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ARTICLE

# Diversity patterns in subarctic stream benthic invertebrate assemblages from the Sahtu Settlement Area, Northwest Territories, Canada

K. Vinke, A.S. Medeiros, and D.J. Giberson

**Abstract:** Benthic invertebrate assemblages were studied across four streams in the Sahtu Settlement Region of the Northwest Territories between July 2010 and October 2011 to provide information on biotic composition and associations with habitat and temporal factors. Overall diversity was similar for all streams, although taxonomic composition varied among the streams. Within streams, richness was highest in riffle and snag (woody debris) habitats and lowest in pools and leafpacks. A substantial portion of taxa (~25%) would have been missed if only riffles had been sampled. Nearly 88% of individuals belonged to eight taxa, with >60% of individuals found in only two families (Chironomidae and Baetidae). While high within-family diversity was observed, samples were also characterized by large numbers of rare taxa, with large temporal differences in abundances. Future benthic assessments in northern streams would benefit from increased sampling effort to ensure representative samples for comparing streams or sites and approaches that target dominant families in the north (e.g., Chironomidae), which can provide a great deal of information on biodiversity when examined at the generic level. Likewise, further analysis of the seasonal compositional turnover for some assemblages may be necessary to distinguish anthropogenic responses from natural variability.

*Key words*: aquatic diversity, subarctic, Sahtu Settlement Region, benthic invertebrates.

**Résumé :** Dans le cadre de cette étude, on a examiné des assemblages d'invertébrés benthiques sur quatre cours d'eau dans la région désignée du Sahtu dans les Territoires du Nord-Ouest entre juillet 2010 et octobre 2011 dans le but de fournir de l'information au sujet de la composition biotique et des associations avec l'habitat et les facteurs temporels. Dans l'ensemble, la diversité était semblable pour tous les cours d'eau, bien que la composition taxonomique variait selon le cours d'eau. Dans les cours d'eau, la richesse la plus grande se trouvait dans les rapides et chicots (débris de bois) et la plus pauvre dans les fausses et les paquets de feuilles. On aurait manqué une portion substantielle de taxons (~25%) si l'on avait uniquement prélevé des échantillons dans les rapides. Presque 88% des individus appartenaient à huit taxons, avec >60% des individus se trouvant dans seulement deux familles (Chironomidae and Baetidae). Alors qu'on a observé une grande diversité au sein des familles, les échantillons se démarquaient aussi par un grand nombre de taxons rares, avec de grandes différences temporelles quant aux abondances. Il serait avantageux que les évaluations benthiques futures se basent sur un échantillonnage plus vaste afin d'assurer des échantillons représentatifs aux fins de comparaisons entre les cours d'eau ou les sites, et des approches visant des familles dominantes dans le nord (ex. Chironomidae), ce qui peut fournir beaucoup d'information sur la biodiversité lorsqu'examiné au niveau générique. De même, de plus amples analyses des changements saisonniers de la composition

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**K. Vinke and D.J. Giberson.** Department of Biology, University of Prince Edward Island, Charlottetown, PE C1A 4P3, Canada.
**A.S. Medeiros.** Department of Geography, York University, Toronto, ON M3J 1P3, Canada.
**Corresponding author:** D.J. Giberson (e-mail: giberson@upei.ca).

de certains assemblages seront requises afin de distinguer les réactions anthropiques de la variation naturelle.

*Mots-clés :* diversité aquatique, subarctique, région désignée du Sahtu, invertébrés benthiques.



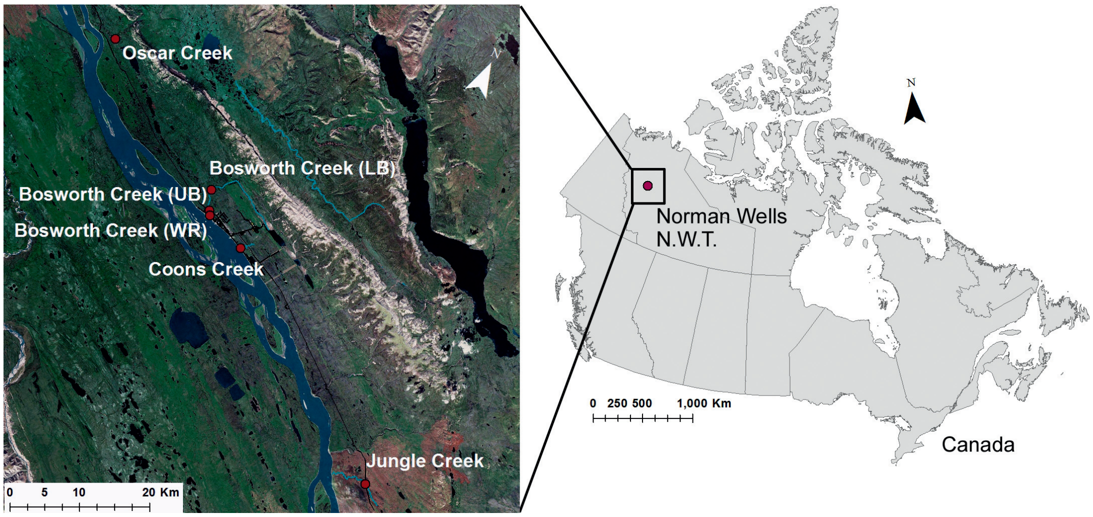
## Introduction

Growing development pressures across the Arctic and subarctic have renewed the need to understand and monitor northern freshwater resources. Knowledge of the biotic structure of aquatic systems is widely applied as an indicator of ecosystem health using biomonitoring approaches (Reynoldson et al. 2001); however, freshwater invertebrate communities shaped by the complex spatial and temporal constraints of northern systems are poorly understood. Arctic environments are characterized by short growing seasons, high habitat variability, extreme cold, and limited food availability (Hinterleitner-Anderson et al. 1992; Danks 2004; Scott et al. 2011). These environmental constraints apply greater selective pressures than temperate environments, resulting in specific adaptations for survival and dispersal. Freshwater invertebrates in northern climates may show prolonged life cycles, greater synchrony of emergence, and cold hardiness (Danks 2004). Their assemblage structure also depends on environmental conditions that affect colonization and dispersal. Diversity of many insect groups declines sharply with increasing latitude (Brunskill et al. 1973; Vinson and Hawkins 2003; Scott et al. 2011) and northern streams are naturally dominated by a few taxonomic groups (e.g., Diptera: Chironomidae and Simuliidae, and Ephemeroptera: Baetidae) that can tolerate these extreme conditions (Oliver 1968; Danks 1981, 2004; Medeiros et al. 2011).

Aquatic monitoring programs using benthic macroinvertebrate indicators are common tools for assessing stream health across Canada (Rosenberg et al. 1999; Reynoldson et al. 2001), but these programs are challenging to implement in northern regions due to limited knowledge of northern freshwater assemblages. Medeiros et al. (2011) noted that the effectiveness of biomonitoring programs in northern regions is highest when methods are calibrated with existing knowledge of diversity and environmental patterns. For example, reduced diversity (Vinson and Hawkins 2003; Scott et al. 2011) and altered life histories (Cowan and Oswood 1984; Danks 2004) of many of the insect groups normally used to assess stream condition can affect interpretation of diversity and abundance patterns. In addition, naturally high metal and suspended sediment levels in some northern streams (Collins et al. 2011) can be mistaken for anthropogenic effects if they are not identified prior to potential impacts (Pippy et al. 2011). Therefore, information is needed on the natural biodiversity and environment of these northern streams to provide a base for future monitoring studies.

The focus of this study is to assess biological and environmental information for four subarctic streams that flow into the Mackenzie River in the Sahtu Settlement Region, a large (283 000 $km^2$) and geographically diverse area that covers four ecozones in the Northwest Territories of northern Canada (Taiga Cordillera, Taiga Plains, Southern Arctic, and Taiga Shield) (Pippy et al. 2011). Past studies in Mackenzie tributaries have either focused on other regions of the Mackenzie River valley (e.g., Brunskill et al. 1973; Wiens et al. 1975) or have not specifically examined patterns between taxa and habitat (e.g., Rempel and Gill 2010; Pippy et al. 2011; Scott et al. 2011). Here, we compare four streams from July to October 2010–2011 to (1) examine differences in biotic composition across sites, (2) assess patterns in abundance and diversity across different habitat types, and (3) examine temporal differences in diversity that may influence interpretations of ecosystem condition. These results should improve our understanding of natural diversity patterns and the effectiveness of future biomonitoring approaches in northern streams.

**Fig. 1.** The Sahtu region of the Northwest Territories showing the study rivers and sampling locations along the Mackenzie River. Map source: ArcGIS Basemap Data 1992–2006. Environmental Systems Research Institute Inc., Redlands, California.




## Site description

Six sites were chosen on four low-gradient Mackenzie River tributaries in the Sahtu Settlement Region of central Northwest Territories near Norman Wells (Fig. 1): Bosworth Creek (three sites), Jungle Ridge Creek, Oscar Creek, and Coons Creek (the local name for an unnamed creek in Norman Wells) (Table 1). Site selection was based on accessibility (by road or helicopter) and physical features that provided a range of stream types representative of the Sahtu region. Other criteria for site selection included consistent flow (some small Sahtu streams become dry for parts of the year) and the presence of suitable sampling habitat (i.e., well-developed riffles and other potential macroinvertebrate habitat such as pools, snags, attached aquatic vegetation, and leafpacks). The streams had generally similar water chemistry (Table 2) but differed in accessibility and human influence, substrate size and composition, stream width, and canopy cover. Coons Creek and Jungle Ridge Creek sites were small and heavily shaded with gravel–cobble–boulder substrates, and Bosworth Creek and Oscar Creek sites were wide with open canopies and gravel–cobble substrates (Table 1). Jungle Ridge and Oscar Creek sites were only accessible by helicopter or boat, but Coons Creek and Bosworth Creek were both located within the community of Norman Wells, so were potentially vulnerable to disturbance from industrial and municipal sources (mainly ATV crossings (e.g., Senes Consultants and Guthrie 2009) and an Imperial Oil refinery near the mouth of Bosworth Creek) (Table 1). The lower reach of Bosworth Creek had been dammed to supply water to a nearby Imperial Oil refinery and the town, but the weir was removed in 2005 and new riffle habitat was constructed (Guthrie 2010). Streams in this part of the Mackenzie may have naturally occurring elevated metal concentrations (especially aluminum, selenium, and iron) (Senes Consultants and Guthrie 2009; Guthrie 2010; Collins et al. 2011) and higher hardness relative to other Mackenzie tributaries (Rempel and Gill 2010).

The study streams all run through the eastern lowlands that border the Mackenzie River. This area has a subarctic continental climate (mean temperatures: annual −5.5 °C, January −26.5 °C, and July 17 °C) with little precipitation (average 290.7 mm per year, 153.4 cm as snow). Riparian areas are black spruce (*Picea mariana* (Mill.) Britton, Sterns & Poggenb.)

**Table 1.** Site details for the six Mackenzie River stream sites sampled during 2010 and 2011.

| Site name (code) | Location | Sampling dates | Characteristics | Potential anthropogenic influence |
|---|---|---|---|---|
| Oscar Creek (Oscar) | 65°26.073'N, 127°22.939'W | **2010:** 30 July, 29 Aug., 17 Sept.; **2011:** 15 Sept. | Open canopy, wide, medium substrate | Distant from human influence |
| Bosworth Creek Lower Bridge (Bos LB) | 65°18.967'N, 126°53.898'W | **2010:** 5 July, 20 Aug., 15 Sept. | Open canopy, moderate width, fine substrate | Close to populated area and oil field, road crossing a few kilometres upstream, immediately upstream of preexisting weir, evidence of ATV crossings |
| Bosworth Creek Upper Bridge (Bos UB) | 65°17.446'N, 126°52.546'W | **2010:** 9 July, 18 Aug., 15 Sept.; **2011:** 15 Sept. 16 Oct. | Open canopy, moderate width, medium substrate | Close to populated area and oil and gas field, road crossing immediately downstream, farther upstream from preexisting weir, evidence of ATV crossings |
| Bosworth Creek Winter Road (Bos WR) | 65°17.113'N, 126°52.007'W | **2010:** 13 July, 29 Aug., 17 Sept.; **2011:**15 Sept. | Open canopy, wide, medium substrate | Distant from most human influence, winter road crossing downstream, Bosworth Creek drains from Hodgeson Lake, a recreational area for fishing, canoeing, and swimming |
| Coons Creek (Coons) | 65°15.931'N, 126°44.101'W | **2010:** 6 July, 23 Aug., 16 Sept.; **2011:** 18 Sept., 16 Oct. | Heavy canopy, narrow, coarse substrate | Close to populated area, traversed by at least two major roads, gravel storage site near banks, flows from a series of wetlands that are close to an oil sump site (i.e., where oil-contaminated water is pumped into the ground), evidence of ATV crossings |
| Jungle Ridge Creek (Jungle) | 65°03.697'N, 126°03.641'W | **2010:** 30 July, 29 Aug., 17 Sept. | Heavy canopy, narrow, coarse substrate, vegetation recovering from 2005 fire | Distant from most human influence, winter road crossing approximately 50 m downstream |

coniferous forests, with white spruce (*Picea glauca* (Moench) Voss), balsam poplar (*Populus balsamifera* L.), white birch (*Betula papyrifera* Marshall), and trembling aspen (*Populus tremuloides* Michx.) occurring on better-drained areas (Brunskill 1986; Veitch et al. 1995). Local geology consists of glacial till or lake-derived material overlaying sedimentary rock of limestone, shale, and sandstone, and the landscape is low-lying with discontinuous permafrost (Brunskill 1986). The streams are ice-covered for about 7 months of the year (Brunskill 1986); some freeze to the substrate, and the channels are ice-scoured during ice breakup in the spring. Peak snowmelt flows in June result in large suspended sediment loads, which clear over the summer (Faria 2002).

## Methods

### Field methods

Field methods were modified from the sampling protocols described in the CABIN field manual (Carter and Pappas 2012); more habitats were sampled at each site (in addition to the riffle samples recommended in CABIN protocols), and higher taxonomic resolution was assessed for a more complete inventory of diversity. In addition, samples were collected using a 200 µm mesh kick net (compared with the 400 µm mesh specified in CABIN). Each study reach was defined as an area of stream about six times the bankfull width containing a pool–riffle–pool sequence. Specific site details recorded for each study reach included details on surrounding land use, stream habitats, and in-stream characteristics (e.g., aquatic

**Table 2.** Chemical and physical parameters from middle to lower reaches of four Mackenzie River tributaries within the Sahtu Settlement Area, Northwest Territories (16–18 September 2011, except as noted).

| | | | | Bosworth Creek | |
|---|---|---|---|---|---|
| | Jungle Creek | Oscar Creek | Coons Creek | Winter Road | Upper Bridge |
| **Chemical habitat parameters** | | | | | |
| pH | 8.35 | 8.33 | 8.27 | 8.43 | 8.42 |
| Conductivity (μS/cm) | 1100 | 469 | 662 | 623 | 620 |
| Alkalinity (mg/L $CaC0_3$) | 248 | 163 | 201 | 176 | 178 |
| Bicarbonate (mg/L) | 293 | 196 | 246 | 205 | 206 |
| Carbonate (mg/L) | BD | BD | BD | 5 | 5.4 |
| Total dissolved solids (mg/L) | 665 | 273 | 395 | 371 | 367 |
| Hardness (mg/L $CaC0_3$) | 426 | 230 | 309 | 294 | 287 |
| Sodium (mg/L) | 65.6 | 10.6 | 19.1 | 16.4 | 13.2 |
| Sodium (dissolved) (mg/L) | 68.7 | 11.2 | 19.6 | 15.5 | 14.1 |
| Chloride (mg/L) | 85.6 | 13.2 | 9.59 | 14 | 13.5 |
| Calcium (dissolved) (mg/L) | 113 | 63.9 | 81.7 | 72.2 | 70.9 |
| Magnesium (dissolved) (mg/L) | 35 | 17 | 25.4 | 27.7 | 26.8 |
| Potassium (dissolved) (mg/L) | 1.55 | BD | 1 | 0.95 | 0.96 |
| Calcium (mg/L) | 109 | 59.8 | 77.7 | 74.8 | 65.4 |
| Potassium (mg/L) | 1.31 | 0.57 | 0.94 | 1.28 | 0.93 |
| Sulfate ($S0_4$) (mg/L) | 212 | 69.8 | 137 | 135 | 134 |
| Aluminum (mg/L) | 0.022 | 0.045 | BD | BD | 0.154 |
| Arsenic (mg/L) | 0.0004 | 0.0005 | 0.0005 | BD | BD |
| Barium (mg/L) | 0.082 | 0.076 | 0.043 | 0.064 | 0.067 |
| Boron (mg/L) | BD | BD | BD | 0.055 | BD |
| Copper (mg/L) | BD | 0.001 | BD | BD | BD |
| Iron (mg/L) | 0.13 | 0.149 | 0.08 | 0.048 | 0.282 |
| Lead (mg/L) | BD | BD | BD | BD | 0.0002 |
| Lithium (mg/L) | 0.014 | BD | BD | BD | BD |
| Magnesium (mg/L) | 33.5 | 15.5 | 23.4 | 26.9 | 24.2 |
| Manganese (mg/L) | 0.007 | 0.019 | 0.004 | 0.002 | 0.008 |
| Nickel (mg/L) | BD | BD | BD | 0.0024 | BD |
| Titanium (mg/L) | BD | 0.002 | BD | BD | 0.003 |
| Uranium (mg/L) | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| **Physical habitat parameters** | | | | | |
| Water temperature (°C) (on sampling date) | | | | | |
| July 2010 | 16 | 17 | 18 | 15 | 20 |
| Aug. 2010 | 10 | 12 | 11 | 10 | 12 |
| Sept. 2010 | 3 | 6 | 4 | 4 | 6 |
| Dissolved oxygen (mg/L), Sept. 2010 | 9.3 | 9.6 | 9.1 | 9.5 | 8.9 |
| Canopy cover (%) | 60 | 4 | 50 | 5 | 7 |
| Mean velocity (m/s) | 0.8 | — | 0.3 | 0.2 | 0.7 |
| Width of flow (m) | 4 | 20 | 3 | 15 | 10 |
| Median rock size (cm) | 13 | 5.2 | 12 | 6.4 | 4.2 |
| Dominant substrate | Cobble–boulder | Gravel–cobble | Cobble–boulder | Gravel–cobble | Gravel–cobble |

**Note:** See Table 1 and Fig. 1 for site locations. BD, below detectable. A dash indicates no data for that date.

vegetation, algae, channel width, depths, velocity and slope, and substrate particle size and embeddedness). Several environmental and biological features were characterized for each study reach on each sampling visit (between July 2010 and October 2011; see Table 1 for specific sampling dates) to give information on surrounding terrestrial habitat, in-stream habitat, and stream hydraulic variables. Temperature, pH, conductivity, and dissolved oxygen were measured with each site visit using a YSI model 556 multimeter (YSI Ltd., 1700/1725 Brannum Lane, Yellow Springs, Ohio). Water velocity measurements were also recorded using a Swoffer model 2100 water velocity meter (Swoffer Instruments, Inc., 1048 Industry Drive, Seattle, Washington). Certain parameters (e.g., bankfull width, substrate size, substrate embeddedness, and water chemistry) were assessed only once. Water chemistry parameters analyzed included major ions and trace metals processed by the ALS Environmental Laboratory Group, Edmonton, Alberta. Substrate size was estimated for the riffle zone of each stream from a random sample of 50 rocks (measured in three dimensions and then averaged (Wolman 1954)), and substrate stability was assessed using indicators in the Pfankuch Habitat Quality Index (embeddedness and substrate distribution and shape (Pfankuch 1975)).

Benthic invertebrates were sampled in all habitats using a 200 μm mesh D-frame kick net. Samples were collected by disturbing substrate upstream of the collecting net while traversing the riffle in a zigzag fashion for 3 min. A comparison of five commonly observed habitat types (riffles, pools, snags, aquatic vegetation, and leafpacks) was conducted following protocols for each habitat type adapted from Barbour et al. (1999). Each habitat type was sampled in relative proportion to its occurrence in each site by disturbing the habitat and then drawing the net through the suspended material. If any of the samples contained excessive inorganic material, they were elutriated on site by swirling the contents in a bucket. Samples were preserved in 80% ethanol.

**Laboratory methods**

Each sample was sorted using a dissecting microscope and was either fully sorted if small (<1500 mL jar) or subsampled for large samples using a gridded tray, sorting one randomly selected grid cell at a time until the cell containing the 300th individual was found (McDermott et al. 2012). Each individual specimen was identified to the lowest practical taxonomic level for assessing assemblage patterns and environmental and temporal associations. Nonarthropod invertebrates were identified to order. Aquatic arthropods were identified to genus if mature enough, except for most Chironomidae (Diptera) and Hydrachnidiae (mites), which were identified to subfamily or order, respectively. Mature specimens from a subset of streams and dates were processed further for the overall biodiversity assessment. Ephemeroptera, Plecoptera, and Trichoptera from these latter samples were identified to species where possible, and chironomid and mite specimens were slide-mounted for genus identification. Sorting and identifications were evaluated for quality control following CABIN recommendations for Quality Assessment/Quality Assurance (QA/QC) (Reynoldson et al. 2001). Ten percent of samples were resorted and sorting efficiency was ≥90% for all resorted samples.

**Data analyses**

All numerical analysis was conducted using R statistical language v3.1.1 with the vegan and labdsv libraries. Community metrics (e.g., taxonomic richness, relative abundance, and functional or taxonomic groupings) were used to characterize biotic assemblages of each site and habitat type. The total number of unique taxa relative to the number of occurrences across all sites and dates was calculated to examine the evenness between samples. A two-factor analysis of variance (ANOVA) was conducted to test the significance of differences observed between site locations and time of sampling. A one-way ANOVA was used to examine differences based on habitat type. The probability of the relative frequency of significant indicator taxa occurring in a particular habitat was calculated using Dufrene–Legendre indicator species analysis (Dufrene and Legendre 1997). Taxonomic and habitat differences among sites were then observed using principal components analysis (PCA).

For PCA analyses, benthic invertebrate data were expressed as relative abundances and were square-root transformed. A *k*-means clustering analysis was then used to determine the specific degree of separation between site types based on PCA site scores. Groupings were considered to be distinct from each other if they showed <40% similarity in the cluster analysis (cutoff percentage used in CABIN to define separate reference site groups (Pippy et al. 2011)). All sites were compared to one another, replicated over 3 months (July, August, September) in 2010, and September and October in 2011 for some site locations to capture autumn assemblages (Table 1).

## Results

### Habitat characteristics

Coons and Jungle Ridge creek sites were small (first and second order, respectively, <5 m width) and heavily shaded (50%–60% cover, mainly deciduous vegetation) with cobble and boulder substrates. The Oscar and Bosworth site locations were larger (third order, >10 m) and more open (4%–7% cover, mainly coniferous vegetation) with gravel and cobble substrates (Tables 1 and 2). Summer temperatures were similar (15–20 °C in July and 10–12 °C in August) across sites (Table 2). Microhabitat varied among sites: all sites had shallow fast riffles, all sites but Coons Creek had pools, snags (large woody debris) were observed in Jungle and Bosworth Creek sites, and leafpacks were found at the bottom of pools and in the crevices between boulders at Coons Creek. All Bosworth Creek sites showed some evidence of disturbance from residential development near the stream (e.g., ATV tracks on the banks and bank damage from the winter road crossing), and substrates were mobile (less stable) compared with substrates in the other streams. All streams were basic (pH 7.9–8.4) with high conductivity (470–1100 µS $cm^{-1}$) and oxygen levels near saturation (7.8–9.7 mg $L^{-1}$) (Table 2). Conductivity and concentrations of dissolved ions (e.g., chloride, magnesium, and sulfate) were particularly high at the Jungle Ridge Creek site, which also had the lowest temperatures recorded. The Bosworth sites had higher aluminum levels and higher temperatures compared with the other sites (Table 2).

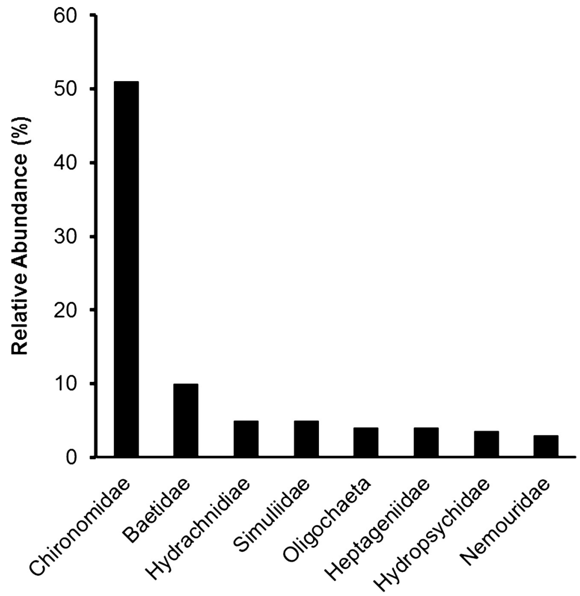
### Benthic macroinvertebrate assemblages

The combination of all samples (including the subset that underwent additional processing for biodiversity assessment) yielded ~73 750 individuals in 169 taxa (including 151 genera and 68 families (see Supplementary Table 1 for a complete list[1]). Insects made up 82% of total taxa and 88% of all individuals, and more than half of all specimens collected were midges (Diptera: Chironomidae). Eight taxa made up >85% of all specimens (Fig. 2), and most genera (77%) were rare (making up <2% of total individuals). Chironomidae were the most diverse taxon (42 genera comprising 25% of taxa, mainly within Orthocladiinae and Chironominae) followed by Trichoptera (30 taxa or 18% of the total). Other relatively diverse groups included the Ephemeroptera (20 taxa, 12%), Plecoptera (16 taxa, 9%), and Hydrachnidae (mites, 15 taxa, 9%).

Specimens could not be slide-mounted and processed for all samples, so site and temporal comparisons were carried out to a consistent "lowest practical taxonomic level" for all sites and dates. This resulted in 85 taxa (genus for most insect groups, subfamily for Chironomidae, and a higher level as necessary for other invertebrates) for environmental and temporal comparisons. Although each site location had different landscape and environmental characteristics (Table 1), the average taxonomic richness was similar across sites (Fig. 3*a*). However, mean abundance varied among sites, largely attributed to variations in abundances of the dominant taxa (e.g., genera of the Chironomidae), especially among

[1]Supplementary material is available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/as-2015-0006.

**Fig. 2.** Relative abundance of the eight most common taxa collected across all study streams in 2010.

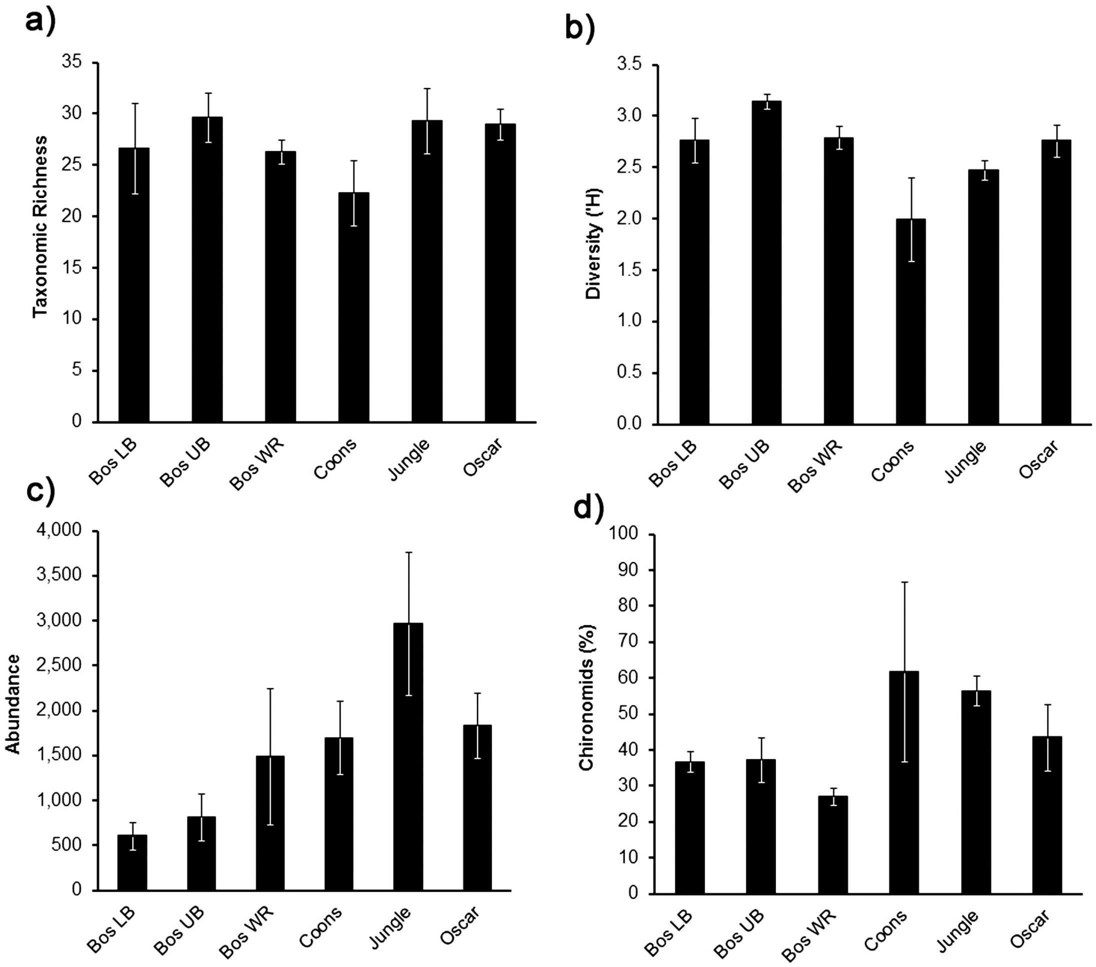



the Coons, Jungle, and Oscar Creek locations (Fig. 3). A two-factor ANOVA comparing sampling month (July–September of 2010) and site location found significant differences ($P < 0.05$) in the abundance, diversity, and percent chironomids of samples (Table 3). Rare taxa were common, with a majority of taxa present in fewer than five samples across all sites and dates (Fig. 4). Fewer than 10 taxa were present in all of the samples collected. While taxonomic richness between sampling months was similar, differences in abundance were notable (Fig. 5; Table 3). Samples collected in September and October of 2011 had the highest abundances (e.g., chironomids were most abundant in September 2010 and October 2011 and least abundant in July) but also the largest variation between samples.

Distinct relationships were observed between benthic invertebrate assemblages and site locations in a PCA (Fig. 6). The largest amount of variation between site locations, represented by PCA1 (22.2%), was between small closed-canopy sites (Jungle and Coons Creek samples) and large open-canopy sites (Bosworth and Oscar Creek samples) (Fig. 6*a*). Hierarchical cluster analysis confirmed that benthic assemblages between these two site groupings were <40% similar ($P = 0.001$), whereas sites within groupings all had ≥40% similarity. Small closed-canopy sites (Jungle and Coons Creek sites) had relatively low diversity and relatively high proportions of noninsect groups like the Hydrachnidiae (mites) compared with the larger open streams, which had higher diversity and more Ephemeroptera, Plecoptera, and Trichoptera. Small closed-canopy sites also had high proportions of shredders (including Nemouridae, some Leptoceridae, some Limnephilidae, Phryganeidae, and some Orthocladiinae and Chironominae), scrapers (e.g., most Hydroptilidae, Glossosomatidae, some Limnephilidae, and Planorbidae), and collector-filterers (e.g., Simuliidae, some Brachycentridae, and some Chironominae). In contrast, large open-canopy sites had high proportions of collector-gatherers and collector-filterers (e.g., Baetidae, Caenidae, Ephemerellidae, Hydropsychidae Elmidae, and Oligochaeta (mainly Naididae)).

Variation reflected by PCA2 (12.9%) was mainly a factor of variation among sites sampled at different times of the summer, including autumn samples from 2011. Lower diversity of chironomids and higher abundances of Planorbidae, *Glossosoma*, Hydrachnidiae, *Oecetis*, Lymnaidae, Valvata, and *Ephemerella* in samples collected in July accounted for a large

**Fig. 3.** Patterns in benthic invertebrate assemblages among the six study sites on the four Sahtu region study streams: (*a*) taxonomic richness, (*b*) Shannon diversity (*H*'), (*c*) mean abundance, and (*d*) percentage of Chironomidae. Error bars indicate the variability over the different sample times for each location (July–September 2010). Taxonomic resolution is at the subfamily/generic level and site codes are defined in Table 1.




difference in benthic assemblages between sampling periods for Jungle, Coons, Bosworth Upper Bridge, and Oscar Creek locations (Fig. 6*b*). In contrast, samples collected in September and October of 2010 and 2011 had higher occurrences of Oligochaeta, Capniidae, *Alloperla*, Nemouridae, and chironomids.

A comparison of habitat types found that richness was highest in riffle habitats followed by snags, aquatic vegetation sweeps, and pools, with leafpacks showing the lowest richness (Table 4; Fig. 7). A one-way ANOVA found that the biotic assemblages were significantly different ($P < 0.05$) between habitat types (based on September 2010 samples). Sixteen taxa at the lowest practical taxonomic level (23%) would have been missed if riffles alone were sampled, including 10 families that were not recorded at all in the riffle samples. Most of the taxa found only in nonriffle habitats were relatively rare (<10 individuals collected) and most were found in the snag habitat. If both riffle and snag habitats were sampled, only three taxa would have been missed (4%). The variation of a PCA of September 2010 samples collected from different habitat types (Fig. 8) was similar to the amount of variation explained between assemblages and site locations (Fig. 6). Indicator species analysis also

**Table 3.** Two-factor ANOVA comparing differences in month of sampling and site location for biotic assemblages.

| Comparison | *F* | *P* |
|---|---|---|
| Richness | | |
| Between sites | 1.09 | 0.42 |
| Between dates | 1.93 | 0.20 |
| Diversity | | |
| Between sites | 4.22 | 0.03 |
| Between dates | 4.67 | 0.04 |
| Abundance | | |
| Between sites | 4.64 | 0.02 |
| Between dates | 5.47 | 0.02 |
| %Chironomids | | |
| Between sites | 5.63 | 0.01 |
| Between dates | 6.31 | 0.02 |
| Habitat[a] | | |
| Between sites | 8.51 | <0.01 |

[a]Differences in habitat type were tested in a one-way ANOVA of samples collected in September 2010 only.

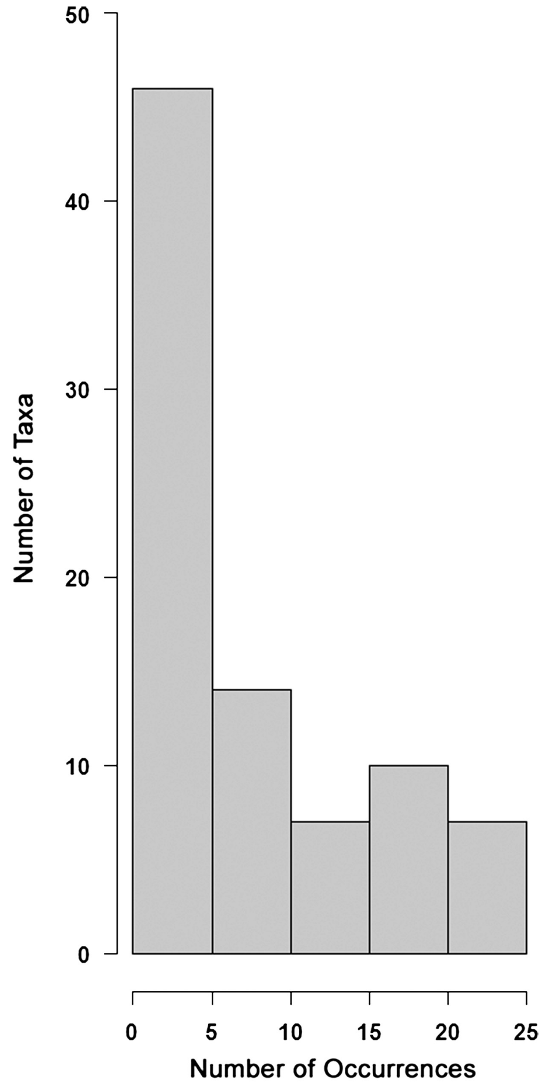
found that several taxa were significantly related ($P < 0.05$) to habitat type, with Chironominae, Heptageniidae, and *Dicranota* found in higher relative frequency in aquatic vegetation samples, Hydrachnidia in snag samples, Ceratopogonidae and Tanypodinae in riffles, Corduliidae in leafpacks, and Orthocladiinae in pools.

## Discussion

Few studies have evaluated taxonomic composition, sampling season, and habitat associations for streams in subarctic or Arctic regions, especially within the Sahtu region. Our results demonstrate important patterns in subarctic benthic invertebrate assemblages across habitats and sampling month, which are essential factors to be considered in the design of stream biomonitoring studies in the subarctic. As expected, relatively few taxa were identified from the four Sahtu streams in our study despite intensive sampling over a number of sample dates. Although other Mackenzie tributary studies recorded higher numbers of taxa overall than found in this study (Wiens et al. 1975 (450 genera and species); Rempel and Gill 2010 (174 genera); Scott et al. 2011 (270 genera)), these previous studies included data from a greater number of streams over a much larger geographical area; for smaller areas or individual streams, the numbers are more comparable.

A growing number of studies question whether low diversity and low abundance of invertebrates in northern streams limits the ability to provide sufficient resolution to distinguish differences between biotic assemblages in northern environments (e.g., Medeiros et al. 2011; Pippy et al. 2011; Scott et al. 2011). In particular, low diversity and high numbers of rare taxa can result in major assemblage differences among streams due to natural variation. Our data reinforce the importance of considering habitat type and time of sampling for characterizing subarctic benthic assemblages due to low diversity, high seasonal variability, and strong habitat associations. Previous studies have attempted to address local diversity issues by analyzing large numbers of reference streams in a reference condition approach (Reynoldson et al. 1997) over broad geographical areas and encompassing a wider range of habitat features (Bailey et al. 1998; Scott et al. 2011). However, large differences in benthic–environmental relations at local and regional spatial scales in the north (Medeiros and Quinlan 2011) make it difficult to identify all but the most extreme anthropogenic

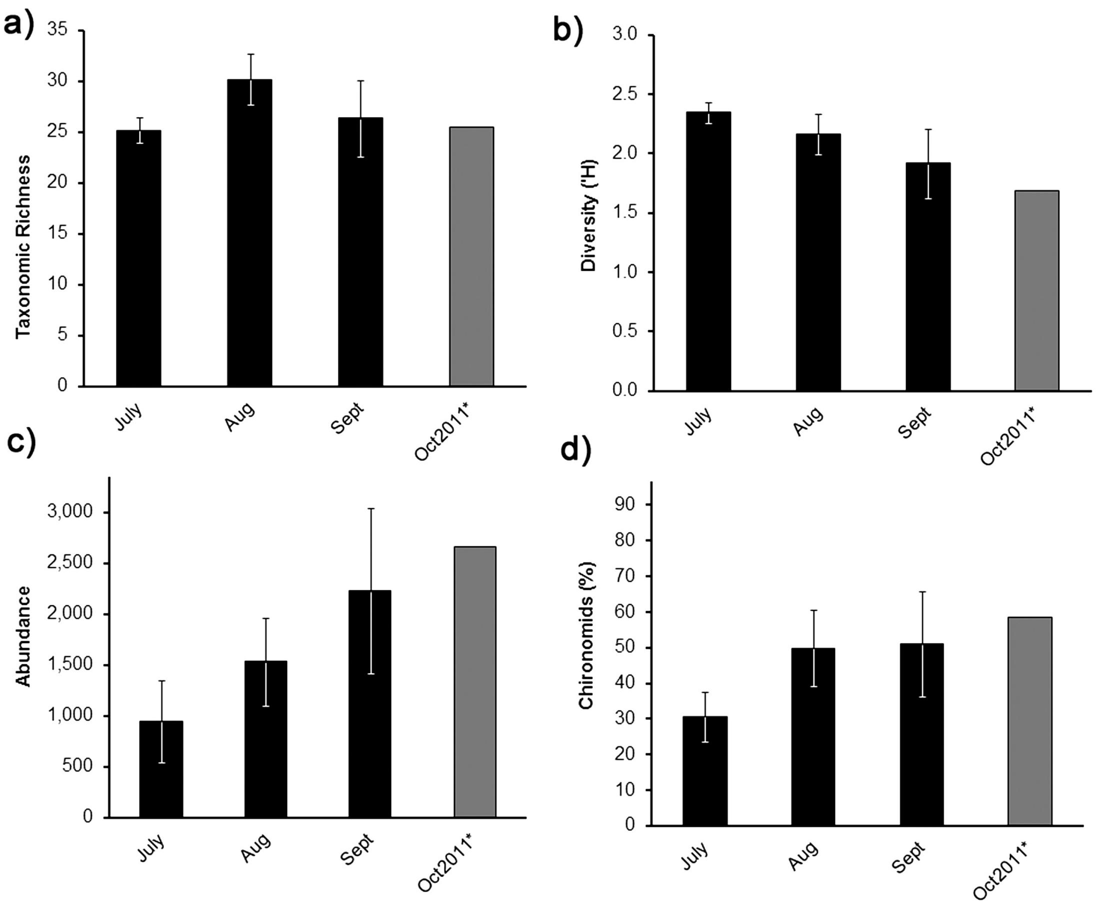
**Fig. 4.** Total number of unique taxa relative to the number of occurrences across all sites and dates indicating that a majority of taxa are rare and occur at a particular site or time of collection.




impacts. The large differences between benthic assemblages across subarctic stream locations, due to strong habitat (this study) and latitudinal associations (Scott et al. 2011), may require before-after-control-impact (BACI) methods for assessing differences in diversity (controlling for local spatial and temporal variation, e.g., Clements and Kiffney 1995). Thus, studies that provide biodiversity data and information on habitat associations, such as this one, provide important baseline information for future biomonitoring approaches in northern environments.

Although not designed to assess specific environmental impacts, this study gives an example of how natural variability can obscure the characterization of diversity in subarctic streams. Taxonomic composition related to stream size, substrate, and canopy cover and assemblages from different habitat types were easily distinguished from one another in this study. Although ATV-related erosion and visible signs of litter were evident in Bosworth

**Fig. 5.** Comparison of temporal differences in abundance and diversity in the six study sites on the four Sahtu region study streams: (*a*) taxonomic richness, (*b*) Shannon diversity (*H*′), (*c*) mean abundance, and (*d*) relative abundance of the Chironomidae. Error bars indicate differences based on sample location variability. Taxonomic resolution is at the subfamily/generic level. Note: parameters calculated from samples collected from October 2011 are plotted for reference.




and Coons sites in and near Norman Wells, a PCA did not distinguish these sites from the more pristine Jungle and Oscar Creek locations, suggesting that any potential "disturbance" was minor compared with differences in habitat.

Two other important observations from this study relate to diversity patterns. Samples were characterized by large proportions of rare taxa that are easily missed through inadequate sampling effort, so some apparent differences in community patterns in streams could be artefacts of sampling effort. Increasing sampling effort could improve the diversity and abundance estimates. We show that as many as 25% of the invertebrate taxa in Sahtu streams could be missed by focusing on the riffle habitats recommended in biomonitoring protocols (Reynoldson et al. 2001), and Medeiros et al. (2011) noted that the standard 3 min kick sample did not provide accurate diversity and abundance estimates in low-nutrient tundra streams. In addition, in northern streams where the small Chironomidae dominate the assemblages, some differences among streams and sampling date might relate to sampling bias from failing to capture small stages or taxa in some sites or seasons.

The dominance in northern streams by Chironomidae and Baetidae (Brunskill et al. 1973; Giberson et al. 2007; Scott et al. 2011) poses particular challenges, since both of these groups

**Fig. 6.** Invertebrate community associations in the four Sahtu study streams based on principal components analysis of samples for each site and sample date (dates without a year indicate 2010). PCA1 explained 22.2% of the variation in assemblages and related primarily to canopy features (open versus closed). PCA2 explained 12.9% of the variation and was mainly represented by differences in seasonality of the samples.

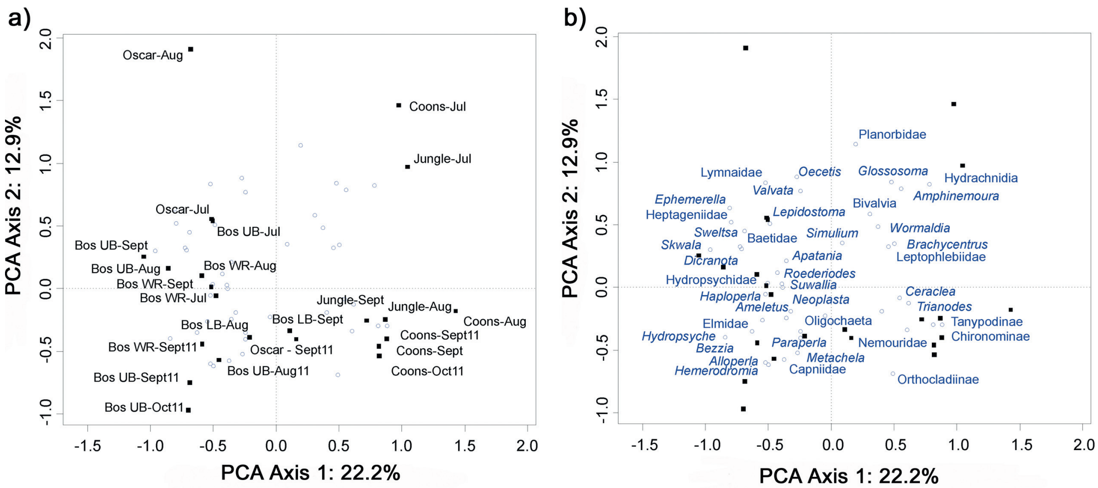



**Table 4.** Higher level taxa (generally family or above) encountered most often in each habitat type in the Sahtu study streams, summer 2011 (see Supplementary Table 1 for specific taxa found within each taxon group).

| Riffle (50 taxa) | Pool (26 taxa) | Snag (46 taxa) | Aquatic vegetation (38 taxa) | Leafpacks (20 taxa) |
|---|---|---|---|---|
| Oligochaeta | Oligochaeta | Oligochaeta | Oligochaeta | Oligochaeta |
| Planorbidae (Gastropoda) | Planorbidae (Gastropoda) | Lymnaeidae (Gastropoda) | Leptophlebiidae | Nemouridae |
| Hydrachnidiae | Hydrachnidiae | Ameletidae | Corixidae | Hydropsychidae |
| Baetidae | Corixidae | Baetidae | Chironominae | Orthocladiinae/ Diamesinae |
| Heptageniidae | Ceratopogonidae | Ephemerelllidae | Orthocladiinae/ Diamesinae | Simuliidae |
| Leptophlebiidae | Chironominae | Leptophlebiidae | Tanypodinae | |
| Capniidae | Orthocladiinae/ Diamesinae | Capniidae | | |
| Chloroperlidae | Tanypodinae | Corixidae | | |
| Nemouridae | | Hydropsychidae | | |
| Elmidae | | Chironominae | | |
| Brachycentridae | | Orthocladiinae/ Diamesinae | | |
| Glossosomatidae | | Tanypodinae | | |
| Hydroptilidae | | Simuliidae | | |
| Lepidostomatidae | | | | |
| Chironominae | | | | |
| Orthocladiinae/Diamesinae | | | | |
| Tanypodinae | | | | |
| Ceratopogonidae | | | | |
| Pediciidae | | | | |
| Simuliidae | | | | |

**Note:** A taxon was included in this list if >10 individuals were found in that habitat type over all dates and sites. Numbers in parentheses for each habitat type indicate the total number of taxa found in that habitat (generally based on family-level identifications).

**Fig. 7.** Mean invertebrate taxa richness (±SE, $n$ = 4 sample sites) among habitat types. Samples were collected in September 2010 using a 200 μm mesh D-Ring kick net (3 min traveling kick in riffles, and other habitats were sampled opportunistically by disturbing sediment and drawing the net through the disturbed suspended material).

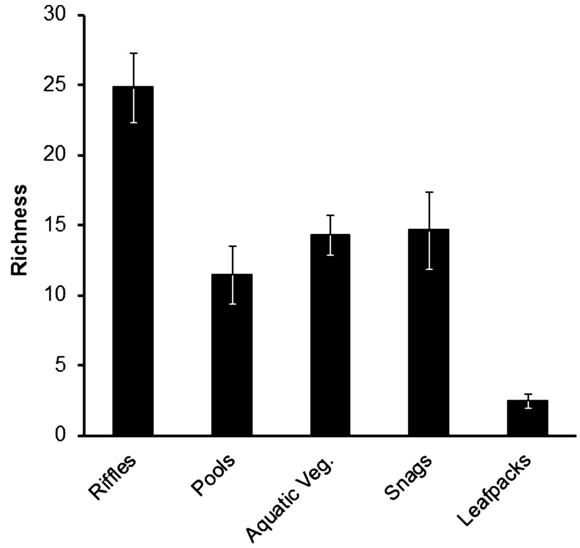
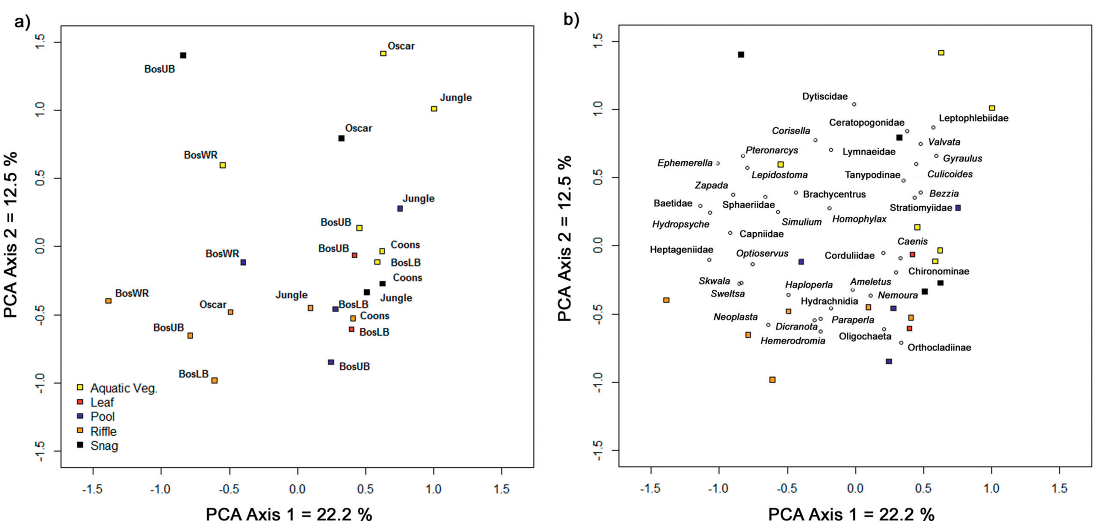



**Fig. 8.** Principal components analysis of invertebrate community associations with habitat type from samples collected in September 2010 in the four Sahtu study streams. PCA1 explained 22.2% of the variation in assemblages and PCA2 explained 12.5% of the variation.




have substantial generic diversity but difficult taxonomy. In this study, >60% of all individuals belonged to these two families, and the differences in interpretation of diversity patterns between genus-level (40 taxa) and family-level identification (two taxa) were dramatic. In sites dominated by a small number of groups with such high within-family diversity, genus-level identification may be required to pick out small differences among assemblages caused by anthropogenic stresses. Jones (2008) also argued that dominant high-information taxa warrant more taxonomic precision, and Medeiros et al. (2011) showed that chironomid assemblages are especially sensitive to anthropogenic influence in Arctic environments. Our data support this premise, and further analysis of the seasonal compositional turnover for chironomid assemblages may be necessary to distinguish anthropogenic responses from natural variability. Indeed, while we identify seasonal variation as an important determinant of benthic assemblages, much of this was due to differences in chironomid assemblages, which are often omitted from biomonitoring studies due to difficulty in identification beyond the family level (Jones 2008) or because benthic index (i.e., tolerance) scores commonly used in stream assessments are calibrated for temperate streams (e.g., Hilsenhoff 1988; Bailey et al. 1998).

Biomonitoring studies in northern streams are increasing in abundance and importance with increased emphasis on environmental assessments for potential resource development impacts. These are complicated by harsh environments that result in low diversity and abundance of invertebrate bioindicators as well as the presence of potential stressors, such as elevated metal levels that may occur naturally (e.g., elevated aluminum in Bosworth Creek (Collins et al. 2011; Pippy et al. 2011)) and result in different communities, even in the absence of anthropogenic impacts. Locally based biomonitoring programs inform local decisions, build community capacity, provide employment opportunities for locals, and increase collaboration between southern scientists, northerners, and policymakers, resulting in greater cultural and environmental sustainability (Government of the Northwest Territories 2009; Tondu et al. 2014). Studies that further our understanding of the natural characteristics and spatial/temporal patterns of subarctic benthic invertebrate assemblages are a critical first step in overcoming stream biomonitoring challenges and, ultimately, in conserving northern aquatic habitats.

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