *et al*., 1999
Cambaridae			
Cambarus sp.	6	c-g	Bode *et al*., 1996
Orconectes obscurus	6	c-g	Bode *et al*., 1996
Orconectes rusticus	6	c-g	Bode *et al*., 1996
Orconectes sp.	6	c-g	Bode *et al*., 1996
Undetermined Cambaridae	6	c-g	Bode *et al*., 1996
CLADOCERA (water fleas)	8	c-f	Barbour *et al*., 1999
Daphnia	8	c-f	Barbour *et al*., 1999
COPEPODA	8	c-g	Barbour *et al*., 1999
CYCLOPOIDA	8	c-f	Barbour *et al*., 1999
OSTRACODA (seed shrimps)	8	c-g	Barbour *et al*., 1999

Taxa	Tolerance	Feeding Habit	Reference
ARTHROPODA (contd.)			
ARACHNIDA			
ACARIFORMES			
ARACHNOIDEA (water mites)			
Arrenuridae			
Arrenurus sp.	6	prd	Bode *et al*., 1996
Lebertiidae	8	prd	Barbour *et al*., 1999
Lebertia sp.	6	prd	Bode *et al*., 1996
	8	prd	Barbour *et al*., 1999
Atractideidae			
Atractides sp.	6	prd	Bode *et al*., 1996
Mideopsidae			
Mideopsis sp.	6	prd	Bode *et al*., 1996
Tyrellidae			
Tyrellia sp.	6	prd	Bode *et al*., 1996
Limnesidae			
Limnesia sp.	6	prd	Bode *et al*., 1996
Limnocharidae			
Limnochares sp.	6	prd	Bode *et al*., 1996
Sperchonidae	8	prd	Barbour *et al*., 1999
Sperchon pseudoplumifer	8	prd	Barbour *et al*., 1999
Sperchon sp.	6	prd	Bode *et al*., 1996
Unionicolidae			
Unionicola sp. 1	6	prd	Bode *et al*., 1996
Unionicola sp. 2	6	prd	Bode *et al*., 1996
Undetermined Acariformes	6	prd	Bode *et al*., 1996
DIPLOPODA			
POLYDESMIDA			
Undetermined Polydesmida	6	c-g	Bode *et al*., 2002

Taxa	Tolerance	Feeding Habit	Reference
ARTHROPODA (contd.)			
INSECTA			
COLLEMBOLA (springtails)	10	c-g	Barbour *et al*., 1999
Isotomidae			
Isotomurus sp.	5	c-g	Bode *et al*., 1996
EPHEMEROPTERA (mayflies)			
Ameletidae			
Ameletus ludens	0	c-g	Bode *et al*., 1996
Ameletus sp.	0	c-g	Bode *et al*., 1996
Siphlonuridae	7	---	Hauer & Lamberti, 1996
	7	c-g	Barbour *et al*., 1999
Siphlonurus sp.	4	c-g	Bode *et al*., 2002
Isonychiidae			
Isonychia	2	c-f	Barbour *et al*., 1999
Isonychia bicolor	2	c-f	Bode *et al*., 2002
Isonychia obscura	2	c-f	Bode *et al*., 2002
Isonychia sp.	2	c-f	Bode *et al*., 2002
Baetidae	4	---	Hauer & Lamberti, 1996
	4	c-g	Barbour et al., 1999
Acentrella ampla	6	c-g	Bode *et al*., 1996
Acentrella sp.	4	c-g	Bode *et al*., 1996
Acerpenna macdunnoughi	5	c-g	Bode *et al*., 1996
Acerpenna pygmaea	4	c-g	Bode *et al*., 1996
Baetis brunneicolor	4	c-g	Bode *et al*., 1996
Baetis flavistriga	4	c-g	Bode *et al*., 1996
Baetis intercalaris	5	c-g	Bode *et al*., 1996
Baetis pluto	6	c-g	Bode *et al*., 1996
Baetis tricaudatus	6	c-g	Bode *et al*., 1996
Baetis sp.	6	c-g	Bode *et al*., 1996
			Barbour *et al*., 1999
Callibaetis sp.	7	c-g	Bode *et al*., 1996
Centroptilum sp.	2	c-g	Bode *et al*., 1996
Cloeon sp.	4	c-g	Bode *et al*., 1996
Diphetor hageni	6	c-g	Bode *et al*., 2002
Heterocloeon curiosum	2	scr	Bode *et al*., 1996
Heterocloeon sp.	2	scr	Bode *et al*., 1996
Plauditus sp.	4	c-g	Bode *et al*., 2002
Pseudocloeon propinquum	6	c-g	Bode *et al*., 2002
Undetermined Baetidae	6	c-g	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
EPHEMEROPTERA (contd.)			
Heptageniidae	4	---	Hauer & Lamberti, 1996
Cinygmula subaequalis	2	scr	Bode *et al*., 1996
Epeorus (Iron) sp.	0	scr	Bode *et al*., 1996
Heptagenia culacantha	2	scr	Bode *et al*., 1996
Heptagenia flavescens	4	scr	Bode *et al*., 1996
Heptagenia marginalis	4	scr	Bode *et al*., 1996
Heptagenia pulla gr.	4	scr	Bode *et al*., 1996
Heptagenia sp.	4	scr	Bode *et al*., 1996
Leucrocuta sp.	1	scr	Bode *et al*., 1996
Nixe (Nixe) sp.	2	scr	Bode *et al*., 1996
Rhithrogena sp.	0	c-g	Bode *et al*., 1996
Stenacron interpunctatum	7	scr	Bode *et al*., 1996
Stenonema exiguum	5	scr	Bode *et al*., 1996
Stenonema femoratum	7	scr	Bode *et al*., 1996
Stenonema ithaca	3	scr	Bode *et al*., 1996
Stenonema luteum	4	scr	Bode *et al*., 2002
Stenonema mediopunctatum	3	scr	Bode *et al*., 1996
Stenonema meririvulanum	2	scr	Bode *et al*., 1996
Stenonema mexicanum integrum	4	scr	Bode *et al*., 2002
Stenonema modestum	1	scr	Bode *et al*., 1996
Stenonema pulchellum	3	scr	Bode *et al*., 1996
Stenonema terminatum	4	scr	Bode *et al*., 1996
Stenonema vicarium	2	scr	Bode *et al*., 1996
Stenonema sp.	3	scr	Bode *et al*., 1996
Undetermined Heptageniidae	3	scr	Bode *et al*., 1996
Leptophlebiidae	2	---	Hauer & Lamberti, 1996
Choroterpes sp.	2	c-g	Bode *et al*., 1996
Habrophlebia vibrans	4	c-g	Bode *et al*., 1996
Habrophlebia sp.	4	c-g	Bode *et al*., 1996
Habrophlebiodes sp.	6	scr	Bode *et al*., 1996
Leptophlebia sp.	4	c-g	Bode *et al*., 1996
Paraleptophlebia guttata	1	c-g	Bode *et al*., 1996
Paraleptophlebia moerens	1	c-g	Bode *et al*., 2002
Paraleptophlebia mollis	1	c-g	Bode *et al*., 1996
Paraleptophlebia volitans	1	c-g	Bode *et al*., 1996
Paraleptophlebia sp.	1	c-g	Bode *et al*., 1996

Undetermined Leptophlebiidae	4	c-g	Bode *et al.*, 1996

Taxa	Tolerance	Feeding Habit	Reference
EPHEMEROPTERA (contd.)			
Ephemerellidae	1	---	Hauer & Lamberti, 1996
Attenella attenuata	1	c-g	Bode *et al.*, 1996
Attenella margarita	1	c-g	Bode *et al.*, 1996
Dannella simplex	2	c-g	Bode *et al.*, 1996
Dannella sp.	2	c-g	Bode *et al.*, 1996
Drunella cornuta	0	c-g	Bode *et al.*, 1996
Drunella cornutella	0	scr	Bode *et al.*, 1996
Drunella lata	0	scr	Bode *et al.*, 1996
Drunella tuberculata	0	scr	Bode *et al.*, 1996
Drunella walkeri	0	scr	Bode *et al.*, 1996
Ephemerella aurivillii	0	c-g	Bode *et al.*, 1996
Ephemerella dorothea	1	c-g	Bode *et al.*, 1996
Ephemerella excrucians?	1	c-g	Bode *et al.*, 1996
Ephemerella invaria	1	c-g	Bode *et al.*, 1996
Ephemerella needhami	1	c-g	Bode *et al.*, 1996
Ephemerella rotunda	1	c-g	Bode *et al.*, 1996
Ephemerella subvaria	1	c-g	Bode *et al.*, 1996
Ephemerella sp.	1	c-g	Bode *et al.*, 1996
Eurylophella funeralis	0	c-g	Bode *et al.*, 1996
Eurylophella temporalis	5	c-g	Bode *et al.*, 1996
Eurylophella verisimilis	2	c-g	Bode *et al.*, 1996
Eurylophella sp.	2	c-g	Bode *et al.*, 1996
Serratella deficiens	2	c-g	Bode *et al.*, 1996
Serratella serrata	2	c-g	Bode *et al.*, 1996
Serratella serratoides	2	c-g	Bode *et al.*, 1996
Serratella sordida	2	c-g	Bode *et al.*, 1996
Serratella sp.	2	c-g	Bode *et al.*, 1996
Undetermined Ephemerellidae	2	c-g	Bode *et al.*, 1996
Leptohyphidae			
Tricorythodes sp.	4	c-g	Bode *et al.*, 1996

Taxa	Tolerance	Feeding Habit	Reference
EPHEMEROPTERA (contd.)			
Caenidae	7	---	Hauer & Lamberti, 1996
Brachycercus maculatus	3	c-g	Bode *et al*., 2002
Caenis	7	c-g	Barbour *et al*., 1999
Caenis amica	6	c-g	Bode *et al*., 1996
Caenis anceps	6	c-g	Bode *et al*., 1996
Caenis diminuta	6	c-g	Bode *et al*., 1996
Caenis latipennis	6	c-g	Bode *et al*., 1996
Caenis macafferti	6	c-g	Bode *et al*., 1996
Caenis punctata	6	c-g	Bode *et al*., 1996
Caenis sp.	6	c-g	Bode *et al*., 1996
Undetermined Caenidae	6	c-g	Bode *et al*., 1996
Baetiscidae	3	---	Hauer & Lamberti, 1996
Baetisca sp.	4	c-g	Bode *et al*., 1996 Barbour *et al*., 1999
Potamanthidae	4	---	Hauer & Lamberti, 1996
Anthopotamus verticus	4	c-g	Bode *et al*., 1996
Anthopotamus sp.	4	c-g	Bode *et al*., 1996
Ephemeridae	4	---	Hauer & Lamberti, 1996
Ephemera guttulata	2	c-g	Bode *et al*., 1996
Ephemera sp.	2	c-g	Bode *et al*., 1996
Hexagenia sp.	6	c-g	Bode *et al*., 1996 Barbour *et al*., 1999
Polymitarcyidae	2	---	Hauer & Lamberti, 1996
Ephoron leukon?	2	c-g	Bode *et al*., 1996
Ephoron sp.	2	c-g	Bode *et al*., 2002
Metretopodidae	2	---	Hauer & Lamberti, 1996
Oligoneuridae	2	---	Hauer & Lamberti, 1996

Taxa	Tolerance	Feeding Habit	Reference
ODONATA (dragonflies and damselflies)			
Gomphidae	1	---	Hauer & Lamberti, 1996
Gomphus sp.	5	prd	Bode *et al*., 1996
Lanthus sp.	5	prd	Bode *et al*., 1996
Ophiogomphus sp.	1	prd	Bode *et al*., 1996
Stylogomphus sp.	1	prd	Bode *et al*., 1996
Stylurus sp.	4	prd	Bode *et al*., 1996
Undetermined Gomphidae	4	prd	Bode *et al*., 1996
Aeshnidae	3	---	Hauer & Lamberti, 1996
Basiaeschna sp.	6	prd	Bode *et al*., 1996
Boyeria sp.	2	prd	Bode *et al*., 1996
Undetermined Aeshnidae	5	prd	Bode *et al*., 2002
Cordulegastridae	3	---	Hauer & Lamberti, 1996
Cordulegaster sp.	3	prd	Bode *et al*., 1996
Corduliidae	5	---	Hauer & Lamberti, 1996
Neurocordulia sp.	2	prd	Bode *et al*., 1996
Libellulidae	9	---	Hauer & Lamberti, 1996
Erythemis sp.	2	prd	Bode *et al*., 2002
Undetermined Libellulidae	2	prd	Bode *et al*., 1996
Macromiidae	3	---	Hauer & Lamberti, 1996
Macromia sp.	2	prd	Bode *et al*., 1996
Calopterygidae	5	---	Hauer & Lamberti, 1996
Calopteryx sp.	6	prd	Bode *et al*., 1996
Hetaerina sp.	6	prd	Bode *et al*., 1996
Undetermined Calopterygidae	6	prd	Bode *et al*., 1996
Coenagrionidae	9	---	Hauer & Lamberti, 1996
Argia sp.	6	prd	Bode *et al*., 1996
Enallagma sp.	8	prd	Bode *et al*., 1996
Ischnura sp. 1	9	prd	Bode *et al*., 1996
Ischnura sp. 2	9	prd	Bode *et al*., 1996
Ischnura sp. 3	9	prd	Bode *et al*., 1996
Ischnura sp. 4	9	prd	Bode *et al*., 1996
Ischnura sp. 5	9	prd	Bode *et al*., 1996
Ischnura sp.	9	prd	Bode *et al*., 1996
Undetermined Coenagrionidae	8	prd	Bode *et al*., 1996
Lestidae	9	---	Hauer & Lamberti, 1996
Lestes sp.	6	prd	Bode *et al*., 2002
HEMIPTERA (water or true bugs)			
Corixidae	5	prd	Barbour *et al*., 1999
Hesperocorixa sp.	5	prd	Bode *et al*., 1996
Undetermined Corixidae	3	prd	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
PLECOPTERA (stoneflies)			
Capniidae	1	---	Hauer & Lamberti, 1996
	1	shr	Barbour *et al*., 1999
Allocapnia vivipara	3	shr	Bode *et al*., 1996
Allocapnia sp.	3	shr	Bode *et al*., 1996 Barbour *et al*., 1999
Paracapnia sp.	1	shr	Bode *et al*., 1996
Undetermined Capniidae	3	shr	Bode *et al*., 1996
Leuctridae	0	---	Hauer & Lamberti, 1996
Leuctra ferruginea	0	shr	Bode *et al*., 1996
Leuctra maria	0	shr	Bode *et al*., 2002
Leuctra tenuis	0	shr	Bode *et al*., 1996
Leuctra sp.	0	shr	Bode *et al*., 1996
Zealeuctra sp.	0	shr	Bode *et al*., 1996
Undetermined Leuctridae	0	shr	Bode *et al*., 1996
Nemouridae	2	---	Hauer & Lamberti, 1996
Amphinemura delosa	3	shr	Bode *et al*., 1996
Amphinemura nigritta	3	shr	Bode *et al*., 1996
Amphinemura wui	3	shr	Bode *et al*., 1996
Amphinemura sp.	3	shr	Bode *et al*., 1996
Nemoura sp.	1	shr	Bode *et al*., 1996
Ostrocerca sp.	2	shr	Bode *et al*., 1996
Shipsa rotunda	2	shr	Bode *et al*., 1996
Undetermined Nemouridae	2	shr	Bode *et al*., 1996
Taeniopterygidae	2	---	Hauer & Lamberti, 1996
Strophopteryx fasciata	3	shr	Bode *et al*., 1996
Taeniopteryx burksi	2	shr	Bode *et al*., 1996
Taeniopteryx lonicera	2	shr	Bode *et al*., 1996
Taeniopteryx nivalis	2	shr	Bode *et al*., 1996
Taeniopteryx parvula	2	shr	Bode *et al*., 1996
Taeniopteryx sp.	2	shr	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
PLECOPTERA (contd.)			
Perlidae	1	---	Hauer & Lamberti, 1996
	1	prd	Barbour *et al*., 1999
Acroneuria abnormis	0	prd	Bode *et al*., 1996
Acroneuria carolinensis	0	prd	Bode *et al*., 1996
Acroneuria lycorias	0	prd	Bode *et al*., 1996
Acroneuria sp.	0	prd	Bode *et al*., 1996
Agnetina annulipes	2	prd	Bode *et al*., 2002
Agnetina capitata	2	prd	Bode *et al*., 1996
Agnetina flavescens	2	prd	Bode *et al*., 1996
Agnetina sp.	2	prd	Bode *et al*., 1996
Eccoptura sp.	3	prd	Bode *et al*., 2002
Neoperla sp.	3	prd	Bode *et al*., 1996
Paragnetina immarginata	1	prd	Bode *et al*., 1996
Paragnetina media	4	prd	Bode *et al*., 2002
Paragnetina sp.	2	prd	Bode *et al*., 2002
Perlesta sp. 1	4	prd	Bode *et al*., 2002
Perlesta sp. 2	4	prd	Bode *et al*., 2002
Perlesta sp.	4	prd	Bode *et al*., 2002
Undetermined Perlidae	3	prd	Bode *et al*., 1996
Peltoperlidae			
Tallaperla sp.	0	shr	Bode *et al*., 1996
Chloroperlidae	1	---	Hauer & Lamberti, 1996
Alloperla sp.	0	c-g	Bode *et al*., 1996
Haploperla brevis	1	prd	Bode *et al*., 1996
Rasvena terna	0	c-g	Bode *et al*., 1996
Suwallia marginata	0	prd	Bode *et al*., 2002
Sweltsa sp.	0	prd	Bode *et al*., 1996
Undetermined Chloroperlidae	0	prd	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
PLECOPTERA (contd.)			
Perlodidae	2	---	Hauer & Lamberti, 1996
	2	prd	Barbour *et al*., 1999
Cultus decisus	2	prd	Bode *et al*., 1996
Diura sp.	2	prd	Bode *et al*., 2002
Helopicus subvarians	2	prd	Bode *et al*., 1996
Isogenoides hansoni	0	prd	Bode *et al*., 1996
Isoperla frisoni	2	prd	Bode *et al*., 1996
Isoperla holochlora	2	prd	Bode *et al*., 1996
Isoperla marlynia	2	prd	Bode *et al*., 2002
Isoperla namata	2	prd	Bode *et al*., 1996
Isoperla transmarina	2	prd	Bode *et al*., 1996
Isoperla sp.	2	prd	Bode *et al*., 1996
Malirekus iroquois	2	prd	Bode *et al*., 1996
Undetermined Perlodidae	2	prd	Bode *et al*., 1996
Pteronarcidae	0	---	Hauer & Lamberti, 1996
Pteronarcys biloba	0	shr	Bode *et al*., 1996
Pteronarcys dorsata	0	shr	Bode *et al*., 1996
Pteronarcys proteus	0	shr	Bode *et al*., 1996
Pteronarcys sp.	0	shr	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
COLEOPTERA (beetles)			
Haliplidae			
Haliplus sp.	5	shr	Bode *et al*., 1996
Peltodytes sp.	5	shr	Bode *et al*., 1996
Dytiscidae			
Agabetes sp.	5	prd	Bode *et al*., 1996
Agabus sp.	5	prd	Bode *et al*., 1996 Barbour *et al*., 1999
Hydroporous sp.	5	prd	Bode *et al*., 1996
Laccophilus sp.	5	prd	Bode *et al*., 1996
Undetermined Dytiscidae	5	prd	Bode *et al*., 1996
Gyrinidae			
Dineutus sp.	4	prd	Bode *et al*., 1996
Gyrinus sp.	4	prd	Bode *et al*., 1996
Hydrophilidae			
Berosus sp.	5	c-g	Bode *et al*., 2002
Crenitis sp.	5	c-g	Bode *et al*., 2002
Helochares sp.	5	prd	Bode *et al*., 1996
Helophorus sp.	5	shr	Bode *et al*., 1996
Hydrobius sp.	5	prd	Bode *et al*., 1996
Hydrochara sp.	5	prd	Bode *et al*., 2002
Hydrochus sp.	5	shr	Bode *et al*., 2002
Laccobius sp.	5	prd	Bode *et al*., 1996
Undetermined Hydrophilidae	5	prd	Bode *et al*., 1996
Psephenidae	4	--	Hauer & Lamberti, 1996
Ectopria sp.	5	scr	Bode *et al*., 1996
Psephenus herricki	4	scr	Bode *et al*., 1996
Psephenus sp.	4	scr	Bode *et al*., 1996
Ptilodactylidae			
Anchytarsus bicolor	3	shr	Bode *et al*., 2002
Dryopidae	5	---	Hauer & Lamberti, 1996
Helichus sp.	5	scr	Bode *et al*., 1996
Scirtidae			
Undetermined Scirtidae	5	scr	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
COLEOPTERA (contd.)			
Elmidae	4	---	Hauer & Lamberti, 1996
Ancyronyx variegatus	5	c-g	Bode *et al*., 1996
Dubiraphia bivittata	6	c-g	Bode *et al*., 1996
Dubiraphia quadrinotata	5	c-g	Bode *et al*., 1996
Dubiraphia vittata	6	c-g	Bode *et al*., 1996
Dubiraphia sp.	6	c-g	Bode *et al*., 1996
Macronychus glabratus	5	c-g	Bode *et al*., 1996
Microcylloepus pusillus	3	scr	Bode *et al*., 1996
Optioservus cryophilus	4	scr	Bode *et al*., 1996
Optioservus fastiditus	4	scr	Bode *et al*., 1996
Optioservus immunis	4	scr	Bode *et al*., 1996
Optioservus ovalis	4	scr	Bode *et al*., 1996
Optioservus nr. *Sandersoni*	4	scr	Bode *et al*., 1996
Optioservus trivittatus	4	scr	Bode *et al*., 1996
Optioservus sp.	4	scr	Bode *et al*., 1996
Oulimnius latiusculus	4	scr	Bode *et al*., 1996
Oulimnius nitidulus	4	scr	Bode *et al*., 2002
Oulimnius sp.	4	scr	Bode *et al*., 2002
Promoresia elegans	2	scr	Bode *et al*., 1996
Promoresia tardella	2	scr	Bode *et al*., 1996
Promoresia sp.	2	scr	Bode *et al*., 1996
Stenelmis bicarinata	5	scr	Bode *et al*., 1996
Stenelmis cheryl	5	scr	Bode *et al*., 1996
Stenelmis concinna	5	scr	Bode *et al*., 1996
Stenelmis crenata	5	scr	Bode *et al*., 1996
Stenelmis mera	5	scr	Bode *et al*., 1996
Stenelmis musgravei	5	scr	Bode *et al*., 1996
Stenelmis sandersoni	5	scr	Bode *et al*., 1996
Stenelmis vittapennis	5	scr	Bode *et al*., 2002
Stenelmis sp.	5	scr	Bode *et al*., 1996
Undetermined Elmidae	5	scr	Bode *et al*., 1996
Curculionidae			
Undetermined Curculionidae	5	shr	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
MEGALOPTERA			
Corydalidae (fishflies, dobsonflies, hellgrammites)	0	---	Hauer & Lamberti, 1996
Chauliodes sp.	4	prd	Bode *et al*., 1996
Corydalus cornutus	4	prd	Bode *et al*., 1996
Nigronia serricornis	4	prd	Bode *et al*., 2002
Sialidae (alderflies)	4	---	Hauer & Lamberti, 1996
Sialis sp.	4	prd	Bode *et al*., 1996 Barbour *et al*., 1999
NEUROPTERA			
Sisyridae (spongillaflies)			
Climacia sp.	5	prd	Bode *et al*., 1996 Hauer & Lamberti, 1996

Taxa	Tolerance	Feeding Habit	Reference
TRICHOPTERA (caddisflies)			
Philopotamidae	3	---	Hauer & Lamberti, 1996
Chimarra aterrima?	4	c-f	Bode *et al*., 1996
Chimarra obscura?	4	c-f	Bode *et al*., 1996
Chimarra socia	2	c-f	Bode *et al*., 2002
Chimarra sp.	4	c-f	Bode *et al*., 1996
Dolophilodes sp.	0	c-f	Bode *et al*., 1996
Wormaldia sp.	2	c-f	Bode *et al*., 2002
Undetermined Philopotamidae	4		Bode *et al*., 2002
Psychomyiidae	2	---	Hauer & Lamberti, 1996
Lype diversa	2	scr	Bode *et al*., 1996
Psychomyia flavida	2	c-g	Bode *et al*., 1996
Undetermined Psychomyiidae	2	c-g	Bode *et al*., 1996
Polycentropodidae	6	---	Hauer & Lamberti, 1996
Cyrnellus fraternus	8	c-f	Bode *et al*., 1996
Cyrnellus sp. 2	8	c-f	Bode *et al*., 1996
Neureclipsis bimaculata	7	c-f	Bode *et al*., 1996
Neureclipsis sp.	7	c-f	Bode *et al*., 1996
Nyctiophylax celta	5	prd	Bode *et al*., 1996
Nyctiophylax moestus	5	prd	Bode *et al*., 1996
Phylocentropus sp.	5	c-f	Bode *et al*., 1996
Polycentropus remotus	6	prd	Bode *et al*., 1996
Polycentropus sp.	6	prd	Bode *et al*., 1996
Undetermined Polycentropodidae	6	prd	Bode *et al*., 1996
Dipseudopsidae			
Phylocentropus sp.	5	c-f	Bode *et al*., 2002

Taxa	Tolerance	Feeding Habit	Reference
TRICHOPTERA (contd.)			
Hydropsychidae	4	---	Hauer & Lamberti, 1996
Arctopsyche sp.	1	c-f	Bode *et al.*, 1996
Cheumatopsyche sp.	5	c-f	Bode *et al.*, 1996
Diplectrona sp.	5	c-f	Bode *et al.*, 2002
Hydropsyche betteni	6	c-f	Bode *et al.*, 1996
Hydropsyche bronta	6	c-f	Bode *et al.*, 1996
Hydropsyche nr. *Depravata*	6	c-f	Bode *et al.*, 1996
Hydropsyche dicantha	2	c-f	Bode *et al.*, 1996
Hydropsyche leonardi	0	c-f	Bode *et al.*, 1996
Hydropsyche morosa	6	c-f	Bode *et al.*, 1996
Hydropsyche orris	5	c-f	Bode *et al.*, 1996
Hydropsyche phalerata	1	c-f	Bode *et al.*, 1996
Hydropsyche recurvata	4	c-f	Bode *et al.*, 1996
Hydropsyche scalaris	2	c-f	Bode *et al.*, 1996
Hydropsyche separata	4	c-f	Bode *et al.*, 1996
Hydropsyche slossonae	4	c-f	Bode *et al.*, 1996
Hydropsyche sparna	6	c-f	Bode *et al.*, 1996
Hydropsyche valanis	6	c-f	Bode *et al.*, 1996
Hydropsyche venularis	4	c-f	Bode *et al.*, 1996
Hydropsyche sp.	4	c-f	Bode *et al.*, 1996
Macrostemum carolina	3	c-f	Bode *et al.*, 1996
Macrostemum zebratum	3	c-f	Bode *et al.*, 1996
Macrostemum sp.	3	c-f	Bode *et al.*, 1996
Parapsyche sp.	0	c-f	Bode *et al.*, 1996
Potamyia sp.	5	c-f	Bode *et al.*, 1996
Undetermined Hydropsychidae	5	c-f	Bode *et al.*, 1996

Taxa	Tolerance	Feeding Habit	Reference
TRICHOPTERA (contd.)			
Rhyacophilidae	0	---	Hauer & Lamberti, 1996
Rhyacophila acropedes	1	prd	Bode *et al*., 2002
Rhyacophila carolina?	1	prd	Bode *et al*., 1996
Rhyacophila carpenteri?	1	prd	Bode *et al*., 1996
Rhyacophila formosa	1	prd	Bode *et al*., 2002
Rhyacophila fuscula	0	prd	Bode *et al*., 1996
Rhyacophila glaberrima	1	prd	Bode *et al*., 1996
Rhyacophila mainensis	1	prd	Bode *et al*., 2002
Rhyacophila manistee	1	prd	Bode *et al*., 2002
Rhyacophila nigrita	1	prd	Bode *et al*., 1996
Rhyacophila torva	1	prd	Bode *et al*., 1996
Rhyacophila sp.	1	prd	Bode *et al*., 1996
Glossosomatidae	0	---	Hauer & Lamberti, 1996
Agapetus sp.	0	scr	Bode *et al*., 1996
Culoptila sp.	1	scr	Bode *et al*., 1996
Glossosoma sp.	0	scr	Bode *et al*., 1996
Protoptila sp.	1	scr	Bode *et al*., 1996
Undetermined Glossosomatidae	1	scr	Bode *et al*., 1996
Hydroptilidae	4	---	Hauer & Lamberti, 1996
Agraylea sp.	8	c-g	Bode *et al*., 1996
Alisotrichia sp.	6	scr	Bode *et al*., 1996
Hydroptila nr. *Albicornis*	6	scr	Bode *et al*., 1996
Hydroptila nr. *Armata*	6	scr	Bode *et al*., 1996
Hydroptila consimilis	6	scr	Bode *et al*., 1996
Hydroptila nr. *Hamata*	6	scr	Bode *et al*., 1996
Hydroptila spatulata	6	scr	Bode *et al*., 1996
Hydroptila nr. *Waubesiana*	6	scr	Bode *et al*., 1996
Hydroptila sp.	6	scr	Bode *et al*., 1996
Ithytrichia sp.	4	scr	Bode *et al*., 1996
Leucotrichia sp.	6	scr	Bode *et al*., 1996
Mayatrichia ayama	6	scr	Bode *et al*., 1996
Neotrichia sp.	2	scr	Bode *et al*., 1996
Orthotrichia sp.	6	shr	Bode *et al*., 1996
Oxyethira sp.	3	c-g	Bode *et al*., 1996
Palaeagapetus celsus	4	shr	Bode *et al*., 1996

Palaeagapetus sp.	1	shr	Bode *et al.*, 1996
Undetermined Hydroptilidae	6	scr	Bode *et al.*, 1996

Taxa	Tolerance	Feeding Habit	Reference
TRICHOPTERA (contd.)			
Phryganeidae	4	---	Hauer & Lamberti, 1996
Oligostomis sp.	2	prd	Bode *et al*., 1996
Ptilostomis sp.	5	shr	Bode *et al*., 1996
Undetermined Phryganeidae	4	shr	Bode *et al*., 2002
Brachycentridae	1	---	Hauer & Lamberti, 1996
Adicrophleps hitchcocki	2	shr	Bode *et al*., 1996
Brachycentrus americanus	1	c-f	Bode *et al*., 1996
Brachycentrus appalachia	0	c-f	Bode *et al*., 1996
Brachycentrus incanus	0	c-f	Bode *et al*., 1996
Brachycentrus lateralis	1	c-f	Bode *et al*., 1996
Brachycentrus numerosus	1	c-f	Bode *et al*., 1996
Brachycentrus solomoni	1	c-f	Bode *et al*., 1996
Micrasema sp. 1	2	shr	Bode *et al*., 1996
Micrasema sp. 2	2	shr	Bode *et al*., 1996
Micrasema sp. 3	2	shr	Bode *et al*., 1996
Undetermined Brachycentridae	2	shr	Bode *et al*., 1996
Goeridae			
Goera sp.	3	scr	Bode *et al*., 2002
Apataniidae			
Apatania sp.	3	scr	Bode *et al*., 2002
Uenoidae	3	----	Hauer & Lamberti, 1996
Neophylax concinnus	3	scr	Bode *et al*., 2002
Neophylax fuscus	3	scr	Bode *et al*., 2002
Neophylax sp.	3	scr	Bode *et al*., 2002
Limnephilidae	4	---	Hauer & Lamberti, 1996
Hesperophylax designatus	3	shr	Bode *et al*., 1996
Hydatophylax sp.	2	shr	Bode *et al*., 1996
Limnephilus sp.	3	shr	Bode *et al*., 1996
Nemotaulius hostilis	3	scr	Bode *et al*., 1996
Platycentropus sp.	4	shr	Bode *et al*., 1996
Pseudostenophylax sp.	0	shr	Bode *et al*., 1996
Psychoglypha sp.	0	c-g	Bode *et al*., 1996
Pycnopsyche sp.	4	shr	Bode *et al*., 1996
Undetermined Limnephilidae	4	shr	Bode *et al*., 1996

Taxa	Toleran ce	Feedi ng Habit	Reference
TRICHOPTERA (contd.)			
Lepidostomatidae	1	---	Hauer & Lamberti, 1996
Lepidostoma sp.	1	shr	Bode *et al*., 1996
Odontoceridae	0	---	Hauer & Lamberti, 1996
Psilotreta sp.	0	scr	Bode *et al*., 1996
Molannidae	6	---	Hauer & Lamberti, 1996
Molanna sp.	6	scr	Bode *et al*., 1996
Helicopsychidae	3	---	Hauer & Lamberti, 1996
Helicopsyche borealis	3	scr	Bode *et al*., 1996
Leptoceridae	4	---	Hauer & Lamberti, 1996
Ceraclea alces	3	c-g	Bode *et al*., 1996
Ceraclea punctata	3	c-g	Bode *et al*., 1996
Ceraclea sp.	3	c-g	Bode *et al*., 1996
Leptocerus americanus	4	shr	Bode *et al*., 1996
Mystacides alafimbriata	4	c-g	Bode *et al*., 1996
Mystacides sepulchralis	4	c-g	Bode *et al*., 1996
Mystacides sp.	4	c-g	Bode *et al*., 1996
Nectopsyche sp.	3	shr	Bode *et al*., 1996
Oecetis avara	5	prd	Bode *et al*., 1996
Oecetis cinerascens	5	prd	Bode *et al*., 1996
Oecetis inconspicua	5	prd	Bode *et al*., 1996
Oecetis sp.	5	prd	Bode *et al*., 1996
Setodes sp.	2	c-g	Bode *et al*., 1996
Triaenodes sp.	6	shr	Bode *et al*., 1996
Undetermined Leptoceridae	4	prd	Bode *et al*., 1996
Calamoceratidae	3	--	Hauer & Lamberti, 1996
Sericostomatidae	3	--	Hauer & Lamberti, 1996
LEPIDOPTERA (butterflies and moths)			
Arctiidae			
Estigmene sp.	5	shr	Bode *et al*., 1996
Nepticulidae			
Undetermined Nepticulidae	5	shr	Bode *et al*., 1996
Pyralidae	5	---	Hauer & Lamberti, 1996
Acentria sp.	5	shr	Bode *et al*., 1996
Nymphula sp.	7	shr	Bode *et al*., 1996
Parapoynx sp.	5	shr	Bode *et al*., 1996
Petrophila sp.	5	scr	Bode *et al*., 1996

Undetermined Lepidoptera	5	shr	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (Two-winged or "true flies")			
Tanyderidae			
Protoplasa sp.	3	c-g	Bode *et al*., 2002
Tipulidae (crane flies)	3	---	Hauer & Lamberti, 1996
Antocha sp. 1	3	c-g	Bode *et al*., 1996
Antocha sp. 2	3	c-g	Bode *et al*., 1996
Antocha sp.	3	c-g	Bode *et al*., 1996
Dicranota sp.	3	prd	Bode *et al*., 1996
Helius sp.	4	c-g	Bode *et al*., 1996
Hexatoma sp. 1	2	prd	Bode *et al*., 1996
Hexatoma sp. 2	2	prd	Bode *et al*., 1996
Hexatoma sp.	2	prd	Bode *et al*., 1996
Limnophila sp.	3	prd	Bode *et al*., 2002
Limonia sp.	6	shr	Bode *et al*., 1996
Pedicia sp.	4	prd	Bode *et al*., 2002
Pilaria sp.	7	prd	Bode *et al*., 1996
Pseudolimnophila sp.	2	prd	Bode *et al*., 1996
Tipula sp.	6	shr	Bode *et al*., 1996
Ulomorpha sp.	4	prd	Bode *et al*., 2002
Undetermined Tipulidae	4	shr	Bode *et al*., 1996
Psychodidae (moth flies)	10	---	Hauer & Lamberti, 1996
Pericoma sp.	4	c-g	Bode *et al*., 1996
Psychoda sp.	10	c-g	Bode *et al*., 1996
Undetermined Psychodidae	10	c-g	Bode *et al*., 1996
Ptychopteridae			
Bittacomorpha sp.	9	c-g	Bode *et al*., 1996
Blephariceridae (net-winged midges)	0	---	Hauer & Lamberti, 1996
Undetermined Blephariceridae	0	scr	Bode *et al*., 1996
Dixidae (dixid midges)			
Dixa sp.	1	c-f	Bode *et al*., 1996
Chaoboridae (phantom midges)			
Chaoborus sp.	8	prd	Bode *et al*., 1996
Undetermined Chaoboridae	8	prd	Bode *et al*., 2002

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Culicidae (mosquitoes)			
Undetermined Culicidae	8	c-f	Bode *et al*., 2002
Ceratopogonidae (biting midges, no-see-ums)	6	---	Hauer & Lamberti, 1996
Atrichopogon sp.	6	prd	Bode *et al*., 1996
Bezzia sp. 1	6	prd	Bode *et al*., 1996
Bezzia sp. 2	6	prd	Bode *et al*., 1996
Culicoides? sp.	10	prd	Bode *et al*., 1996
Forcipomyia sp.	6	scr	Bode *et al*., 1996
Probezzia sp. 1	6	prd	Bode *et al*., 1996
Probezzia sp. 2	6	prd	Bode *et al*., 1996
Sphaeromais sp.	6	prd	Bode *et al*., 1996
Undetermined Ceratopogonidae	6	prd	Bode *et al*., 1996
Simuliidae (black flies)	6	---	Hauer & Lamberti, 1996
Cnephia mutata	2	c-f	Bode *et al*., 1996
Prosimulium hirtipes	2	c-f	Bode *et al*., 1996
Prosimulium magnum	1	c-f	Bode *et al*., 1996
Prosimulium rhizophorum	2	c-f	Bode *et al*., 1996
Simulium aureum	7	c-f	Bode *et al*., 1996
Simulium decorum	7	c-f	Bode *et al*., 1996
Simulium fibrinflatum	6	c-f	Bode *et al*., 1996
Simulium gouldingi	3	c-f	Bode *et al*., 1996
Simulium jenningsi	4	c-f	Bode *et al*., 1996
Simulium latipes	4	c-f	Bode *et al*., 1996
Simulium parnassum	7	c-f	Bode *et al*., 1996
Simulium pictipes	4	c-f	Bode *et al*., 1996
Simulium rugglesi	5	c-f	Bode *et al*., 1996
Simulium tuberosum	4	c-f	Bode *et al*., 1996
Simulium venustum	5	c-f	Bode *et al*., 1996
Simulium vittatum	7	c-f	Bode *et al*., 1996
Simulium sp.	5	c-f	Bode *et al*., 1996
Tabanidae (horse and deer flies)	6	---	Hauer & Lamberti, 1996
Chrysops sp.	5	c-g	Bode *et al*., 1996
Tabanus sp.	5	prd	Bode *et al*., 1996

Undetermined Tabanidae	5	prd	Bode *et al.*, 1996

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Athericidae	2	---	Hauer & Lamberti, 1996
Atherix sp.	4	prd	Bode *et al*., 1996
Stratiomyidae (soldier flies)			
Euparyphus sp.	7	c-g	Bode *et al*., 1996
Stratiomys sp.	7	c-g	Bode *et al*., 1996
Undetermined Stratiomyidae	7	c-g	Bode *et al*., 1996
Empididae (dance flies)	6	---	Hauer & Lamberti, 1996
Chelifera sp.	6	prd	Bode *et al*., 1996
Clinocera sp.	6	prd	Bode *et al*., 1996
Hemerodromia sp.	6	prd	Bode *et al*., 1996
Wiedemannia sp.	6	prd	Bode *et al*., 1996
Dolichopodidae	4	---	Hauer & Lamberti, 1996
Undetermined Dolichopodidae	4	prd	Bode *et al*., 1996
Ephydridae (shore flies, brine flies)	6	---	Hauer & Lamberti, 1996
Dimecoenia spinosa	6	shr	Bode *et al*., 1996
Hydrellia sp.	6	shr	Bode *et al*., 1996
Muscidae	6	---	Hauer & Lamberti, 1996
Undetermined Muscidae	6	prd	Bode *et al*., 1996
Anthomyiidae (root maggot flies)			
Undetermined Anthomyiidae	6	prd	Bode *et al*., 1996
Scathophagidae (dung flies)			
Undetermined Scathophagidae	6	shr	Bode *et al*., 1996
Syrphidae	10	---	Hauer & Lamberti, 1996

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Chironomidae (non-biting or true midges)			
Subfamily Tanypodinae			
Ablabesmyia annulata	8	prd	Bode *et al*., 1996
Ablabesmyia idei	8	prd	Bode *et al*., 2002
Ablabesmyia janta	8	prd	Bode *et al*., 2002
Ablabesmyia mallochi	8	prd	Bode *et al*., 1996
Ablabesmyia monilis	8	prd	Bode *et al*., 1996
Ablabesmyia peleensis	8	prd	Bode *et al*., 1996
Ablabesmyia philosphagnos	8	prd	Bode *et al*., 1996
Ablabesmyia simpsoni	8	prd	Bode *et al*., 1996
Ablabesmyia sp.	8	prd	Bode *et al*., 1996
Alotanypus aris	9	prd	Bode *et al*., 2002
Apsectrotanypus johnsoni	7	prd	Bode *et al*., 2002
Clinotanypus pinguis	8	prd	Bode *et al*., 1996
Clinotanypus sp.	8	prd	Bode *et al*., 2002
Coelotanypus scapularis	4	prd	Bode *et al*., 1996
Coelotanypus sp.	4	prd	Bode *et al*., 1996
Conchapelopia aleta	6	prd	Bode *et al*., 1996
Conchapelopia dusena	6	prd	Bode *et al*., 1996
Conchapelopia goniodes	6	prd	Bode *et al*., 1996
Conchapelopia rurika	6	prd	Bode *et al*., 1996
Conchapelopia telema	6	prd	Bode *et al*., 1996
Conchapelopia sp.	6	prd	Bode *et al*., 1996
Guttipelopia guttipennis	5	prd	Bode *et al*., 1996
Hayesomyia senata	6	prd	Bode *et al*., 1996
Helopelopia cornuticaudata	6	prd	Bode *et al*., 1996
Hudsonimyia karelena	2	prd	Bode *et al*., 1996
Hudsonimyia parrishi	2	prd	Bode *et al*., 1996
Krenopelopia sp.	4	prd	Bode *et al*., 2002
Labrundinia pilosella	7	prd	Bode *et al*., 1996
Labrundinia nr. Virescens	7	prd	Bode *et al*., 1996
Labrundinia sp.	7	prd	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Chironomidae (contd.)			
Subfamily Tanypodinae (contd.)			
Larsia canadensis	6	prd	Bode *et al*., 1996
Larsia sp.	6	prd	Bode *et al*., 2002
Macropelopia decedens	9	prd	Bode *et al*., 2002
Meropelopia americana	6	prd	Bode *et al*., 2002
Meropelopia flavifrons	6	prd	Bode *et al*., 2002
Natarsia baltimorea	8	prd	Bode *et al*., 2002
Natarsia sp. A	8	prd	Bode *et al*., 1996
Natarsia sp.	8	prd	Bode *et al*., 2002
Nilotanypus fimbriatus	8	prd	Bode *et al*., 1996
Nilotanypus sp.	6	prd	Bode *et al*., 1996
Paramerina sp.	6	prd	Bode *et al*., 1996
Pentaneura inconspicua	6	prd	Bode *et al*., 2002
Pentaneura sp.	6	prd	Bode *et al*., 1996
Procladius bellus	9	prd	Bode *et al*., 1996
Procladius sublettei	9	prd	Bode *et al*., 1996
Procladius sp.	9	prd	Bode *et al*., 1996
Psectrotanypus dyari	10	prd	Bode *et al*., 1996
Psectrotanypus sp.	10	prd	Bode *et al*., 1996
Rheopelopia acra gr.	4	prd	Bode *et al*., 2002
Rheopelopia sp. 2	4	prd	Bode *et al*., 2002
Rheopelopia sp. 3	4	prd	Bode *et al*., 2002
Rheopelopia sp.	4	prd	Bode *et al*., 2002
Tanypus neopunctipennis	10	prd	Bode *et al*., 2002
Tanypus punctipennis	10	prd	Bode *et al*., 1996
Tanypus stellatus	10	prd	Bode *et al*., 1996
Tanypus sp.	10	prd	Bode *et al*., 2002
Telopelopia okoboji	8	prd	Bode *et al*., 1996
Thienemannimyia gr. spp.	6	prd	Bode *et al*., 1996
Thienemannimyia norena	6	prd	Bode *et al*., 1996
Trissopelopia ogemawi	4	prd	Bode *et al*., 1996
Zavrelimyia sinuosa	8	prd	Bode *et al*., 1996
Zavrelimyia sp.	8	prd	Bode *et al*., 1996
Undetermined Tanypodinae	7	prd	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Chironomidae (contd.)			
Subfamily Podonominae			
Paraboreochlus sp.	1	c-g	Bode *et al*., 1996
Subfamily Diamesinae			
Diamesa sp.	5	c-g	Bode *et al*., 1996
Pagastia orthogonia	1	c-g	Bode *et al*., 2002
Potthastia gaedii gr.	2	c-g	Bode *et al*., 2002
Potthastia longimana gr.	2	c-g	Bode *et al*., 2002
Pseudokiefferiella sp.	1	c-g	Bode *et al*., 1996
Sympotthastia sp.	2	c-g	Bode *et al*., 1996
Undetermined Diamesinae	2	c-g	Bode *et al*., 1996
Subfamily Prodiamesinae			
Monodiamesa sp.	7	c-g	Bode *et al*., 2002
Odontomesa sp.	5	c-g	Bode *et al*., 2002
Prodiamesa olivacea	8	c-g	Bode *et al*., 2002
Prodiamesa sp. 2	8	c-g	Bode *et al*., 2002

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Chironomidae (contd.)			
Subfamily Orthocladiinae			
Acricotopus nitidellus.	10	c-g	Bode *et al*., 2002
Brillia flavifrons	5	shr	Bode *et al*., 1996
Brillia parva	5	shr	Bode *et al*., 1996
Brillia sera	5	shr	Bode *et al*., 1996
Brillia sp.	5	shr	Bode *et al*., 1996
Cardiocladius albiplumus	5	prd	Bode *et al*., 1996
Cardiocladius obscurus	5	prd	Bode *et al*., 1996
Cardiocladius sp.	5	prd	Bode *et al*., 2002
Chaetocladius vitellinus gr.	6	c-g	Bode *et al*., 1996
Chaetocladius sp.	6	c-g	Bode *et al*., 2002
Corynoneura nr. celeripes	4	c-g	Bode *et al*., 2002
Corynoneura lobata	4	c-g	Bode *et al*., 2002
Corynoneura sp.	4	c-g	Bode *et al*., 1996
Cricotopus absurdus	5	shr	Bode *et al*., 2002
Cricotopus bicinctus	7	scr	Bode *et al*., 1996
Cricotopus nr. cylindraceus	7	shr	Bode *et al*., 1996
Cricotopus elegans	7	shr	Bode *et al*., 1996
Cricotopus festivellus gr.	7	c-g	Bode *et al*., 1996
Cricotopus intersectus gr.	7	shr	Bode *et al*., 1996
Cricotopus nostocicola	7	shr	Bode *et al*., 1996
Cricotopus sylvestris gr.	7	scr	Bode *et al*., 1996
Cricotopus tremulus gr.	7	shr	Bode *et al*., 1996
Cricotopus triannulatus	7	shr	Bode *et al*., 1996
Cricotopus trifascia gr.	6	shr	Bode *et al*., 1996
Cricotopus vierriensis	7	shr	Bode *et al*., 1996
Cricotopus sp.	7	shr	Bode *et al*., 2002
Diplocladius cultriger	8	c-g	Bode *et al*., 2002
Epoicocladius sp.	4	c-g	Bode *et al*., 1996
Eukiefferiella brehmi gr.	4	c-g	Bode *et al*., 1996
Eukiefferiella brevicalcar gr.	4	c-g	Bode *et al*., 1996
Eukiefferiella claripennis gr.	8	c-g	Bode *et al*., 1996
Eukiefferiella coerulescens gr.	4	c-g	Bode *et al*., 1996
Eukiefferiella devonica gr.	4	c-g	Bode *et al*., 1996
Eukiefferiella gracei gr.	4	c-g	Bode *et al*., 1996

Eukiefferiella pseudomontana gr.	8	c-g	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Chironomidae (contd.)			
Subfamily Orthocladiinae (contd.)			
Gymnometriocnemus sp.	4	c-g	Bode *et al*., 2002
Heterotrissocladius marcidus gr.	4	c-g	Bode *et al*., 1996
Heterotrissocladius sp.	4	c-g	Bode *et al*., 2002
Hydrobaenus pilipes	8	c-g	Bode *et al*., 1996
Krenosmittia sp.	1	c-g	Bode *et al*., 1996
Limnophyes sp.	8	c-g	Bode *et al*., 1996
Lopescladius sp.	4	c-g	Bode *et al*., 1996
Nanocladius (Plecopt.) branchicolus	3	prd	Bode *et al*., 2002
Nanocladius (Plecopt.) downesi	3	prd	Bode *et al*., 2002
Nanocladius (Plecopt.) sp.	3	prd	Bode *et al*., 2002
Nanocladius alternantherae?	7	c-g	Bode *et al*., 1996
Nanocladius nr. Balticus	7	c-g	Bode *et al*., 1996
Nanocladius crassicornus	7	c-g	Bode *et al*., 1996
Nanocladius distinctus	7	c-g	Bode *et al*., 1996
Nanocladius minimus	7	c-g	Bode *et al*., 1996
Nanocladius rectinervis	7	c-g	Bode *et al*., 1996
Nanocladius spiniplenus	6	c-g	Bode *et al*., 1996
Nanocladius sp.	7	c-g	Bode *et al*., 1996
Orthocladius (Eudactylocladius) sp.	6	c-g	Bode *et al*., 1996
Orthocladius (Euortho.) luteipes	6	c-g	Bode *et al*., 2002
Orthocladius (Euortho.) rivicola	6	c-g	Bode *et al*., 2002
Orthocladius (Euortho.) rivulorum	6	c-g	Bode *et al*., 2002
Orthocladius (Euorthoclad.) sp.	6	c-g	Bode *et al*., 2002
Orthocladius annectens	6	c-g	Bode *et al*., 1996
Orthocladius carlatus	6	c-g	Bode *et al*., 1996
Orthocladius curtiseta	6	c-g	Bode *et al*., 1996
Orthocladius nr. dentifer	6	c-g	Bode *et al*., 1996
Orthocladius obumbratus	6	c-g	Bode *et al*., 1996
Orthocladius nr. robacki	6	c-g	Bode *et al*., 1996
Orthocladius trigonolabis	6	c-g	Bode *et al*., 1996

Taxa	Tolerance	Feedin g Habit	Reference
DIPTERA (contd.)			
Chironomidae (contd.)			
Subfamily Orthocladiinae (contd.)			
Orthocladius (Symposio) lignicola	5	c-g	Bode *et al*., 2002
Orthocladius sp.	6	c-g	Bode *et al*., 1996
Parachaetocladius sp.	2	c-g	Bode *et al*., 1996
Paracricotopus sp.	4	c-g	Bode *et al*., 1996
Parakiefferiella triquetra gr.	4	c-g	Bode *et al*., 1996
Parakiefferiella sp.	4	c-g	Bode *et al*., 1996
Paralimnophyes sp.	7	c-g	Bode *et al*., 1996
Parametriocnemus lundbecki	5	c-g	Bode *et al*., 1996
Parametriocnemus sp.	5	c-g	Bode *et al*., 2002
Paraphaenocladius sp.	4	c-g	Bode *et al*., 1996
Paratrichocladius sp.	5	shr	Bode *et al*., 1996
Psectrocladius nigrus	8	c-g	Bode *et al*., 1996
Psectrocladius psilopterus gr.	8	c-g	Bode *et al*., 1996
Psectrocladius sordidellus gr.	8	c-g	Bode *et al*., 1996
Psectrocladius vernalis	8	c-g	Bode *et al*., 1996
Psectrocladius sp.	8	c-g	Bode *et al*., 1996
Pseudorthocladius sp.	0	c-g	Bode *et al*., 1996
Psilometriocnemus triannulatus	4	c-g	Bode *et al*., 2002
Rheocricotopus robacki	5	c-g	Bode *et al*., 1996
Rheocricotopus tuberculatus	6	c-g	Bode *et al*., 1996
Rheocricotopus sp. 2	6	c-g	Bode *et al*., 1996
Rheocricotopus sp. 4	6	c-g	Bode *et al*., 1996
Rheocricotopus sp.	6	c-g	Bode *et al*., 2002
Smittia sp.	6	c-g	Bode *et al*., 2002
Stilocladius sp.	3	c-g	Bode *et al*., 1996
Symbiocladius equitans	2	prd	Bode *et al*., 2002
Synorthocladius nr. semivirens	6	c-g	Bode *et al*., 1996
Thienemanniella lobapodema	6	c-g	Bode *et al*., 2002
Thienemanniella xena	6	c-g	Bode *et al*., 2002
Thienemanniella sp.	6	c-g	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Chironomidae (contd.)			
Subfamily Orthocladiinae (contd.)			
Trissocladius sp.	5	c-g	Bode *et al*., 1996
(*Trissocladius* lakes- these become stratified, but are of inconsistent trophic status, Williams & Feltmate, 1992)			
Tvetenia bavarica gr.	4	c-g	Bode *et al*., 1996
Tvetenia vitracies	5	c-g	Bode *et al*., 1996
Tvetenia sp.	5	c-g	Bode *et al*., 2002
Unniella multivirga	4	c-g	Bode *et al*., 1996
Zalutschia zalutschicola	4	shr	Bode *et al*., 1996
Orthocladiinae sp. C	5	c-g	Bode *et al*., 2002
Undetermined Orthocladiinae	5	c-g	Bode *et al*., 2002

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Chironomidae (contd.)			
Subfamily Chironominae			
Blood-red Chironomidae-Tribe Chironomini	8	---	(Hauer & Lamberti, 1996)

Profundal Chironomid Fauna (Williams & Feltmate, 1992):

- Mesotrophic (Lake Type II/III): *Chironomus* lakes- these have oxygen curves typical of lakes of intermediate nutrient content, and characteristically support species of *Chironomus* that lack ventral abdominal gills. *Chironomus atritibia* and *Sergentia coracina* lakes in North america, and *Stictochironomus rosenschoeldi* and *Sergentia coracina* lakes in Europe.

- Eutrophic (Lake Type III): *Chironomus* lakes- these are usually shallow and turbid, and have, in general, oxygen curves characteristic of eutrophic (nutrient-rich) lakes. They are dominated by species of *Chironomus* (Subfamily Chironominae: Tribe Chironomini) in which the larvae typically have two pairs of ventral abdominal gills. *Chaoborus* is often present in open water.
  - Moderately eutrophic: *Chironomus decorus* lakes in North America, and *C. anthracinus* lakes in Europe.
  - Strongly eutrophic: *Chironomus plumosus* in North America as well as in Europe.

- Dystrophic (Lake Type IV): these also have variable amounts of nutrients, but they are always high in humic compounds which colour the water brown. They tend to be shallow but can experience oxygen deficiencies in deeper parts. *Chironomus* sp. lakes (with *Zalutschia zalutschicola*) in North America, and *Chironomus tenuistylus* lakes (with *Zalutschia zalutschicola*) in Europe. *Chaoborus* are often present but their densities are low.

Taxa	Tolerance	Feeding Habit	Reference
Axarus festivus gr.	6	c-g	Bode *et al*., 1996
Chironomus decorus gr.	10	c-g	Bode *et al*., 1996
Chironomus riparius gr.	10	c-g	Bode *et al*., 1996
Chironomus sp.	10	c-g	Bode *et al*., 1996
Cladopelma sp.	9	c-g	Bode *et al*., 1996
Cryptochironomus fulvus gr.	8	prd	Bode *et al*., 1996
Cryptochironomus ponderosus	8	prd	Bode *et al*., 1996
Cryptochironomus sp.	8	prd	Bode *et al*., 1996
Cryptotendipes casuarius	6	c-g	Bode *et al*., 1996
Cryptotendipes emorsus	6	c-g	Bode *et al*., 1996
Cryptotendipes pseudotener	6	c-g	Bode *et al*., 1996
Cryptotendipes sp.	6	c-g	Bode *et al*., 1996
Demicryptochironomus cuneatus	8	c-g	Bode *et al*., 1996
Demicryptochironomus sp. 3	8	c-g	Bode *et al*., 1996

Demicryptochironomus sp.	8	c-g	Bode *et al.*, 2002

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Chironomidae (contd.)			
Subfamily Chironominae (contd.)			
Dicrotendipes fumidus	8	c-g	Bode *et al*., 1996
Dicrotendipes lucifer	8	c-g	Bode *et al*., 1996
Dicrotendipes modestus	8	c-g	Bode *et al*., 1996
Dicrotendipes neomodestus	8	c-g	Bode *et al*., 1996
Dicrotendipes nervosus	8	c-g	Bode *et al*., 1996
Dicrotendipes simpsoni	8	c-g	Bode *et al*., 1996
Einfeldia natchitocheae	9	c-g	Bode *et al*., 2002
Einfeldia sp.	9	c-g	Bode *et al*., 1996
Endochironomus nigricans	10	shr	Bode *et al*., 1996
Endochironomus subtendens	10	shr	Bode *et al*., 1996
Endochironomus sp.	10	shr	Bode *et al*., 1996
Glyptotendipes dreisbachi	10	shr	Bode *et al*., 2002
Glyptotendipes lobiferus	10	shr	Bode *et al*., 1996
Glyptotendipes sp. 2	10	shr	Bode *et al*., 1996
Glyptotendipes sp.	10	shr	Bode *et al*., 1996
Goeldichironomus sp.	8	c-g	Bode *et al*., 1996
Harnischia curtilamellata	8	c-g	Bode *et al*., 1996
Lauterborniella agrayloides	8	c-g	Bode *et al*., 1996
Microchironomus sp.	8	c-g	Bode *et al*., 1996
Microtendipes pedellus gr.	6	c-f	Bode *et al*., 2002
Microtendipes rydalensis gr.	4	c-f	Bode *et al*., 1996
Nilothauma babiyi	6	c-g	Bode *et al*., 1996
Nilothauma sp.	6	c-g	Bode *et al*., 1996
Pagastiella sp.	7	c-g	Bode *et al*., 2002
Parachironomus abortivus	10	prd	Bode *et al*., 1996
Parachironomus carinatus	10	prd	Bode *et al*., 1996
Parachironomus frequens	10	prd	Bode *et al*., 1996
Parachironomus hirtalatus	10	prd	Bode *et al*., 1996
Parachironomus sp.	10	prd	Bode *et al*., 1996
Paracladopelma nais	7	c-g	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Chironomidae (contd.)			
Subfamily Chironominae (contd.)			
Paracladopelma nereis	7	c-g	Bode *et al*., 1996
Paralauterborniella nigrohalteralis	8	c-g	Bode *et al*., 1996
Paralauterborniella sp.	8	c-g	Bode *et al*., 1996
Paratendipes albimanus	6	c-g	Bode *et al*., 1996
Paratendipes sp.	6	c-g	Bode *et al*., 1996
Phaenopsectra dyari?	7	scr	Bode *et al*., 1996
Phaenopsectra flavipes	7	scr	Bode *et al*., 1996
Phaenopsectra sp.	7	scr	Bode *et al*., 1996
Polypedilum aviceps	4	shr	Bode *et al*., 1996
Polypedilum digitifer	8	shr	Bode *et al*., 1996
Polypedilum fallax gr.	6	shr	Bode *et al*., 1996
Polypedilum flavum	6	shr	Bode *et al*., 2002
Polypedilum griseopunctatum	6	shr	Bode *et al*., 1996
Polypedilum halterale gr.	6	shr	Bode *et al*., 2002
Polypedilum illinoense	7	shr	Bode *et al*., 2002
Polypedilum laetum	6	shr	Bode *et al*., 1996
Polypedilum obtusum	6	shr	Bode *et al*., 1996
Polypedilum scalaenum gr.	6	shr	Bode *et al*., 1996
Polypedilum simulans gr.	6	shr	Bode *et al*., 1996
Polypedilum sordens	6	shr	Bode *et al*., 1996
Polypedilum tuberculum	6	shr	Bode *et al*., 1996
Polypedilum (Tripodura) sp.	6	shr	Bode *et al*., 1996
Polypedilum sp.	6	shr	Bode *et al*., 2002
Pseudochironomus sp. 1	5	c-g	Bode *et al*., 1996
Pseudochironomus sp. 2	5	c-g	Bode *et al*., 1996
Pseudochironomus sp. 3	5	c-g	Bode *et al*., 1996
Pseudochironomus sp.	5	c-g	Bode *et al*., 1996
Robackia claviger	4	c-g	Bode *et al*., 2002
Saetheria tylus	4	c-g	Bode *et al*., 1996
Saetheria sp.	4	c-g	Bode *et al*., 1996
Sergentia? sp.	5	c-g	Bode *et al*., 1996
Stelechomyia perpulchra	7	c-g	Bode *et al*., 2002
Stenochironomus hilaris	5	c-g	Bode *et al*., 1996
Stenochironomus macateei	5	c-g	Bode *et al*., 1996

Stenochironomus poecilopterus	5	c-g	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Chironomidae (contd.)			
Subfamily Chironominae (contd.)			
Stenochironomus sp.	5	c-g	Bode *et al*., 1996
Stictochironomus sp.	9	c-g	Bode *et al*., 1996
Tribelos atrum	7	c-g	Bode *et al*., 1996
Tribelos fuscicorne	7	c-g	Bode *et al*., 1996
Tribelos jucundum	7	c-g	Bode *et al*., 1996
Tribelos sp.	7	c-g	Bode *et al*., 1996
Xenochironomus xenolabis	4	prd	Bode *et al*., 2002
Undetermined Chironomini	6	c-g	Bode *et al*., 1996

Profundal Chironomid Fauna (Williams & Feltmate, 1992):

- Oligotrophic (Lake Type II): *Tanytarsus* sp. (Subfamily Chironominae: Tribe Tanytarsini) lakes (with *Monodiamesa tuberculata* and *Heterotrissocladius changi*) in North America, and *Tanytarsus lugens* lakes (with *Heterotrissocladius grimshawi* or *H. scutellatus*) in Europe- these are usually deep lakes which never lack oxygen in deep water. *Chaoborus* tends to be absent).

Taxa	Tolerance	Feeding Habit	Reference
Cladotanytarsus nr. dispersopilosus	5	c-f	Bode *et al*., 1996
Cladotanytarsus nr. mancus	5	c-f	Bode *et al*., 1996
Cladotanytarsus sp. 2	5	c-f	Bode *et al*., 1996
Cladotanytarsus sp. 4	5	c-f	Bode *et al*., 1996
Cladotanytarsus sp.	5	c-f	Bode *et al*., 1996
Constempellina sp. 1	4	c-g	Bode *et al*., 1996
Constempellina sp. 2	4	c-g	Bode *et al*., 1996
Micropsectra aristata gr.	5	c-f	Bode *et al*., 2002
Micropsectra deflecta	4	c-f	Bode *et al*., 2002
Micropsectra dives gr.	4	c-f	Bode *et al*., 2002
Micropsectra notescens gr.	7	c-f	Bode *et al*., 2002
Micropsectra polita	7	c-f	Bode *et al*., 2002
Micropsectra sp.	7	c-f	Bode *et al*., 2002
Paratanytarsus confusus	6	c-f	Bode *et al*., 1996
Paratanytarsus dimorphis	6	c-f	Bode *et al*., 1996

Taxa	Tolerance	Feeding Habit	Reference
DIPTERA (contd.)			
Chironomidae (contd.)			
Subfamily Chironominae (contd.)			
Paratanytarsus sp.	6	c-f	Bode *et al*., 1996
Rheotanytarsus exiguus gr.	6	c-f	Bode *et al*., 1996
Rheotanytarsus pellucidus	4	c-f	Bode *et al*., 2002
Rheotanytarsus sp.	6	c-f	Bode *et al*., 1996
Stempellina nr. bausei	2	c-g	Bode *et al*., 1996
Stempellina johannseni	2	c-g	Bode *et al*., 1996
Stempellina nr. subglabripennis	2	c-g	Bode *et al*., 1996
Stempellina sp. 1	2	c-g	Bode *et al*., 1996
Stempellina sp. 4	2	c-g	Bode *et al*., 1996
Stempellina sp. 5	2	c-g	Bode *et al*., 1996
Stempellina sp.	2	c-g	Bode *et al*., 1996
Stempellinella sp. 1	4	c-g	Bode *et al*., 1996
Stempellinella sp. 2	4	c-g	Bode *et al*., 1996
Stempellinella sp. 3	4	c-g	Bode *et al*., 1996
Stempellinella sp.	4	c-g	Bode *et al*., 1996
Sublettea coffmani	4	c-f	Bode *et al*., 1996
Tanytarsus brundini	6	c-f	Bode *et al*., 1996
Tanytarsus eminulus gr.	6	c-f	Bode *et al*., 1996
Tanytarsus glabrescens gr.	6	c-f	Bode *et al*., 1996
Tanytarsus guerlus gr.	6	c-f	Bode *et al*., 1996
Tanytarsus sp.	6	c-f	Bode *et al*., 1996
Zavrelia sp.	4	c-f	Bode *et al*., 1996
Undetermined Tanytarsini	6	c-f	Bode *et al*., 1996
Undetermined Chironominae	6	c-g	Bode *et al*., 1996

Appendix B

Table-5: Average Score Per Taxon (ASPT)

Armitage *et al.* (1983); Friedrich *et al.* (1996); Hynes (1998); Mackie (2001)

The Average Score Per Taxon (ASPT) represents the average tolerance score of all taxa within the community, and is calculated by dividing the BMWP (Table-6 overleaf) by the number of families represented in the sample. Also *cf*. Chapter III, (e), pg. 24 this report.

ASTP value	Water Quality Assessment
>6	Clean Water
5-6	Doubtful quality
4-5	Probable moderate pollution
<4	Probable severe pollution

Table-6: Pollution sensitivity grades for families (higher levels in a few cases) of river macroinvertebrates for SIGNAL (S) and BMWP (B) scores.

Families not occurring in North America have been omitted. N represents families found in N. America and are graded according to the inverse of Bode *et al*. (1991) and Plafkin *et al*. (1989) tolerance values to correspond to SIGNAL and BMWP scores (modified from Mackie, 2001)

The Biological Monitoring Working Party score (BMWP) provides single values, at the family level, representative of the organisms' tolerance to pollution. The greater their tolerance towards pollution, the lower the BMWP score. Also *cf*. Chapter III, (d), pg. 24 this report.

Family	Grade			Family	Grade			Family	Grade		
	N	B	S		N	B	S		N	B	S
Acariformes	6	-	-	Gammaridae	4	6	6	Peltoperlidae	9	-	-
Aeolosomatidae	2	-	-	Gerridae	5	5	4	Perlidae	8	10	10
Aeshnidae	6	8	6	Glossiphoniidae	3	3	3	Perlodidae	8	10	-
Agrionidae	4	8	-	Glossosomatidae	10	-	8	Philopotamidae	7	8	10
Ancylidae	4	6	6	Gomphidae	6	8	7	Phryganeidae	7	-	-
Anthomyiidae	4	-	-	Gordiidae	8	10	7	Physidae	2	3	3
Anthuridae	4	-	-	Gyrinidae	5	5	5	Piscicolidae	5	4	-
Asellidae	2	3	-	Haliplidae	5	5	5	Planariidae	4	5	3
Arctiidae	5	-	-	Haplotaxidae	1	1	5	Planorbidae	3	3	3
Arrenuridae	4	-	-	Helicopsychidae	7	-	10	Platyhelminthidae	6	-	-
Astacidae	4	8	-	Helodidae	5	5	-	Pleidae	5	5	-
Athericidae	6	-	7	Heptageniidae	7	10	-	Pleuroceridae	4	-	-
Atractideidae	4	-	-	Hirudinea	0	-	-	Polycentropodidae	4	7	8
Baetidae	5	4	5	Hyalellidae	2	-	-	Polychaeta	4?	-	-
Baetiscidae	6	-	-	Hydridae	5	-	4	Polymetarcyidae	8	-	-
Belostomatidae	5	-	5	Hydrobiidae	4	3	5	Potamanthidae	6	10	-
Blephariceridae	10	-	10	Hydrometridae	5	5	5	Psephenidae	6	-	5
Branchiobdellidae	4	-	-	Hydrophilidae	5	5	5	Psychodidae	8	8	2
Brachycentridae	9	10	-	Hydropsychidae	6	5	5	Psychomyiidae	8	8	-
Caenidae	5	7	-	Hydroptilidae	5	6	6	Pteronarcidae	10	-	-
Calopterygidae	4	-	-	Hygrobiidae	5	5	5	Ptychopteridae	1	-	-
Capniidae	8	10	-	Idoteidae	5	-	-	Pyralidae	5	-	6
Ceratopogonidae	4	-	6	Isotomidae	5	-	-	Rhyacophilidae	9	-	7
Chaoboridae	2	-	-	Lebertiidae	4	-	-	Sabellidae	4	-	-
Chironomidae	1	2	1	Lepidostomatidae	10	10	-	Scirtidae	5	5	8

(Table-6 continued)

Family	Grade			Family	Grade			Family	Grade		
	N	B	S		N	B	S		N	B	S
Chloroperlidae	10	10	-	Leptoceridae	6	10	7	Sialidae	6	4	4
Chrysomelidae	5	5	-	Leptophlebiidae	7	10	10	Simuliidae	5	-	5
Coenagrionidae	2	6	7	Lestidae	1	-	7	Siphlonuridae	8	10	-
Collembola	5?	-	-	Leuctridae	10	10	-	Sphaeriidae	4	3	6
Corbiculidae	4	-	6	Libellulidae	8	8	8	Spurchonidae	4	-	-
Corduliidae	7	8	7	Limnephilidae	7	7	8	Sisyridae	5	-	-
Cordulegasteridae	7	8	-	Limnesidae	4	-	-	Tabanidae	5	-	5
Corixidae	5	5	5	Limnocharidae	4	-	-	Taeniopterygidae	8	10	-
Corydalidae	6	-	4	Lumbriculidae	2	1	1	Talitridae	2	-	-
Culicidae	1	-	2	Lymnaeidae	4	3	-	Thiaridae	6	-	7
Dixidae	10	-	8	Mesoveliidae	5	5	4	Tipulidae	7	5	5
Dolichopodidae	6	-	-	Mideopsidae	4	-	-	Tricorythidae	6	-	-
Dreissenidae	2	-	-	Molannidae	4	10	-	Tubificidae	1	1	1
Dryopidae	5	5	-	Muscidae	4	-	3	Tyrellidae	4	-	-
Dytiscidae	5	5	5	Naididae	3	1	1	Unionidae	4	6	-
Elmidae	5	5	7	Nemouridae	8	7	-	Unionicolidae	4	-	-
Empididae	4	-	4	Nepidae	5	5	-	Valvatidae	2	3	-
Enchytreidae	1	1	-	Nepticulidae	5	-	-	Veliidae	5	-	4
Ephemerellidae	10	10	-	Notonectidae	5	5	4	Viviparidae	4	6	-
Ephemeridae	8	10	-	Odontoceridae	10	10	8				
Ephydridae	4	-	2	Oedicerotidae	4	-	-				
Erpobdellidae	3	3	3	Oligochaeta	2	-	-				

Note: The grades under (N) above should be used in the said indices (there is some question as regards the grades of the taxa which have been noted along with a `?')