Biotic Indices of the Littoral Benthic Community from the Bay of Quinte, eastern Lake Ontario

R. Dermott [1] and A. Pachkevitch [2]

[1] Fisheries and Oceans Canada
Great Lakes Lab for Fisheries and Aquatic Sciences
PO Box 5050, 867 Lakeshore Road
Burlington, ON L7R 4A6

[2] 850 Sweetwater Crescent, Mississauga, ON L5H 4A8

2012

Canadian Manuscript Report of Fisheries and Aquatic Sciences 2996

Fisheries and Oceans Canada **Pêches et Océans Canada**

Canadian Manuscript Report of
Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 901-1425 were issued as Manuscript Reports of the Fisheries Research Board of Canada. Numbers 1426-1550 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport manuscrit canadien des
sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministére des Pêches et des Océans, e'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications complète. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports manuscrits sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques,* et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 900 de cette série ont été publiés à titre de manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Les rapports manuscrits sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 2996

2012

Biotic Indices of the Littoral Benthic Community from the Bay of Quinte, eastern Lake Ontario

by

Ron Dermott [1] and Alexei Pachkevitch [2]

Fisheries and Oceans Canada
Great Lakes Laboratory for Fisheries and Aquatic Sciences
PO Box 5050, 867 Lakeshore Road
Burlington, Ontario L7R 4A6

Cat. No Fs 97-4/2996 ISSN 0706-6473

Correct citation for this publication:

Dermott, R. and Pachkevitch, A. 2012. Biotic indices of the littoral benthic community from the Bay of Quinte, eastern Lake Ontario. Can. Manuscr. Rep. Fish. Aquat. Sci. 2996: vi + 33 pp.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES con't

LIST OF APPENDICES

ABSTRACT

Dermott, R. and Pachkevitch, A. 2012. Biotic indices of the littoral benthic community for the Bay of Quinte, eastern Lake Ontario. Can. Manuscr. Rep. Fish Aquat. Sci. 2996: vi + 33 pp.

The littoral benthic community was sampled on soft sediments at 2 m depth and on cobble at <1 m in both the Upper Bay of Quinte (Trenton to North Port) and Lower Bay (Glenora to Amherst Island) during transect surveys done in 1966 and between 1988 and 2001. The cobble in the Upper Bay near Trenton supported a littoral community very similar to that on cobble in the Lower Bay, with a large biomass of fluvial species and presence of several species indicative of high water quality. Two biotic indices developed for hard substrates in streams were used to analyse the data from rocky substrates. The results indicated an expected gradation of water quality increasing from the Upper Bay to exposed Amherst Island, with very high index values also present at Massasauga Point near Belleville. Scores for the BioMAP and IOWA MBI indices indicated the area between Trenton and Big Bay had a community similar to that found in rivers with slight pollution. The littoral community in the Lower Bay was comparable to that on the shores of southeast Georgian Bay. The Lake Biotic Index (LBI), developed to compare the littoral community on soft sediments with the community inhabiting the deeper areas, was calculated for various parts of the bay. Results showed there was a slight reduction in community taxon richness between the littoral and deeper zones for the Trenton area and Lower Bay during 1966. There was less of a bathymetric decrease in faunal richness at Big Bay in 1966. The MBI and LBI indices found no evidence of an impaired benthic community in the Bay of Quinte during 1990 or 2001 when compared to other lakes.

RÉSUMÉ

Dermott, R. et Pachkevitch, A. 2012. Indices biotiques de la communauté benthique littorale de la baie de Quinte, lac Ontario Est. Rapp. Man. Can. Sci. Halieut. Aquat. 2996: vi + 33 pp.

On a prélevé des échantillons de la communauté benthique littorale sur les sédiments meubles, à deux mètres de profondeur, et sur les cailloux, à moins de 1 mètre, dans la partie supérieure de la baie de Quinte (de Trenton à North Port) et la partie inférieure de la baie (de Glenora à l'île Amherst) lors de relevés par échantillonnage en transect effectués en 1966 et entre 1988 et 2001. Les cailloux dans la partie supérieure de la baie près de Trenton abritaient une communauté benthique très semblable à celle que l'on a retrouvée sur les cailloux dans la partie inférieure de la baie, une grande biomasse d'espèces fluviales et la présence de plusieurs espèces indiquant une haute qualité de l'eau. Deux indices biotiques développés pour les substrats durs dans les cours d'eau ont été utilisés sur les données provenant de substrats rocheux. Les résultats ont indiqué une gradation attendue de la qualité de l'eau depuis la partie supérieure de la baie jusqu'à l'île d'Amherst exposée, ainsi que la présence de valeurs-indices très élevées à la pointe Massasauga près de Belleville. Les résultats des indices BioMAP et IOWA MBI ont révélé que la zone entre Trenton et Big Bay abritait une communauté semblable à celle que l'on s'attend de trouver dans les rivières légèrement polluées. La communauté littorale dans la partie inférieure de la baie était comparable à celle sur les rives du sud-est de la baie Georgienne. L'indice biotique lacustre (IBL), développé pour comparer la communauté littorale sur des sédiments meubles habitant les zones plus profondes, a été calculé pour diverses parties de la baie. Les résultats ont indiqué une légère réduction de la richesse taxonomique de la communauté entre le littoral et les zones plus profondes pour la région de Trenton et la partie inférieure de la baie durant l'année 1966. On a observé une diminution bathymétrique moins importante dans la richesse faunique à Big Bay en 1966. Les indices MBI et IBL n'ont révélé aucun signe de détérioration de la communauté benthique dans la baie Quinte durant 1990 ou 2001 comparativement aux autres lacs.

INTRODUCTION

Biomonitoring aquatic environments using their benthic communities developed from the concept of the saprobic Index of Kolkwiz and Marsson (1909) and Sladecek (1973). The habitat and oxygen requirements of organisms coupled with their pollution tolerances cause different species to be common in various environmental conditions. The presence of more sensitive invertebrates permits the rapid biological quality assessment of watercourses (De Pauw and Vanhooren 1983). The concept of indicator communities has been developed into a variety of biotic indices such as the E.P.T. taxa richness (Ephemeroptera - mayflies; Plecoptera - stoneflies; and Trichoptera - caddisflies), which is used to assess stream quality based on easy identification of those insect orders, their perceived intolerance to disturbance, or poor water quality (Lenet 1988). Similar indices include Saether's (1979) Chironomid Classification, Milbrink's Oligochaete Index (Milbrink 1983) and Hilsenhoff's (1988) Family Biotic Index for stream communities. These indices deal mainly with organic pollution or eutrophication.

Biotic indices, based on measured multimetric variables, have been developed from the Index of Biotic Integrity (IBI) approach of Karr (1981) used originally to assess fish communities. Biotic indices produce a score according to the tolerances of the species present, usually to organic pollution or oxygen deficits, and a measure of their relative abundance. This score then provides a measure of the pollution status of the sites sampled. Most indices were developed for the benthic fauna in streams and wetlands, few have been developed for large rivers and lakes (Rosenberg et al. 2007). A number of statistically complex predictive models have also been designed based on the Reference Condition Approach, to compare test sites to presumed least-impacted reference sites that have similar environmental conditions. This multivariate predictive approach has been used in the River Invertebrate Predictive and Classification System (RIVPACS), the Australian River Assessment System (AUSRIVAS), and is used in the Benthic Assessment of Sediment (Reynoldson et al. 2000; Rosenberg et al. 2007).

Two indices originally developed for rapid stream assessment were used on the littoral benthic community of the Bay of Quinte. Barton and Hynes (1978) had found that the littoral fauna of the Great Lakes often had a large proportion of stream species. BioMAP was developed to assess water quality of Ontario watercourses (Griffiths 1996). This index has also been applied to assess conditions at rocky wave-swept nearshore waters in large lakes (Griffiths 2003). The second index used was an IBI tool developed by the Iowa Department of Natural Resources (DNR) to evaluate aquatic communities along a gradient of environmental disturbances in sluggish prairie streams (Wilton 2004). In it, a series of 12 component metrics were combined to create their Benthic Macroinvertebrate Index of Biotic Integrity (BMIBI) that is used together with their Fish Index of Biotic Integrity (FIBI) to assess Iowa streams. One metric of the BMIBI index, the IOWATER Macroinvertebrate Biotic Index (MBI), is similar to BioMAP in that it incorporates tolerance values for the various Families and Orders, and counts of each organism present.

The Lake Biotic Index (LBI) was specifically developed to measure the ecological status of lakes by examining the decrease in biodiversity with increasing depth (Verneaux et al. 2004). This decrease of species occurs naturally in lakes, but is enhanced in lakes with anthropogenic inputs. The LBI compares the benthic community present in littoral sediments at 2 m depth, with the species present in the profundal zone at approximately 66% of the lakes maximum depth (Zmax). The LBI provides two indices. The first is the bathymetric taxonomic deficit index (Df ; Verneaux et al. 1993), which compares the lake's ability to support a profundal community compared to the littoral community due to low O_2 and sediment refractory organics. This Dysbiotic scale ranges from dystrophic lakes with low efficiency and high percentage of refractory organics matter (i.e. brown water lakes), to lakes with efficient energy transfer (Eubiotic). This index (Df) is similar to the biotic indices of streams based on a tolerance scale of dominant genera and the number of genera present in the littoral zone. The second LBI scale, the littoral biotic index (Bl), is a trophic scale from Oligobiotic to Polybiotic which is a measure of the lake's capacity to produce littoral invertebrates and the diversity of the community (Borderelle et al. 2005).

Under the Great Lakes Water Quality Agreement (IJC 1987) extensive efforts were made to reduce the inputs of nutrients, especially phosphorus in to the Great Lakes. To address the eutrophication problems in the Bay of Quinte on eastern Lake Ontario, a Remedial Action Plan (RAP) was drawn up, which listed the degraded ecosystem components and established restoration goals (Bay of Quinte RAP 1993). The degradation of the benthos was identified as "Beneficial Use Impairment #6" in the Bay of Quinte Remedial Action Plan (RAP). One goal of the RAP is to restore the benthic community degraded by eutrophication, and to "demonstrate a positive change in the benthic macroinvertebrate community structure, and to measure increased species, and community diversity in a community typical of mesotrophic conditions". Monitoring and collection of sufficient data was recommended in order to judge whether the Bay has attained a balanced and healthy benthic community.

The object of this analysis was to examine the quality of the littoral community in the Bay of Quinte using several Biotic Indices. The data used were collected at several transects independently from the annual benthic monitoring which is done at 4 Benthic Index sites (Johnson and McNeil 1986). Littoral data existed from several sites and years. The sites covered a wide trophic gradient from the eutrophic Upper Bay near the Trent River, downstream to the relatively pristine condition on the shore of Amherst Island, and Point Traverse in eastern Lake Ontario. Shallow water data were available from three widely separated time periods, 1966 (Pre-Phosphorous reduction), 1988-1990 (Post P-reduction), and 2001 (Post-Dreissena). No littoral data were available from the post-Goby time stanza (2002-2008). Portions of these data were presented in the Project Quinte Annual Reports for 1991, 2007, and 2008.

METHODS

TIME PERIODS

A series of transects were sampled in the Bay of Quinte during 1966-1967 (Figure 1a) by Murray Johnson (Johnson and Brinkhurst 1971). The upper bay, as used in this study is from Trenton to Deseronto, the middle bay extends to Glenora, and the lower bay is from Glenora to Amherst Island. These transects began at the Murray Canal near Trenton (Transect U1: Figures 1a and 2) and extended down the bay to Prince Edward Bay and Point Traverse in Lake Ontario (Transect U44: Figures 1a and 2). A second series of transects (Johnson and McNeil 1986) were sampled periodically from 1972 until 1991 (Figure 1b) from Glenora (Transect T1: Figure 1a, Figure 2) to Amherst Island (Transect T17: Figures 1a and 2) in the Lower Bay. Benthic samples were collected at several sites along these transects with the same large 9 inch Ekman (0.05 m^2) and sieved through a 0.58 mm mesh screening bucket as used to sample the annual Benthic Index sites.

Between 1988 and 1990, many of these transects were resampled (Figure 2; also see Figure 4) with the same methods used in 1966 and 1972. In addition, the shore ends of selected transects were sampled at depths less than 2 m using an Ekman if the substrate was soft, or a method adapted to sample on the predominant shoreline substrates of gravel, cobble, or bedrock. A suction method was devised to sample the fauna within a quadrat placed on the cobble at a depth of 0.6 to 0.7 m. Data from between two to seven replicate suction samples were averaged at each site over the year that site was sampled. Littoral samples were collected from the Upper Bay in May and July 1988 and July 1989. The Lower Bay was sampled in July 1989, and samples from May, July and December 1990 were again mostly from the Lower Bay. In December 1990, divers sampled the shore ends of several transects at 1.5 and 4 m depth using an airlift and Surber frame of 0.09 m^2.

In 2001, a nearshore + offshore project sampled the nearshore in Big Bay and offshore transects at 5.8 to 7 m depth (Figure 2). A "mini" or petit-PONAR grab (0.0227 m^2 area) was used to sample the littoral community on sand and gravel or in plant beds at 1.5 to 2 m depth. A large Ekman was used at the offshore transects during June, August, and October 2001. These samples were screened and processed following methods of Johnson and McNeil (1986), and provided data for the LBI Index. Data were averaged for all samples collected during 2001 at each depth zone (n = 9 per site).

The Lake Biotic Index (LBI) requires data from the littoral zone at a depth of 2 m collected from soft sediments and samples taken at 0.66 of the maximum depth taken from the lake. In the Upper Bay, mid channel depths are normally between 5 and 7 m, which is about 60% of the maximum depth in the Upper Bay (10 m near Massasauga Point). Thus, for the Upper Bay, data from Ekman samples from sites less than 3 m in the transect series were compared to data from sites beyond 5 m depth, including the Big Bay Index site. In the Lower Bay, the steep slopes result in few areas of soft bottom at 2 m depth, while gravel and sand can be found at depths of 10 m. As a result, all samples collected by Ekman from sand or silt at depths between 2 and 9 m were used as the littoral samples for the Lower Bay. Samples from mid-channel depths between 30 and 45 m, including the Conway Index site, were used as the 66% Zmax profundal samples (max depth of 60 m). The nearshore + offshore samples from Big Bay in 2001 also fit the depth requirements of the LBI. For comparison, LBI scores were calculated for pristine Batchawana Bay, Lake Superior using DFO data from 1977 (Dermott 1984) and for polluted Hamilton Harbour using unpublished data from 2002 to 2007 (Dermott and Bonnell 2010).

SUCTION SAMPLING ON COBBLE

Where the shore ends of the transects were cobble and rock, the littoral fauna was sampled using a two-person suction method (Dermott et al. 1993) consisting of a quadrat, hand-operated bilge pump, and collecting net of 0.36 mm mesh. The quadrat was a frame from a tall 6 inch Ekman (0.0244 m^2) with jaws, springs, and top flaps removed. A 1 m long piece of floating rope was attached to the Ekman's handle. The bilge pump (Guzzler brand) had simple flap valves which allowed the passage of pebbles the size of acorns. The pump was attached to an inverted L-shaped wooden frame that could be held over a person's lower arm or on the gunnel of a boat. Attached to the pump was a 4 m long inlet hose of 24 mm ID clear tubing and a short 0.5 m outlet hose. A 19 mm ID diameter rigid acrylic pipe of 0.3 m length was inserted into the inlet hose to prevent gravel lodging inside the flexible hose. A net sock of 0.36 mm mesh with draw string was attached to the outlet hose to collect the debris and invertebrates.

One person waded into the water to approximately 0.7 m depth (arm's length) and placed the Ekman frame onto the gravel or cobble bottom, while the second person operated the bilge pump either standing in the water or from inside a boat. When ready, the surface of the gravel inside the Ekman frame, including the corners, was "vacuumed" on command. After the first pass over the surface, small loose rocks completely inside the Ekman frame were removed and placed into a 0.58 mm meshed screen bucket. The surface inside the frame was again vacuumed while stirring the gravel with the end of the hard plastic pipe or a small garden trowel. After the second stirring of the gravel, and vacuuming in all corners of the frame, the end of the plastic pipe was held just above the bottom inside the frame and the pumper instructed to clear out the hose and pump. After clearing the bilge pump of all debris, the pumper took the pump, hose and net sock to the shore or boat, while the wader carried the screen bucket with surface rocks to the shore or boat. Each rock was carefully examined to remove attached invertebrates and molluscs with tweezers or a wash bottle spray, after which the rocks were discarded. The net sock was inverted and its contents washed into a basin. Any sticks and large pebbles were also inspected to remove invertebrates and the debris later discarded. The screen bucket and net sock were inspected for attached insects and worms. These were removed using tweezers and wash bottle spray and added to the sample. The invertebrates and debris from both the net sock and screen bucket were washed through a # 80 (0.18 mm) brass screen, then transferred to a wide mouth 1 L jar for preservation in 8% neutral formalin.

The finer 0.36 and 0.18 mm meshes were preferred over a coarser 0.5 mm standard screen size because the worms weave themselves into the 0.5 mm mesh and the claws of the insects, especially the Heptageniidae, hold onto mesh larger that 0.4 mm resulting in many missing legs. After preservation, the samples can be re-screened in the lab on a courser 0.5 mm sieve to separate the macroinvertebrates from the few meio-invertebrates that inhabit the wave zone. Initial suction samples from May 1988 used a large 9 inch Ekman frame (area 0.05 m^2) in order to be comparable with the sample area of the offshore transect sites. This sample area produced too large a sample volume, so the quadrat size was reduced to the 6 inch Ekman frame. The diver airlift samples from December 1990 used a Surber frame (0.09 m^2) as the quadrat.

For BioMAP and LBI calculations, all data were converted to a common area of 1 m^2.

BIOMAP AND IOWA BIOTIC INDEX CALCULATIONS

Littoral density from rocky sites at 1 m depth or less collected in 1988 and 1990 were used to calculate BioMAP values. These littoral sites included: Onderdonk opposite Trenton (U4_01 = Upper Transect 4 - site 1), Rednersville (U6_01), Wallbridge Point opposite Belleville (U9_08), Massasauga Point (U10_01), and Big Island shore (U14_01) in the Upper Bay (Figure 4). In the Lower Bay, the sites sampled were: Prinyer Cove (T10_F = Lower Transect 10 - site F) and Amherst Island (T15_G); and in eastern Lake Ontario at Point Traverse (U44_01) and Point Petre (LOT62_1) (Figure 4). The BioMAP index was also calculated for the gravel and plant covered littoral sites in Big Bay sampled during 2001 with a mini-PONAR. These sites were BQ1, BQ2, BQ3, BQ21, BQ23, BQ25, BQ29, BQ31, and BQ32 (Figure 2). Data were averaged over the year of collection for each site sampled to calculate average density m^{-2} for each taxa present.

The BioMAP index is based on the abundance of the invertebrates collected and a sensitivity value for each taxon. This index uses the natural log of the average density of each taxon over the year at each of the sample sites, and a proportional pollution sensitivity scale given to each taxa. Species typical of headwater streams have a higher sensitivity value than those species typical of lakes and ponds. Calculations for BioMAP follow that of Griffiths (1993, 1999), using the revised sensitivity values from Appendix of Sensitivity Values at website link: :http://www.execulink.com/~bugman/

$$\text{BioMAP WQ} = [\text{Sum}_{1\text{ to }n}(\text{Exp}^{SVi}\ \text{logn}(Xi+1))] / [\text{Sum}_{1\text{ to }n}\ (\text{logn}(Xi+1)]$$

where SVi is the sensitivity value for taxon(i); Xi is density of taxon(i), n is number of each taxa (n=1 to i) in the sample, and logn is the natural log. The typical range of calculated values for BioMAP is between 5 and 25 in riverine systems of Ontario. The BioMAP index has also been used to evaluate water quality in the littoral zone of several bays in Georgian Bay (Griffiths and Muter 2003) using the benthic invertebrates present.

A similar biotic index developed for the sluggish streams of Iowa (IOWATER Program, Wilton 2004), based on the Hilsenhoff Index (Hilsenhoff 1988), was also used to evaluate the littoral community on cobble and rocks sampled between 1988 and 2001. As in the BioMAP index, each species or genus present is given a tolerance index value. Calculations for this index and several others followed the IOWATER Benthic Macroinvertebrate Metrics found in the Iowa DNR report (Wilton 2004) at http://www.igsb.uiowa.edu/wqm/Biological/IA_Stream_Bioassessment.pdf

The species tolerance values came from the Iowa Appendix of macroinvertebrate index MBI tolerance values, adapted from Hilsenhoff (1988). Data tables of the average benthic species composition at the littoral sites were prepared for each of the littoral sites sampled in 1988 or 1990. Information did not exist to allow calculation of the IOWATER indices for Multi-habitat taxa richness or the functional feeding index, thus the overall BMIBI score from all the 12 metrics could not be calculated. The Macroinvertebrate Biotic Index (MBI) was calculated as:

MBI =Sum(density(i) x tolerance value(i)) / (total density all taxa - density of taxa without tolerance value)

where i is the value for each taxa present from 1 to n, n= number different taxa, and the tolerance value is the biotic index value for species i (from Wilton (2004) Appendix 1.2). The pollution tolerance values for the various genera and families were obtained from Appendix 1.2 in the IOWA web site listed above. The IOWA Biotic Index Values vary from 10 for pollution tolerant Tubificidae worms to 0 for the stonefly *Acroneuria*. In addition, secondary metrics were calculated for each of the littoral sites as listed below:

- Taxa Richness - as overall number of different taxa identified, calculated from the average composition at each littoral site.
- Percent Chironomids - as average number of chironomid midges/average Total number of organisms at each littoral site.

- Percent Ephemeroptera - as average number of mayflies/average Total number of organisms at each littoral site.
- E.P.T. taxa Richness - as the count of discrete taxa in each standard habitat sample that belongs to the insect orders Ephemeroptera, Plecoptera, and Trichoptera (mayfly, stonefly and caddisfly).
- Percent E.P.T. - as percentage of total organisms classified as E.P.T. taxa in the total number of organisms in the sample. For example, if 15 out of 80 organisms identified are in the E.P.T. orders then the % EPA is 18.75%.
- Percent 3 Most Dominant Taxa - as the relative percent of the total sum as abundance of the organisms in the 3 most abundant taxa divided by the total number of organisms identified at that site.
- M.B.I. Index - using counts of the families and the pollution tolerance values taken from the Appendix 1.2 in the IOWA web site listed above. The IOWA Biotic Index Values vary from 10 for pollution tolerant Tubificidae worms to 0 for the stonefly *Acroneuria*.

LAKE BIOTIC INDEX

The European Lake Biotic Index (LBI) was tested using data sets from the Bay of Quinte collected in 1967, 1990, and 2001. The LBI is used to rank French lakes under the European Water Framework Directive (Verneaux et al. 2004; Borderelle et al. 2005). This index measures the decrease in macroinvertebrate biodiversity of the communities inhabiting soft sediments in the deeper zone of a lake compared to the littoral zone due to changing temperature, oxygen levels, and lake functional capacity. The littoral community inhabiting soft sediment at 2 m depth from a number of transects around a lake is compared to the community at 0.66 Zmax (66% of the lake's maximum depth). Calculations use the number of littoral genera, littoral density, number of taxa at 0.66 Zmax, and a littoral quality index based on the most sensitive indicator genera that is present in 50% of the littoral samples. For the French lakes, most invertebrates are only identified to genus, except nematodes and Hydracarina that have only one level of identification. Oligochaetes are identified only into 3 types: tubificids with hair seta, tubificids with no hairs, and non-Tubificidae.

Metrics calculated include: littoral taxonomic richness (vl); littoral density (dl); littoral quality index (Ql); and deep taxonomic richness ($\mathrm{v}f$) based on formulas in Verneaux et al. (2004). Two intermediate indices are calculated: the Littoral Biotic Index (Bl); and the Taxonomic Deficit Index (Df). The Littoral Biotic Index is calculated as: $\mathrm{Bl} = \mathrm{SQRT}(\mathrm{vl}) \cdot (\mathrm{logn\ dl})$; where vl is the littoral taxonomic richness or number of taxa collected at 2 m, and logn dl is the natural log of the littoral density per m^2 at 2 m depth. The Taxonomic Deficit Index is: $\mathrm{Df} = \mathrm{SQRT}[(\mathrm{k\ v}f / \mathrm{vl})] \cdot (\mathrm{Ql})$; where $\mathrm{v}f$ is deep taxonomic richness or number of genera at depth Zf(= 0.66 Zmax); k = corrective coefficient = $(0.033\ \mathrm{vl})+1$; Ql is the littoral quality index which has a value from 0.1 to 1.0 depending the most sensitive taxon that is presence in 50% of the littoral samples. Tubificid sewage worms have a Ql of 0.1 while more sensitive Plecoptera have a value of 1.0. The resulting values for Bl and Df are then used to calculate the Lake Biotic Index (LBI) based on the formula:

$\mathrm{LBI} = 2.5\ \mathrm{SQRT}(\mathrm{Bl} \cdot \mathrm{Df})$; where the expected range of LBI is 0 to 20

Data sets collected along transects in the Upper Bay near Big Bay existed for the years 1966-67 and 2001. Densities were converted to number per m^2. As the maximum depth in the Upper Bay is about 10 m, Ekman samples from Big Bay index site (6.5 m) and mid-channel samples from 5.5 to 7 m were used as the deep sites for Big Bay. LBI was calculated for the 1966-67 data set from the area between Belleville and Big Bay (Transects U8 to U17; Figure 2). A series of Upper Bay transect data also existed from the Trenton basin (Murray Canal to Rednersville, along transects U1 to U6) which was sampled in 1966 and again in 1989 (Figure 2). The LBI was also calculated for this area using data from the sites at the transects ends at 1.9 to 2 m depth, and using the mid transect sites as the deep sites (>4 m for Trenton). There were too few sites analyzed from Big Bay on soft substrates at 2 m depth in the 1989 data set to allow calculation of the LBI for that area of the Upper Bay, as emphasis in the 1989 survey was the rocky littoral sites. In 2001, the series of nearshore-offshore transects in Big Bay included littoral samples from sand and gravel, or in plant beds at 1.5 to 2 m depth (Figure 2). These were used with the 2001 data from the offshore transects and the Big Bay Index site to calculate the LBI for Big Bay in 2001.

In the Lower Bay, transects between Glenora and Amherst Island were sampled in 1966-1967 and 1989-1990. As only a few sites at 2 m depth were sampled, and because gravel and sand extend down to 10 m in the Lower Bay, sites between 2 to 9 m depth were used as the littoral samples for the Lower Bay. These were paired with the Conway samples and mid channel sites of nearby transects at depths of 28 to 42 m which averaged about 60% of the Zmax (about 60 m) in the Lower Bay. Comparative data from Batchawana Bay (eastern Lake Superior) from 1977 used littoral samples collected from depths between 1 and 3 m and deeper sites between 25 to 35 m (Zmax = 45 m). In Hamilton Harbour, samples included Ekman and Ponar samples from sites between 1.5 and 3 m, and 14 to 19 m depth (Zmax = 24m). Our calculations from Trenton and Batchawana Bay were checked by Dr. Valerie Verneaux of the Laboratoire de Biologie Environnementale, Besançon, France.

RESULTS AND DISCUSSION

LITTORAL COMMUNITY

Preliminary data on the littoral community of the Bay of Quinte were reported in the Project Quinte Annual Reports of 1988, 1990, 1991, and at the International Association of Great Lakes Research conference (IAGLR) in June 1992 (Dermott, Morton, and Barton 1992). The shoreline substrate in most of the bay is cobble and rock, with soft silt beginning at depths below 2 m. A few areas such as near the Murray Canal, Muscote Bay, near Adolphustown, and at the edges of the marshes have silty sand or silt at depths less than 2 m.

Littoral biomass was often 3 to 4 times that collected in the offshore samples on the same transects. During July 1988-1990, the wave zone of the Upper Bay supported a wet biomass of 13.0 to 55.7 g m^{-2} compared to 1.7 to 24.1 g m^{-2} in the soft sediments (>5 m depth) of the offshore portion of the same transects (Tables 1 and 2). In the Lower Bay, littoral biomass in the wave zone near Prinyer Cove and on Amherst Island was much greater than at the mid-channel sites on the same transects (Table 3). The Amherst Island site T15_G had the highest taxa richness, with over 52 taxa collected per 6 inch Ekman frame in July 1990, and densities as high as 98,000 m^{-2}. The dominant fauna on the cobble were small crustaceans, naidid worms, and numerous small Chironomidae. Density on the bare bedrock at Point Petre in eastern Lake Ontario (site LOT62_1; Figure 2) was 21,200 m^{-2} during May 1990, of which 14,300 m^{-2} were small orthoclad chironomids. In spite of the small average size of the invertebrates, total wet biomass averaged 55.7 g m^{-2} at Big Bay and 67.3 g m^{-2} at Amherst Island in July 1990 during the Pre-*Dreissena* time stanza. Before *Dreissena* arrived, the littoral biomass was dominated by amphipods and chironomids. The high densities partly reflected the finer mesh size used for the littoral samples compared to the offshore Ekman samples (360 versus 580 micron), but the biomass was independent of mesh size.

Several fluvial insects such as *Hydropsyche, Stenonema, Psephenus,* and *Antocha* were common in the wave zone at Big Island and especially on Amherst Island (Table 4). The waterpenny (*Psephenus*), cranefly (*Antocha*), and winter stonefly Capniidae are often used as indicators of excellent stream water quality, indicating that in 1990 the wave zone of the Bay of Quinte supported a rich and healthy invertebrate community. Although no littoral samples, except for *Dreissena,* were processed in the Post-*Dreissena* and Post-Goby periods (after 2002), the state of the littoral community in the Bay of Quinte is now likely the same as that in Lakes Erie and Ontario (Dermott et al. 1993; Haynes et al. 2005). Haynes et al. showed that many of the insects, especially the Heptagenid mayflies and Hydrophyschid caddisflies could not compete with *Dreissena,* yet the amphipods *Gammarus* and *Echinogammarus* did very well on cobble. Likewise, it is expected that predation by the Round Goby (*Neogobius melanostoma*) has seriously reduced littoral populations of all invertebrates similar to what occurred on the shores of Lake Erie and Michigan (Barton et al. 2005; Lederer et al. 2008). In July 1990, total dry shell-free biomass on rocky cobble in Lake Erie at <1 m depth was much greater than in the Bay of Quinte due to the establishing *Dreissena* and associated *Gammarus* community (Figure 3; from Dermott et al. 1992; Dermott et al. 1993).

LITTORAL INDICES

The stream index BioMAP was used to compare the littoral benthic community living on rocky shores less than 1 m deep in 1988 and 1990. An example of the BioMAP calculations are provided by the littoral samples (n=2) from bare bedrock at Point Petre in July 1990 (Table 5). The average calculated BioMAP values of the littoral community in 1988 and 1990 showed a gradual increase from the Upper Bay opposite Trenton (transect U4_01 at Onderdonk Point) to the Lower Bay at Amherst Island and out to exposed Point Traverse in eastern Lake Ontario (transect U44_04). Expectedly, exposed Amherst Island near the Upper Gap of Lake Ontario had the highest BioMAP index value (7.7) within the Bay of Quinte (Table 6). The exception was the high BioMAP value (7.5) calculated for the littoral benthic community on the rocks at Massasauga Point, at the narrows between Belleville and Big Bay (Table 6). This narrow channel has a bedrock shore and scoured depth to 10 m, likely due to wind induced currents which favour a more riverine fauna in the wave zone.

The only littoral area that was sampled in multiple years was at Big Island (transect U14_01) on Big Bay, which showed a range in BioMAP values from 5.5 in 1988 to 6.11 in 1990. The area east of Big Island near North Port was sampled in 2001. There, the BioMAP value on the gravel substrate was only 4.1 and 4.3 in the plant beds (Table 6). Wave induced currents would have been much less at the Ponar sampled sites on sand and gravel substrates and in the sheltered plant beds than on the exposed rocky shore of Big Island (transect U14_01). The sheltered plant beds supported fewer riverine species with high sensitivity values than did the more exposed rocky shore of Big Island, thus the resulting lower BioMAP score in the plant beds. By 2001, competition with the zebra mussel population would have reduced the number of algae grazing mayflies (Heptageniidae) and filter feeding caddisflies (family Hydropsychidae) that had been common on wave swept shorelines of the Great Lakes (Barton and Hynes 1978; Dermott et al. 1993). Both of these insects have high BioMAP sensitivity values, being more abundant in rocky habitats with high water quality. Comparative BioMAP values for the shoreline community in south-eastern Georgian Bay averaged 6.9 (Figure 8) with a range of 5.3 to 7.7 (Griffiths and Muter 2003). Following the same scoring pattern for Georgian Bay, scores less than 6.0 for the area between Trenton and Big Bay in 1989, and in the plant beds of Big Bay during 2001, would indicate reduced water quality. In contrast, the rocky shoreline of eastern Hamilton Harbour (Figure 8) had a BioMAP index of only 3.9 (Project Quinte Annual Report 2007).

Scores for the Iowa Macro-Benthic Index (MBI), developed for the slower prairie streams, increase with declining water quality. Thus, the shoreline of Amherst Island and Point Traverse, in the least impacted parts of the Quinte region, had the lowest MBI scores (Table 6) indicating the best water quality. Typical MBI scores for wadeable streams in Iowa are between 4.8 and 7.0 (Wilton 2004). The MBI score for Amherst Island (4.7) indicated that site had the best water quality in the Bay of Quinte, even better than typical Iowa streams. The MBI scores for the Upper Bay between Trenton and Big Bay was above 7, indicating a community typical of poor stream quality. The exception was the community at Massasauga Point for which the MBI indicated a poor water quality yet the BioMAP score indicated it represented very high water quality. Calculated MBI scores for the Big Island littoral community showed a change in its MBI score between 1988 and 1990 corresponding to a similar change in BioMAP values. Although the value for percent Ephemeroptera decreased at Big Bay between 1988 and 2001, the percent E.P.T. (Ephemeroptera + Plecoptera + Trichoptera) remained at 17% in the plant beds during 2001 compared to 17.5% on cobble in 1990. This was due the presence of other caddisfly families associated with the vegetation, such as the Leptoceridae and Hydroptilidae.

LAKE BIOTIC INDEX

An example of the calculations using the French Lake Biotic Index (LBI) is provided for the Trenton area samples collected in 1966 (Table 7). The two sub-indices calculated in the LBI were plotted in Figure 5. Low values of the Littoral Index (Bl) are indicative of oligobiotic conditions with low density such as in oligotrophic lakes. Low values of the Taxonomic Deficit (Df) indicate dystrophy or periodic anoxic conditions that limit the types of genera present in the deeper samples. The most oligotrophic of the French lakes (Lac Crop) plotted at the top-left of Figure 5 with high Df values but a low littoral Index Bl due to low densities. French dystrophic Lac Narley plotted to the bottom-left due to its low Taxonomic Deficit Index (Df) from the limited types of invertebrates present in its dystrophic sediment containing high refractory organics. Similarly, Hamilton Harbour had a low Df score due a community restricted by anoxia and contaminated sediments, but its very high oligochaete density created a higher Bl score.

Based on comments by Dr. Valerie Verneaux (personal communications, March 2011) on the values in Table 7: "The calculated values for Trenton classify the area as mesobiotic and slightly dysbiotic (excess of organic matter compared to its capacity of assimilation). The elevated Df values suggest little depth separation between the littoral samples and the deeper Vf samples. The moderate QI value of 0.7 shows that the disturbance of the lake had affected both the deepest zone and also the shallow littoral zone. In the littoral zone the most sensitive taxa had disappeared so that the depth related loss of taxa (Df) was still low despite the disturbance".

In contrast, calculations for pristine Batchawana Bay (Lake Superior) had a LBI score of 19.9 out of 20 (Table 8). For its calculations, Dr. Verneaux commented: "The calculated values for Batchawana Bay indicate it is polybiotic (with high littoral biodiversity) related to its high conductivity (conductivity = 190, pH of 8), good habitat and eubiotic state (optimal organic matter transfer throughout the foodweb)". Although located at the east end of oligotrophic Lake Superior, the benthic community of warm and shallow Batchawana Bay has a very high diversity (Dermott 1984). Thus, the bay has a high or polybiotic score in the Lake Biotic Index (BI).

Trenton in 1966 (T1966) and the lower bay in 1966 (LQ1966) had lower Df values than did the benthic community at the same locations in 1989 and 1990, respectively (Figure 5). The higher values in 1989 suggest improvements in environmental conditions since 1966. The low Df suggested poor conditions but with no major deficit in deepwater community caused by low oxygen problems. Low oxygen has not been an issue for the benthic fauna in the Upper Bay, which does not stratify, nor in the Lower Bay. Low oxygen had been an issue only in a few deeper areas of the middle Bay of Quinte (near Hay Bay), which had periodic low oxygen (<1.0 ppm) between 1970-1980 (Minns and Johnson 1986). The low Df values for the Trenton area may also be due to either insufficient depth separation between the littoral samples (2 m) and the deeper samples, (4-5 m), or that the eutrophic conditions of the upper-most part of the bay affected both the shallow littoral community and deeper zone.

The LBI value for the Trenton area in 1966 was more dysbiotic than that for Big Bay during the same year. Big Bay 1966 (BB1966) had a high Df value of 0.95 (Table 8, Figure 5). The Upper Bay has very high sediment organic content, the organic content at Trenton in 1966 was 26.0%, less than the 30.5% found at Big Bay (M. Johnson, data unpublished). Verneaux et al. (2004) considered a sediment organic content above 10% to indicate onset of dysbiotic features for macro-consumers. Johnson and Brinkhurst (1971) had noted that Big Bay had a high input of refractory allochthonous material from the surrounding wetlands making the sediment soft and easily disturbed. The poorer community in the Trenton basin in 1966 may have been due to the greater eutrophication problems in the upper-most bay prior to Phosphorous reduction, and slight toxicity of sediments near the mouth of the Trent River as shown by the BEAST assays done in 2000 (Milani and Grapentine 2006).

The LBI values for Trenton and the Lower Bay increased compared to what they were in 1966 (Figure 5). During 2001, the benthic community in Big Bay plotted near the right which indicated more mesotrophic conditions, but again with Df values near the maximum. This indicated no impairment to the benthic fauna from dystrophy or oxygen problems at Trenton or Big Bay. Df values in Quinte increased as the difference between the number of genera in the littoral and deeper zone decreased, and genera with a higher Quality Index (QI) became more common.

The calculated LBI score for the Bay of Quinte sites after 1988 approached or exceeded the maximum of 20 calculated for the French mountain lakes, and also exceeded the LBI score for Batchawana Bay (Table 8). Part of the discrepancy of the Bay of Quinte score from the expected maximum LBI values was that littoral densities were an order of magnitude greater than the densities in the French lakes. The maximum littoral population in Quinte was 32,450 m^{-2} (including zebra mussels in Big Bay, 2001) compared to only 7645 m^{-2} in the French lakes. These greater densities inflate the calculated Littoral Index (BI) values. This was made worse in 2001 with the huge density of settled *Dreissena* in the littoral samples from Big Bay. The LBI may not have accurately reflected conditions at Trenton, as the small depth difference between the littoral (2 m) and deepest zone (5 m) near Trenton does not allow for much difference in the two benthic communities inhabiting the two depth zones. The LBI index was designed for deeper lakes that undergo some stratification and thus have a greater difference in invertebrate composition inhabiting the 2 m versus the 0.66 Zmax depth zone. In addition, the LBI was designed to sample the benthic community present in the spring, while the transect data for the Bay of Quinte, Batchawana Bay, and Hamilton Harbour all used data from multiple seasons (May to September) in order to have sufficient samples for the calculations. This may have increased the number of taxa found compared to just samples collected in the spring from more sites. These factors are responsible for elevating the value of the LBI to above the expected maximum of 20 (Table 8).

CONCLUSIONS

The littoral indices BioMAP and MBI indicated that by 1990, the Bay of Quinte supported a relatively healthy littoral community on its cobble and rocky shores. In the Trenton area, this community was similar to that expected in rivers with slight pollution problems, but were typical of a littoral community inhabiting cleaner areas of the Great Lakes. The LBI index indicated that during the earliest sample period in 1966, the benthic community in the Trenton area was mesobiotic with an excess of organic matter greater than its capacity to assimilate. After phosphate reduction, there was no indication of an impairment of the benthic community in either the Lower Bay of Quinte or in Big Bay during 1990 and 2001, respectively. Evidence presented suggests that the degradation of the benthos, identified in the Bay of Quinte RAP as Beneficial Use Impairment #6, has been corrected by the management action plan to reduce phosphorous inputs to the bay.

With all the changes to the benthic community in Quinte since the arrival of the invasive species, the species mix and energy flow are now quite different than before 1990. The community will never be able to revert to one similar to that which existed in the 1950s prior to the eutrophication of the bay. However, the MBI and LBI score together with the improved diversity suggest that the community is healthy in comparison to other lakes. In spite of the dominance of *Dreissena*, there is a high benthic diversity with no apparent dysbiotic restriction in the deeper portions of the bay. In 1990, there was a very rich littoral fauna in the Upper Bay indicating limited impact of poor water quality on the benthic community in that decade.

ACKNOWLEDGEMENTS

Special thanks are extended to Bud Timmins, who assisted with the Ekman collections and littoral sampling over 15 years. Robert Bonnell, Jocelyn Gerlofsma, Michele Burley assisted with collections in 2001. Bill Morton did most of the identifications, with the exception of the 1990 rocky littoral samples which were identified by Dave Barton. Murray Johnson provided the data from 1966 which was collected by Gary Westlake, Ron Hunsinger and Rob Peters. Ken Minns provided guidance with the FORTRAN database. Our appreciation is given to the dozens of students and crew members on the vessels Surf, Shark, Bayfield, and the Leslie J over the years of sampling. We thank the staff of the Ontario Ministry of Natural Resources at Glenora for assistance and lab space.

REFERENCES

Barton, D.R., and Hynes, H.B.N. 1978. Wave zone macrobenthos of the exposed Canadian shores of the St. Lawrence Great Lakes. J. Great Lakes Res. 4: 26-45.

Barton, D.R., Johnson, R.A., Campbell, L., Petruniak, J., and Patterson, M. 2005. Effects of round gobies (*Neogobius melanostomus*) on dreissenid mussels and other invertebrates in eastern Lake Erie, 2002-2004. J. Great Lakes Res. 31 (Suppl. 2): 252-261.

Bay of Quinte RAP. 1993. "Time to Act, The Bay of Quinte Remedial Action Plan Stage 2 Report." Bay of Quinte RAP Coordinating Committee, September, 1993. Ontario Ministry of the Environment, Kingston, Ontario. 257 pp.

Borderelle, A.L., Verneaux, V., and Gerdeaux, D. 2005. Biological quality assessment of three French Alpine lakes (Lake Annecy, Lake Crop, Lake Grand Domenon) using the Lake Biotic Index (LBI). Arch. Hydrobiol. 162: 497-509.

De Pauw, N., and Vanhooren, G. 1983. Method for biological quality assessment of watercourses in Belgium. Hydrobiologia 100: 153-168.

Dermott, R.M., 1984. Benthic fauna assemblages in Batchawana Bay, Lake Superior. Can. Tech. Rep. Fish. Aquat. Sci. 1265: iii + 17 pp.

Dermott, R., and Bonnell, R. 2010. Benthic fauna in Hamilton Harbour and adjacent Lake Ontario 2002-2005 in comparison to 1964. Aquat. Ecosy. Health Manag. 13: 413-428.

Dermott, R., Bonnell, R., Carou, S., Dow, J., and Jarvis, P. 2003. Spatial distribution and population structure of the mussels *Dreissena polymorpha* and *Dreissena bugensis* in the Bay of Quinte, Lake Ontario, 1998 and 2000. Can. Tech. Rep. Fish. Aquat. Sci. 2479: v + 58 pp.

Dermott, R., Mitchell, J., Murray, I., and Fear, E. 1993. Biomass and production of zebra mussels (*Dreissena polymorpha*) in shallow waters of northeastern Lake Erie. In Zebra mussels: biology impacts, and control. Edited by T. Nalepa and D. Schloesser (eds). Lewis Publishers, Boca Raton, Florida. pp. 399-413.

Dermott, R., Morton, W., and Barton, D. 1992. Benthic fauna in the wave zone of the Bay of Quinte, Ontario; an unseen river? Presentation at International Association of Great Lakes Research (IAGLR), Waterloo, June 1992.

Griffiths, R.W. 1996. BioMAP: A biological measure of water quality for creeks, streams and rivers. Ontario Ministry of Environment and Energy, Southwestern Region, London, Ontario. Report SWR-4

Griffiths, R.W. 1999. BioMAP: Bioassessment of water quality for southern Ontario watercourses. (Published by Niagara College, Glendale Campus, Niagara on the Lake, Ontario. 110 pp) revised sensitivity values from web link BIOMAP CENTRAL Appendix of Sensitivity Values : :http://www.execulink.com/~bugman/

Griffiths, R., and Muter, M. 2003. Water quality along the southeastern shoreline of Georgian Bay in 2003. Report to the Georgian Bay Area (GBA) Foundation. December 2003.

Haynes, J.M., Tisch, N.A., Mayer, C.M., and Rhyne, R.S. 2005. Benthic macroinvertebrate communities in southwestern Lake Ontario following invasion of *Dreissena* and *Echinogammarus*: 1983 to 2000. J. North Amer. Benthol Soc. 24: 148-167.

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. J. North Amer. Benthol. Soc. 7: 65-68.

International Joint Commission. 1987. Great Lakes Water Quality Agreement of 1978, Agreement, with Annexes and Terms of Reference, between the United States and Canada signed at Ottawa, November 22, 1978 and Phosphorus Load Reduction Supplement signed October 7, 1983 as amended by Protocol signed November 18, 1987. Consolidated by the International Joint Comm., Windsor, Ontario.

Johnson, M.G., and Brinkhurst, R.O. 1971. Associations and species diversity in benthic macroinvertebrates of Bay of Quinte and Lake Ontario. J. Fish. Res. Bd. Can. 28: 1683-1697.

Johnson, M.G., and McNeil, O.C., 1986. Changes in abundance and species composition in benthic invertebrate communities of the Bay of Quinte, 1966-84. Can. Spec. Publ. Fish. Aquat. Sci. 86: 177-189.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6: 21-27.

Kolkwitz, R., and Marsson, M. 1909. Okologie de tierischen Saprobien. Int. Rev. Hydrobiol. 2: 126-152.

Lederer, A.M., Janssen, J., Reed, T., and Wolf, A. 2008. Impacts of the introduced Round Goby (*Apollonia melanostoma*) on dreissenids (*Dreissena polymorpha* and *Dreissena bugensis*) and on macroinvertebrate community between 2003 and 2006 in the littoral zone of Green Bay, Lake Michigan. J. Great Lakes Res. 34: 690-697.

Lenat, D.R. 1988. Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. J. North Amer. Benthol. Soc. 7: 222-233.

Margalef, R., 1958. Information theory in ecology. Gen. Syst. 3: 36-71.

Milani, D., and Grapentine, L.C. 2006. Assessment of sediment quality in the Bay of Quinte Area of Concern, 2000. NWRI contribution No. 04-002, July 2006. Environment Canada, Water Science Technology Directorate, Burlington, Ontario. 43 pp.

Milbrink, G. 1983. An improved environmental index based on the relative abundance of oligochaete species. Hydrobiologia 102: 89-97.

Minns, C.K., and Johnson, M.G. 1986. Temperature and oxygen conditions and oxygen depletion in the Bay of Quinte, Lake Ontario. Can. Spec. Publ. Fish. Aquat. Sci. 86: 40-49.

Project Quinte Annual Report. 2007. Bay of Quinte RAP Restoration Council / Project Quinte, Monitoring Report # 17. Bay of Quinte Remedial Action Plan, Kingston, Ontario, Canada. March 2009.

Reynoldson, T.B., Day, K.E., and Pascoe, T. 2000. The development of the BEAST: a predictive approach for assessing sediment quality in the North American Great Lakes. In Assessing the biological quality of fresh waters: RIVPACS and other techniques. Edited by J.F. Wright, D.W. Sutcliffe, and M.T. Furse. Freshwater Biological Association, Chapter 11. pp. 165-180.

Rosenberg, D.M., Resh, V.H., and King, R. 2007. Use of aquatic insects in biomonitoring. In An introduction to the aquatic insects of North America, 4th ed. Edited by R. W. Merritt, K. W. Cummins, and M. Berg. Kendall/Hunt Publishing Company. Chapter 7. pp 123-137.

Saether, O.A. 1979. Chironomid communities as water quality indicators. Holarctic Ecol. 2: 65-74.

Sládecek, V. 1973. The future of the saprobity system. Wat. Res. 7: 995-1002.

Verneaux, J., Schmitt, A., and Verneaux, V. 1995. Classification biologique des lacs jurassiens à l'aide d'une nouvelle méthode d'analyse des peuplements benthiques. III. Relations entre données biologiques et variables du milieu. Annls Limnol. 31: 277-286.

Verneaux, V., Verneaux, J., Schmitt, A., Lovy, C., and Lambert, J.C. 2004. The Lake Biotic Index (LBI): an applied method for assessing the biological quality of lakes using macrobenthos; the Lake Chalain (French Jura) as an example. Ann. Limnol. - Int. J. Lim. 2004. 40: 1-9.

Wilton, T.F. 2004. Biological assessment of Iowa's wadeable streams. Environmental Services Division, Iowa Department of Natural Resources. Oct. 2004.
website link: :http://www.igsb.uiowa.edu/wqm/Biological/IA_Stream_Bioassessment.pdf

JOHNSON AND BRINKHURST: BENTHIC MACROINVERTEBRATES IN LAKE ONTARIO

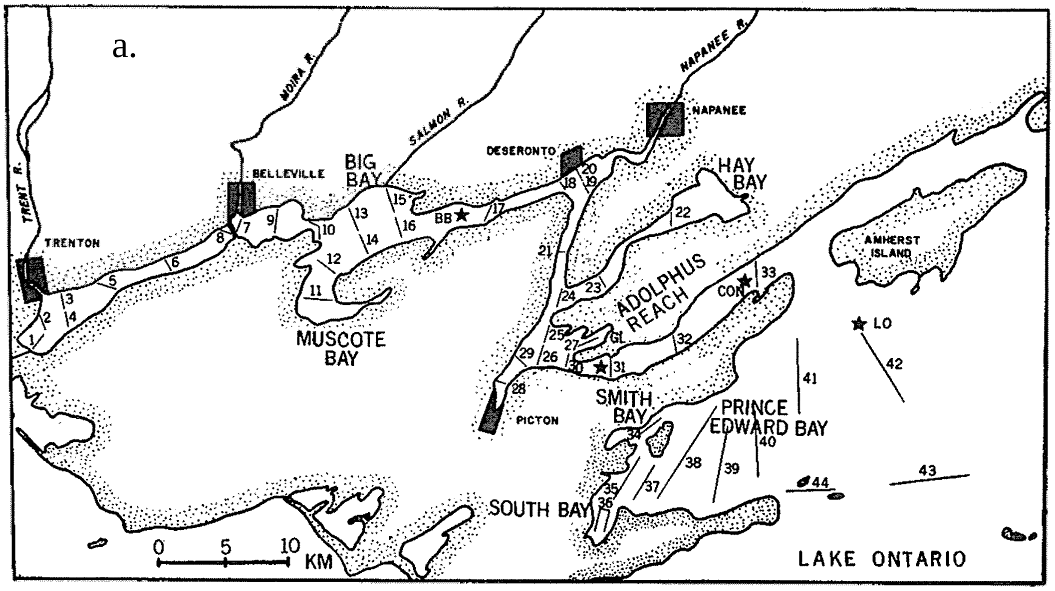

Figure 1a. Quinte study area showing sites used in the extensive collecting of macroinvertebrates (numerals) and the main sites used in intensive collecting (BB, Big Bay; GL, Glenora; CON, Conway; LO, Lake Ontario). The source of the FWPCA samples, near the middle of Lake Ontario,

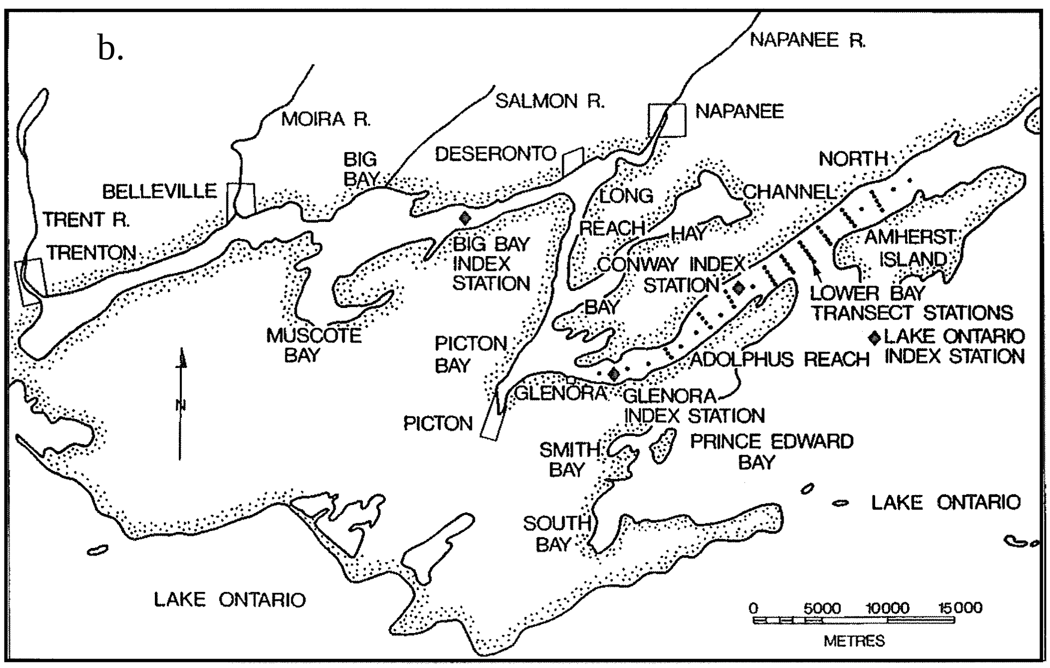

Figure 1b. Locations of 4 benthic Index sites (Big Bay, Glenora, Conway, and Lake Ontario) and 52 transect sites in the lower Bay of Quinte (Adolphus Reach and the mouth of the bay) The upper bay, as used in this study is from Trenton to Deseronto, the middle bay extends to Glenora, and the lower bay is from Glenora to Amherst Island.

Figure 1. Benthic transect locations in the Bay of Quinte: figure 1a = transects from 1966 in Johnson and Brinkhurst 1971; figure 1b = lower Bay transects from Johnson and McNeil 1986.

Bay of Quinte Benthic Index sites and transects

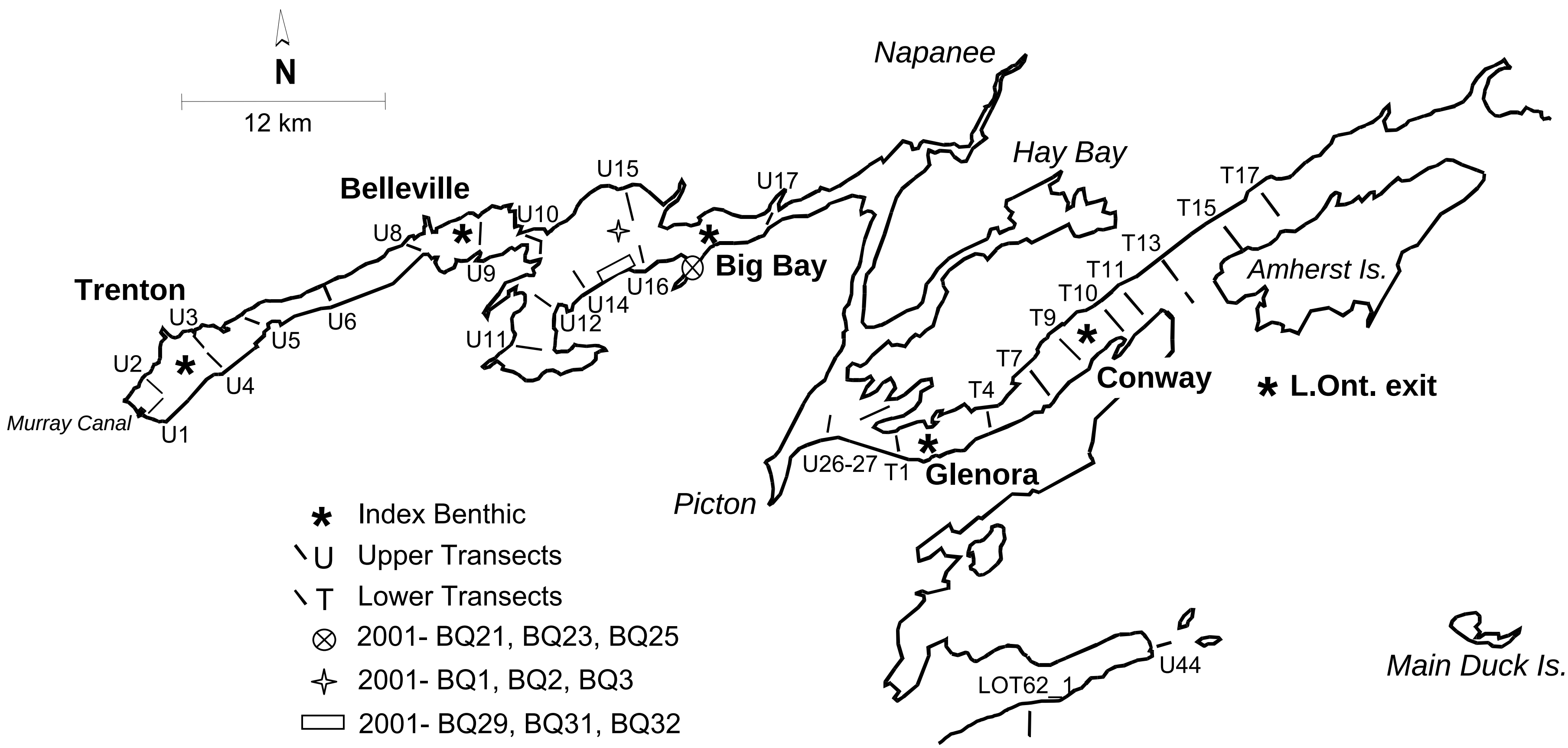

Figure 2. Location of Index sites and Transects used for the BioMAP, and French LBI calculations with data from 1966, 1990, and 2001. Rocky littoral samples collected at shore ends of select transects in 1988, 1990, and 2001.

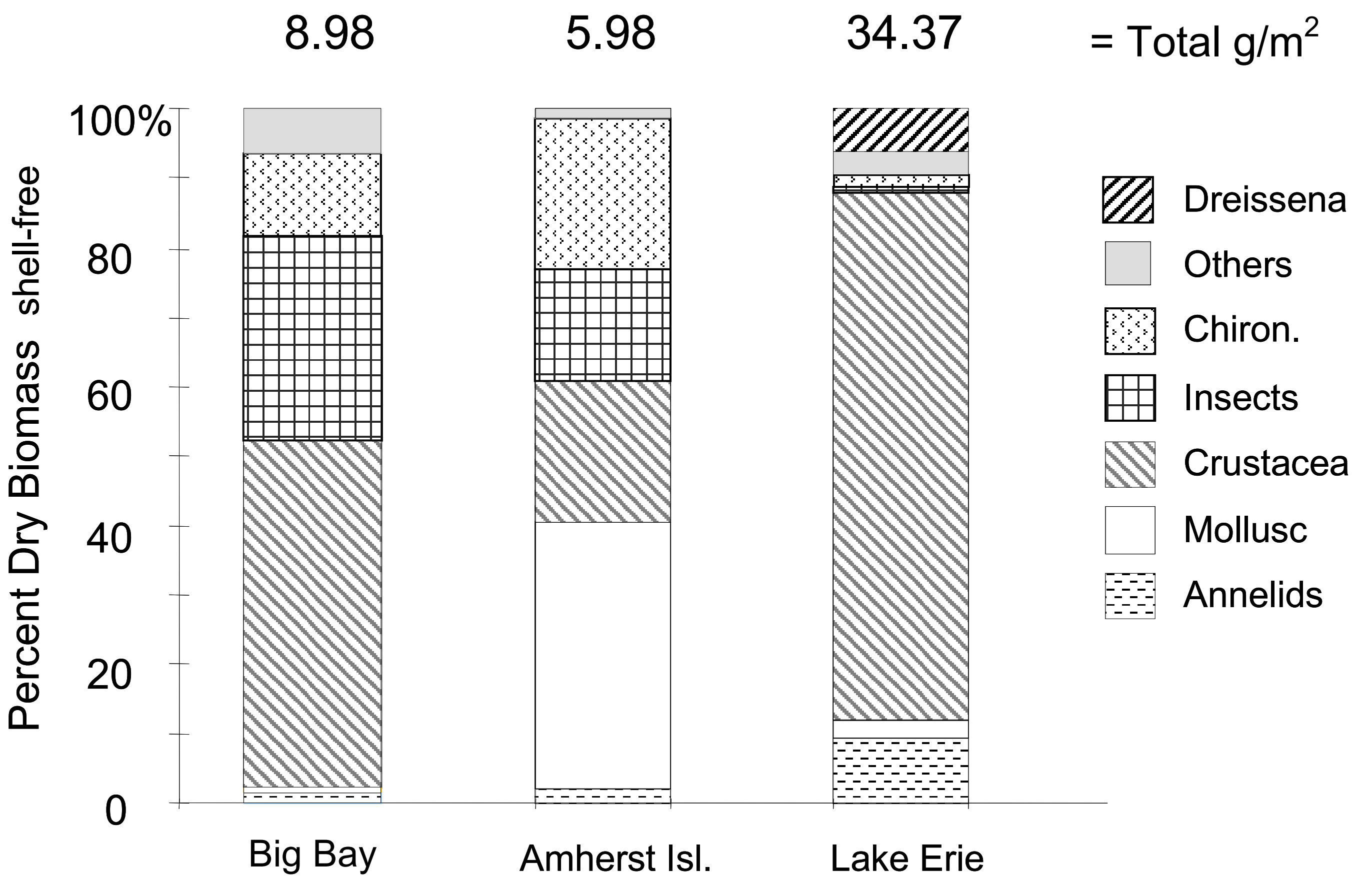

Figure 3. Comparative dry benthic biomass (g • m^{-2} shell-free) of the littoral community at Big Bay and Amherst Island (Bay of Quinte), and eastern Lake Erie sampled in July 1990.

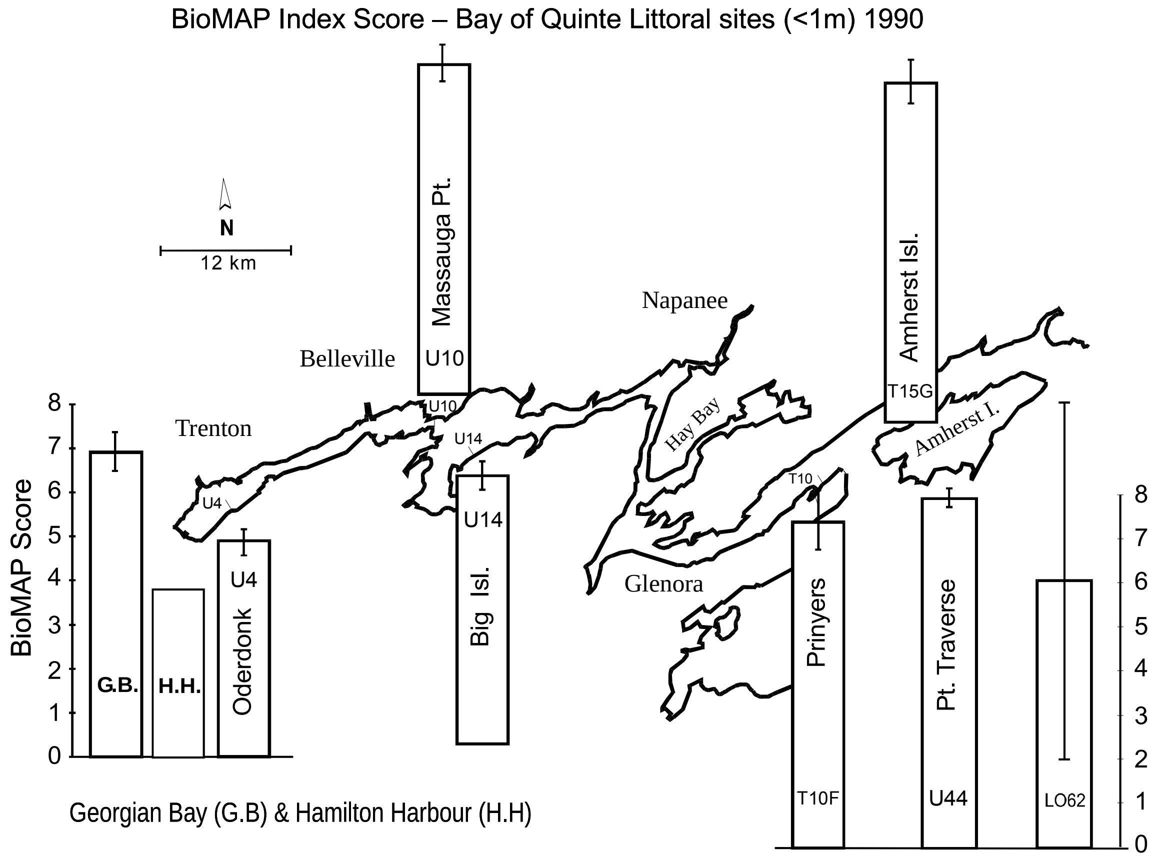

Figure 4. Calculated BioMAP index values for the 1990 littoral community on rocky shores in the Bay of Quinte, including comparative values for southeast Georgian Bay and Hamilton Harbour. Data for Georgian Bay from Griffiths and Muter 2003.

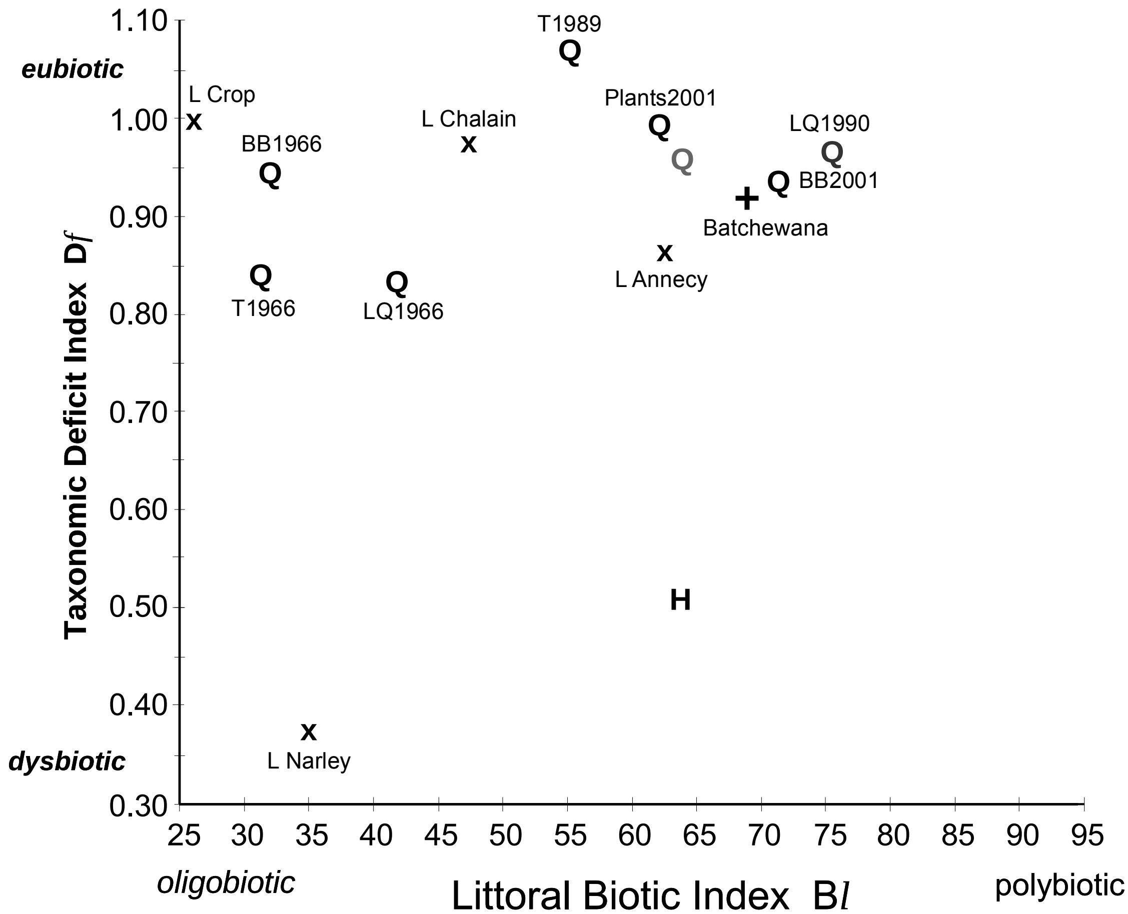

Figure 5. Typological plot of the littoral biotic index (Bl) and taxonomic deficit index (Df) used in the calculations for the Lake Biotic Index (Verneaux et al. 2004) from several transect surveys in the Bay of Quinte (**Q**), Batchawana Bay (**+**) (Lake Superior), and Hamilton Harbour (**H**). Data for French lakes (**x**) from Borderelle et al. 2005. Comparative Batchawana Bay and Hamilton Harbour data from Department of Fisheries and Oceans.

Table 1. Numbers/m^2 and wet biomass + shells (mg/m^2) of invertebrates in the Upper Bay of Quinte during 1988 at littoral shore sites (<1 m) and offshore Index sites.

	UPPER BAY JULY 1988				BIG BAY JULY 1988			
	Oderdonk 1m		Trenton (T) 4m		Inshore 1m		Offshore 6m	
TAXA	Number	Biomass	Number	Biomass	Number	Biomass	Number	Biomass
Taxa / sample	46	-	29	-	30	-	9	
Total / m^2	90190	23425	7640	10623	43770	13008	1500	1758
Hydra	1250	34	0	-	0	-	0	-
Nematoda	180	16	566	26	0	-	35	2
Turbellaria	2560	1283	60	40	1090	721	0	-
Oligochaete	2180	384	2573	860	2950	654	710	1116
Leeches	20	110	7	8	0	-	0	-
Sphaeriidae	650	250	680	542	130	159	225	63
Gastropods	440	937	60	1025	10	528	0	-
Ostracoda	67520	3679	7	3	22130	880	0	-
Amphipods	3810	5506	20	15	7770	6864	10	4
Isopods	30	451	0	-	0	-	0	-
Mayflies	940	915	0	-	2300	1077	0	-
Trichoptera	1160	584	13	8	80	284	0	-
Coleoptera	3230	2078	7	6	1100	584	5	9
Chironomids	6040	7136	2987	8041	6020	1267	430	472
Other Diptera	20	25	20	26	0	-	60	73
Collembola	10	2	0	-	0	-	0	-
Mites	150	36	20	20	190	13	25	19

Table 2. Numbers/m^2 and wet biomass + shells (mg/m^2) of invertebrates in Big Bay (Bay of Quinte) during 1990 at a littoral shore site (1 m deep), and the offshore Index site.

	BIG BAY JULY 1990			
	Onshore 1 m		Index Site 6 m	
TAXA	Number	Biomass mg	Number	Biomass mg
Taxa / sample	40	-	15	
Total / m^2	62853	55712	4314	24109
Hydra	1933	92	0	0
Nematoda	-	-	9	1
Turbellaria	7880	4753	0	0
Oligochaete	7493	854	1318	1709
Leeches	53	109	0	0
Sphaeriidae	53	49	321	135
Gastropods	1173	286	0	0
Ostracoda	-	-	61	5
Amphipods	26187	29737	24	13
Isopods	93	220	14	19
Mayflies	1400	1680	0	0
Trichoptera	2333	6383	0	0
Coleoptera	3240	1903	5	7
Chironomids	10173	9642	1266	22184
Other Diptera	93	81	5	13
Collembola	373	4	0	0
Mites	0	0	19	3

Table 3. Numbers/m^2 and wet biomass + shells (mg/m^2) of invertebrates in the Lower Bay of Quinte during 1990 at littoral shore sites (<1 m) and offshore Index sites.

	LOWER BAY JULY 1990				AMHERST ISLAND JULY 1990			
	Prinyer Cove 1m		Conway 42m		Inshore 1m		Trans.#15 >20m	
TAXA	Number	Biomass	Number	Biomass	Number	Biomass	Number	Biomass
Taxa / sample	40	-	14	-	52	-	13	
Total / m^2	48196	26021	8822	14098	77000	67359	11434	22565
Hydra	5480	232	0	-		-	0	-
Nematoda	0	-	0	-		-	77	4
Turbellaria	1107	344	16	17	1093	349	3	1
Oligochaete	1813	229	2370	2569	8813	590	2783	4437
Leeches	13	7	0	-	53	5	89	148
Sphaeriidae	520	199	684	859	160	89	491	1205
Gastropods	1306	7228	4	408	1120	41455	26	987
Ostracoda	320	72	0	-	240	17	0	-
Amphipods	11520	6822	5180	8874	10320	7664	5983	11979
Isopods	0	-	296	332		-	669	1244
Mayflies	1826	180	0	-	14427	276	0	-
Trichoptera	7786	1200	0	-	3120	4367	9	5
Coleoptera	493	318	0	-	267	137	0	-
Chironomids	12266	8294	268	1037	32907	11853	609	2425
Other Diptera	2160	658	0	-	493	22	0	-

Table 4. Abundance of fluvial insects (numbers/m^2) and their wet biomass + shells (mg/m^2) on the cobble at littoral shore sites in the Bay of Quinte, July 1988, and 1990.

	TRENTON JULY 1988		BIG BAY JULY 1990		PRINYER COVE JULY 1990		AMHERST ISLAND JULY 1990	
Average No. Taxa / sample	46.0		40.6		39.0		52.5	
Total / m^2	No. / m^2	Biomass	No. / m^2	Biomass	No. / m^2	Biomass	No. / m^2	Biomass
	90,190	23,426	62,853	55,713	48,197	26,021	77,000	67,359
FLUVIAL SPECIES								
Capniidae	-	-	@	-	@	-	-	-
Stenacron interpunctatum	490	n.a	480.0	428.5	0.0	0.0	32.0	112.6
Stenonema tripunctatum	10	n.a	120.0	119.1	26.0	1.9	4808.0	104.77
Ephemerella sp.	-	-	586.0	591.3	0.0	0.0	105.0	73.76
Cheumatopsyche sp.	30	n.a	1346.6	3137.8	213.3	4.36	3920.0	1775.1
Helicopsyche borealis	260	n.a	-	0.0	3520.0	127.7	64.0	134.4
Hydroptila sp.	60	n.a	280.0	804.6	0.0	0.0	48.0	41.8
Stenelmis crenata	2840	n.a	2533.3	1985	480.0	315.5	8.0	1.28
Dubiraphia sp.	110	n.a	693.3	469.3	13.3	8.1	48.0	9.77
Psephenus sp.	@	n.a	@	-	40.0	232	8.0	8.8
Antocha sp.	20	n.a	80.0	-	2106.6	664.8	192.0	22.1

@ = present at these locations in May or December samples

Table 5. BioMAP and IOWATER MBI calculations for benthic littoral site LOT62_1 on bare bedrock at Point Petre (Lake Ontario), July 1990.

Name of Taxa	BCODE ID.SP#	LOT62_1 Ave No./m^2	Ln(num+1)	BioMAP Sensitivity Value	IOWA Biotic Index Value	exp (SV) × Ln(num+1)	EPT taxa	N × IOWA Index
Turbellaria	2300	1200	7.0909	1	7	19.2751	-	8400.0
Nematoda	1000	200	5.3033	2	6	39.1864	-	1200.0
Hydra	2200	140	4.9488	1	5	13.4521	-	700.0
Nais spp.	3406	72	4.2905	2	7.6	31.7024	-	547.2
Limnesia	4302	800	6.6859	1	5.7	18.1741	-	4560.0
Polyphemus	6126	100	4.6151	1	7	12.5452	-	700.0
Eurycercus	6165	880	6.7811	1	7	18.4328	-	6160.0
Harpacticoida	6201	300	5.7071	1	6	15.5135	-	1800.0
Copepodites	6300	340	5.8319	1	7	15.8527	-	2380.0
Candona	6402	80	4.3944	1	7	11.9454	-	560.0
Cypridae	6403	700	6.5525	0	9	6.5525	-	6300.0
Gammarus spp.	6703	480	6.1759	2	4	45.6338	-	1920.0
Collembola	7010	20	3.0445	1	7	8.2759	-	140.0
Psephenidae	7404	20	3.0445	3	5	61.1509	-	100.0
Antocha spp.	7803	100	4.6151	3	3	92.6972	-	300.0
Tanypods	8100	140	4.9488	1	8	13.4521	-	1120.0
Orthoclads	8400	14300	9.5681	2	5	70.6991	-	71500.0
Rheotanytarsus	8504	960	6.8680	3	4	137.9470	-	3840.0
Chironomini	8600	400	5.9940	1	6	16.2933	-	2400.0
		Sum	106.4602	-	-	648.7815	-	114627.2
		BioMAP Index	**6.094**					

Total all animals	21232.0
Total Animals (with IOWA values)	21232.0
Total 3 Most Dominant	16460.0
Taxa Richness	19.0
EPT Taxa Richness	0.0
% E.P.T.	0.0
Iowa Biotic Index MBI	**5.399**
% 3 Most Dominant	77.5
% Chironomid abundance	74.4
% Ephemeroptera abundance	0.0

Table 6. BioMAP and IOWATER MBI averages and Standard Error per site for Bay of Quinte Littoral sites (< 2 m) in 1988, 1990, 2001.

Transect Site	Year	Reps	BIOMAP	S.E	# TAXA	S.E	% E.P.T.	S.E	% Chir.	S.E	% Ephem.	S.E	IOWA MBI*	S.E
Trenton U4_01	1988	4	4.86	0.30	50.3	5.6	16.6	2.7	8.6	1.4	0.8	0.3	7.58	0.39
Rednersville U6_01	1988	4	4.62	0.04	39.0	4.9	9.7	0.7	10.3	3.1	1.3	0.5	7.20	0.53
Belleville U9_08	1988	2	5.28	0.16	47.0	5.0	12.0	2.3	14.3	0.6	0.8	0.8	6.73	0.09
Massasauga U10_01	1988	4	7.51	0.41	40.3	3.6	18.9	1.9	12.6	2.5	3.2	0.9	7.14	0.37
Big Island U14_01	1988	4	5.53	0.19	35.5	3.9	18.5	3.3	10.0	3.3	3.4	1.4	7.22	0.13
Big Island U14_01	1990	4	6.11	0.33	39.8	0.9	17.5	2.2	17.1	2.4	1.6	0.7	5.91	0.36
Prinyer Cove T10_F	1990	5	7.45	0.70	31.2	5.9	23.1	4.0	14.9	5.8	11.0	5.4	4.91	0.23
Amherst T15_G	1990	6	7.74	0.52	35.6	7.4	18.5	2.5	33.6	4.4	11.4	2.8	4.74	0.14
Pt. Traverse U44_04	1990	7	7.96	0.21	28.0	4.3	19.8	2.0	16.6	4.3	3.2	1.9	4.83	0.29
Pt. Petre LOT62_1	1990	2	6.09	-	19.0	-	0.0	-	74.4	-	0.0	-	5.40	-
BB Inshore gravel	2001	9	4.07	0.10	34.0	2.1	24.0	3.8	11.1	2.2	1.7	0.5	7.58	0.18
BB Inshore Plants	2001	9	4.30	0.23	29.0	1.5	17.2	1.4	13.7	3.2	0.9	0.5	7.72	0.10

* MBI (Macroinvertebrate Biotic Index) values lowest in high water quality streams with high abundance of Plecoptera stoneflies. IOWA stream values between 4.8 and 7.0 (Wilton 2004 Iowa DNR).

Table 7a. Lake Biotic Index calculations on Bay of Quinte benthic data from 1966 Trenton littoral sites (2.0 m depth). Identifications to genera following Verneaux et al. 2004.

Species / Site Depth	U4_03 2.0	U1_02 2.0	U5_01 1.7	U1_03 2.0	U1_01 1.9	Site Average	% Occurrence	Ql
Caecidotea (asellus)	40	-	-	-	20	12	40	-
Ceratopigonid	-	-	-	-	60	12	20	-
Chaoborus albatus	-	-	-	40	-	8	20	-
Chironomus spp	-	220	80-	260-	40	120	80	0.4
Coelotanypus concinnus	-	100	20	200	60	76	80	0.7
Cryptochironomus	-	-	20	-	40	12	40	-
Endochironomus	20	-	-	-	-	4	20	-
Gammarus fasciatus	60	-	40	20	100	44	80	-
Glyptotendipes spp.	60	20	-	20	60	32	80	0.5
Harnischia	-	-	100	-	60	32	40	-
Hyalella azteca	40	-	-	-	-	8	20	-
Hydrolimax grisea	40	-	-	-	-	8	20	-
Tubificids no hairs	200	800	200	1800	180	636	100	0.2
Marstonia decepta	20	-	-	-	-	4	20	-
Hydracarina	-	20	-	-	40-	12	50	-
Oecetis	-	-	-	-	20	4	20	-
Pisidium spp.	100	-	20	-	40	32	60	0.6
Polypedilum halterale	20		20	-	-	8	40	-
Procladius spp.	-	180	340	180	480	236	80	0.4
Grand Total	600	1340	840	2520	1200	**1300.0**	-	-

Littoral taxonomic richness	Vl :	19
Littoral density (m^{-2})	Dl :	1300
Littoral biotic index = ((√ Vl) • ln(D*l*))	Bl :	31.25
Corrective coefficient of loss from Zl to Z*f* k =(0.033 V**l**) + 1	k :	1.627
Littoral fauna quality index	Ql :	0.70
Taxonomic deficit index	D*f* :	0.84
Lake Biotic Index	LBI :	12.84

Table 7b. Lake Biotic Index calculations for 1966 Trenton deep sites >4 m depth.

Genera / Site	U3_05	U4_10	U4_05	U4_06	U1_05	U2_02	U2_03	No./m^2
Depth	4.0	4.6	4.5	4.3	4.0	4.0	4.0	Average
Caecidotea (asellus)	-	-	-	-	-	-	20	3
Ceratopigonid	-	40	-	-	-	-	-	6
Chaoborus albatus	-	-	-	20	20	20	-	9
Chironomus spp	180	100	80	120	140	100	40	108
Coelotanypus concinnus	240	60	60	40	100	40	80	89
Cryptochironomus spp.	40	20	40	-	-	40	60	29
Glyptotendipes	-	-	-	20	-	-	20	6
Harnischia	-	40	-	-	-	-	-	6
Helobdella stagnalis	-	20	-	-	-	-	20	6
Hyalella azteca	20	20	-	-	-	-	-	6
Hydrolimax grisea	20	-	-	20	-	-	-	6
Non Tubificids	-	-	-	20	-	20	-	6
Tubificids	900	40	300	2000	1320	200	220	711
Musculium lacustre	-	-	20	-	-	-	-	3
Paratendipes	-	-		20	-	-	-	3
Pisidium nitidum	-	-		20	-	-	-	3
Procladius spp.	260	200	280	60	440	60	160	208
Tanytarsus	-	80	-	-	120	40	40	40
Grand Total	1660	620	780	2340	2140	520	660	**1246**

Deep taxonomic richness	V*f*:	17
Profundal density (m^{-2})	Dp :	1246

Table 8. Lake Biotic Index values for areas in Bay of Quinte, Batchawana Bay (Lake Superior), Hamilton Harbour, and French lakes*. Littoral transects at sites <3 m depth vs. 66% maximum depth near mid channel of the Bay of Quinte. Zmax in Trenton and Big Bay = 10 m, lower Bay of Quinte = 60 m, Batchawana Bay = 46 m, and Hamilton Harbour = 24 m.

Year	Lake	Littoral Index BI	Taxonomic deficit Df	Lake Biotic Index LBI	Littoral Density No. / m^2	Littoral QI
1966	Trenton	31.2	0.85	12.8	1300	0.7
1989	Trenton	55.4	1.08	19.3	5740	0.8
1966	Big Bay	31.9	0.95	13.7	1260	0.7
2001	Big Bay all†	71.2	0.94	20.4	32450	0.9
2001	BB inshore gravel	64.0	0.96	19.6	21953	0.9
2001	BB in plant beds	62.2	1.00	19.7	42946	0.9
1966	Lower Quinte	41.8	0.84	14.8	1293	0.7
1990	Lower Quinte	75.3	0.97	21.3	5662	0.9
1977	Batchawana Bay	68.7	0.92	19.9	1813	1.0
2006	Hamilton Harbour	64.9	0.51	14.5	25275	0.6
2003	Lac Chalain (F*)	47.3	0.98	17.1	2657	1.0
2003	Lac Annecy (F*)	62.6	0.87	18.5	7645	1.0
2003	Lac Crop (F*)	26.2	1.0	13.0	857	0.9
2003	Lac Narlay (F*)	35.0	0.38	9.1	880	-

F* = French lakes from Borderell et al. 2005, Verneaux et al. 1995, with Lac Narlay listed as a highly dystrophic lake.
† = all Big Bay transect data combined (gravel + plant beds).

Appendix 1. Bay of Quinte littoral benthic species list for 1990 with frequency of occurrence, BioMAP and IOWATER sensitivity values, and LBI biotic values.

Taxa Name	FORTRAN BCODES	ITIS Species Name	ITIS TSN	Frequency	BioMAP Value	IOWATER Value	Lake Biotic Value
NEMATODA	1000	Nematoda	59490	1	2	6	0.1
HYDRA	2200	Hydra	50845	13	1	5	-
PLANARIA	2310	Planaria	54528	1	1	6	-
PROCOTYLA (FLUVIATILUS)	2315	Procotyla fluviatilis	54471	4	2	5	-
DUGESIA TIGRINA	2316	Dugesia tigrina	54504	12	1	6	-
RHABDOCOELIDAE	2330	Neorhabdocoela	54280	1	2	6	-
HYDROLIMAX GRISEA	2401	Hydrolimax grisea	54465	18	1	6	-
PROSTOMA SP. (CANAD.)	2910	Prostoma	57577	5	2	5	-
OLIGOCHAETA	3000	Oligochaeta	68422	2	1	8.5	0.2
STYLODRILUS HERINGIANUS	310201	Stylodrilus heringianus	68452	3	3	3	0.3
ENCHYTRAEIDS	3200	Enchytraeidae	68510	3	3	3	0.3
IMM TUBIFICIDS + HAIRS	3301	Tubificidae	68585	11	1	10	0.1
IMM TUBIFICIDS NO HAIRS	3302	Tubificidae	68585	21	1	8.5	0.2
SPIROSPERMA FEROX	330701	Peloscolex ferox	68609	6	1	8	0.1
CHAETOGASTER DIAPHANUS	340101	Chaetogaster diaphanus	68935	6	1	7.6	0.3
CHAETOGASTER LONGI	340104	Chaetogaster longi	68941	3	1	7.6	0.3
UNCINAIS UNCINATA	340401	Uncinais uncinata	68990	1	2	6	0.3
NAIS SPP.	3406	Nais	68946	8	2	7.6	0.3
NAIS COMMUNIS	340601	Nais communis	68950	3	2	7.6	0.3
NAIS VARIABILIS	340602	Nais variabilis	68959	6	2	7.6	0.3
NAIS SIMPLEX + BARBATA	340605	Nais simplex	68957	5	2	7.6	0.3
NAIS PARDALIS	340606	Nais pardalis	68954	3	2	7.6	0.3
NAIS BRETSCHERI	340609	Nais bretscheri	68961	1	2	7.6	0.3
V. INTERMEDIA	340802	Vejdovskyella intermedia	69015	2	1	7	0.3
STYLARIA LACUSTRIS	341001	Stylaria lacustris	68872	3	1	7	0.3
PIGUETIELLA MICHIGANENS	341101	Piguetiella michiganensis	68994	4	3	3	0.3
PRISTINA SPP.	3413	Pristina	68876	2	3	3	0.3
HIRUDINEA(GEN. LEECH)	3800	Hirudinea	69290	4	1.5	7.5	-
HELOBDELLA STAGNALIS	380101	Helobdella stagnalis	69398	7	2	6.7	-
GLOSSIPHONIA	3802	Glossiphonia	69380	1	2	7	-
GLOSSIPHONIA COMPLANATA	380201	Glossiphonia complanata	69381	2	2	7	-
ERPOBDELLA PUNCTATA	381401	Erpobdella punctata	69445	2	1	7.8	-
MANAYUNKIA SPECIOSA	390101	Manayunkia speciosa	68172	2	2	5	0.3
ACARIFORME	4010	Acari	733321	4	1	5.7	-
HYDRACHNA	4101	Hydrachna	83123	15	1	5.7	-
LIMNESIA	4302	Limnesia	83051	2	1	5.7	-
PHYSA SPP.	5101	Physella	76698	10	0	8	-
PHYSELLA GYRINA	510102	Physella gyrina	76735	8	0	8	-
FOSSARIA EXIGUA	510401	Fossaria exigua	76499	1	1	3	-
FOSSARIA MODICELLA	510402	Fossaria modicella	76501	6	1	3	-
GYRAULUS PARVUS	510701	Gyraulus parvus	76595	7	1	8	-
PROMEN. EXACUOUS	510802	Promenetus exacuous	76622	4	2	6	-
GONIO.(ELIMA) LIVESCENS	511201	Elimia livescens	71868	3	2	2.5	-
PLEUROCERA ACUTA	511301	Pleurocera acuta	71550	4	1	3	-

continued

Appendix 1. Continued. Bay of Quinte littoral benthic species list for 1990.

Taxa Name	FORTRAN BCODES	ITIS Species Name	ITIS TSN	Frequency	BioMAP Value	IOWATER Value	Lake Biotic Value
BITHYNIA TENTACULATA	511401	Bithynia tentaculata	70794	7	1	8	-
VALVATA TRICARINATA	511501	Valvata tricarinata	70354	7	1	8	-
VALVATA SINCERA	511502	Valvata sincera	70349	1	2	8	-
AMNICOLA LIMOSUS	511601	Amnicola limosus	70748	14	2	6	-
AMNICOLA WALKERI	511602	Amnicola walkeri	70751	1	2	6	-
MARSTONIA DECEPTA	511801	Marstonia decepta	70534	6	2	6	-
PROBYTHINELLA LACUSTRIA	511901	Probythinella lacustris	70508	1	2	6	-
UNIONIDAE CLAM	5200	Unionidae	79913	1	1	8	-
SPHAERIUM SPP.	5301	Sphaerium	81391	5	1	8	0.6
PISIDIUM SPP.	5303	Pisidium	81400	18	1	8	0.6
DREISSENA POLYMORPHA	550101	Dreissena polymorpha	81339	2	0	9	-
POLYPHEMUS	6126	Polyphemus	83968	1	1	7	-
EURYCERCUS	6165	Eurycercus	84016	1	1	7	-
HARPACTICOIDA	6201	Harpacticoida	86110	1	1	6	-
COPEPODITES	6300	Copepoda	85257	2	1	7	-
CANDONA	6402	Candona	85132	3	1	7	-
CYPRIDAE	6403	Cyprididae	84462	2	0	9	-
CAECIDOTEA RACOVITZAI	660103	Caecidotea racovitzai	92692	12	1	8	-
HYALELLA AZTECA	670101	Hyalella azteca	94026	12	2	8	-
GAMMARUS SPP.	6703	Gammarus	93773	2	2	4	-
GAMMARUS FASCIATUS	670301	Gammarus fasciatus	93780	28	2	4	-
CRANGONYX GRACILIS	670401	Crangonyx gracilis	95086	4	3	4	-
COLLEMBOLA	7010	Collembola	99237	11	1	7	-
CAPNIIDAE	7140	Capniidae	102643	3	3	5	0.9
BAETIS FLAVISTRIGA	721102	Baetis flavistriga	100835	2	1	4	0.9
EPHEMERELLA SP.	7231	Ephemerella	101233	6	3	2	0.9
HEPTAGENIIDAE	7240	Heptageniidae	100504	1	2	4	0.9
HEPTAGENIA SP.	7241	Heptagenia	100602	1	3	3	0.9
STENONEMA SP.	7242	Stenonema	100507	4	2	3.7	0.9
STENONEMA TRIPUNCT	724201	Stenonema tripunctatum	100543	4	3	4	0.9
STENONEMA VICARIUM	724208	Stenonema vicarium	100548	1	3	2	0.9
TRICORYTHODES SP.	7245	Tricorythodes	101405	6	2	4	0.9
STENACRON INTERPUCTATUM	724702	Stenacron interpunctatum	100714	3	2	7	0.9
CAENIS	7261	Caenis	101478	11	1	7	0.5
HELICOPSYCHE (BOREALIS)	7301	Helicopsyche borealis	117020	10	2	3	0.9
MOLANNA	7302	Molanna	116474	3	2	6	0.9
POLYCENTROPUS	7309	Polycentropus	117044	6	1	6	0.9
LEPTOCERIDAE	7310	Leptoceridae	116547	10	0	4	0.9
CERACLEA SP.	7311	Ceraclea	116684	3	1	3	0.9
CERACLEA DILUTUS	731102	Ceraclea diluta	116686	5	1	3	0.9
CERACLEA FLAVA	731103	Ceraclea flava	116705	1	1	3	0.9
CERACLEA ALAGMUS	731104	Ceraclea alagma	116737	1	1	3	0.9
C.C. MACULATA	731114	Ceraclea maculata	116725	1	1	3	0.9
LEPTOCERUS AMERICANUS	731201	Leptocerus americanus	116678	1	0	4.6	0.9
SETODES	7314	Setodes	116548	1	2	8	0.9

continued

Appendix 1. Continued. Bay of Quinte littoral benthic species list for 1990.

Taxa Name	FORTRAN BCODES	ITIS Species Name	ITIS TSN	Frequency	BioMAP Value	IOWATER Value	Lake Biotic Value
OECETIS	7315	Oecetis	116607	12	2	8	0.9
OECETIS AVARA GRP.	731502	Oecetis avara	116608	7	2	8	0.9
NECTOPSYCHE	7316	Nectopsyche	116651	7	1	3	0.9
MYSTACIDES SEPCULCHRAL.	7317	Mystacides sepulchralis	116599	9	1	8	0.9
MYSTACIDES ALAFIMBRIATA	731702	Mystacides alafimbriatus	116603	2	1	8	0.9
MYSTACIDES LONGICORNIS	731703	Mystacides longicornis	116601	1	1	8	0.9
TRIAENODES SP.	7318	Triaenodes	116565	1	1	6	0.9
LEPIDOSTOMA	7346	Lepidostoma	116794	16	4	1	0.9
HYDROPTILA	7352	Hydroptila	115641	10	2	6	0.9
PYCNOPSYCHE SP.	7377	Pycnopsyche	116409	3	3	4	0.9
CHEUMATOPSYCHE SP.	7382	Cheumatopsyche	115408	16	2	5	0.9
HYDROPSYCHE RECURVATA	738407	Hydropsyche recurvata	115520	10	2	4	0.9
HYD. SEPARATA(GLUTTATA)	738408	Hydropsyche guttata	115498	1	2	4	0.9
MICRASEMA	7393	Micrasema	116958	1	4	2	0.9
AGARODES	7398	Agarodes	116983	3	3	2	0.9
PSEPHENIDAE	7404	Psephenidae	114069	5	3	5	-
DYTISCIDAE	7410	Dytiscidae	111963	2	1	5	-
HYDROVATUS	7417	Hydrovatus	112257	1	0	3.7	-
ELMIDAE	7420	Elmidae	114093	1	2	4	-
DUBIRAPHIA	7421	Dubiraphia	114126	10	1	6	-
OPTIOSERVUS	7424	Optioservus	114177	1	2	4	-
STENELMIS CRENATA	742601	Stenelmis crenata	114102	12	2	5	-
ECTOPRIA NERVOSA	742801	Ectopria nervosa	114088	1	3	5	-
COENAGRIONIDAE	7640	Coenagrionidae	102077	1	1	8	-
NYMPHULA SP.	7752	Nymphula	117659	1	0	7	-
ANTOCHA SP.	7803	Antocha	119656	11	3	3	-
EMPIDIDAE	7845	Empididae	135830	10	2	6	-
CERATOPIGONID	7900	Ceratopogonidae	127076	1	0	6	-
PERICOMA	7922	Pericoma	125514	1	2	4	-
TANYPODS	8100	Tanypodinae	127994	2	1	8	0.7
PROCLADIUS SPP.	8101	Procladius	128277	6	0	9	0.4
ABLABESMYIA SPP.	8102	Ablabesmyia	128079	10	2	5	0.7
THIENEMANNIMYIA GRP.	8107	Thienemannimyia	128236	18	2	5	0.7
CLINOTANYPUS	8108	Clinotanypus	127996	1	1	7	0.7
POTTHASTIA LONGIMANA	820301	Potthastia longimana	128412	1	2	4.3	0.6
ORTHOCLADS	8400	Orthocladiinae	128457	4	2	5	0.8
CORYNONEURA	8401	Corynoneura	128563	9	2	5	0.8
THIENEMANNIELLA	8402	Thienemanniella	129182	7	2	5	0.8
NANOCLADIUS (MICROCR.)	8404	Microcricotopus	130049	8	3	4	0.8
PSECTROCLADIUS SP.	8407	Psectrocladius	129018	6	1	5	0.8
PARAKIEFFERIELLA	8409	Parakiefferiella	128968	3	2	5	0.8
DIPLOCLADIUS	8410	Diplocladius	128670	1	3	4	0.8
EUKIEFFERIELLA	8411	Eukiefferiella	128689	1	1	5	0.8
ORTHOCLADIUS SPP.	8413	Orthocladius	128874	13	2	4	0.8
ORTHOCLADIUS LACTEIPENN	841302	Orthocladius mallochi	128916	5	2	4	0.8

continued

Appendix 1. Continued. Bay of Quinte littoral benthic species list for 1990.

Taxa Name	FORTRAN BCODES	ITIS Species Name	ITIS TSN	Frequency	BioMAP Value	IOWATER Value	Lake Biotic Value
CRICOTOPUS BICINCTUS	841402	Cricotopus bicinctus	128583	8	2	4	0.5
CRIC. FESTIVELLUS GRP.	841404	Cricotopus festivellus	128594	3	2	4	0.5
CRICOTO. TREMULUS GRP.	841406	Cricotopus tremulus	128651	11	3	4	0.5
CRICOTO. TRIFASCIA GRP.	841407	Cricotopus trifascia	128659	2	3	4	0.5
CRICOTOPUS (ISOCLADIUS)	841408	Cricotopus (Isocladius)	568515	1	0	8	0.5
CRICOTO. SYLVESTRIS GRP.	841409	Cricotopus sylvestris	128645	2	2	5	0.5
HYDROBAENUS	8418	Hydrobaenus	128750	1	1	6	0.8
SYNORTHOCLADIUS	8419	Synorthocladius	129161	3	3	4	0.8
METRIOCNEMUS	8421	Metriocnemus	128821	1	3	4	0.8
PSEUDOSMITTIA	8423	Pseudosmittia	129071	3	2	5	0.8
TVETENIA	8427	Tvetenia	129197	1	2	4.3	0.8
TANYTARSINI	8500	Tanytarsini	129872	1	2	5	0.6
RHEOTANYTARSUS	8504	Rheotanytarsus	129952	4	3	4	0.8
PARATANYTARSUS	8505	Paratanytarsus	129935	1	1	6	0.8
CLADOTANYTARSUS	8506	Cladotanytarsus	129873	9	2	6	0.6
TANYTARSUS	8507	Tanytarsus	129978	16	2	5	0.6
MICROPSECTRA	8508	Micropsectra	129890	5	3	3	0.8
ZAVRELIA	8512	Zavrelia	130038	1	2	4.3	0.8
CHIRONOMINI	8600	Chironomini	129229	5	1	6	0.7
PSEUDOCHIRONOMUS	8601	Pseudochironomus	129851	12	1	6	0.7
XENOCHIRONOMUS (AXARUS)	860205	Xenochironomus	129837	2	2	4	0.7
DEMICRYPTOCHIRONOMUS	8604	Demicryptochironomus	129421	1	1	6	0.7
CRYPTOCHIRONOMUS SP.	8605	Cryptochironomus	129368	10	1	6	0.7
PARACHIRONOMUS	8606	Parachironomus	129564	8	1	6	0.7
CHIR. ANTHRACINUS GRP.	861202	Chironomus anthracinus	129258	6	1	8	0.4
CHIR. SEMIREDUCTUS GRP.	861203	Chironomus plumosus	129303	1	0	9	0.4
DICROTENDIPES FUMIDUS	861401	Dicrotendipes fumidus	129436	19	0	8	0.5
DICROTENDIPES MODESTUS	861402	Dicrotendipes modestus	129448	9	0	8	0.5
DICROTEND. NEOMODESTUS	861403	Dicrotendipes neomodestus	129450	6	0	8	0.5
GLYPTOTENDIPES	8615	Glyptotendipes	129483	11	0	8	0.5
POLYPEDILUM SP. (TR)	8617	Polypedilum	129657	3	0	6	0.7
POLYP. ILLINOENSE	861706	Polypedilum illinoense	129686	4	1	6	0.7
POLYPEDILUM CONVECTUM	861707	Polypedilum convictum	129671	1	2	4	0.7
POLYPEDILUM LAETUM	861708	Polypedilum laetum	129692	3	2	4	0.7
POL(TRIPODURA)SCALAENUM	861715	Polypedilum scalaenum	129708	3	1	6	0.7
POL.(TRIPODURA)SIMULANS	861716	Polypedilum simulans	129711	4	1	6	0.7
NILOTHAUMA	8618	Nilothauma	129548	5	1	6	0.7
ENDOCHIRONOMUS	8619	Endochironomus	129470	8	0	8	0.7
PHAENOPSECTRA SPP.	8620	Phaenopsectra	129637	9	1	6	0.5
PHAENOPSECTRA FLAVIPES	862003	Phaenopsectra flavipes	129642	1	1	6	0.5
PARALAUTERBORNIELLA SP.	8621	Paralauterborniella	129616	1	0	7	0.7
STICTOCHIRONOMUS	8622	Stictochironomus	129785	9	2	5	0.7
MICROTENDIPES	8623	Microtendipes	129535	21	2	5	0.7
PARATENDIPES	8624	Paratendipes	129623	6	2	4.3	1.0
BRYOZOA	9000	Bryozoa	155469	1	1	6	