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Benthic Biomonitoring in Arctic Tundra Streams: A Community-Based Approach in Iqaluit, Nunavut, Canada

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ABSTRACT. Recent residential, commercial, and industrial development in the catchments of several Arctic streams has heightened the need to assess these freshwater systems accurately. It was imperative to develop methods that would be both effective at judging ecological condition of tundra streams and suitable for use by local groups. An investigation of two streams influenced by urbanization in Iqaluit, Nunavut, was carried out between July and August each year in 2007–09. Simple summary metrics (e.g., Shannon Index) and multivariate analysis (DCA, RDA) both demonstrated biological impairment in the benthic community at site locations downstream of urbanized portions of a local stream. This impairment was characterized by a loss of diversity and a dramatic shift of the benthic community to one dominated by chironomids from the subfamily Orthocladiinae. Elevated levels of total nitrogen (TN) and total phosphorus (TP) and several metals (Zn, Sr, Rb, Al, Co, Fe) were also found to be significantly related to benthic assemblages within these disturbed areas. This investigation also addressed taxonomic sufficiency, indicating that while family-level taxonomic identifications were sensitive enough to differentiate between pristine and impacted stream sites, a more precise taxonomic identification of the dominant benthos taxa (Insecta: Diptera: Chironomidae) to sub-family/tribe level identified a significant shift towards pollution-tolerant taxa. This higher taxonomic resolution will allow for the adaptation of protocols and the use of simple summary metrics to be effective for a community-based biomonitoring program in Arctic tundra streams.

Key words: Arctic, streams, benthos, benthic invertebrates, biomonitoring, Nunavut, aquatic systems

RÉSUMÉ. De récents développements résidentiels, commerciaux et industriels dans les bassins versants de plusieurs cours d'eau de l'Arctique ont intensifié la nécessité de bien évaluer ces systèmes d'eau douce. Il était impératif de mettre au point des méthodes qui permettraient de juger des conditions écologiques des cours d'eau de la toundra et qui seraient utilisables par divers groupes de la région. Entre juillet et août des années 2007 à 2009, une enquête a été effectuée sur deux cours d'eau influencés par l'urbanisation à Iqaluit, au Nunavut. De simples mesures sommaires (indice de Shannon par exemple) et une analyse à variables multiples (DCA, RDA) ont permis de démontrer la dégradation biologique de la communauté benthique à divers lieux du site, en aval de segments urbanisés d'un cours d'eau local. Cette dégradation était caractérisée par une perte de diversité et un changement dramatique de la communauté benthique qui est maintenant dominée par des chironomidés de la sous-famille Orthocladiinae. Nous avons également constaté que les taux élevés d'azote total (AT), de phosphore total (PT) et de plusieurs métaux (Zn, Sr, Rb, Al, Co, Fe) étaient fortement liés aux assemblages benthiques faisant partie de ces zones perturbées. Cette enquête a également porté sur la suffisance taxonomique, ce qui a laissé croire que bien que les identifications taxonomiques au niveau de la famille étaient assez sensibles pour différencier entre les sites de cours d'eau vierges et les sites perturbés, une identification taxonomique plus précise allant des taxons benthiques dominants (Insecta:Diptera: Chironomidae) jusqu'au niveau de la sous-famille et de la tribu ont permis d'identifier un virage important vers des taxons tolérants à la pollution. Cette résolution taxonomique supérieure permettra l'adaptation de protocoles et l'utilisation de simples mesures sommaires efficaces en vue de l'établissement d'un programme de biosurveillance communautaire dans les cours d'eau de la toundra de l'Arctique.

Mots clés : Arctique, cours d'eau, benthos, invertébrés benthiques, biosurveillance, Nunavut, systèmes aquatiques

Traduit pour la revue *Arctic* par Nicole Giguère.

INTRODUCTION

Freshwater ecosystems of the Canadian Arctic are expected to be substantially altered by changes in runoff, water levels, river-ice regimes, and biogeochemistry resulting from climate change (Oswood et al., 1992; Rouse et al., 1997; Wrona et al., 2005). These systems are characterized by precipitous shifts in seasonality, with productive summers and non-productive winters. Temperature, precipitation, light availability, nutrient cycling, abiotic processes, and

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the geographic distribution of biological communities are highly governed by this seasonality.

Across the Arctic, from Alaska to eastern Nunavut, residents have observed changes in river ice conditions, runoff, flow regimes, and water levels that have made travel more hazardous and impeded access to important fishing areas (Fox and Huntington, 2005). These environmental changes have led to renewed focus on examining how climate change affects Arctic aquatic systems (Rouse et al., 1997; Vincent, 2005). However, these systems have also been exposed to a range of anthropogenic stressors. Residues from industrial contaminants (e.g., pesticides and metals) transported from global sources via long-range atmospheric pathways have been detected in Arctic freshwater fish for at least the past 10 years, often at concentrations that exceed known thresholds for human health impairment (INAC, 2003). Increased resource exploration justifies renewed interest in aquatic systems, which are vulnerable to tailings and effluents from a growing number of mining exploration and development activities (Bailey et al., 1998; Clements et al., 2000).

Rapid municipal development in many Arctic communities results in a variety of disturbances, including runoff and leaching from municipal landfill sites and sewage containment areas, hydrocarbon and chemical spills (waste oil, fuel, lubricants, de-icing liquids), industrial activity, residential waste, stream channel diversion (which often accompanies road construction), and increased sedimentation from gravel haul operations. The residents of many Arctic communities drink water from local streams and rivers and harvest sea-run and land-locked char (*Salvelinus alpinus*). As the health of Arctic community residents depends on ecosystem condition much more directly than is typical in other North American settlement areas, monitoring these systems is fundamentally important for community well-being. However, it is difficult to evaluate the combined affects of climate change, contaminants, and local development on Arctic freshwater ecosystems accurately because we lack knowledge of the biodiversity and natural variability of these systems in their undisturbed state.

Bailey et al. (1998) succeeded in distinguishing streams disturbed by mining contamination from pristine environments in the Yukon using a predictive model and a reference condition approach. Although this approach has the potential to detect major benthic invertebrate responses, less extreme disturbances are expected to be much more difficult to quantify with simple summary metrics and may require more robust multivariate analysis to quantify ecological condition (Reynoldson et al., 1997; Bowman and Somers, 2005). In addition, Yoder and Rankin (1998) demonstrated that errors in overly simplistic estimates of ecological condition are reduced if a robust biological assessment of stream condition is incorporated that evaluates biocriteria in conjunction with water chemistry and toxicological parameters.

Although we recognize that it may be impossible to find Arctic stream sites that are truly undisturbed by global human activity, bioassessment can be conducted by comparing test sites with known or perceived disturbance to "control" sites that are less affected by local pollution or physical disturbance (Stoddard et al., 2006). Thus, biological impairment will be defined as a significant difference in the biological and chemical condition of sampling locations between areas of perceived disturbance and control locations. Several standard Canadian protocols for conducting this type of analysis exist, such as the Canadian Aquatic Biomonitoring Network. However, many focus on using family-level identifications with quantitative indices to assess the health of streams. Such assessments, while common for temperate systems, may be problematic for Arctic tundra streams. Jones (2008) highlights the tradeoff between higher taxonomic resolution and information content and higher costs, logistics, and data quality. The problem inherent in working with reduced taxonomic detail is that detection of responses depends on sufficient taxonomic richness (Jones, 2008). The naturally low diversity in Arctic streams provides less information for distinguishing sites than is found in temperate systems; therefore, low (family-level) taxonomic resolution may result in unacceptable loss of the critical information necessary to identify stream impairment. For example, one of the dominant, and most diverse, groups in the Arctic is the Family Chironomidae (Oliver and Dillon, 1997). Several species within this family are specially adapted for specific habitats and environmental conditions (Pinder, 1995) and also have widely different tolerances to anthropogenic pollution (Clements et al., 2000; Mousavi et al., 2003). Thus, within-group variability of key taxa may provide sufficient information to be applied to a biomonitoring program within a tundra stream environment. In addition, without an understanding of the baseline biodiversity and community structure of benthic invertebrates within undisturbed Arctic systems, it may be difficult to determine ecological condition using a biological indicator approach.

The difficulty, expertise, and cost involved in using species-level identifications for any taxa may limit their applicability to most Arctic community–based biomonitoring programs. Any method and identification of taxa must be geared towards residents with limited expertise and training, yet be powerful enough to distinguish between control sites and disturbed areas. Thus, the objectives of this study were first to investigate whether shifts in the composition of benthic invertebrates in Arctic streams could be used to detect and quantify impairment downstream of known areas of point-source contamination, and second to adapt or modify methods to suit a local community-based biomonitoring program for Arctic streams. To this end, we asked the following questions: (1) Is it possible to detect a response in the benthic invertebrate community downstream from sources of contamination adjacent to Arctic streams? (2) What level of taxonomic precision is necessary to detect responses in the benthic community with the use of simple summary metrics? and (3) Can the results from these community-based methods and summary metrics be confirmed by a robust interpretation of the biological and chemical data used to quantify ecological condition?

From early July to early August in 2007 – 09, we investigated Airport Creek and the Apex River, two local streams that flow through the city of Iqaluit. In addition to quantifying the ecological condition within the urbanized portions of these streams, this investigation also provides a framework for developing a benthic biomonitoring program that is suitable for assessing Nunavut's streams and can be carried out by locally trained residents.

STUDY AREA

The City of Iqaluit (63˚45′8″ N, 68˚33′ 50″ W) is located on the southern tip of Baffin Island (Fig. 1). The area is characterized by a large number of small shallow ponds, lakes, and high-gradient streams that are due to the impermeability of permafrost and the underlying geology, dominated by Precambrian bedrock and glacial deposition. Catchment vegetation is sparse and consists primarily of dwarf prostrate shrubs (e.g., *Salix* sp.), grasses, sedges, and a variety of tundra forbs.

Airport Creek

Airport Creek (also known as Carney Creek) drains a small basin of approximately 8 km^2, and its lower reaches are exposed to industrial, military (historic), and urban impacts (Fig. 2). At the northern edge of the city's industrial zone, the municipality mines the banks on both sides of the stream for gravel, which contributes considerable sediment to the stream. The city has also dug a trench approximately 200 m long to divert the river flow around industrial areas. An abandoned military landfill and scrap yard located close to a gravel-hauling operation could also be affecting stream water quality during the melt season as water flows from the dumpsite into small ephemeral streams that discharge into the main channel.

Airport Creek has numerous inputs from additional industrial sources, including the Iqaluit airport, which discharges de-icing fluids into the stream. In addition, waste oil and chemicals have reportedly been dumped into the main channel, where the creek flows through the city's industrial park. During one such incident in 2007, approximately 170 L of crankcase oil were dumped into the creek over the course of 48 hours (Neary, 2006). A commercial greenhouse (built in 2008) is situated along the stream bank upstream of the airport (site ACGMid), and several teams of sled dogs are tethered along the stream bank (Fig. 2B) at two downstream locations (sites ACDMid and ACMouth). The elevated concentrations of dissolved lead, aluminum, manganese, and iron that have been reported in water samples for several years may be due to the numerous metal contamination points along the urbanized portion of the stream (Peramaki and Decker, 2000; INAC, 2008). High concentrations of short- and medium-chained chlorinated paraffins have also been reported in sediment and water from several locations along Airport Creek downstream of the military landfill and gravel haul operation (Dick et al., 2010). The city has recently started building a road to a new gravel source in Airport Creek's headwaters, which may further affect this stream's ecosystem in the future.

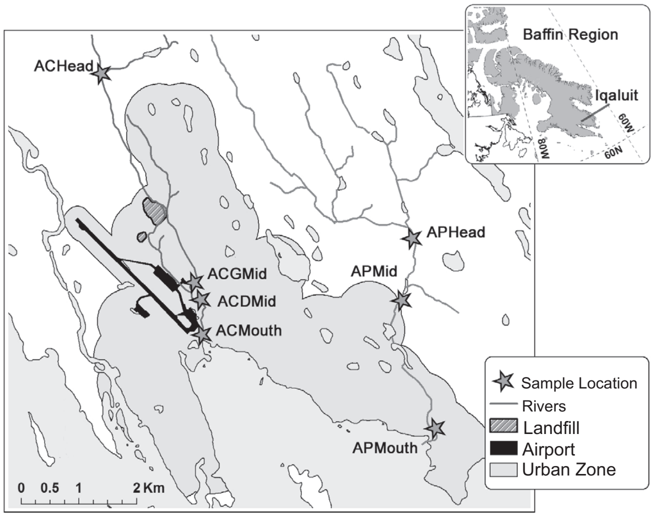

FIG. 1. Location of benthic sampling sites for Airport Creek and the Apex River, Iqaluit, Nunavut Territory.

Apex River

The Apex River, located on the eastern side of Iqaluit, flows into the community of Apex, a subdivision of the city of Iqaluit that is home to approximately 1500 people, many of whom hunt, fish, and trap. The Apex river catchment area has been estimated at approximately 60 km^2, and elevations within the watershed reach as high as 365 m a.s.l. at the headwaters (Obradovic, 1986). The river flows through two gorges, which cover 4 km of the creek's 8 km length. During the open-water period, sea-run Arctic char feed in the estuarine areas near the river mouth. Several local families fish these char with gillnets throughout the summer period. Additionally, many residents drink Apex River water during the ice-free period (approximately June to October). The city of Iqaluit has also identified several reaches of the Apex River as the preferred alternative withdrawal site for freshwater to recharge the city's drinking water reservoir during times of low water availability.

Unlike Airport Creek, the Apex River does not have any known contamination points along its reaches. The main inputs to the river are limited to areas adjacent to gravel haul operations, approximately 2 km upstream from the river mouth, where the city of Iqaluit has excavated gravel for the last ~10 – 12 years to produce material for local development. The gravel excavation, concentrated primarily along the east bank of the main channel, results in sediment loading downstream. Stream modification is limited to an area of channelization to support a bridge that connects a road from the city to these gravel excavation sites. The city of Iqaluit also announced in late 2009 that the west bank of the river, approximately 3 km upstream of its mouth, will be an area for future development, including the city's new

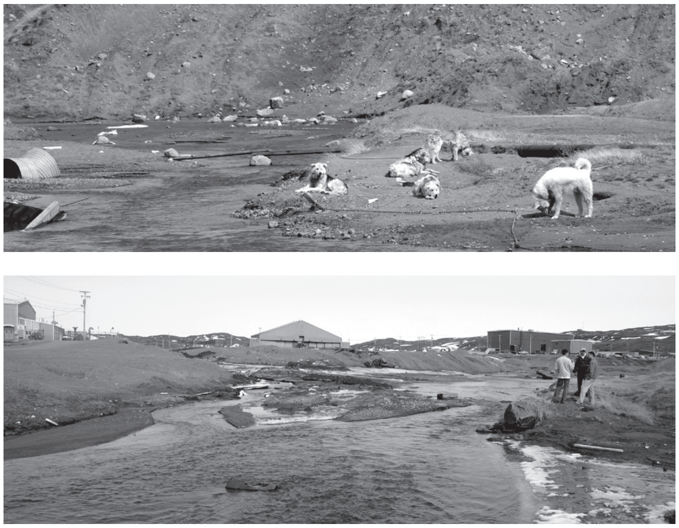

FIG. 2. Airport Creek, Iqaluit, Nunavut. (a) Midpoint sampling location near dog teams; (b) Downstream of midpoint sampling location.

cemetery that is currently under construction. These plans for the west bank of the Apex River underscore the need to document baseline benthic biodiversity before the development occurs, which would also allow comparison between the local Apex River and Airport Creek biota.

METHODS

Benthic Invertebrate Sampling

Benthic invertebrates were sampled at several locations along Airport Creek and the Apex River in Iqaluit, Nunavut Territory, Canada. Sampling was conducted between early July and August in each year from 2007 to 2009. A control versus impact (C/I) sampling regime was implemented; samples were collected at sites along the mouth of each stream, at the headwaters or source, and at a midpoint between the headwaters and the mouth. All sites were sampled several times during the ice-free season (from peak to base-flow periods) in order to address issues of seasonality and flow that may affect abundances and community composition.

Benthic invertebrates were sampled with a kick-and-sweep method using a 30 × 30 cm dip-net with a 500 µm aperture mesh. One “pool” and two riffle or run samples (5 min sampling effort each) were collected along the reach at each site. During benthic sampling, water samples were collected in pre-cleaned polyethylene bottles at 0.5 m below the water surface at all sites and treated immediately in the field, following the protocols outlined by Environment Canada (1994). Samples were then sorted in the lab for benthic invertebrates using a stereomicroscope and sorting trays. Since the total number of individuals obtained per individual sample (pool vs. riffle/run) was often below 300, sub-sampling was deemed unnecessary, and each five-minute sampling effort sample was sorted and counted in its entirety.

Laboratory Methods

Invertebrates were identified to Family using Pennak (1978) and Merritt and Cummins (1996) and placed into scintillation vials containing 95% ethanol. Ephemeroptera, Plecoptera, and Trichoptera (EPT) and Chironomidae were further identified to sub-family, tribe, or genus (where possible) using a Nikon SMZ1500 stereomicroscope and referring to Morihara and McCafferty (1979), Oliver and Roussel (1983), Wiederholm (1983), Epler (2001), Rieradevall and Brooks (2001), and Brooks et al. (2007). In addition, 10% of the Chironomidae individuals from these samples were mounted permanently on glass microscope slides in Euparal® mounting medium and then identified to genus. These specimen identifications were made at 400× magnification to the highest taxonomic resolution possible.

As one of our main objectives is to develop a community-based biomonitoring program within small Arctic towns, some samples were identified by local personnel, including students enrolled in the Environmental Technology Program at Nunavut Arctic College, Iqaluit. However, because of inconsistency noted between specimen identifications done by locally trained personnel and those done by professional researchers, this initial identification of Chironomidae to genus was conducted on only a portion of each sample. Subsequent analyses were conducted with finer-resolution Chironomidae identifications (to sub-family, genus, or species) via “obvious” diagnostic structures that the authors believe would be readily apparent to local personnel with minimal training and equipment. These identifications make the procedure suitable for a community-based approach to monitoring.

Water samples collected at each sampling point for each stream were analyzed by the National Laboratory for Environmental Testing (NLET) at the Canadian Centre for Inland Waters (CCIW), Burlington, Canada. A cooler containing the water samples for a number of sites for 2007 was lost in transit, and therefore several sites did not have corresponding water chemistry available. For these sites, we substituted water quality data from samples collected by Indian and Northern Affairs Canada (INAC) and analyzed by the Taiga Environmental Laboratory, Yellowknife, Northwest Territories.

Statistical Analysis

Several commonly used indices of taxonomic composition (e.g., CABIN; Reynoldson et al., 2006) were calculated in order to compare “undisturbed” upstream locations and those downstream of perceived urban influence. These included the Shannon Index of diversity (H’), Pielou’s Evenness Index (J’), Simpson’s Reciprocal Index (1/D’), and % EPT. Patterns observed in the benthic community were similar for all of the simple summary metrics; therefore, analysis has been illustrated with the Shannon Index. Composition was summarized as mean index values of the riffle/run and pool samples from each site, and the standard error of this

TABLE 1. List of taxa found in Airport Creek and the Apex River from June to September 2007–09. Taxa that were retained for our analysis (rare taxa were removed) are indicated, along with the taxonomic precision recommended for community-based biomonitoring.

Taxon	Retained	Recommended taxonomic precision
Athericidae		Family Athericidae
Ameletus opinatus		Family Ameletidae
Acerpenna pygmaea	•	Family Baetidae
Acentrella lapponica	•	Family Baetidae
Hydroporus sp.	•	Family Dytiscidae
Agabus sp.	•	Family Dytiscidae
Clinocera sp.	•	Family Empididae
Hydrachnidae	•	Family Hydrachnidae
Oligochaeta	•	Class Oligochaeta
Plecoptera	•	Order Plecoptera
Simuliidae	•	Family Simuliidae
Tipulidae	•	Family Tipulidae
Trichoptera	•	Order Trichoptera
Pagastia sp.	•	Sub-family Diamesinae
Cricotopus sp.	•	Sub-family Orthocladiinae
Hydrobaenus sp.	•	Sub-family Orthocladiinae
Orthocladius (*Orthocladius*) gr.	•	Sub-family Orthocladiinae
Orthocladius type S	•	Sub-family Orthocladiinae
Psectrocladius (*Mesopsectrocladius*) gr.		Sub-family Orthocladiinae
Arctopelopia sp.	•	Sub-family Tanypodinae
Derotanypus sp.		Sub-family Tanypodinae
Procladius sp.	•	Sub-family Tanypodinae
Chironomus sp.	•	Tribe Chironomini
Tanytarsini	•	Tribe Tanytarsini
Trichotanypus sp.	•	*Trichotanypus* sp.
Corynoneura sp.	•	*Corynoneura* sp.
Krenosmittia sp.		*Krenosmittia* sp.

mean was calculated for 2008 and 2009 samples. Samples analyzed in 2007 were aggregates of the three transect samples (two riffles and one pool) from each site location; therefore composition was summarized as index values calculated from the pooled sample. The mean index values of coarse (family-level) vs. fine (higher-taxonomic-resolution) identifications for all study factors were then compared using one-way analysis of variance (ANOVA), or the Kruskal-Wallis test if a variable was not normally distributed.

Multivariate Analysis

A detrended correspondence analysis (DCA) was performed on samples in CANOCO v4.53 (ter Braak and Šmilauer, 1998), with taxa identified to recommended levels of taxonomic resolution (Table 1). In order to give taxa equal weights for the DCA analysis, abundance was calculated as the percentage of total identifiable individuals, and square root–transformed. This allowed for the observation of any intra-site comparisons (riffle/run vs. pool) as well as any gradients among taxa at the different sampling locations. Rare taxa, identified as those occurring at a relative abundance of less than 1% and in no more than two samples, were excluded from ordination analysis. Total phosphorus (TP), total nitrogen (TN), Pb, Mn, Mo, and Rb were log-transformed to normality, while nitrite+nitrate (NO_2/NO_3), dissolved inorganic carbon (DIC), Ca, K, Na, Cr, Al, Co, Cu, Fe, Ni, Sr, and Zn were square root–transformed for subsequent analysis. Individual correlations of water chemistry variables and DCA axes were then tested by the Spearman rank correlation coefficients with leave-one-out jackknifing ($r_{\text{s jack}}$).

The 20 sampled site locations from 2007–09 were classified by Two-Way INdicator SPecies ANalysis (TWINSPAN; Hill, 1979), with pseudo-species cut levels for relative abundance data of benthic invertebrates defined as 0%, 2%, 5%, 10%, and 20%. An ANOVA was conducted on the species abundance and water chemistry variables among groups. Significant differences ($p < 0.05$) between TWINSPAN divisions were also tested with an independent *t*-test of DCA sample scores from the first two axes from each site. These significant groups were used to distinguish "disturbed" sites from "undisturbed" sites for further analysis.

Direct gradient analysis was then used to determine environmental variables that explained a significant ($p < 0.05$) direction of variation in benthic invertebrate assemblages. The significance of each environmental variable was tested using redundancy analysis (RDA, linear models) in an ordination constrained to each water-chemistry variable, performed with CANOCO using 999 unrestricted Monte Carlo permutations (reduced model). Backwards selection was conducted and included only environmental variables that were non-collinear (variance inflation factors < 10) and significant ($p < 0.05$) in an ordination constrained to one environmental variable at a time.

RESULTS

Total abundances of retained specimens in five-minute-collection samples generally ranged from 110 to 1465 individuals, except at the ACGMid location of Airport Creek sampled in 2008 (downstream from a private greenhouse), which contained over 4000 specimens (Fig. 3). Taxonomic richness ranged from 4 to 16 identifiable groups at each sampling location (Fig. 4). In total, 27 taxa were identified (Table 1). Samples collected during 2007 contained fewer individuals and fewer taxa than 2008 and 2009 samples, probably because summer temperatures were colder that year (Figs. 3 and 4; Environment Canada, 2010). While the upstream locations of both the Apex River and Airport Creek contained similar taxonomic richness, locations downstream of the area of urban influence along the reaches of Airport Creek contained fewer taxa in samples collected in 2008 and 2009 (Fig. 4A). Total abundances also declined in these Airport Creek downstream site locations compared to the upstream site, with the exception of the ACGMid location sampled in 2008 (Fig. 3). In the Apex River samples, in contrast, taxonomic richness and total abundance differed in each of the three years (Figs. 3 and 4).

Taxonomic Resolution

While family-level identification of taxa did distinguish between "disturbed" and "control" portions of Airport Creek

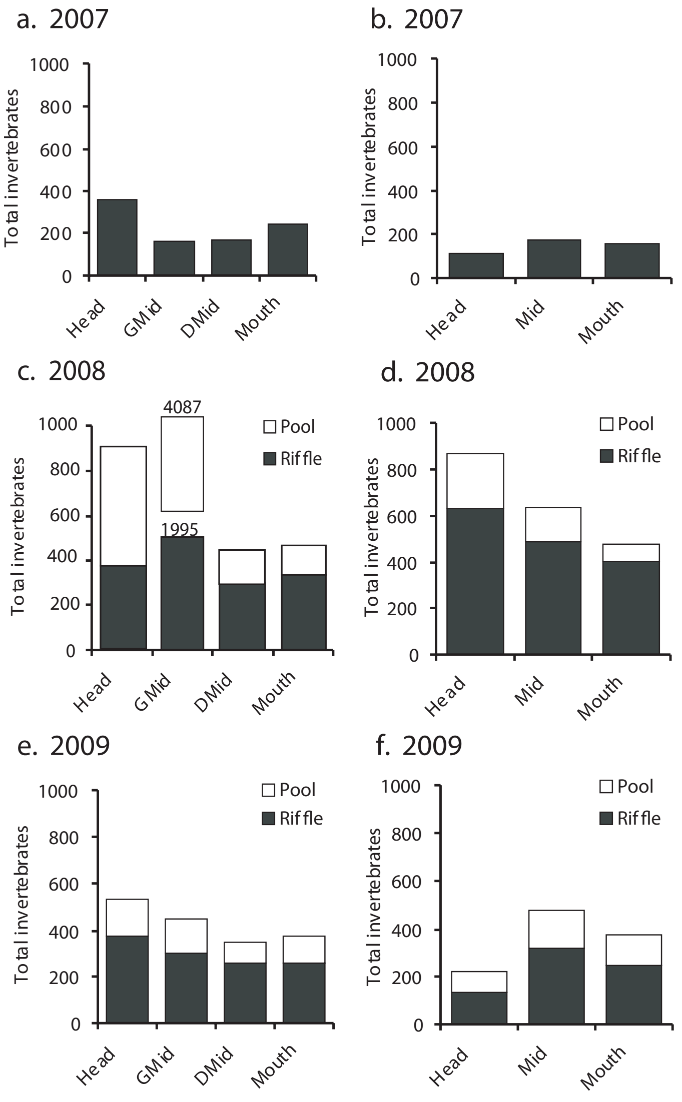

FIG. 3. Total number of invertebrates collected from riffle/run and pool samples at the head, mid, and mouth locations in the Airport Creek and Apex River in (a, b) 2007, (c, d) 2008, and (e, f) 2009.

(Fig. 5), the increased taxonomic resolution of identifications increased the significance of comparisons for all metrics examined (Table 2) and elucidated patterns that allowed the identification of several sensitive taxa that were extirpated from sites in Airport Creek downstream of urbanized zones (Fig. 6). This higher resolution also allowed us to compare intra-family differences in the dominant family for each sampling location in both Airport Creek (Fig. 6A) and the Apex River (Fig. 6B). The upstream site locations for both rivers contained a higher taxonomic richness of Chironomidae than locations within the urbanized areas. In addition, the absence of several taxa, indicating disturbances to the ecosystem, would not have been elucidated using a lower taxonomic resolution. The interpretation of metrics was also more complicated using family-level identifications because the low evenness of dominant groups skewed the community descriptors for the headwater sites (Fig. 7B).

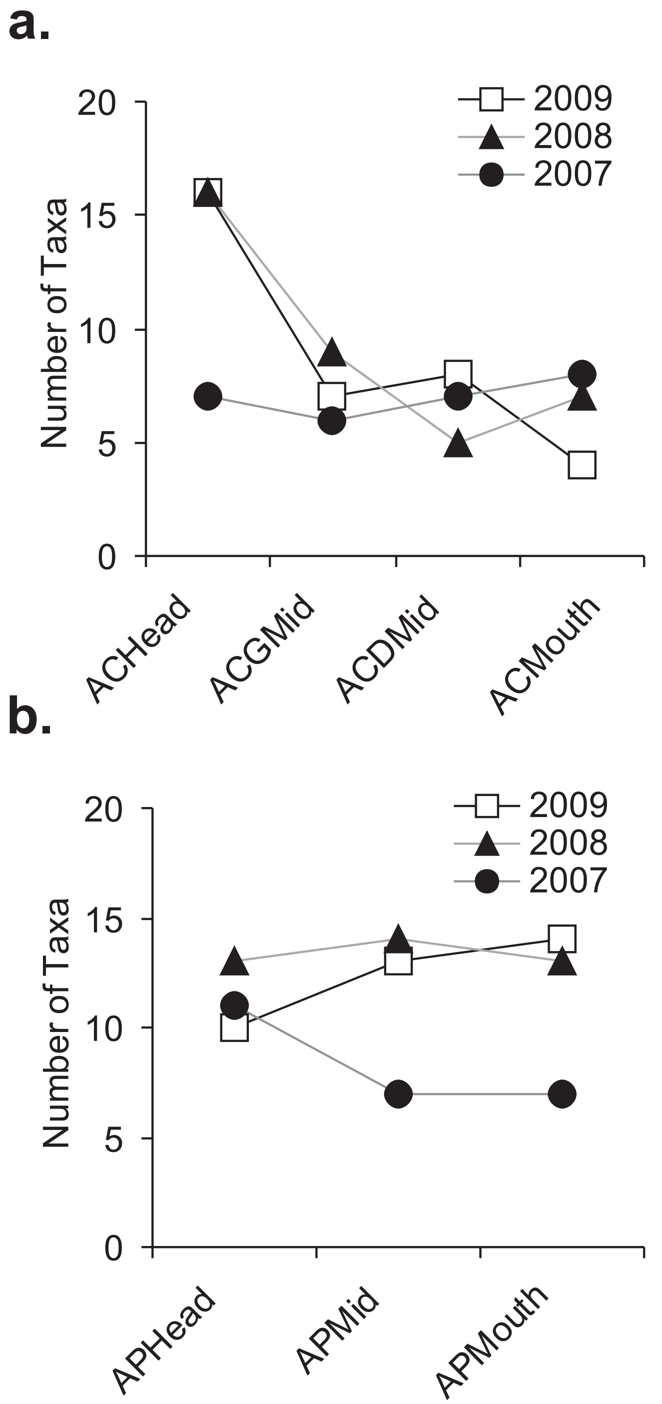

FIG. 4. The total number of taxa identified from each sampling site at (a) Airport Creek and (b) Apex River in 2007–09.

The increased taxonomic resolution from further identification increased the ability to distinguish the extirpation of numerous chironomid taxa downstream of the many point-sources of pollution along Airport Creek (Fig. 6A). The taxa absent in the downstream samples included Tanytarsini, *Trichotanypus* sp. (Diptera: Podonominae), *Pagastia* sp., *Procladius* sp., *Protanypus* sp., *Arctopelopia* sp., *Thienemanniella* sp., *Corynoneura* sp., and *Psectrocladius* (*Mesopsectrocladius*) gr. As a result, the chironomid assemblages downstream, within urbanized areas, were

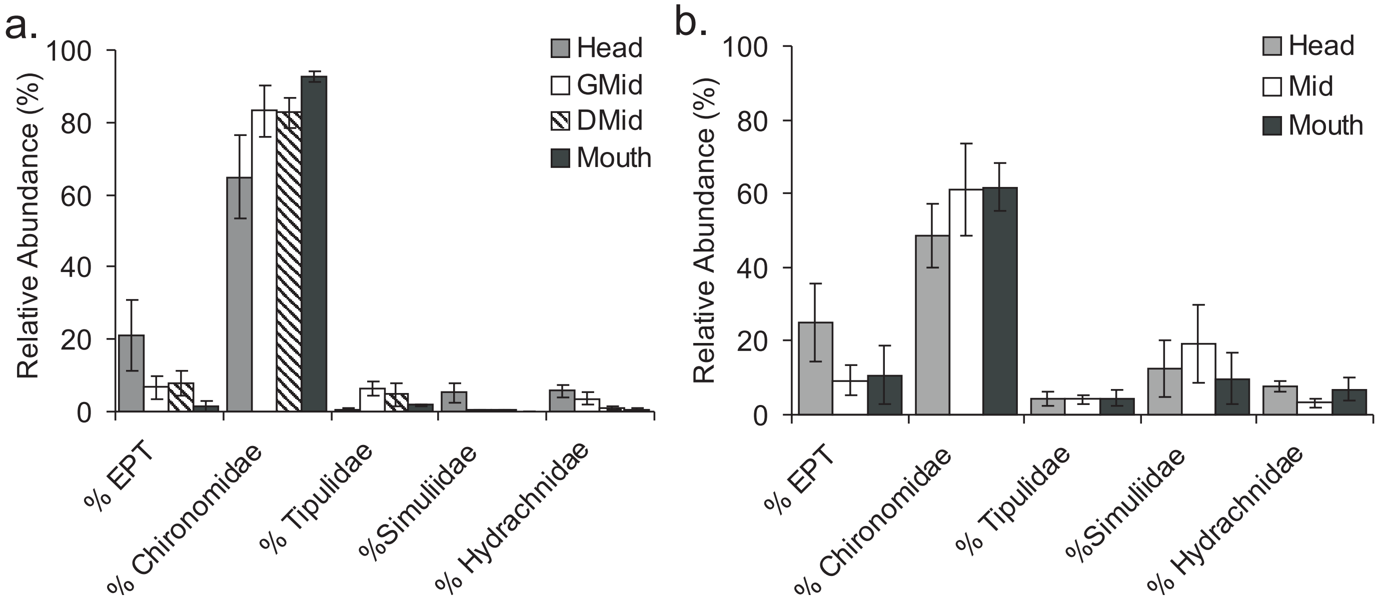

FIG. 5. Mean relative abundance (%) of major taxonomic groups of benthic invertebrates from head, midpoint, and mouth sampling locations within (a) Airport Creek and (b) Apex River. Standard error bars of means are indicated.

TABLE 2. Summary of one-way ANOVA analysis of metrics derived from Airport Creek and Apex River samples in 2007–09. F_1 and P_1 denote higher taxonomic resolution of identifications; F_2 and P_2 denote lower (family) taxonomic resolution of identifications. Abbreviations; C/I = Control versus impacted sites, Stream = difference between Airport Creek and the Apex River sites, Years = difference between 2007, 2008, and 2009 sampling years, Habitat = difference between pool vs. riffle/run samples. Bold type indicates statistically significant values ($p < 0.05$). An asterisk (*) indicates a significant difference between 2009 and 2007 (Tukey post hoc test).

Factor	Metric	F_1	P_1	F_2	P_2
C/I	DCA AX1	118.99	< **0.001**	23.04	< **0.001**
	DCA AX2	2.70	0.12	2.94	0.10
	H’	50.44	< **0.001**	6.94	**0.02**
	D’	15.59	< **0.001**	12.30	< **0.001**
Stream	DCA AX1	26.12	< **0.001**	7.73	0.01
	DCA AX2	5.44	**0.03**	2.94	0.10
	H’	15.97	< **0.001**	5.46	0.03
	D’	15.92	< **0.001**	6.34	0.02
Years	DCA AX1	0.37	0.70	2.23	0.14
	DCA AX2	6.59	**0.01***	3.28	0.06
	H’	0.16	0.85	0.87	0.44
	D’	0.62	0.55	1.12	0.35
Habitat	DCA AX1	0.87	0.36	0.64	0.43
	DCA AX2	0.36	0.55	0.27	0.61
	H’	0.01	0.95	0.01	0.94
	D’	0.02	0.90	0.09	0.76

almost entirely represented by species of the sub-family Orthocladiinae (Fig. 6A). These included *Hydrobaenus* sp., *Cricotopus bicinctus*, *Cricotopus* (*Cricotopus*) *tremulus* gr., *Orthocladius* type S, and *Orthocladius* (*Orthocladius*) gr. Several *Krenosmittia* sp. were also identified at the ACG-Mid sampling location of Airport Creek, which was characterized by a heavily modified gravel-cobblestone substrate.

While differences in benthic assemblages in downstream samples from the Apex River were not as pronounced as those in samples from Airport Creek locations, some taxonomic differences were observed at the midpoint sampling location, where the relative abundances of Chironomini and Simuliidae were higher (Figs. 5B, 6B). The Tanypodinae accounted for more than 70% of samples from the upstream sampling sites of the Apex River (Fig. 6B), but made up less than 10% of the upstream community from Airport Creek (Fig. 6A). Several taxa were also found exclusively in the Apex River, including *Chironomus* (Diptera: Chironomidae, Tribe Chironomini), *Derotanypus* (Diptera: Chironomidae, Tribe Macropelopiini), and *Ameletus inopinatus* (Ephemeroptera: Ameletidae).

Assessment Metrics

The diversity metrics (Shannon, Simpson’s Reciprocal, Pielou’s evenness indices) all indicated that Airport Creek

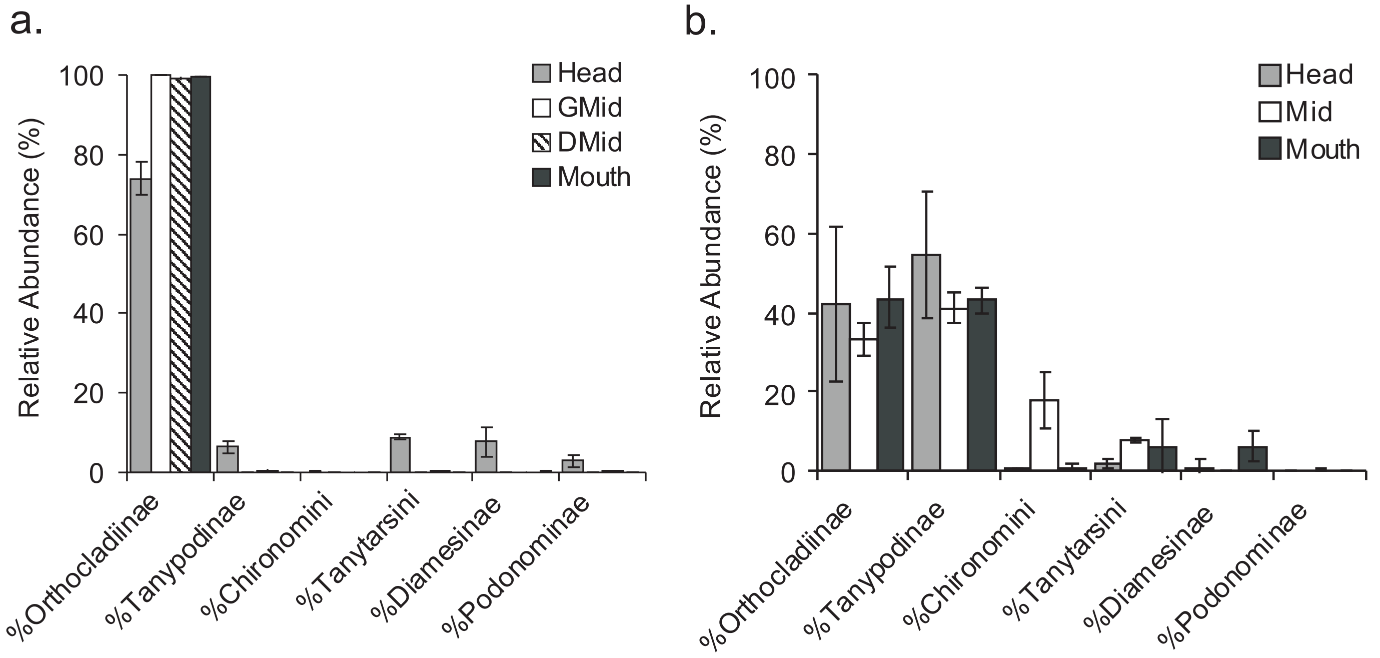

FIG. 6. Mean relative abundance (%) of Chironomidae and Podonominae from head, midpoint, and mouth sampling locations within (a) Airport Creek and (b) Apex River. Standard error bars of means are indicated.

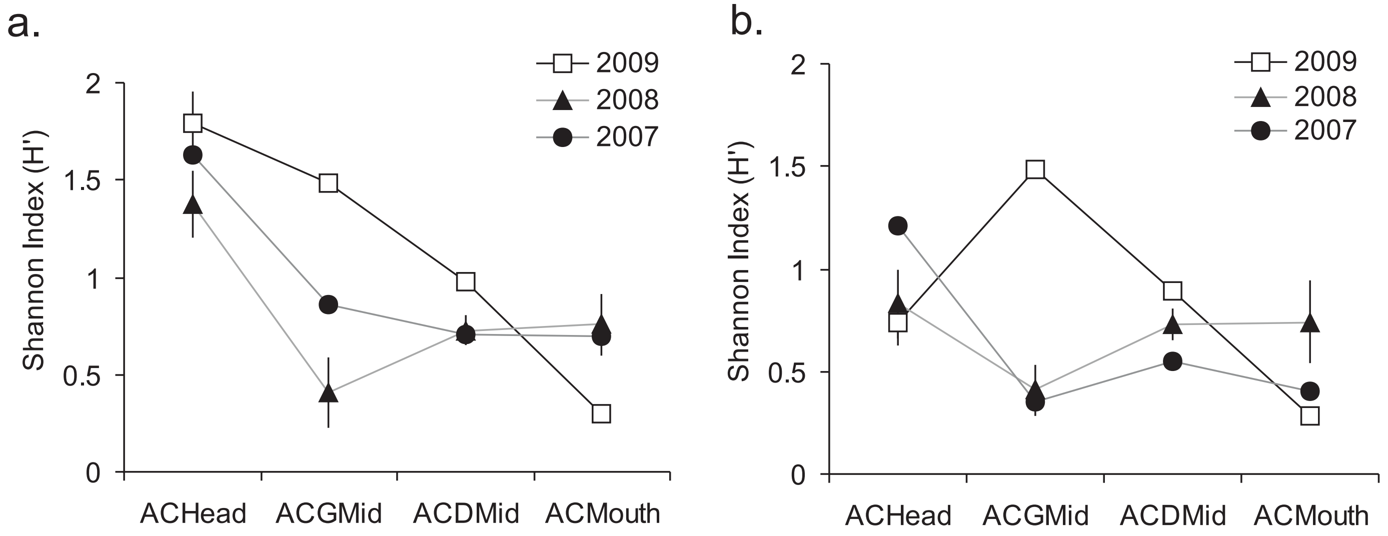

FIG. 7. Mean Shannon Index (H') values for sampling locations within Airport Creek (a) with tribe/sub-family taxonomic identification of Chironomidae and (b) with Family-level taxonomic identification. Standard error bars of means are indicated for 2008 and 2009 samples.

sampling sites downstream of the urbanized zone (Fig. 1) had significantly lower diversity and were more uneven than the upstream control location for all years (Fig. 7). For the Apex River, however, the metrics showed little difference between control and downstream locations (Fig. 8). Chironomids represented the largest overall taxonomic group from 2007 to 2009 (Fig. 5). The upstream control location of Airport Creek also contained more chironomid taxa than downstream locations (Fig. 6A); thus, the Shannon Index scores were higher when the metric took this increased taxonomic resolution into account (Fig. 7A).

Similarly, the upstream locations contained higher relative abundances of EPT than were found downstream for both Airport Creek (Fig. 5A) and the Apex River (Fig. 5B). Although % EPT was similar for the two rivers, Airport Creek generally contained higher abundances of Plecoptera, whereas the Apex River had more Ephemeroptera. The approximate hatching and emergence dates for Baetids were deduced from the week when larvae began to be represented in samples, which was observed to occur rapidly in early July (approximately 10 to 15 July). Adult emergence was observed starting in early August in all three sampling years. *Ameletus* (Ameletidae) larvae were also observed in the Apex River immediately after ice melt (late June – early July), but were rarely found thereafter. Low abundances of Trichoptera and predaceous water beetle larvae (Coleoptera:

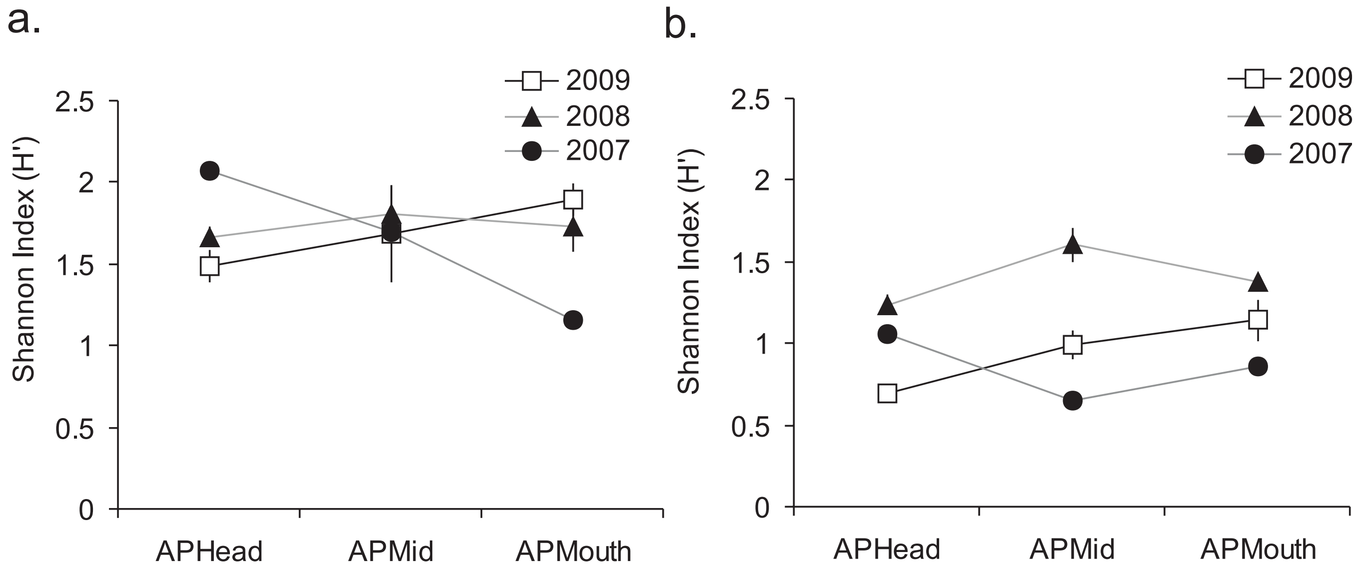

FIG. 8. Mean Shannon Index (H’) values for sampling locations within the Apex River (a) with tribe/sub-family taxonomic identification of Chironomidae and (b) with Family-level taxonomic identification. Standard error bars of means are indicated for 2008 and 2009 samples.

Dytiscidae) were found in both rivers, comprising less than 2% of the total samples.

Multivariate Analysis

A robust examination of differences between site locations based on the relative abundances of benthic invertebrates was conducted to support the results and interpretation of the simple assessment metrics. A TWINSPAN analysis (Hill, 1979) was conducted to detect major differences in the samples based on major indicator taxa. The analysis ordinates the relative abundance values of all taxa in each sample using reciprocal averaging, produces a dichotomy using a calculated centroid line, and uses the resulting binomial divisions to create a hierarchical classification of sites (Hill, 1979). The TWINSPAN analysis of benthic invertebrate assemblages clearly separated the Airport Creek sampling sites downstream of urbanized influence from the headwater control site and the Apex River locations (Fig. 9).

Relationships between benthic community composition and samples were then examined using ordinations performed with CANOCO v4.53 (ter Braak and Šmilauer, 1998). The detrended correspondence analysis (DCA), a variation of reciprocal averaging (correspondence analysis), was conducted (with detrending by segments, square-root transformation of species abundance, and down-weighting of rare taxa) in order to observe the relationship between samples in ordinal space. The DCA sample scores were then used to delineate statistically (with a one-way ANOVA of the TWINSPAN classified division) groups of sites that represented specific environmental relationships.

The first TWINSPAN division produced groups that had significantly different DCA Axis 1 scores ($t = -10.9$, $p < 0.05$), while the second division produced groups that had significantly different DCA Axis 2 scores (C2/3 $t = 4.58$, $p < 0.01$; D2/3 $t = -2.8$, $p < 0.05$). ANOVAs of TWINSPAN divisions indicated that nine taxa had significantly different relative abundances, with the first division representing significant differences in Orthocladiinae and Tanypodinae (Fig. 9). Subsequent ANOVAs conducted on TWINSPAN divisions, DCA axes, and benthos metrics indicated significant differences between control versus disturbed sites, significant within-stream variation, and potential differences between sampling years (Table 2). When limited to a specific year’s samples (2009 only), separated by habitat type, axis 1 of the DCA (Fig. 10) distinguished downstream disturbed sites of Airport Creek from both the upstream “undisturbed” location and the Apex River sites. DCA axis 2 corresponded to the habitat-specific differences within the three individual transects sampled at each site location, separating the riffle/run samples from the pool samples.

Water chemistry samples taken downstream of the urbanized portions of Airport Creek indicated elevated concentrations of metals and nutrients (Table 3), including total phosphorus (TP), total nitrogen (TN), sodium, iron, chromium, manganese, rubidium, strontium, and zinc. Water samples collected from the ACGMid site in 2008, in particular, contained much higher concentrations of NO_2/NO_3 (nitrite+nitrate), sodium, potassium, molybdenum, and strontium than the upstream samples (Table 3). The concentrations of all water chemistry variables examined generally remained consistent throughout all samples of the Apex River (Table 3). Spearman correlations of water chemistry to DCA axes indicated that potassium ($r = 0.78$), sodium ($r = 0.71$), molybdenum ($r = 0.73$), and strontium ($r = 0.74$) were significantly correlated ($p < 0.05$) to DCA axis 1, and TP ($r = 0.59$), calcium ($r = 0.75$), magnesium ($r = 0.70$), TN ($r = 0.54$), molybdenum ($r = 0.64$), and strontium ($r = 0.65$) were significantly correlated ($p < 0.05$) to axis 2.

A redundancy analysis (RDA) allowed for an examination of the relationship between assemblage data and water

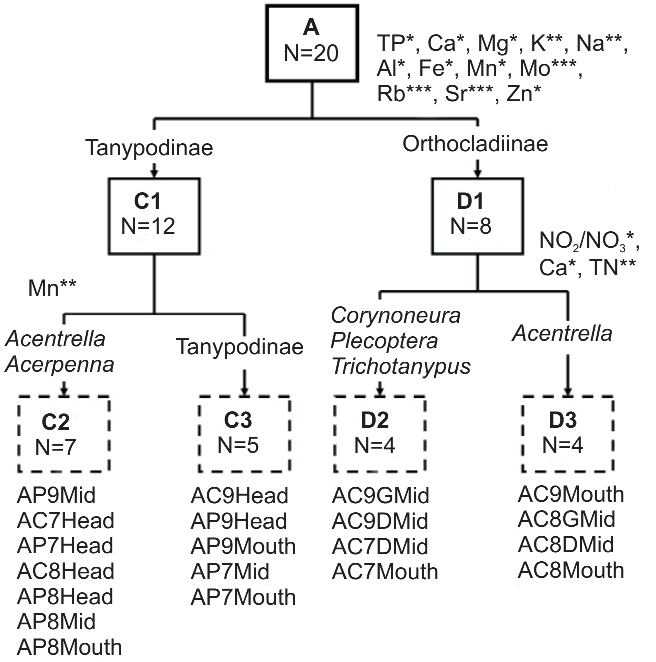

FIG. 9. TWINSPAN classification of river benthos assemblages from Airport Creek and the Apex River from 2007–09. Taxa listed are the TWINSPAN indicator taxa. Environmental variables showing a significant difference at a division are given: (*) $p < 0.05$; (**) $p < 0.01$; and (***) $p < 0.001$. Significant differences ($p < 0.05$) between TWINSPAN divisions via ANOVA of sample scores for DCA Axis 1 (solid-line boxes) and DCA Axis 2 (dashed-line boxes) are indicated.

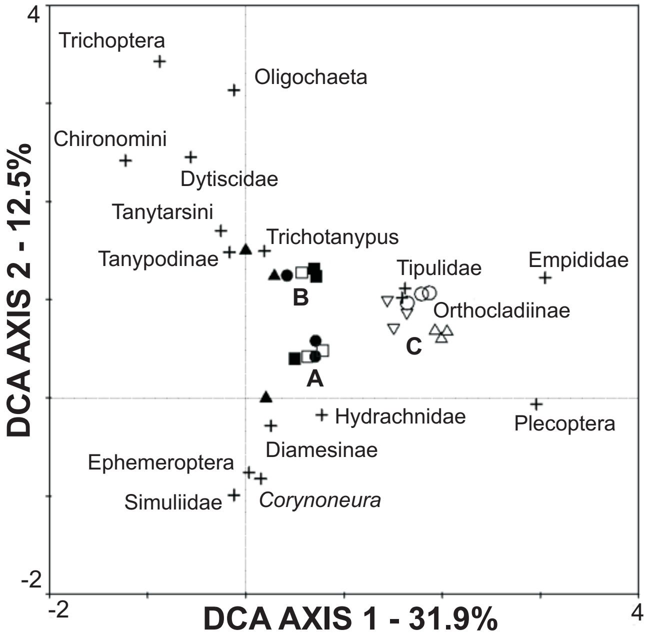

FIG. 10. Detrended correspondence analysis of 2009 samples indicating sample locations relative to taxonomic groupings. A) kick-sweep samples from pool transects; B) kick-sweep samples from riffle/run transects; and C) impaired site locations. Sites: ■ = APHead, ▲ = APMid, ● = APMouth, □ = ACHead, △ = ACGMid, ▽ = ACDMid, ○ = ACMouth.

chemistry variables for each sample. The gradient length of the DCA ordination of all pooled 2007–09 sites was 1.74 SD for Axis 1, indicating species-environment relationships would be best described by linear models. Ordinations constrained to each normalized water chemistry variable in our dataset determined that variables that influenced significant ($p < 0.05$) amounts of variation in the species dataset were NO_2/NO_3, TP, Al, Ca, Co, Fe, K, Mg, Mo, Na, Rb, Sr, and Zn. A backwards elimination process, which sequentially removed collinear variables, eliminated Ca, Na, Mg, and Sr as variables retained in the final canonical ordination.

The first two RDA axes accounted for 39.7% of the variance between benthic invertebrate assemblages (Table 4), and the first two RDA axes were each found to explain significant portions of canonical variation ($p < 0.001$). The eigenvalues of the first axis (0.397) and second axis (0.108) explained 50.5% of the species variation (Table 4). The RDA also separated sites located downstream of the urbanized portion of Airport Creek from control sites and Apex River sites along the first axis (Fig. 11). Relationships between water chemistry variables and the benthic invertebrate dataset were examined through regression coefficients of variables of the first two axes and the interset correlations of the water chemistry variables (Table 5). The correlations indicated that RDA Axis 1 reflects the influence of a gradient in metal concentrations, while RDA Axis 2 may reflect differences between the sampling years.

DISCUSSION

Biological Response

The comparison of sampling locations upstream and downstream of urbanized areas of Airport Creek indicated the severe impact from urban pollution sources on this Arctic stream. Substantial streambank and catchment modifications of several portions of Airport Creek are evident as a casual observer travels from the mouth of the river to the headwaters (Fig. 2). Disturbances from several commercial, industrial, and legacy sources (closed metals landfill, abandoned military dump) along multiple portions of the river are likely responsible for shifts in the benthic community. The loss of several major taxa (e.g., Tanypodinae, Tanytarsini, Diamesinae, Podonominae) from assemblages at downstream sampling locations (Fig. 6A) is likely due to inputs of heavy metals to the stream from the local metals landfill. Similarly, Mousavi et al. (2003) found that the relative abundance of Orthocladiinae was highest at sampling locations in Subarctic Norwegian lakes that contained high concentrations of heavy metal pollution. Likewise, chironomid richness has been shown to be significantly reduced in proportion to heavy metal pollution (Winner et al., 1980; Clements et al., 2000; Mousavi et al., 2003). Stream modification, channelization, and substrate modification are also likely to have altered the benthic community within downstream locations. For example, larvae of the chironomid genus *Krenosmittia*, which occur primarily in streams with a gravel bed (Brooks et al., 2007), are not found at any sampling locations except a

TABLE 3. Water chemistry for Airport Creek (AC) and the Apex River (AP) 2007–09. Asterisk (*) indicates substituted INAC data (see Methods for details). NO_2/NO_3 = nitrite+nitrate, TP = total phosphorus, TN = total nitrogen, DIC = dissolved inorganic carbon.

Sites	NO_2/NO_3 µg/L	TP µg/L	TN µg/L	DIC mg/L	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	Al µg/L	Cr µg/L	Co µg/L	Cu µg/L	Fe µg/L	Pb µg/L	Mn µg/L	Mo µg/L	Ni µg/L	Rb µg/L	Sr µg/L	Zn µg/L
AC9Head	71	1.9	175	9.1	14.8	1.82	0.16	0.86	13.2	0.05	0.02	1.69	45.3	0.31	1.5	0.24	0.33	0.29	22.2	2.83
AC9GMid	37	2.8	104	8.5	12.2	1.67	0.51	1.89	15.4	0.10	0.02	1.10	15.2	0.02	1.3	0.41	0.13	0.39	26.4	2.22
AC9DMid	38	18.8	118	7.7	9.9	1.25	0.30	1.16	52.9	0.18	0.08	3.09	110.0	0.13	8.7	0.25	0.23	0.38	17.9	4.40
AC9Mouth	43	7.4	184	11.9	17.2	2.13	0.56	2.51	29.1	0.16	0.12	1.21	161.0	0.07	41.9	0.46	0.22	0.54	32.5	7.77
AC8Head	120	5.0	120	0.5	31.0	3.10	0.20	1.40	4.7	0.01	0.20	0.50	5.0	0.01	0.3	0.20	0.10	0.30	28.5	2.30
AC8GMid	217	6.2	319	17.1	24.5	3.77	1.46	8.32	27.5	0.18	0.04	1.74	39.9	0.08	1.9	1.32	0.18	0.86	60.1	1.63
AC8DMid	140	20.0	290	3.3	20.6	1.80	0.20	1.30	25.0	0.01	0.20	0.90	428.0	0.20	26.4	0.30	0.60	0.50	31.0	3.60
AC8Mouth	310	5.0	360	2.0	38.9	5.10	1.00	6.40	19.7	0.20	0.30	1.50	425.0	0.01	132.0	0.60	0.50	0.80	70.8	16.3
AC7Head*	50	0.5	130	0.2	10.1	1.30	0.10	0.60	9.7	0.01	0.10	0.70	50.0	0.01	0.70	0.20	0.20	0.20	12.8	1.10
AC7DMid	17	1.4	107	3.6	5.7	0.71	0.21	0.71	26.4	0.20	0.05	1.80	44.0	0.01	1.8	0.25	0.20	0.77	27.6	1.99
AC7Mouth*	31	0.5	36	1.4	17.4	2.40	0.40	2.10	44.1	0.01	0.10	1.20	209.0	0.01	49.0	0.40	0.30	0.40	27.1	5.60
AP9Head	18	0.7	95	4.8	6.9	0.84	0.16	0.70	18.4	0.06	0.03	0.42	16.4	0.01	2.3	0.08	0.25	0.34	11.6	0.60
AP9Mid	15	1.2	103	4.1	6.0	0.77	0.13	0.52	8.5	0.02	0.01	0.52	13.7	0.01	2.6	0.12	0.15	0.30	10.5	0.47
AP9Mouth	14	1.2	84	4.2	6.0	0.75	0.14	0.54	12.6	0.05	0.01	0.49	19.4	0.01	1.1	0.09	0.17	0.31	10.4	0.29
AP8Head	58	3.6	191	5.5	8.6	1.10	0.20	0.82	19.4	0.08	0.08	0.93	65.2	0.03	4.9	0.13	0.24	0.45	15.1	1.90
AP8Mid	74	1.1	166	6.2	9.2	1.26	0.18	0.81	11.4	0.06	0.03	2.17	42.5	0.05	5.9	0.19	0.18	0.42	16.5	0.35
AP8Mouth	47	4.1	116	6.0	9.2	1.21	0.16	0.84	17.1	0.12	0.02	1.04	45.0	0.03	1.4	0.16	0.23	0.45	16.7	2.18
AP7Head	89	3.1	166	5.2	8.1	0.96	0.18	1.16	42.5	0.11	0.15	2.70	76.3	0.21	9.7	0.08	0.29	0.37	12.9	3.79
AP7Mid	59	2.4	134	5.3	7.9	0.92	0.17	0.98	29.5	0.01	0.07	3.33	68.4	0.09	7.3	0.09	0.20	0.38	13.0	1.46
AP7Mouth*	10	0.5	90	0.4	7.0	1.00	0.10	0.60	30.0	0.80	0.10	0.60	50.0	0.50	1.6	0.10	0.20	0.20	10.2	10.0

TABLE 4. Eigenvalues, species-environment correlations, and cumulative percent species variance of each Redundancy Analysis (RDA) axis.

	RDA Axis 1	RDA Axis 2	Total Variance
Eigenvalues	0.397	0.108	1.0
Species-environment correlations	0.976	0.733	
Cumulative percentage variance of species data	39.7	50.5	
Cumulative percentage variance of species-environment relation	62.8	79.8	
Sum of all eigenvalues			1.0
Sum of all canonical eigenvalues			0.633

midpoint site where gravel inputs have altered the streambed composition.

In addition to impacts that may result from contamination from the military landfill and scrap yard, Airport Creek has several other point sources of potential contamination and impairment of the benthic community. The particularly high abundance of chironomids observed at the AC8GMid sampling site is likely due to the elevated concentrations of nutrients found at this location (Fig. 3, Table 2). This site is directly downstream from a small private greenhouse situated on the north bank of the stream, approximately 5 m from the water's edge. The operator of this greenhouse also diverts water from the stream through a crude hose and pump to water plants. It is likely that runoff enriched with nutrients from plant fertilizers used in the greenhouse has leached into the stream, as higher concentrations of nutrients commonly found in plant fertilizers (e.g., boron, molybdenum, and nitrogen) were found in water samples from this location in 2008 than in 2007 (before the construction of the greenhouse). Benthic samples collected directly upstream from the greenhouse contained normal abundances of all taxa compared to other samples from Airport Creek and did not have elevated concentrations of any nutrients (Table 2). Since downstream samples did not contain high specimen abundances (Fig. 3), the largest impact of the greenhouse may be localized to a small portion downstream from the greenhouse where available nutrients are readily mobilized by the localized benthic and microbial communities.

Taxonomic Sufficiency and Simple Summary Indices

Several species of chironomids are known to be sensitive to the types of stressors found along the urbanized portions of the streams in Iqaluit (Clements et al., 2000; Mousavi et al., 2003; Porinchu and MacDonald, 2003), and they are often the dominant taxa within these systems. Although it is a time-consuming process, the further identification of the Chironomidae to higher taxonomic resolutions may be necessary in order to describe specific differences in the benthic community response to point-sources of anthropogenic pollution that would account for the extirpation of several taxa (e.g., Tanytarsini, Tanypodinae). Jones (2008) indicates that dominant, high-information taxa often warrant more taxonomic precision; therefore, change within chironomid assemblages could be the primary indicator of disturbances within the urbanized portions of both Iqaluit streams. As future economic development in Nunavut may influence water quality in other communities, a pan-Nunavut biomonitoring program should include further identification of Chironomidae specimens.

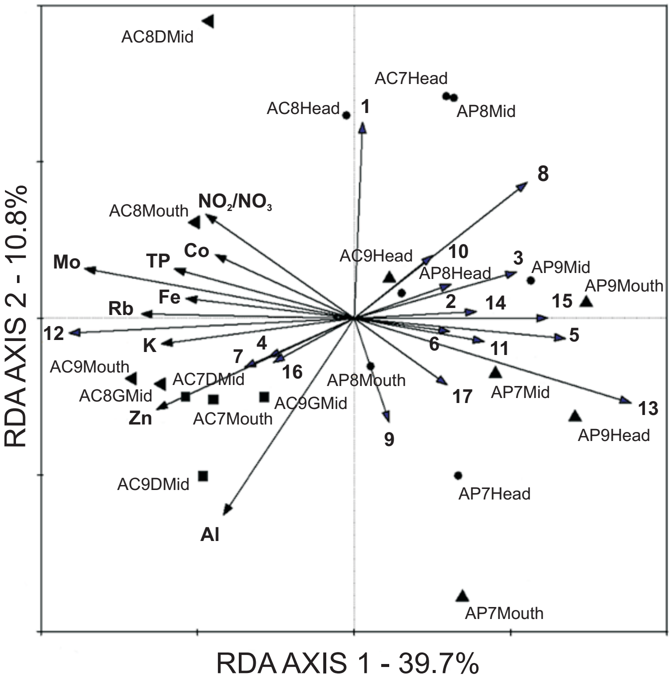

FIG. 11. Redundancy analysis indicating sample locations relative to significant ($p = < 0.05$) water chemistry variables. Groups: ■ = TWINSPAN group D2, ◀ = TWINSPAN group D3, ▲ = TWINSPAN Group C3 - Midpoint, ● = TWINSPAN Group C2. Species arrows: 1. *Acentrella* sp., 2. *Acerpenna* sp., 3. Dytiscidae, 4. Empididae, 5. Hydrachnidae, 6. Oligochaeta, 7. Plecoptera, 8. Simuliidae, 9. Tipulidae, 10. Trichoptera, 11. Diamesinae, 12. Orthocladiinae, 13. Tanypodinae, 14. Chironomini, 15. Tanytarsini, 16. *Trichotanypus* sp., 17. *Corynoneura* sp.

Diversity and abundance indices (e.g., the Shannon Index, Simpson's Reciprocal Index) are attractive to community-based biomonitoring programs because they allow minimally trained personnel to manipulate complex ecological data and generate values that can be compared mathematically to values at reference sites (Jones et al., 2004). Although these metrics indicated a disturbance to the benthic community at downstream locations of Airport Creek within urbanized areas (Fig. 3), the power of these metrics was substantially increased when the taxonomic resolution was increased (Fig. 7, Table 3). For example, identifications made at a higher taxonomic resolution (Table 1) indicated specific impacts to the benthic community composition, as samples were shown to skew towards pollution-tolerant Orthocladiinae chironomids (Fig. 6). This shift in benthic composition is discernable only when the diversity metrics are of sufficient taxonomic resolution to reflect the lower diversity and lower evenness found in sampling sites downstream of the urbanized zone of Airport Creek.

Multivariate Analysis

While the large shift in benthic taxa downstream of urbanized areas in Airport Creek was observed with the use of simple summary metrics (Figs. 5–8), the use of multivariate techniques allowed for a robust examination of significant relationships between biological and chemical data. The Apex River and Airport Creek are different systems, each with its own unique disturbances; however, both the TWINSPAN analysis (Fig. 9) and the DCA ordination of sampling sites indicated that the benthic communities of both rivers responded to a gradient of disturbance (DCA axis 1). The DCA analysis indicated a significant difference in DCA axis 2 scores between the 2007 and 2009 sampling years (Table 3). Milner et al. (2006) also found that annual and interannual variability made biomonitoring of Alaskan streams difficult to interpret with current protocols, impeding comparison of samples collected in subsequent sampling years. For example, when we restricted the analysis to 2009 samples only, the second axis of the DCA indicated a separation of habitat types, with the upstream undisturbed sampling location of Airport Creek grouping alongside sampling locations of the Apex River (Fig. 10). However, downstream samples from Airport Creek did not separate along DCA axis 2, indicating insensitivity to localized habitat characteristics (riffles vs. pools).

TABLE 5. Regression coefficients of the first two RDA axes and interest correlations for backwards-selected environmental variables. A single asterisk (*) indicates $p < 0.01$, while two (**) indicate $p < 0.05$.

Environmental variable	Regression Coefficients		Interset Correlations	
	Axis 1	Axis 2	Axis 1	Axis 2
Mo	-1.00*	0.68	-0.84	0.12
Rb	-0.37*	-0.11	-0.66	0.01
Zn	-0.19	-0.85**	-0.62	-0.21
K	0.50*	-0.67	-0.60	-0.06
TP	-0.15	0.07	-0.56	0.12
Fe	0.19	0.46	-0.52	0.05
NO_2/NO_3	0.19	0.35	-0.46	0.24
Al	-0.21**	-0.54	-0.41	-0.46
Co	-0.20	0.45	-0.43	0.15

The combination of the TWINSPAN analysis and ordination techniques (DCA, RDA) successfully separated the site locations where a loss of diversity and a dramatic shift to a benthic community dominated by Orthocladiinae have occurred at locations downstream of urbanized portions of Airport Creek. Thus, our analysis indicated that the identification of Chironomidae to sub-family/tribe allowed us to separate anthropogenically affected reaches of Airport Creek from minimally disturbed areas. In addition, the RDA of sites suggests that portions of Airport Creek within the urbanized zone of Iqaluit have water quality significantly different from that of the control sites and the Apex River for several key parameters that may be influencing benthic invertebrate assemblages (Fig. 11). This separation of sampling locations in these disturbed areas with the use of TWINSPAN and DCA analysis, in combination with constrained ordinations indicating the relationship with elevated metal and nutrient concentrations, confirms the relationships seen with the simple summary metrics that will be targeted for use by community groups to sample and monitor local resources.

CONCLUSIONS AND RECOMMENDATIONS

The core objective of this project was to evaluate the ability to conduct biomonitoring within Arctic tundra streams that may be influenced by localized point-source pollution. Our results indicated that simple taxonomic summary metrics are able to detect changes in stream assemblages with small adjustments to widely used biomonitoring protocols (e.g., CABIN). The power of these biotic metrics to discriminate sites and specific relationships to contamination is improved by more precise taxonomic identifications of the Chironomidae (Table 3, Fig. 6). We observed specific intra-family benthic-invertebrate responses to point-source pollution (shifts towards pollution-tolerant Orthocladiinae species of chironomids). We therefore recommend a level of taxonomic precision that is both statistically significant for the quantification of stream health and feasible for local groups to carry out with limited training and expertise on Arctic benthos (Table 1). The examination of these data through the use of multivariate assessment methods also supported the results and interpretation of the simple assessment metrics that would be appropriate for local biomonitoring. The application of these multivariate analyses allows for a robust examination of the data for further scientific review and confirmation of the results beyond the target audience of local community members.

It will likely be necessary to monitor how consistently and accurately the community can employ these methods, and to revise the field and laboratory protocols and develop additional reference materials accordingly. It would also be worthwhile to sample benthic invertebrates on a wider scale, across several streams that may be influenced by local development. Adding to our knowledge of how benthic assemblages in Arctic tundra systems may respond to anthropogenic disturbances would allow a broader examination of the biocriteria for indices in future bioassessment studies.

Although the scope of this study did not include ecotoxicological approaches, the relationship between biotic degradation and increased concentrations of metals and nutrients indicates a strong association between benthic invertebrates and anthropogenic pollution along the urbanized reaches of Airport Creek (Fig. 11). It would be worthwhile to conduct further toxicological analysis to determine whether additional compounds may also be influencing the benthic invertebrate community at sites along the urbanized portions of Airport Creek. Additionally, it would be interesting to explore the possibility that these species may suffer detrimental effects from contaminants at concentrations lower than current water quality guidelines (which are largely based on temperate zone data) in the extreme environmental conditions at the northern threshold of their ranges in this region of the Arctic.

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