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A Comparison of Urbanization Effects on Stream Benthic Macroinvertebrates and Water Chemistry in an Urban and an Urbanizing Basin in Southern Ontario, Canada

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Benthic invertebrate communities were compared in several watersheds within an urban basin and an urbanizing basin in southern Ontario, Canada. The urban watersheds of the Lake Ontario basin and the urbanizing watersheds within the Lake Simcoe basin share similar geologies, soils, and climates, but differ in the stage of urban development within these two basins. Correspondence analysis showed that invertebrate populations formed distinct groups split between these two basins owing to intense urban development in the Lake Ontario watersheds versus the agricultural nature of the Lake Simcoe basin. Canonical correspondence analysis ordinations indicated that the major environmental gradients were related to urban land cover (imperviousness), chloride, nitrates and stream order factors. Urban land cover and chloride were most strongly associated with the first axis. The typical logarithmic relationship between urban land cover and benthos found in other studies was not evident in this study. Rather, 9 of the 12 metrics tested had significant linear relationships with urban land cover. The Hilsenhoff Family Biotic Index and percent Oligochaeta metrics showed the strongest positive linear relationships with urban land cover. Pollution sensitive groups (Ephemeroptera, Plecoptera, and Trichoptera) along with richness and diversity measures decreased with increasing urbanization.

Key Words: **benthos, macroinvertebrate, urbanization, impervious, chloride**

Introduction

Human activities play a complex role in shaping aquatic ecosystems. Urbanized, highly populated areas are characterized by significant proportions of impermeable surfaces and insufficient areas of green space. Urbanization causes alterations of the chemical, physical, and hydrologic properties of streams, which in turn affect algae, fish, and invertebrate communities (e.g. Winter and Duthie 1998; Sonneman et al. 2001; Morse et al. 2003; Stanfield and Kilgour 2006). Significant amounts of impervious surfaces contribute to increased stormwater runoff and peak discharges, decreased infiltration and recharge, and reductions in baseflow (Leopold 1968; Klein 1979). Urban streams are often subject to increased sediment loads, channelization, and stream burial. In addition, they have higher loads of contaminants such as road salts, metals, nutrients, and pesticides, and are usually higher in temperature than natural river systems (Mackie 2001; Paul and Meyer 2001).

The merit of using benthic macroinvertebrates (benthos) as stream quality indicators has been summarized by several authors (e.g. Rosenberg and Resh 1993; Stepenuk et al. 2002; Wang and Kanehl 2003). Urban development simplifies biotic assemblages, decreases diversity and taxonomic richness, and increases the density of pollution tolerant taxa (Meyer et al. 2005). Numerous studies have linked increased urbanization to changes in benthic communities (e.g. Jones and Clark 1987; May et al. 1997; Yoder et al. 1999). More recent work includes the investigation of 20 catchments in Maine (Morse et al. 2003) and 43 streams in Wisconsin (Stepenuck et al. 2002), which found that the percentage of sensitive orders (Ephemeroptera, Plecoptera, Trichoptera [EPT]) along with richness and density decreased with increasing imperviousness in the catchments. In Colorado rivers, Voelz et al. (2005) found that the number of scraper and clinger taxa were lower in urban streams relative to reference sites due to shifts in algal assemblages which reflect changes in food and habitat resources for the benthic community.

Numerous studies have attempted to determine a value of watershed imperviousness which defines the maximal amount of impervious cover which results in little or no impairment to the biological community. Although a universal threshold cannot be established because of widespread differences in urban development and associated mitigation measures, most studies have found an approximate threshold value between 5-15% impervious cover within a watershed. Schueler and Galli (1992) determined that benthic macroinvertebrate diversity was good to fair when imperviousness was less than 10%, but diversity became poor when imperviousness exceeded 12%. Steedman (1988)

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used a measure of urban land use (both pervious and impervious urban areas) to determine that fish diversity changed from fair to poor around the 35% mark, which corresponds to approximately 7-10% imperviousness (Booth and Reinhelt 1993). Jones and Clark (1987), Shaver and Maxted (1995), May et al. (1997), Yoder et al. (1999), and Stanfield and Kilgour (2006) demonstrated a threshold response in the benthic macroinvertebrate community between 8-15% impervious cover. Using high resolution imagery, Ourso and Frenzel (2003) found a lower threshold response in macroinvertebrate metrics at 1-8% imperviousness.

Studies of the effects of urban land use on benthos can be divided into three categories: those examining a gradient of increasing urbanization in one catchment; those looking at an urbanized versus reference catchment; and large studies considering urban gradients and invertebrate response in several catchments (Paul and Meyer 2001). Most studies fall into the first two categories due to budgetary constraints and political (i.e. agency) boundaries. With the exception of Stanfield and Kilgour (2006) few large scale, multi-watershed studies of urbanization effects on benthos can be found for Ontario. Tributary streams to Lake Ontario and Lake Simcoe offer a unique opportunity to compare adjacent basins with similar geologies in different stages of urbanization. Development in the Lake Simcoe basin is following a similar pattern to the Lake Ontario basin where agricultural land is being urbanized; however, development is lagging behind by several decades in the Lake Simcoe basin. For this study, benthos and water quality were sampled along an urban gradient across the Lake Ontario and Lake Simcoe basins in the greater Toronto and surrounding area. This study examined the relationship between benthos community composition and urbanization in an urbanized (Lake Ontario) and urbanizing basin (Lake Simcoe). The objectives of the study were: 1. to compare benthic assemblages in two large-scale, adjacent basins in different stages of urbanization; 2. to determine the association between water quality variables and benthic invertebrate community composition; and 3. to characterize the nature of biotic response to urbanization using benthic macroinvertebrate metrics.

Methods

Study Area

Prior to the 1800s, Upper Canada was almost completely forested with a mixture of pine and deciduous forests (Steedman 1988). By the late 1800s, most of the forests had been cleared for agriculture. Today, the City of Toronto has a population of 2.5 million people with an additional 750,000 people in the City of Mississauga and 165,000 in the City of Oakville located to the west of Toronto (Statistics Canada 2007). Urbanization in this area began to substantially increase following the Second World War (Steedman 1988). In the Toronto and Region Conservation Authority jurisdiction (which includes Toronto watersheds but excludes the Credit River watershed), about 9% of the region is devoted to agriculture, 44% is covered by woodland, wetland, scrubland, and meadow, and 48% is urbanized (TRCA 2007). Lake Simcoe is the largest lake in southern Ontario, outside of the Great Lakes. Currently, about 47% of the Lake Simcoe basin is devoted to agriculture, 40% is covered with woodlands, wetlands, and scrubland, and 12% is urbanized (Winter et al. 2007). The population of the Lake Simcoe basin is approximately 400,000 (LSRCA 2009) with the city of Barrie being the largest urban centre with a population of 128,000 people (Statistics Canada 2007).

The geology of the study area is similar in both the Lake Simcoe and Lake Ontario basins and is characterized by soils comprised mainly of glacially deposited sediment (Eyles 2002). The headwaters of the streams flowing into the south shore of Lake Simcoe and the majority of Lake Ontario tributaries in the Toronto area are located on the Oak Ridges Moraine. The Oak Ridges Moraine is situated between the Trent River and the Niagara Escarpment at approximate elevations of 300-400 m above mean sea level. The moraine forms the surface water divide between Lake Simcoe and Lake Ontario and consists of five major geological units common to both basins: Whitby Shale, Thorncliffe Formation, Newmarket Till, Oak Ridges Moraine sediments, and Halton Till (Eyles 2002).

Study Design

Samples were collected from 13 watersheds in the Lake Simcoe basin and 6 watersheds along the north shore of Lake Ontario (Fig. 1). Thirty-three study sites across the two basins were selected to represent a wide range of urban land cover in an urban basin and an urbanizing basin in southern Ontario (Fig. 1). Study sites were selected over the entire range of an urban gradient within each basin. The lower end of the gradient was represented by selecting sampling locations upstream of major urban centres and in the upper reaches of urban centres. The higher end of the urbanization gradient was represented by selecting sites within urban centres and in the lowest reaches of urban centres. Sites along the entire gradient were required to investigate the relationship between benthic metrics and urbanization. Potential study sites were identified using geographical information system data, and were based on the amount of urban land cover and site access. To minimize influences from point sources of pollution, areas downstream of landfills, sewage treatment plants, and golf courses were avoided. Samples were collected upstream of bridge crossings and major storm sewer outfalls. Historical land use information was used to avoid selecting sites with former point sources (e.g. tanneries, landfills). Hence, resulting study sites represented ambient urban conditions ranging

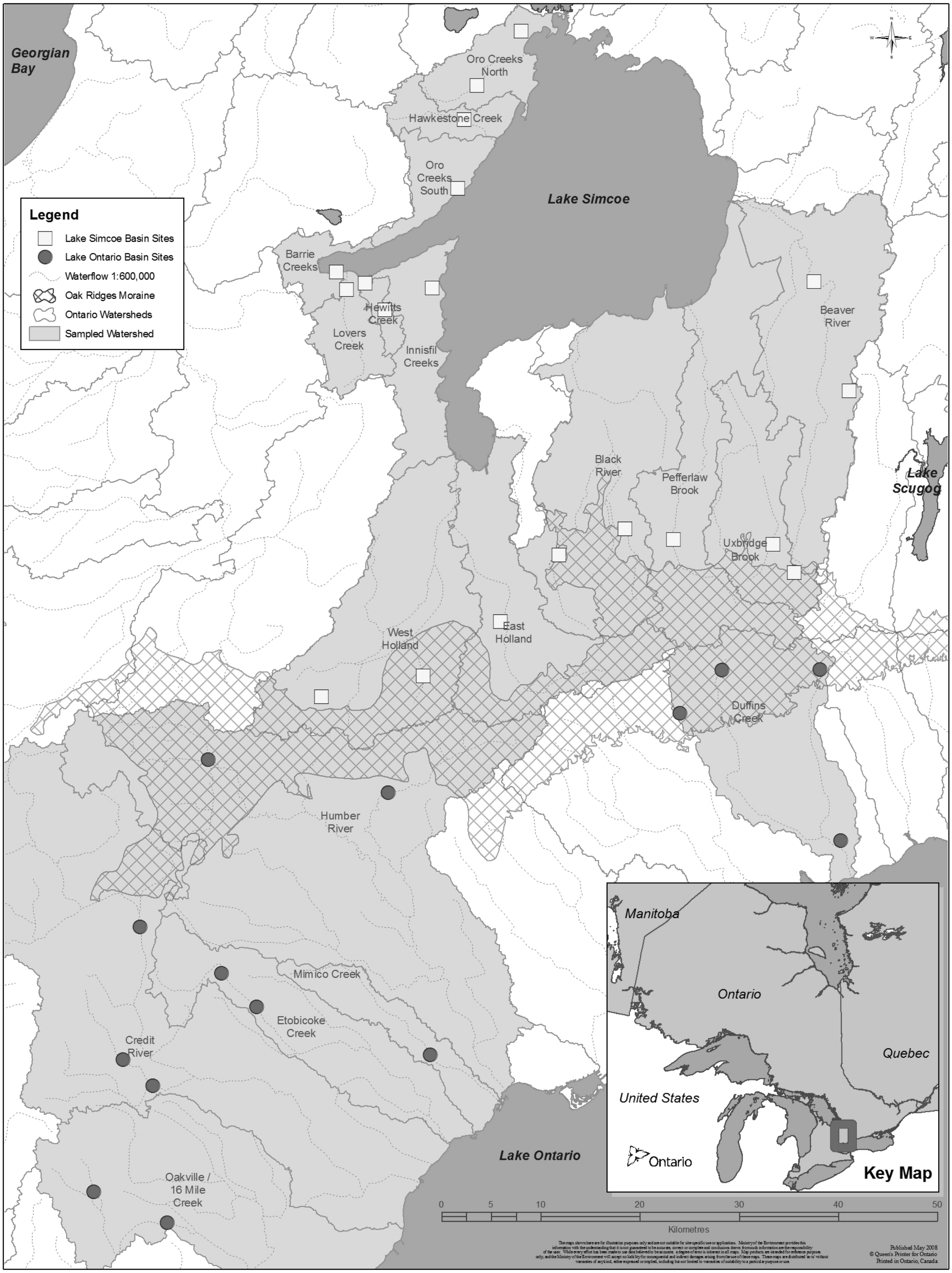

Fig. 1. Benthos and water chemistry sampling sites in the Lake Ontario and Lake Simcoe basins.

TABLE 1. Summary of site characteristics for 14 sites in the Lake Ontario basin, and 19 sites in the Lake Simcoe basin.

Site Characteristics	Lake Ontario			Lake Simcoe		
	Min	*Median*	*Max*	*Min*	*Median*	*Max*
Catchment Area (ha)	144	2136	9824	204	1972	12392
Urban (%)	3	10	45	0	11	86
Width (m)	2.4	5	8.9	1.8	4	22
Stream order	2	4	6	2	3	4
Monthly mean air temperature 2001 (°C)	-2.0	8.1	24.2	-9.5	8.3	27.9
Monthly mean air temperature 2002 (°C)	-4.1	9.5	23.2	-7.5	7.2	29.1
Total Annual Precipitation 2001 (mm)	11.6	59.1	103.2	65.4	75.8	157.6
Total Annual Precipitation 2002 (mm)	31.2	45.5	108.8	36.5	69.7	127.8

from 0-86% urbanization (Table 1). Study sites within the Lake Ontario and Lake Simcoe basin were similar in catchment size, width, and stream order (Table 1). Sampling occurred during summer baseflow conditions in 2001 and 2002. Local weather station data showed that temperature and precipitation were comparable between the two basins between years (Table 1).

Data Collection and Sampling Procedures

Water chemistry. Prior to benthos sampling, grab samples were collected during baseflow at mid-depth of the thalweg and analyzed for pH, chloride, 5-day biological oxygen demand (BOD), nutrients, and metals. Chemistry samples were analyzed at the Ontario Ministry of the Environment laboratory using standard methods.

Benthos community collection. Quantitative benthic invertebrate samples were collected using a Hess sampler (0.1 m^2 area, 582 µm mesh net size). Sampling was limited to riffle habitat where invertebrate biomass is greatest (Rosenfeld and Hudson 1997). Subtle impacts are detectable in single habitat benthos samples without being obscured by multiple habitat variability (Kerans et al. 1992; Parsons and Norris 1996; Hewlett 2000). Hence, three replicate samples were taken within each riffle to account for microhabitat differences. Rocks within the sampler were brushed to dislodge any attached invertebrates and then removed. The remaining substrate was disturbed manually to a depth of approximately 5 cm for 3 min. Dislodged invertebrates were removed from the collection net and collector. The three replicate samples were stored separately and preserved in 70% ethanol. All organisms were hand-picked from each replicate using a 10X magnifying lens. For each replicate, a 100+ organism sub-sample was taken using a grid and random numbers for a total of 300+ organisms per site. Invertebrates were identified to family level (exception Acari [subclass], Nemata [phylum], Oligochaeta [subclass], Turbellaria [class]; all were treated as families for analytical purposes) using appropriate keys (Pennak 1989; Merritt and Cummins 1996).

Determination of urban land cover. Urban areas within the catchment upstream of each site was calculated using ArcView 3.1 with 1999 orthoimagery, a digital elevation model, and subwatershed delineations provided by the local conservation authorities. Urban areas considered as development within a watershed included residential, commercial and industrial areas and incorporated both pervious and impervious surfaces. Stream order was an anticipated co-variable and was calculated according to Strahler (1957) using ArcGIS 9.2.

Data Analysis

Benthos community composition – Basin comparison. A two pronged approach was used to evaluate similarities and differences of the benthos communities in the tributary streams to Lake Ontario and Lake Simcoe. First, presence-absence data was examined to determine if there were families in common and/or families unique to each basin. Second, correspondence analysis (CA) was used to determine if there was separation between Lake Ontario and Lake Simcoe tributary streams in terms of community assemblage. Because the two lake basins are adjacent and experience similar weather patterns and climate, it is assumed that the species pool and the colonization and dispersal rates of benthos in the study basins are similar. Furthermore, undisturbed streams (i.e. not influenced by anthropogenic activity) with similar watershed and habitat characteristics (e.g. geology, catchment size, substrate, velocity) should have comparable benthic communities (Lavoie et al. 2006). Differences in benthos communities between the two basins are assumed to be a reflection of anthropogenic disturbance history (i.e. agriculture and urbanization).

Water chemistry and benthos community structure. To determine if inter-basin differences in water chemistry existed, one-tailed unpaired t-tests (α<0.05) were used. Canonical Correspondence Analysis (CCA) is a direct gradient analysis technique that was used to examine the association between water chemistry variables and benthic invertebrate community composition and to identify environmental gradients. In this study, CCA was used to identify environmental gradients in water chemistry, stream order, and land use in relation to benthos community structure and to determine which benthos groups were associated with urban water chemistry parameters (i.e. metals, nutrients, chloride, BOD). Prior to analysis, the data was log (X+1) transformed to improve normality and lessen the influence of abundant taxa. Families which did not occur at greater than 10% of the sites were excluded to reduce the influence of rare taxa on ordinations. The ratio of eigenvalues resulting from the constrained (CCA) and unconstrained (CA) ordinations indicated to which extent the selected environmental variables explained BMI community composition. All CA and CCA analyses were performed using the Biplot add-in for Excel.

Benthos response to urbanization. The benthic macroinvertebrate community was described by ten univariate metrics that have been shown to be sensitive to urbanization (Table 2). A combination of richness metrics (richness, EPT richness, trichoptera richness), compositional metrics (percent EPT, percent Chironomidae, percent Oligochaeta), functional measures (percent clingers, percent scrapers), a diversity measure (Simpson's diversity), and one weighted index (Hilsenhoff's modified Family Biotic Index [FBI]) were used. Unlike multivariate approaches which look at the benthos community as a whole, univariate metrics provide summation statistics for individual groups, thus providing greater insight into biological properties like pollution and disturbance tolerance, feeding ecology, and taxonomic diversity (e.g. Ourso and Frenzel 2003). Two multivariate metrics were also calculated: correspondence axis 1 (CAI) and correspondence axis 2 (CAII). The significance of inter-basin differences in benthic metrics was determined using one-tailed t-tests ($\alpha<0.05$).

The relationship between percent urban land cover and the 12 benthos community metrics was examined using regression analysis. Regression analysis provided a tool to statistically determine if any metrics varied as a function of urban land use. Linear models have been shown to describe the relationship between urbanization and benthic community metrics where an increase or decrease in a community attribute is observed with increases in urbanization (e.g. Morse et al. 2003). Non-linear relationships can describe a threshold response of benthic and fish community assemblages to urbanization whereby further increases in urbanization do not result in further deterioration of biotic communities (e.g. Stepenuck et al. 2002; Ourso and Frenzel 2003; Walsh et al. 2005; Stanfield and Kilgour 2006). First, second, and third order (i.e. x, x^2, and x^3) polynomial terms of the independent variable in multiple regressions for each metric were used to determine the type of relationship

TABLE 2. Metrics used to analyze benthos data and their predicted response

Metric	*Response to urbanization*	*Reference(s)*
Richness Measures		
Family richness	Decrease	Garie and MacIntosh 1986; Walsh et al. 2001; Stepenuck et al. 2002; Morse et al. 2003; Voelz et al. 2005
EPT family richness	Decrease	Garie and MacIntosh 1986; Walsh et al. 2001; Stepenuck et al. 2002; Morse et al. 2003; Voelz et al. 2005
Trichoptera family richness	Decrease	Barbour et al. 1999
Compositional Measures		
% EPT	Decrease	Pratt et al. 1981; Duda et al. 1982; Pitt and Bozeman 1982; Jones and Clark 1987; Hachmoller et al. 1991; Walsh et al. 2001; Stepenuck et al. 2002; Morse et al. 2003; Voelz et al. 2005
% Chironomidae	Increase	Pratt et al. 1981; Duda et al. 1982; Whiting and Clifford 1983; Garie and MacIntosh 1986; Maxted 1996
% Oligochaeta	Increase	Pratt et al. 1981; Duda et al. 1982; Pitt and Bozeman 1982; Voelz et al. 2005
Functional Grouping Measures		
% Clingers	Decrease	Voelz et al. 2005
% Scrapers	Decrease	Stepenuck et al. 2002; Voelz et al. 2005
Diversity Measures		
Simpson's Diversity	Decrease	Klein 1979; Benke et al. 1981; Pratt et al. 1981, Whiting and Clifford 1983; Shutes 1984; Hachmoller et al. 1991; Stepenuck et al. 2002
Weighted Indices		
Hilsenhoff Family Biotic Index (Hilsenhoff 1988; Bode et al. 1996)	Increase	Stepenuck et al. 2002; Voelz et al. 2005

between the 12 response variables and urban land cover (linear or curvilinear). To avoid multicollinearity among the polynomial terms, the independent variable (percent urbanization) was first centered and standardized. Centering the independent variable to a mean of zero and a standard deviation of one ensured that the resulting quadratic and cubic terms are not highly correlated with one another. The resulting regression coefficients and constants reflect the standardized (or beta) coefficients typically reported. Statistically significant quadratic and cubic terms indicate that a curvilinear relationship exists between urban land cover and the biological response variable. By contrast, a statistically significant linear regression coefficient where no additional significant quadratic and cubic coefficients are significant indicated that a linear relationship best described the biotic response to urbanization. Regression coefficients were considered significant at $\alpha<0.05$. Regression analysis was performed using the StatPro add-in for Excel.

Results

Water Chemistry Response

Lake Ontario streams had significantly higher total copper, chloride, and BOD, and significantly lower nitrates compared to the Lake Simcoe sites ($p<0.05$) (Table 3). Typically, elevated chloride and copper represent an urban signal from urban runoff while elevated nitrates represent an agricultural signal from fertilizer, manure, and decaying organic matter. The range in copper concentrations at Lake Ontario sites was 0.15 to 97.9 µg/L which was much greater than the observed range of 0.14 to 2 µg/L for Lake Simcoe tributaries. Eight sites in the Lake Ontario basin had concentrations of copper that were higher than the maximal value found at Lake Simcoe sites. Chloride concentrations at three Lake Ontario tributaries exceeded the maximum value of 194 mg/L found at Lake Simcoe sites. Two Lake Ontario tributaries exceeded the highest BOD value of 1.5 mg/L for Lake Simcoe sites. Five Lake Simcoe tributaries exceeded the maximal total nitrate value of 2.03 µg/L for Lake Ontario tributaries. Lake Ontario streams were not statistically different from Lake Simcoe streams in terms of pH, ammonia, total Kjeldahl nitrogen (TKN), phosphate, total phosphorus, aluminum, cadmium, cobalt, manganese, and nickel ($p>0.05$) (Table 3).

Benthos Community Response

Basin comparison. Sixty-seven macroinvertebrate families were collected, of which, 34 families were common to both basins (Table 4). The most common families were Chironomidae, Elmidae and Hydropsychidae which were found at almost every site. There were 60 families found in the Lake Ontario watersheds and 41 families

TABLE 3. Comparison of median water chemistry results based on a single baseflow grab sample for 14 sites in the Lake Ontario basin (2001), and 19 sites in the Lake Simcoe basin (2002.)

Parameter	*Lake Ontario*			*Lake Simcoe*			*p**
	Min	*Median*	*Max*	*Min*	*Median*	*Max*	
pH	7.4	7.9	8.4	7.7	7.9	8.0	0.316
BOD (mg/L)	0.2	0.9	2.0	0.2	0.7	1.5	**0.022**
Nitrates (mg/L)	0.08	0.45	2.03	0.10	1.04	3.37	**0.015**
Ammonia (mg/L)	0.002	0.012	0.100	0.002	0.002	0.054	0.066
TKN (mg/L)	0.004	0.350	0.780	0.22	0.38	0.81	0.327
Phosphate (mg/L)	0.0005	0.005	0.0345	0.0005	0.007	0.0763	0.413
Phosphorous (mg/L)	0.012	0.028	0.062	0.010	0.023	0.095	0.378
Chloride (mg/L)	3.6	68.1	493	7.9	34.3	194	**0.051**
Aluminum (µg/L)	11.3	32.8	12	12.4	26.5	133	0.271
Cadmium (µg/L)	0.083	0.300	0.051	0.03	0.21	0.33	0.104
Cobalt (µg/L)	0.111	0.670	0.750	0.02	0.75	1.11	0.315
Chromium (µg/L)	0.045	0.500	0.781	0.011	0.500	0.984	0.367
Copper (µg/L)	0.15	1.67	97.90	0.14	0.77	2	**0.038**
Iron (µg/L)	41.8	113.5	240.0	22.5	99.8	350	0.431
Manganese (µg/L)	1.0	23.3	96.6	6.3	25.1	65.5	0.166
Nickel (µg/L)	0.07	0.61	1.89	0.07	0.48	1.15	0.147
Zinc (µg/L)	0.16	1.77	12.90	0.19	1.00	9.36	0.130

* A bold p value indicates that the comparison was significant at $\alpha \leqslant 0.05$.

in the Lake Simcoe watersheds (Table 4). The median (± standard deviation) number of families for Lake Ontario sites (18±6.13) was not significantly different from the Lake Simcoe sites (14±2.97) ($p=0.087$). The most environmentally sensitive insect orders are the Ephemeroptera, Plecoptera, and Trichoptera. The Lake Ontario basin contained 23 EPT families while the Lake Simcoe basin contained 19 EPT families. Fourteen EPT families were common to both basins. The Lake Ontario basin contained eight non-insect invertebrate groups indicative of poor water quality that were absent in the Lake Simcoe basin (Table 4).

Correspondence analysis of the benthos community (Fig. 2) revealed a separation of the Lake Simcoe and Lake Ontario sites along CAI. Eight Lake Ontario sites loaded positively along CAI and six of the eight also loaded positively along CAII. This separation was based on the abundance of several pollution tolerant families (e.g. Caenidae, Hirudinea, Gammaridae). The majority of Lake Simcoe sites loaded negatively along CAI and CAII. Families on the left side of the ordination are more sensitive to anthropogenic disturbance (e.g.

TABLE 4. Families found at 14 sites in the Lake Ontario basin and 19 sites in the Lake Simcoe basin over a range of urbanization.

Phylum	*Class*	*Order*	*Family*	*Lake Ontario*	*Lake Simcoe*
Annelida	Clitellata		Hirudinea*	+	
			Oligochaeta*	+	+
Arthropoda	Arachnida		Acari*	+	+
	Entognatha	Collembola	Isotomidae	+	
	Insecta	Coleoptera	Elmidae	+	+
			Haliplidae	+	
			Hydrophilidae	+	
			Psephenidae	+	+
			Curculionidae	+	
		Diptera	Ceratopogonidae	+	+
			Chironomidae	+	+
			Empididae	+	+
			Ephydridae	+	+
			Muscidae	+	+
			Psychodidae	+	
			Simuliidae	+	+
			Tabanidae	+	
			Tipulidae	+	+
		Ephemeroptera	Ephemerellidae	+	+
			Ephemeridae	+	
			Heptageniidae	+	+
			Isonychiidae	+	
			Leptophlebiidae	+	+
			Oligoneuriidae		+
			Potamanthidae		+
			Siphlonuridae	+	
			Tricorythidae	+	
			Baetidae	+	+
			Caenidae	+	
		Hemiptera	Saldidae	+	+
			Corixidae	+	
		Lepidoptera	Pyralidae	+	
		Megaloptera	Corydalidae	+	+
		Odonata	Aeshnidae	+	
			Calopterygidae	+	+
			Coenagrionidae		+
			Gomphidae		+

		Plecoptera	Chloroperlidae	+	+
			Perlidae	+	+
			Perlodidae		+
			Pteronarcyidae	+	
		Trichoptera	Rhyacophilidae	+	+
			Brachycentridae	+	
			Glossosomatidae	+	+
			Helicopsychidae	+	+
			Hydropsychidae	+	+
			Hydroptilidae	+	+
			Lepidostomatidae		+
			Leptoceridae		+
			Limnephilidae	+	+
			Odontoceridae	+	
			Philopotamidae	+	+
			Polycentropodidae	+	+
			Psychomyiidae	+	
	Malacostraca	Amphipoda	Gammaridae	+	+
			Talitridae	+	
		Isopoda	Asellidae	+	+
		Decapoda	Cambaridae	+	
Mollusca	Bivalvia	Veneroida	Pisidiidae	+	+
		Unionoida	Unionidae	+	
	Gastropoda	Basommatophora	Ancylidae	+	+
			Lymnaeidae	+	
			Physidae	+	+
			Planorbidae	+	+
		Neotaenioglossa	Pleuroceridae	+	
Nemata			Nemata*	+	
Platyhelminthes	Turbellaria		Turbellaria*	+	

*higher level identification

Ephemerellidae, Glossosomatidae, Leptophlebiidae) than those on the right side. The first three CA axes accounted for 37% of the variation in the invertebrate community (Table 5).

The CCA biplot was based on 19 taxa from the 33 sites and 19 environmental variables. In the CCA biplot, the environmental variables are represented as vectors and taxa are represented as dots. The length of the vectors represents their relative importance and their direction relates to approximate correlation with the axes. The CCA revealed that the benthos communities were strongly influenced by *(i)* the percentage of urban land cover and (*ii)* chloride concentration along CCA Axis I (CCAI). Additionally, stream order loaded most strongly on CCA Axis II (CCAII) with minor influences from nitrates and TKN. CCAI represented a land use gradient such that sites on the far left were highly urbanized and those on the far right were less urbanized. The first three axes accounted for 55.8% of the constrained variation in the benthos community, with the first axis accounting for 25.3% (Table 5). By comparing the eigenvalues from the CA to the CCA, the environmental variables that were selected accounted for 47.9% of the total variation in the benthos community.

Metrics. Five biotic metrics were statistically different between Lake Ontario and Lake Simcoe streams (Table 6). Overall, Lake Ontario streams were less diverse and had higher proportions of pollutant tolerant organisms in comparison to Lake Simcoe streams. Lake Ontario tributary streams had significantly fewer EPT ($p=0.013$) and clinger ($p<0.001$) organisms per sample than Lake Simcoe tributary streams. Simpson's diversity index and percent Oligochaeta were slightly higher in Lake Simcoe streams in comparison to Lake Ontario tributary streams ($p=0.045$ and 0.026, respectively). EPT richness and Trichoptera richness did not differ between Lake Ontario and Lake Simcoe basin streams. Family richness and FBI were higher for Lake Ontario sites, but the difference was not significant ($p=0.056$ and 0.055, respectively). The proportion of Chironomidae per sample was significantly lower in Lake Simcoe streams in comparison to Lake Ontario streams ($p=0.002$).

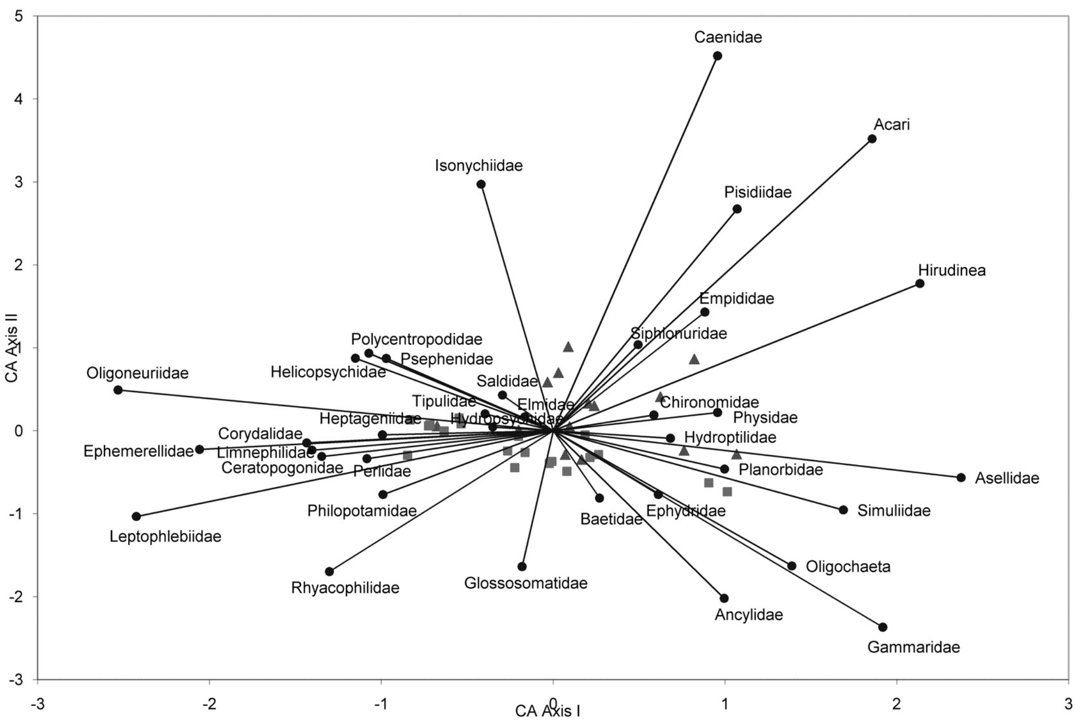

Fig. 2. Benthos community composition using Correspondence Analysis (CA) for 14 sites in the Lake Ontario basin (▲) and 19 sites in the Lake Simcoe basin (■).

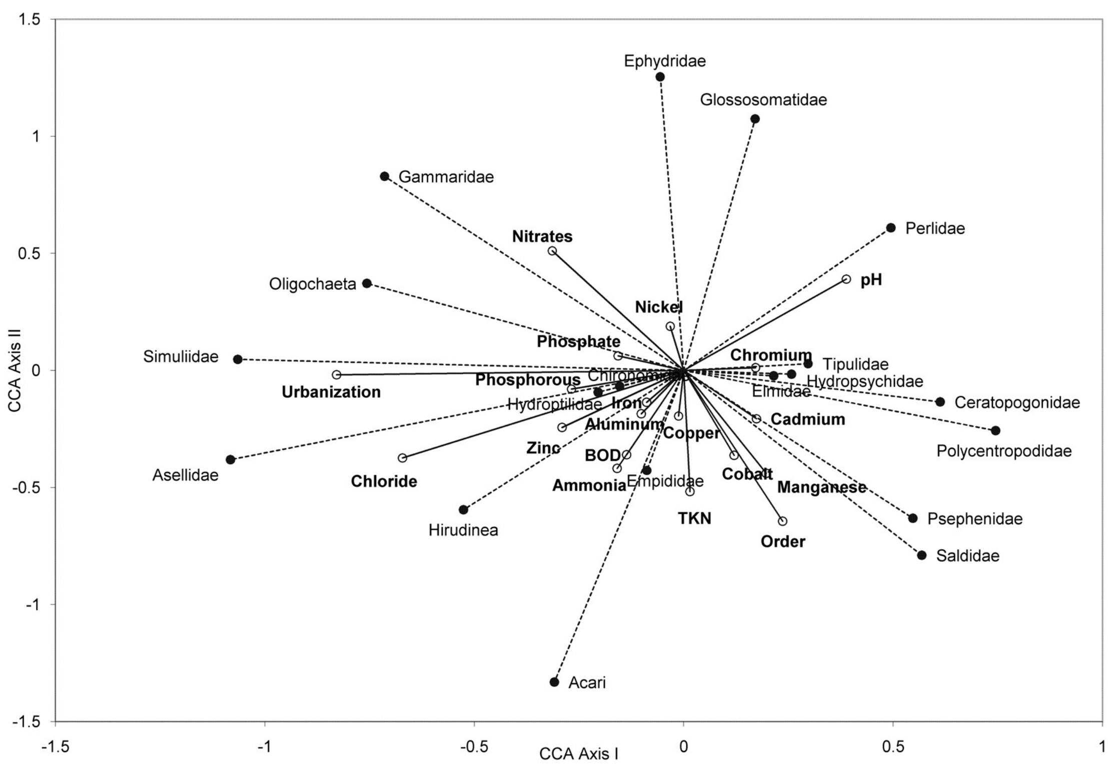

Fig. 3. Canonical Correspondence Analysis (CCA) for benthos, water chemistry, percent urban land use and stream order for 33 sites in the Lake Ontario and Lake Simcoe basins.

TABLE 5. Eigenvalues from the first three axes of Correspondence Analysis (CA) and Canonical Correspondence Analysis (CCA)

	Eigenvalues	*Cumulative % of Eigenvalues*	*Sum of Eigenvalues*
	0.27123	16.8	
CA	0.17908	27.8	1.61743
	0.15594	37.5	
	0.19586	25.3	
CCA	0.12638	41.6	0.77387
	0.10967	55.8	

TABLE 6. Comparison of median benthos metric results for Lake Ontario sites (n=14) and Lake Simcoe sites (n=19)

Metric	*Lake Ontario*			*Lake Simcoe*			*p**
	Min	*Median*	*Max*	*Min*	*Median*	*Max*	
# Families	8	18	30	10	14	21	0.056
# EPT Families	2	8	12	3	7	11	0.493
# Trichoptera Families	1	4	7	2	4	6	0.159
% EPT Organisms	1.9	41.3	72.2	22.9	62.6	81.5	**0.013**
% Chironomidae	1.9	24.8	74.3	1.5	6.0	35.9	**0.002**
% Oligochaeta	0.00	0.00	0.01	0.0	0.3	13.3	**0.026**
% Clinger	7.4	63.5	90.6	45.2	84.4	96.2	**<0.001**
% Scraper	3	21.8	45.4	2.7	28.5	61.6	0.145
Simpson's Diversity	0.44	0.74	0.86	0.45	0.79	0.88	**0.045**
FBI	3.72	5.51	6.79	4.17	4.92	6.86	0.055

* A bold *p* value indicates that the comparison was significant at $\alpha \leqslant 0.05$.

TABLE 7. Regression relationships between 12 benthic community metrics and % urbanization from 33 streams in the Lake Ontario and Lake Simcoe basin across a gradient of urbanization

Metric	R^2	*F*	*p **	*Equation*
Richness Measures				
Richness	0.23	8.93	**<0.001**	Y= - 0.0943x + 16.941
EPT family richness	0.38	19.32	**<0.001**	Y= - 0.0748x + 8.0482
Trichoptera family richness	0.39	18.86	**<0.001**	Y= - 0.0328x + 4.3528
Compositional Measures				
% EPT	0.17	6.47	**0.016**	Y= - 0.4025x + 54.694
% Chironomidae	0.08	2.65	0.114	Y= 0.2382x + 14.89
% Oligochaeta	0.42	22.37	**<0.001**	Y= 0.0849x + 0.0935
Functional Grouping Measures				
% Clingers	0.13	4.75	**0.037**	Y= - 0.3321x + 74.032
% Scrapers	0.26	11.04	**0.002**	Y= - 0.3105x + 28.381
Diversity Measures				
Simpson’s Diversity	0.07	2.307	0.139	Y= - 0.015x + 0.7543
Weighted Indices				
Hilsenhoff Family Biotic Index	0.42	22.60	**<0.001**	Y= 0.0215x + 4.972
Multivariate Metrics				
CAI	0.36	17.40	**<0.001**	Y= 0.0261x + 0.332
CAII	0.07	2.40	0.131	Y= -0.0111x – 0.0818

* A bold *p* value indicates that the regression was significant at $\alpha \leqslant 0.05$.

Multiple Regression Analysis. Multiple regression analysis of the centered and standardized first, second, and third order polynomials with percent urban land use showed that only first order terms had regression coefficients significantly different from zero. Quadratic and cubic regression coefficients were not significant predictors of benthos community metrics. Of the 12 metrics considered, 9 metrics showed statistically significant linear relationships with urban land use (Table 7).

All metrics followed the predicted response to increasing urbanization indicated in previous studies. Richness, EPT richness, percent EPT, Trichoptera richness, percent clingers, percent scrapers, and CAI decreased linearly with increasing amounts of urbanization (Fig. 4). The FBI and percent Oligochaeta metrics had the strongest positive relationship with urban land cover (r^2=0.42 and 0.42, respectively). This was expected, as the FBI is a weighted index that measures the tolerance of benthic invertebrates to organic pollution whereby the higher the value at a site, the greater the probability of organic pollution (Hilsenhoff 1988). Similarly, Oligochaeta are known to inhabit streams with soft silty substrates high in organic content which has greater potential to bind organic pollutants than gravel or cobbly substrate. CAI was positively related to urbanization such that axis scores increased with increases in urbanization. Highly negative CAI scores were associated with pollution sensitive families such as Perlidae, Ephemerellidae, and Heptageniidae whereas positive CAI scores were associated with pollution tolerant groups like Oligocheata, Hirudinea, Simuliidae, and Chironomidae. Simpson's diversity, CAII, and percent Chironomidae showed the weakest relationship with urban land use and were not statistically significant.

Variability in metric values was greater at the lower end of the urbanization gradient for most metrics. For example, the FBI ranged from 3.72 to 5.78 when percent urbanization was zero. This ranges from excellent to fairly poor water quality according to the Hilsenhoff scale (Hilsenhoff 1988). Similarly, richness ranged from 10 to 30 families when urbanization was less than 20%. Variability in richness declined to a much smaller range of 8 to 12 families when urbanization was greater than 20%.

Discussion

The Lake Ontario and Lake Simcoe basins have similar geologic development. However, access to the Great Lakes for marine shipping purposes has catalyzed rapid urbanization along the northern shoreline of Lake Ontario when compared to its more rural counterpart. Not surprisingly, when these two basins were compared, this study found that both the water chemistry variables and the benthos communities differed. The CA clearly showed a difference between the two basins based on taxonomic composition, whereby pollutant tolerant organisms were generally found in the more urbanized Lake Ontario watershed. Invertebrate diversity was highest in the less urbanized Lake Simcoe basin. Most studies agree that increasing diversity is related to the increasing health of the benthic community and increased diversity suggests that habitat requirements (i.e. space, food, and physical parameters) are adequate to support survival, growth, and reproduction of benthic populations (e.g. Resh and Jackson 1993; Barbour et al. 1999).

Previous studies have suggested that stream invertebrate distributions are controlled by broad-scale factors rather than local habitat characteristics (Palmer et al. 1996; Poff and Huryn 1998; Vinson and Hawkins 1998). In this study, urban land cover represented a broad-scale anthropogenic factor that influenced invertebrate occurrence. Urban land cover can alter the physical, chemical and hydrologic characteristics of streams. In particular, urban land cover was correlated with chloride concentrations (R^2=0.538) and CCA results indicated that these two factors were a major influence on the benthos community. Ourso and Frenzel (2003) reported that a reduced diversity and greater abundance of tolerant organisms may have been related to elevated concentrations of constituents associated with deicing salts. Crowther and Hynes (1977) suggested the possibility of degraded insect communities from road salt induced drift. Williams et al. (1997, 2000) found a strong relationship between the composition of macroinvertebrate communities in Toronto springs with chloride concentrations ranging from 8–1149 mg/L. In a review of road salt use in Canada, Mayer et al. (1999) found that Toronto streams had the second highest salt concentrations in the country. Cunningham et al. (2008) found that urban areas accumulate more salt than rural areas and that the rate of accumulation is dependent upon soil type.

Other broad-scale factors such as forest cover and stream order within the upstream catchment may have also played a role in structuring benthos community composition. Stream order ranged from 2 to 6 in this study and showed strong associations with CCAII. However, removing stream order from the set of explanatory variables in the CCA and re-calculating the ratio of eigenvalues for CCA/CA revealed that stream order accounted for less than 1% of the variance in the BMI community. This indicated that stream order had little influence on BMI community structure relative to the other explanatory variables. Although forest cover was not investigated in this study, it may be an important factor in regulating BMI communities. Booth et al. (2002) recommend that maintaining forest cover in watersheds is more important than limiting imperviousness to protect the hydrological properties of streams. Small scale factors such as hydraulic habitat, substrate characteristics, and organic food resources were outside the scope of this study; however, these factors may account for some of the remaining variation in the benthos community (e.g. Vinson and Hawkins 1998; Ourso and Frenzel 2003; Lamouroux et al. 2004).

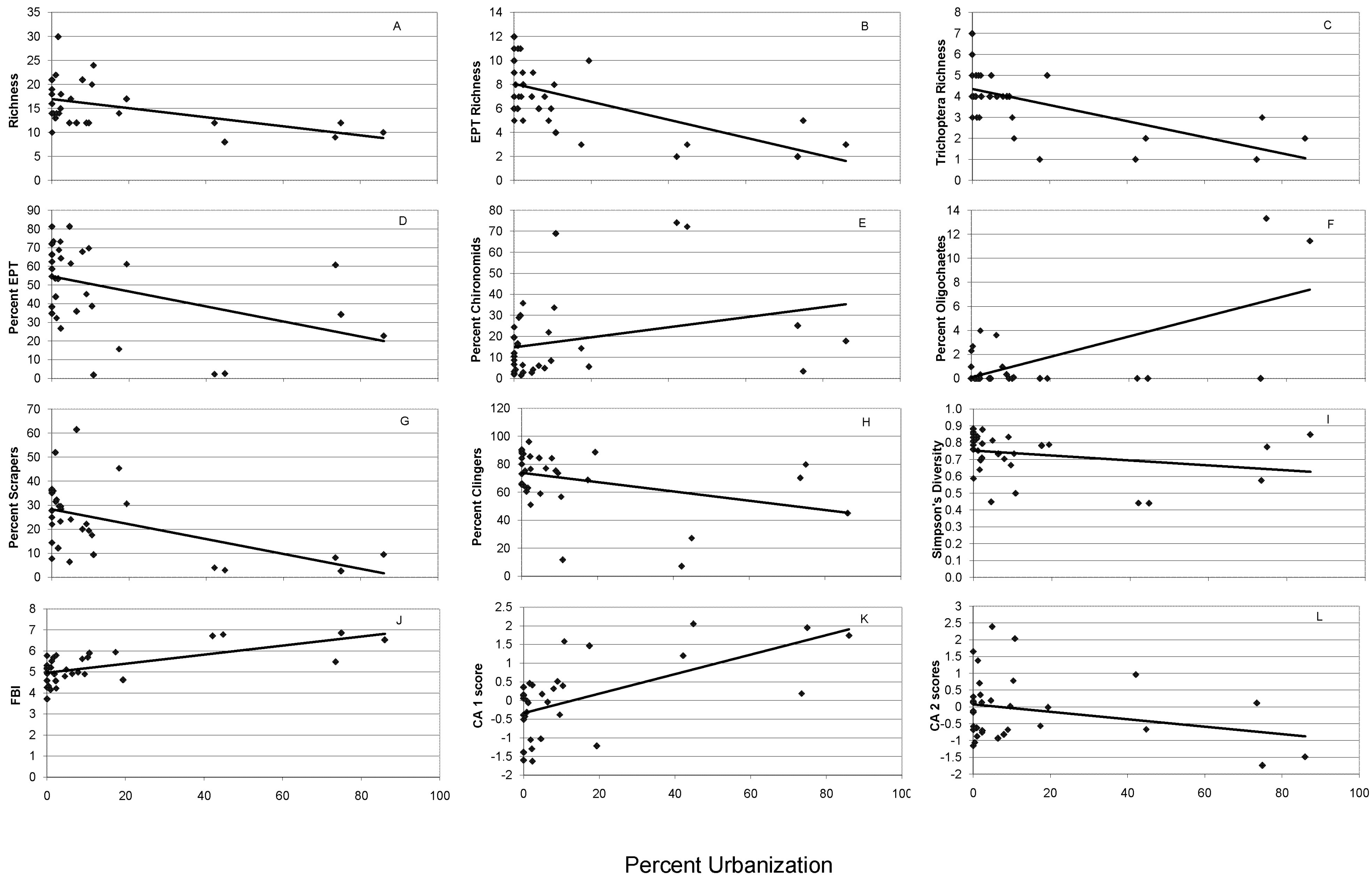

Fig. 4. Benthic macroinvertebrate metrics for 33 streams in the Lake Ontario and Lake Simcoe basins across a gradient of urbanization.

A multitude of studies have attempted to develop relationships between urbanization, often expressed as impervious cover, and benthos community structure (e.g. Klein 1979; Booth and Reinhelt 1993; Schueler 1994; Schiff and Benoit 2007). Using the benthic index of biotic integrity, Horner et al. (1997) found a logarithmic relationship with total impervious area. May et al. (2000) and Schiff and Benoit (2007) found the same relationship using a variety of different indicator communities. Subsequently, a "threshold-of-effect" was developed which suggests that development greater than 5-15% total imperviousness leads to poor stream health. This study found that 9 of the 12 metrics tested had significant linear relationships with urban land cover. Several reasons for the linear rather than the logarithmic relationships are possible including increased variability in metric values at low levels of urban land cover and coarse measurements of land use. This is similar to the findings of Booth and Jackson (1997), Karr (1998), Horner and May (1999), Karr and Chu (2000), and Booth et al. (2004).

The group of richness metrics used in this study showed the strongest relationship with urban land cover. Percent Oligochaeta and FBI had the strongest linear relationship with urban land cover (R^2>0.4). This observation is similar to Ourso and Frenzel (2003) who found a positive correlation between impervious area in Anchorage, Alaska, and Hilsenhoff's FBI and percent Oligochaeta metrics. Stanfield and Kilgour (2006) showed a strong relationship between percent impervious cover and Oligochaeta in Ontario streams. Hilsenhoff's FBI has proven to be sensitive to urbanization (Stepenuck et al. 2002; Ourso and Frenzel 2003; Roy et al. 2003; Wang and Kanehl 2003; Voelz et al. 2005; Schiff and Benoit 2007). In a study of 583 stream sites in southern Ontario, Stanfield and Kilgour (2006) found that Hilsenhoff scores increased with increasing impervious cover in the contributing catchment. They suggest that the results exhibited a weak threshold response at approximately 10% impervious cover. Using the water quality categories outlined by Hilsenhoff (1988), substantial pollution is likely at index scores greater than 5.76. This corresponds to approximately 39% urban land cover in this study or 10% imperviousness based on the conversion factor used by Booth and Reinhelt (1993).

This study suggests that deterioration in the biological quality of streams is associated with watershed urbanization. Urbanization itself does not cause biological decline, rather, it alters the landscape and changes the stressors which affect stream biota (Booth et al. 2004). Urbanization is a complex process which affects biota in a variety of ways. In general, the sites in the Lake Simcoe basin were healthier compared to the more urbanized Lake Ontario basin, despite extensive agriculture which negatively impacts stream benthos (Barton 1996).

The population in urban centres within the Lake Simcoe basin continues to grow faster than originally anticipated based on past estimates. The Lake Simcoe Protection Act and the subsequent Lake Simcoe Protection Plan have recently been implemented to protect the ecological health of Lake Simcoe (OMOE 2009). The plan promotes immediate action to address threats to the ecosystem such as excessive phosphorus (OMOE 2009). This includes targeting chlorides for monitoring and analysis. This study showed that urban land cover was correlated to stream chloride concentrations and that these two factors were influencing stream benthos community composition. Further studies to help pinpoint the causes of stream health degradation should be conducted to help protect and restore the quality of Lake Simcoe and the surrounding watershed.

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