Characterization of high arctic stream diatom assemblages from Cornwallis Island, Nunavut, Canada

Dermot Antoniades and Marianne S.V. Douglas

Abstract: Distinct diatom assemblages often characterize stream habitats, providing the potential to reconstruct past precipitation, snowmelt, and streamflow levels in high arctic watersheds by analyzing fossil assemblages preserved in downstream lake sediments. Diatom assemblages were studied from seven streams and two rivers surrounding Lake Sophia, Cornwallis Island, Nunavut, Canada (75°06′N, 93°36′W). A total of 64 diatom taxa were identified from epilithic and epiphytic assemblages in these lotic habitats. Of these, certain diatom taxa exhibited clear microhabitat preferences. *Hannaea arcus* (Ehrenberg) Patrick, *Achnanthes minutissima* (Kützing) Hustedt, *Achnanthes petersenii* Hustedt, and *Meridion circulare* (Greville) Agardh were the most common taxa on epilithic substrates, and as a group made up 61–95% of the diatom epilithon. *Achnanthes* taxa (mainly *A. petersenii* and *A. minutissima*) were the dominant taxa in moss habitats, representing between 45 and 73% of the diatom epiphyton. The relative abundance of *H. arcus* in epilithic habitats was negatively correlated with water temperature ($r^2 = 0.71$, $n = 8$). *Hannaea arcus* was found in greater abundances in cool, fast-flowing streams. This apparent correlation may more closely reflect current speed, which is inversely correlated to temperature in these streams. When these streams discharge into lake basins, the characteristic stream diatoms *H. arcus* and *M. circulare* are deposited in lakes. These diatom taxa have the potential to infer past streamflows using paleolimnological techniques.

Key words: diatoms, arctic, stream, rheophilous, Lake Sophia, *Hannaea arcus*.

Résumé : Des ensembles distincts de diatomées caractérisent souvent les habitats des rivières, ce qui peut permettre de reconstruire les précipitations, les fontes de neige et les niveaux des cours d'eau dans les bassins hydrologiques du haut arctique, en analysant les ensembles de fossiles conservés dans les sédiments des lacs situés en aval. Les auteurs ont étudié les ensembles de diatomées de sept lacs et de deux rivières entourant le lac Sophia de l'île Cornwallis, au Nunavut, Canada (75°06′N, 93°36′O). Au total, ils ont identifié 64 taxons de diatomées à partir des ensembles épilithes et épiphytes de ces habitats lotiques. Parmi ceux-ci, certains taxons de diatomées montrent de nettes préférences de microhabitat. Les *Hannaea arcus* (Ehrenberg) Patrick, *Achnanthes minutissima* (Kützing) Hustedt, *Achnanthes petersenii* Histedt et *Meridion circulare* (Greville) Agardh sont les taxons les plus communs sur les substrats épilithes, lesquels comme groupe forment de 61 à 95% des diatomées de l'épilithon. Les taxons d'*Achnantes* (surtout les *A. petersenii* et *A. minutissima*) sont les taxons dominants dans les habitats de mousses, représentant entre 45 et 73% des diatomées de l'épiphyton. L'abondance relative de l'*H. arcus* dans les habitats épilithes est négativement corrélée avec la température de l'eau ($r^2 = 0,71$, $n = 8$). L'*H. arcus* est plus abondant dans les cours d'eau frais et à écoulement rapide. Cette corrélation apparente pourrait refléter plus étroitement la vitesse du courant, laquelle est inversement corrélée avec la température de ces cours d'eau. Lorsque ces rivières se déchargent dans les bassins lacustres, les diatomées caractéristiques des cours d'eau, l'*H. arcus* et l'*H. circulare* se déposent dans les lacs. Ces taxons de diatomées permettent d'inférer les écoulements des rivières du passé, en utilisant des techniques paléolimnologiques.

Mots clés : diatomées, arctique, rivière, rhéophiles, lac Sophia, *Hannaea arcus*.

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Introduction

The High Arctic is increasingly being recognized as an important reference area for global environmental change, as

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it has been shown to be among the first places on Earth to show the effects of climate changes (Rouse et al. 1997). However, the detection of climatic trends and changes is limited by the lack of long-term meteorological observations, with high arctic instrumental records spanning roughly the last 50 years, and then only at a few sites (Maxwell 1982). Paleolimnological techniques are capable of addressing this deficiency by providing valuable insights about long-term climate change through proxy records developed from lake sediments (Douglas and Smol 1999; MacDonald et al. 2000). Although a growing body of knowledge is emerging from the investigation of aquatic bioindicators in

arctic lakes and ponds, relatively little research on diatom communities from high arctic streams has been undertaken (e.g., Moore 1974; Ludlam et al. 1996). Some additional studies have been completed at lower northern latitudes within the Canadian Arctic (Moore 1977, 1979), in Alaska (Miller et al. 1992), and in Siberia (Potapova 1996). However, stream diatom autecology and distribution patterns within the High Arctic remain poorly understood.

An earlier study of stream diatoms from northern Ellesmere Island identified a rheophilic component (i.e., characteristic of running water) of the diatom assemblage in arctic streams which was distinct from communities within lakes (Ludlam et al. 1996). Within this rheophilic community, the relative abundances of certain diatom taxa differed according to microhabitat (i.e., rock or moss). Higher relative abundances of stream diatoms within lake sediments coincided with years of higher sedimentation rates; these changes were attributed to increases in runoff. If stream diatoms are more abundant in the sedimentary record in years of higher runoff, then they have potential paleolimnological applications (Ludlam et al. 1996; Douglas et al. 1996; Douglas and Smol 1999). Thus, by using the changing abundances of stream diatoms within dated lake sediment cores, past inferences of streamflow, snowmelt, and other climate-related variables could be drawn. To date, such studies have been completed only from northern Ellesmere Island (Ludlam et al. 1996).

The objectives of our study were to characterize the diatoms present in the streams of Lake Sophia's catchment to determine whether these rheophilic diatom assemblages are consistent with those from other high arctic drainage basins, and to determine the degree of microhabitat specificity exhibited by rheophilic diatoms within these stream environments.

Materials and methods

Lake Sophia is a meromictic lake situated on the east coast of Cornwallis Island, Nunavut (75°06′N, 93°36′W), in the Canadian Arctic Archipelago (Fig. 1). It has been the site of previous limnological study (e.g., Ouellet et al. 1987; Stewart and Platford 1986; Pagé et al. 1984, 1987). Situated approximately 4 m above sea level, the lake drains directly into the Arctic Ocean. Lake Sophia sits in a valley of moderate relief that is ~1 km wide and ~5 km long which is the result of glacial and fluvial erosion (Ouellet et al. 1987; Edlund 1991). The streams in the catchment flow mostly north–south, with the exception of the Sophia River, which flows eastward from the head of the valley into the western end of Lake Sophia (Fig. 2). The catchment drains a 40 km^2 area including several small lakes and ponds (Braun et al. 2000). Carbonate bedrock and highly alkaline surface sediments that result from bedrock weathering underlie the watershed (Edlund 1991). Lake Sophia is covered by ice during most of the year. Melt begins in summer, and the lake is ice-free for approximately 1 month (ca. August) each year (Stewart and Platford 1986).

The nearest weather station to Lake Sophia is located at Resolute Bay (74°43′N, 94°49′W), approximately 60 km to the southwest on Cornwallis Island (Fig. 1). A strong correlation exists between meteorological records from Lake Sophia and Resolute (Braun et al. 2000). Resolute has an annual daily mean temperature of –16.6°C. It is located in the polar desert, and receives an average of 139.6 mm of precipitation per year (Atmospheric Environment Service 1993). Streamflow in Lake Sophia's catchment closely follows the seasonal pattern of snowmelt in the area. Seasonal maxima in the Sophia River discharge values occur in early July, then decrease until mid-July, after which discharge remains low (Braun et al. 2000). By mid-July, flow has decreased or ceased entirely in many of the smaller streams.

Diatoms were collected from epilithic and epiphytic (moss) habitats on 17 July 1994 from seven streams and two rivers in Lake Sophia's catchment (Fig. 2). Several of the streams shown in Fig. 2 had, in fact, ceased flowing by this date, and although stream beds were evident, they were not sampled (i.e., streams 2, 3, 4, 8, 10, and 12). Streams were generally sampled near their inlet. The rate of flow was noted qualitatively and ranged on a four-level scale from slow trickle (1) to high flow (4) (Fig. 3). Three locations were sampled in the Sophia River (Fig. 2). Water temperatures ranged from 4° to 11°C, and pH from 7.9 to 8.2 (Table 1).

Moss samples were collected from several submerged moss patches per sampling site and placed in vials, following the methods used in Douglas and Smol (1995). Rock substrates were sampled using a toothbrush to brush the diatoms from at least five rocks into a sampling vial. All samples were preserved with Lugol's solution. Samples were placed in 15-mL polypropylene centrifuge tubes and processed using the following steps. Ten millilitres of 10% HCl was added in 2-mL increments to remove carbonates, and the samples were heated in a hot water bath (100°C) to speed the neutralizing reaction. Once the reaction was complete, the samples were centrifuged and the supernatant was aspirated from the tubes. The samples were resuspended in distilled water and centrifuged, and excess water was removed by aspiration. This rinse process was repeated until the slurry was of neutral pH. A 1:1 solution of H_2SO_4:HNO_3 was then added to the samples in 2-mL increments, as needed, to completely oxidize organic matter. The heating and rinsing steps subsequent to the addition of HCl were then repeated until the slurry was of neutral pH.

The cleaned slurries were then plated on glass cover slips and mounted in Naphrax® mounting medium. Diatoms were identified using a Nikon Optiphot X-2 light microscope at 1000× magnification. Between 245 and 484 valves were counted per sample (mean = 347). Samples not counted to at least 300 valves (n = 3) were those in which a single taxon made up a large portion of the diatom assemblage (i.e., >65%). Following counting, the dataset was screened prior to statistical analysis and reduced to include only those taxa present at a relative abundance of ≥1% in at least three sites. This reduced the dataset to 22 diatom taxa. Examination of community patterns within the dataset was done primarily using principal components analysis (PCA) and detrended correspondence analysis (DCA). Two-sample t-tests using PCA axis scores were used to analyze assemblage differences between moss and rock microhabitats and calculate the significance of differing relative abundances between microhabitats for individual species.

Results

Sixty-four diatom taxa were identified in the samples examined (Table 2). The species composition of the diatom communities differed mostly according to microhabitat. In epilithic habitats, the most common diatom was *Hannaea arcus* (Ehrenberg) Patrick; its relative abundance on rock was higher than that in epiphytic samples. Overall, the mean relative abundance of *H. arcus* was 21%, and in epilithic microhabitats it represented an average of 36% of the enumerated diatom community (epilithic range 15–71%). Relative abundance of *H. arcus* reached its highest levels in the epilithic microhabitats of sites with high current (i.e., current speed 3 or 4). In these streams (i.e., streams 1, 5, and 13 and the Sophia River), the mean relative abundance of *H. arcus* was 42%, and reached 71% in the epilithon of stream 1. *Hannaea arcus* was less abundant in epiphytic samples, where it had a mean relative abundance of 8% and a maximum of 17% in stream 13.

In moss samples, the most abundant diatoms were taxa from the genus *Achnanthes* ($n = 9$), which accounted for 59–71% of the epiphyton in small streams and 51% in the Sophia River. *Achnanthes* was more commonly associated with moss samples than with epilithic samples (62% versus 34% mean relative abundance). *Achnanthes* taxa were also present in higher mean relative abundances in streams with slow current (i.e., current speed 1 or 2) (59%) than in fast-flowing streams (40%).

By far the most abundant species of *Achnanthes* were *Achnanthes minutissima* (Kützing) Hustedt and *Achnanthes petersenii* Hustedt. Combined, these two species made up between 68 and 100% of the *Achnanthes* valves counted in each sample. *Achnanthes minutissima* and *A. petersenii* each had a mean relative abundance of 15% of the diatom community in epilithic samples. In epiphytic microhabitats, however, *A. petersenii* was more common, representing an average of 50% of the diatoms compared with only 8% for *A. minutissima*. *Achnanthes petersenii* reached the highest abundance in the sample of aerophilic moss (70%), in the smallest, slowest streams (53–66%), and had a significantly different mean between moss and rock samples ($p = 0.0008$, $n = 16$). Although the average relative abundance of *A. minutissima* was higher in epilithic habitats than in epiphytic habitats, the mean moss and rock values were not significantly different ($p \geq 0.05$). Both *A. minutissima* and *A. petersenii* were common in benthic habitats from Lake Sophia ($n = 3$; data not shown).

Although it was rare in almost all samples, the relative abundance of *Meridion circulare* (Greville) Agardh reached values of 21 and 12% in the epilithic habitats of the fastest streams (i.e., current speed 4). *Meridion circulare* abundances exceeded 1% in only one other sample, and it was rare or absent in both epilithic and epiphytic microhabitats.

All other taxa were present at low relative abundances and showed little if any substrate preference. *Cymbella* spp. ($n = 11$) made up, on average, 6% of epilithic assemblages and 9% of epiphytic assemblages. The most common species was *Cymbella minuta* Hilse, which had a mean relative abundance of 3% in all samples. All other *Cymbella* taxa (Table 2) had mean relative abundances at or below 1%.

Fig. 1. Location map for Cornwallis Island in the Canadian Arctic Archipelago.
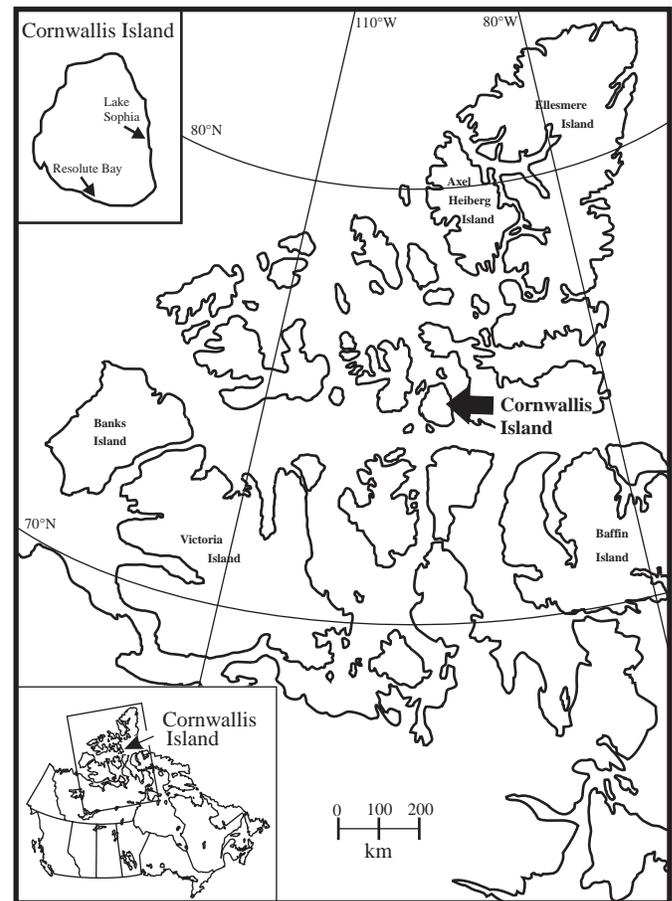
Fragilaria spp. ($n = 5$) were relatively minor components of the stream diatom assemblages and had a mean relative abundance of 5% on both epilithic and epiphytic substrates. *Fragilaria capucina* Desmazières was the most common *Fragilaria* species, with 3% mean relative abundance. *Nitzschia* spp. ($n = 6$) were also present at an average relative abundance of 5% in rock and moss microhabitats. *Nitzschia perminuta* Grunow had a mean relative abundance of 2% and was the only *Nitzschia* species with an average of over 1%. *Navicula* spp. ($n = 9$) were rare in the Lake Sophia stream samples, with a mean relative abundance below 1%.

Some sites had distinct diatom assemblages. In stream 7, *Diatoma* sp. 1 composed 20% of the epilithic diatom community, but was not observed in any other stream. The outflow river had a diatom assemblage distinct from those at all other sites and was dominated by *Diatoma tenuis* Agardh and *Nitzschia clausii* Hantzsch. This river was tidally influenced, which would explain the distinct nature of its assemblage.

While microhabitat exercised some control over diatom assemblages, physical characteristics of the streams also appear to have influenced species abundances. The pH of all sites fell within a limited range (7.9–8.2; Table 1) and did not appear to play a role in between-stream diatom community variation. However, certain physical factors appear to affect diatom communities. Snowmelt is the main water

Fig. 2. Map of Lake Sophia on Cornwallis Island, showing the location of sampling stations at the mouth of 13 streams flowing into the lake. x, sampling stations in the Sophia River.
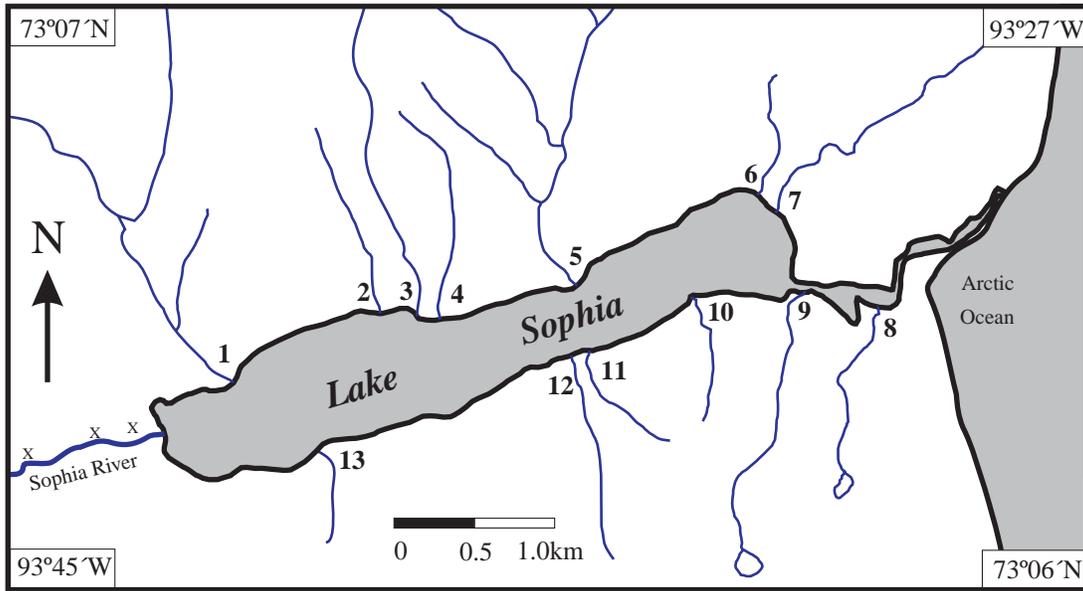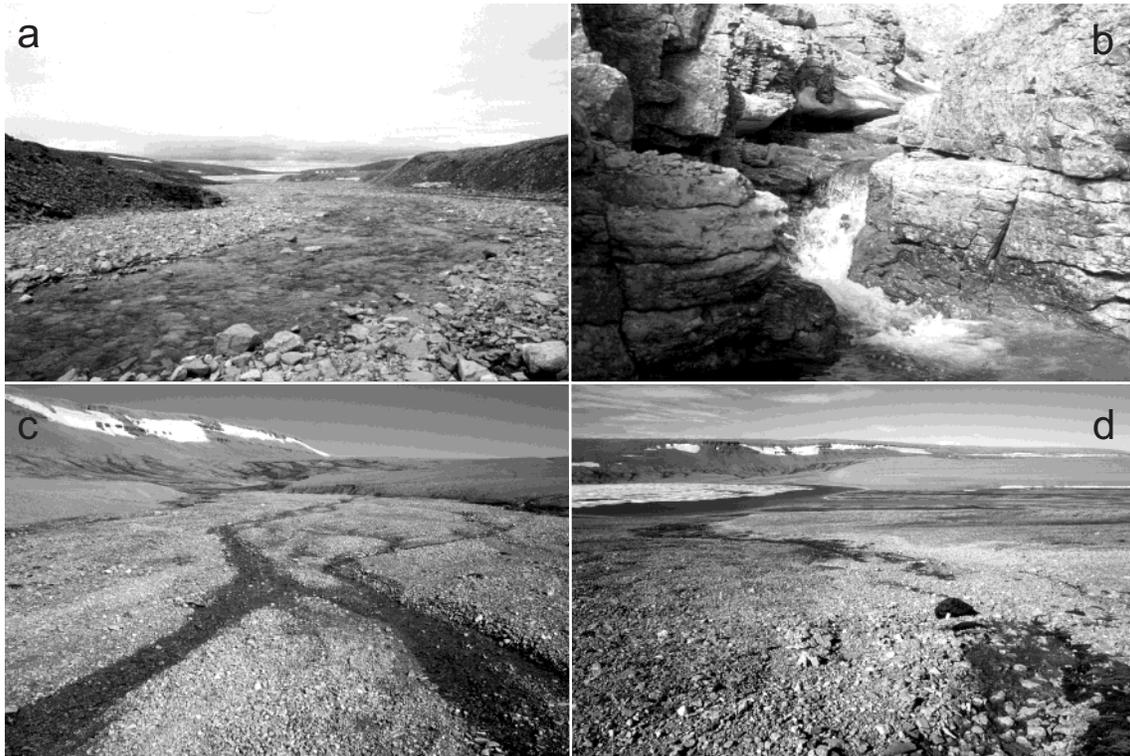

Fig. 3. Typical streams in Lake Sophia's catchment: (*a*) Sophia River; (*b*) stream 5, a high current speed stream; (*c*) typical small, slow stream with only rock substrates; and (*d*) typical small, slow stream with moss and rock microhabitats.

source of arctic streams, and current speed and temperature are inversely related. The mean temperature of high-current streams was 4.5°C, as compared with a mean of 8°C for slow streams. A correlation between decreasing temperature and increasing *H. arcus* abundance in epilithic habitats was observed and produced an r^2 value of 0.71 ($p = 0.008$, $n = 8$). This correlation between low water temperatures and

H. arcus relative abundance may be a product of increased current speed, decreased temperatures, or both.

An examination of PCA analysis scores indicated that the first axis (eigenvalue, $\lambda = 0.29$) was controlled largely by microhabitat (Table 3). Two-sample *t*-tests of the first axis scores for rock and moss samples indicated that the means for each group were significantly different ($p = 0.001$, $n = 16$).

Table 1. Physical characteristics of sample sites and relative abundances for selected diatom taxa.

Sample site:	Sophia River	Sophia River	Sophia River	Sophia River	Sophia River	Sophia River	Stream 1	Stream 5	Stream 6	Stream 6	Stream 7	Stream 9	Stream 11	Stream 13	Stream 13	Outflow
Sample code:	SR-R1	SR-R2	SR-R3	SR-M1	SR-M2	SR-AM	1-R	5-R	6-R	6-M	7-R	9-M	11-M	13-R	13-M	OF-R
Microhabitat sampled:	Rock	Rock	Rock	Moss	Moss	Aerophilic moss	Rock	Rock	Rock	Moss	Rock	Moss	Moss	Rock	Rock	Rock
Physical characteristics																
pH	8.1	8.1	8.0	8.0	8.0		8.1	7.9	8.2	8.2	8.1	8.0	8.1	8.0	8.0	8.0
T (°C)	7	7	8	8	9		5	4	11	11	9	5	8	5	5	7
Current speed*	3	3	3	3	3		4	4	2	2	2	1	1	3	3	1
Taxa																
Achnanthes chlidanos	0	1.8	1.3	4.9	0	0	0	8.4	5.6	1.4	3.1	2.1	6.2	0	0	0.2
Achnanthes minutissima	33.6	47.7	5.9	21.7	25.2	0	0	1.3	24.8	2.2	9.4	0.9	5.2	3.3	0	0.9
Achnanthes petersenii	10.5	9.5	19.2	15.5	25.6	69.8	1.2	20.7	22.6	66.5	20.2	53.2	50.6	16.8	65.5	13.4
Achnanthes subatomoides	1.6	1.6	0	4.9	1.3	0	0.4	0	4.7	1.2	5.0	2.4	5.9	0	0	2.0
Cymbella arctica	2.0	0	5.2	3.1	7.1	0	0	0	0	1.2	0	0	0	0	0	0.5
Cymbella latens	1.0	0.2	12.1	2.3	1.6	0.8	0	0	0.6	0	0.7	0	0	2.6	0.7	0
Cymbella minuta	0	0.2	3.3	1.2	0.7	12.2	0	2.3	0	0.2	0	0	0	12.2	10.0	0
Diatoma tenuis	7.2	2.7	8.5	15.5	7.4	0	0	0	0	0	1.2	0	0	0.7	0	39.5
Diatoma sp. 1	0	0	0	0	0	0	0	0	0	0	19.7	0	0	0	0	0.4
Fragilaria capucina	5.6	0.7	5.9	6.6	6.8	0	0	0.4	8.8	3.3	4.8	3.4	1.1	3.3	2.6	0.2
Hannaea arcus	31.3	22.6	27.0	1.2	8.7	0	70.6	48.3	15.4	1.6	19.5	16.1	10.7	52.0	17.1	1.3
Meridion circulare	1.3	0	0	0.8	0	0	21.0	12.3	0.9	0	1.2	4.2	0	0	0	0.4
Nitzschia clausii	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0	19.4
Nitzschia perminuta	2.6	0	2.9	1.9	3.2	9.0	0	1.5	0	0.9	0.2	2.9	1.1	3.3	1.9	1.6
Nitzschia sp. 1	0	0	0	0	1.6	0	0	0	0	7.5	1.4	0	0.8	0	0	8.5

*Current speed based on a four-level qualitative scale: 1, slow trickle; 2, moderate flow; 3, medium-fast current; 4, fast flow. See Fig. 3 for representative examples.

Table 2. List of diatom taxa identified from Lake Sophia stream and river samples.

Achnanthes chlidanos Hohn & Hellerman
Achnanthes coarctata (Brébisson) Grunow
Achnanthes delicatula ssp. *septentrionalis* (Øestrup)
   Lange-Bertalot
Achnanthes flexella (Kützing) Brun
Achnanthes minutissima (Kützing) Hustedt
Achnanthes ninckei Guermeur & Manguin
Achnanthes petersenii Hustedt
Achnanthes subatomoides Lange-Bertalot & Archibald
Achnanthes sp.aff. *petersenii*
Amphora libyca Ehrenberg
Amphora pediculus Kützing
Aulacoseira roseana Rabenhorst
Caloneis silicula (Ehrenberg) Cleve
Cocconeis neothumensis Krammer
Cocconeis pediculus Ehrenberg
Cyclotella antiqua W. Smith
Cyclotella michiganiana Skvortzow
Cymbella arctica (Lagerstedt) Schmidt
Cymbella cuspidata Kützing
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot
Cymbella latens Krasske
Cymbella minuta Hilse
Cymbella rupicola Grunow
Cymbella tumidula Grunow
Cymbella sp.aff. *arctica*
Cymbella sp. 1
Cymbella sp. 2
Denticula elegans Kützing
Diatoma tenuis Agardh
Diatoma sp. 1
Diploneis elliptica Kützing
Eunotia bilunaris (Ehrenberg) Mills
Fragilaria capucina Desmazières
Fragilaria construens Grunow
Fragilaria pinnata Ehrenberg
Fragilaria cf. *vaucheriae* (Kützing) Petersen
Fragilaria sp. 1
Gomphonema angustatum (Kützing) Rabenhorst
Gomphonema sp. 1
Hannaea arcus (Ehrenberg) Patrick
Meridion circulare (Greville) Agardh
Navicula contenta Grunow
Navicula gallica Lagerstedt
Navicula mutica Kützing
Navicula mutica Kützing var. *ventricosa* Cleve & Grunow
Navicula nivalis Ehrenberg
Navicula perpusilla Grunow
Navicula pusilla W. Smith
Navicula vitrea Krasske
Navicula vulpina Kützing
Nitzschia alpina Hustedt
Nitzschia clausii Hantzsch
Nitzschia homburgiensis Lange-Bertalot
Nitzschia perminuta Grunow
Nitzschia sp. 1
Nitzschia sp. 2

Table 2 (*concluded*).

Pinnularia balfouriana Grunow
Pinnularia ignobilis (Krasske) Cleve-Euler
Pinnularia obscura Krasske
Stauroneis anceps Ehrenberg
Stephanodiscus cf. *medius* Håkansson
Surirella ovata Kützing
Tabellaria quadriseptata Knudson

Sites with negative first axis scores were predominantly rock samples, while those with positive scores were moss samples. The second PCA axis ($\lambda = 0.25$) was controlled by differences between small, shallow streams and the Sophia River. The mean axis 2 scores from the Sophia River and the small streams were significantly different ($p = 0.006$, $n = 16$).

A spatial ordination of the species data using DCA resulted in several groupings of samples (Fig. 4). At the high end of DCA axis 2, the moss samples from small streams were grouped together along with a sample of aerophilic moss taken beside the Sophia River, and the small stream epilithic samples were grouped at the left end of DCA axis 1. The five submerged samples taken from the Sophia River were grouped together, including epilithic and epiphytic samples. Lastly, the sample from Lake Sophia's outflow was isolated at the right end of DCA axis 1.

Discussion

Both microhabitat and current speed affected diatom assemblages. As indicated by PCA axis 1 scores (Table 3), the species most closely associated with epilithic assemblages were *H. arcus* and *M. circulare*, whereas *A. petersenii* was the dominant component of epiphytic assemblages. Other taxa also showed differences in relative abundance between microhabitats, as indicated by the difference in average PCA axis 1 scores between rock and moss samples.

The differences between moss and rock diatom communities were further reflected in their groupings on the DCA ordination (Fig. 4). Moss samples from small streams were distinctively grouped (Fig. 4, group A), reflecting the higher relative abundance of *Achnanthes* in their assemblages. The epilithic samples from small streams were grouped together (Fig. 4, group B), although more loosely clustered than the mosses. This grouping is, in large part, a reflection of the dominance of *H. arcus* in these samples. The Sophia River samples were also clustered on the ordination (Fig. 4, group C). Diatom assemblages in rock and moss microhabitats of the Sophia River samples were distinct from each other. However, the grouping of the Sophia River's samples together on the DCA ordination shows that epiphytic and epilithic communities there had significant overlap. This may reflect the large difference between the sizes and flow levels of the Sophia River compared with the other much smaller streams. The isolation of the outflow from Lake Sophia to the ocean on the ordination is a result of its tidal influence and high conductivity, which resulted in a diatom assemblage that was distinct from those found in any of the other streams.

Within the Sophia River, community differences between microhabitats were not as pronounced as those in the smaller

streams. *Hannaea arcus* was common in the Sophia River's epilithic habitats, but these habitats also had high relative abundances of *Achnanthes* (particularly *A. minutissima*) compared with the small streams. Epiphytic habitats within the Sophia River had abundances of *Achnanthes* and *H. arcus* which were similar to those of the small stream samples.

Both *H. arcus* and *M. circulare* are rheophilic species (Patrick and Reimer 1966; Lowe 1974). In our study, *H. arcus* was present in all streams flowing into Lake Sophia, regardless of current velocity, but its relative abundance was positively correlated with stream velocity. It was the most common diatom in epilithic samples (mean = 36%), but was also an important component of epiphytic assemblages (mean = 8%). *Hannaea arcus* was absent in epilithic habitats examined from within Lake Sophia ($n = 2$) and was present only in trace quantities (i.e., <1%) in an epiphytic sample from Lake Sophia (data not shown).

Other studies have found similar results. *Hannaea arcus* was present only in the faster flowing streams of a northern Ellesmere Island catchment and was not present "in significant quantities" in littoral habitats (Ludlam et al. 1996). It was the dominant diatom in a small Svalbard stream (Beyens and Van de Vijver 2000), and in an undisturbed oligotrophic Alaskan stream (Miller et al. 1992). *Hannaea arcus* was present in a study of epipelic samples from Baffin Island streams, however, relative abundance never exceeded 10% (Moore 1974). A variety of *H. arcus* was also common in epilithic samples in Siberian streams (*Ceratoneis arcus* var. *linearis* Holmboe) (Potapova 1996).

Meridion circulare was characteristic of flowing waters on northern Ellesmere Island and was more abundant in smaller streams (Ludlam et al. 1996). It was abundant in an Ohio stream for short periods each spring when water temperatures reached 7–10°C, and subsequently disappeared as water temperatures increased (Krejci and Lowe 1987). In Lake Sophia's streams, *M. circulare* was present in significant abundance (i.e., >2%) only in the faster, cooler streams and reached its highest values in epilithic habitats. Within slower streams, there was little difference in the relative abundance of *M. circulare* between epiphytic and epilithic habitats. It was absent from benthic samples taken within Lake Sophia (data not shown). In summary, *H. arcus* and *M. circulare* were indicative of flowing water.

While species from the genus *Achnanthes* were common in both rock and moss samples, they dominated epiphytic microhabitats. Only *A. petersenii* showed significant habitat specificity, with its highest relative abundances in aerophilic moss and the smallest, shallowest streams (where current speeds are very slow and where water flows may be intermittent). This may be related to the ability of *A. petersenii* to withstand periodic desiccation. This is supported by the observation that *A. petersenii* was at its highest relative abundance in the sample of aerophilic moss collected from beside the Sophia River (SR-AM) and at its lowest relative abundance in the submerged moss samples of the Sophia River (SR-M1 and SR-M2). Although *A. minutissima* was qualitatively more abundant in rock samples than in mosses, this greater relative abundance was not statistically significant. Other *Achnanthes* species were present in both epilithic and epiphytic samples in similar relative

Table 3. PCA sample scores for first two ordination axes.

| Site	Axis 1	Axis 2
1-R	−1.7064	1.9341
SR-R1	−1.1574	−0.7609
SR-R2	−1.1251	−0.9134
5-R	−0.6157	1.4846
6-R	−0.5490	−0.3460
7-R	−0.4589	−0.2327
13-R	−0.3937	0.8909
SR-R3	−0.3284	−0.2560
SR-M1	−0.1208	−1.7199
SR-M2	−0.0811	−1.1817
OF-R	0.5146	−1.1893
9-M	0.5551	0.7507
11-M	0.6448	0.1099
13-M	1.1581	1.0353
6-M	1.4676	−0.0429
SR-AM	2.1964	0.4373
Eigenvalue	0.29	0.25

abundances (Table 1). In addition, *Achnanthes* species, particularly *A. petersenii*, were common in benthic habitats within Lake Sophia. The similar relative abundance values in epilithic and epiphytic microhabitats and low PCA axis 1 scores for *Cymbella* species indicate that they showed little substrate preference in the streams examined.

In short, with the exception of *A. petersenii*, *Achnanthes* spp. and *Cymbella* spp. were generalists with respect to habitat specificity. These conclusions concerning the lack of habitat specificity for *Achnanthes* and *Cymbella* also agree with the findings of earlier high arctic studies (Ludlam et al. 1996). Given that these genera occur in both stream and lake environments, they do not allow us to distinguish between stream deposition and within-lake communities. In contrast, *H. arcus* and *M. circulare* characterize streams and are absent or very rare within Lake Sophia, and so their presence in its sedimentary record can be used to infer deposition from streams.

Differences in the relative abundances of *H. arcus*, *M. circulare*, *A. petersenii*, and *A. minutissima* in fast and slow streams can be attributed, to some extent, to the availability of substrates within a given stream (i.e., the presence of only moss and (or) rock). Extensive moss growth was present only in slow, shallow streams. In many cases, no exposed rocks were present. In faster, deeper streams, where erosional forces and substrate instability were increased, moss growth was limited or absent, and rock substrates dominated. In several streams (1, 5, 7, 9, 11, and OF), a sample from only one substrate was examined (i.e., either epilithic or epiphytic) because the other substrate was not present.

The negative correlation between water temperature and *H. arcus* abundance ($r^2 = 0.71$) most likely reflects the relationship between high current and low temperature. Streamflow in Lake Sophia's catchment is controlled by snowmelt (Braun et al. 2000), and faster flowing meltwater has less time to absorb radiation. Therefore, although there is a strong correlation between water temperature and *H. arcus* abundance, since *H. arcus* is rheophilic, it is possible that this is an artifact of current regime.

Fig. 4. DCA biplot of species data for Lake Sophia stream samples. Sample codes are given in Table 1. See text for a description of the sample groupings.
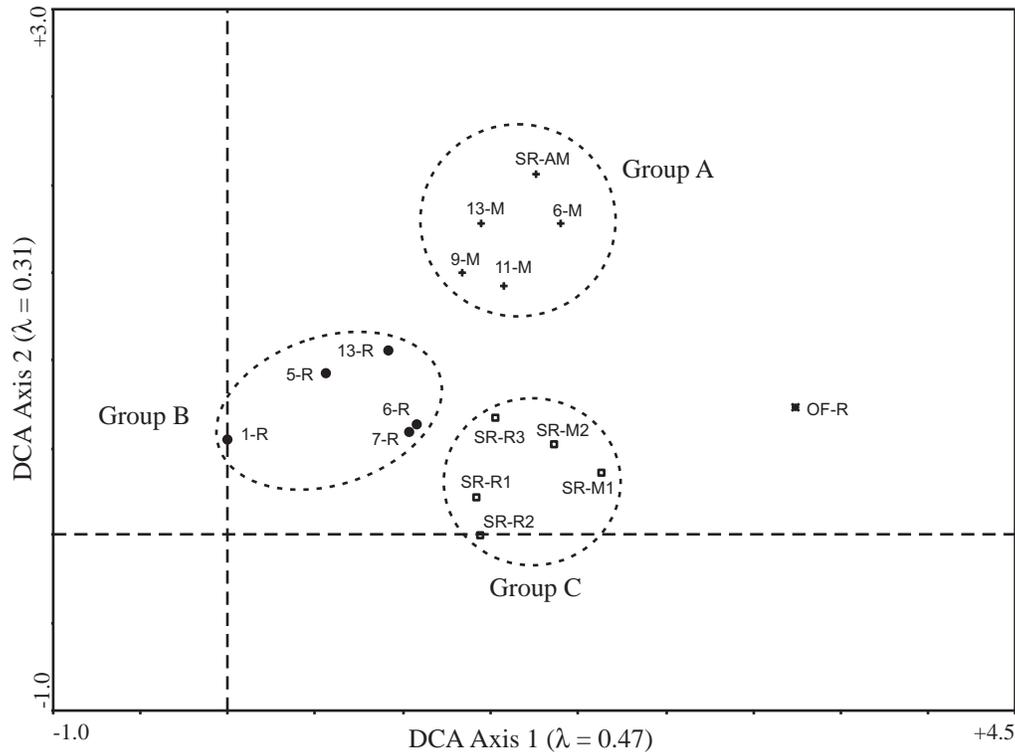
We can infer from the characteristic presence of *H. arcus* and *M. circulare* in high arctic streams that their occurrence in lake sediments should track patterns of deposition from lotic environments. Analyses of sediment-trap and core samples have shown that, although *H. arcus* and *M. circulare* are rare or absent in benthic habitats of Lake Sophia, they are deposited and preserved within its sedimentary record (data not shown). These diatoms may therefore potentially be used to infer past streamflow levels, and so augment interpretations of arctic paleoclimates. Due to the close dependence of streamflow on snowmelt in the Arctic, years of greater precipitation should result in higher levels and longer durations of streamflow, which in turn result in longer growing seasons for stream diatoms. Changing abundances of *H. arcus* and *M. circulare* in the sedimentary record may thus provide a proxy indicator of past precipitation levels, snowmelt, and subsequent streamflow in arctic systems. Transferring such diatom-based methods to other regions where reconstructions of past streamflow are important (e.g., Nesje et al. 2001) may eventually be possible.

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