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PAR
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RECONSTITUTION PALÉOLIMNOLOGIQUE DES CONDITIONS ENVIRONNEMENTALES RÉCENTES
DANS LA RÉGION DE SAGLEK, LABRADOR

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RÉSUMÉ

Le réchauffement climatique contemporain et l'expansion du réseau d'infrastructures en Arctique exercent de multiples stress sur les écosystèmes lacustres de ces régions polaires. En considérant l'importance des changements attendus en Arctique au cours des prochaines décennies, il apparaît essentiel d'approfondir notre compréhension de l'évolution historique de ces écosystèmes afin de mieux anticiper les impacts du réchauffement actuel sur les écosystèmes et les populations arctiques et extra-polaires.

Le présent projet visait à rendre compte de l'évolution des conditions environnementales et climatiques qui ont prévalu au cours des derniers 300 ans dans le Nord du Labrador par l'utilisation d'une approche paléoenvironnementale fondée sur l'analyse des assemblages fossiles de diatomées. Si le Labrador semble faire preuve d'une grande résilience aux changements climatiques de l'Holocène supérieur, peu d'études portent actuellement sur l'évolution récente (~ 150 ans) du climat de cette région. Dans le but de densifier le réseau d'observations paléoenvironnementales au Nord du Labrador, deux lacs situés dans la région de Saglek ont été échantillonnés en août 2008 dans le cadre d'un projet de recherche du réseau ArcticNet : *Comprendre et répondre aux effets des changements climatiques et de la modernisation au Nunatsiavut*. Les résultats obtenus témoignent de changements limnologiques relativement faibles par comparaison à ce qui prévaut dans de nombreuses régions polaires de l'Hémisphère Nord (Archipel arctique canadien, Ouest de l'Arctique canadien, Fennoscandie, Nord du Groenland) où des changements biologiques abruptes ont été rapportés ces dernières décennies. Nos observations suggèrent donc que le climat de la région de Saglek soit demeuré stable au cours des 300 dernières années et que l'ampleur du réchauffement global y ait été négligeable tout au long du 20^e siècle. Si les résultats présentés dans le cadre de cette étude semblent contredire l'actuel scénario de réchauffement global largement documenté à travers l'Arctique, ils font écho à de nombreux projets réalisés dans la portion nord du Québec et du Labrador où aucune évidence significative du réchauffement contemporain n'avait été observée jusqu'à tout récemment.

AVANT-PROPOS

Ce mémoire, réalisé dans le cadre de la Maîtrise en Ressources Renouvelables à l'Université du Québec à Chicoutimi, est divisé en trois chapitres. Une introduction générale (chapitre 1) dresse un portrait du contexte d'émergence du projet et met en perspective le sujet de l'étude. Le deuxième chapitre, qui constitue le cœur de l'étude, est rédigé en anglais, à la manière d'un article scientifique et sera soumis à la revue « Arctic, Antarctic and Alpine Research ». Les co-auteurs de l'article sont Murray Hay, Guillaume St-Onge, Reinhard Pienitz et Thomas Richerol. Murray Hay a agi en tant que directeur du projet et a participé à la conception et à la rédaction de l'article. Guillaume St-Onge a participé à l'acquisition et l'interprétation des données paléomagnétiques et a contribué à l'article en apportant conseils et réflexions. Reinhard Pienitz a agi en tant qu'instigateur du projet et a contribué à l'article de par ses conseils et connaissances en paléolimnologie. Finalement, Thomas Richerol a fourni grand nombre de données et a contribué au projet par ses réflexions sur l'article. Le mémoire se termine finalement par une conclusion générale (chapitre 3) où sont résumées les retombées importantes de l'étude.

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CHAPITRE I

INTRODUCTION GÉNÉRALE

Introduction

Les changements climatiques rapides qui ont cours depuis le début de l'ère industrielle font aujourd'hui consensus au sein de la communauté scientifique internationale (IPCC 2007). L'augmentation des émissions de gaz à effet de serre, conjuguée à la variabilité naturelle du système climatique et à la multitude de mécanismes rétroactifs impliqués (i.e albédo), entraîne déjà d'importants changements sur les plans environnemental et climatique. La fonte accélérée du couvert de glace marine en arctique, dont l'étendue a diminuée de 40 % entre 1980 et 2007, ne constitue que l'un des nombreux témoins de ces changements qui surviennent actuellement à l'échelle mondiale (Walter *et al.* 2006, Overland 2009). Les effets actuels et projetés des changements climatiques devraient, selon plusieurs experts, s'accroître au cours des prochaines décennies (ACIA 2005), entraînant bon nombre de répercussions sur la santé et l'organisation des écosystèmes et de nos sociétés.

Dans le présent contexte où les enregistrements climatiques ont une portée temporelle souvent trop courte (~50 ans) pour permettre la mise en perspective historique des changements observés (Smol 2008), il apparaît essentiel de développer des méthodes alternatives qui puissent fournir de l'information sur l'évolution à long-terme du climat et de ses impacts sur la dynamique des écosystèmes. L'étude des écosystèmes arctiques et subarctiques présente de nombreuses possibilités quant à la reconstitution à long-terme des patrons climatiques en milieux polaires. La grande sensibilité de ces écosystèmes aux variations climatiques et environnementales ainsi que la simplicité des interactions

écologiques qui y ont cours, fournissent aux scientifiques des terrains d'étude de grande valeur (Overpeck *et al.* 1997). Leur éloignement par rapport aux principales sources de pollution anthropique en fait également de précieux témoins des changements climatiques; l'organisation et la structure de ces écosystèmes étant moins susceptibles d'avoir été modifiées par des apports locaux de polluants que leurs équivalents méridionaux.

Les lacs et les étangs, omniprésents à travers l'Arctique, sont écologiquement sensibles aux changements climatiques et fournissent ainsi de précieuses informations sur l'évolution passée des conditions environnementales (Rouse *et al.* 1997). Étant couverts de glace durant la majeure partie de l'année, ces écosystèmes d'eau douce évoluent en étroite relation avec le climat, lequel influe directement sur l'étendue et la persistance du couvert de glace et de neige en été (Michelutti *et al.* 2007). Sous l'influence de l'actuel réchauffement global, l'évolution de la glace lacustre en Arctique accuse une diminution progressive en termes d'étendue et de durée (Smol *et al.* 2005). En retour, cette réduction de l'étendue et de la durée du couvert de glace tend à affecter les processus de mélange et de stabilité de la colonne d'eau, la profondeur de la zone photique, la longueur de la saison de croissance et la distribution des nutriments, lesquels jouent un rôle structurant dans l'organisation des communautés algales (Smol 2008). Toute modification de ces paramètres limnologiques, intimement liés au contexte climatique en place, est ainsi susceptible d'induire d'importants changements au sein des communautés phytoplanctoniques dont la structure et l'organisation sont étroitement liées à la superficie et la diversité d'habitats disponibles (Rouse *et al.* 1997, Schindler and Smol 2006). D'autres paramètres environnementaux tels que la densité et le type de végétation établi en bordure d'un plan d'eau, ses propriétés physico-chimiques et l'état de la cryosphère, sont également susceptibles d'influencer l'évolution à long terme des assemblages planctoniques en milieux lacustres (Finney *et al.* 2004).

Au cours des derniers 150 ans, une modification de la dynamique et de la structure des communautés phytoplanctoniques a été observée dans plusieurs lacs arctiques et subarctiques (Douglas *et al.* 1994, Smol *et al.* 2005, Rühland *et al.* 2008). Ces changements limnologiques sont cohérents avec le réchauffement contemporain et résultent vraisemblablement de la réduction accrue du couvert de glace en été et de la modification récente des conditions environnementales qui prévalent à l'échelle des bassins versants (Douglas *et al.* 1994, Overpeck *et al.* 1997, Sorvari *et al.* 2002).

Considérant l'importance du réchauffement attendu en Arctique au cours des prochaines décennies et l'intensification de l'exploitation des ressources nordiques, il apparaît essentiel de consolider nos connaissances de l'évolution post-industrielle du climat arctique afin d'évaluer l'ampleur et la nature du réchauffement contemporain par rapport à la variabilité naturelle et historique de ces écosystèmes. Cette mise en perspective des changements récents permettra de définir le contexte climatique qui sous-tend le réchauffement actuel et d'estimer la portée de ses impacts sur les écosystèmes et les populations arctiques et extra-polaires.

Indicateur biologique

Les études paléolimnologiques fondées sur l'analyse des assemblages sub-fossiles de diatomées offrent un potentiel considérable pour la reconstitution à long-terme des conditions environnementales et climatiques des régions arctiques (Overpeck *et al.* 1997, Wolfe 2003, Stewart and Lamoureux 2012). Les diatomées (Classe : *Bacillariophyceae*) sont des algues unicellulaires dont le rôle écologique, à la base de la chaîne trophique, est fondamental dans les écosystèmes aquatiques en régions polaires (Douglas and Smol 1995). L'abondance des diatomées dans les environnements lacustres, leur courte durée de vie, les préférences d'habitats et la tolérance écologique propre à chaque espèce assurent une réponse

relativement rapide des communautés de diatomées aux changements limnologiques induits, directement ou indirectement, par des variations environnementales et/ou climatiques (Douglas and Smol 1999, Douglas *et al.* 2004, Smol and Stoermer 2010). Dotées d'un exosquelette siliceux, le frustule des diatomées, dont la forme, la taille et l'ornementation permettent l'identification jusqu'à l'espèce, sont généralement bien préservées dans les sédiments lacustres. Elles fournissent ainsi d'importantes informations sur la variabilité climatique du passé et permettent de pallier la faible quantité d'enregistrements à long terme actuellement disponible dans les milieux arctiques et subarctiques (Hobbie *et al.* 2003, ACIA 2005, Smol 2008).

Contexte paléoenvironnemental

Plusieurs études paléolimnologiques réalisées à travers l'archipel arctique canadien documentent de nombreuses réorganisations limnologiques distinctes survenues au cours de l'Holocène supérieur, lesquelles témoignent de changements environnementaux significatifs. Une première restructuration majeure des assemblages fossiles de diatomées est généralement observée entre 4800 et 2300 cal. BP selon les régions (Wolfe 2003, LeBlanc *et al.* 2004, Michelutti *et al.* 2006, Finkelstein and Gajewski 2007). Cette modification significative de la structure des communautés de diatomées, généralement associée à une réduction de la diversité spécifique et de la productivité limnologique, marque vraisemblablement la fin de la période hypsithermique de l'Holocène (HTM – Holocene Thermal Maximum) et le début du refroidissement néoglaciale dans le Nord-Est de l'Arctique canadien.

Ce refroidissement postglaciaire culmina, dans la plupart des régions, au cours du petit âge glaciaire (LIA – Little Ice Age) (750 à 150 cal. BP), lequel constitue vraisemblablement l'intervalle de temps le plus froid de l'Holocène (Kaufman *et al.* 2009). Une réavancée circumarctique des glaciers alpins et des calottes polaires est généralement associée à cette

période néoglaciale et témoigne de conditions estivales relativement fraîches à travers l'Arctique (Anderson *et al.* 2008, Miller *et al.* 2009). Des études paléolimnologiques récentes ont d'ailleurs relevé une série de changements limnologiques significatifs, survenus entre 1500 et 150 cal. BP et pouvant être associée au LIA (Wolfe 2003, LeBlanc *et al.* 2004, Michelutti *et al.* 2006, Finkelstein and Gajewski 2007). L'abondance de diatomées observée dans les sédiments lacustres correspondant à cette période est généralement faible. Une étude menée sur la péninsule de Fosheim dans l'Arctique canadien démontre que les diatomées sont même demeurées absentes des séquences sédimentaires tout au long des derniers 2.5 ka ans et ce, jusqu'à l'avènement de l'ère industrielle (~ 1850 AD) (Perren *et al.* 2003).

À la suite du LIA, le climat en Arctique s'est rapidement et considérablement réchauffé, si bien que les températures actuelles sont susceptibles d'avoisiner les maxima de températures qui ont vraisemblablement prévalu au cours de l'Holocène inférieur (HTM) (Overpeck *et al.* 1997). Un vaste corpus d'études paléolimnologiques supporte l'évidence d'un tel réchauffement à travers l'Arctique canadien et corrobore les indications climatiques issues des enregistrements et des modélisations climatiques (Douglas *et al.* 1994, Perren *et al.* 2003, Wolfe 2003, Michelutti *et al.* 2006, Antoniades *et al.* 2007, Finkelstein and Gajewski 2007, Smol and Douglas 2007, Rühland *et al.* 2008, Perren *et al.* 2012, Catalan *et al.* 2013). Il demeure toutefois certaines régions polaires où l'ampleur des changements climatiques semble avoir été atténuée au cours des dernières décennies, tel est le cas de la portion nord du Québec et du Labrador (Smol *et al.* 2005).

Les études paléoécologiques réalisées dans cette région n'ont effectivement enregistré aucune évidence significative de changements directionnels survenus au sein des communautés biologiques depuis au moins 3000 ans, suggérant ainsi que le climat de la région soit demeuré relativement stable tout au long de l'Holocène supérieur, accompagné d'une

légère tendance au refroidissement (Short and Nichols 1977, Lamb 1980, 1984, Engstrom and Hansen 1985, Ponader *et al.* 2002, Fallu *et al.* 2005, Viau and Gajewski 2009). Peu d'études paléoenvironnementales ont toutefois porté sur l'évolution récente (~ 250 ans) du climat de la péninsule arctique du Québec/Labrador (Laing *et al.* 2002, Paterson *et al.* 2003, Smol *et al.* 2005, Richerol *et al.* Submitted). La plupart des projets réalisés dans cette région ont plutôt mis l'accent sur l'Holocène et ainsi, ne permettent qu'une interprétation temporelle limitée (faible résolution) de l'évolution post-industrielle du climat dans cette portion de l'Arctique canadien, relativement peu étudiée.

Objectifs de recherche

Le présent projet vise donc à reconstituer les paléoenvironnements qui ont prévalu au cours des derniers 300 ans dans la région du fjord de Saglek, Nord-Est du Labrador, à partir des séquences sédimentaires de deux lacs subarctiques. Un premier lac est situé en altitude à environ 35 km de la côte et un deuxième, plus près de la mer, se trouve à l'extrémité de la piste d'atterrissage d'une ancienne base militaire (LAB-004 (Üppatik) - 58°25'0.6"N / 63°09'58.6"W; LAB-003 (Killirvik)- 58°28'8.8"N / 62°38'11.8"W) (noms informels). Ce dernier a subi une contamination aux BPCs (Paterson *et al.* 2003, Pier *et al.* 2003). Les objectifs spécifiques de l'étude sont 1) d'évaluer la sensibilité des écosystèmes lacustres et plus particulièrement des communautés de diatomées aux influences environnementales des derniers 300 ans, 2) d'évaluer l'importance relative des changements climatiques post-industriels dans la région et 3) de préciser l'influence plus récente des activités anthropiques sur les écosystèmes lacustres de la région (i.e contamination aux BPCs).

Ce projet d'étude s'intègre dans un volet de recherche du réseau ArcticNet, qui vise à comprendre puis à répondre aux effets des changements climatiques et de la modernisation au Nunatsiavut. Cette recherche rendra compte de la variabilité climatique des derniers 300

ans et de la modification subséquente des écosystèmes aquatiques de cette région relativement peu étudiée. De plus, l'analyse des assemblages de diatomées fossiles permettra d'évaluer la valeur de ces algues phytoplanctoniques en tant qu'indicateurs de la santé d'un écosystème lacustre arctique suite à des perturbations d'origine anthropique.

CHAPITRE II

DIATOM-BASED RECONSTRUCTION OF RECENT PALEOENVIRONMENTAL CONDITIONS IN SAGLEK REGION, NORTHERN LABRADOR

Introduction

Rapid climate changes observed since the start of the industrial era form part of a consensus within the international scientific community that anthropogenic-modification of the climate system is now occurring (IPCC 2007, 2013). A combination of increased greenhouse gas emissions, natural climate variability and positive feedbacks is already causing significant environmental and social change at a global scale. Such generalized trends, however, are neither spatially nor temporally uniform. High-latitude regions, considered exceptionally sensitive to anthropogenic warming due to cryosphere-albedo feedbacks (Overpeck *et al.* 1997, Smol *et al.* 2005, Smol and Douglas 2007), have warmed faster over the past decades than lower latitudes (ACIA 2005). Therefore, these highly sensitive ecosystems can provide early indications of the environmental impacts of global warming.

Assessing the widening scope of climate change and its consequences for ecosystems and societies requires long-term monitoring data. However, in northern polar regions, long-term instrumental records are generally too sparse and too short (<50 years) to place any observed change into a broader context and consequently, understand the processes involved (Smol 2008). Long-term ecological studies are essential for monitoring global change across the Arctic (Hobbie *et al.* 2003) for establishing environmental histories in this climatically sensitive area (Douglas *et al.* 2004).

Lakes and ponds, which are ubiquitous features of these northern environments, can provide reliable regional assessments of environmental change, through the paleolimnological approach. Physical, chemical and biological indicators accumulated within lacustrine sediments provide information about past environments, making remote arctic lakes excellent ecological sentinels (Smol 2008). Diatoms, microscopic siliceous unicellular algae, have proven to be especially effective biomonitors of limnological conditions in Arctic regions (Douglas and Smol 1999, Douglas *et al.* 2004). Their abundance in freshwater environments coupled with the specific ecological requirements of a number of taxa allows for reconstruction of past environmental conditions in areas where long-term monitoring data are sometimes lacking (Smol and Stoermer 2010).

As part of the ArcticNet project “Nunatsiavut Nuluak : Understanding and responding to the effects of climate change and modernization in Nunatsiavut”, the present study aims to reconstruct the environmental conditions of a poorly studied region in the western subpolar north Atlantic, the Nunatsiavut. Here, we present a detailed diatom analysis of recent limnological change in two subarctic lakes from the Saglek area in Northeastern Labrador. Diatom profiles will be placed in local and regional post-industrial context in order to assess the relative importance of recent climate change in this under-studied region.

Among the few paleoecological studies that have focused on the Labrador area, paleolimnological records have been based on fossil pollen and spore assemblages as bioindicators (Short and Nichols 1977, Lamb 1980, 1984, Engstrom and Hansen 1985, Viau and Gajewski 2009), fossil chironomids and diatoms (Fallu *et al.* 2002, Laing *et al.* 2002, Fallu *et al.* 2005, Smol *et al.* 2005), with paleoceanographic records from fjords based on dinoflagellate cysts assemblages (Richerol *et al.* Submitted) and terrestrial records using tree rings (D'Arrigo *et al.* 1996, D'Arrigo *et al.* 2003). The results of these studies depicted limited directional

change in ecological communities for at least the last 5000 years and hence suggested that climate has remained relatively stable in this area throughout the late-Holocene. Furthermore, no recent warming trend that could be related to anthropogenic activities was recorded from these studies that, on the contrary, reported a slight cooling over the last 200 years (Smol *et al.* 2005, Richerol *et al.* Submitted). These results seem contradictory to the accumulating evidence of global warming reported from other circum-arctic regions (ACIA 2005, Smol *et al.* 2005, Rühland *et al.* 2008) but are in agreement with paleoecological studies from arctic Quebec, west of our study area, where the magnitude of recent climate warming has also been muted until very recently (Laing *et al.* 2002, Ponader *et al.* 2002, Fallu *et al.* 2005, Smol *et al.* 2005, Bouchard *et al.* 2013).

The spatial and temporal heterogeneity of climate changes observed across the Arctic heightens the need to increase the number of long-term studies in these key areas in order to better understand underlying processes of natural climate variability. Information on past environmental changes provides a context for assessing present and future global change and to develop predictive models of the impacts of climatic changes on societies and ecosystems.

Study area

Saglek fjord is an unglaciated fjord located on the northeastern coast of Labrador, within the Inuit region of Nunatsiavut (Figure 1). The adjacent Labrador Sea has a strong influence on the local climate. The cold Labrador Current which flows southward from the Arctic Ocean and along the Labrador coast contributes to maintaining a strong climatic contrast between inland and coastal Labrador (Engstrom and Hansen 1985). In July and August, the mean temperature is higher inland than along the coast while in winter these conditions are reversed (Short and Nichols 1977, Ullah *et al.* 1992). The overall climate of the region is characterized by short cool and moist summers and by long cold winters. The annual average temperature is about -6°C

and rises to about 4°C in summer. Annual rainfall varies between 400 and 700 mm in the northern part of the province (Environnement Canada 2000).

The Saglek region is located in an area of extensive but discontinuous permafrost, mainly underlain by granitic-gneissic Precambrian rocks of the Canadian Shield (Environnement Canada 2000). The landscape is mostly dominated by rocky outcrops with only the main valleys covered with glacial and fluvioglacial deposits from the last deglacial period (Wardle *et al.* 1997). Evidence for glaciation occurs in the form of cirques and the ubiquitous deep U-shape valleys. The retreat of the Laurentide Ice Sheet occurred between 11 and 6 ka yr BP in the region (Lamb 1980, Engstrom and Hansen 1985). Tundra vegetation, characterized by a sparse moss carpet, with lichens, sedges and herbs, dominates the Saglek landscape. Shrubs persist only on sheltered south-facing slopes (Environnement Canada 2000).

The two lakes studied in this project are located on either side of the Saglek fjord. Lake LAB003 (Killirvik) is located at the southeast end of the Saglek airstrip and was contaminated with PCBs during the fifties and sixties, due to contaminant infiltration from adjacent military installations (Paterson *et al.* 2003, Pier *et al.* 2003). The lake, located at about 5 km from the Labrador Sea, is a shallow ($Z_{\max} = 7$ m), oligotrophic, chemically dilute and circumneutral water body (pH = 6.85), composed of two main basins (Table 1). Its area is about 5 ha. Lake LAB003 is located 77 m above sea level, in a valley where bedrock outcrops predominate. A sparse moss and lichen carpet is present around the lake.

Lake LAB004 (Üppatik), located at about 30 km from the Labrador Sea, is nearly circular having a maximum depth of about 53 meters. The lake is chemically dilute, oligotrophic with a circumneutral pH of 6.92. Its area is about 25 ha (Table 1). Perched at an altitude of 647 m within the hollow of a glacial cirque, the lake is surrounded by relatively steep cliffs. There is

virtually no vegetation outside of some lichen and very scattered moss within the lake catchment.

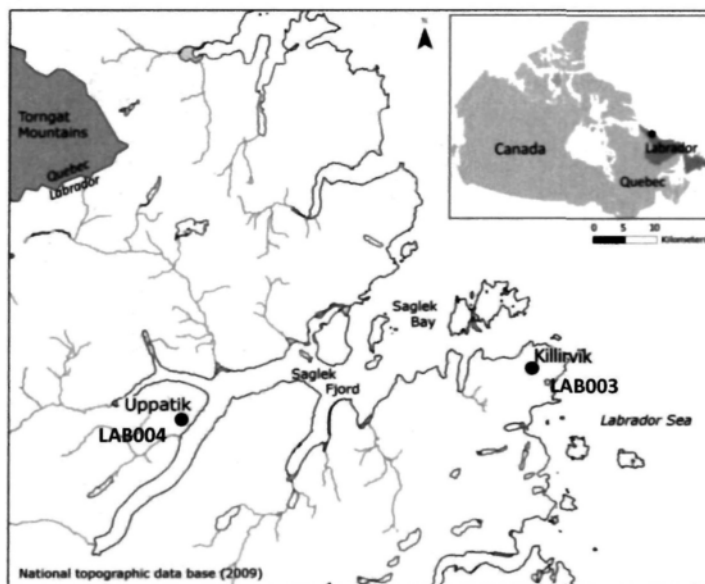


Figure 1 : Map of the Saglék Fjord region showing locations of the study lakes (LAB003-Killirvik and LAB004-Uppatik), Labrador.

Table 1 : Geographical coordinates, topographical (altitude, surface area and depth) and limnological properties (Secchi depth, surface temperature, conductivity, pH, chlorophyll A, dissolved organic carbon, dissolved inorganic carbon and percentage of oxygen) of lakes LAB003 (Killirvik) and LAB004 (Uppatik). Sampling conducted between August 4 and 6, 2008.

| | LAB003 Killirvik | LAB004 Uppatik |
|-------------------------------------|-----------------------------|-----------------------------|
| Geographic coordinates | 58°28'8.8"N 62°38'11.8"W | 58°25'0.6"N 63°09'58.6"W |
| Altitude (m) | 77 | 647 |
| Area (ha) | 5 | 25 |
| Max depth (m) | 7 | 53 |
| Secchi depth (m) | 7 | 15 |
| Surface temperature (°C) | 12.52 | 12.80 |
| Conductivity (ms cm ⁻¹) | 0.032 | 0.024 |
| pH | 6.85 | 6.92 |
| ChlA (ug L ⁻¹) | 0.8 | 0.3 |
| DOC (mg L ⁻¹) | 0.8 | 0.3 |
| DIC (mg L ⁻¹) | 1.9 | 2.3 |
| % O ₂ | 94.5 | 93.6 |

Materials and methods

Core recovery and handling

Replicate sediment cores were collected in August 2008 from the approximate center of each lake using a piston corer mounted with 9.6 cm-diameter plastic tubes (© Aquatic Research Instruments) (Table 2). One core (core A) from each lake was kept intact for subsequent non-destructive analysis (imagery, physical properties and paleomagnetism). The other core (core B) was subsampled into 0.5 cm stratigraphic intervals, wrapped in Whirl Paks© and kept refrigerated prior to the lab analyses (radio-isotope, physical properties and micropaleontology). The two replicate cores were correlated stratigraphically using organic matter content and/or magnetic susceptibility. Analyseries software (v.2.0.4) was used for the core matching process (Paillard 2006).

Table 2 : Length of the cores A and B from lakes LAB003 (Killirvik) and LAB004 (Üppatik).

| Lake | Core | Length (cm) |
|--------|------|-------------|
| LAB003 | A | 31.5 |
| | B | 25 |
| LAB004 | A | 22 |
| | B | 17.5 |

Chronological control

The chronology of the sediments recovered from the study lakes was established by the combined use of ^{210}Pb dating (Laboratoire de radiochronologie du Centre d'Études Nordiques, Université Laval), AMS radiocarbon analysis (KeckCarbon Cycle AMS Facility, California University) and magnetostratigraphic correlation (Institut des Sciences de la Mer de Rimouski, Université du Québec à Rimouski). The measurements of ^{210}Pb total activity were performed on the uppermost 10 cm of each core and transformed into Bq g^{-1} . The unsupported ^{210}Pb was subtracted from the natural supported ^{210}Pb activity and its natural

logarithm was plotted against the cumulative dry mass. After analysis of the curve and comparison of a number of models (CRS – constant rate of supply; CIC – constant initial concentration; CF-CS - Constant Flux – Constant Sedimentation), the latter CF-CS model was deemed to be the most reliable (Appleby and Oldfield 1978, Sorgente *et al.* 1999, Appleby 2001).

Determination of ^{14}C -AMS (Accelerated Mass Spectrometry) age was obtained on three bulk sediment samples from each core (LAB003 and LAB004). The preparation of the samples was performed at the Radiochronology Laboratory of the Center for Northern Studies (Université Laval) and the analyses conducted at the KeckCarbon Cycle AMS Facility (California University). All ^{14}C results were corrected for isotopic fractionation following the conventions of Stuiver and Polach (1977) and calibrated using CALIB 6.0 (Stuiver *et al.* 2011).

Due to the potential errors from ^{14}C dating of bulk sediments, and the need to establish the age of the basal portion of each core, paleomagnetic secular variation related to geomagnetic field models were utilized as discussed in Barletta *et al.* (2010a) and Haberzettl *et al.* (2012). Three geomagnetic field models were used for the chronological control process: CALS3k4 (Korte and Constable 2011), CALS10k (Korte *et al.* 2011) and Eastern Canadian stack (Barletta *et al.* 2010b).

Physical and biological properties

Magnetic susceptibility was measured at a 0.5 cm resolution using a Multi-Sensor Core Logger on the intact cores (core A) and a Bartington MS2 meter for the subsamples (core B). Loss-on-ignition (LOI) analysis was performed on ~ 1 g subsamples of wet sediment at 1-cm intervals. Subsamples were first dried at 105°C for 24h to determine water content and then, burned at 550°C for 4h in order to measure the organic matter content of the sample (Heiri *et al.* 2001).

Diatom analysis followed the preparation techniques of Renberg (1990) with minor modifications. In summary, 15 to 20 mg of freeze-dried sediment was added to a 20 ml scintillation vial. Four ml of hydrogen peroxide (H_2O_2 , 35 %) were then added to each vial and heated at 80°C in order to oxidize the organic matter. Once the reaction was completed, 0.5 ml of hydrochloric acid (HCl, 10 %) was added to the vial and heated at 80°C to remove carbonate material. The vials were heated until the slurry became transparent. The remaining acids were completely eliminated by repeated cycles (5X) of rinsing with distilled water after settling for 24 hrs. After the final rinse, each vial was filled with distilled water up to 20 ml. A known quantity of microspheres was then added to selected vials in order to determine the absolute abundance of diatoms (Battarbee and Kneen 1982). Slurries of known sediment concentration were plated onto 18x18mm-square coverslips, allowed to dry at room temperature and mounted onto microscope slides using Naphrax™ (refractive index = 1.78). Diatoms were counted at 1000x magnification using a Leica DM2500 microscope mounted with a 100x (oil objective, NA = 1.25) and Nomarski optics. Counts followed the convention established by Schrader and Gersonde (1978). For each sample from Lake LAB003, 500 valves were counted along previously established transects. For the samples from the Lake LAB004, a minimum of 400 valves were counted on each slide (exception: 8.5 to 11.5 cm depth where only 150 valves were counted because of the low diatom concentration). Total counts (400 vs 500 diatoms per sample) were determined through assessment of cumulative counts and identifying the count threshold when relative abundance estimates of dominant taxa remained stable. Diatom identification was mainly based on standard and regional floras : Krammer and Lange-Bertalot (1991 - 1997), Camburn and Charles (2000), Fallu *et al.* (2000), Antoniadou *et al.* (2008) and Lavoie *et al.* (2008). Physical and biostratigraphic data were plotted using the C2 software (Juggins 2011).

Statistical analysis

Diatom species included in the analysis occurred in at least 5 samples and had a relative abundance greater than 0.5% in at least one sample. Of the total number of species identified, 67 and 72 taxa from lakes LAB003 and LAB004 matched these criteria and were included in the analysis. These sub-totals represented 92.7% and 94.5% of the original diatom assemblages from lakes LAB003 and LAB004, respectively. A detrended correspondence analysis (DCA) with linear segments and logarithmically transformed data was performed using CANOCO v. 4.55 for Windows (Ter Braack and Šmilauer 2002). Lake LAB004 samples from 7.5 - 12.5 cm depth were excluded from the statistical analysis due to these samples possibly reflecting remobilized material (discussed below). The longest gradient length obtained with the DCA was less than 2 standard deviation units for the two cores (LAB003 = 1.028; LAB004 = 0.825). We therefore used principal components analysis (PCA) in order to summarize the overall changes in diatom composition through time. PCA was performed with a logarithmic transformation of the species data. The PCA was also centered and normalized by samples and normalized by species in order for PCA to be applied to quantitative abundance data having many zero values (Legendre and Birks 2012). Constrained Incremental Sums of Squares cluster analysis – (CONISS) of the complete diatom assemblages for each lake was performed, using PSIMPOLL v. 4.25 (Bennett, 2009) to identify the main stratigraphic diatom zones. A broken-stick model, again in PSIMPOLL, was used to identify the number of statistically significant zones in both diatom sequences (Bennett 1996). Species diversity was quantitatively calculated using the Hill's diversity N_2 index. Detrended canonical correspondence analysis (DCCA) was also conducted to estimate the total amount of compositional turnover (β -diversity) in diatom stratigraphic assemblages for each site. Beta-diversity is estimated as the gradient length of a DCCA of diatom data constrained to sample age. It is expressed as

standard deviation (SD), which can be compared between lakes and across regions. The methods proposed in Smol *et al.* (2005) were used to generate directly comparable results with this and other comparable studies of long-term species turnover in Arctic lake systems.

Results

Core description and sediment properties

Lake LAB003 (Killirvik)

Visual inspection of the sediment sequences showed only subtle changes down-core. The 31.5 cm long sediment record from Lake LAB003 was relatively homogenous with only a small color change occurring at the upper 2.5 cm of the core, changing from grey-brown at the bottom to grey-beige at the top. The Lake LAB003 sediment record contained primarily minerogenic sediments, mainly composed of silt (\bar{x} = 79%) and sand (\bar{x} = 21%) (Figure 2).

Magnetic susceptibility values recorded from Lake LAB003 were negative or incoherent and were thus excluded from subsequent analysis. Organic content varied between 17 and 27 % throughout the cores, generally decreasing from the bottom to the top of the sediment records. Percent organic matter remained relatively stable below 25 cm depth and became more variable near the surface. The uppermost sample could suggest a recent increase in the organic content that should be interpreted with caution as this observation is based on only one sample, although reproduced in both cores from Lake LAB003.

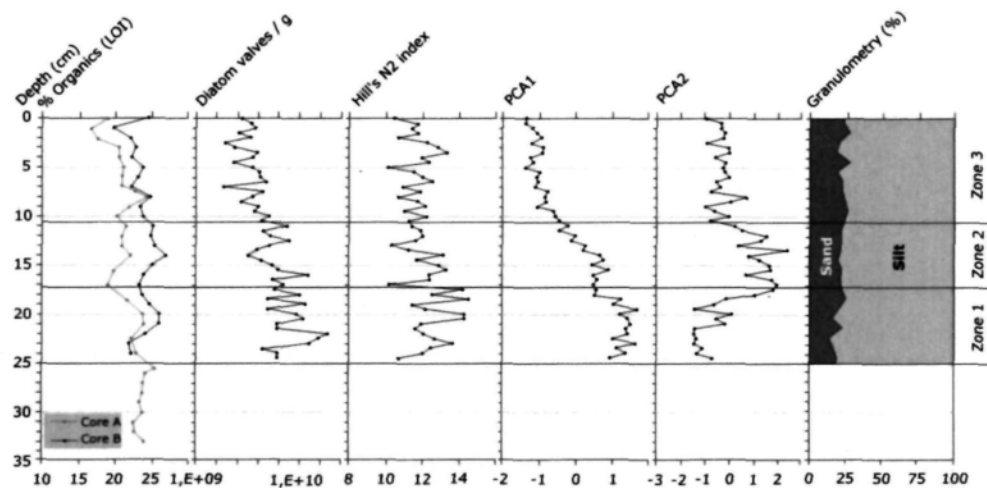


Figure 2 : Sedimentological (organic content and granulometry) and biostratigraphic (diatom concentration and Hill's N2 diversity index) data from the sediment cores a and b from the Lake LAB003 (Killarvík). The major zones were identified using CONISS.

Lake LAB004 (Úppatik)

The 22 cm long sediment core from Lake LAB004 was subtly laminated throughout the core and reddish in color. The record was mainly composed of silt ($\bar{x} = 80\%$) and sand ($\bar{x} = 20\%$) with a peak of sandy material occurring in the middle of the core, reaching 48 % at 10.5 cm depth (Figure 3). Sand and gravel material were also observed between 7.5 and 12.5 cm depth in this sediment core.

Magnetic susceptibility increased from 22 to 19.5 cm depth then remained stable (around 51.5 SI) until 12.5 cm depth. An important peak of magnetic susceptibility was observed between 12.5 and 7.5 cm depth with maximum values recorded at 11.5 cm (133 SI for core A and 514.6 SI for core B). This peak in magnetic susceptibility can be related to an increase in the proportion of coarser material recorded between 12.5 and 7.5 cm depth from core A. Following this time period, magnetic susceptibility decreased to some of the lowest values recorded in the cores and remained low until 4 cm depth where another small peak can be observed (45 SI for core A and 60 SI for core B). Differences between the magnetic

susceptibility records from the two cores could be explained by the material heterogeneity found at these depths and by the different instruments used for the two replicate cores. The trends observed in both cores, however, are consistent. Organic matter remained low throughout the core, varying between 2 and 8 % with a minimum value recorded at 10 cm depth (2.97%). No macrofossils remains of vascular plants or aquatic mosses were observed by visual inspection within either sediment cores.

Given the magnetic susceptibility and grain-size analyses, we considered the anomalous interval in the core as representing a rapidly deposited layer. Samples from this interval were thus excluded from the dating models, as well as diatom and statistical analyses.

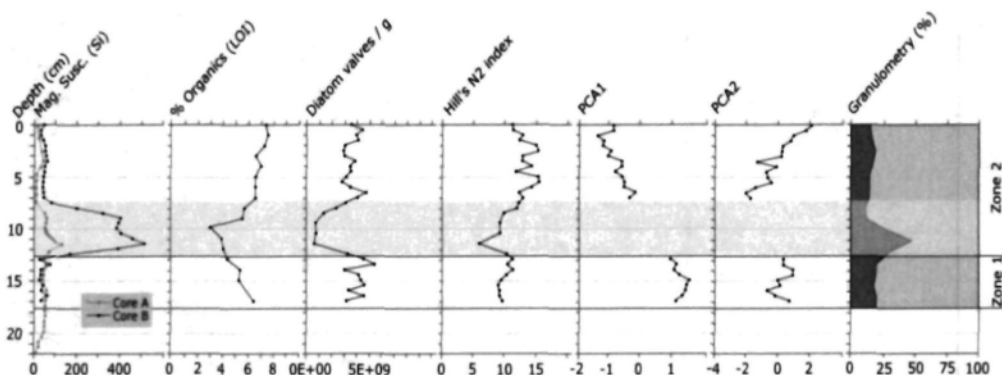


Figure 3 : Sedimentological (magnetic susceptibility, organic content and granulometry) and biostratigraphic (diatom concentration and Hill's N2 diversity index) data from the sediment cores a and b from Lake LAB004 (Üppatik). The major zones were identified using CONISS. The grey zone between 7.5 and 12.5 cm depth represents the rapidly deposited layer that was excluded from analysis.

Chronology and age model

Lead-210

The recent sediment samples showed low ^{210}Pb activities in both cores, ranging from 0.088 to 0.176 Bq g^{-1} for Lake LAB003 and from 0.011 to 0.367 Bq g^{-1} for Lake LAB004. Unsupported ^{210}Pb disappeared below 1.75 cm for Lake LAB003 and 3 cm for Lake LAB004.

Although these values are low, they appear to have equivalents in other Arctic sites (e.g. Douglas *et al.* 1994). Down-core ^{210}Pb values within Lake LAB003 were very low, highly variable and did not show the expected logarithmic decrease with depth. As such, no ^{210}Pb -based chronology or sedimentation rate could be derived for Lake LAB003. As there is insufficient sediment material remaining from Lake LAB003 for ^{210}Pb using gamma-counting, samples have been sent for alpha-based ^{210}Pb determination. Due to the limited availability of laboratories offering this approach and a related backlog, the results for Lake LAB003 sediment are not expected for a number of months.

For the Lake LAB004 sediment record, a constant sedimentation rate of $0.0081 \text{ g cm}^{-2} \text{ year}^{-1}$ was estimated from the 3 uppermost centimetres (7 samples). The age model deduced from this sedimentation rate goes back to 1896 AD (Figure 4). As the sedimentation rate was apparently constant, using the dry bulk density we were able to extrapolate an average sedimentation rate of 0.025 cm yr^{-1} for Zone 2. The age model proposed for the uppermost sediments from Lake LAB004 above the rapidly deposited layer (RDL) (0 to 7 cm depth) was therefore estimated to represent the period 1680 AD to the present. Given the sediment and magnetic susceptibility patterns presented above, the presence of a rapidly deposited layer between 7.5 and 12.5 cm complicates the downcore chronology. Furthermore, diatom assemblages recovered within the unit suggest probable erosion and loss of the sediment record beneath this deposit. For example, a number of diatom taxa (e.g. *Staurosira pinnata*, *S. pseudoconstruens*) showed abrupt changes in relative abundance between the sediments directly above and below the RDL and PCA values reflecting the general make-up of diatom assemblages also illustrate large, non-gradual shifts between the upper and lower sediment zones (Figure 3Figure 5).

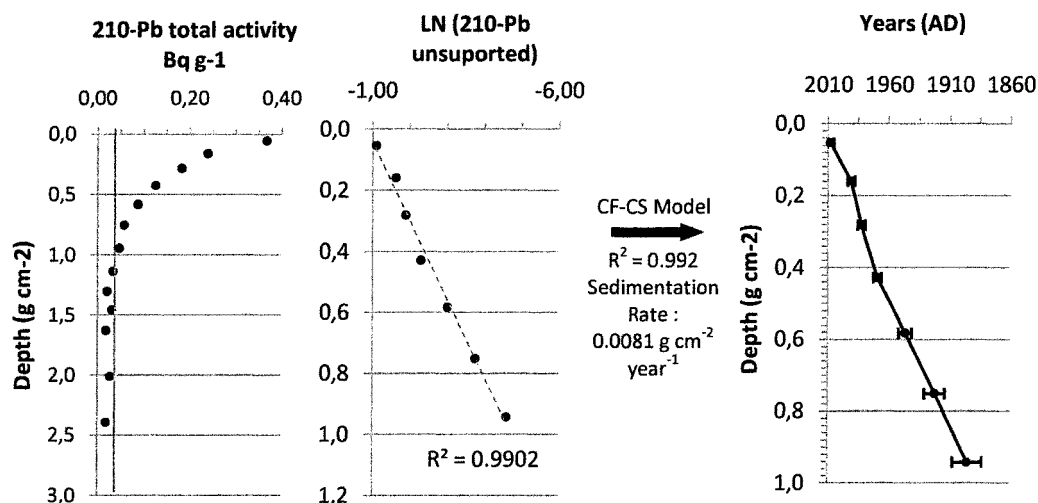


Figure 4 : Results of Pb210 dating from Lake LAB004 (Üppatik) recent sediments. The 210Pb total activity (Bq g⁻¹), the natural logarithm of the unsupported 210Pb activity and the age model (AD) are plotted against the Cumulative Dry Mass (g cm⁻²) in order to minimize the sediment compaction. The vertical red line on the curve of the 210Pb total activity represents the estimated supported 210Pb activity.

Paleomagnetism

Paleomagnetic results could not be obtained for Lake LAB003 likely due to the type of minerals found within the sediment record (G. St-Onge, ISMER-UQAR, pers. comm. 2013). Analysis from Lake LAB004 sediment core provided significant and reliable magnetostratigraphic results (MAD values ranging between 1.8 and 4.0° along the entire core). Once the sediment interval corresponding to the RDL was removed, the limited length of the remaining sediment record was shown to be deposited during the late Holocene however there could not be a direct linking of this paleomagnetic data to regional and global models (CALS3k4 (Korte and Constable 2011), CALS10k (Korte *et al.* 2011) and Eastern Canadian stack (Barletta *et al.* 2010b)). As such, the basal age for the core and the amount of erosion from the RDL emplacement could not be determined. Paleomagnetic analyses performed on other sediment sequences recovered from the Saglék area (unpublished data) support our estimations for the sedimentation rates of the upper portion of the Lake LAB004 record.

Radiocarbon dating

Dates provided through ^{14}C produce sediment sequences having a very low sedimentation rates of about 0.0045 and 0.005 cm years⁻¹ for lakes LAB003 and LAB004 respectively, each centimeter representing an average of about 200 years (Table 3). However, the dating of bulk sediment possibly introduced some bias leading to an overestimation of the sediment ages. Radiocarbon dating of bulk sediment in high latitude lakes is often complicated by the influx of old carbon and/or reservoir effects (Barnekow *et al.* 1998, Björck and Wohlfarth 2001, Fallu *et al.* 2004). On the other hand, it is frequently difficult to find suitable macrofossils or pollen for radiocarbon dating in high latitude lakes having low aquatic productivity, making bulk sediment the only readily available material (Fallu *et al.* 2004). An important source of error in dating bulk sediment is related to input of allochthonous old carbon into the lake by a variety of natural processes that may lead to a contamination of the sediment and biased the radiocarbon ages (Björck and Wohlfarth 2001). In northern Quebec and Labrador, the contamination of sediments by old organic matter derived from deposits of early to mid-Wisconsinian has been reported, for example by Allard *et al.*, Clark *et al.* (1989) and Saulnier-Talbot *et al.* (2009). In the case of Saglék lakes, which are oligotrophic with low aquatic productivity, the allochthonous organic fraction may account for a significant part of the total organic matter contained in sediments. If this allochthonous fraction of organic matter was washed into the lakes from adjacent soil and bedrock, it is quite plausible that radiocarbon dates were older than the true age of sediment deposition. Due to these uncertainties related to bulk sediment dating, the reliable ^{210}Pb data for Lake LAB004, as well as the apparent lack of comparison with regional paleomagnetic models when using the ^{14}C -derived chronologies, we chose to develop our chronological sequence based on the ^{210}Pb results.

Table 3 : Radiocarbon ages from LAB003 and LAB004 cores.

| Lake | Core | Depth (cm) | UCIAMS number | Material dated | ^{14}C Age (^{14}C yr BP) | Cal Age (calyr BP) 2- σ range | Probability distribution (%) |
|--------|------|-------------|---------------|----------------|--|--------------------------------------|------------------------------|
| LAB003 | B | 7.5 - 8.0 | 109155 | Bulk | 2945 \pm 15 | 3061 – 3167 | 86.9 |
| LAB003 | B | 17.0 - 17.5 | 109154 | Bulk | 4145 \pm 20 | 4581 – 4743 | 71.4 |
| LAB003 | B | 24.0 - 24.5 | 65007 | Bulk | 4585 \pm 20 | 5287 - 5322 | 80.0 |
| LAB004 | B | 6.5 - 7.0 | 120646 | Bulk | 1140 \pm 15 | 978 - 1077 | 100 |
| LAB004 | B | 14.0 - 14.5 | 120659 | Bulk | 5565 \pm 20 | 2302 - 2343 | 55.9 |
| LAB004 | B | 16.5 - 17.0 | 65002 | Bulk | 2970 \pm 20 | 3072 - 3218 | 99.1 |

Diatom stratigraphies

Diatoms were well preserved throughout the two study cores with valves showing little dissolution or breakage. A total of 129 and 126 diatom taxa were identified from lakes LAB003 and LAB004 respectively, with many taxa recorded in one or two samples at a very low abundance. Appendix A presents the taxonomy and authority for main diatom species (>1% relative abundance) found in both study lakes. Diatom counts of those main taxa are listed in appendix B for Lake LAB003 and C for Lake LAB004. Appendix D presents plates of diatom species whose relative abundance was greater than 2 % in at least one of the two lakes.

Lake LAB003 (Killirvīk)

Diatom concentrations decreased up-core above 17 cm. Diatom abundance was greatest below 17 cm depth, showing some variability however with no apparent trend (Figure 2). A maximum value (1.37^{10} valves g^{-1}) was recorded at 22 cm. Diatom diversity was also greatest in the lowermost portion of the sediment record (17-25 cm) and then remaining relatively stable from 17 cm until the top of the core. This index should however be interpreted with caution since it can be highly influenced by variations in the sedimentation rate and as such may provide biased information (Smol 1981).

In Lake LAB003, the diatom assemblage was dominated by small benthic taxa belonging to the genus *Stauroforma* (*Stauroforma exiguiformis*) and *Psammothidium* (*Psammothidium curtissimum*, *P. marginulatum*) as well as the heavily silicified, tychoplanktonic *Aulacoseira* ssp. (*Aulacoseira alpigena*, *A. nivalis*), together with diverse taxa from the genera *Encyonema*, *Navicula*, *Achnantheidium*, *Nitzschia*, *Hygropetra* and *Staurosirella* (Figure 5). From 25 to 15 cm depth, the proportion of planktonic taxa remained stable, representing about 30 % of the total assemblage, then started to decrease upcore, accounting for about 20 % of the assemblage in the near-surface samples (Figure 9). *Stauroforma exiguiformis* was the dominant taxa throughout the sediment record, maintaining a mean relative abundance of about 16 %, ranging between 12 and 21 %. This taxa mainly occurs in circumneutral to slightly acidic water bodies and thus, reflects the pH measured from Lake LAB003 in August 2008. Also present throughout the core, having a stable relative abundance around 2 %, were the small benthic *Achnantheidium minutissimum*, *Navicula seminulum*, *N. schmassmannii*, *Nitzschia fonticola* and *N. perminuta* and the tychoplanktonic *Aulacoseira perglabra*. The most striking changes recorded in Lake LAB003 assemblages occur for some taxa having very low (<5%) relative abundance including *Staurosirella pinnata*, *Hygropetra balfouriana*, *Brachysira* sp. [cf-*procera*] and *Frustulia saxonica*. Although a gradual increase in the relative abundance of *Psammothidium marginulatum* and a slight decrease in *Aulacoseira nivalis* was observed over time, the abundance of the dominant taxa previously mentioned remained relatively stable throughout the core; the total amount of diatom turnover in sediment being low over this time period (0.864 SD).

Ordination resulting from the PCA confirmed the difference between the flora composition of the 3 statistically distinct zones identified through CONISS (Figure 6Figure 2). However, if zones 1 (25 - 17.5 cm depth) and 3 (10.5 - 0 cm depth) show relatively distinct

diatom assemblages, Zone 2 (17.5 - 10.5 cm depth) consists of a transition flora sharing characteristics of zones 1 and 3. PCA axis 1 (explaining 36.51% of the total variance) remained stable in Zone 1 then decreased upcore until Zone 3 where a relative stability can be observed. PCA axis 2 (explaining 6.95% of the total variance) shows little variations in zones 1 and 3, the major change recorded occurring in Zone 2 (Figure 2).

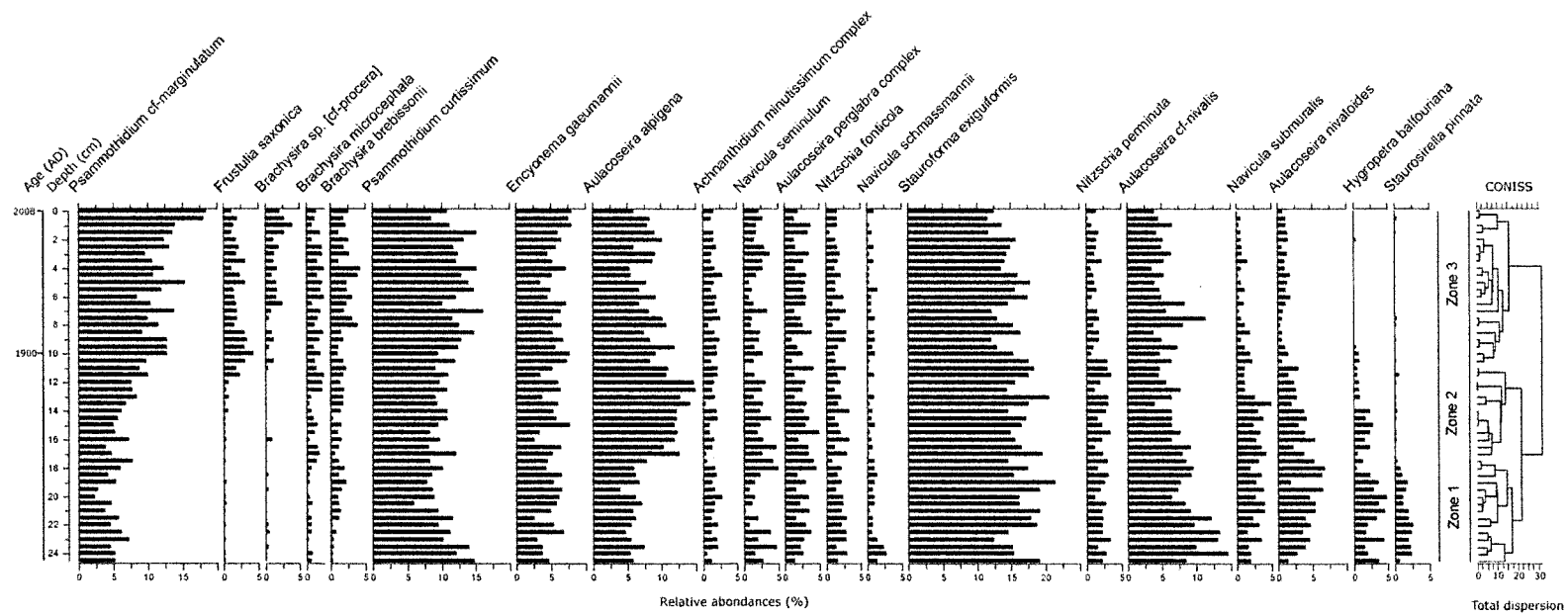


Figure 5 : Diatom stratigraphy for Lake LAB003 (Killirvik), showing the relative abundance of the most abundant taxa (representing 80% of the total assemblages) ordered by increasing PCA axis 1 species scores (left to right).

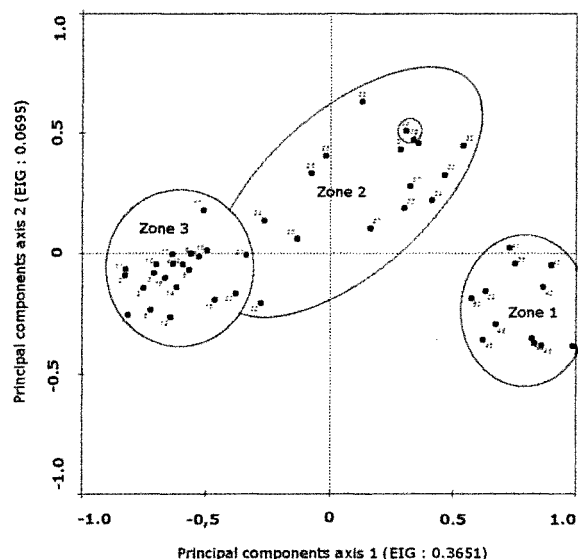


Figure 6 : Principal component analysis (PCA) of samples from Lake LAB003 (Killirvik), grouped by zones as defined by CONISS.

Zone 1 (25 – 17.5 cm)

Stauroforma exiguiformis (12-21%) dominated the assemblage in association with the acidophilic taxa *Psammothidium curtissimum* (6-15%) and *Aulacoseira nivalis* (6-15%), together comprising about 37 % of the total fossil assemblages. *Aulacoseira nivalis* reached its maximum abundance in Zone 1 (14.6%) then declined gradually until Zone 3 where its minimum abundance was recorded (3.6%). Other acidophilic taxa such as the small benthic/periphitic *Psammothidium marginulatum*, *Encyonema gaeumannii*, *Hygropetra balfouriana* and the planktonic *Aulacoseira nivaloides*, *A. alpigena* and *A. perglabra* were also important components of the assemblage, with an average relative abundance varying from 2.8 to 6.1 %. *Aulacoseira nivaloides* reached a maximum abundance (6.8%) at the end of Zone 1. Also present in the assemblages were the alkaliphilous taxa *Navicula submuralis* (1-4%), *Nitzschia fonticola* (1-3%), *N. perminuta* (1-3%) and *Staurosirella pinnata* (0.5-3%). The small

tychoplanktonic *Staurosirella pinnata*, almost exclusively present in that zone, mostly disappeared from the record above 17 cm depth. From 25 to 20 cm depth, the proportion of alkaliphilous taxa increased, reaching a maximum abundance at 22 cm depth (12.9 %) before gradually declining upcore. Inversely, the proportion of *Achnanthes sensu lato* (mainly *Psammothidium cf. marginulatum*, *P. curtissium* and *Achnanthidium minutissimum*) decreased from 25 to 20 cm depth where it reached its minimum abundance (16.4%) then increased gradually until Zone 3 where its maximum abundance was recorded (39.6%). *Brachysira* ssp (*B. microcephala* and *B. brebissonii*) became noticeable at the end of Zone 1 and remained relatively stable to present day. This zone also contains the highest valve concentrations and Hill's N2 index for the sediment sequence recovered in Lake LAB003.

Zone 2 (17.5 – 10.5 cm)

This zone was dominated by *Stauroforma exiguiformis* representing 14 to 21% of the assemblage. The benthic/periphitic *Psammothidium curtissimum* (8-12%) and *Encyonema gaeumannii* (3-8%) remained abundant and stable throughout this zone. This zone, however tends to reflect a transition zone with many species either beginning a long-term decrease or increase. *Psammothidium marginulatum* (4-10%) began a steady increase from around 15 cm depth continuing into the present day, as did the acidobiontic *Frustulia saxonica*. The planktonic *Aulacoseira alpigena* (10-15%) gained more importance, reaching its maximum abundance at 12.5 cm depth (15%), while in contrast, the abundance of *A. nivalis* (4-9%) and *A. nivaloides* (2-5%) started to decrease. *Aulacoseira nivaloides* declined throughout the zone until around 10.5 cm depth, where it reached its minimum value (0.4%) similar to the periphitic *Hygropetra balfouriana* (0-3%) having decreasing abundance levels and disappeared almost completely by 10 cm depth.

Zone 3 (10.5 – 0 cm)

Zone 3 was dominated by the small benthic *Stauroforma exiguiformis* (11-18%), *Psammothidium curtissimum* (9-16%) and *P. marginulatum* (8-18%) that together, accounted for about 40% of the total assemblage. *Encyonema gaeumannii* (4-8%), *Aulacoseira alpigena* (5-12%) and *A. nivalis* (4-11%) were still found to have a relatively important proportion throughout this zone. Sub-dominant taxa recorded in previous zones such as *Nitzschia perminuta*, *Navicula submuralis* and *Aulacoseira nivaloides* were also observed at low abundance in Zone 3. This zone was also marked by the increasing presence of the acidobiontic *Frustulia saxonica* (1-4%) in the assemblage and by the occurrence of *Brachysira* [*cf. procera*], although remaining at a low abundance throughout the zone.

Lake LAB004 – (Üppatik)

The diatom valve concentration remained stable around at 3.79×10^9 valves g^{-1} throughout the core with an isolated sediment sequence of lower diatom concentrations between 7.5 and 12.5 cm depth (mean of 1.73^9 valves g^{-1}) coincident with the magnetic susceptibility peak and the coarser material of the RDL (Figure 3). A general increase in diatom diversity was observed from 17 to 2 cm depth with an isolated drop observed at 11.5 cm. The uppermost 2 cm show diatom diversity to be slightly decreased.

The diatom assemblage from Lake LAB004 was dominated by small benthic Fragilariaceae taxa (*Pseudostaurosira brevistriata*, *P. pseudoconstruens*, *Staurosirella pinnata*), benthic and periphitic *Achnantheidium minutissimum* and *Hygropetra balfouriana* and small centric, planktonic species from the genus *Cyclotella* and *Discostella* (*Cyclotella ocellata*, *C. rossii*, *Discostella stelligera* complex) (Figure 7). Sub-dominant species belonged to the genera *Psammothidium*, *Rossethidium*, *Brachysira*, *Eunotia*, *Karayevia*, *Nitzschia* and *Navicula* and their relative abundance never exceeded 5 %. The proportion of planktonic taxa within the

total assemblage was about 28 % from 17 to 12 cm depth increasing to 42 % from 7 cm upcore (Figure 10). Diatom assemblages analyzed between 7.5 and 12.5 cm were excluded due to irregularities in physical properties recorded within this sediment interval.

CONISS divided the diatom assemblage from Lake LAB004 into two discrete biostratigraphic zones. The sample ordination resulting from the PCA generally confirmed the difference between the flora composition of those major zones (Figure 8**Erreur ! Source du renvoi introuvable.**). Although diatom assemblages within zones 1 (17 to 13 cm) and 2 (7 cm to 0 cm) showed some differences, the overall diatom assemblage remained relatively stable throughout the late-Holocene, the total amount of diatom turnover in sediment was low over this time period (0.834 S.D. for the complete core and 0.634 S.D. for Zone 2). PCA axis 1 (explaining 40.99 % of the total variance) decreased gradually throughout the sediment core. PCA axis 2 (explaining 8.41 % of the total variance) showed little variation in zone 1 but increased upcore throughout Zone 2 (Figure 3).

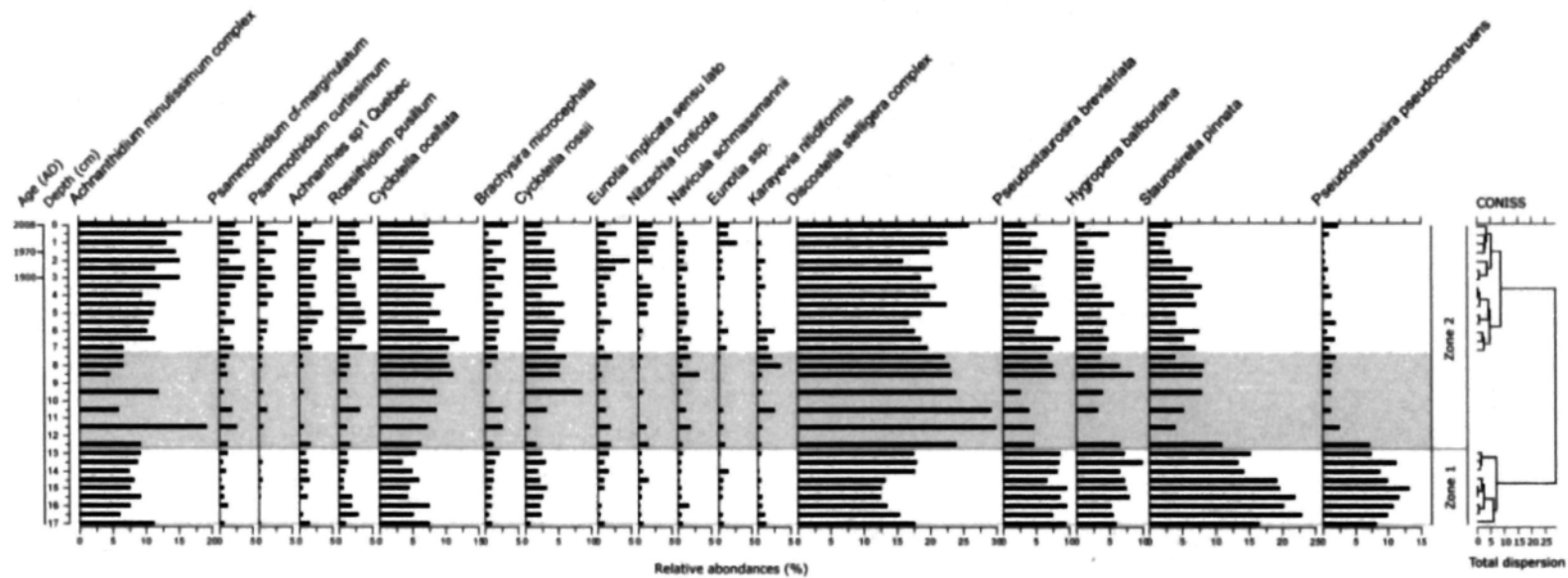


Figure 7 : Diatom stratigraphy for Lake LAB004 (Üppatik), showing the relative abundance of the most abundant taxa (representing 80% of the total assemblages) ordered by increasing PCA axis 1 species scores (left to right).

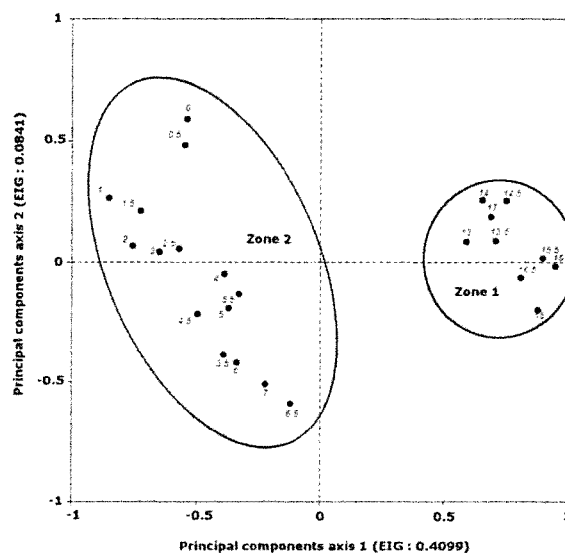


Figure 8 : Principal component analysis (PCA) of samples from Lake LAB004, grouped by zones as defined by CONISS.

Zone 1 (17 – 12 cm)

Zone 1 was dominated by the alkaliphilous, tychoplanktonic, benthic fragiliaceae (*Pseudostaurosira brevistriata* (7-10%), *P. pseudoconstruens* (8-13%) and *Staurosirella pinnata* (13-23%)), together representing about 37 % of the total diatom assemblage. Both *S. pinnata* and *P. pseudoconstruens* reached their maximum relative abundance at 15.5 cm depth, then declined throughout the end of Zone 1. While the relative abundance of *P. brevistriata* and *S. pinnata* decreased gradually to the present day, the abundance of *P. pseudoconstruens* dropped rapidly at about 13 cm depth and remained low throughout the remainder of the core (max. 2.5%). The total proportion of *Fragilaria sensu lato* within the fossil assemblages declined throughout the core from about 45 to 10 % with a significant drop observed between zones 1 and 2. A concomitant decreased in the proportion of alkaliphilous taxa can be observed, going from about 65 to 40 % upcore. Other important components of the assemblage were the small

centric, circumneutral to slightly alkaliphilous *Discostella stelligera* (13-18%) and *Cyclotella ocellata* (3-8%), the alkaliphilous *Achnantheidium minutissimum* (6-11%) and the benthic acidophilous *Hygropetra balfouriana* (5-10%). The proportion of *Achnanthes* spp. *sensu lato* increased throughout the core from about 15 to 30 %. In Zone 1, sub-dominant species account together for about 9 % of the total diatom assemblage.

Zone 2 (7 - 0 cm depth)

Zone 2 overlies an interval of very high magnetic susceptibility and relatively lower diatom concentrations (mean = 1.73^9 valves g^{-1}). The diatom assemblage of Zone 2 was dominated by the small planktonic *Discostella stelligera* representing between 16 and 26 % of the assemblage. *Achnantheidium minutissimum* (7-16%) also gained more importance in the zone, reaching its maximum abundance (15.5% at 0.5 cm depth). All the small acidophilous *Achnantheaceae* (*Psammothidium marginulatum*, *P. curtissimum*, *Rossithidium pusillum* and *Achnanthes* sp.1 Quebec), together with the periphitic, acidophilous *Eunotia* ssp. and some taxa of the genus *Brachysira* and *Nitzschia* also increased in abundance. A concomitant decline in the abundance of both small centric *Cyclotella ocellata* (6-12%) and *C. rossi* (3-6%), the benthic *Hygropetra balfouriana* (1-7%) as well as *Pseudostaurosira brevistriata* (4-9%) and *Staurosirella pinnata* (2-8%) was also recorded beginning from about 7 cm depth.

Discussion

Lake LAB003

Although three statistically significant diatom zones were observed in the down-core record of LAB003, the stratigraphies and DCCA gradient lengths highlight a general stability over the sediment sequence. Only secondary species (<5% relative abundance) experienced major shifts in relative abundance down-core. Diatom assemblages observed in Lake LAB003 are typical of clear, oligotrophic and circumneutral to slightly acidic waterbodies. The majority

of taxa recorded are cosmopolitan species, commonly found in arctic and alpine regions (Krammer and Lange-Bertalot 1991 - 1997, Fallu *et al.* 2000).

Dating of the sediment record from Lake LAB003 was problematic (mineralogy preventing use of paleomagnetism, old ^{14}C dates and an unreliable ^{210}Pb record), however diatom assemblages resemble those recovered from an adjacent lake (Saglek 2) studied by Paterson *et al.* (2003). In particular, both records recorded the increase in *P. marginulatum* (*Achnanthes marginulata* in Paterson *et al.* (2003)) and concomitant decrease in *Aulacoseira* spp. Lead-210 dating of the Paterson *et al.* (2003) record places this shift at ca. 100 years BP. As such we may correlate this date to our record, giving Lake LAB003 sediment an approximate age of ca. 260 years if we assume sedimentation rates to be fairly constant. New ^{210}Pb dating of the Lake LAB003 sediments should confirm (and add more precision) to this age estimate.

Stauroforma exiguiformis, generally observed in circumneutral to slightly acidic environments, was the most abundant taxa recorded throughout the sediment core. This taxa was also observed in abundance in the fossil assemblages of several lakes from arctic and subarctic Quebec and Labrador (Fallu and Pienitz 1999, Fallu *et al.* 2000, Saulnier-Talbot and Pienitz 2001, Laing *et al.* 2002, Paterson *et al.* 2003). However, the specific autecology of this species remain largely unknown (Laing *et al.* 2002). Its continuous downcore abundance suggests that no abrupt limnological changes have occurred over the last 260 years in Lake LAB003.

Small *Achnanthes* taxa (e.g. *P. marginulatum* and *P. curtissimum*), another major component of Lake LAB003 assemblage, are commonly found in dilute and oligotrophic environments (Fallu *et al.* 2002). A gradual increase in the relative abundance of these small benthic species over time was observed and matched by a slight decrease in proportion of *Stauroforma exiguiformis* and species of the genus *Aulacoseira*, strongly silicified diatoms

requiring an important vertical mixing of the water column to maintain their position within the photic zone (e.g. *Aulacoseira nivalis*, *A. alpigena*, *A. perglabra*) (Kilham *et al.* 1996). *Aulacoseira* taxa are known to flourish in deeper arctic lakes where the open landscape provides higher wind-induced turbulence (Korhola *et al.* 1996, Sorvari and Korhola 1998).

At first glance, given its relatively shallow nature, Lake LAB003 would seem to offer less opportunity for the development of a planktonic community. However, the lake is located at the bottom of a valley connected to the Saglek fjord, in a position that may be windy enough to ensure a constant mixing of the water column and thus, allow these strongly silicified diatoms to flourish. Another possibility is that the oligotrophic and transparent nature of the lake allows for visible light to penetrate through the entire water column, making the tychoplanktonic (occurring in benthic and planktonic habitats) *Aulacoseira* species able to temporarily survive on the lake bottom.

The increasing importance of *Achnanthes* species *sensu lato* (mainly *Psammothidium marginulatum*) throughout zones 2 and 3 is mostly due to a concomitant and gradual decrease in the absolute abundance of *Stauroforma exiguiformis* and *Aulacoseira* species; the absolute abundance of *Achnanthes* taxa remained stable throughout the sediment record (Figure 9). This slight and gradual decrease of the highly silicified planktonic diatoms recorded in sediment, may reflect gradual changes of microhabitat availability that were expressed, for example, through an increasing availability and variety of littoral environments over time (increasing abundance of mosses or littoral macroalgae). Changes in inter-species dynamics may also explained such minor changes in diatom community structure.

Global trends observed in Lake LAB003 diatom community may also suggest a slight acidification of the lake over time, potentially induced by a gradual cooling. As proposed by Michelutti *et al.* (2006, 2007), in the presence of highly dilute lake waters, the regulation of

acid-base equilibria is closely dictated by ice-cover duration, which is ultimately governed by climate. Michelutti *et al.* (2007) concluded that climate-related processes have a greater influence on chemical and biological evolution (throughout the Holocene) in arctic glaciated lake ecosystems than watershed processes as suggested by Engstrom *et al.* (2000). Moreover, fossil diatom assemblages from Lake LAB003 resemble those documented in lakes from alpine (Koinig *et al.* 1998) and mid-arctic (Wolfe 2002) regions where pH changes modulated by environment are considered to be mainly responsible for floristic changes. An extensive ice-cover due to a colder period tends to preclude the evasion of respired CO₂ to the atmosphere and hence lower lakewater pH. A gradual, although subtle, cooling in the Saglek region and an associated acidification (Michelutti *et al.* 2006) could thus explain the decreased diatom production observed in Lake LAB003, the recent emergence of some acidobiontic species (*Frustulia saxonica*, *Brachysira microcephala*), the disappearance of the alkaliphilous *Staurosirella pinnata* and the decreased abundance of *Aulacoseira* species over time; a genus that Michelutti *et al.* (2003a, 2006) associated to a longer growing season.

Although this study was conducted at a relatively high sampling resolution, it was impossible to detect neither recent warming trend that could be related to anthropogenic activities nor any evidence of PCB contamination based on fossil diatom assemblages. The very low sedimentation rate reported from Lake LAB003 sediment record makes it difficult or nearly impossible to detect such short-term changes. Another study conducted by Paterson *et al.* (2003) in Saglek area revealed little change in the diatom or chrysophycean assemblages over the last two hundred years and did not report any changes related to PCB contamination of their study lake.

The apparent lack of response of phytoplankton communities to PCB contamination within these subpolar lakes suggests that diatoms may not be significantly affected by this type

of pollutant. These observations support the results presented in Paterson *et al.* (2003) where it was suggested that the effects of PCBs contamination, although not observed within primary producer communities, can be more easily observed at higher trophic levels through bio-accumulation and bio-concentration processes. These results, however, do have important implications for climate change research within circumpolar regions. As presented in Paterson *et al.* (2003), it suggests that arctic lake pollution by contaminants (via direct input or long-range transport) have comparatively little effect on algal communities and support the hypothesis, now widely sustained, that defines climate as the first-order factor explaining recent limnological changes observed across the entire Arctic.

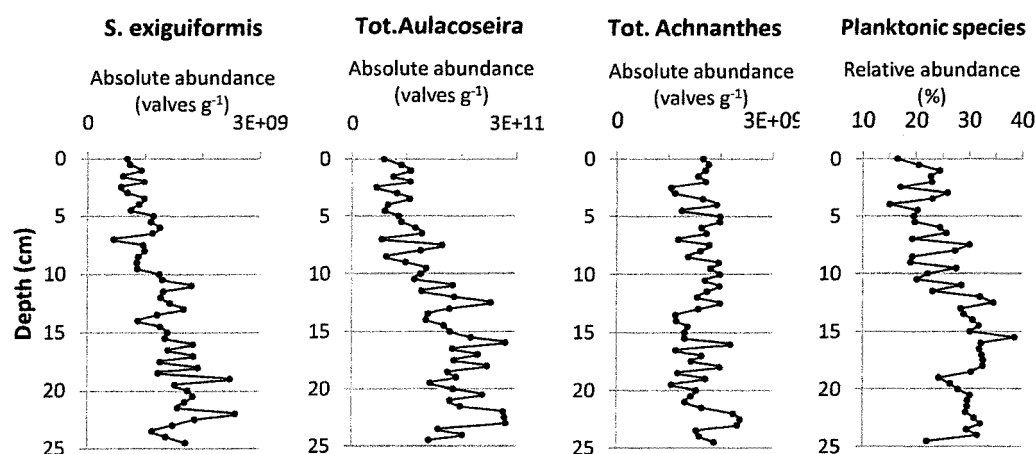


Figure 9 : Absolute abundance (valves g⁻¹) of key species and genera (*Stauroforma exiguiiformis*, *Aulacoseira* species (*A. alpigena*, *A. nivalis*, *A. nivaloides* and *A. perglabra*) and *Achnanthes* *sensu lato* species (*Psammothidium marginulatum*, *P. curtissimum* and *Achnanthidium minutissimum*)) with the ratio of planktonic versus benthic species recovered from Lake LAB003 sediments, Saglék.

Lake LAB004

Similar to the previous site, Lake LAB004 diatom assemblages were marked by a stability over the last 3 centuries. The RDL within the core prevents the interpretation of a continuous sediment record, but nonetheless confirms a long-term stability within the lake sediment record. Diatom assemblages observed in Lake LAB004 are typical of an arctic, clear, oligotrophic and circumneutral waterbody. Zones 1 and 2 showed statistically distinct diatom assemblages, although the total amount of diatom turnover in sediment was low over the entire sediment record (0.834 S.D.)

Diatom assemblages from Zone 1 was dominated by small alcaliphilous *Fragilariaceae* (*Staurosirella pinnata*, *Pseudostaurosira pseudoconstruens*, *P. brevistriata*), commonly found in arctic tundra lakes (Pienitz and Smol 1993, Laing *et al.* 1999, Lotter and Bigler 2000). *Staurosirella pinnata* are considered to be pioneering diatoms, able to grow in harsh conditions and have been well documented as an indicator of cool environments with a short growing season in both Arctic (Douglas *et al.* 1994, Michelutti *et al.* 2003a) and alpine lakes (Lotter and Bigler 2000). This taxa is also commonly found in pre-industrial polar environments (Smol *et al.* 2005). Relative abundance of these benthic *Fragilariaceae* dropped abruptly between zones 1 and 2, then remained stable throughout Zone 2. This drop in the relative and absolute abundances of these small alcaliphilous taxa may suggest slightly warmer conditions in Zone 2, having a reduced ice cover. During colder periods, the extended ice cover tends to inhibit growth in the planktonic zone, reducing possibilities for the development of a large planktonic community and promoting benthic species such as *Staurosirella pinnata* (Rühland *et al.* 2008). An increase in species richness between zones 2 and 1 may also suggest a greater diversity of available habitats in Zone 2. The lack of chronological control of Zone 1 prevents us from identifying the timing of this potentially cooler period.

The proportion of small planktonic species from the genus *Discostella/Cyclotella* (*Discostella stelligera*, *Cyclotella ocellata* and *Cyclotella rossii*), although major components of Zone 1, increased abruptly between zones 1 and 2 and become the most important taxa recorded in Zone 2. *Discostella stelligera* is a planktonic, cosmopolitan, circumneutral and oligotrophic species, also common and abundant in many arctic and subarctic waterbodies (Krammer and Lange-Bertalot 1991 - 1997, Cremer *et al.* 2001, Sorvari *et al.* 2002, Cremer and Wagner 2004, Rühland and Smol 2005, Rühland *et al.* 2008).

An increase in the relative proportion of planktonic species is often related to warmer conditions and subsequent decrease in the duration and extent of ice cover in summer (Sorvari *et al.* 2002). An increasing temperature may lead to the strengthening of the thermal stratification, which promotes small planktonic species such as *Cyclotella / Discostella* taxa that compete well in a stratified water column (Sorvari *et al.* 2002, Rühland *et al.* 2003, Rühland and Smol 2005, Rühland *et al.* 2008, Catalan *et al.* 2013). Thus, the increased relative abundance of *Cyclotella / Discostella* species in Zone 2 may suggest slightly warmer conditions in Lake LAB004 relative to the underlying zone.

Moreover, a recent increase (last 150 years) in the proportion of planktonic species mainly belonging to the genus *Cyclotella* was observed in assemblages from several arctic and subarctic lakes (Sorvari *et al.* 2002, Rühland and Smol 2005, Rühland *et al.* 2008, Catalan *et al.* 2013). This often pronounced increase usually occurs at the expense of small benthic species (e.g. *Fragilariaceae*). Many authors explained the recent success of *Cyclotella* species by the reduced ice cover duration and extent in summer and / or by the intensification of thermal stratification associated to the recent anthropogenic warming (Sorvari *et al.* 2002, Rühland *et al.* 2003, Rühland and Smol 2005, Rühland *et al.* 2008). However, changes observed in *Discostella stelligera* in Lake LAB004 occurred prior to the beginning of the industrial era and

are mainly due to a decrease in the absolute abundance of the *Fragilariaceae* species (Figure 10). The absolute abundance of *Discostella stelligera* remained stable downcore and suggest that no abrupt limnological changes have occurred over the last 325 years in Lake LAB004. Organic matter content and diatom concentration also remained stable throughout the sediment record confirming this interpretation.

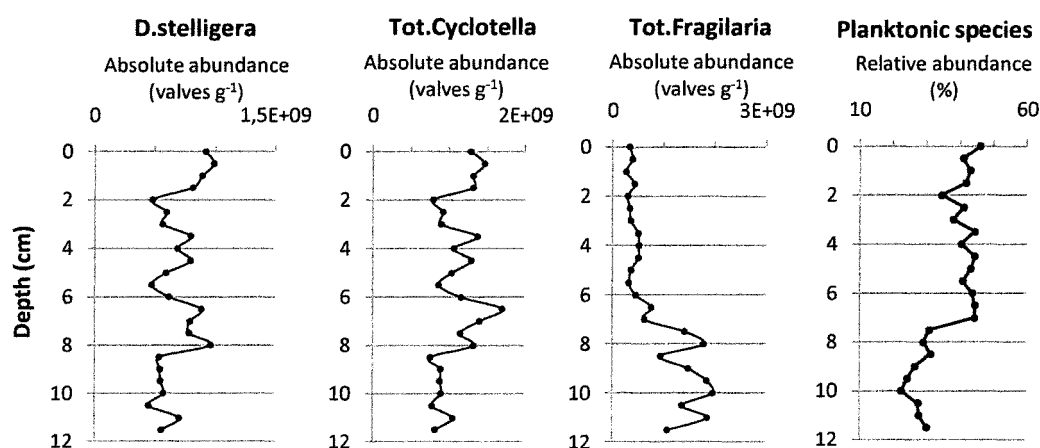


Figure 10 : Absolute abundance (valves g⁻¹) of key species and genera (*Discostella stelligera*, *Cyclotella* species *sensu lato* (*Discostella stelligera*, *Cyclotella ocellata* and *C. Rossii*) and fragilaroid taxa (*Staurosirella pinnata*, *Pseudostaurosira pseudoconstruens* and *P. brevistriata*)) with the ratio of planktonic versus benthic species recovered from Lake LAB004 sediments, Saglék.

Differences between the diatom flora of lakes LAB003 and LAB004

The composition of diatom species assemblages is strikingly different from one lake to the other, dominant taxa recorded in Lake LAB003 (e.g. *Stauroforma exiguiformis*) being absent from Lake LAB004 (e.g. *Discostella stelligera*) and vice versa. Those differences observed between diatom communities could be explained by differences in local conditions (morphological, limnological and geographical properties, etc.) specific to each lake. These

local conditions may also greatly influence diatom ecological response to larger-scale regional environmental change (Smol *et al.* 2005). Due to their geographical proximity (35 km), both ecosystems have likely been subjected to the same long-term climate influences. Thus, as an initial hypothesis, diatom assemblages from each lake should react in a similar manner to any climate variability.

However, many factors, such as ice cover and lake depth, could play a significant role in how changes in climate would affect diatom flora (Keatley *et al.* 2008). Variation in the persistence of ice cover in summer, and associated limnological changes in the physical, chemical, and biological characteristics of deeper versus shallower lakes were proposed to have major influences on diatom species composition in arctic lakes (Keatley *et al.* 2008).

Length of the ice-free season

The duration and extent of ice cover may produce significant changes in key limnological variables, including the timing, duration and strength of thermal stratification, nutrient distribution, light penetration, gas exchange and, in poorly-buffered waterbodies, fluctuation of lakewater pH (Douglas and Smol 1999). As diatoms are known to be particularly sensitive to ice-cover and physicochemical-related properties (Lotter and Bigler 2000, Smol *et al.* 2005, Smol and Stoermer 2010), such as light penetration, mixing processes and pH, we suspect these variables to be partially responsible for the floristic differences observed between lakes LAB003 and LAB004.

Lake LAB004 being larger, deeper and located at a much higher altitude than Lake LAB003, the duration of summer melt season should be expected to be shorter also making the ice-free period shorter. In such limited summer open-water situations, light penetration and primary productivity would be expected to be significantly reduced (Wolfe 2002). The low diatom concentrations (average of 3.79^9 valves g^{-1}) and organic matter content (7%) recorded in Lake

LAB004 compared with Lake LAB003 (7.96^9 valves g^{-1} and 24 % respectively) may reflect this reduced primary productivity, likely associated to a shorter ice free season in Lake LAB004 area. However, the higher organic matter content recorded in Lake LAB003 sediments may also originate from the watershed, where the vegetation is more abundant and diversified.

An extensive ice-cover is also expected to reduce the duration and strength of the thermal stratification (Sorvari *et al.* 2002, Rühland *et al.* 2008). In Lake LAB004, the temperature profile recorded in August 2008 did not actually show any strong thermal stratification, although more important than that observed in Lake LAB003 where no thermocline was noted.

In the presence of highly dilute lake waters, pH is also expected to decline with an increase of the duration and extent of ice cover, which tends to preclude the evasion of respired CO_2 to the atmosphere (Wolfe 2002, Michelutti *et al.* 2006). Dissolved inorganic carbon speciation driven by within-lake processes (i.e. photosynthesis and respiration), which is ultimately governed by the duration and extent of ice cover, has been demonstrated to exert a first-order control on pH in several poorly buffered lakes in alpine and Arctic regions (Wolfe 2002, Larsen *et al.* 2006, Michelutti *et al.* 2006, Michelutti *et al.* 2007). However, the pH values recorded in both study lakes are nearly identical and prevent us from using pH as an indicator of ice-cover duration on lakes LAB003 and LAB004. Furthermore, other climate-related processes such as weathering rates and catchment vegetation may cause pH to change over time (Koinig *et al.* 1998, Michelutti *et al.* 2007).

Differences in lake ice regime between the two study lakes may be too subtle to significantly interfere in limnological variables such as pH, thermal stratification or light availability. However, those ice-related properties may certainly affect physical habitat availability which, in turn, play a significant role in diatom dynamics and community structure. For example, a colder climate associated with a more persistent central float of ice limits the

establishment of large planktonic diatom population in arctic lakes, while a longer ice-free season allows both planktonic and benthic diatom to flourish (Michelutti *et al.* 2003b).

Lake depth and habitat availability

Lake LAB003 is shallower and much smaller than Lake LAB004. This difference increases the diversity and quantity of potential habitats for benthic / periphytic species in Lake LAB003 while pelagic environments are dominant in Lake LAB004. As such, planktonic taxa were less abundant in Lake LAB003 (mean of 27% of the assemblages) than in Lake LAB004 (mean of 42% of the assemblages in Zone 2) throughout the sediment records, likely reflecting the proportional reduction of planktonic available habitats with water depth decrease (Wolin and Duthie 1999, Laing *et al.* 2002). The habitat type available (aerophilic, shallow-water periphytic, planktonic) for diatom growth is also known to play a significant role in determining which taxa ultimately dominate the assemblage and become incorporated into sediments (Michelutti *et al.* 2003b). Thus, the higher proportion of periphytic taxa found in Lake LAB003 could be explained by greater opportunities for the development of a periphytic diatom community in shallower lakes where benthic microhabitats are more abundant.

As variations in ice cover and water depth are among the principle determinant of shifting diatom species composition in arctic lakes (Keatley *et al.* 2008), differences between diatom species composition observed between lakes LAB003 and LAB004 could probably be explained by differences in local conditions of each ecosystem and related microhabitats availability.

Regional comparison

Lakes in most areas of the Arctic have undergone significant changes in their microfloral and zooplankton assemblages over the last 150 years reflected by an elevated turnover of species in the sediment assemblages (Overpeck *et al.* 1997, Smol *et al.* 2005, Rühland *et al.* 2008). Our estimates of diatom composition turnover (beta-diversity) since ~1850 AD in lakes

LAB003 (0.692 S.D.) and LAB004 (0.698 S.D.) are among the lowest for arctic lakes and are below the reference value of 1 S.D. for “unimpacted lakes” defined from lower latitude waterbodies by Smol *et al.* (2005). These results suggest that limnological changes in lakes LAB003 and LAB004 have been negligible since the beginning of the industrial era and that the magnitude of recent climate change in the Saglek regions is muted compared with many arctic sites from the High (Douglas *et al.* 1994, Perren *et al.* 2003) and Central Canadian Arctic (Rühland and Smol 2005), Finnish Lapland (Sorvari *et al.* 2002), northern Greenland (Perren *et al.* 2012) and polar Russia (Solovieva *et al.* 2005) where abrupt shifts in aquatic communities have been reported. This compositional stability is similar, however, to other subarctic sites from Quebec/Labrador (Saulnier-Talbot and Pienitz 2001, Laing *et al.* 2002, Ponader *et al.* 2002, Paterson *et al.* 2003, Fallu *et al.* 2005, Richerol *et al.* Submitted) and West Greenland (Perren *et al.* 2008) where no directional changes in aquatic communities have been recorded. Our study and others from Quebec and Labrador region testify the western subpolar region of the North Atlantic having warmed less than other Arctic regions over the 20th century. Instrumental records and climate models also corroborate these observations (Serreze *et al.* 2000, Moritz *et al.* 2002, Hanna 2003). However, some ice regime and ecological changes have been reported from the Hudson Bay region within the last 15 – 20 years and may suggest the start of a shift to a new climate regime in subarctic Quebec (Payette 2004, Hochheim and Barber 2010).

At a longer time-scale, our data also suggests that the Saglek area has remained climatically stable throughout at least the last 300 years. No directional changes within diatom assemblages were recorded from lakes LAB003 and LAB004 sediments over this time period.

Influences of the Labrador Sea on terrestrial conditions of the Saglek area are poorly known. However, it has been argued that marine conditions have had a dominant influence

on millennial-scale climate variability over the late Holocene around the Labrador Sea (Kaplan *et al.* 2001). Payette (2007) also documented tree-line dynamics along the Labrador coast linking the long-term evolution of climate conditions with the position of the Labrador Current over the Holocene. Reconstructions of paleoceanographic conditions along the Labrador coast, based on dinocyst assemblages, highlight a general climate stability over the last 6000 years (Levac and De Vernal 1997) and, at a higher resolution (~150 years), this climate stability is accompanied by a slight cooling (Richerol *et al.* Submitted). The similarity observed between terrestrial and marine reconstructions for the northern Labrador region suggest a strong coupling between terrestrial ecosystems and inland climate and the moderating marine conditions in Labrador Sea. As such, given the current context of global warming, attention must be paid to a better understanding of this climatically stable region in order to better understand the natural climate variability of the North Atlantic area and to understand the extent to which the Labrador Sea will continue to buffer northeastern Quebec and Labrador from regional warming.

Conclusions

The use of sedimentary diatom remains allowed us to establish the recent (~ 300 years) climate history of the Saglék region and subsequent modification in aquatic ecosystems. Our results suggest that the Saglék area remained climatically stable throughout the last 300 years, with no significant changes in diatom assemblages recorded from lakes LAB003 and LAB004 sediments. Shifts in the composition of diatom taxa (beta-diversity) recorded within both lake sediments were very limited over the last 150 years in comparison to most other Arctic regions (Canadian Arctic Archipelago, Western Arctic Canada, northern Greenland, Fennoscandia and polar Russia), where abrupt limnological and biological changes have been reported in recent decades. However, the stability of the diatom community composition corroborates other

observations from northern Quebec/Labrador and testify to the western subpolar region of the North Atlantic remaining relatively unaffected by generalized Arctic warming over the 20th century.

CHAPITRE III

RÉSUMÉ ET CONCLUSIONS GÉNÉRALES

Le présent projet a été réalisé dans le cadre d'un volet de recherche du réseau ArcticNet, dont l'objectif vise à comprendre puis à répondre aux effets des changements climatiques et de la modernisation au Nunatsiavut. Plus précisément, cette étude visait à rendre compte de la variabilité climatique des derniers 300 ans et de la modification subséquente des écosystèmes aquatiques de cette région relativement peu étudiée. Le nombre d'études paléoécologiques qui ont portées sur l'évolution récente (~ 200 ans) des conditions climatiques et environnementales au Labrador est effectivement limité (Laing *et al.* 2002, Paterson *et al.* 2003, Richerol *et al.* Submitted). La plupart des projets réalisés dans la région ont plutôt mis l'accent sur l'ensemble de l'Holocène, ne permettant qu'une interprétation temporelle limitée (faible résolution) de l'évolution post-industrielle du climat de la région (Short and Nichols 1977, Lamb 1980, 1984, Engstrom and Hansen 1985, Fallu *et al.* 2005, Viau and Gajewski 2009).

Les résultats présentés dans ce mémoire ont donc permis de préciser notre compréhension de l'évolution récente (~ 300 ans) des conditions environnementales et climatiques de la région de Saglek, située dans le Nord-Est du Labrador. Plus spécifiquement, ils ont permis 1) d'évaluer l'importance relative des changements limnologiques récents (~ 150 ans) survenus dans la région par comparaison avec ceux qui sont observés ailleurs à travers l'Arctique et 2) de préciser l'influence des activités anthropiques sur les écosystèmes lacustres

étudiés (i.e. contamination aux BPCs). Les principaux résultats rapportés dans le cadre de ce mémoire peuvent être résumés en quelques points :

1) Les changements paléontologiques (diatomées) observés au sein des lacs étudiés sont relativement faibles depuis le début de l'ère industrielle par comparaison à ce qui prévaut dans de nombreuses régions polaires de l'Hémisphère Nord (Archipel arctique canadien, Ouest de l'Arctique canadien, Fennoscandie, Nord du Groenland) où des changements limnologiques et biologiques abruptes ont été rapportés ces dernières décennies (Smol *et al.* 2005, Rühland *et al.* 2008). Cette stabilité des assemblages diatomifères observée au sein des lacs LAB003 et LAB004 suggère que le climat de la région de Saglek soit demeuré stable au cours des 300 dernières années et que l'ampleur du réchauffement global y ait été négligeable tout au long du 20^e siècle. Si les résultats présentés dans le cadre de cette étude semblent contredire l'actuel scénario de réchauffement global largement documenté à travers l'Arctique (ACIA 2005), ils font écho à de nombreux projets réalisés dans la portion nord du Québec et du Labrador où aucune évidence significative du réchauffement contemporain n'avait été observée jusqu'à tout récemment (i.e. Hudsonie) (Saulnier-Talbot and Pienitz 2001, Laing *et al.* 2002, Ponader *et al.* 2002, Paterson *et al.* 2003, Fallu *et al.* 2005, Smol *et al.* 2005, Bouchard *et al.* 2013, Richerol *et al.* Submitted). La présente étude suggère donc que la région subpolaire de Saglek, située dans l'Ouest de l'Atlantique nord, ait accusé un réchauffement moins important au cours du 20^e siècle que la plupart des autres régions arctiques et subarctiques.

2) Les résultats obtenus dans le cadre de ce projet n'ont permis de détecter aucune évidence de la contamination aux BPCs du Lac LAB003 situé à proximité de l'ancienne base militaire de Saglek (Paterson *et al.* 2003, Pier *et al.* 2003). La structure des assemblages diatomifères étant demeurée stable tout au long des 300 dernières années, nos observations suggèrent que les communautés de diatomées ne sont pas affectées par ce type de polluant.

Ces observations corroborent les résultats présentés dans Paterson *et al.* (2003), où il est notamment suggéré que les effets d'une contamination aux BPCs, sans être observée au niveau des producteurs primaires, puissent plus facilement se manifester à des niveaux trophiques supérieurs, à travers les processus de bio-accumulation et de bio-concentration. L'apparente absence de réponse des communautés phytoplanctoniques à l'infiltration de BPCs dans ces lacs subpolaires ont néanmoins d'importantes implications pour la recherche sur les changements climatiques des régions circumpolaires. Tel que présenté dans Paterson *et al.* (2003), ces résultats suggèrent que la pollution des écosystèmes lacustres par des contaminants n'ont que peu d'effets sur les communautés phytoplanctoniques et soutiennent l'hypothèse, aujourd'hui largement répandue (Douglas *et al.* 1994), qui définit le climat comme un facteur de premier ordre, permettant d'expliquer les changements limnologiques abruptes récemment observés à travers l'Arctique.

3) Bien que les assemblages diatomifères des deux lacs étudiés ne témoignent d'aucun changement limnologique significatif, la composition floristique observée dans les sédiments de chacun des plans d'eau est étonnamment différente. L'espèce dominante retrouvée dans les sédiments du Lac LAB003 (i.e. *Stauroforma exiguiformis*) est absente des sédiments du Lac LAB004 (i.e. *Discostella stelligera*) et vice versa. Ces différences floristiques peuvent être expliquées, entre autre, par les disparités locales propres à chacun des plans d'eau (propriétés morphologiques, physico-chimiques, géographiques, etc) ainsi que par le type d'habitats disponibles pour la croissance des diatomées (aérophile, pélagique, benthique, etc.). Ces résultats témoignent du rôle de première importance que jouent les conditions locales et les microhabitats qui leur sont associés sur la détermination des espèces qui domineront les assemblages et qui, ultimement, seront incorporées dans les sédiments.

En conclusion, il serait intéressant d'étendre la portée temporelle de cette étude afin d'élargir le contexte historique qui sous-tend la stabilité climatique récente (~300 ans) que suggèrent les résultats obtenus dans le cadre du projet. Une meilleure perspective historique permettrait de cerner plus efficacement les principaux processus et mécanismes responsables de cette stabilité climatique que l'on observe généralement dans Nord du Québec et du Labrador depuis le début de l'ère industrielle et d'évaluer s'il s'agit d'un patron environnemental constant à l'échelle de l'Holocène. Il serait également pertinent d'approfondir notre compréhension des influences locales et régionales exercées par les courants océaniques de la Mer du Labrador sur le climat régional en comparant plus exhaustivement les données paléolimnologiques et paléocéanographiques disponibles dans la région.

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APPENDIX A : Taxonomy used for diatom species (>1% relative abundance) found in lakes LAB003 and LAB004, Saglek.

| Taxon | Authority |
|---|--|
| <i>Achnanthes bicapitata</i> | Hustedt |
| <i>Achnanthes</i> sp.1 Quebec | Fallu, Allaire & Pienitz |
| <i>Achnanthidium minutissimum</i> complex | (Kützing) Czarnecki |
| <i>Amphora inariensis</i> | Krammer |
| <i>Aulacoseira alpigena</i> | (Grunow) Krammer |
| <i>Aulacoseira lirata</i> | (Ehrenberg) Ross |
| <i>Aulacoseira</i> cf. <i>nivalis</i> | (W. Smith) English & Potapova |
| <i>Aulacoseira nivaloides</i> | (Camburn) English & Potapova |
| <i>Aulacoseira perglabra</i> complex | (Østrup) E.Y.Haworth |
| <i>Brachysira brebissonii</i> | Ross in Hartley |
| <i>Brachysira microcephala</i> | (Grunow) Compère |
| <i>Brachysira</i> sp. [cf. <i>procera</i>] | Lange-Bertalot & Moser |
| <i>Cavinula cocconeiformis</i> | (Gregory ex Greville) Mann & Stickle in Round, Crawford & Mann |
| <i>Cavinula pseudoscutiformis</i> | (Hustedt) Mann & Stickle in Round, Crawford & Mann |
| <i>Chamaepinnularia mediocris</i> | (Krasske) Lange-Bertalot in Lange-Bertalot & Metzeltin |
| <i>Cyclotella bodanica</i> | Eulenstein ex Grunow |
| <i>Cyclotella ocellata</i> | Pantocsek |
| <i>Cyclotella rossii</i> | Håkansson |
| <i>Cyclotella tripartita</i> | Håkansson |
| <i>Cymboppleura lapponica</i> | Grunow (Krammer) |
| <i>Discostella stelligera</i> complex | (Cleve & Grunow) Houk & Klee |
| <i>Encyonema gaeumannii</i> | (Meister) Krammer |
| <i>Encyonema gracile</i> | Ehrenberg |
| <i>Encyonema silesiacum</i> | (Bleisch) Mann in Round, Crawford & Mann |
| <i>Encyonopsis cesatii</i> | (Rabenhorst) Krammer |
| <i>Encyonopsis descripta</i> | (Hustedt) Krammer |
| <i>Encyonopsis microcephala</i> | (Grunow) Krammer |
| <i>Encyonopsis minuta</i> | Krammer & E.Reichardt |
| <i>Eolimna minima</i> | (Grunow) Lange-Bertalot & Schiller |
| <i>Eunotia arculus</i> | (Grunow) Lange-Bertalot & Nörpel |
| <i>Eunotia implicata sensu lato</i> | Nörpel, Lange-Bertalot & Alles |
| <i>Fragilaria</i> cf. <i>tenera</i> | (W.Smith) Lange-Bertalot |
| <i>Frustulia rhomboides</i> | (Ehrenberg) De Toni |
| <i>Frustulia saxonica</i> | Rabenhorst |
| <i>Hygropetra balfouriana</i> | (Grunow ex Cleve) Krammer & Lange-Bertalot in Krammer |
| <i>Karayevia laterostrata</i> | (Hustedt) Bukhtiyarova |
| <i>Karayevia nitidiformis</i> | (Lange-Bertalot) Bukhtiyarova |
| <i>Kobayasiella micropunctata</i> | (H. Germain) Lange-Bertalot |
| <i>Navicula</i> aff. <i>minuscula</i> | Grunow in van Heurck |

APPENDIX A : continued

| Taxon | Authority |
|--|--|
| <i>Navicula cf. cryptocephala</i> | Kützing |
| <i>Navicula schmassmannii</i> | Hustedt |
| <i>Navicula seminulum</i> | Grunow |
| <i>Navicula</i> sp.1 Saglek | - |
| <i>Navicula</i> sp.37 Quebec | Fallu, Allaire & Pienitz |
| <i>Navicula submuralis</i> | Hustedt |
| <i>Navicula venerabilis</i> | Hohn & Hellerman |
| <i>Nitzschia alpina sensu</i> Krammer & Lange-Bertalot | Hustedt |
| <i>Nitzschia fonticola</i> | (Grunow) Grunow in Van Heurck |
| <i>Nitzschia perminuta</i> | (Grunow in Van Heurck) Peragallo |
| <i>Nitzschia</i> sp.2 Saglek | - |
| <i>Nitzschia</i> sp.3 Saglek | - |
| <i>Nupela pennsylvanica</i> | (Patrick) Potapova |
| <i>Pinnularia interrupta</i> | Smith |
| <i>Psammothidium cf. marginulatum</i> | (Grunow) Bukhtiyarova & Round |
| <i>Psammothidium curtissimum</i> | (J.R. Carter) M. Aboal |
| <i>Psammothidium didymum</i> | (Hustedt) Bukhtiyarova & Round |
| <i>Psammothidium kuelbsii</i> | (Lange-Bertalot) Bukhtiyarova & Round |
| <i>Psammothidium levanderi</i> | (Hustedt) Bukhtiyarova & Round |
| <i>Psammothidium</i> sp.2 Saglek | - |
| <i>Pseudostaurosira brevistriata</i> | (Grunow) Williams & Round |
| <i>Pseudostaurosira pseudoconstruens</i> | (Marciniak) Williams & Round |
| <i>Rosithidium pusillum</i> | (Grunow) Round & Bukhtiyarova |
| <i>Stauroforma exiguiiformis</i> | (Lange-Bertalot) Flower, Jones & Round |
| <i>Stauroneis neohyalina</i> | Lange-Bertalot & Krammer |
| <i>Staurosirella pinnata</i> | (Ehrenberg) Williams & Round |
| <i>Tabellaria flocculosa</i> | (Roth) Kützing |

APPENDIX B : Diatom counts for Lake LAB003 sedimentary profile, Saglek

| Interval (cm) | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 |
|---|----|-----|----|-----|----|-----|----|-----|----|-----|----|-----|----|-----|----|
| <i>Psammothidium curtissimum</i> | 54 | 43 | 56 | 76 | 67 | 59 | 62 | 61 | 76 | 65 | 70 | 74 | 61 | 51 | 81 |
| <i>Psammothidium kuelbsii</i> | 6 | 10 | 7 | 6 | 1 | 4 | 5 | 4 | 3 | 7 | 6 | 8 | 6 | 5 | 5 |
| <i>Psammothidium levanderi</i> | 2 | 8 | 1 | 5 | 0 | 7 | 6 | 2 | 8 | 1 | 0 | 2 | 2 | 7 | 1 |
| <i>Psammothidium cf-marginulatum</i> | 92 | 91 | 70 | 68 | 62 | 66 | 48 | 53 | 62 | 54 | 77 | 60 | 42 | 52 | 69 |
| <i>Achnantheidium minutissimum</i> complex | 8 | 6 | 1 | 8 | 8 | 10 | 7 | 6 | 9 | 15 | 8 | 6 | 10 | 9 | 11 |
| <i>Rossethidium pusillum</i> | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 0 | 0 | 3 | 2 | 1 |
| <i>Psammothidium</i> sp2 Saglek | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 |
| <i>Achnanthes</i> sp1 Quebec | 1 | 0 | 1 | 1 | 0 | 2 | 5 | 1 | 2 | 0 | 1 | 3 | 0 | 2 | 0 |
| <i>Aulacoseira alpigena</i> | 30 | 42 | 40 | 45 | 51 | 30 | 46 | 44 | 27 | 28 | 39 | 34 | 46 | 34 | 41 |
| <i>Aulacoseira lirata</i> | 1 | 3 | 4 | 5 | 5 | 2 | 0 | 8 | 1 | 4 | 1 | 8 | 5 | 6 | 2 |
| <i>Aulacoseira cf-nivalis</i> | 20 | 23 | 33 | 21 | 26 | 25 | 32 | 27 | 18 | 27 | 20 | 24 | 25 | 42 | 28 |
| <i>Aulacoseira nivaloides</i> | 4 | 6 | 6 | 7 | 8 | 3 | 7 | 5 | 5 | 9 | 7 | 6 | 9 | 6 | 4 |
| <i>Aulacoseira perglabra</i> complex | 10 | 7 | 19 | 17 | 7 | 8 | 18 | 14 | 8 | 16 | 15 | 14 | 16 | 15 | 7 |
| <i>Brachysira brebissonii</i> | 13 | 10 | 11 | 6 | 13 | 10 | 14 | 6 | 22 | 20 | 12 | 12 | 16 | 12 | 10 |
| <i>Brachysira microcephala</i> | 7 | 6 | 4 | 10 | 4 | 11 | 11 | 8 | 13 | 8 | 11 | 10 | 14 | 4 | 10 |
| <i>Brachysira</i> sp. [cf- <i>procera</i>] | 11 | 14 | 20 | 14 | 6 | 10 | 7 | 6 | 9 | 5 | 8 | 9 | 8 | 13 | 4 |
| <i>Discostella stelligera</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 2 |
| <i>Encyonema gaeumannii</i> | 40 | 38 | 40 | 30 | 33 | 29 | 23 | 26 | 36 | 26 | 18 | 25 | 23 | 36 | 32 |
| <i>Encyonema gracile</i> | 1 | 3 | 1 | 3 | 2 | 0 | 0 | 1 | 5 | 1 | 2 | 1 | 3 | 1 | 1 |
| <i>Cymboplectra lapponica</i> | 1 | 4 | 2 | 4 | 1 | 1 | 1 | 0 | 0 | 3 | 2 | 2 | 1 | 0 | 0 |
| <i>Encyonopsis minuta</i> | 1 | 3 | 1 | 1 | 6 | 3 | 7 | 3 | 0 | 2 | 2 | 2 | 2 | 3 | 1 |
| <i>Encyonema silesiacum</i> | 2 | 0 | 2 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 4 | 4 | 2 |
| <i>Eunotia implicata</i> | 1 | 0 | 0 | 2 | 1 | 0 | 2 | 2 | 0 | 3 | 5 | 0 | 2 | 0 | 1 |
| <i>Stauroforma exiguiformis</i> | 63 | 58 | 69 | 59 | 79 | 75 | 72 | 71 | 68 | 80 | 89 | 78 | 87 | 73 | 61 |
| <i>Staurosirella pinnata</i> | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Staurosira pseudoconstruens</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Frustulia rhomboides</i> | 2 | 4 | 4 | 3 | 3 | 5 | 2 | 0 | 3 | 3 | 2 | 2 | 0 | 4 | 2 |
| <i>Frustulia saxonica</i> | 6 | 10 | 7 | 6 | 9 | 11 | 9 | 16 | 6 | 12 | 16 | 7 | 8 | 9 | 10 |
| <i>Chamaepinnularia mediocris</i> | 5 | 2 | 0 | 3 | 3 | 5 | 4 | 5 | 4 | 0 | 1 | 5 | 9 | 2 | 1 |
| <i>Kobayasiella micropunctata</i> | 1 | 0 | 5 | 7 | 1 | 2 | 4 | 5 | 1 | 3 | 2 | 4 | 4 | 0 | 2 |
| <i>Eolimna minima</i> | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Cavinula pseudoscutiformis</i> | 6 | 7 | 4 | 6 | 6 | 5 | 5 | 7 | 13 | 4 | 3 | 5 | 5 | 2 | 4 |
| <i>Navicula schmassmannii</i> | 5 | 0 | 2 | 4 | 1 | 5 | 2 | 5 | 2 | 2 | 2 | 8 | 3 | 3 | 3 |
| <i>Navicula seminulum</i> | 11 | 14 | 9 | 9 | 8 | 15 | 19 | 14 | 14 | 9 | 4 | 6 | 4 | 7 | 17 |
| <i>Navicula submuralis</i> | 0 | 3 | 2 | 3 | 3 | 4 | 4 | 8 | 3 | 1 | 3 | 6 | 2 | 5 | 2 |
| <i>Navicula</i> sp1 Saglek | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Navicula</i> sp37 Quebec | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| <i>Nitzschia fonticola</i> | 8 | 8 | 8 | 3 | 7 | 8 | 10 | 9 | 6 | 11 | 7 | 7 | 13 | 5 | 14 |
| <i>Nitzschia perminuta</i> forme 1 | 7 | 1 | 4 | 9 | 7 | 7 | 6 | 11 | 3 | 5 | 6 | 7 | 4 | 1 | 8 |
| <i>Nitzschia</i> sp2 Saglek | 2 | 2 | 1 | 0 | 0 | 2 | 0 | 0 | 2 | 1 | 1 | 0 | 2 | 0 | 0 |
| <i>Hygropetra balfouriana</i> | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 |
| <i>Pinnularia interrupta</i> | 3 | 5 | 1 | 0 | 4 | 3 | 1 | 3 | 2 | 4 | 6 | 5 | 5 | 3 | 4 |
| <i>Tabellaria flocculosa</i> | 5 | 5 | 5 | 3 | 8 | 7 | 3 | 7 | 6 | 8 | 8 | 2 | 5 | 7 | 4 |

APPENDIX B : (continued)

| Interval (cm) | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 | 11 | 11.5 | 12 | 12.5 | 13 |
|---|-----|----|-----|----|-----|----|------|----|------|----|------|-----|
| <i>Psammothidium curtissimum</i> | 58 | 63 | 74 | 65 | 62 | 48 | 60 | 46 | 55 | 49 | 54 | 46 |
| <i>Psammothidium kuelbsii</i> | 4 | 5 | 2 | 7 | 1 | 2 | 1 | 1 | 7 | 3 | 5 | 3 |
| <i>Psammothidium levanderi</i> | 1 | 3 | 1 | 8 | 1 | 2 | 0 | 4 | 8 | 4 | 5 | 4 |
| <i>Psammothidium cf-marginulatum</i> | 50 | 58 | 46 | 64 | 64 | 64 | 49 | 44 | 50 | 38 | 39 | 42 |
| <i>Achnanthidium minutissimum</i> complex | 13 | 4 | 9 | 12 | 10 | 11 | 6 | 11 | 11 | 8 | 7 | 9 |
| <i>Rossithidium pusillum</i> | 2 | 0 | 0 | 1 | 2 | 1 | 3 | 5 | 3 | 2 | 2 | 0 |
| <i>Psammothidium</i> sp2 Saglek | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Achnanthes</i> sp1 Quebec | 2 | 0 | 2 | 1 | 1 | 4 | 2 | 2 | 1 | 1 | 1 | 2 |
| <i>Aulacoseira alpigena</i> | 51 | 54 | 37 | 42 | 60 | 46 | 42 | 55 | 54 | 74 | 75 | 64 |
| <i>Aulacoseira lirata</i> | 3 | 4 | 4 | 1 | 6 | 0 | 3 | 2 | 2 | 7 | 2 | 6 |
| <i>Aulacoseira cf-nivalis</i> | 57 | 41 | 19 | 25 | 37 | 24 | 32 | 24 | 23 | 28 | 39 | 32 |
| <i>Aulacoseira nivaloides</i> | 3 | 2 | 3 | 3 | 5 | 8 | 3 | 15 | 8 | 12 | 13 | 14 |
| <i>Aulacoseira perglabra</i> complex | 12 | 13 | 20 | 5 | 9 | 13 | 5 | 21 | 7 | 15 | 13 | 7 |
| <i>Brachysira brebissonii</i> | 16 | 20 | 8 | 9 | 6 | 5 | 9 | 11 | 9 | 7 | 10 | 9 |
| <i>Brachysira microcephala</i> | 8 | 6 | 12 | 9 | 5 | 10 | 6 | 7 | 13 | 11 | 11 | 3 |
| <i>Brachysira</i> sp. [cf-procera] | 3 | 0 | 5 | 6 | 3 | 0 | 6 | 2 | 0 | 0 | 1 | 1 |
| <i>Discostella stelligera</i> | 1 | 2 | 4 | 4 | 5 | 2 | 5 | 4 | 2 | 5 | 5 | 4 |
| <i>Encyonema gaeumannii</i> | 27 | 33 | 26 | 34 | 28 | 39 | 37 | 26 | 18 | 30 | 32 | 19 |
| <i>Encyonema gracile</i> | 3 | 3 | 0 | 0 | 0 | 1 | 0 | 3 | 2 | 4 | 1 | 2 |
| <i>Cymboplectra lapponica</i> | 1 | 3 | 1 | 0 | 0 | 1 | 1 | 3 | 3 | 0 | 0 | 3 |
| <i>Encyonopsis minuta</i> | 2 | 2 | 3 | 5 | 0 | 4 | 4 | 1 | 1 | 3 | 2 | 2 |
| <i>Encyonema silesiacum</i> | 3 | 2 | 0 | 2 | 3 | 3 | 3 | 0 | 0 | 2 | 0 | 4 |
| <i>Eunotia implicata</i> | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| <i>Stauroforma exiguiformis</i> | 65 | 77 | 82 | 61 | 65 | 77 | 88 | 92 | 88 | 78 | 72 | 103 |
| <i>Staurosirella pinnata</i> | 2 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 3 | 1 | 0 | 1 |
| <i>Staurosira pseudoconstruens</i> | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 |
| <i>Frustulia rhomboides</i> | 1 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| <i>Frustulia saxonica</i> | 10 | 8 | 15 | 17 | 15 | 22 | 16 | 9 | 12 | 4 | 2 | 4 |
| <i>Chamaepinnularia mediocris</i> | 2 | 1 | 5 | 3 | 3 | 11 | 3 | 3 | 5 | 2 | 6 | 0 |
| <i>Kobayasiella micropunctata</i> | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 4 | 1 | 0 | 5 | 1 |
| <i>Eolimna minima</i> | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| <i>Cavinula pseudoscutiformis</i> | 6 | 5 | 4 | 5 | 6 | 7 | 7 | 3 | 3 | 6 | 1 | 10 |
| <i>Navicula schmassmannii</i> | 6 | 0 | 5 | 6 | 4 | 6 | 2 | 1 | 5 | 1 | 1 | 5 |
| <i>Navicula seminulum</i> | 6 | 5 | 12 | 11 | 8 | 14 | 7 | 0 | 8 | 16 | 13 | 7 |
| <i>Navicula submuralis</i> | 3 | 6 | 10 | 3 | 6 | 10 | 11 | 6 | 5 | 6 | 6 | 13 |
| <i>Navicula</i> sp1 Saglek | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 5 | 3 | 2 | 2 |
| <i>Navicula</i> sp37 Quebec | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 |
| <i>Nitzschia fonticola</i> | 10 | 5 | 15 | 14 | 9 | 6 | 7 | 14 | 8 | 10 | 6 | 11 |
| <i>Nitzschia perminuta</i> | 9 | 5 | 9 | 9 | 5 | 3 | 15 | 15 | 18 | 10 | 6 | 16 |
| <i>Nitzschia</i> sp2 Saglek | 0 | 4 | 1 | 0 | 1 | 0 | 3 | 0 | 0 | 1 | 1 | 0 |
| <i>Hygropetra balfouriana</i> | 0 | 1 | 1 | 0 | 2 | 4 | 5 | 3 | 3 | 4 | 4 | 5 |
| <i>Pinnularia interrupta</i> | 3 | 5 | 3 | 3 | 1 | 2 | 0 | 0 | 2 | 2 | 1 | 1 |
| <i>Tabellaria flocculosa</i> | 6 | 3 | 11 | 2 | 7 | 4 | 3 | 7 | 3 | 5 | 10 | 5 |

APPENDIX B : (continued)

| Interval (cm) | 13.5 | 14 | 14.5 | 15 | 15.5 | 16 | 16.5 | 17 | 17.5 | 18 |
|---|------|----|------|----|------|----|------|----|------|----|
| <i>Psammothidium curtissimum</i> | 47 | 54 | 54 | 48 | 42 | 49 | 41 | 61 | 42 | 51 |
| <i>Psammothidium kuelbsii</i> | 4 | 6 | 4 | 10 | 6 | 4 | 5 | 4 | 9 | 10 |
| <i>Psammothidium levanderi</i> | 3 | 8 | 5 | 4 | 3 | 1 | 0 | 1 | 3 | 5 |
| <i>Psammothidium cf-marginulatum</i> | 34 | 31 | 28 | 25 | 26 | 36 | 20 | 24 | 39 | 30 |
| <i>Achnanthidium minutissimum complex</i> | 2 | 10 | 11 | 5 | 5 | 8 | 7 | 2 | 3 | 9 |
| <i>Rossethidium pusillum</i> | 0 | 1 | 0 | 1 | 1 | 4 | 3 | 1 | 1 | 2 |
| <i>Psammothidium</i> sp2 Saglek | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Achnanthes</i> sp1 Quebec | 1 | 3 | 0 | 2 | 5 | 3 | 1 | 1 | 0 | 0 |
| <i>Aulacoseira alpigena</i> | 71 | 61 | 61 | 60 | 62 | 60 | 52 | 63 | 39 | 30 |
| <i>Aulacoseira lirata</i> | 6 | 0 | 4 | 2 | 3 | 4 | 7 | 2 | 13 | 5 |
| <i>Aulacoseira cf-nivalis</i> | 20 | 32 | 32 | 32 | 39 | 32 | 46 | 40 | 43 | 48 |
| <i>Aulacoseira nivaloides</i> | 10 | 19 | 21 | 15 | 20 | 27 | 11 | 19 | 26 | 34 |
| <i>Aulacoseira perglabra complex</i> | 16 | 14 | 18 | 15 | 34 | 10 | 17 | 17 | 21 | 23 |
| <i>Brachysira brebissonii</i> | 9 | 7 | 2 | 8 | 5 | 8 | 6 | 3 | 6 | 10 |
| <i>Brachysira microcephala</i> | 2 | 3 | 5 | 8 | 6 | 2 | 8 | 9 | 7 | 3 |
| <i>Brachysira</i> sp. [cf- <i>procera</i>] | 1 | 0 | 0 | 1 | 0 | 5 | 0 | 1 | 1 | 1 |
| <i>Discostella stelligera</i> | 2 | 6 | 3 | 1 | 3 | 2 | 2 | 1 | 2 | 1 |
| <i>Encyonema gaeumannii</i> | 30 | 27 | 29 | 39 | 17 | 13 | 32 | 26 | 23 | 22 |
| <i>Encyonema gracile</i> | 4 | 3 | 2 | 4 | 6 | 1 | 2 | 0 | 4 | 0 |
| <i>Cymboplectra lapponica</i> | 1 | 0 | 0 | 5 | 1 | 0 | 0 | 0 | 3 | 3 |
| <i>Encyonopsis minuta</i> | 7 | 5 | 0 | 0 | 1 | 0 | 5 | 3 | 1 | 2 |
| <i>Encyonema silesiacum</i> | 0 | 0 | 2 | 1 | 3 | 1 | 0 | 1 | 5 | 0 |
| <i>Eunotia implicata</i> | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| <i>Stauroforma exiguiiformis</i> | 88 | 73 | 86 | 83 | 75 | 78 | 83 | 98 | 73 | 87 |
| <i>Staurosirella pinnata</i> | 1 | 2 | 1 | 0 | 1 | 1 | 0 | 0 | 2 | 4 |
| <i>Staurosira pseudoconstruens</i> | 0 | 0 | 3 | 1 | 2 | 0 | 0 | 0 | 0 | 1 |
| <i>Frustulia rhomboides</i> | 1 | 0 | 3 | 3 | 2 | 3 | 2 | 1 | 3 | 1 |
| <i>Frustulia saxonica</i> | 1 | 3 | 1 | 1 | 1 | 2 | 1 | 0 | 1 | 0 |
| <i>Chamaepinnularia mediocris</i> | 4 | 2 | 1 | 6 | 1 | 1 | 12 | 0 | 1 | 1 |
| <i>Kobayasiella micropunctata</i> | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 |
| <i>Eolimna minima</i> | 0 | 0 | 3 | 0 | 2 | 0 | 1 | 0 | 1 | 0 |
| <i>Cavinula pseudoscutiformis</i> | 2 | 7 | 5 | 4 | 3 | 4 | 6 | 5 | 3 | 3 |
| <i>Navicula schmassmannii</i> | 2 | 4 | 3 | 6 | 2 | 3 | 4 | 1 | 5 | 5 |
| <i>Navicula seminulum</i> | 14 | 12 | 20 | 12 | 10 | 14 | 24 | 13 | 21 | 25 |
| <i>Navicula submuralis</i> | 29 | 15 | 19 | 12 | 17 | 14 | 18 | 21 | 16 | 10 |
| <i>Navicula</i> sp1 Saglek | 4 | 1 | 0 | 2 | 0 | 0 | 0 | 5 | 0 | 3 |
| <i>Navicula</i> sp37 Quebec | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Nitzschia fonticola</i> | 9 | 17 | 6 | 9 | 10 | 17 | 6 | 15 | 4 | 11 |
| <i>Nitzschia perminuta</i> | 16 | 14 | 8 | 11 | 17 | 11 | 6 | 12 | 15 | 8 |
| <i>Nitzschia</i> sp2 Saglek | 1 | 1 | 1 | 3 | 0 | 0 | 5 | 2 | 2 | 0 |
| <i>Hygropetra balfouriana</i> | 1 | 12 | 9 | 14 | 12 | 8 | 12 | 3 | 7 | 2 |
| <i>Pinnularia interrupta</i> | 1 | 1 | 2 | 2 | 4 | 2 | 0 | 2 | 2 | 1 |
| <i>Tabellaria flocculosa</i> | 2 | 3 | 2 | 6 | 1 | 7 | 4 | 4 | 7 | 3 |

APPENDIX B : (continued)

| Interval (cm) | 18.5 | 19 | 19.5 | 20 | 20.5 | 21 | 21.5 | 22 | 22.5 | 23 |
|--|------|-----|------|----|------|----|------|----|------|----|
| <i>Psammothidium curtissimum</i> | 43 | 40 | 44 | 45 | 30 | 48 | 58 | 48 | 56 | 51 |
| <i>Psammothidium kuelbsii</i> | 4 | 13 | 0 | 6 | 3 | 5 | 2 | 4 | 1 | 1 |
| <i>Psammothidium levanderi</i> | 7 | 4 | 5 | 8 | 3 | 4 | 5 | 1 | 2 | 1 |
| <i>Psammothidium cf-marginulatum</i> | 21 | 27 | 14 | 12 | 24 | 19 | 29 | 23 | 31 | 36 |
| <i>Achnanthis minutissimum</i> complex | 10 | 7 | 9 | 14 | 9 | 8 | 6 | 11 | 6 | 10 |
| <i>Rosithidium pusillum</i> | 4 | 0 | 3 | 1 | 1 | 4 | 1 | 3 | 1 | 3 |
| <i>Psammothidium</i> sp2 Saglek | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 |
| <i>Achnanthes</i> sp1 Quebec | 5 | 4 | 7 | 1 | 5 | 5 | 7 | 2 | 5 | 4 |
| <i>Aulacoseira alpigena</i> | 31 | 34 | 20 | 31 | 36 | 29 | 31 | 28 | 24 | 28 |
| <i>Aulacoseira lirata</i> | 3 | 4 | 6 | 2 | 5 | 1 | 1 | 4 | 2 | 2 |
| <i>Aulacoseira cf-nivalis</i> | 47 | 39 | 37 | 32 | 42 | 46 | 61 | 49 | 67 | 66 |
| <i>Aulacoseira nivaloides</i> | 32 | 9 | 33 | 23 | 27 | 27 | 20 | 24 | 18 | 23 |
| <i>Aulacoseira perglabra</i> complex | 9 | 15 | 8 | 17 | 11 | 18 | 8 | 15 | 19 | 14 |
| <i>Brachysira brebissonii</i> | 6 | 11 | 8 | 5 | 6 | 7 | 6 | 1 | 4 | 2 |
| <i>Brachysira microcephala</i> | 2 | 2 | 0 | 2 | 4 | 1 | 3 | 3 | 3 | 1 |
| <i>Brachysira</i> sp. [cf-procera] | 2 | 1 | 2 | 1 | 1 | 0 | 1 | 2 | 3 | 0 |
| <i>Discostella stelligera</i> | 3 | 3 | 2 | 0 | 4 | 2 | 2 | 2 | 2 | 1 |
| <i>Encyonema gaeumannii</i> | 33 | 27 | 33 | 31 | 29 | 25 | 13 | 27 | 34 | 15 |
| <i>Encyonema gracile</i> | 2 | 2 | 3 | 3 | 4 | 2 | 0 | 0 | 0 | 1 |
| <i>Cymboplectra lapponica</i> | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 |
| <i>Encyonopsis minuta</i> | 1 | 2 | 2 | 3 | 0 | 1 | 1 | 1 | 0 | 0 |
| <i>Encyonema silesiacum</i> | 0 | 0 | 2 | 3 | 0 | 1 | 1 | 5 | 0 | 5 |
| <i>Eunotia implicata</i> | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| <i>Stauroforma exiguiformis</i> | 77 | 107 | 96 | 81 | 81 | 96 | 89 | 94 | 73 | 62 |
| <i>Staurosirella pinnata</i> | 5 | 9 | 8 | 6 | 6 | 10 | 10 | 13 | 12 | 10 |
| <i>Staurosira pseudoconstruens</i> | 3 | 4 | 9 | 0 | 7 | 0 | 9 | 8 | 6 | 5 |
| <i>Frustulia rhomboides</i> | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 0 | 1 | 0 |
| <i>Frustulia saxonica</i> | 0 | 2 | 0 | 1 | 2 | 1 | 0 | 1 | 0 | 1 |
| <i>Chamaepinnularia mediocris</i> | 10 | 2 | 2 | 6 | 4 | 3 | 6 | 1 | 3 | 2 |
| <i>Kobayasiella micropunctata</i> | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 0 | 0 |
| <i>Eolimna minima</i> | 0 | 5 | 5 | 1 | 5 | 1 | 3 | 10 | 0 | 8 |
| <i>Cavinula pseudoscutiformis</i> | 9 | 6 | 11 | 12 | 7 | 5 | 3 | 6 | 13 | 6 |
| <i>Navicula schmassmannii</i> | 7 | 5 | 4 | 5 | 5 | 2 | 4 | 4 | 3 | 7 |
| <i>Navicula seminulum</i> | 12 | 8 | 4 | 8 | 6 | 1 | 10 | 4 | 19 | 10 |
| <i>Navicula submuralis</i> | 18 | 14 | 19 | 13 | 20 | 20 | 11 | 16 | 7 | 18 |
| <i>Navicula</i> sp1 Saglek | 0 | 0 | 3 | 0 | 0 | 5 | 1 | 0 | 4 | 1 |
| <i>Navicula</i> sp37 Quebec | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| <i>Nitzschia fonticola</i> | 8 | 11 | 7 | 12 | 12 | 11 | 15 | 11 | 14 | 14 |
| <i>Nitzschia perminuta</i> | 16 | 13 | 10 | 6 | 14 | 11 | 12 | 11 | 11 | 17 |
| <i>Nitzschia</i> sp2 Saglek | 5 | 0 | 1 | 2 | 2 | 0 | 0 | 1 | 0 | 0 |
| <i>Hygropetra balfouriana</i> | 12 | 18 | 15 | 24 | 18 | 23 | 17 | 10 | 9 | 22 |
| <i>Pinnularia interrupta</i> | 2 | 2 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 |
| <i>Tabellaria flocculosa</i> | 10 | 2 | 2 | 8 | 7 | 8 | 3 | 3 | 4 | 5 |

APPENDIX B : (continued)

| Interval (cm) | 23.5 | 24 | 24.5 |
|---|------|----|------|
| <i>Psammothidium curtissimum</i> | 70 | 61 | 74 |
| <i>Psammothidium kuelbsii</i> | 6 | 2 | 4 |
| <i>Psammothidium levanderi</i> | 1 | 10 | 2 |
| <i>Psammothidium cf-marginulatum</i> | 23 | 26 | 26 |
| <i>Achnanthidium minutissimum</i> complex | 11 | 3 | 6 |
| <i>Rossithidium pusillum</i> | 0 | 0 | 0 |
| <i>Psammothidium</i> sp2 Saglek | 0 | 5 | 0 |
| <i>Achnanthes</i> sp1 Quebec | 5 | 6 | 7 |
| <i>Aulacoseira alpigena</i> | 37 | 27 | 29 |
| <i>Aulacoseira lirata</i> | 1 | 3 | 9 |
| <i>Aulacoseira cf-nivalis</i> | 50 | 73 | 43 |
| <i>Aulacoseira nivaloides</i> | 20 | 14 | 7 |
| <i>Aulacoseira perglabra</i> complex | 11 | 13 | 7 |
| <i>Brachysira brebissonii</i> | 2 | 1 | 1 |
| <i>Brachysira microcephala</i> | 0 | 4 | 3 |
| <i>Brachysira</i> sp. [cf-procera] | 2 | 0 | 1 |
| <i>Discostella stelligera</i> | 6 | 4 | 4 |
| <i>Encyonema gaeumannii</i> | 19 | 19 | 24 |
| <i>Encyonema gracile</i> | 0 | 4 | 1 |
| <i>Cymboplectra lapponica</i> | 2 | 0 | 1 |
| <i>Encyonopsis minuta</i> | 4 | 1 | 0 |
| <i>Encyonema silesiacum</i> | 0 | 0 | 1 |
| <i>Eunotia implicata</i> | 0 | 0 | 0 |
| <i>Stauroforma exiguiformis</i> | 76 | 77 | 96 |
| <i>Staurosirella pinnata</i> | 11 | 12 | 3 |
| <i>Staurosira pseudoconstruens</i> | 0 | 3 | 1 |
| <i>Frustulia rhomboides</i> | 1 | 0 | 0 |
| <i>Frustulia saxonica</i> | 0 | 1 | 1 |
| <i>Chamaepinnularia mediocris</i> | 1 | 0 | 7 |
| <i>Kobayasiella micropunctata</i> | 1 | 0 | 0 |
| <i>Eolimna minima</i> | 6 | 2 | 3 |
| <i>Cavinula pseudoscutiformis</i> | 10 | 7 | 4 |
| <i>Navicula schmassmannii</i> | 12 | 14 | 7 |
| <i>Navicula seminulum</i> | 24 | 8 | 14 |
| <i>Navicula submuralis</i> | 8 | 10 | 10 |
| <i>Navicula</i> sp1 Saglek | 0 | 1 | 1 |
| <i>Navicula</i> sp37 Quebec | 2 | 5 | 4 |
| <i>Nitzschia fonticola</i> | 7 | 15 | 8 |
| <i>Nitzschia perminuta</i> | 8 | 14 | 11 |
| <i>Nitzschia</i> sp2 Saglek | 1 | 0 | 1 |
| <i>Hygropetra balfouriana</i> | 8 | 10 | 18 |
| <i>Pinnularia interrupta</i> | 0 | 0 | 2 |
| <i>Tabellaria flocculosa</i> | 7 | 4 | 11 |

APPENDIX C : Diatom counts for Lake LAB004 sedimentary profile, Saglék

| Interval (cm) | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 5.5 |
|--|-----|-----|----|-----|----|-----|----|-----|----|-----|
| <i>Achnanthes bicapitata</i> | 2 | 0 | 0 | 1 | 3 | 0 | 3 | 1 | 0 | 1 |
| <i>Achnantheidium minutissimum</i> complex | 53 | 62 | 53 | 59 | 61 | 58 | 61 | 49 | 38 | 53 |
| <i>Karayevia laterostrata</i> | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 1 |
| <i>Karayevia nitidiformis</i> | 1 | 0 | 3 | 1 | 5 | 3 | 3 | 5 | 2 | 3 |
| <i>Nupela pennsylvanica</i> | 0 | 2 | 1 | 1 | 3 | 2 | 0 | 0 | 1 | 1 |
| <i>Psammothidium curtissimum</i> | 4 | 12 | 4 | 11 | 4 | 11 | 10 | 5 | 9 | 7 |
| <i>Psammothidium didymum</i> | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 5 | 4 | 0 |
| <i>Psammothidium levanderi</i> | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 3 | 3 | 3 |
| <i>Psammothidium cf-marginulatum</i> | 10 | 13 | 9 | 13 | 6 | 20 | 15 | 10 | 7 | 12 |
| <i>Rosithidium pusillum</i> | 13 | 11 | 13 | 6 | 13 | 17 | 8 | 11 | 11 | 21 |
| <i>Achnanthes</i> sp1 Quebec | 8 | 3 | 16 | 11 | 10 | 9 | 11 | 9 | 10 | 14 |
| <i>Amphora inariensis</i> | 0 | 1 | 2 | 0 | 1 | 1 | 0 | 2 | 2 | 2 |
| <i>Brachysira</i> sp. [cf- <i>procera</i>] | 0 | 3 | 0 | 3 | 0 | 7 | 2 | 0 | 2 | 5 |
| <i>Brachysira microcephala</i> | 15 | 3 | 11 | 5 | 13 | 9 | 12 | 6 | 11 | 11 |
| <i>Cyclotella bodanica</i> | 0 | 1 | 0 | 0 | 4 | 2 | 2 | 2 | 2 | 0 |
| <i>Cyclotella ocellata</i> | 30 | 30 | 33 | 31 | 23 | 30 | 28 | 40 | 33 | 38 |
| <i>Cyclotella rossii</i> | 11 | 13 | 10 | 18 | 18 | 24 | 16 | 20 | 10 | 30 |
| <i>Cyclotella tripartita</i> | 4 | 4 | 1 | 4 | 4 | 7 | 3 | 3 | 3 | 10 |
| <i>Discostella stelligera</i> complex | 104 | 90 | 91 | 80 | 64 | 102 | 75 | 84 | 80 | 84 |
| <i>Encyonopsis cesatii</i> | 4 | 4 | 2 | 3 | 3 | 3 | 2 | 0 | 2 | 2 |
| <i>Encyonopsis descripta</i> | 8 | 1 | 8 | 1 | 2 | 3 | 2 | 1 | 2 | 1 |
| <i>Encyonema gaeumannii</i> | 4 | 4 | 2 | 2 | 2 | 11 | 3 | 8 | 1 | 11 |
| <i>Encyonema silesiacum</i> | 2 | 4 | 6 | 1 | 6 | 6 | 2 | 2 | 5 | 2 |
| <i>Encyonopsis minuta</i> | 8 | 4 | 3 | 10 | 3 | 3 | 2 | 4 | 5 | 7 |
| <i>Encyonopsis microcephala</i> | 7 | 0 | 4 | 2 | 4 | 4 | 1 | 0 | 2 | 2 |
| <i>Eunotia</i> ssp. | 7 | 6 | 12 | 2 | 3 | 3 | 4 | 1 | 1 | 3 |
| <i>Eunotia implicata sensu lato</i> | 5 | 12 | 6 | 8 | 21 | 14 | 8 | 4 | 5 | 11 |
| <i>Eunotia arcus</i> | 1 | 0 | 1 | 4 | 2 | 2 | 1 | 1 | 0 | 0 |
| <i>Fragilaria cf-tenera</i> | 3 | 0 | 4 | 2 | 2 | 3 | 3 | 0 | 1 | 2 |
| <i>Pseudostaurosira brevistriata</i> | 14 | 21 | 17 | 27 | 24 | 21 | 23 | 17 | 26 | 26 |
| <i>Pseudostaurosira pseudoconstruens</i> | 10 | 4 | 1 | 2 | 2 | 4 | 2 | 4 | 6 | 10 |
| <i>Staurosirella pinnata</i> | 14 | 10 | 9 | 13 | 14 | 33 | 23 | 32 | 27 | 21 |
| <i>Frustulia saxonica</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| <i>Cavinula cocconeiformis</i> | 0 | 2 | 4 | 2 | 0 | 0 | 2 | 1 | 2 | 4 |
| <i>Kobayasiella micropunctata</i> | 3 | 4 | 2 | 3 | 6 | 6 | 4 | 2 | 3 | 2 |
| <i>Navicula cf-cryptocephala</i> | 3 | 1 | 2 | 3 | 0 | 1 | 2 | 5 | 1 | 2 |
| <i>Navicula schmassmannii</i> | 2 | 4 | 6 | 5 | 4 | 8 | 3 | 5 | 5 | 7 |
| <i>Navicula submuralis</i> | 4 | 0 | 4 | 7 | 4 | 3 | 1 | 4 | 6 | 1 |
| <i>Navicula venerabilis</i> | 1 | 0 | 1 | 0 | 1 | 2 | 1 | 1 | 1 | 1 |
| <i>Navicula aff minuscula</i> | 0 | 0 | 0 | 1 | 4 | 0 | 1 | 0 | 0 | 0 |
| <i>Nitzschia fonticola</i> | 9 | 12 | 11 | 7 | 9 | 1 | 3 | 8 | 9 | 0 |
| <i>Nitzschia</i> sp2 Saglék | 2 | 1 | 4 | 5 | 3 | 0 | 3 | 3 | 2 | 2 |
| <i>Nitzschia</i> sp3 Saglék | 1 | 5 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| <i>Nitzschia Alpina sensu</i> Krammer & Lange-Bertalot | 0 | 2 | 1 | 1 | 1 | 5 | 1 | 2 | 0 | 8 |
| <i>Hygropetra balfouriana</i> | 5 | 20 | 7 | 11 | 11 | 13 | 9 | 15 | 16 | 23 |
| <i>Stauroneis neohyalina</i> | 2 | 1 | 0 | 2 | 0 | 2 | 2 | 0 | 1 | 1 |

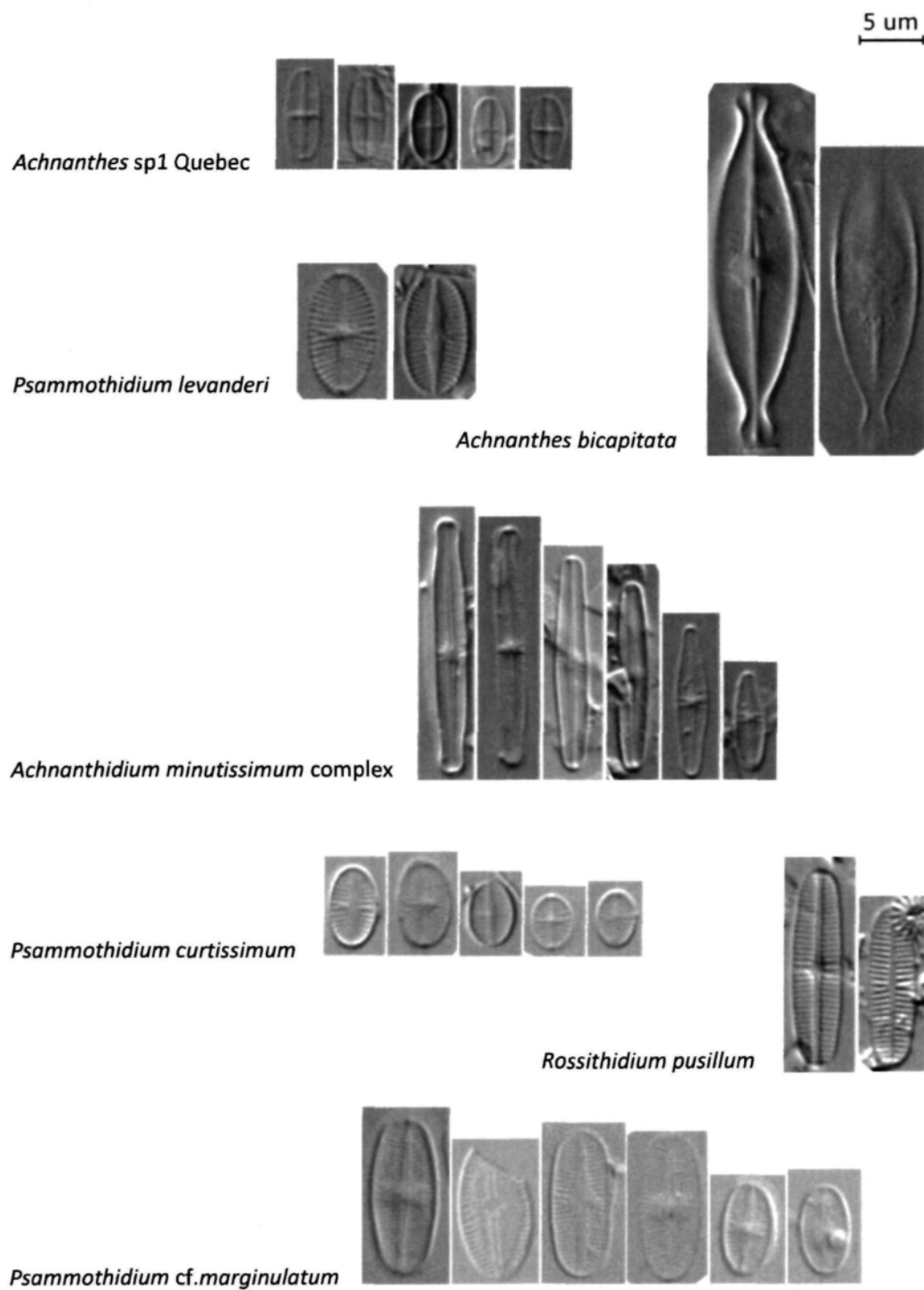
APPENDIX C : (continued)

| Interval (cm) | 4.5 | 5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 |
|--|-----|----|----|-----|----|-----|----|-----|----|-----|
| <i>Achnanthes bicapitata</i> | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Achnantheidium minutissimum</i> complex | 47 | 45 | 41 | 47 | 27 | 37 | 44 | 30 | 33 | 31 |
| <i>Karayevia laterostrata</i> | 0 | 0 | 0 | 5 | 4 | 2 | 0 | 0 | 0 | 3 |
| <i>Karayevia nitidiformis</i> | 2 | 2 | 11 | 6 | 7 | 2 | 1 | 1 | 2 | 1 |
| <i>Nupela pennsylvanica</i> | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| <i>Psammothidium curtissimum</i> | 6 | 0 | 5 | 3 | 3 | 0 | 3 | 1 | 2 | 1 |
| <i>Psammothidium didymum</i> | 0 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 1 | 1 |
| <i>Psammothidium levanderi</i> | 3 | 4 | 2 | 3 | 4 | 2 | 1 | 0 | 0 | 2 |
| <i>Psammothidium cf-marginulatum</i> | 7 | 4 | 3 | 7 | 9 | 5 | 3 | 4 | 1 | 3 |
| <i>Rossithidium pusillum</i> | 14 | 16 | 11 | 8 | 17 | 5 | 7 | 4 | 3 | 3 |
| <i>Achnanthes</i> sp1 Quebec | 7 | 15 | 8 | 6 | 8 | 4 | 7 | 5 | 6 | 2 |
| <i>Amphora inariensis</i> | 1 | 3 | 3 | 2 | 5 | 0 | 1 | 2 | 3 | 3 |
| <i>Brachysira</i> sp. [cf- <i>procera</i>] | 0 | 1 | 0 | 2 | 1 | 2 | 3 | 2 | 1 | 1 |
| <i>Brachysira microcephala</i> | 5 | 12 | 9 | 7 | 8 | 9 | 8 | 5 | 5 | 4 |
| <i>Cyclotella bodanica</i> | 1 | 3 | 0 | 4 | 1 | 1 | 0 | 3 | 2 | 0 |
| <i>Cyclotella ocellata</i> | 32 | 37 | 41 | 50 | 42 | 22 | 17 | 20 | 24 | 18 |
| <i>Cyclotella rossii</i> | 24 | 18 | 21 | 20 | 18 | 10 | 16 | 8 | 9 | 13 |
| <i>Cyclotella tripartita</i> | 3 | 4 | 3 | 7 | 1 | 1 | 4 | 0 | 3 | 0 |
| <i>Discostella stelligera</i> complex | 91 | 75 | 71 | 77 | 79 | 70 | 90 | 71 | 53 | 51 |
| <i>Encyonopsis cesatii</i> | 1 | 1 | 0 | 0 | 1 | 0 | 2 | 2 | 4 | 0 |
| <i>Encyonopsis descripta</i> | 1 | 6 | 2 | 0 | 0 | 6 | 1 | 0 | 3 | 4 |
| <i>Encyonema gaeumannii</i> | 8 | 3 | 3 | 2 | 2 | 6 | 5 | 0 | 4 | 1 |
| <i>Encyonema silesiacum</i> | 7 | 5 | 6 | 5 | 3 | 1 | 6 | 9 | 4 | 3 |
| <i>Encyonopsis minuta</i> | 4 | 7 | 7 | 3 | 11 | 7 | 2 | 11 | 9 | 6 |
| <i>Encyonopsis microcephala</i> | 0 | 3 | 2 | 2 | 2 | 1 | 2 | 0 | 3 | 0 |
| <i>Eunotia</i> ssp. | 0 | 3 | 6 | 2 | 5 | 1 | 1 | 6 | 3 | 2 |
| <i>Eunotia implicata sensu lato</i> | 6 | 2 | 4 | 2 | 4 | 7 | 5 | 7 | 4 | 4 |
| <i>Eunotia arcus</i> | 0 | 1 | 0 | 2 | 2 | 0 | 0 | 0 | 1 | 1 |
| <i>Fragilaria</i> cf- <i>tenera</i> | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| <i>Pseudostaurosira brevistriata</i> | 28 | 24 | 19 | 36 | 30 | 35 | 43 | 33 | 27 | 39 |
| <i>Pseudostaurosira pseudoconstruens</i> | 0 | 5 | 3 | 8 | 4 | 30 | 56 | 35 | 40 | 53 |
| <i>Staurosirella pinnata</i> | 29 | 16 | 30 | 22 | 28 | 61 | 67 | 57 | 77 | 79 |
| <i>Frustulia saxonica</i> | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Cavinula cocconeiformis</i> | 0 | 0 | 5 | 4 | 0 | 0 | 3 | 1 | 1 | 1 |
| <i>Kobayasiella micropunctata</i> | 5 | 1 | 2 | 4 | 2 | 1 | 1 | 2 | 0 | 1 |
| <i>Navicula</i> cf- <i>cryptocephala</i> | 3 | 2 | 5 | 2 | 1 | 5 | 3 | 5 | 3 | 2 |
| <i>Navicula schmassmannii</i> | 5 | 7 | 3 | 8 | 6 | 3 | 3 | 2 | 1 | 2 |
| <i>Navicula submuralis</i> | 1 | 1 | 7 | 2 | 2 | 2 | 2 | 0 | 0 | 0 |
| <i>Navicula venerabilis</i> | 0 | 2 | 1 | 3 | 1 | 0 | 3 | 0 | 0 | 1 |
| <i>Navicula</i> aff <i>minuscula</i> | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| <i>Nitzschia fonticola</i> | 6 | 6 | 3 | 2 | 1 | 2 | 2 | 3 | 6 | 2 |
| <i>Nitzschia</i> sp2 Saglek | 4 | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| <i>Nitzschia</i> sp3 Saglek | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Nitzschia Alpina sensu</i> Krammer & Lange-Bertalot | 2 | 4 | 1 | 3 | 0 | 1 | 4 | 3 | 2 | 4 |
| <i>Hygropetra balfouriana</i> | 23 | 15 | 16 | 20 | 18 | 29 | 51 | 26 | 29 | 30 |
| <i>Stauroneis neohyalina</i> | 0 | 0 | 2 | 0 | 2 | 1 | 0 | 1 | 2 | 0 |

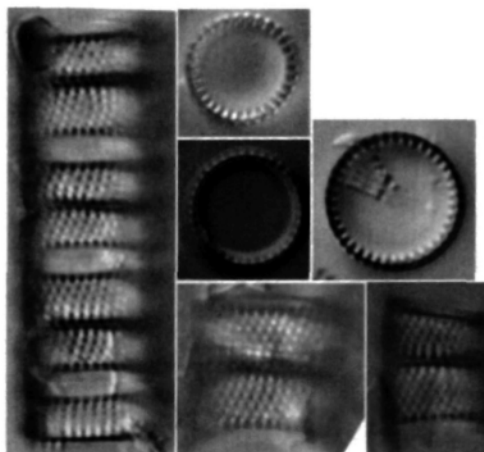
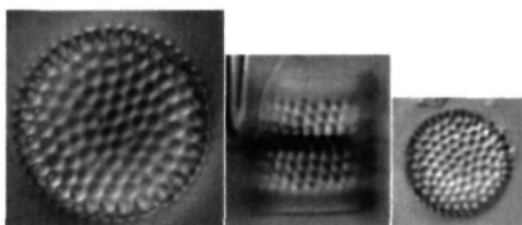
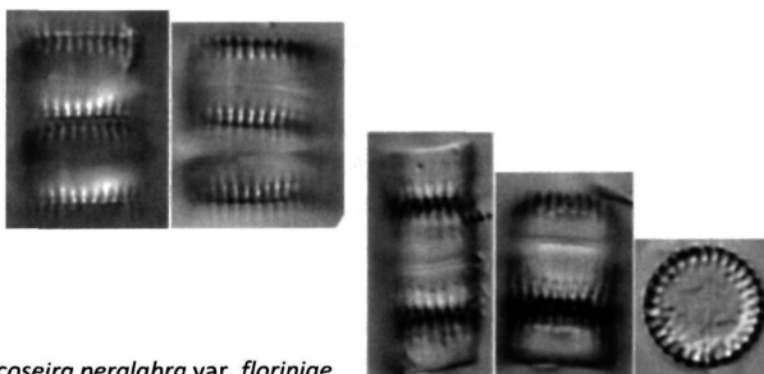
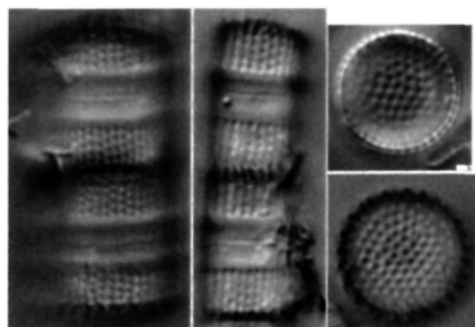
APPENDIX C : (continued)

| Interval (cm) | 10 | 10.5 | 11 | 11.5 |
|--|----|------|-----|------|
| <i>Achnanthes bicapitata</i> | 2 | 0 | 2 | 0 |
| <i>Achnantheidium minutissimum</i> complex | 37 | 31 | 31 | 45 |
| <i>Karayevia laterostrata</i> | 1 | 2 | 2 | 0 |
| <i>Karayevia nitidiformis</i> | 3 | 3 | 6 | 5 |
| <i>Nupela pennsylvanica</i> | 0 | 0 | 2 | 0 |
| <i>Psammothidium curtissimum</i> | 1 | 0 | 1 | 1 |
| <i>Psammothidium didymum</i> | 0 | 0 | 1 | 1 |
| <i>Psammothidium levanderi</i> | 0 | 1 | 2 | 0 |
| <i>Psammothidium cf-marginulatum</i> | 3 | 5 | 1 | 3 |
| <i>Rosithidium pusillum</i> | 8 | 8 | 15 | 4 |
| <i>Achnanthes</i> sp1 Quebec | 5 | 0 | 3 | 6 |
| <i>Amphora inariensis</i> | 0 | 0 | 3 | 3 |
| <i>Brachysira</i> sp. [cf- <i>procera</i>] | 1 | 0 | 3 | 2 |
| <i>Brachysira microcephala</i> | 4 | 4 | 3 | 4 |
| <i>Cyclotella bodanica</i> | 0 | 1 | 1 | 0 |
| <i>Cyclotella ocellata</i> | 17 | 30 | 26 | 30 |
| <i>Cyclotella rossii</i> | 11 | 9 | 12 | 3 |
| <i>Cyclotella tripartita</i> | 0 | 0 | 4 | 1 |
| <i>Discostella stelligera</i> complex | 50 | 54 | 77 | 71 |
| <i>Encyonopsis cesatii</i> | 0 | 0 | 2 | 3 |
| <i>Encyonopsis descripta</i> | 0 | 2 | 3 | 3 |
| <i>Encyonema gaeumannii</i> | 0 | 0 | 6 | 4 |
| <i>Encyonema silesiacum</i> | 5 | 4 | 0 | 0 |
| <i>Encyonopsis minuta</i> | 4 | 4 | 9 | 2 |
| <i>Encyonopsis microcephala</i> | 4 | 1 | 5 | 0 |
| <i>Eunotia</i> ssp. | 2 | 0 | 3 | 3 |
| <i>Eunotia implicata sensu lato</i> | 0 | 2 | 2 | 4 |
| <i>Eunotia arcus</i> | 0 | 0 | 1 | 0 |
| <i>Fragilaria cf-tenera</i> | 1 | 0 | 0 | 0 |
| <i>Pseudostaurosira brevistriata</i> | 35 | 39 | 38 | 38 |
| <i>Pseudostaurosira pseudoconstruens</i> | 47 | 43 | 50 | 33 |
| <i>Staurosirella pinnata</i> | 88 | 81 | 115 | 66 |
| <i>Frustulia saxonica</i> | 0 | 0 | 0 | 0 |
| <i>Cavinula cocconeiformis</i> | 1 | 2 | 1 | 3 |
| <i>Kobayasiella micropunctata</i> | 0 | 1 | 1 | 1 |
| <i>Navicula cf-cryptocephala</i> | 1 | 2 | 0 | 0 |
| <i>Navicula schmassmannii</i> | 2 | 7 | 3 | 3 |
| <i>Navicula submuralis</i> | 0 | 1 | 2 | 0 |
| <i>Navicula venerabilis</i> | 0 | 0 | 2 | 0 |
| <i>Navicula aff minuscula</i> | 0 | 2 | 0 | 1 |
| <i>Nitzschia fonticola</i> | 2 | 1 | 2 | 3 |
| <i>Nitzschia</i> sp2 Saglek | 0 | 0 | 0 | 0 |
| <i>Nitzschia</i> sp3 Saglek | 1 | 0 | 0 | 0 |
| <i>Nitzschia Alpina sensu</i> Krammer & Lange-Bertalot | 3 | 3 | 2 | 3 |
| <i>Hygropetra balfouriana</i> | 32 | 21 | 28 | 24 |
| <i>Stauroneis neohyalina</i> | 0 | 0 | 0 | 0 |

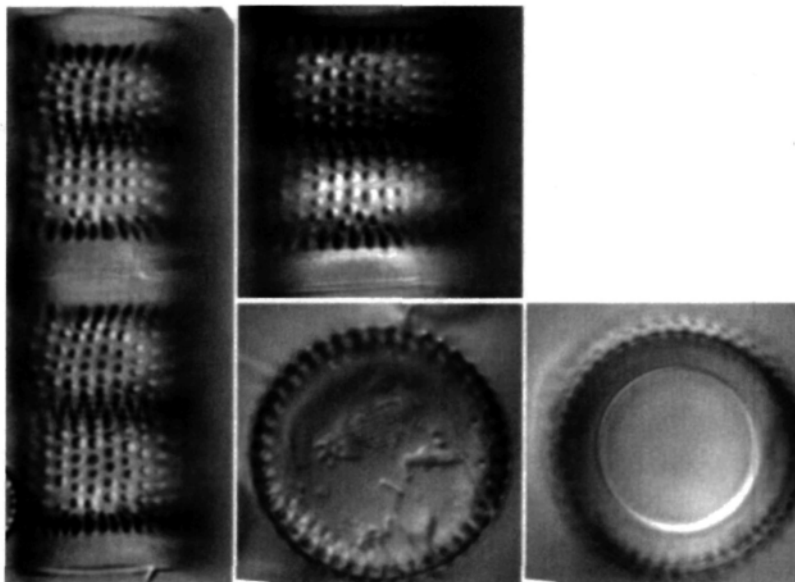
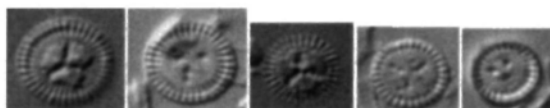
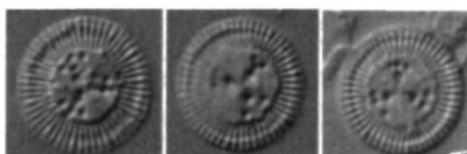
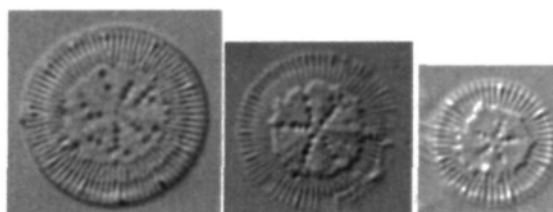
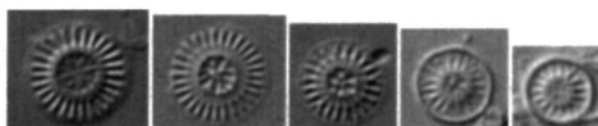
APPENDIX D : Microphotographic plates of the main taxa (>2% relative abundance) found in the sedimentary record from lakes LAB003 and LAB004, Saglék.



APPENDIX D : Continued

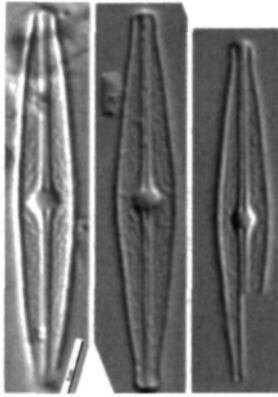
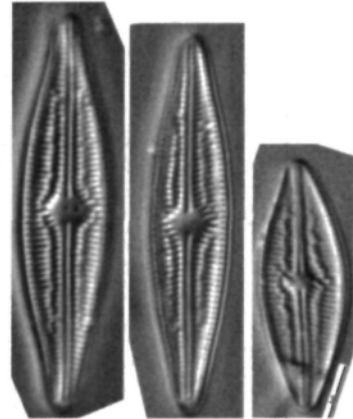
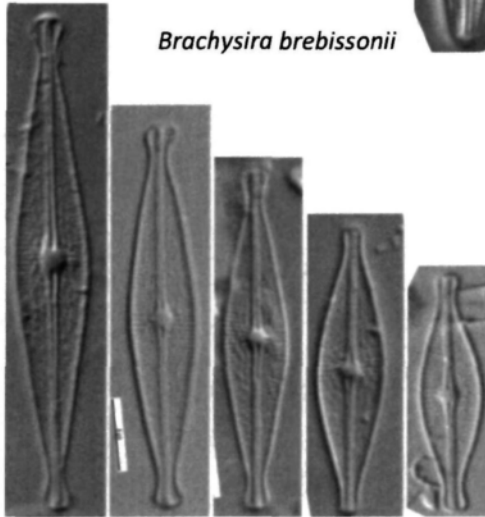
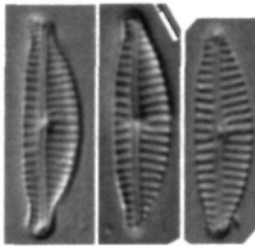
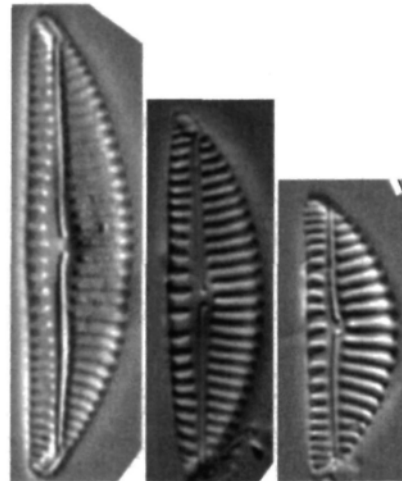
5 μ m*Aulacoseira alpigena**Aulacoseira* cf. *nivalis**Aulacoseira perglabra**Aulacoseira perglabra* var. *floriniae**Aulacoseira nivaloides*

APPENDIX D : continued

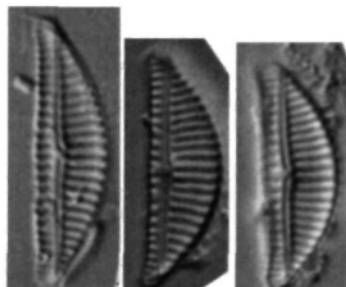
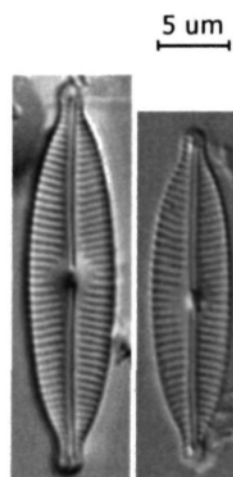
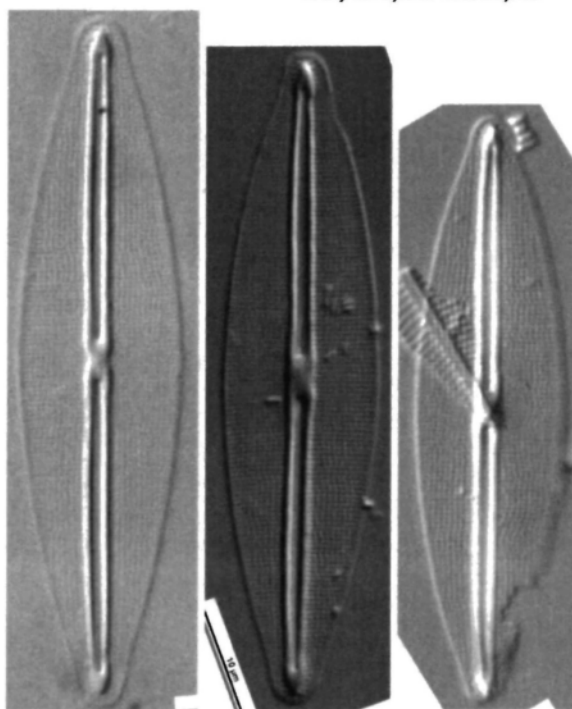
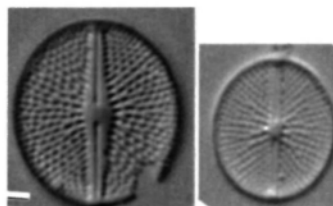
5 μ m*Aulacoseira lirata**Cyclotella ocellata**Cyclotella tripartita**Cyclotella rossii**Discostella stelligera* complex

5 μ m

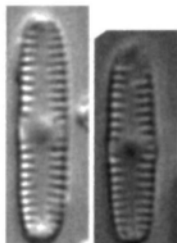
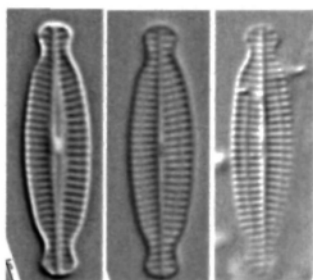
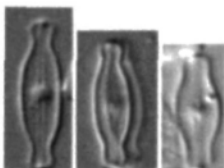
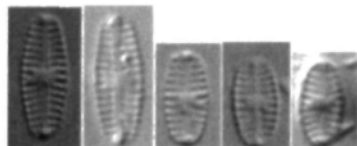
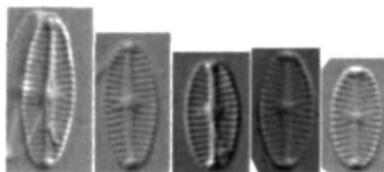
APPENDIX D : continued

Brachysira cf. procera*Brachysira brebissonii**Brachysira microcephala**Encyonema gaeumannii**Encyonema silesiacum*

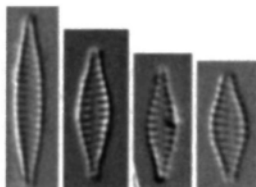
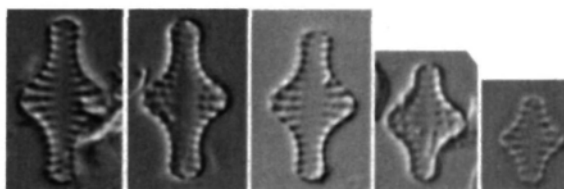
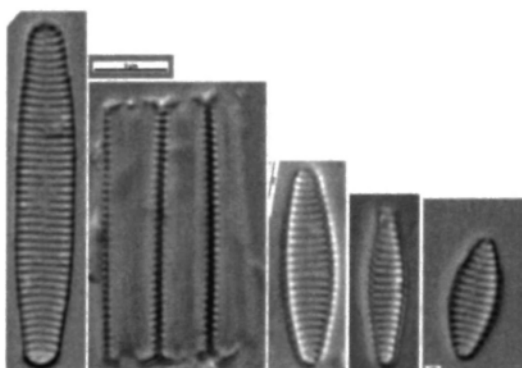
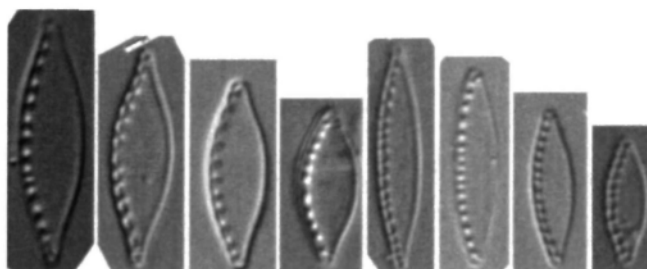
APPENDIX D : continued

Encyonopsis minuta*Encyonopsis descripta**Frustulia saxonica**Cavinula pseudoscutiformis**Cavinula cocconeiformis*

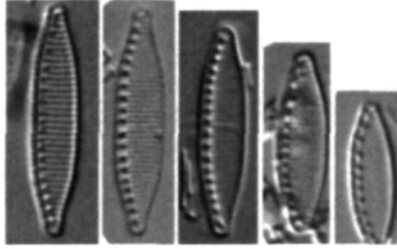
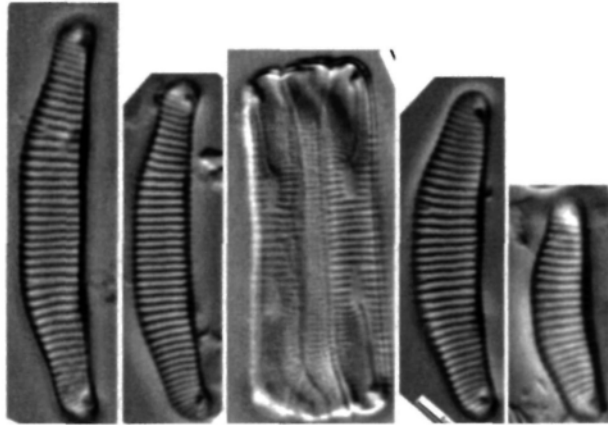
APPENDIX D : continued

5 μ m*Chamaepinnularia mediocris**Karayevia nitidiformis**Navicula schmassmannii**Navicula seminulum**Navicula submuralis**Navicula venerabilis**Hygropetra balfouriana*

APPENDIX D : continued

5 μ m*Pseudostaurosira brevistriata**Pseudostaurosira pseudoconstruens**Stauroforma exiguiformis**Staurosirella pinnata**Nitzschia fonticola*

APPENDIX D : continued

5 μm *Nitzschia perminuta**Eunotia implicata sensu lato**Tabellaria flocculosa*